



Stable Isotope Analysis of Mammalian Enamel From the Early Pleistocene Site of Madigou, Nihewan Basin: Implications for Reconstructing Hominin Paleoenvironmental Adaptations in North China

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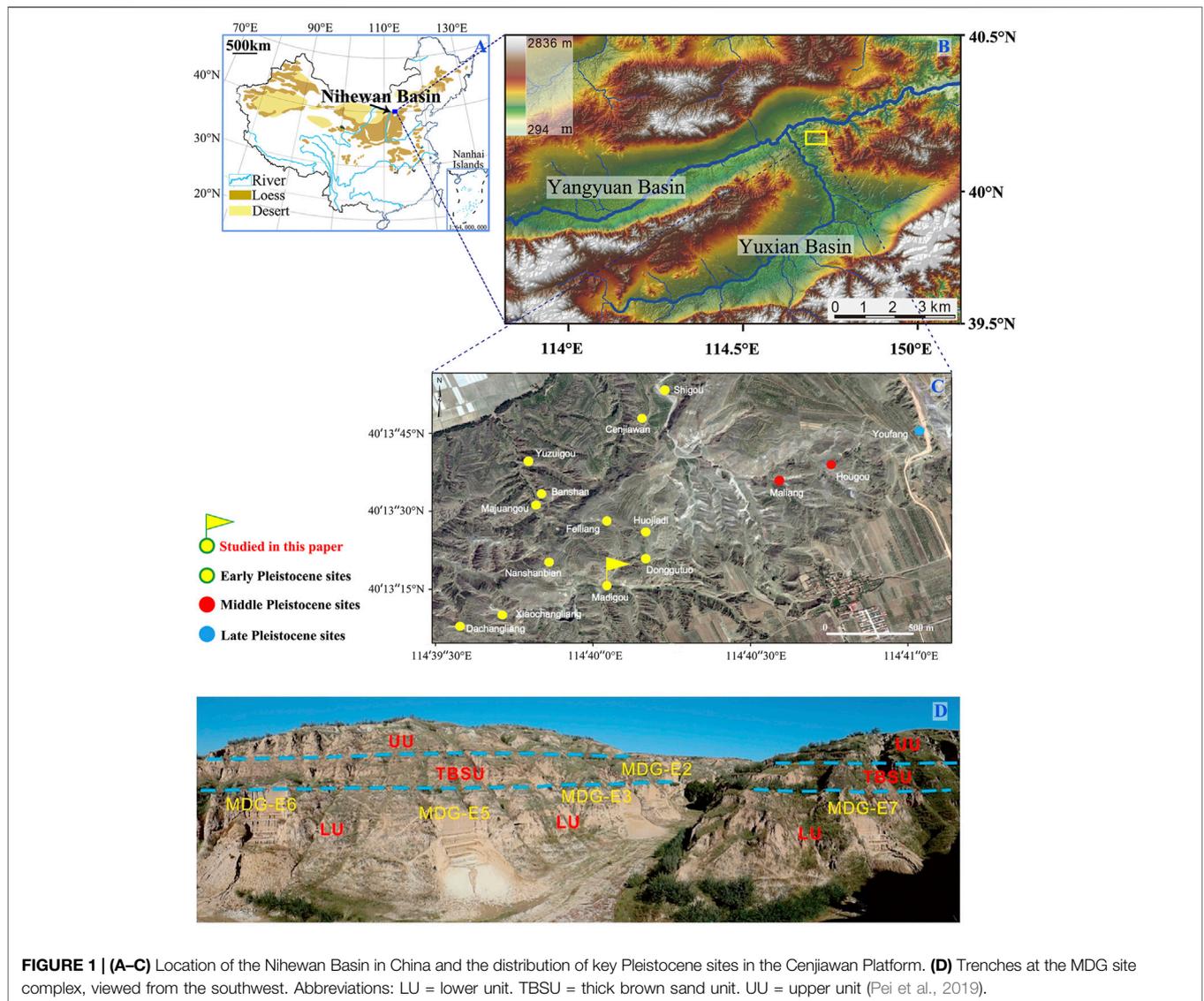
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The reconstruction of environmental and climatic changes in the Pleistocene is an essential contribution to our understanding of human evolutionary and behavioral adaptations. Well preserved fluvio-lacustrine sediments at Nihewan basin have yielded a rich record of Early Pleistocene Paleolithic sites and mammalian fossils which provide a unique opportunity for exploring hominin behavior and paleoecology in North China. Taxonomic studies of mammalian fossils have provided important clues to the general environmental setting and landscapes of Early Pleistocene humans in the fluvio-lacustrine basin of Nihewan, but little is known about their isotopic signatures. In this paper, mammal teeth species at the Madigou archaeological site (ca. 1.2 Ma) were selected for bulk and sequential enamel stable isotope (C, O) analysis. Results show a variety of ecological environments, including grassland and sparse forest landscapes, and distinct patterns across taxa. C₃-C₄ mixed vegetation predominated, but C₄ vegetation was also relevant at times. Madigou early humans likely experienced cold/warm or dry/wet fluctuations in this northern China basin. We hypothesize that the environmental fluctuations and diversified landscapes may have driven flexibility in various aspects of early human technological behaviors, and allowed hominins to face the environmental challenges of northern latitudes after the initial expansion from Africa into East Asia at the onset of the Middle Pleistocene Climate Transition.

