**Supplementary Data**

**Technological Innovations at the Onset of the** **Mid-Pleistocene Climate Transition in High-Latitude East Asia**

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**Supplementary Notes**

**Note 1.** **The Nihewan Basin and surrounding area**

The Nihewan Basin is located at the northeastern edge of the Loess Plateau and at the transition zone between the North China Plain and the Inner Mongolia Plateau (Figure 1). The basin contains up to 150 m of exposed deposits that accumulated in and around a weak to semi-saline palaeolake (Figure 1 and Supplementary Figure 1) [1], dating from the Late Pliocene [2-4] to the Middle Pleistocene, at ca. 420−260 ka [5-6], when the water body finally dried up.

There is no long, high-resolution record concerning changes in flora and fauna of the basin. In order to understand the ecological background of the Nihewan Basin over the long term, it is necessary to consult the geological and paleoenvironmental record of the surrounding region. A key, recent study of a drill core placed in the North China Plain revealed a long sequence of changes in paleovegetation patterns, which was compared against changes in large mammal communities [7]. This study illustrated climatic fluctuations during the Mid-Pleistocene climate transition (MPT) and linkages with ecosystems. Before 1.2 Ma, vegetation was mainly composed of alternating warm temperate forests and temperate forests; after 1.2 Ma, vegetation was mainly characterized by alternations in forests and grasslands [7]. The Mu Us Desert to the west of the Nihewan Basin also shows an episode of the expansion at about 1.2 Ma, and intensified aridification after 0.7 Ma [8-9]. Up to the onset of the Late Pleistocene, the region is characterized by a warm coniferous-broadleaved mixed forest with woody-grassland, as well as an increase in the extent of wetlands [7]. Pollen studies of the Nihewan Basin from key sections indicate that a relatively dry and cold desert grassland environment was present early on, as shown in the Nangou section from 2.5 to 2.0 Ma [10]. A well-developed forest was present until the transition to the MPT, with pollen evidence indicating the existence of subtropical plants, such as Sapindaceae*, Hymenophyllum sm.,* and *Lyodium sw.* [11]. During the MPT, at ca. 1.2-1.0 Ma, a stepwise intensification of aridification is recorded by the presence of grasses and herbs at Donggutuo [11-13]. The limited information available from the Nihewan Basin is generally consistent with the sequences established in the North China Plain.

For Figure 4, we gathered paleoclimatic and ecological information in and around the Nihewan Basin, including the benthic isotope data from ODP Site 1143 of the South China Sea and the pollen data of the drilling core from the North China Plain. Figure 4 illustrates the environmental background, assisting in interpretations about the context of changes in stone tool knapping through time.

## Note 2. Samples and data collection

Xiaochangliang, Donggutuo and Cenjiawan are key Early Pleistocene sites in the Nihewan Basin, and include ca. 5,000 lithic artefacts (Supplementary Table 4). Xiaochangliang (40º13'10"N, 114º39'44"E) was discovered in 1978 and later dated to ca. 1.36 Ma by magnetostratigraphy. In the current study, a total of 1184 lithic artefacts were included in the analyses. Donggutuo (40º13'22"N, 114º40'11"E) is situated in the eastern margin of the Nihewan Basin and was identified in 1981. The Donggutuo cultural layers date to ca. 1.1 Ma by magnetostratigraphy. In the current study, 2315 pieces artefacts were included in the analyses. Cenjiawan (40º13'21"N, 114º40'17"E) was identified in 1984, and dated to ca. 1.1 Ma by magnetostratigraphy. In the current study, 1383 artefacts were analyzed. The lithic artefacts from the three sites have been systematically studied and compared using the same methods, making it possible to have a comprehensive understanding of inter-assemblage lithic variability through the creation of a single comparative database.

