

<https://helda.helsinki.fi>

---

## Rediscovery and stratigraphic calibration of the classic Nihewan Fauna, Hebei Province, China

Farjand, Arya

2023-02-10

---

Farjand , A , Zhang , Z , Kaakinen , A , Bi , S , Gibbard , P L & Wang , L 2023 , ' Rediscovery and stratigraphic calibration of the classic Nihewan Fauna, Hebei Province, China ' , Quaternary International , vol. 646 , pp. 1-10 . <https://doi.org/10.1016/j.quaint.2022.12.001>

---

<http://hdl.handle.net/10138/354944>

<https://doi.org/10.1016/j.quaint.2022.12.001>

---

cc\_by\_nc\_nd

publishedVersion

---

*Downloaded from Helda, University of Helsinki institutional repository.*

*This is an electronic reprint of the original article.*

*This reprint may differ from the original in pagination and typographic detail.*

*Please cite the original version.*



## Rediscovery and stratigraphic calibration of the classic Nihewan Fauna, Hebei Province, China

Arya Farjand<sup>a</sup>, Zhaoqun Zhang<sup>b,c,d,\*</sup>, Anu Kaakinen<sup>f</sup>, Shundong Bi<sup>a,e</sup>, Philip L. Gibbard<sup>g</sup>, Wang Lihua<sup>a</sup>

<sup>a</sup> Centre for Vertebrate Evolutionary Biology, School of Life Sciences, Yunnan University, Kunming, China

<sup>b</sup> Key Laboratory of Vertebrate Evolution and Human Origins of Chinese Academy of Sciences, Institute of Vertebrate Paleontology and Palaeoanthropology, Chinese Academy of Sciences, Beijing, 100044, China

<sup>c</sup> College of Earth and Planetary Sciences, University of Chinese Academy of Sciences, Beijing, 100049, China

<sup>d</sup> CAS Center for Excellence in Life and Paleoenvironment, Beijing, 100044, China

<sup>e</sup> Department of Biology, Indiana University of Pennsylvania, Indiana, PA, USA

<sup>f</sup> Department of Geosciences and Geography, University of Helsinki, P.O. Box 64, Helsinki, 00014, Finland

<sup>g</sup> Scott Polar Research Institute, University of Cambridge, Cambridge, CB2 1ER, UK

### ARTICLE INFO

#### Keywords:

Classic Nihewan fauna  
Xiashagou  
Early pleistocene  
Emile licent

### ABSTRACT

The classic Nihewan Fauna, as the representative of early Pleistocene Asian Land Mammal Age Nihewanian, has long been cited for bio- and chronostratigraphic correlation. However, its precise provenance and stratigraphic horizon have remained unsolved till now. The authors successfully extracted the vital information by rediscovering 30 of the original excavation localities. The fossils were catalogued with their provenance through an extensive field survey and comprehensive inspection of the Tianjin Natural History Museum collection. A review of the original description of these fossil localities, using satellite images, and subsequent lithological examination of the Xiashagou strata in the field verified the new findings. The survey produced the first stratigraphic profile calibrated with fossil horizons of the Nihewan formation in the Xiashagou section. Correlated with the published magnetostratigraphical profile of the section, an age of ~2.4–1.8 Ma is estimated for the classic Nihewan Fauna.

### 1. Introduction

The classic Nihewan Fauna, as the representative of early Pleistocene Asian Land Mammal Age Nihewanian, has long been cited for bio- and chronostratigraphic correlation. However, its precise provenance and stratigraphic horizon have remained unsolved till now.

Initiated from 1922, George B. Barbour, a young Scottish geologist participating in the Asiatic Expeditions, undertook the geological survey in the Kalgan area (Zhangjiakou). During his exploration in 1922–25, he and a French missionary Emile Licent, for the first time, reported the mammalian fossil record in the Nihewan Basin (Barbour, 1924, 1925; Barbour et al., 1926), 150 km northeast of Beijing, Hebei Province (Fig. 1).

In the following years (1925–1929), Licent undertook excavations around the Nihewan village by hiring local villagers and recording daily

events (Licent, 1935). They described the Nihewan Formation as the strata underlying loess (Malan Loess) and overlying the late Pliocene *Hipparion* unit (Shixia Formation). The excavations in the Nihewan Formation around the Xiashagou village unexpectedly unearthed approximately 2000 fossil specimens (Fig. 2). These specimens were eventually transported to Tianjin (currently the Tianjin Natural History Museum).

While the excavations in the Nihewan Basin were ongoing (1924–1934), a French philosopher, vertebrate palaeontologist, and Jesuit priest, Pierre Teilhard de Chardin, began studying these specimens (Teilhard de Chardin and Piveteau, 1930). Their investigations revealed that the Nihewan Fauna includes various families of large mammals (Table 1) of Pleistocene age. These taxa, solely discovered from the strata near the Xiashagou village, are widely cited as the classic Nihewan Fauna. Since then, this classic Nihewan Fauna has frequently

\* Corresponding author. Key Laboratory of Vertebrate Evolution and Human Origins of Chinese Academy of Sciences, Institute of Vertebrate Paleontology and Palaeoanthropology, Chinese Academy of Sciences, Beijing 100044, China.

E-mail address: [zhangzhaoqun@ivpp.ac.cn](mailto:zhangzhaoqun@ivpp.ac.cn) (Z. Zhang).

<https://doi.org/10.1016/j.quaint.2022.12.001>

Received 31 August 2022; Received in revised form 1 December 2022; Accepted 7 December 2022

Available online 15 December 2022

1040-6182/© 2022 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

been compared to that of the European Villafranchian (Qiu, 2000).

The discovery of mammalian fossils from the Nihewan Basin demonstrated the palaeontological importance of these deposits. However, the outbreak of the Second World War curtailed further palaeontological studies of the Nihewan strata (e.g., Shixia, Daodi, Nihewan, Malan Formations), ranging from Pliocene to Late Pleistocene. Following the hiatus, during the 1970s–1980s, a new generation of Chinese palaeontologists undertook further excavations. These excavations revealed over a dozen new localities (Wei, 1976; You et al., 1979; Tang et al., 1981; Zheng, 1981; Y. Li, 1984b) and also produced important Palaeolithic sites (Gai and Wei, 1974; Chia et al., 1979; Wei et al., 1985; Feng and Hou, 1998; Schick and Toth, 2011; Yang et al., 2016), which yielded globally significant evidence of early human occupation in East Asia. Nevertheless, discovering new sites across the Nihewan Basin further broadened the understanding of the age range represented by the Nihewan strata. This gave rise to a significant debate among workers regarding the correlation of different exposures. Therefore, further studies have endeavoured to clarify the relationship between the newly established fossil localities. In particular, the recovery and identification of small mammals in the basinal deposits marked a significant advancement in the biostratigraphy of the Nihewan strata (Cai, 1987; Zhang et al., 2003). Based on the appearance of various small mammals Cai et al. (2013) distinguished five assemblage biozones, three of which were assigned to the Nihewan Formation.

The excavations in the Nihewan Basin proved the continuous presence of mammalian taxa in the Nihewan strata during the Plio-Pleistocene. However, the Nihewan studies mainly neglected the biostratigraphic status of these faunas (e.g., Daodi, Danangou, classic Nihewan). Consequently, the detailed chronology of the classic Nihewan Fauna and their lithostratigraphical context in the Xiashagou section remain obscure. This possibly results from the lack of knowledge of the precise find sites and stratigraphic setting of the classic Nihewan faunal discoveries. The importance of determining stratigraphical sequence, together with the palaeontological value of the classic Nihewan Fauna, provoked the writers to undertake extensive fieldwork in the Xiashagou sections. Therefore, all the available information concerning the classic Nihewan Fauna and their original excavation sites was assembled and is

assessed herein.

## 2. Geological settings, material and methods

A lithostratigraphical study of the Xiashagou section was conducted at five locations (Fig. 3). The outcrops were selected taking into account the degree of exposure and their proximity to the fossil localities and previous paleomagnetic sampling sites. The base of the composite section was situated south of the Xiashagou village, where the lowest visible portion of the Nihewan Formation is exposed. The deposits in the individual sections were traced laterally by using Abney level and Jacob's staff, while the lithological changes were observed between the outcrops.

The measurements were recorded at four additional localities, Global Positioning System (GPS) data and a digital range finder were used to detect elevation changes of sedimentary beds. Combining these data and the regional measurements of dip and strike at each site provided the three-dimensional structure of the sedimentary units in the Xiashagou section. These data show that the Xiashagou strata dip gently ( $2^{\circ}$ – $3.5^{\circ}$ ) towards the southeast and reach a total thickness of c.116 m (the precise thickness of the deposits varies across their distribution area). The GPS and Barometer data also showed that the Xiashagou Basin is located at 797 m (near the Sanggan river bed) to 1066 m (North of Xiashagou valley) above sea level.