Keywords: stable isotopes, paleoenvironmental variability, Middle Pleistocene Climate Transition (MPT), human adaptations, Madigou site, Nihewan basin, North China

INTRODUCTION

Understanding the impact of paleoenvironmental variability on hominin behavioral adaptations is a key area of research in human evolution (deMenocal, 1995; Ambrose, 2001; Behrensmeier, 2006), and is of crucial relevance for understanding the initial dispersal of humans from Africa into Eurasia (Gabunia et al., 2000; Bar-Yosef and Belfer-Cohen, 2001; Van der Made, 2011) and hominin



behavioral adaptations during the Middle Pleistocene Climate Transition (MPT) at ~ 1.25–0.7 Ma, which is marked by a progressive increase in the amplitude of climate oscillations (Ruddiman et al., 1986; Mudelsee and Schulz, 1997; Clark et al., 2006; Wang et al., 2017). It has been hypothesized that the MPT triggered substantial hominin dispersals from Africa to Eurasia (Larick and Ciochon, 1996; Wu and Liu, 2001; Deng et al., 2007; Abbate and Sagri, 2012), and it may be linked to a more sustained settlement by *Homo erectus* in northern latitudes of East Asia. A more continuous occupation of northern latitudes would be aided by a diversity of adaptive behaviors, following patterns observed elsewhere (deMenocal, 2011; Grove, 2012; Potts, 2012, 2013; Potts and Faith, 2015), in which human biological evolution and lithic technological innovations were coupled with a high frequency of climatic fluctuation cycles.

The Nihewan Basin (Figure 1) in North China is well known for its abundance of archaeological sites through the Lower and Upper Pleistocene (Schick et al., 1991; Zhu et al., 2001, 2004;

Deng et al., 2006, 2007; Ao et al., 2010, 2013; Zuo et al., 2011). Nihewan paleoenvironments have been reconstructed through the analysis of sedimentary features and mammalian enamel stable isotopes (Deng et al., 2001; An et al., 2005; Ding et al., 2005; Pei et al., 2009), pollen (Li et al., 1996; Wu et al., 2007; Pei et al., 2009), magnetic susceptibility (Deng et al., 2007; Pei et al., 2009, 2019), iron oxides (Pei et al., 2009), soluble salts (Li et al., 2010), and site formation processes (Jia et al., 2019). Recent archaeological studies (Pei et al., 2017, 2019; Yang et al., 2017, 2020, 2021) have discussed the links between climatic variability and human adaptations, suggesting that changes in lithic technological strategies occurred at the beginning of the MPT. Such changes would be evidenced by the flexibility in raw material procurement, diversification of flaking techniques, a refinement of retouching techniques, and an increase of tool types. However, the environmental context in which such new technological patterns emerged has not yet been properly ascertained.

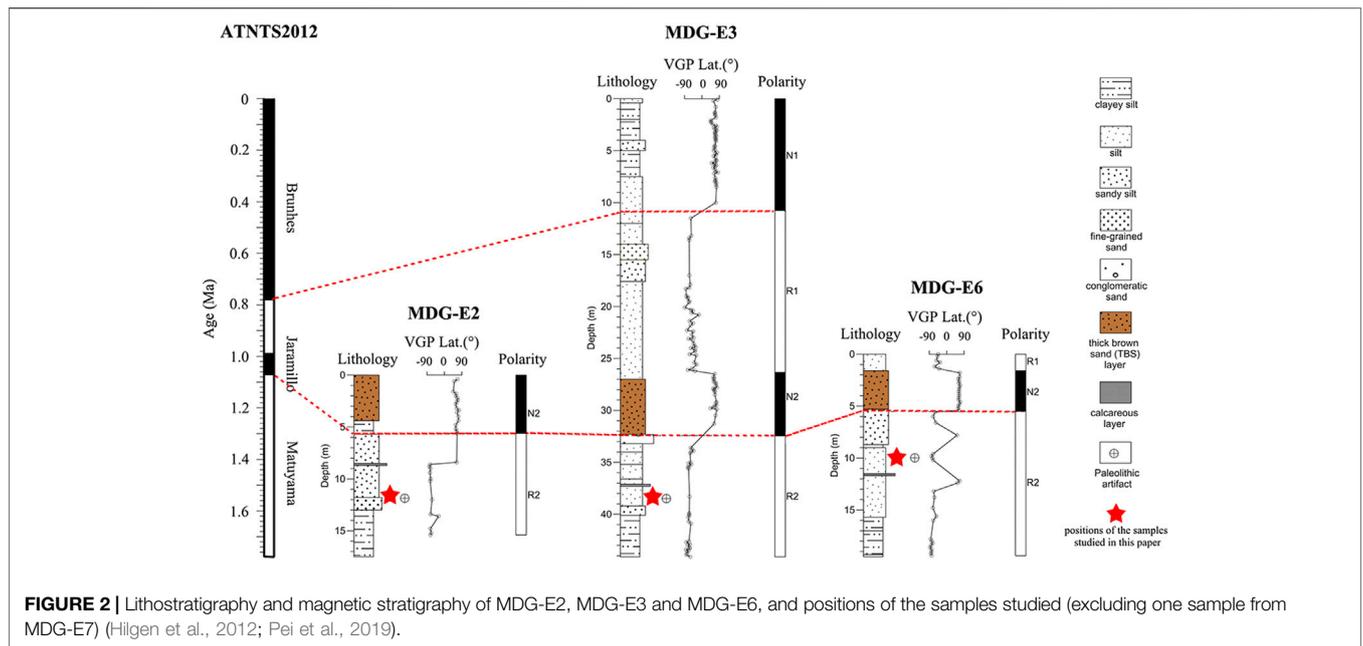


FIGURE 2 | Lithostratigraphy and magnetic stratigraphy of MDG-E2, MDG-E3 and MDG-E6, and positions of the samples studied (excluding one sample from MDG-E7) (Hilgen et al., 2012; Pei et al., 2019).