The key attributes of the main classes of artefacts, i.e., cores, flakes, and shaped tools, have been compared in each of the Nihewan lithic assemblages. The classification systems used in East African Oldowan assemblages has been followed [14-18], while taking the characteristics of the Nihewan lithic assemblages and raw materials into account. The Xiaochangliang, Donggutuo and Cenjiawan sites contain retouched tools which are significance for learning about tool use and the skills of early hominins. Several attributes (e.g., size charateristics of retouched pieces; blank retouch types; tool types; the average maximum retouch extent and the average maximum retouch depth) were taken into account for inter-site comparison.

## Note 3. Refitting study

The Cenjiawan site, with a relative high refitting rate of stone artefacts (33.4 %, or 462 pieces of 1383 artefacts), was selected in order to conduct a study of stone tool knapping skills and to assess the cognitive ability of early humans. Previous refitting studies [19-22] provided important background information on knapping sequences. Most of the refitting groups are from an area of 5m2, including the excavation of units M, N, O, P and Q (each unit is 1mx1m). The maximum distance in vertical depth of refits is ca. 16 cm (Supplementary Figure 5).

In describing the refitting artefact sets, we follow Cziesla [23] in distinguishing between refits and conjoins. Refits are sets of artefacts split from each other by controlled fracture (e.g., a flake whose ventral side joins to the surface of a core or the dorsal surface of another flake). Conjoins are fragments of formerly whole artefacts broken by forces other than conchoidal fracture (i.e., natural flaws, bending fractures). The most common form of conjoins are distal and proximal fragments of the same flake, or the left and the right fragments of the same flake. In our study, we checked the previously refit artefacts and obtained 105 refitted groups and 41 conjoined groups. To reconstruct knapping sequences, we used the refitted group data, examining the type of the exploitation methods that the prehistoric knappers employed.

**Note 4. Dating results of Xiaochangliang and Donggutuo**

Magnetostratigraphic dating of the fluvio-lacustrine sequence in the Nihewan Basin has been a significant undertaking, permitting evaluation of the timing of basin infilling and dating of associated mammalian faunas and archaeological sites [2,24-25]. Magnetostratigraphic dating of long stratigraphic sequences requires assumptions about sedimentation rates, hence anchoring of age estimates are always best achieved through the application of multiple chronometric methods. Though debated and subject to change, overall, magnetochronological findings indicate that the earliest archeological sites of the fluvio-lacustrine Nihewan Beds date from the post-Olduvai Matuyama chron (~1.66 Ma for MJG-III) to the middle Brunhes chron (ca. 395 ka for Hougou)[26].

The site of Xiaochangliang has four estimated ages. In the current study, we cited the result of 1.36 Ma by Zhu et al. (2001) [25]. Here we summarise other age estimates and their potential problems:

* The age of 1.48 Ma is from Ao et al. (2010) [27] was obtained through stratigraphic correlation between the Dachangliang (also named Xiantai) section and the Xiaochangliang section. Thus, the age estimate of 1.48 Ma for the Xiaochangliang section is obtained indirectly.
* The age estimate of 1.26 Ma was obtained on the basis of sedimentological comparisons and sediment grain size distributions from the Xiaodukou and Xiaochangliang sections [28]. In Li et al.’s paper [28], magnetostratigraphic studies were carried out on the Xiaodukou and Donggutuo sections, not on the Xiaochangliang section. Therefore, the age of 1.26 Mais an indirect age estimate.
* The age of 1.67 Ma was obtained based on the presence of certain types of mammalian fauna,as well as unpublished information about the magnetostratigraphy, informally provided by other scientists [29]. According to palaeomagnetic results obtained using cryogenic magnetometers, e.g., Zhu et al. (2001) [25] and Li et al. (2008) [28], the Xiaochangliang cultural layer is not located just above the Olduvai normal subchron.Thus, its age should be significantly younger than the age of the upper boundary of Olduvai (1.77 Ma).

