Paleo-environment and paleo-diet inferred from Early Bronze Age cow dung at Xiaohe Cemetery, Xinjiang, NW China

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Abstract

Well preserved Early Bronze Age cow dung in Xinjiang provides a unique opportunity to investigate important issues concerning environment, landscape, and livestock at about 3.4–3.7 ka in northwestern China. In this study, pollen and phytolith analyses, in conjunction with identification of macrofossil plant remains in the cow dung were carried out. Seeds, plant fragments, pollen and phytoliths extracted from four cow pies from the Xiaohe Cemetery indicate that the area was a typical oasis, where reeds (Phragmites australis), lovegrass (Eragrostis), and Aster-type Asteraceae probably served as the main cattle feed. Xerophilous taxa, such as Chenopodiaceae and Artemisia, were present as well. The paleo-diet of these cattle mainly consisted of C3 plants, accompanied by small numbers of C4 plants. Archaeological and archaeobotanical evidence reveals that the environmental conditions of ancient Xiaohe and the surrounding area were very different to that of the present day, surrounded by desert.

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1. Introduction

Animals, especially herbivores, pass pollen, phytoliths, seeds and other fragments in their dung after ingesting, which help the dispersal of many plant species indirectly (Pakeman et al., 2002; Miller, 2012). Analyses of macrofossil and microfossil plant remains are of great significance for the reconstruction of the paleo-environment, paleo-ecology, and paleo-diet of both humans and animals. Macrofossil remains of plants, such as wood, seeds and fruits, together with phytoliths, are considered as the most reliable and direct physical evidence for paleoethnobotanical studies, as they are of local origin, and could reflect the vegetation at a site or sites of collection or grazing (Piperno, 1988). On the other hand, pollen is a regional indicator which reflects the landscape over a wider area where the animals grazed (Robinson and Aaby, 1994).

Due to their special chemical composition (sporopollenin and silica), both pollen/spores and phytoliths can resist mechanical and biological processes and are thus concentrated in herbivore feces (Shahack-Gross et al., 2003; Delhon et al., 2008). As a result, the combination of macrofossil and microfossil analyses of animal coprolites is indispensable for research into early animal husbandry, paleo-environment, human interaction with animals, or even the state of health of the animals (Fall et al., 1990; Scott, 1990; Scott and Bousman, 1990; Schelvis, 1992; Scott and Cooremans, 1992; Akeret and Jacomet, 1997; Anderson and Ertug-Yaras, 1998; Zhou and Zheng, 2000; Fuller et al., 2009). Stable isotope analysis of the coprolites plays a complementary role to the macro- and microfossil analyses, as it gives an indication of the ratio of plants with different metabolic pathways in the animals’ diet. Combining pollen analysis and variations of δ13C values in hyrax coprolites at different time intervals reveal differentiated diets and the associated environmental conditions (Scott and Vogel, 2000).

Archaeological finds of fossil coprolites, particularly those of domesticated animals, such as sheep/goat (Moe, 1983; Rasmussen, 1993; Akeret and Jacomet, 1997; Akeret et al., 1999), cattle (Carrión...
et al., 2000; Akeret and Rentzel, 2001), dog (Horrocks et al., 2003), camel (Zhang et al., 2013), humans (Fry and Hall, 1975; William-Dean and Bryant, 1975; Reinhard and Danielson, 2005) and some megafauna (Beltrame et al., 2013), are uncommon. Morphological description, macro- and/or microfossil (pollen/phytolith) analyses have been undertaken, and valuable information about local or regional environment, vegetation, and animal/human diet unveiled (King, 1977; Lin et al., 1978; Thompson et al., 1980; Bryant and Holloway, 1983; Moe, 1983; Fry, 1985; Davis and Anderson, 1987; Scott and Cooremans, 1992; Carrión et al., 2000; Akeret and Rentzel, 2001; Rosen et al., 2005; Delhon et al., 2008). In the case of the Iron Age cow pies from Southern Africa, the herbaceous pollen assemblages suggest that the cattle were kept in more open vegetation areas than the woody environments of today (Carrión et al., 2000).