The materials referred to as comprising the Nihewan Fauna in this study principally consist of the original fossil mammal remains collected by E. Licent during his 1920s excavations. Most of these specimens, except those transported to the Muséum National d'Histoire Naturelle in Paris, are housed in the Tianjin Natural History Museum and consist of roughly 1600 specimens. Since then, these materials have been partially examined by various palaeontologists. The second author, during his visit, discovered the unique identification numbers preserved on some specimens related to their excavation localities (Fig. 2). These numbers consist of the precise or general time of their discovery and locality (i.e., 3 VII 29-4 or 1925–18). Subsequently, the first author catalogued these specimens based on their taxonomical identification. In addition, this catalogue includes a short description of each specimen and the

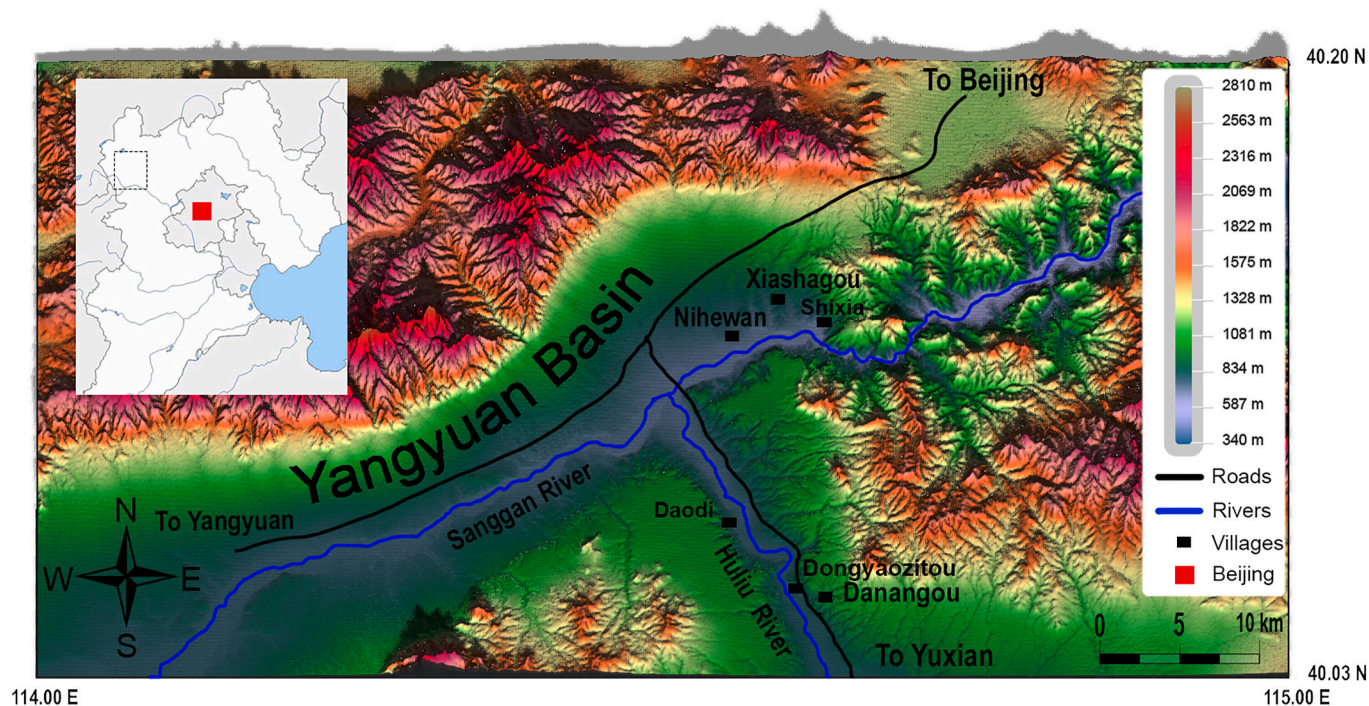


Fig. 1. The location of Nihewan (Xiashagou section) and Danangou palaeontological sites in the Nihewan Basin.

lithology at the original excavation site (Fig. 2).

To identify the original excavation sites of the classic Nihewan fauna, the first author reviewed E. Licent's diaries that record his expedition in China, particularly the time he spent excavating at the Xiashagou valley. This series incorporates several hand-drawn maps that show the relative locations of some of these sites around Xiashagou village (Fig. 3). However, topographical changes and the expansion of agricultural activities during the last century have made these maps difficult to use for accurate positioning. The maps were therefore compared to satellite images to pinpoint each site's possible locality (Table 2). For this purpose, the original map was redrawn and rescaled using the satellite image of the Xiashagou valley. By adjusting the lines with the centre of the gullies, it was possible to pinpoint the localities marked on the original map on the satellite images (Fig. 3).

The fieldwork was conducted from 2017 to 2019. All the gullies and original fossil find sites marked on satellite images were visited during the field seasons. By visiting these places, comparing the depositional sequences, and recovering fossilised remains, it was possible to confirm the localities of some of these sites. The deposits were logged at each of these sites.

Thickness, grain size, structure, colour, hardness, and presence of fossils, together with any noticeable features of each unit, were recorded. These features were then compared to sediments attached to the semi-prepared specimens with valid locality numbers in the Tianjin Natural History Museum (TNHM). After finding equivalent sediments, a Jacob's staff and range finder were used to trace the newly rediscovered fossil beds to their precise locality in the nearest measured stratigraphical section. Abbreviations are defined in Appendix 1.

A basin-wide lithostratigraphic framework, as reviewed by Cai et al. (2013), consists of Pliocene red clay (Shixia Formation), late Pliocene fine-grained fluviolacustrine and palustrine Daodi Formation, Pleistocene Nihewan Formation and late Pleistocene Malan loess. Although overlapping/synonymous and finer divisions exist, they have not gained wide acceptance.

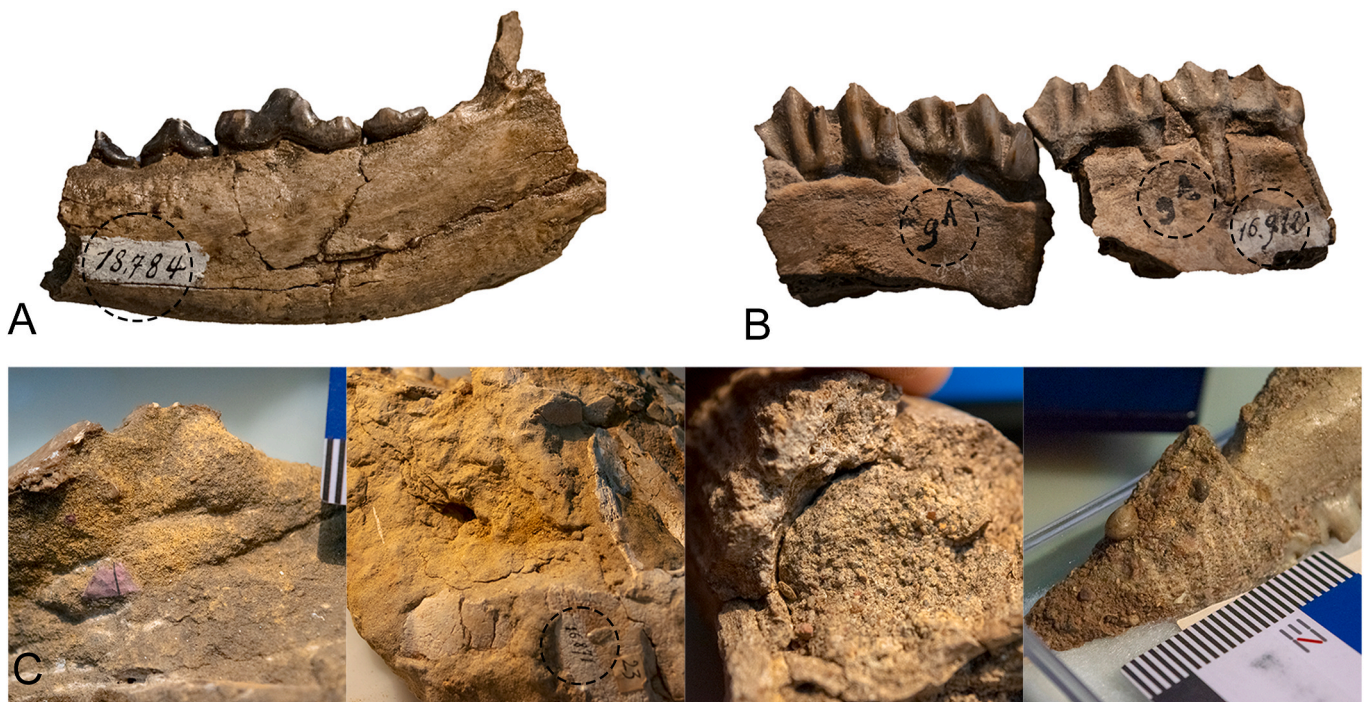
Previous studies of the Nihewan Formation revealed that the