Taking into account the above-mentioned age estimates for the Xiaochangliang site, a range from 1.67 Ma to 1.26 Ma has been suggested [28-29]. However, we maintain that the age of 1.36 Ma obtained by Zhu et al. (2001) is the best age estimate for the Xiaochangliang site, and fits well in the synthetic diagram from well-dated sections in the Nihewan Basin [25].

Magnetostratigraphic dating of the Donggutuo cultural layers has been conducted by several scholars since 1980s’ [30-32], and these dating projects have obtained similar results. According to the latest dating work [28,32], the age of the Donggutuo cultural layer is prior to the onset of Jaramillo normal subchron, which has been dated at 1.053±0.006 Ma [33]or 1.072 Ma [34]. The detailed magnetostratigraphic work by Wang et al. (2005) described the short interval with a possible geomagnetic excursion (E3) within the pre-Jaramillo Matuyama reverse chron (and also within the Donggutuo artifact layer) [32]; this may be correlated to the Punaruu normal geomagnetic excursion, which has an 40Ar/39Ar age determination of 1.105 ± 0.005 Ma [33]. This lends further support to the contention that the Donggutuo Palaeolithic site has an age of about 1.1 Ma [32].

**Note 5. Timing of the Mid-Pleistocene climate transition (MPT)**

Milanković’s theory suggested that orbitally induced summer insolation change at high-latitude region of the Northern Hemisphere played a key role in driving the ice cycles during the Pleistocene [35]. A significant shift occurred around the end of Early Pleistocene, and afterward into the Middle Pleistocene, with the length and intensity of the glacial-interglacial cycles significantly increasing, and with the dominant periodicity of high-latitude climate oscillations changing from 41 kye to 100 kyr. These significant changes in climate is named the mid-Pleistocene climate transition (MPT). Since its first recognition by Pisias and Moore (1981) [36], there have been extensive discussions about timing, duration, and mechanisms [37-43].

The timing of MPT is of importance when discussing the topic on human evolution. The MPT began at about 1.25 Ma [39] or about 1−0.8 Ma [44-47] and terminated at about 0.7–0.6 Ma [46-47]. Correlation between the grain size records of Chinese loess-paleosol sequence and the marine oxygen isotope records revealed a change in the dominant climatic periodicity from 41 kyr to 100 kyr at about 1–0.8 Ma [44].

**Supplementary Tables**

**Supplementary Table 1.** Lithic assemblage components and refitting information from Cenjiawan

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Category** | **Current study** | **%** | **refitted** | **% refitted** |
| Core (Freehand) | 61 | 3.78 | 25 | 40.98 |
| Flake (Freehand) | 282 | 17.45 | 119 | 42.20 |
| Flake fragment | 324 | 20.05 | 73 | 22.53 |
| Bipolar Core and splinter | 18 | 1.11 | 2 | 11.11 |
| Retouched pieces | 54 | 3.34 | 16 | 29.63 |
| Shatter | 681 | 42.14 | 81 | 13.11 |
| Angular fragment | 173 | 10.71 | 95 | 54.91 |
| Pebble/unmodified pieces | 23 | 1.42 | - | - |
| TOTAL | 1616 | 100 | 411 | 25.43 |

**Supplementary Table 2.** Overall count of refitting groups from Cenjiawan

|  |  |  |
| --- | --- | --- |
| **No. of pieces per refitting group** | **No. of refitting groups** | **Total** |
| 2 | 42 | 84 |
| 3 | 21 | 63 |
| 4 | 13 | 52 |
| 5 | 9 | 45 |
| 6 | 8 | 48 |
| 7 | 4 | 28 |
| 8 | 1 | 8 |
| 9 | 3 | 27 |
| 10 | 2 | 20 |
| 11 | 1 | 11 |
| 25 | 1 | 25 |
| -- | 105 | 411 |

**Supplementary Table 3.** Flaking direction among the refitted groups from Cenjiawan

|  |  |  |
| --- | --- | --- |
| **The direction no.** | **No. of groups** | **% of the refitted group** |
| One direction | 66 | 62.86 |
| Two directions | 25 | 23.81 |
| Three directions | 11 | 10.48 |
| Four directions | 3 | 2.86 |
| TOTAL | 105 | 100 |