In China, related findings and research are exceedingly rare. Among these, pollen studies of hyaenid coprolites from the Peking Man Site at Zhoukoudian near Beijing (about 500,000 a) suggest that Peking Man (Homo erectus pekinensis) lived in an area of temperate forest steppe, which is in good agreement with pollen analyses from corresponding cave sediments (Li et al., 1966; Du and Yu, 1980). Research carried out on hyaenid coprolites from the Tuozzi Cave in Nanjiang, Jiangsu (early Pleistocene) (Hao et al., 2008) suggested a similar environment and vegetation to that of the Peking Man Site.

Meantime, recent work focused on historical periods. For example, dung of sheep/goat from the Yanghai Cemetery (around 2.3–2.4 ka) (Ghosh et al., 2008; Jiang et al., 2013) and camel dung from ancient Loulan City (AD 50–770) (Zhang et al., 2013) in Xinjiang help us to obtain reliable information about the paleo-environment of Northwest China, which were then oases. Nevertheless, neither well preserved earlier fossil dung was excavated, nor were comprehensive analytical methods including macro- and micro-fossil analyses applied to the dung.

Located in Central Asia, Xinjiang served as one of the crossroads of ancient East–West economic and cultural exchange. As a result, it has attracted the attention of historians, archaeologists, and archeobotanical researchers. Studies have been undertaken in the use of plants (Jiang et al., 2006, 2007a, 2007b, 2008, 2009) and the paleo-diet (Gong et al., 2011; Chen et al., 2012a) in ancient Xinjiang. Research on reconstructing the paleo-environment of this area, however, has been rarely reported. Some work including phytoliths retrieved from animal dung (Zhang et al., 2013), pollen and phytolith analysis of pottery sherds (Yao et al., 2012), and single-grain pollen analysis of mud coffins (Li et al., 2013) shed light on the ancient environment and vegetation of the Xinjiang area. Nevertheless, either most of these materials are no more than 3 ka old, or little information about animal husbandry was revealed. In this respect, cow pies unearthed in the Xiaohe Cemetery are potentially valuable sources of paleo-environmental information in areas where sources of proxy information are scarce or nearly nonexistent. Macrofossils, phytoliths and pollen were extracted from these cow pies, which, because they were deposited in a dry climate, are well preserved. These provide proxy evidence of the physical conditions existing at the Xiaohe Cemetery in the past.

2. Physical setting and site description

The Xiaohe Cemetery is located in the Lop Desert, 60 km from the south valley of the lower Peacock River, about 60 km north of the Gumugou Cemetery, and 102 km east of the ancient Loulan City (40°20.2′N, 88°40.3′E, 823 m asl) (Fig. 1). The Cemetery occupies a critical position on the Peacock Valley channel from ancient Loulan City to Yanqi and Korla to the west. Kuruktag Mountain is located to the north, at a low altitude. The Peacock River flowed WNW, but is now dry (Wang, 1993).

The Xiaohe Cemetery was discovered by Ördek, a hunter living in Lop Nur, at the beginning of the 20th century, and then investigated by Folke Bergman, a Swedish archaeologist, who attempted to excavate it. It was not until the start of the 21st century (2002–2005) that Chinese archaeologists conducted a comprehensive scientific excavation. As a representative of the Xiaohe Culture, the Xiaohe Cemetery was named as one of China’s top ten archaeological discoveries in 2004 (XICRA, 2005, 2007). The Cemetery consists of a 7.75 m high oval sand hill, covering an area of 2500 m² (Fig. 2A). Apart from more than one hundred looted tombs, the 167 tombs excavated were divided into southern and northern areas by wooden piles of euphrates poplar (Populus euphratica). Thousands of well-preserved funerary objects were unearthed, including clothes, leather, plants (especially crops), animal bones and sharp-edged, wooden carvings, wooden bows and arrows, and bronze. Cereal staples included bread wheat (Triticum aestivum) and common millet (Panicum miliaceum), while cattle and sheep were the main livestock (XICRA, 2003, 2005, 2007).

The suitability of the study area for addressing the paleo-environmental and paleo-diet issues was due to extremely dry conditions and the unique context of deposition. Biogenic materials, especially pollen, are well preserved under dry sedimentation conditions (Davis, 1990; Navarro Camacho et al., 2000), which, as a result, enhances the value of paleo-botanical analyses in this case. The animal dung excavated in the Xiaohe Cemetery was separated from the remainder of the archaeological sediments, making it
Fig. 2. The Xiaohe Cemetery and unearthed cow dung. (A) Landscape of the Xiaohe Cemetery; (B) Cow pies unearthed in front of the coffin of M20; (C) M32-2; (D) Cow pies of M20; (E) X-collected from the ground of the Xiaohe Cemetery; (F) M32-1. (C) and (F) were unearthed and collected in the tomb of M32. Scale bars = 2 cm.