**Table 1**

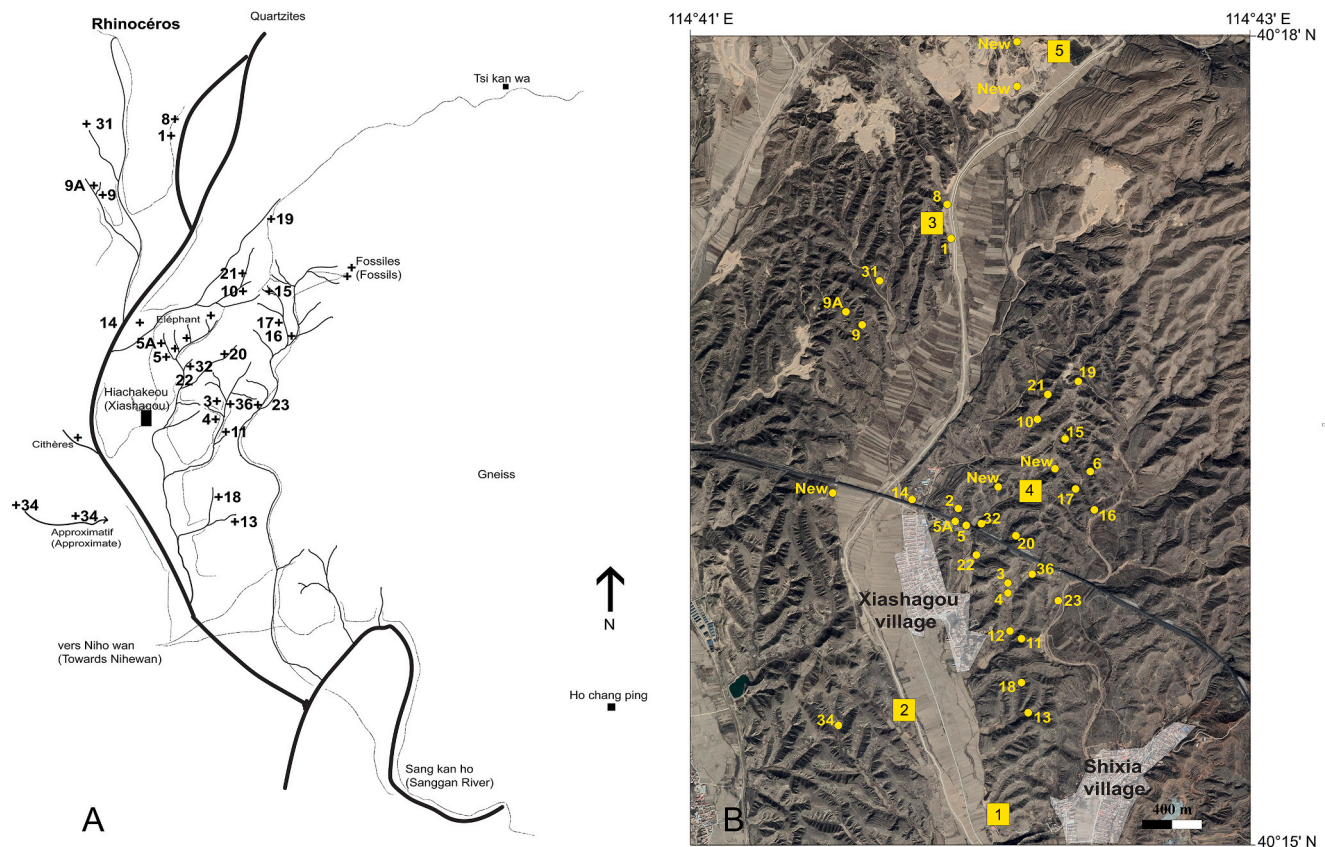
Identified fossil specimens of large mammals by Pierre Teilhard de Chardin and Jean Piveteau.

Family	Genus	Species
Elephantidae	<i>Elephas</i>	<i>namadicus</i>
Rhinocerotidae	<i>Rhinoceros</i>	<i>sinensis</i>
	<i>Rhinoceros</i>	cf. <i>tichorhinus</i>
	<i>Elasmotherium</i>	sp.
Chalicotheriidae	<i>Chalicotherium</i>	sp.
Equidae	<i>Hipparion (Proboscipparion)</i>	<i>sinensis</i>
	<i>Equus</i>	<i>sanmeniensis</i>
Suidae	<i>Sus</i>	cf. <i>lydekkeri</i>
Camelidae	<i>Camelus (Paracamelus)</i>	<i>gigas</i>
Cervidae	<i>Cervulus</i>	cf. <i>sinensis</i>
	<i>Cervus (Elaphurus)</i>	<i>bifurcatus</i>
	<i>Cervus (Eucladoceros)</i>	<i>boulei</i>
	<i>Cervus (Rusa)</i>	<i>elegans</i>
Bovidae	<i>Gazella</i>	<i>sinensis</i>
	<i>Gazella</i>	cf. <i>subgutturosa</i>
	Antilope	gen. indet.
	<i>Spirocerus</i>	<i>wongi</i>
	<i>Ovis</i>	<i>shantungensis</i>
	Ovibovine	gen. indet.
	<i>Bison</i>	<i>palaeosinensis</i>
	<i>Vulpes</i>	sp.
Canidae	<i>Canis (Nyctereutes)</i>	<i>sinensis</i>
	<i>Canis</i>	<i>chihliensis</i>
Ursidae	<i>Ursus</i>	cf. <i>etruscus</i>
Hyaenidae	<i>Hyaena</i>	<i>sinensis</i>
Mustelidae	<i>Lutra</i>	<i>Licenti</i>
	<i>Mustela</i>	<i>pachygnatha</i>
	<i>Meles</i>	cf. <i>leucurus</i>
Felidae	<i>Felis (Lynx)</i>	sp.
	<i>Cynailurus</i>	<i>pleistocaenicus</i>
	<i>Machairodus</i>	<i>nihowanensis</i>

deposits could be divided into four members, the gravel and sand, marl, yellow sand, and the sandy clay units each with distinctive lithology and micro-macrofossil assemblages (Liu and Xia, 1983; Cai et al., 2004;



**Fig. 2.** Examples of the fossil specimens catalogued in the Tianjin Natural History Museum and the sediment attached to the specimens used for rediscovering the fossil localities: A. Mandible fragments of *Nyctereutes sinensis*; B. Broken maxilla of a cervid, Loc. 9A; C. From left to right Specimen TNP15175, *Cervus* sp., Loc. 4.; Specimen THP16871, *Cervus* sp., Loc. 23.; Specimen TNP15557, *Ovis ammon*, Loc. 9A.; Specimen THP16790, *Cervus* sp.; Loc. 5. Note the attached sediment on the specimens and the locality numbers (9A, 23).



**Fig. 3.** Rediscovered original fossil localities of the classic Nihewan fauna in the Xiashagou section A. The redrawn version of the original hand-drawn map by Emile Licent. B. Satellite image of the Xiashagou section. The yellow dots show the rediscovered original excavation sites based on a combination of satellite imagery and fieldwork. Numbers 1 to 5 show the sites of the stratigraphical logs. (The high resolution of each image provided as the digital supplementary). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Wang et al., 2013). However, the appearance of more primitive fossils than the classic Nihewan Fauna in the Danangou gully near the village Dongyaozitou (Tang and Ji, 1983) and the Late Pliocene Daodi Formation and fauna (Du et al., 1988) exposed the basal part of the Nihewan Formation and the underlying strata. The Dongyaozitou faunal composition and magnetostratigraphy suggested that the deposits dated from the transitional Plio-Pleistocene period (Tang and Ji, 1983; Li, 1984a), while the Daodi Formation and fauna is of Late Pliocene origin (Du et al., 1988). The most recent magnetostratigraphical profiles of these two sections show that the Danangou fauna is comparable with the classic Nihewan Fauna. At the same time, the Dongyaozitou Fauna occurs below the Gauss/Matuyama paleomagnetic boundary (Liu et al., 2021), and is therefore older than 2.6 Ma. Nonetheless, the present study demonstrates the absence of the Dongyaozitou fauna and deposits around the Xiashagou valley, indicating that the Nihewan Formation in the Xiashagou section directly overlies the Early Pliocene Shixia Formation.