Stable isotope (C, O) analysis of tooth enamel provides direct evidence of the ecology and habitat of fossil mammals (Quade et al., 1992; Cerling et al., 1997; Cerling and Harris, 1999; Van der Merwe, 2013; Rivals et al., 2018; Uno et al., 2018), but is yet to be applied systematically to the Nihewan Pleistocene sequence. Here we contribute to this effort by presenting the first analysis of isotope values to mammalian teeth from the Madigou site (MDG). Our study includes bulk sampling from the whole teeth enamel and sequential sampling of several specimens, which were used to reconstruct paleolandscapes and seasonal variability in Early Pleistocene Nihewan, and to contextualize both with dynamics observed in the use of stone tools by early humans at the site.

PRINCIPLES OF STABLE ISOTOPE (C, O) ANALYSIS OF FOSSIL ENAMEL

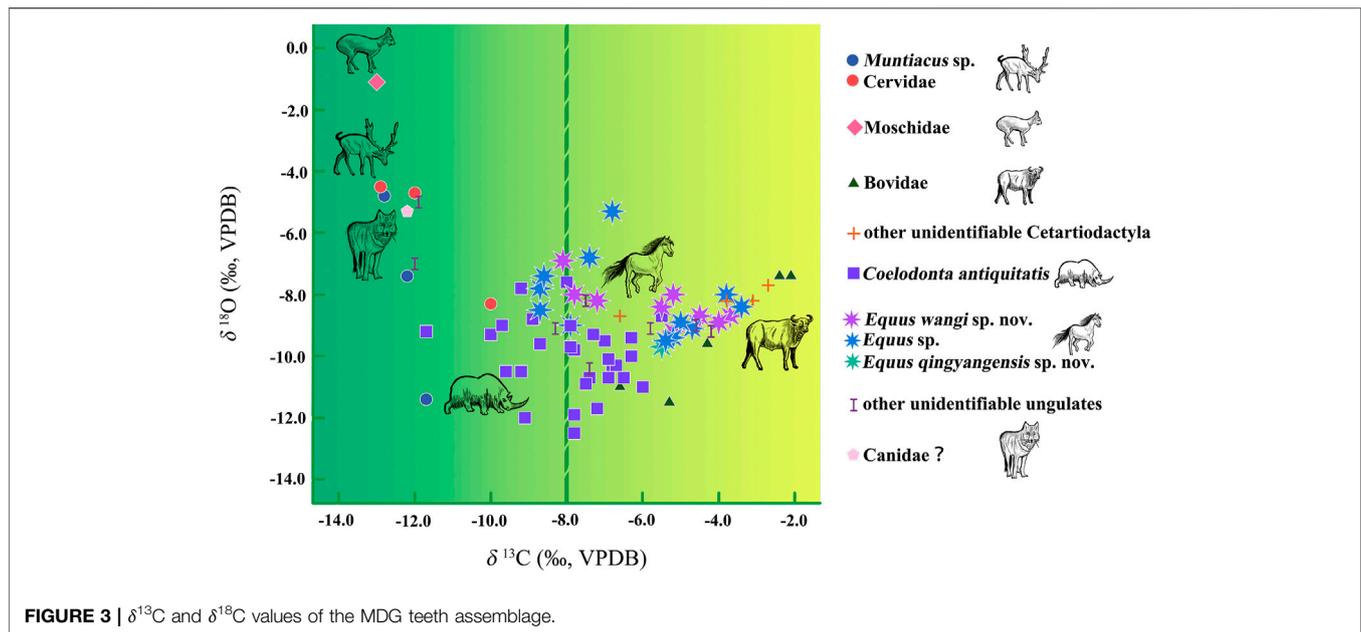
According to different pathways of photosynthesis, terrestrial plants are generally divided into three categories, C₃ (Calvin), C₄ (hatch slack) and CAM (Crassulacean acid metabolic acid), which cause the differences of carbon isotopic fractionation during the processes of carbon fixation. δ¹³C values of C₃ plants, including trees, shrubs and cold-tolerant herbs (Deng et al., 2001), range from -34‰ to -22‰, while those of C₄ plants, typical of drier and warmer environments (Raven et al., 1999), range from -17‰ to -9‰ (O’Leary, 1988; Farquhar et al., 1989; Cerling et al., 1997). Other factors such as rainfall, altitude, light intensity, atmospheric carbon dioxide concentration and the canopy effect also affect the δ¹³C values of plants (Farquhar et al., 1989). δ¹³C values of C₃ plants become more negative with the increase of the rainfall, altitude and latitude (Kohn, 2010). Isotopic fractionation takes place from diets to teeth enamel when plants are eaten by herbivores, and when herbivores are consumed by carnivores. Compared to those in plants, δ¹³C

TABLE 1 | Sampled teeth per taxa and trench at MDG.