**Supplementary Table 4.** Lithic assemblage components from Xiaochangliang (XCL), Donggutuo (DGT) and Cenjiawan (CJW)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Lithic class** | **XCL** | **%** | **DGT** | **%** | **CJW** | **%** |
| Core (Freehand) | 43 | 3.63 | 245 | 10.58 | 61 | 3.78 |
| Flake (Freehand) | 160 | 13.51 | 380 | 16.41 | 282 | 17.45 |
| Flake fragment | 129 | 10.90 | 300 | 12.96 | 324 | 20.05 |
| Bipolar Core and splinter | 439 | 37.08 | 269 | 11.62 | 18 | 1.11 |
| Retouched pieces | 45 | 3.80 | 228 | 9.85 | 54 | 3.34 |
| Shatter | 292 | 24.66 | 558 | 24.11 | 681 | 42.14 |
| Angular fragment | 76 | 6.42 | 335 | 14.47 | 173 | 10.71 |
| Pebble/ unmodified pieces | -- | -- | -- | -- | 23 | 1.42 |
| TOTAL | 1184 | 100 | 2315 | 100 | 1616 | 100 |

**Supplementary Table 5.** Cores from Xiaochangliang (XCL), Donggutuo (DGT) and Cenjiawan (CJW) (in mm).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Length** | | **Width** | | **Thickness** | |
| **Mean** | **Std.D** | **Mean** | **Std.D** | **Mean** | **Std.D** |
| XCL | 52.7 | 28.8 | 47.7 | 23.9 | 35.2 | 19.2 |
| DGT | 37.80 | 16.43 | 49.53 | 20.29 | 36.18 | 19.97 |
| CJW | 33.07 | 13.9 | 40.44 | 23.04 | 29.74 | 33.1 |

**Supplementary Table 6.** Statistical tests results of the cores’ maximum length from Xiaochangliang (XCL), Cenjiawan(CJW) and Donggutuo(DGT)

|  |  |  |
| --- | --- | --- |
| **The** **compared pair** | **Student's t test results (P value)** | **Mann-Whitney U test (P value)** |
| CJW-DGT | 0.1038 | 0.0678 |
| CJW-XCL | <0.01 | <0.01 |
| DGT-XCL | <0.05 | <0.05 |

**Supplementary Table 7.** Tool types from Xiaochangliang (XCL), Donggutuo (DGT) and Cenjiawan (CJW)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Tool type** | **XCL** | **%** | **DGT** | **%** | **CJW** | **%** |
| Scraper | 32 | 71.11 | 176 | 77.19 | 38 | 70.37 |
| Borer | 3 | 6.67 | 10 | 4.38 | 4 | 7.41 |
| Notch | 4 | 8.88 | 17 | 7.46 | 4 | 7.41 |
| Denticulate | 3 | 6.67 | 5 | 2.19 | 2 | 3.7 |
| Pointed tool | -- | -- | 3 | 1.32 | -- | -- |
| Unidentified | 3 | 6.67 | 17 | 7.46 | 6 | 11.11 |
| Total | 45 | 100 | 228 | 100 | 54 | 100 |