The onset of the Nihewan Formation in the Xiashagou section is represented by thick layers of gravel at its base that directly overlie the basal unconformity on the Shixia Formation. The magnetostratigraphy of the strata underlying the Nihewan Formation near the Xiashagou section shows that the Red Clay in the Shixia profile is slightly younger than the Lower Pliocene Cochiti Subchron, the basal age of which is 4.19 Ma (Liu et al., 2018). The outcropping Nihewan Formation has yielded different basal ages throughout the basin. While a basal age of ca 3.7 Ma has been reported in the Yangshuizhan section, close to the depocentre of the basin (Ao et al., 2013), the magnetostratigraphic age estimation for the base of the Nihewan Basin in the Xiashagou section is < 2.8 Ma (i.e. the late Gauss Chron) (Liu et al., 2012), supported by the cosmogenic  $^{26}\text{Al}/^{10}\text{Be}$  burial dating of Tu et al. (2022).

Following the proposal by Liu and Xia (1983) and Cai et al. (2013) to divide the Nihewan Formation into four members, Cai et al. (in Wang et al., 2013) recommended that the Danangou section to be defined as a stratotype of the Nihewan Formation. However, the discovery of hominin remains and artefacts in the Nihewan Basin necessitated the exploration of the upper member of the Nihewan Formation. In common with the lower member, the stratigraphical interpretation of the upper part of the formation deposits also continues to be debated. A comprehensive investigation required clarifying the onset and termination of the Nihewan formation in the Lower and Upper members, respectively. In the Xiashagou section (Cai et al., 2013), the upper part of the Nihewan Formation is overlain by the latest Pleistocene Malan Loess, showing that erosion of the upper member of the Nihewan Formation had occurred throughout the Middle or even Late Pleistocene. The Malan loess deposit forms a distinctive topography across the basin, the erosional basal contact marking the upper boundary of the Nihewan Formation. The magnetostratigraphy of the Xujiayao Palaeolithic sites suggested that some of the hominin sites might occur slightly below the Matuyama-Brunhes (M/B) magnetic boundary (0.78 Ma; Fan et al., 2002). However, the more recent cosmogenic nuclide dating and electron-spin resonance (ESR) showed that this cultural stratum is located above the Matuyama-Brunhes magnetic boundary (Tu et al., 2015; Ao et al., 2017). The most prominent archaeological localities, including those at Maliang, Feiliang, and Majuangou, near the Xiashagou section (Zhu et al., 2007; Li et al., 2008; Liu et al., 2010), have since been substantially excavated. Subsequently, the age estimation for sites close to Xiashagou suggests younger ages (c.0.78 to 1.66 Ma) compared to the Xiashagou units and its contained classic Nihewan Fauna that have an estimated age of c. 2.2–1.7 Ma (Ao et al., 2012; Liu et al., 2012). Consequently, regarding the age estimation of these strata,

**Table 2**

The Global Positioning System (GPS) coordinates of original fossil localities. MNHN: Muséum national d'Histoire naturelle.

Locality number	Specimen in Tianjin	Specimen in MNHN	Marked in original maps	Latitude	Longitude
1	62	3	Yes	40°17'35.36"N	114°42'29.93"E
2	66	0	Yes	40°16'47.79"N	114°42'36.77"E
3	221	23	Yes	40°16'33.73"N	114°42'47.41"E
4	110	11	Yes	40°16'32.08"N	114°42'46.43"E
5	74	6	Yes	40°16'44.66"N	114°42'35.31"E
6	51	2	Yes	40°16'53.86"N	114°43'5.61"E
7	23	0	No	40°15'52.86"N	114°41'21.00"E
8	136	0	Yes	40°17'39.45"N	114°42'28.20"E
9	101	5	Yes	40°17'19.16"N	114°42'9.16"E
10	39	3	Yes	40°17'4.06"N	114°42'52.40"E
11	151	3	Yes	40°16'23.90"N	114°42'49.85"E
12	4	0	Yes	40°16'25.03"N	114°42'46.34"E
13	12	2	Yes	40°16'8.40"N	114°42'51.39"E
14	1	0	Yes	40°16'45.70"N	114°42'26.11"E
15	68	1	Yes	40°16'59.72"N	114°42'59.43"E
16	1	1	Yes	40°16'48.39"N	114°43'8.21"E
17	10	2	Yes	40°16'51.16"N	114°43'3.12"E
18	6	0	Yes	40°16'13.56"N	114°42'49.96"E
19	0	0	Yes	40°17'11.47"N	114°43'1.19"E
20	1	2	Yes	40°16'42.34"N	114°42'46.23"E
21	1	0	Yes	40°17'8.04"N	114°42'53.34"E
22	3	1	Yes	40°16'38.97"N	114°42'37.87"E
23	21	1	Yes	40°16'29.53"N	114°42'58.53"E
24	0	0	No	–	–
25	3	0	No	–	–
26	0	0	No	–	–
27	0	0	No	–	–
28	1	0	No	–	–
29	4	0	No	–	–
30	0	0	No	–	–
31	2	2	Yes	40°17'27.36"N	114°42'11.60"E
32	12	26	Yes	40°16'43.39"N	114°42'38.13"E
33	1	0	No	40°15'33.84"N	114°41'0.96"E
34	20	0	Yes	40°16'4.83"N	114°42'4.97"E
35	0	1	No	–	–
36	2	1	Yes	40°16'34.79"N	114°42'53.58"E
5A	60	8	Yes	40°16'45.62"N	114°42'33.70"E
6A	1	0	No	–	–
9A	14	2	Yes	40°17'20.22"N	114°42'6.35"E

these sites are equivalent to the Nihewan Formation's upper member.

### 3. Results

During his expedition in the Nihewan Basin, Licent recorded the localities near Xiashagou village, assigning each an individual number. These numbers range between 1 and 36, together with localities 5A, 6A, and 9A, which are adjacent to localities 5, 6, and 9. Additionally, several sites are designated by species names (i.e., Elephant, *Fossiles* [in French], *Rhinoceros*, etc.).

Twenty-eight of these original excavation sites have been rediscovered by the authors based on the original map Licent drew. These localities produced 81% of the classic Nihewan Fauna housed in the Tianjin Natural History Museum (Table 2). However, the cataloguing of these specimens involves 33 localities with designated specimens. This implies that the localities 19, 24, 26, 27, 30 and 35 have no fossils preserved in neither the Tianjin Natural History Museum nor the Muséum national d'Histoire Naturelle in Paris. Therefore, it is concluded that the localities lacking designated specimens result from improper secondary preparation, erasing and missing original descriptions or labels.

In addition, the absence of localities 24, 25, 26, 27, 28, 29, 30, 33, 35 and perhaps 6A in the original maps possibly results from the ambiguity in the place of early excavation by villagers and uncertainties by Licent in recording the precise place of discovery on his hand-drawn map. Here the precise GPS coordinates for the 30 confirmed sites are presented (Table 2).

The outcrops at localities 5, 5A, 14, 20, 32, and 36 had been

significantly modified during the subsequent railway construction. Consequently, although 193 fossil specimens could be assigned to these localities, these specimens or their excavation sites were not included in the analysis presented herein.

The fossil localities and lithostratigraphical sequences were correlated to the previously published magnetostratigraphical profile of the Xiashagou section (Liu et al., 2012; Tu et al., 2022). Therefore, the biostratigraphy indicates the age of the classic Nihewan Fauna based upon previously established evidence. The combination of this information confirms the Early Pleistocene age of the classic Nihewan fauna (2.4–1.8 Ma). It is also concluded that at least six fossil assemblage zones can be identified within this period.