Fig. 3. Micrographs of reed (Phragmites australis) fragments recovered from cow pies. (A) Upper epidermis of reed showing smooth surface. Scale bar = 3 mm. (B) Lower epidermis of reed showing coarse surface. Scale bar = 3 mm. (C) Lower epidermis of reed showing intercostal long-cells nearly similar and intercostal short-cells paired. Scale bar = 50 μm. (D) Magnification of the lower epidermis presenting rough jagged long-cells and paired short-cells. Scale bar = 20 μm.
almost uncontaminated, which not only provides an opportunity to investigate what the animals really ate, but also helps us to gain a good understanding of the fodder used as well as the paleo-environment thousands of years ago.

3. Material and methods

3.1. Sample description and preparation

These coprolites (Fig. 2C–F), which were yellow-brown, nearly round to irregular, with smooth surfaces, are excellently preserved without oxidation or decay by fungi and/or bacteria. With a typically hollow center and dense outer margins, this dung includes some fine silt and has a multi-layered structure, resembling typical cow pies according to Courty et al. (1991) and Macphail et al. (1997).

After removing the outer surfaces mechanically, 2.0 g of dried material from the interior of the dung was soaked for 24 h with 100 ml 10% HCl. Crushed well with glass stirring rods, the samples were vibrated in an ultrasonic cleaner (38 Khz, 250 W) for 2 h to separate the particles. Then, the samples were transferred to a 50 ml polypropylene centrifuge tube,

Fig. 4. Light and SEM micrographs of seeds recovered from cow pies. (A)–(C) Seeds of Eragrostis from M32-2; (D)–(F) Seeds of Carex from M32-1. (A) Seeds of Eragrostis showing contraction. Scale bar = 0.3 mm. (B) Lophate ornamentation on testa epidermis. Scale bar = 0.3 mm. (C) Magnification of testa epidermis showing lophate ornamentation. Scale bar = 100 μm. (D) Ventral seed surface. Scale bar = 1 mm. (E) Magnification of testa epidermis displaying regular polygonal, honeycomb-like depressions. Scale bar = 100 μm.

Fig. 5. Micrographs of unknown fragments recovered from cow pies. (A), (B) Fragments resembling grass leaves. Scale bar = 1 mm. (C), (D) Insect or parasite. Scale bar = 1 mm. (E), (F) Chitinous carapace. Scale bar = 3 mm.
centrifuged (3000 rpm, 5 min), decanted and washed 3 times, then screened (0.3 mm mesh size). The coarse fragments above and fine debris and microfossils below the sieve were collected for macrofossil and microfossil (palynomorph and phytolith) analyses respectively.

### 3.2. Dating

Two cow pies were dated with an accelerator mass spectrometer (AMS) $^{14}$C in Peking University. Some accompanied plant remains were dated with an AMS $^{14}$C in $^{14}$CHRONO Centre, Queens.
University Belfast, then calibrated using IntCal 09.14c (Reimer et al., 2009) and OxCal v3.10 (Bronk Ramsey, 2005).

3.3. Macrofossil analysis

Seeds and other plant macroremains were identified using descriptions by Chen et al. (1993) and Wang (1999), respectively. Comparisons were made with the modern reference plant collection at the Key Laboratory of Vertebrate Evolution and Human Origins of the Chinese Academy of Sciences, Institute of Vertebrate Paleontology and Paleoanthropology (IVPP), Chinese Academy of Sciences (CAS) and the Department of Scientific History and Archaeometry, University of Chinese Academy of Sciences (UCAS). Plant nomenclature follows the English version of the Flora of China.

3.3.1. Stereo microscope examination

The samples were placed in a petri dish with distilled water and teased apart with dissecting needles and forceps under a stereo microscope for further identification.

3.3.2. LM (light microscope) examination

Stereo microscope for further identification. Photographs were placed on stubs and coated with Platinum using a Quorum SC 7620 Sputter Coater, and then examined and photographed under a Nikon SMZ1000 stereo microscope for further identification.