Species	Location				Total
	E2	E3	E6	E7	
<i>Muntiacus</i> sp.	3	0	0	0	3
Cervidae gen. et sp. Indet	3	0	0	0	3
Moschidae gen. et sp. Indet	1	0	0	0	1
Bovidae gen. et sp. Indet	5	0	0	0	5
Other unidentifiable Cetartiodactyla	4	0	0	0	4
<i>Coelodonta antiquitatis</i>	22	6	1	0	29
<i>Equus wangi</i> sp. Nov.	9	1	0	0	10
<i>Equus qingyangensis</i> sp. Nov.	0	0	0	1	1
Other <i>Equus</i> sp.	11	1	0	0	12
Other unidentifiable ungulates	8	0	0	0	8
<i>Canis chihliensis?</i>	1	0	0	0	1
Total (n)	67	8	1	1	77

values of teeth enamel from large herbivores and carnivores increase by ~14‰ and ~9‰ respectively (Cerling and Harris, 1999; Tejada-Lara et al., 2018). Following earlier work (Cerling et al., 1997; Wang et al., 2008; Biasatti et al., 2010; Uno et al., 2018), the δ¹³C values in tooth enamel lower than -8‰ are attributed in this study to animals that only eat C₃ food, from -8‰ to -2‰ to those with a C₃-C₄ mixed diet, and higher than -2‰ to those consuming mainly C₄ foods.

The oxygen isotope composition in mammalian teeth is mainly determined by that of body water, which derives directly from drinking water (Pederzani and Britton, 2019). Due to evaporation, δ¹⁸O values in plant leaves are higher than those in meteoric water. This results in leaf-eating herbivores having higher δ¹⁸O values than those drinking meteoric water (Pederzani and Britton, 2019), thus enabling to distinguish browsers from grazers. Additionally, δ¹⁸O values vary with the altitude, temperature and latitude, which helps to track



animal movement across different ecozones (Pederzani and Britton, 2019).

Two sampling strategies are usually applied to the isotopic analysis of fossil teeth enamel. Bulk sampling of the whole enamel is used to reconstruct the average diet and ecological setting during the period of tooth formation (Feranec and MacFadden, 2000). Sequential sampling of the enamel along the direction of enamel growth may reveal the spatiotemporal dietary and environmental changes throughout the development of the tooth (Balasse, 2002).

MATERIAL AND METHODS

Geological Setting of the Madigou Site

The Nihewan Basin (which includes the Yangyuan Basin and Yuxian Basin in Hebei Province, and the Datong Basin in Shanxi Province), is an intermontane basin between the Inner Mongolian Plateau and North China (Deng et al., 2019; Pei et al., 2019) (Figure 1A). It is well known for its extensive late Cenozoic fluvio-lacustrine sequence (the Nihewan Beds), reliably-constrained geochronology, and abundant archaeological sites (Schick et al., 1991; Zhu et al., 2001, 2004; Deng et al., 2006, 2007; Ao et al., 2010, 2013; Zuo et al., 2011). (Figures 1A–C). The Nihewan Beds contain fluvio-lacustrine deposits from the Late Pliocene to the late Middle/Upper Pleistocene (Zhao et al., 2010; Nian et al., 2013; Deng et al., 2019). These deposits include the Pliocene-Pleistocene boundary (Liu et al., 2012) and the Nihewan faunas (*sensu lato*) (Teilhard de Chardin and Piveteau, 1930; Zhou et al., 1991; Qiu and Qiu, 1995), and are constrained at the bottom by the Pliocene red clay and overlain by the Late Pleistocene Malan loess (Deng et al., 2019) at the top of the sequence. Current geochronological and archaeological research show that early hominins may have

continuously occupied the Nihewan Basin from 1.66 Ma (Zhu et al., 2004) to the Late Pleistocene (Schick et al., 1991; Zhu et al., 2001, 2004; Pei et al., 2019).

Madigou (40°13'07"–16"N, 114°39'58"–40'18"E) is located in the northwest margin of the Cenjiawan platform (eastern part of the Nihewan Basin). Paleomagnetism indicates that the MDG stratigraphy comprises the early Brunhes normal chron and the late Matuyama reverse chron, including the Jaramillo normal subchron (Figure 2). The MDG archaeological layers are positioned within the pre-Jaramillo Matuyama chron, with an estimated age of ca. 1.2 Ma, i.e., chronologically within the onset of the MPT. Stratigraphic correlations of seven trenches excavated at MDG indicate that the MDG chronostratigraphic sequence begins with MDG-E2, followed by MDG-E3, MDG-E5 and MDG-E7, and contains the most recent units at MDG-E6 (Figure 1D) (Pei et al., 2019). A total of 1,517 lithic artifacts and over 900 fossil remains, including *Equus*, *Coelodonta antiquitatis*, Cervidae, Bovidae, and others, were unearthed from the lower part of the sequence in each trench, especially in MDG-E2 and MDG-E3 (Pei et al., 2019). Predominance of ungulates in the fossil assemblage suggested open grasslands and a sparse steppe (Pei et al., 2019).

Chert dominates among lithic raw materials, followed by siliceous dolomite (Pei et al., 2019). MDG knappers showed a preference for specific rock types, such as siliceous dolomite cobble for bipolar knapping, brecciated chert blocks for freehand hard hammer flaking, and high-quality chert for retouching tools (Pei et al., 2019).