#### 3.1. The lower member of the Nihewan Formation

The proposed type section of this member is located at the base station from which the Xiashagou 1 profile was measured (Fig. 4). The lower member is up to 15 m thick and is characterised by the prevalence of dark brownish clays and silts that commonly exhibit horizontal lamination. Based on the sedimentological evidence, the lacustrine origin of this member has been proposed previously (Chen et al., 2015; Yuan et al., 2009) and is tentatively accepted herein. The thick gravel beds identified by Cai et al. (2004) in the Danangou section as the basal member of the Nihewan Formation are only recognisable at Xiashagou base station. Although the basal contact to the underlying Shixia Formation is not seen in the Xiashagou it is exposed in the neighbouring area at Shixia. It is considered that the lowermost gravel beds represent the lower extension of the lower member of the Nihewan Formation

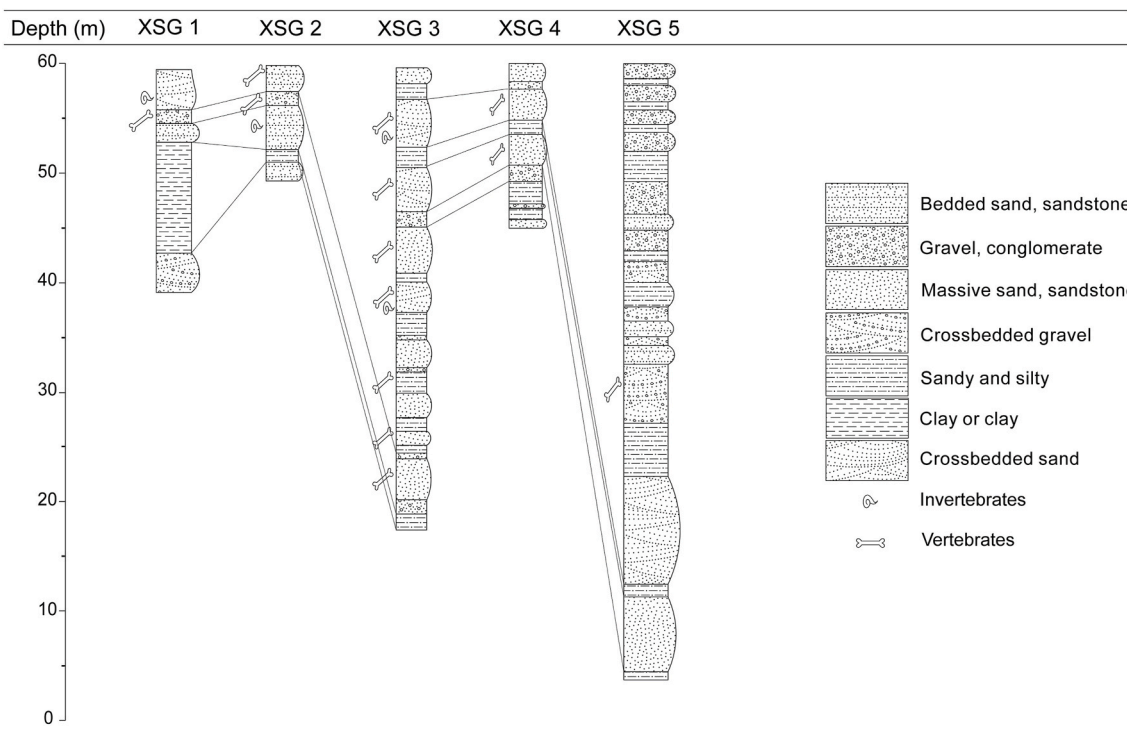


Fig. 4. Lithostratigraphical profiles and their correlations in the Xiashagou Valley. Note that this simplified profile does not show the calcareous layers at the top and bottom of the middle section (XSG 3). The fossil marked on the profiles represents the fossil fragments found during fieldworks.

instead of a separate unit, as suggested by Cai et al. (2004) (Fig. 5).

Several bone fragments associated with Equidae (*Hipparion* sp.) were collected from the interbedded minor sand units. However, the rediscovery of original excavation sites shows that none of the new sites nor those previously known for the classic Nihewan fauna were found from this member.

### 3.2. The middle member of the Nihewan Formation

The suggested type section of this member is located at the Xia-shagou 3 outcrop (Fig. 4). The fine-grained deposits of the lower member of the Nihewan Formation are overlain by multiple cycles of cross-bedded yellowish sand, cemented silt and fine sand, and brownish silty clay (Fig. 5). These beds constitute the middle member of the Nihewan Formation. Based on the magnetostratigraphic correlation, it is

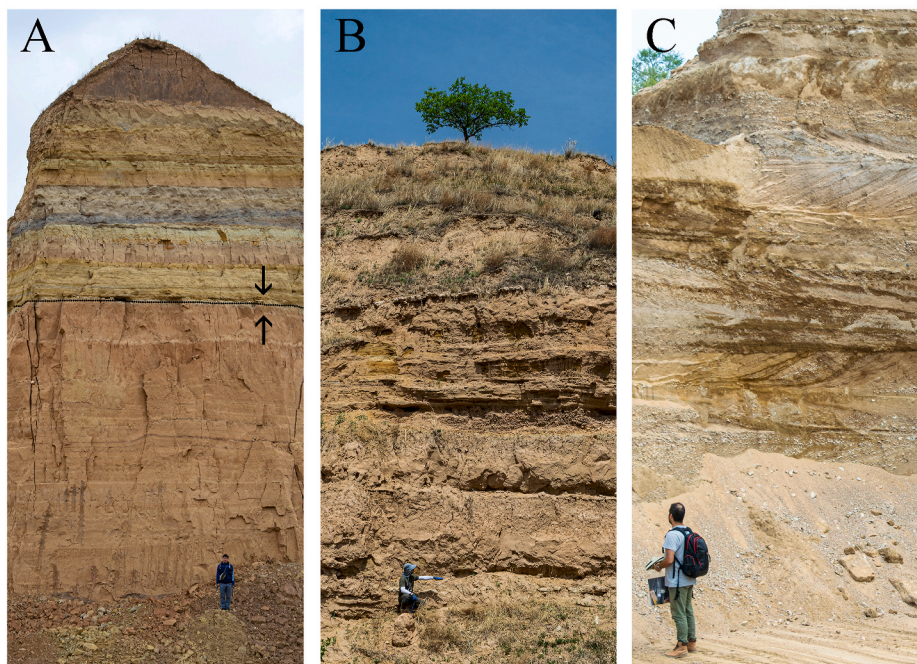


Fig. 5. Photographs of: A. Lower Member. B. lower part of the Middle Member. C. middle part of the Upper Member, type sections. The arrows in photograph A show the boundary of the Lower and Middle Member in the type section of the Lower Member (XSG 1).

estimated that the lower part of this member was deposited after 2.4 Ma (Fig. 6). This age estimation was provided by correlating the lower boundary of the middle member of the Nihewan Formation (yellowish cross-bedded silty sand) with the magnetostratigraphy profile (Liu et al., 2016) of the same locality (at the Xiashagou 1 site). The cross-bedded structure of the sand units indicates that the distal Nihewan palaeo-lake deposits were succeeded by a series of fluvial and alluvial fan facies prograding across the area. The present study shows that all the known fossil localities are distributed within this member.

The frequent changes in the lithology and cycles of fluvial and alluvial fan deposits in this member appear to suggest that fossil material preferentially occurs within specific lithologies, e.g., in the fine sand and silt facies (Fig. 6).

The similarity of the fossil-bearing lithologies, combined with a gentle dip towards the southeast, caused the earlier investigators to assume that the classic Nihewan fauna occurred predominantly in a single horizon. Although Liu et al. (2012) identified three fossil-bearing layers of the Nihewan Fauna, they failed to recognise which specific localities the layers represented. By contrast, the present observations

confirm that instead, the finds are distributed throughout this member. These complexities also gave rise to confusion when determining the actual thickness of the Xiashagou strata. However, according to the measurements undertaken in this study, the middle member of the Nihewan Formation does not exceed 40 m in thickness.

### 3.3. The upper member of the Nihewan Formation

The proposed type section of this member is located at the Xiashagou 5 exposure (Fig. 4). The upper member of the Nihewan Formation in the Xiashagou section is characterised by alternating beds of sand and gravel (Fig. 5). This member is distinct north of the Xiashagou village where it is exposed in multiple local sand quarries in both the Xiashagou and Langdonggou valleys. Although no known original excavation site could be attributed to this member, bone fragments and cranial elements of Cervidae were recovered during this survey. The deposition of the upper member began at approximately 1.8 Ma and is marked by the development of larger flow channels and infill of the depressions by aeolian sediments (Malan loess). These deposits occur in various places