**Supplementary Table 8.** Dating estimates and endocranial capacity of fossil hominins from China

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **No.** | **Hominid cranial** | **Age (Ma)** | **Brain size (cc)** | **Dating ref.** | **Brain size ref.** |
| 1 | Gongwangling | 1.61 | 780 | [48] | [49] |
| 2 | Zhoukoudian II | 0.77±0.08 | 1030 | [50] | [49] |
| 3 | Zhoukoudian VI | 0.77±0.08 | 850 | [50] | [49] |
| 4 | Zhoukoudian X | 0.77±0.08 | 1225 | [50] | [49] |
| 5 | Zhoukoudian XI | 0.77±0.08 | 1015 | [50] | [49] |
| 6 | Zhoukoudian XII | 0.77±0.08 | 1030 | [50] | [49] |
| 7 | Zhoukoudian III | 0.77±0.08 | 937.5 | [50] | [49] |
| 8 | Hexian | 0.41 | 1305 | [51] | [49] |
| 9 | Hualongdong | 0.30 | 1150 | [52] | [49] |
| 10 | Dali | 0.281+0.046/-0.041 | 1160 | [53] | [49] |
| 11 | Xuchang | 0.125-0.105 | 1800 | [54] | [54] |
| 12 | Upper Cave 101 | 0.035-0.033 | 1500 | [55] | [49] |
| 13 | Upper Cave 102 | 0.035-0.033 | 1380 | [55] | [49] |
| 14 | Upper Cave 103 | 0.035-0.033 | 1290 | [55] | [49] |

**Supplementary Figures**



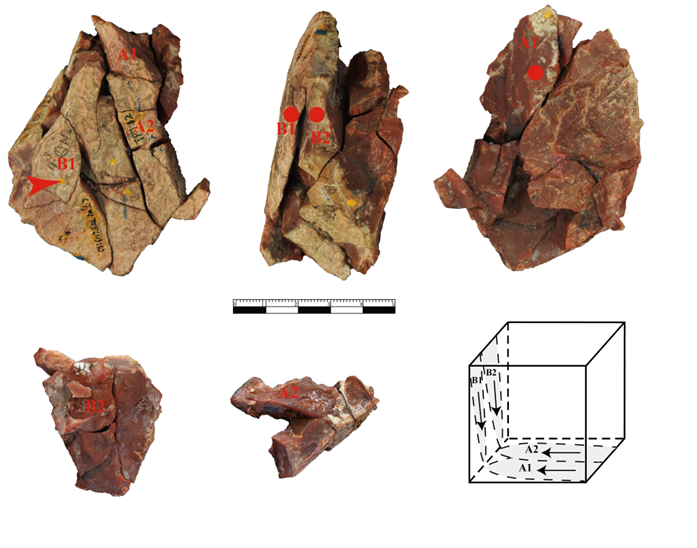
**Supplementary Figure 1. Fluvio-lacustrine deposits in Nihewan Basin of North China**

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**Supplementary Figure 2.** Conjoined pieces from Cenjiawan

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**Supplementary Figure 3.** Examples of simple refitting groups among flakes at Cenjiawan. Flake refits in these groups provide information about reduction sequences and core exploitation methods.



**Supplementary Figure 4.** A well-defined refitting group including a finely retouched tool from Cenjiawan. This refitting group consists of 35 pieces, including a retouched piece, broken flakes and broken flake fragments. This refitting group is a two directional reduction sequence. No whole flakes were produced. A long flake was used to produce a borer. The tip of the borer was made at the middle portion of the flake, along a single lateral edge.

**Supplementary Figure 5.** Cores sizes from Xiaochangliang (XCL), Donggutuo (DGT) and Cenjiawan (CJW)



**Supplementary Figure 6.** Tool types with diagnostic characteristics (1. Denticulate; 2. Borer; 3. Notch)

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**Supplementary Figure 7.** Representative tool types from Xiaochangliang (XCL), Donggutuo (DGT) and Cenjiawan (CJW). Nos. 1, 2 from DGT and No. 1 from CJW are intentionally retouched borer tips. Scrapers with long and strait retouched ends were identified in the three assemblages (XCL-2, 3; DGT-3, 4; CJW-2, 3, 4); in the latter two the retouch scars were more invasive and regular.

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**Supplementary Figure 8.** The plan and profile of refitting groups at Cenjiawan. Most of the refitting groups are from an area of 5 m2, including excavation units M, N, O, P and Q (each unit is 1x1 m). The maximum distance in vertical depth of refits is ca. 16 cm [21].

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