3.3.3. SEM (scanning electron microscope) examination

Ancient seeds and plant fragments obtained from these cow pies were placed on stubs and coated with Platinum using a Quorum SC 7620 Sputter Coater, and then examined and photographed under a Nikon Eclipse LV100POL microscope and a KEYENCE VHC-600E microscope for depth composition (to obtain a clearer picture).

3.4. Microfossil analysis

For pollen and phytolith analyses, the samples were processed with reference to Davis and Anderson (1987), Danielson and Reinhard (1998), Carrión et al. (2000), Lentfer (2000), Horrocks et al. (2003), Scott et al. (2004), and Reinhard and Danielson (2005).

The samples were first treated with 10% KOH and heated, followed by washing with distilled water. Then, a tablet of Lycopodium (~18 583 spores per tablet) was added to each sample in order to estimate the concentrations of samples (grains/g dry weight) before mineral separation with a heavy liquid CdI2/KI (d = 2.4). Finally, the material was acetylated (1 ml concentrated H2SO4, 9 ml acetic anhydride). Slides were mounted in glycerin and Canada balsam for pollen and phytolith identification and counting respectively. Identifications of pollen and phytoliths were undertaken using a Nikon Eclipse LV100POL microscope employing a number of keys (Twiss et al., 1969; Piperno, 1988; Piperno and Pearsall, 1998; HICRA, 1999; Pearsall, 2000; Xu et al., 2006; Li et al., 2009) and comparative material at the Key Laboratory of Vertebrate Evolution and Human Origins of the Chinese Academy of Sciences, Institute of Vertebrate Paleontology and Paleoanthropology (IVPP), Chinese Academy of Sciences (CAS). Pollen/phytolith percentages are based on a sum of at least 500 pollen/phytolith grains. The results of the percentages and concentrations are presented in Figs. 7 and 8, which were drawn using the Tilia and Tilia-GRAPH program (Grimm, 1991/1993, 1991). Phytolith nomenclature follows Madella et al. (2005).

3.5. Stable C/N isotope analysis

The interior of dried cow pies were ground to powder for stable carbon and nitrogen isotope analysis. The measurement of contents of C, N and the C, N stable isotope ratios of these cow pies were carried out using an Elemental Vario-Isoprime 100 IRMS at the Measuring Center of the Institute of Agricultural Environment and Substantial Development, Chinese Academy of Agricultural Sciences (CAAS). Sulfanilamide served as the standard for measuring the contents of C and N, CO2 (PDB as standard) and N2 (AIR as standard) in steel bottles normalized by USGS 24 and IAEA-N-1 respectively were used as standards for the C, N stable isotope ratios.

4. Results

4.1. Age

The date obtained from cow pies of M32-1 and X (the collected one) was determined to be cal. 1610–1425 BC, while that of the grains of common millet (P. miliaceum) and wheat (T. aestivum) collected from Tomb No. M20 was cal. 1726–1438 BC (Table 1), which is in good agreement with that of early AMS dating results (cal. 1980–1390 BC) by an AMS 14C on some grains and other organic remains at Peking University (XICRA, 2007; Li, 2010).

Table 1

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Sample</th>
<th>Deposition Unit</th>
<th>14C years (T120 ~ 5568)</th>
<th>Dendrocalibrated age ranges (+13, 68.2%)</th>
<th>Dendrocalibrated age ranges (+20, 95.4%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BA131749</td>
<td>Cow pies</td>
<td>M32</td>
<td>3205 ± 25</td>
<td>1500 BC (68.2%) 1445 BC</td>
<td>1520 BC (95.4%) 1425 BC</td>
</tr>
<tr>
<td>BA131750</td>
<td>Cow pies</td>
<td>X</td>
<td>3250 ± 30</td>
<td>1610 BC (14.4%) 1570 BC</td>
<td>1610 BC (95.4%) 1440 BC</td>
</tr>
<tr>
<td>UBA21939</td>
<td>Common millet grains</td>
<td>M20</td>
<td>3330 ± 33</td>
<td>1540 BC (42.2%) 1490 BC</td>
<td>1540 BC (95.4%) 1450 BC</td>
</tr>
<tr>
<td>UBA22086</td>
<td>Wheat grains</td>
<td>M20</td>
<td>3240 ± 32</td>
<td>1480 BC (11.6%) 1450 BC</td>
<td>1480 BC (95.4%) 1410 BC</td>
</tr>
</tbody>
</table>