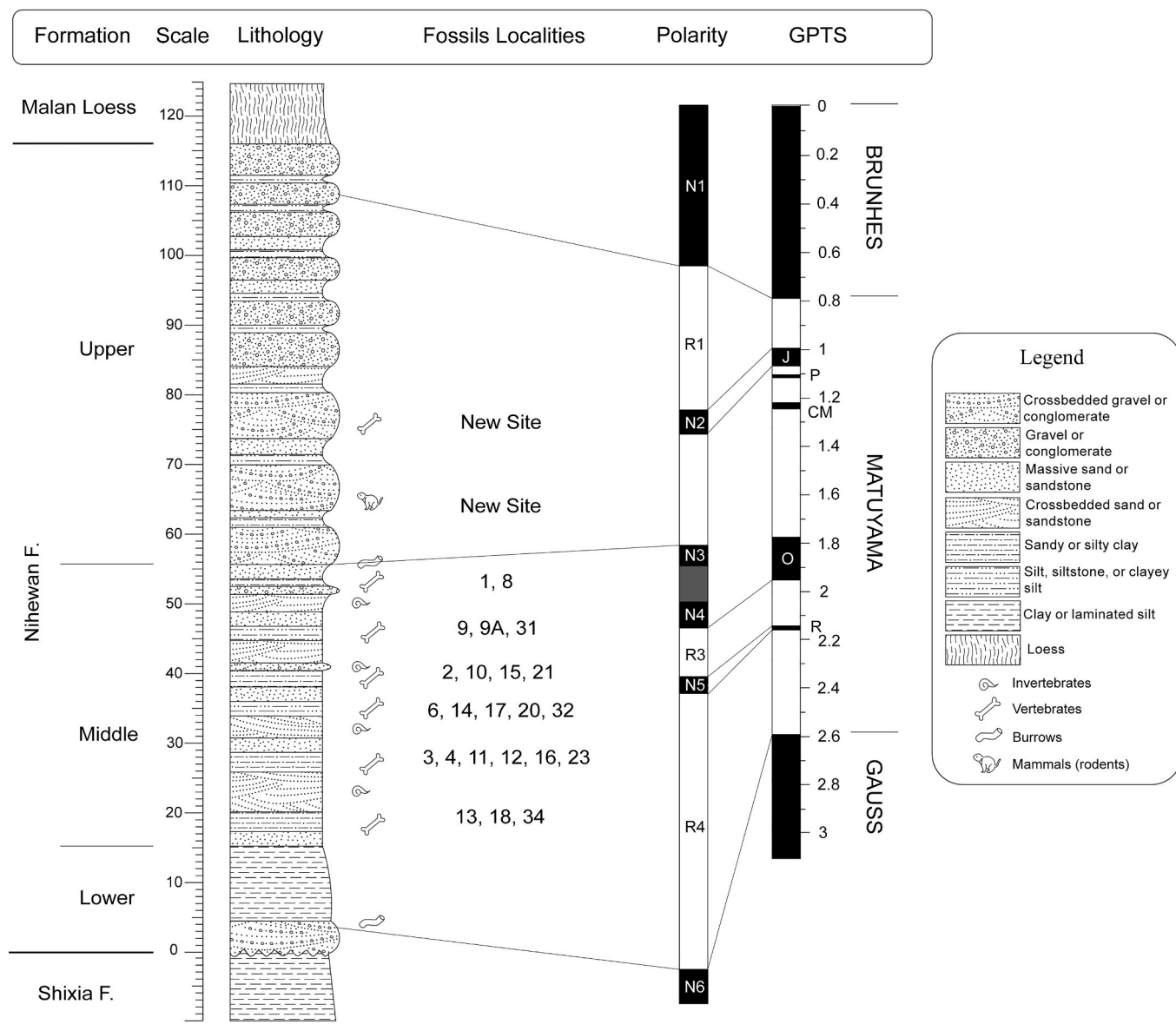


Fig. 6. Litho-biostratigraphical profile of the Xiashagou section and its correlation with the corresponding magnetostratigraphic sequence (Liu et al., 2016). The six fossil-bearing deposits identified are marked on the profile in addition to the newly discovered fossil localities (GPTS: Geomagnetic Polarity Time Scale).



throughout the Nihewan Basin (Wang et al., 2008) resting on an erosional surface, also burying the upper part of the lower and middle members. However, the greatest concentration of these deposits is on the northern side of Xiashagou, where they abruptly overlie the middle member. The upper member of the Xiashagou section thins and pinches-out below the highway north of the Xiashagou village (Fig. 1). This member reaches an average thickness of ~60 m.

## 4. Discussion

### 4.1. Nihewan Formation

For decades the classic Nihewan Fauna, preserved in the Tianjin Natural History Museum, has been testimony to the rich fossiliferous strata from the Xiashagou section. However, the lack of precise localities of the original discoveries reduced their value for biostratigraphical research. By contrast, the new approach, based on rediscovering the actual excavation sites and placing them into the synthetic lithostratigraphical profile from the Xiashagou section, has clarified these important findings.

Examination of the newly discovered original excavation sites and their associated stratigraphical profiles demonstrates that the classic Nihewan Fauna, does not represent a single fossiliferous stratum. On the contrary, the fossil localities were concentrated in six discrete fossil locality assemblages around the Xiashagou village (Fig. 6). These assemblages were differentiated based on surveying lithological properties and fossil abundance. For example, the preliminary excavations have demonstrated that the fossils found south of the Xiashagou village are commonly embedded within a dark brownish clayey silt, very fine sand with coarse sand lenses (middle member). However, the new fossil finds collected from the north of the village were mostly recovered from thick layers of grey sand, coarse sand and massive beds of gravel (upper member).

The late Cenozoic is widely known for its worldwide climate instabilities (Raymo et al., 1998; Lisiecki and Raymo, 2007; Wang et al., 2016). Subsequently, the multi-storey structure of the sheet-flood deposits, comprising the middle member, potentially represents punctuated deposition under fluctuating climatic conditions. The climatic fluctuations have been demonstrated in a recent palynological study of the Xiashagou strata (Zhang et al., 2020) and northern China (Tian et al., 2020), and the evolution of *Nyctereutes sinensis* and *Nyctereutes tingi* (Farjand et al., 2021). The authors of the former study identified several warm and cold oscillations within the Nihewan sequence (i.e., Early Pleistocene). Since the Nihewan Basin is of tectonic origin (Chen et al., 2015), this activity, coupled with the global climatic changes during the Pleistocene, could have contributed to the periodic drainage or retreating of the Nihewan palaeo-lake, contemporaneous with the deposition of both the Shixia and Nihewan Formations (Liu et al., 2018). This interaction promoted the lithological complexity of the Nihewan strata giving rise to rapid changes in the depositional environments. The three members of the Nihewan Formation can be distinguished both lithologically and biostratigraphically (Figs. 5 and 6). The deposition of these three members indicates progradation of the fluvio-alluvial system through the period represented.

Within each of these three members, multiple depositional events can be distinguished. Whether these events reflect climatic changes or those relating to intense precipitation events cannot be determined at present. Nevertheless, the palaeontological assemblages seen through this Formation are independent of the observed facies changes. The first author has demonstrated the uneven distribution of the classic Nihewan Fauna in different fossil horizons of the Nihewan Formation (Farjand, 2020). For instance, his study shows the disappearance of large Felidae, Hyaenidae, Mustelidae and Camelidae in the early Early-Pleistocene (e.g., localities 7, 11) and their replacement by the middle Early Pleistocene elements, including *Dicerorhinus*, *Sus lydekkeri*, *Ovis ammon*, *Bison palaeosinensis* (e.g., localities 1, 8).

### 4.2. The original fossil localities

Rediscovery of the original excavation sites shows that they are irregularly distributed across the Xiashagou section. The majority of the sites occur to the east and northeast of the Xiashagou village. These localities yielded more fossil mammal remains than those to the south or north of the village. While some of the localities allocated to a specific fossil assemblage zone occur within different lithologies and stratigraphic levels (e.g., localities 4 and 23), a discrete fossil bed may be present in some cases (e.g., localities 13, 18 and 34 in XBH1). This reflects the lateral and vertical sedimentary facies variability throughout the sequence.

Localities 13, 18 and 34 include the lowest fossil-bearing zone of the Middle Member. Only 38 fossil specimens associated with these localities have been identified in the Tianjin Museum. The stratum from which these specimens were collected consists of dark brownish clayey silt/fine sand that is partially cemented. This bed is 6 m above the boundary and the base of the Middle Member. By identifying the Gauss-Matuyama (G/M) magnetic boundary at the base of this member, the age of this fossil horizon is estimated at c. 2.4 Ma, marking the first appearance of the classic Nihewan Fauna. This age is based on interpolating the age between the polarity zones Gauss/Matuyama paleomagnetic boundary (2.6 Ma) and the top of Olduvai normal subchron (1.8 Ma) that was presented by Liu et al. (2016). The stratigraphy profile presented here, besides validating the previous studies, provided a higher-resolution lithological profile of the same section with the correct appearance of each fossil horizon that enabled the determination of the appearance of classic Nihewan Fauna at c. 2.4 Ma.

The localities 1 and 8, on the other hand, include the top-most identified fossiliferous bed of the Middle Member. Nearly 200 fossil specimens associated with these localities were identified in the Tianjin Museum. These localities occur c. 5 m below the base of the Upper Member and consists of cross-bedded yellowish silty sand interbedded with pebble lenses. Here, the onset of the Olduvai Subchron was identified. Hence, this top most fossil-bearing horizon is estimated to date from approximately c. 1.8 Ma. The remaining four fossil locality assemblages would then occur intermediate between these two bracketing horizons (Fig. 6). A detailed description of these six fossil-bearing assemblages (Table 3) is provided by Farjand (2020). Finally, several brief excavations around the Xiashagou valley confirmed that the fossil localities have been correctly rediscovered.