The MDG fossils were spatially associated with stone artifacts, and preliminary zooarchaeological results suggest human action over part of the fossil assemblage (Pei et al., 2019). Thus, the ecological and environmental data retrieved from the isotopic

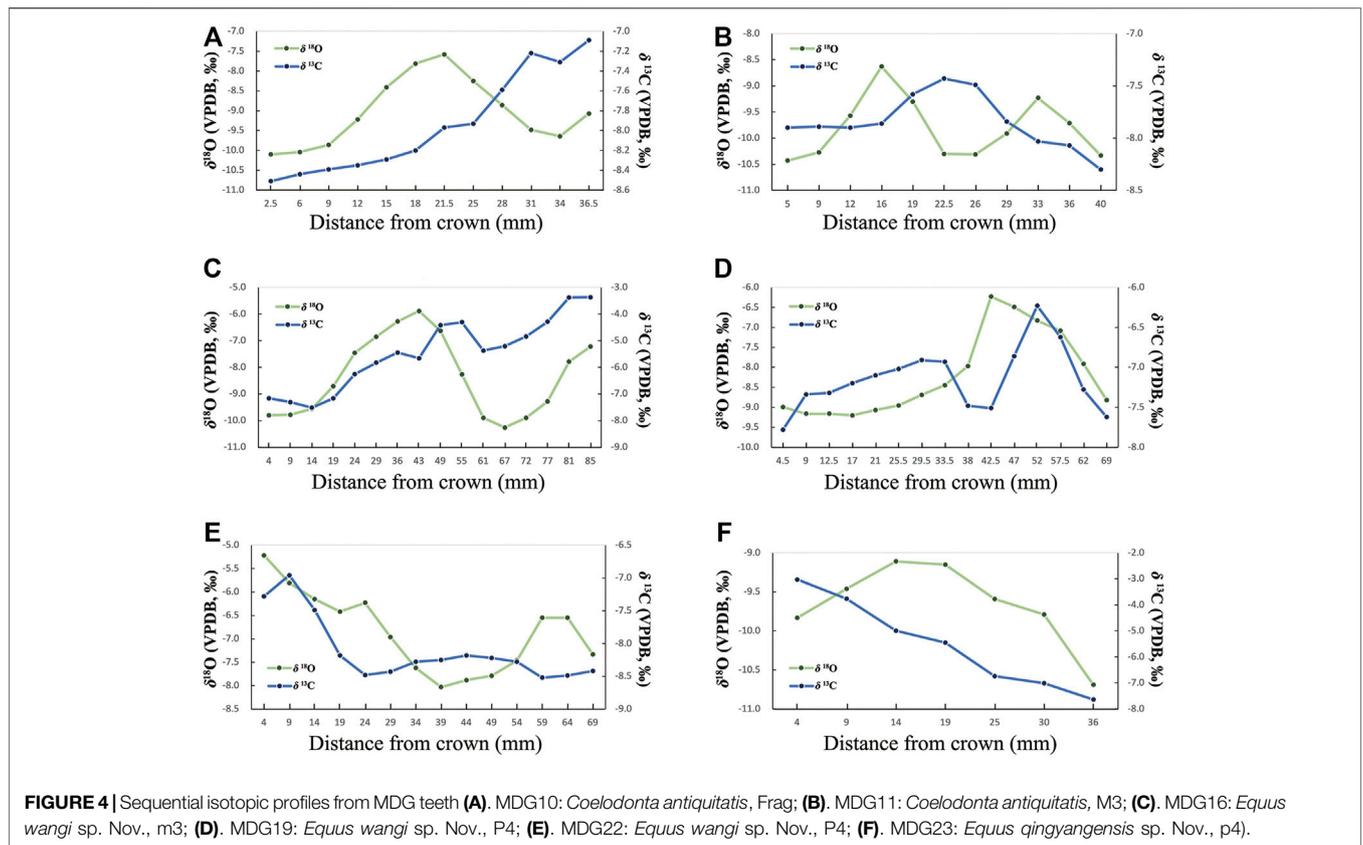


TABLE 2 | Serial sampling data of MDG teeth.

Taxa	Lab code	n	δ ¹³ C (‰)				δ ¹⁸ O (‰)			
			Median	SD	Max	Min	Median	SD	Max	Min
<i>Coelodonta antiqunitatis</i>	MDG10	12	-7.9	0.5	-7.1	-8.5	-9.0	0.9	-7.6	-10.1
	MDG11	11	-7.8	0.3	-7.4	-8.3	-9.8	0.6	-8.6	-10.4
<i>Equus wangi</i> sp. Nov.	MDG16	16	-5.5	1.3	-3.4	-7.5	-8.4	1.5	-5.9	-10.3
	MDG19	15	-7.2	0.4	-6.2	-7.8	-8.2	1.1	-6.2	-9.2
<i>Equus qingyangensis</i> sp. Nov.	MDG22	14	-8.1	0.5	-7.0	-8.5	-6.9	0.9	-5.2	-8.0
	MDG23	7	-5.5	1.7	-3.0	-7.6	-9.7	0.5	-9.1	-10.7

analysis of fossil enamel presented herein also informs on the landscapes occupied by early humans at Nihewan.

Sample Selection

Seventy-seven fossil teeth from archaeological layers at MDG were selected for isotopic analysis: 67 from trench MDG-E2, 8 from trench MDG-E3, and one from each MDG-E6, and MDG-E7 (Figure 2). Bulk sampling was made from 71 teeth of Cervidae (*Muntiacus* sp.), Moschidae, Bovidae, Rhinocerotidae (*Coelodonta antiqunitatis*), Equidae (*Equus wangi* sp. Nov. and *Equus qingyangensis* sp. Nov.), Canidae (*Canis chihliensis*?) and others (Table 1; Supplementary Table S1).

Six additional teeth were serially sampled: 2 of *Coelodonta antiqunitatis*, 3 of *Equus wangi* sp. Nov., and 1 of *Equus qingyangensis* sp. Nov. (see details in Supplementary Tables

S2–7). No first molars were included, to prevent the breastfeeding effect on isotopic data.