The contents of all four cow pies were dominated by innumerable small fragments which resembled grass straw. As well, other macrofossils, including fragments and seeds, were identified from these coprolites.
4.2.1. Fragments of reed (*Phragmites australis*)

Fragments with a smooth upper epidermis and a rough lower epidermis were present in large quantities (Fig. 3). The fragments are 4.0–7.1 mm long ($\bar{x}=5.3$ mm, $N=50$), 0.9–2.3 mm wide ($\bar{x}=1.5$ mm, $N=50$). Rough jagged long-cells and paired short-cells on the abaxial surface of the samples resemble those of reed (*P. australis*).
4.2.2. Seeds of Eragrostis and Carex

A total of 83 small seeds (51 grains in M32-2, 32 grains in X) and two larger ones (one is intact, another broken in M32-1) were picked out and identified as Eragrostis sp. (Fig. 4A–C) and Carex sp. (Fig. 4D–F), respectively. Most of the small seeds with lophate ornamentation on the testa epidermis of Eragrostis are shrunk. Both the ventral and dorsal seed surfaces of Carex display regular polygonal, honeycomb-like depressions.

4.2.3. Other macroremains

In addition to the above macrofossils, there are still some fragments that cannot be accurately identified. However, morphological characteristics suggest they originated from blades of grass, an insect or parasite, and the chitinous carapace of an arthropod respectively (Fig. 5). Pieces of unknown plant fiber were extracted for future study.

4.3. Microfossils

The samples contain common grass phytolith morphotypes, including elongate plicate, elongate dendritic, and elongate echi- nate long cells, cuneiform bulliform cells, rondels, bilobate, square, and rectangular short cells, acicular hair cells, as well as scarce polyhedral aggregates, short-saddle and sponge spicules (Fig. 6A–O). Bulliform and scutiform-bulliform types, identified as reed-type bulliform, were the commonest forms in the assemblages (varying from 11% to 20% and from 11% to 16%, respectively) and occur at significant concentrations (varying from 33,000 to 100,000 and from 29,000 to 84,000 grains/g dry sample, respectively) (Fig. 7). The phytolith assemblage of M32-1 depicted a different diet record from the other three samples. For example, both percentages and concentrations of bulliform, scutiform-bulliform, rectangular short cells, and polyhedral aggregates reached the highest value of the four samples, whilst those of rondels and bilobate short cells, and acicular hair cells are least common in M32-1.

Arboreal pollen was not represented in the pollen spectra, although there was a diversity of pollen of shrubs and herbs, such as Aster-type Asteraceae, Poaceae, Chenopodiaceae, Artemisia, and Cyperaceae. The pollen spectra were dominated by Aster-type Asteraceae, and secondly Poaceae, with noticeable amounts of Chenopodiaceae and Typha in several samples. Some additional forms were also present, such as monolette and trilete spores, thought to be fern and moss spores (Figs. 6P–W and 8).

Pollen percentages and concentrations were similar in value, except for those from sample M32-1, which showed a high value of Aster-type Asteraceae and Chenopodiaceae and a low percentage of Poaceae, as well as a very low concentration of each pollen or spore compared to the other three samples. In general, pollen concentrations varied greatly from 132,000 to 469,000 (341,000 on average) grains/g dry sample. Sample M32-1 was exceptional with only 4150 grains/g dry sample. It is noticeable that pollen of Aster-type Asteraceae concentrations varied from 81,000 to 329,000 (184,000 on average) grains/g dry sample, except for sample M32-1, which only had 3000 grains/g dry sample.

4.4. Stable C/N isotope data

Cow pies represent fermented products, which were formed after digestion by gastric juices twice over. As a result, stable isotope analysis was based on these excreted wastes. The contents of C, N and the C:N stable isotope ratios of these four cow pies are presented in Table 2 and Fig. 9. In general, the contents of C and N range from 15.3% to 35.5% and from 0.7% to 1.8% respectively, indicating they were derived from plants directly. The δ¹³C values of all cow pies except M32-1 were close to each other (−25.0‰ on average), while the δ¹⁵N values have a wide range (4.8‰–7.9‰) with an average of 6.7‰ (N = 4). M32-1, however, has a much higher δ¹³C value (−22.8‰) than the others and a relatively high δ¹⁵N value (7.7‰).