### 4.3. The composition of the classic Nihewan fauna

The analytical study of the composition of the classic Nihewan faunal assemblage preserved in the Tianjin Museum shows that Equidae, Cervidae, Bovidae and Rhinocerotidae are the most abundant families recovered, consisting of 37.5%, 22%, 20% and 11.4% of the original specimens, respectively. At the same time, at least 45 species have been recognised as the classic Nihewan faunal assemblage in the original literature. The re-identification of original sites illustrates that various mammals' palaeobiodiversity and appearance were compositionally inconsistent during the Early Pleistocene in the region. For example, the appearance of Felidae is uniquely limited to localities 11, 15 and 23.

**Table 3**

Identified six fossil horizons in the Xiashagou section and their allocated localities. Abbreviations: XFH, Xiashagou Fossil horizon; TNHM, Tianjin Natural History Museum; MNHN, Muséum national d'Histoire naturelle.

Fossil Horizon	Locality Numbers	Specimens (TNHM)	Specimens (MNHN)
XFH-1	13, 18, 34	38	2
XFH-2	3, 4, 11, 12, 16, 23	508	39
XFH-3	6, 14, 17, 20, 32	75	32
XFH-4	2, 10, 15, 21	174	4
XFH-5	9, 9A, 31	117	9
XFH-6	1, 8	198	3

These sites, located south of the Xiashagou village, represent the lower part of the Nihewan Formation Middle Member. By contrast, the scarce appearance of *Suidae* and *Dicerohinus* sp. is limited to localities 1 and 8, respectively. These sites occur north of Xiashagou and represent the upper part of the Middle Member. The detailed biostratigraphical profile of the classic Nihewan Fauna will be published in a separate article.

## 5. Conclusions

This study has provided a reliable stratigraphical setting and precise coordination of the localities from which the classic Nihewan Fauna was collected in the early 1920s. Twenty-eight of these original localities have been discovered (Table 2). The detailed stratigraphical context presented here also provides a broadly reliable time frame for the appearance, peak abundance and subsequent disappearance of the classic Nihewan fauna.

Furthermore, this study shows that the classic Nihewan Fauna belongs to various fossiliferous stratigraphical levels (unlike previous assumptions), and the age of these horizons varies between 2.4 and 1.8 Ma (i.e., the Gelasian Stage). Therefore, the faunal assemblages represent an extended period during the Early Pleistocene. Meanwhile, they are distinguishable from the Late Pliocene Daodi and Plio-Pleistocene transitional Dongyaozitou faunas based on their age and composition.

In addition, this study provides important evidence to refine the lithological definition and distribution of the faunal assemblages within the Nihewan Formation. The evidence indicates that the deposits mainly consist of fluvial and alluvial fan sediments underlain by the Hipparion Red Clay (Shixia Formation) and the Daodi Formation and overlain by the Late Pleistocene Malan loess. Regarding the lithological composition of the Xiashagou deposits, further studies are required to define this section as the potential stratotype of the Nihewan Formation to replace that in Danangou proposed by Cai et al. Consequently, it is suggested that new studies should not use synonymous or localised formation names to describe neighbouring outcrops to avoid further confusion. Instead, the subdivision of the Nihewan Formation into three members is confirmed, and a correlation to a previous magnetostratigraphic profile is provided. Further work is required to determine the nature of the basal boundary of the Nihewan Formation on the underlying Shixia Formation.

## Data availability

Datasets related to this article can be found in Tables 1–3

## CRediT authorship contribution statement

**Arya Farjand:** Conceptualization, Writing – review & editing. **Zhaoqun Zhang:** Supervision, Project administration, Funding acquisition. **Anu Kaakinen:** Investigation, Writing – review & editing, Funding acquisition. **Shundong Bi:** Data curation, Resources. **Philip L. Gibbard:** Validation, Writing – review & editing. **Wang Lihua:** Visualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgement

The authors wish to thank the IVPP employees and academic staff who kindly facilitated this research during the past four years. The authors also thank the TNHM management and Mrs. Zheng Min for providing access to their precious collection. For access to the Muséum national d'histoire naturelle collections, we thank the courtesy and

assistance offered by Dr. Christine Argot and Dr. Guillaume Billet. The scholarship grant provided by CAS-TWAS provided financial assistance, and the Chinese Academy of Sciences and the fund number 2014FY110300 of the Ministry of Science and Technology of China. AK gratefully acknowledges the support of the Academy of Finland (grants 316799 and 341622).

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.quaint.2022.12.001>.

## References

- Ao, H., An, Z.S., Dekkers, M.J., Wei, Q., Pei, S.W., Zhao, H., Zhao, H.L., Xiao, G.Q., Qiang, X.K., Wu, D.C., Chang, H., 2012. High-resolution record of geomagnetic excursions in the Matuyama chron constrains the ages of the Feiliang and lanpo paleolithic sites in the Nihewan Basin, north China, geochem. Geophys. Geosyst. 13, Q08017. <https://doi.org/10.1029/2012GC004095>.
- Ao, H., Dekkers, M.J., An, Z., Xiao, G., Li, Y., Zhao, H., Qiang, X., Chang, H., Chang, Q., Wu, D., 2013. Magnetostratigraphic evidence of a mid-Pliocene onset of the Nihewan Formation - implications for early fauna and hominid occupation in the Nihewan Basin, North China. Quat. Sci. Rev. 59, 30–42. <https://doi.org/10.1016/j.quaint.2012.10.025>.
- Ao, H., Liu, C.R., Roberts, A.P., Zhang, P., Xu, X.W., 2017. An updated age for the xujiayao hominin from the Nihewan Basin, north China: implications for middle Pleistocene human evolution in East Asia. J. Hum. Evol. 106, 54–65. <https://doi.org/10.1016/j.jhevol.2017.01.014>.
- Barbour, G.B., 1924. Preliminary observations in the kalgan area. Bull. Geol. Surv. Can. 3, 153–168.
- Barbour, G.B., 1925. The deposits of the sang kan Ho valley. Bull. Geol. Surv. Can. 4, 53–55.
- Barbour, G.B., Licent, E., Teilhard de Chardin, P., 1926. Geological study of the deposits of the sangkanho basin. Bull. Geol. Surv. Can. 5, 263–278.
- Cai, B., 1987. A preliminary report on the late Pliocene micromammalian fauna from yangyuan. Vertebr. Palasiat. 25, 126–136.
- Cai, B.Q., Zhang, Z.Q., Zheng, S.H., Qiu, Z.D., Li, Q., Li, Q., 2004. New advances in the stratigraphic study on representative sections in the Nihewan Basin, Hebei. Prof. Pap. Stratigr. Palaeontol. 28, 267–285.
- Cai, B., Zheng, S., Liddicoat, J., Li, Q., 2013. Chapter 8. Review of the Litho-, Bio-, and Chronostratigraphy in the Nihewan Basin, Hebei, China. In: Wang, X., Flynn, L., Fortelius, M. (Eds.), Fossil Mammals of Asia: Neogene Biostratigraphy and Chronology. Columbia University Press, New York Chichester, West Sussex, pp. 218–242. <https://doi.org/10.7312/wang15012-008>.
- Chen, X.Q., Chi, Z.Q., Dong, S.W., Yan, Z., Yang, J.S., Shi, W.S., Min, L.R., Wang, Y., Yao, P.Y., 2015. Late cenozoic sedimentation of Nihewan Basin, central north China and its tectonic significance. J. Asian Earth Sci. 114, 242–257. <https://doi.org/10.1016/j.jseas.2015.06.020>.
- Chia, L.P., Wei, Q., Li, C.R., 1979. Report on the excavation of Hsuchiayao man site in 1976. Vertebr. Palasiat. 17, 277–293.
- Du, H., Wang, A., Zhao, Q., Cai, B., 1988. A new late Pliocene stratigraphic unit in the nihewan region: the Daodi Fm. Earth Sci. J. China Univ. Geosci. 13, 561–568.
- Fan, X., Su, P., Reidar, L., 2002. Magnetostratigraphic evidence for the age of the Xujiayao Paleolithic layer and the xujiayao Formation. J. Stratigr. 248–252, 4.
- Feng, X., Hou, Y., 1998. Huojiadi a new paleolithic site discovered in the Nihewan Basin. ACTA Anthropologica Sinica 17, 310–316.
- Farjand, A., 2020. Lithostratigraphy, Biostratigraphy, and Geochronology of Xiashagou Strata with Focus on the Classic Nihewan Fauna. Institute of Vertebrate Paleontology and Paleoanthropology of China. Ph.D. Thesis. Chinese Academy of Sciences.
- Farjand, A., Zhang, Z.Q., Liu, W.H., Jiao, C.H., Wang, L.H., 2021. The evolution of Nyctereutes (carnivora: canidae) in the Nihewan Basin, Hebei, northern China. Palaeoworld 30, 373–381. <https://doi.org/10.1016/j.palwor.2020.07.002>.
- Gai, P., Wei, Q., 1974. Discovery of stone tools in the early Pleistocene in Nihewan. Vertebr. Palasiat. 12, 69–74.
- Li, H., Yang, X., Heller, F., Li, H., 2008. High resolution magnetostratigraphy and deposition cycles in the Nihewan Basin (North China) and their significance for stone artifact dating. Quat. Res. 69, 250–262. <https://doi.org/10.1016/j.yqres.2007.11.002>.
- Li, Y., 1984a. Fossil mammals and their stratigraphic age from danangou, yuxian Co., Hebei Province. Vertebr. Palasiat. 22, 60–68.
- Li, Y., 1984b. The early Pleistocene mammalian fossils of danangou, yuxian, Hebei. Vertebr. Palasiat. 22, 60–69.
- Licent, É., 1935. Hoang Ho-Pai Ho. Comptes-rendus de onze années (1923–1933) de séjour et d'exploration dans le Bassin du Fleuve Jaune, du Pai Ho et des autres tributaires du Golfe du Pei-Tcheu-Ly. Musée Hoang Ho-Pai ho, Tianjin.
- Lisiecki, L.E., Raymo, M.E., 2007. Plio–Pleistocene climate evolution: trends and transitions in glacial cycle dynamics. Quat. Sci. Rev. 26 (1–2), 56–69. <https://doi.org/10.1016/j.quascirev.2006.09.005>.
- Liu, P., Deng, C., Li, S., Cai, S., Cheng, H., Baoyin, Y., Wei, Q., Zhu, R., 2012. Magnetostratigraphic dating of the Xiashagou fauna and implication for sequencing the mammalian faunas in the Nihewan Basin, north China. Palaeogeogr.