Sample Preparation and Isotopic Measurements

Bioapatite pretreatment was undertaken at the Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences (IVPP), and followed the protocols described in Lee-Thorp et al. (1989), Bocherens et al. (1994), Koch et al. (1997), and Wright and Schwarcz (1999). Before sampling, any contaminations on the enamel surface were removed with a dental drill. For the 71 teeth selected for bulk sampling, 15–30 mg enamel powder were extracted evenly from different parts of the enamel and grinded to below 200 meshes with agate mortar. Sequential samples of six additional teeth were

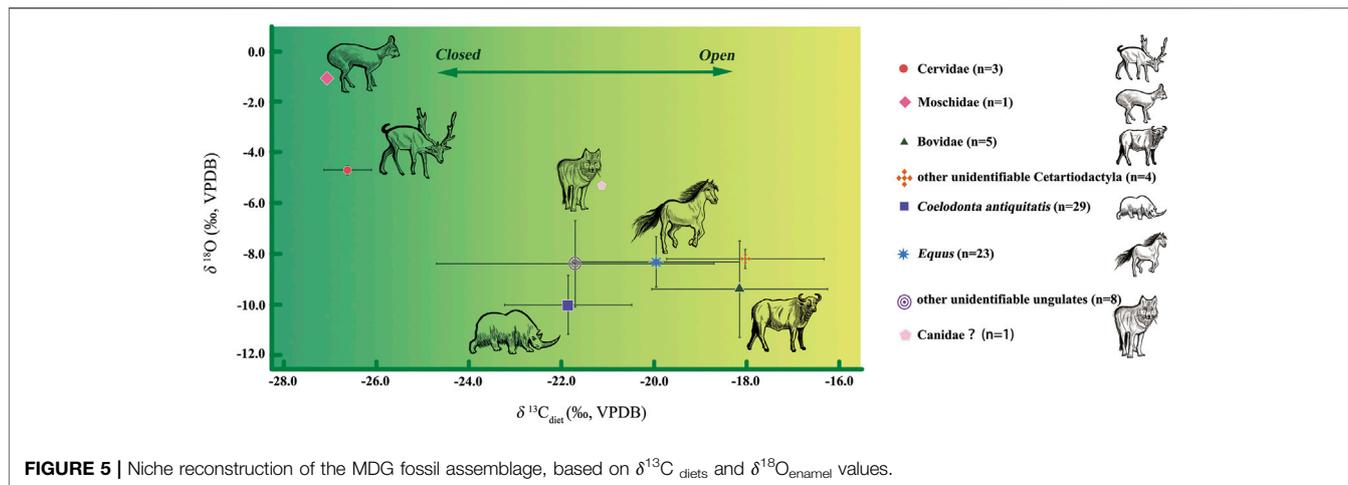


FIGURE 5 | Niche reconstruction of the MDG fossil assemblage, based on $\delta^{13}\text{C}_{\text{diets}}$ and $\delta^{18}\text{O}_{\text{enamel}}$ values.

collected from crown to neck along the enamel growth axis. The average sampling interval was 5 mm, and 15–20 mg of each sample was collected.

To remove the organic matter, about 1.5 ml of 2.5% sodium hypochlorite was added into the 2.0 ml tubes for each sample. After full reaction, samples were centrifuged and washed to neutrality with distilled water. Subsequently, 1.5 ml of 1 M acetic acid was added for 20 h to each sample to remove the secondary carbonate. Samples were subsequently cleaned with distilled water, freeze-dried and ground into powder again.

Isotopic measurements were undertaken in an Isotope Ratio Mass spectrometer (MAT-253) combined with a Gas bench system in the Laboratory for Stable Isotope Geochemistry, Institute of Geology and Geophysics, Chinese Academy of Sciences. The isotopic results were expressed as $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$, relative to the VPDB. The isotopic standards used for isotopic calibration were NBS 18, NBS 19 and GBW04405 ($\delta^{13}\text{C}_{\text{VPDB}} = 0.57 \pm 0.03\text{‰}$, $\delta^{18}\text{O}_{\text{VPDB}} = -8.49 \pm 0.14\text{‰}$; Certified reference material approved by the State Bureau of Technical Supervision, the People’s Republic of China). The precisions of $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values are better than 0.15‰ and 0.20‰ respectively. Isotopic data are listed in **Supplementary Tables S1–7**.

RESULTS

Isotopic Analysis of Bulk Samples

Figure 3 shows large isotopic variations among specimens that suggest different niches. The $\delta^{13}\text{C}$ values range from -13.0‰ to -2.1‰ and average $-7.3 \pm 2.7\text{‰}$ ($n = 77$), while the $\delta^{18}\text{O}$ values range from -12.5‰ to -1.1‰ and average $-8.8 \pm 1.9\text{‰}$ ($n = 77$).

Artiodactyls

The $\delta^{13}\text{C}$ value of Moschidae ($n = 1$) is -13.0‰ , indicating a closed C_3 environment. This sample shows the highest $\delta^{18}\text{O}$ value (-1.1‰).