### Table 2

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>C%</th>
<th>N%</th>
<th>δ¹³C (%)</th>
<th>δ¹⁵N (%)</th>
<th>C₃ (%)</th>
<th>C₄ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>35.5</td>
<td>1.8</td>
<td>−25.1</td>
<td>4.8</td>
<td>93.1</td>
<td>6.9</td>
</tr>
<tr>
<td>M32-1</td>
<td>15.3</td>
<td>0.7</td>
<td>−22.8</td>
<td>7.7</td>
<td>75.4</td>
<td>24.6</td>
</tr>
<tr>
<td>M32-2</td>
<td>32.8</td>
<td>1.6</td>
<td>−25.0</td>
<td>6.3</td>
<td>92.3</td>
<td>7.7</td>
</tr>
<tr>
<td>M20</td>
<td>28.3</td>
<td>1.5</td>
<td>−25.0</td>
<td>7.9</td>
<td>92.3</td>
<td>7.7</td>
</tr>
</tbody>
</table>

### 5. Discussion

#### 5.1. Why were cow pies put into tombs?

Archaeological excavations and corresponding research on the Xiaohe Cemetery suggest that cowhides were used to wrap wooden or mud coffins, while cattle skulls, milk lumps, and even cattle dung were placed in these coffins as funerary objects (XICRA, 2003, 2005, 2007; Liang et al., 2012). Therefore, it is evident that cattle served as a very important livestock resource in the Xiaohe area at least from 3.7 to 3.4 ka. Based on the concept of treating the deceased as the living, these cow pies placed in the coffins or close to the wooden piles as illustrated in Fig. 2B, should have some special significance. Archaeological findings, combined with ethnographic fieldwork, have shown that animal dung has served as a rich resource since ancient times. For example, it could be utilized as the principle source of fertilizer/manure for the fields. Because the firing temperatures of animal dung range from 550 °C to 900 °C (Rice, 1987), it could also be utilized as fuel in cooking and pottery production (Winterhalder et al., 1974; Sillar, 2000; Harris, 2011) especially in treeless areas. Animal dung is even included as an ingredient in ritual drinking in the highlands of Peru and Bolivia today (Sillar, 2000).
5.2. The paleo-diet and feeding strategy of Xiaohe cattle

Valamoti and Charles (2005) observed that wild plant seeds are present in goat dung one or two days after experimental feeding, which suggests that ruminant digestion could have a considerable effect on the plant materials. Based on a study of Neolithic cattle dung, Akeret and Rentzel (2001) proposed that if seeds were eaten in sufficient quantity, they would be found in the feces. Moreover, young stems and leaves of reeds, especially those growing on dry land, are rich in protein, starch, and sugar, which makes it a high-quality forage grass today (Cai, 2011). Because the cattle dung of the present study contains seeds of Eragrostis and fragments of P. australis in large quantities, this suggests that both plants were utilized as important fodder in the Xiaohe area more than three thousand years ago. As well, their seasonal fruiting cycle makes plants good potential indicators for seasons of habitation (Valamoti, 2007). The seeds of Eragrostis and Carex contained in the cow dung unearthed from the Xiaohe Cemetery were mature and fully developed, indicating that the cattle were grazing in the late summer or autumn.

The macro- and micro-fossil data from this cow dung indicate that the vegetation in the Xiaohe area consisted mainly of the C3 type including P. australis, Aster-type Asteraceae, Arumitia and Chenopodiaceae. Together with C4 plants such as Eragrostis and Carex (Cyperaceae), these plants could have been responsible for a slight isotope enrichment in these samples. Based on the generally accepted mean values for C3 (−26%o) and C4 plants (−13%o) (Cai and Qiu, 1984; Scott and Vogel, 2000), we calculated the percentages of C3 and C4 plants consumed by the cattle (Table 2). As stable isotope data were obtained from a fermented product after digestion by cattle, the relatively high δ15N value is reasonable. In agreement with the values of δ13C, all samples except M32-1 have limited percentages of C4 plants (6.9%–7.7%), implying these cattle mainly ate C3 type plants, together with a small amount of C4 type plants. However, the percentage of C4 plants in M32-1 reaches 24.6%, implying that more C4 plants were consumed (although C3 plants still formed the majority). As well, the contents of C, N, as well as the δ13C value of M32-1 throw light on differences with the other samples. The phytolith and pollen spectra from coprolite sample M32-1 also demonstrated the low value of Poaceae. The differences between M32-1 and the other three cow pies may have originated from differences in diet, feeding or grazing time, and/or individuals.