- Palaeoclimatol. Palaeoecol. 315–316, 75–85. <https://doi.org/10.1016/j.palaeo.2011.11.011>.
- Liu, P., Deng, C., Li, S., Zhu, R., 2010. Magnetostratigraphic dating of the huojiadi paleolithic site in the Nihewan Basin, north China. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 298, 399–408. <https://doi.org/10.1016/j.palaeo.2010.10.027>.
- Liu, P., Qin, H.F., Li, S.H., Yuan, B.Y., 2021. Magnetostratigraphic dating of the danangou and dongyaozitou mammalian faunas in the Nihewan Basin, North China. *Quat. Sci. Rev.* 257, 106855 <https://doi.org/10.1016/j.quascirev.2021.106855>.
- Liu, P., Yue, F., Liu, J., Qin, H., Li, S., Zhao, X., Xu, J., Yuan, B., Deng, C., Zhu, R., 2018. Magnetostratigraphic dating of the Shixia red sediments and implications for Formation of Nihewan paleo-lake, North China. *Quat. Sci. Rev.* 193, 118–128. <https://doi.org/10.1016/j.quascirev.2018.06.013>.
- Liu, P., Wu, Z., Deng, C., Tong, H., Qin, H., Li, S., Yuan, B., Zhu, R., 2016. Magnetostratigraphic dating of the Shanshenmiaozui mammalian fauna in the Nihewan Basin, North China. *Quat. Int.* 400, 202–211. <https://doi.org/10.1016/j.quaint.2014.09.024>.
- Liu, X., Xia, Z., 1983. A suggestion on the division and correlation of the Nihewan Formation. *Mar. Geol. Quat. Geol.* 3, 75–85.
- Qiu, Z., 2000. Nihewan fauna and Q/B boundary in China (in Chinese with English abstract). *Quat. Sci.* 20, 142–154.
- Raymo, M., Ganley, K., Carter, S., Oppo, D.W., McManus, J., 1998. Millennial-scale climate instability during the early Pleistocene epoch. *Nature* 392, 699–702.
- Schick, K., Toth, N., 2001. Paleanthropology at the millennium. In: Feinman, G.M., Price, T.D. (Eds.), *Archaeology at the Millennium*. Springer, Boston, MA. [https://doi.org/10.1007/978-0-387-72611-3\\_3](https://doi.org/10.1007/978-0-387-72611-3_3).
- Tang, Y., Ji, H., 1983. A Pliocene - Pleistocene transitional fauna from yuxian, northern Hebei. *Vertebr. Palasiat.* 21, 245–255.
- Tang, Y., You, Y., Li, Y., 1981. Some new fossil localities of early Pleistocene from yangyuan and yuxian basins, northern hopei. *Vertebr. Palasiat.* 19, 256–268.
- Teilhard de Chardin, P., Piveteau, J., 1930. Les mammifères fossiles de Nihowan (chine) *Annales de Paléontologie*. *Annales de Paléontologie* 19, 1–154.
- Tu, H., Luo, L., Deng, C.L., Ou, Z.L., Lai, Z.P., Shen, G.J., Bae, C.J., Granger, D., 2022. Isochron 26Al/10Be burial dating of the Xiashagou Fauna in the Nihewan Basin, northern China: implications for biogeography and early hominin dispersals. *Quat. Sci. Rev.* 283, 107447 <https://doi.org/10.1016/j.quascirev.2022.107447>.
- Tu, H., Shen, G.J., Li, H.X., Xie, F., Granger, D.E., 2015. 26Al/10Be burial dating of xujiayao-houjiayao site in Nihewan Basin, northern China. *PLoS One*. <https://doi.org/10.1371/journal.pone.0118315>.
- Wang, X., Flynn, L.J., Fortelius, M., 2013. *Fossil Mammals of Asia*. Columbia University Press.
- Wang, X., Wei, H., Taheri, M., Khormali, F., Danukalova, G., Chen, F.H., 2016. Early Pleistocene climate in western arid central Asia inferred from loess-palaeosol sequences. *Sci. Rep.* 6, 20560 <https://doi.org/10.1038/srep20560>.
- Wang, X.S., Løvlie, R., Su, P., Fan, X.G., 2008. Magnetic signature of environmental change reflected by Pleistocene lacustrine sediments from the Nihewan Basin, North China. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 260, 452–462. <https://doi.org/10.1016/j.palaeo.2007.12.006>.
- Wei, Q., 1976. Recent find of fossil palaeoioxodon namadicus from nihewan beds, NW Hebei (in Chinese with English abstract). *Vertebr. Palasiat.* 14, 53–60.
- Wei, Q., Meng, H., Cheng, S., 1985. New paleolithic site from the Nihewan (Nihowan) beds. *ACTA Anthropológica Sinica* 4, 223–233.
- Yang, S., Hou, Y., Yue, J., Petraglia, M.D., Deng, C., Zhu, R.X., 2016. The lithic assemblages of xiaochangliang, Nihewan Basin: implications for early Pleistocene hominin behaviour in north China. *PLoS One* 11, e0155793. <https://doi.org/10.1371/journal.pone.0155793>.
- Yuan, B.Y., Tong, H.W., Wen, R.L., Wang, Y.H., 2009. The formation mechanism of the Nihewan paleo-lake and its relationship with living environment for early ancient human (in Chinese with English abstract). *Geomech* 77–87, 01.
- You, Y., Tang, J., Li, Y., 1979. The discovery of Xiaochangliang site in Nihewan Formation and its significance. *Chin. Sci. Bull.* 8, 365–367.
- Zhang, Z., Zheng, S., Liu, J., 2003. Pliocene micromammalian biostratigraphy of Nihewan Basin, with comments on the stratigraphic division. *Vertebr. Palasiat.* 41, 306–313.
- Zhang, Z., Li, Y.C., Li, C.Z., Xu, Q.H., Zhang, R.C., Ge, Y.W., Li, B., Deng, C.L., Li, Z.G., Zhang, L., 2020. Pollen evidence for the environmental context of the early Pleistocene Xiashagou fauna of the Nihewan Basin, north China. *Quat. Sci. Rev.* 236, 106298 <https://doi.org/10.1016/j.quascirev.2020.106298>.
- Zheng, S., 1981. Newly discovered small mammals from the nihewan beds. *Vertebr. Palasiat.* 19, 348–358.
- Zhu, R., Deng, C., Pan, Y., 2007. Magnetochronology of the fluvio-lacustrine sequences in the Nihewan Basin and its implications for early human colonisation of Northeast Asia. *Quat. Sci.* 27 (6), 922–944.