Cervidae ($n = 6$) includes *Muntiacus* sp. and other unidentifiable Cervidae taxa. Their $\delta^{13}\text{C}$ values range

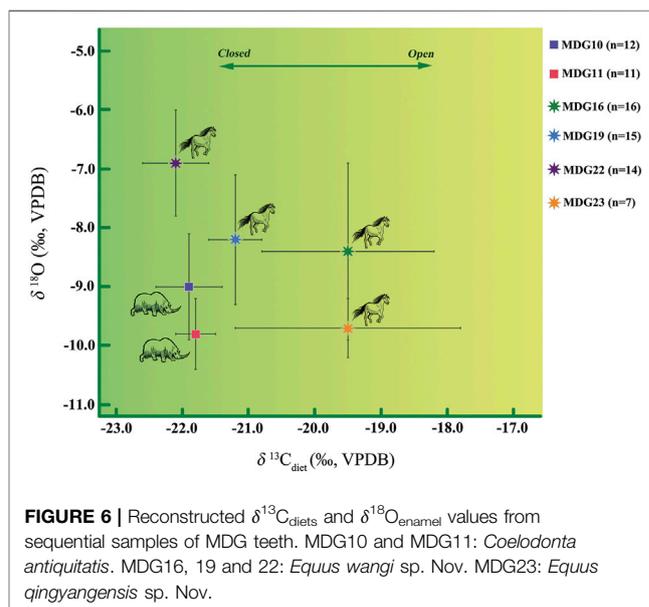


FIGURE 6 | Reconstructed $\delta^{13}\text{C}_{\text{diets}}$ and $\delta^{18}\text{O}_{\text{enamel}}$ values from sequential samples of MDG teeth. MDG10 and MDG11: *Coelodonta antiqutatis*. MDG16, 19 and 22: *Equus wangi* sp. Nov. MDG23: *Equus qingyangensis* sp. Nov.

from -12.9‰ to -10.0‰ , with a mean of $-12.0 \pm 1.1\text{‰}$. $\delta^{18}\text{O}$ values range between -11.4‰ and -4.5‰ , averaging $-6.9 \pm 2.7\text{‰}$ ($n = 6$). However, given the abnormally low $\delta^{18}\text{O}$ values of MDG13 (-8.3‰), MDG55 (-7.4‰) and MDG57 (-11.4‰), which might be due to the fact that the individuals come from other regions, the isotope data from those teeth are excluded from the following statistical analysis and discussion. The mean values of $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ in remaining Cervidae ($n = 3$) are $-12.6 \pm 0.5\text{‰}$ and $-4.7 \pm 0.1\text{‰}$ respectively, which indicates that MDG Cervidae fed in a pure C_3 environment.

Bovidae ($n = 5$) show $\delta^{13}\text{C}$ values from -6.6‰ to -2.1‰ , averaging $-4.2 \pm 1.9\text{‰}$ and $\delta^{18}\text{O}$ values from -11.5‰ to -7.4‰ (average of $-9.4 \pm 1.9\text{‰}$). This suggests that they consumed mixed $\text{C}_3\text{-C}_4$ plants. It is notable that one specimen (MDG61) has the highest $\delta^{13}\text{C}$ value (-2.1‰) among the entire assemblage, indicating a nearly neat C_4 environment.

Perissodactyls

The $\delta^{13}\text{C}$ values of *Coelodonta antiquitatis* ($n = 29$) differ from those of carnivores and artiodactyls, ranging from -11.7‰ to -5.5‰ (mean = $-7.9 \pm 1.4\text{‰}$). This indicates that the habitat of *Coelodonta antiquitatis* ranged between closed forest and open grassland landscapes. MDG *Coelodonta* teeth yield the lowest average $\delta^{18}\text{O}$ value [$-10.0 \pm 1.2\text{‰}$, ($n = 29$)] in the entire assemblage, which could be related to consumption of meteoric water.

The $\delta^{13}\text{C}$ values of *Equus* ($n = 23$) range from -8.7‰ to -3.4‰ (average of $-6.0 \pm 1.8\text{‰}$) and their $\delta^{18}\text{O}$ values range from -9.7‰ to -5.3‰ (mean = $-8.3 \pm 1.0\text{‰}$). This indicates their preference for more open environments compared to *Coelodonta antiquitatis*.

Carnivores

The $\delta^{13}\text{C}$ value of a sole specimen of Canidae is -12.2‰ . Its $\delta^{18}\text{O}$ value is -5.3‰ , higher than those from *Coelodonta*, *Equus*, and Bovidae.

Isotopic Analysis of Sequential Samples

The $\delta^{13}\text{C}$ profiles from sequential samples of *Coelodonta antiquitatis*, *Equus wangi* sp. Nov., and *Equus qingyangensis* sp. Nov., suggest considerable variations of the diet throughout the life history of these specimens. Pure C_3 or nearly pure C_4 vegetation predominated occasionally, but C_3 - C_4 mixed vegetation dominated. Variations observed in $\delta^{13}\text{C}$ profiles could indicate an oscillation between dry and wet seasons, while variability in $\delta^{18}\text{O}$ profiles may indicate periodic or seasonal fluctuations in precipitation (Figure 4; Table 2).

DISCUSSION

Niche Reconstruction in the Nihewan Basin at the Beginning of the MPT

Considering the fractionation of carbon isotope from diet to enamel bioapatite (with an enrichment of 14‰ in large herbivorous and of 9‰ in carnivores) (Tieszen et al., 1983; Cerling and Harris, 1999; Tejada-Lara et al., 2018), the niches of the MDG fauna can be reconstructed on the basis of isotopic data from bulk samples (Figure 5). We conclude that the fauna accumulated at the MDG site occupied a relatively broad niche, from open grassland to closed forest.

In terms of $\delta^{13}\text{C}_{\text{diets}}$ values, Moschidae and Cervidae have the highest negative $\delta^{13}\text{C}_{\text{diets}}$ values, indicative of a closed forest. On the other end, *Equus* and Bovidae have the most positive $\delta^{13}\text{C}_{\text{diets}}$ values, typical of open environments. The large standard deviations in Bovidae ($\delta^{13}\text{C}_{\text{diets}}$: 1.9‰) and *Equus* ($\delta^{13}\text{C}_{\text{diets}}$: 1.8‰) suggest that they had a more flexible dietary breadth. Conversely, the smaller standard deviations in *Coelodonta antiquitatis* ($\delta^{13}\text{C}_{\text{diets}}$: 1.4‰) may indicate a more specialized diet.