Pollen analysis of fresh cow dung suggested that a bias in favor of Poaceae pollen is of minor significance (Horowitz, 1992; Carrió et al., 2000). As a result, the dominance of Aster-type Asteraceae in the pollen assemblages suggests that it probably served as an important ingredient of the cattle’s diet. On the other hand, it may also be due to a conscientious choice of animal fodder. Some archaeological and archaeozoological research has suggested that changes in animal diet may be related to specific purposes. For example, pigs and cattle were fed surplus cereals and husks of foxtail millet (Setaria italica) for meat (Chen et al., 2012b), alpaca are grazed on the puna flora (typified by perennial C3 grasses Festuca, Calamagrostis, Stipa, and Poa) to obtain wool, while llamas are fed on maize for pack transport or riding (Fimucane et al., 2006), or when used as sacrificial animals. The reason for the rich content of pollen from Aster-type Asteraceae in the present study is still an open question.

5.3. Ancient landscape of Xiaohe

The absence of tree pollen along with the diversity of herbaceous pollen and non-pollen groups might indicate a limited number of trees at or around the site. Populus euphratica probably grew along the ancient rivers or near the oasis, but its pollen is poorly preserved. Carrió et al. (2000) proposed that warm, wet climates should produce both abundant tree and grass pollen, while cool, dry conditions may result in relatively more tree pollen. During their research on hyrax dung, Scott and Vogel (1992) showed that tree pollen is masked by grass pollen during the wet periods or seasons. The presence of aquatic or semi-aquatic palynomorphs, such as Typha pollen, fern and moss spores, as well as sponge spicules suggested water input, through ingestion by cattle of stagnant, shallow, or open water (Mahlabalé, 1968; Carrió et al., 2000). Based on the pollen and phytolith assemblages, it seems plausible that the surroundings of the Xiaohe Cemetery represented a well-watered oasis ca. 3.4–3.7 ka. However, a certain number of common xerophilous taxa were found, such as Artemisia and Chenopodiaceae, the pollen of which reached 12% on occasion. This corroborates previous studies on climate change in Lop Nur (Wu, 1994; Yan et al., 1998; Yuan and Yuan, 1998) and recent work on environmental analysis of the Xiaohe Cemetery by palynomorphs extracted from the mud coffins (Li et al., 2013).

Paleo-environmental studies suggest that the past 3000 years have been marked by environmental and ecological degradation, with increased droughts, shriveled rivers and lakes, and a decrease in biodiversity (Zhou, 2002, 2007). In this context, the desertification of the Xiaohe Cemetery and the demise of ancient Loulan City occurred in Xinjiang, where there was a climatically-sensitive ecotone. As well, the influence of people should not be underestimated. The felling of trees and destruction of reeds and other wetland vegetation exacerbated environmental degradation. Ultimately, the oasis near the Xiaohe Cemetery was concealed by a vast dune, and the ancient Xiaohe people died out, or migrated to other places.

Both wheat and common millet were found in these tombs, but no grains or fragments of their stalks and chaffs were extracted from the cow dung, which probably indicates that the cattle were mainly herded. This is in agreement with the Xiaohe people’s nomadic way of life as reflected by archaeological findings. For example, they preferred grass baskets and leather bags to pottery, while wooden bows and arrows and small twigs of Ephedra were buried with the deceased for use in the afterlife. According to the present study, the ancient Xiaohe people lived in an oasis, mainly engaged in animal husbandry (cattle, goat/sheep), together with a little agriculture such as common millet and wheat cultivation.

6. Conclusion

The biodiversity of the archaeobotanical assemblages retrieved from this cow dung suggests a well-watered oasis around the Xiaohe Cemetery about 3.4 – 3.7 ka. The livestock fed mainly on C3 plants (such as Phragmites), together with different proportions of C4 plants (such as Eragrostis). These taxa were either eaten by the cattle in or around the site, or gathered and brought into the shelter by the people.

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