Regarding $\delta^{18}\text{O}_{\text{enamel}}$ values, Figure 4 shows that Moschidae (-1.1‰) and Cervidae ($-4.7 \pm 0.1\text{‰}$) have more positive average $\delta^{18}\text{O}_{\text{enamel}}$ values than *Equus* ($-8.3 \pm 1.0\text{‰}$), Bovidae ($-9.4 \pm$

1.9‰) and *Coelodonta antiquitatis* ($-10.0 \pm 1.2\text{‰}$). This indicates a preference in Moschidae and Cervidae for more ^{18}O -enriched foods (such as leaves). Overall, the standard deviation in *Coelodonta antiquitatis* ($\delta^{13}\text{C}_{\text{diets}}$: 1.4‰ , $\delta^{18}\text{O}_{\text{enamel}}$: 1.2‰) suggests more limited foraging flexibility, habitat and narrower ecological adaptability than *Equus* ($\delta^{13}\text{C}_{\text{diets}}$: 1.8‰ , $\delta^{18}\text{O}_{\text{enamel}}$: 1.0‰) and Bovidae ($\delta^{13}\text{C}_{\text{diets}}$: 1.9‰ , $\delta^{18}\text{O}_{\text{enamel}}$: 1.9‰).

As shown in Figure 6, the isotopic profiles from *Coelodonta antiquitatis* and *Equus* indicate seasonal changes. MDG23 (*Equus qingyangensis* sp. Nov.) ($\delta^{13}\text{C}_{\text{diets}}$: 1.7‰) and MDG16 (*Equus wangi* sp. Nov.) ($\delta^{13}\text{C}_{\text{diets}}$: 1.4‰) have the largest variation in the $\delta^{13}\text{C}_{\text{diets}}$ standard deviation, which suggests their adaptability to varied landscapes in nearly pure C_4 , mixed C_3 - C_4 and nearly pure C_3 vegetation. In contrast, the low standard deviation in MDG11 (*Coelodonta antiquitatis*) ($\delta^{13}\text{C}_{\text{diets}}$: 0.3‰) indicates a relatively fixed niche and narrow ecological adaptability for this individual. On the other hand, standard deviations of MDG16 ($\delta^{18}\text{O}_{\text{enamel}}$: 1.5‰), MDG19 (*Equus wangi* sp. Nov.) ($\delta^{18}\text{O}_{\text{enamel}}$: 1.1‰), MDG10 (*Coelodonta antiquitatis*) ($\delta^{18}\text{O}_{\text{enamel}}$: 0.9‰) and MDG22 (*Equus wangi* sp. Nov.) ($\delta^{18}\text{O}_{\text{enamel}}$: 0.9‰) are large, which reflects a seasonal variation of regional temperature and precipitation.

Changing Landscapes and Human Behavioral Adaptations in the Nihewan Basin at the Onset of the MPT

It has been proposed that human occupation of the Nihewan Basin during the Early Pleistocene was discontinuous and that the area would only be populated during interstadial periods and in the warm seasons (Dennell, 2003, 2013). While systematic testing is still needed through multiple proxies and across the archaeological sequence (de la Torre et al., 2020), our contribution on the isotopic analysis of the MDG faunal assemblages does not seem to support such hypothesis. Variability of patterns in $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values (Figure 4) strongly suggests input of mammal carcasses to the site during various seasons. In addition, considering other archaeological evidence in the Nihewan Basin, it has been suggested that Early Pleistocene humans in North China could have adopted flexible technological strategies as a response to environmental fluctuations (Pei et al., 2019).

In the case of MDG, early humans preferentially used preferentially siliceous dolomite cobbles in the bipolar technique, breccia chert blocks for freehand hard-hammer percussion, and selected high-quality chert for retouching tools (Pei et al., 2017, 2019). This suggests a structured procurement of raw materials based on the technological requirements of each knapping activity.

CONCLUSION

Mammal fossils unearthed in archaeological sites play an important role in assessing the impact of environmental instability in human behavioral adaptations. This paper analyzed stable isotope ratios of fossil tooth enamel at the

recently discovered Early Pleistocene site of MDG, in the Nihewan Basin. Isotopic data from bulk teeth enamel shows that the MDG fauna occupied a wide niche, including pure C₃, C₃-C₄ mixed, and nearly pure C₄ environments. The δ¹³C and δ¹⁸O profiles of tooth sections indicate substantial regional dry/cold and warm/wet fluctuations and seasonal variations.

Most likely, changing environments had an impact on human behavioral adaptations archaeologically detectable through stone tool technological variability. Previous studies (Pei et al., 2019) have discussed the technological plasticity of MDG hominins in raw material procurement strategies, knapping techniques, tool preferences and lithic reduction sequences, all of which might potentially be linked to environmental fluctuations such as those reported in this study. Further studies should explore other paleoenvironmental proxies and their application to other archaeological assemblages at the Nihewan Basin, in order to test how early humans coped with the instability characteristic of the MPT, and to portrait more accurately dynamics of hominin occupation in north China during this period.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

ZX: Investigation, analysis, writing, and original draft preparation. SP: Investigation, designed the research and

writing. YH: Academic support and writing. IdlT: Writing. DM: Investigation and analysis. All authors have contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/feart.2021.789781/full#supplementary-material>

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