SCIENCE CHINA
Earth Sciences

• RESEARCH PAPER •

February 2017 Vol.60 No.2: 268–276
doi: 10.1007/s11430-016-5123-8

The subsistence patterns of the Shengedaliang site (~4,000 yr BP) revealed by stable carbon and nitrogen isotopes in northern Shaanxi, China

CHEN XiangLong[1*], GUO XiaoNing[2], WANG WeiLin[2], HU SongMei[2], YANG MiaoMiao[2], WU Yan[3] & HU YaoWu[3,4]

[1] *Institute of Archaeology, Chinese Academy of Social Sciences, Beijing 100710, China;*
[2] *Shaanxi Provincial Academy of Archaeology, Xi'an 710054, China;*
[3] *Key Laboratory of Vertebrate Evolution and Human Origins, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing 100044, China;*
[4] *University of Chinese Academy of Sciences, Beijing 100049, China*

Received April 8, 2016; accepted September 19, 2016; published online December 7, 2016

Abstract In order to explore subsistence patterns in northern Shaanxi Province around 4,000 yr BP, 28 human and 24 animal bones from the Shengedaliang site were sampled for stable carbon and nitrogen isotope ratio analysis. The results show that most people primarily subsisted on C_4 resources, e.g. millet and millet-related animal products, despite the fact that there was some intake of C_3 plants by some individuals. Stable nitrogen isotope values indicate that there were differences in meat consumption between individuals at the site. Pigs were mainly foddered with millet and millet byproducts, as well as some cattle, according to their high δ^{13}C values. However, most cattle and the sheep/goats consumed wild C_3 plants at Shengedaliang. Our above findings indicates that subsistence patterns in northern Shaanxi around 4,000 yr BP were characterized by millet farming, while the grassland animal husbandry, e.g. cattle and sheep/goats raising, displayed very little contribution to local economy. The intensive millet farming in northern Shaanxi provided enough food for population growth, ensured the accumulation of wealth, and consequently accelerated social differentiation and complexity.

Keywords Northern Shaanxi, 4,000 yr BP, Shengedaliang, Stable carbon and nitrogen isotope, Subsistence patterns

Citation: Chen X L, Guo X N, Wang W L, Hu S M, Yang M M, Wu Y, Hu Y W. 2017. The subsistence patterns of the Shengedaliang site (~4,000 yr BP) revealed by stable carbon and nitrogen isotopes in northern Shaanxi, China. Science China Earth Sciences, 60: 268–276, doi: 10.1007/s11430-016-5123-8

1. Introduction

There has been an increasing interest in understanding the connections between technology/economy development and the transition of archaeological cultures for the formation of state-level societies and early civilization in Chinese prehistory. It is debated that technology and economy patterns to some extent might influence the trajectory and process of social evolution (Yuan, 2009a, 2009b). Therefore, to investigate subsistent economy in specific regions is critical for further understanding the culture evolution and its possible drivers, which is one of key issues for the exploration of the formation process and impetus of early Chinese civilization.

Northern Shaanxi Province is located on the south of the farming-pastoral transitional zone, which is between the semi-arid and semi-humid regions in northern China. The environmental condition and soil productivity here were inferior in comparison with those in the Guanzhong Basin in the south, however, field surveys have documented a large number of archaeological sites around 4,000 yr BP in northern Shaanxi. Take Yulin city in the north Shaanxi

* Corresponding author (email: chenxianglong09@hotmail.com)

Province as an example, the number of archaeological sites of the Longshan period were two times larger than that of the Yangshao period, and some large scale sites emerged, such as Shimao, Zhaomao, Xinhua, among which Shimao was the most important (State Administration of Cultural Heritage, 1998). The large scale of this site (4,000,000 m^2), skilled construction technique as well as an integrated defense system made Shimao an outstanding site among Neolithic walled settlements in East Asia (Sun and Shao, 2016). This indicates that local sociopolitical organization and early civilization in north Shaanxi had evolved to a high level.

The cultural upheaval in northern Shaanxi coincided with sudden increase of Neolithic technology and socioeconomic system (Sun and Shao, 2016). In fact, food-producing technology and a subsistence economy were fundamental factors sustaining human activities and hence would undoubtedly influence the sociopolitical situation. Therefore, it is important to investigate subsistence transition processes of local Neolithic communities in order to get a comprehensive understanding of the cultural and societal changes. This will enrich our knowledge on subsistent economy process in agricultural-pastoral transition zone, and will also be helpful for understanding formation process of early civilization and corresponding drivers in such regions.

Previous studies over the past few years have provided independent evidence for human adaptations from the Yangshao to Longshan periods (Wang et al., 2014). Stable isotopic data found that millet farming had achieved great progress since late the Yangshao period and millet food was used for pig raising at the Wuzhuangguoliang site (Guan et al., 2008). Consequently during the Longshan period, grassland husbandry emerged and began to be crucial part in the local subsistence economy (Wang et al., 2014) and abundant cattle and sheep/goat bones were observed at sites including Huoshiliang (Hu et al., 2008), Xinhua (Xue et al., 2005), which might have resulted from interactions with the Qijia and other archaeological cultures of the surrounding regions (Ma, 2009). However, it appears that people here still subsisted on millet agriculture according to stable carbon and nitrogen isotope studies on Muzhuzhuliang and other sites (Atahan et al., 2014; Chen et al., 2015). While great contributions have been made to interactions between archaeological cultures (Wei, 2000; Han, 2007; Ma, 2009), it is still a topic of continuing research before well knowing subsistent practices around 4,000 yr BP in northern Shaanxi. In this work, stable carbon and nitrogen isotope analysis was conducted on human and animal bones from Shengedaliang at Shenmu County to reconstruct their diets. Independent and direct dietary evidence at the site and regional levels through comparison to published research are also provided for a discussion of local adaptations and subsistence economy around 4,000 yr BP.

2. Material and methods

2.1 The study site

The Shengedaliang site (38°38′N, 109°56′E) is located 5 km in the southwest of the town of Dabaodang, very close to the Tuwei River (Figure 1). Excavations in 2013 and 2014 uncovered 28 tombs, 13 house foundations, as well as 57 trash pits, and many bones, pottery sherds and stone tools. It is believed that there was no special burial area, since graves were interspersed in the living area, among house foundations and trash pits. All graves were long and rectangular pits dug into the earth. Grave M7 was the largest with two individuals buried inside. One was a male in extended supine position buried in the middle with inner and outer coffins, the other was a young female lying on the right side of and facing the male. A niche was found on the right of the grave wall and

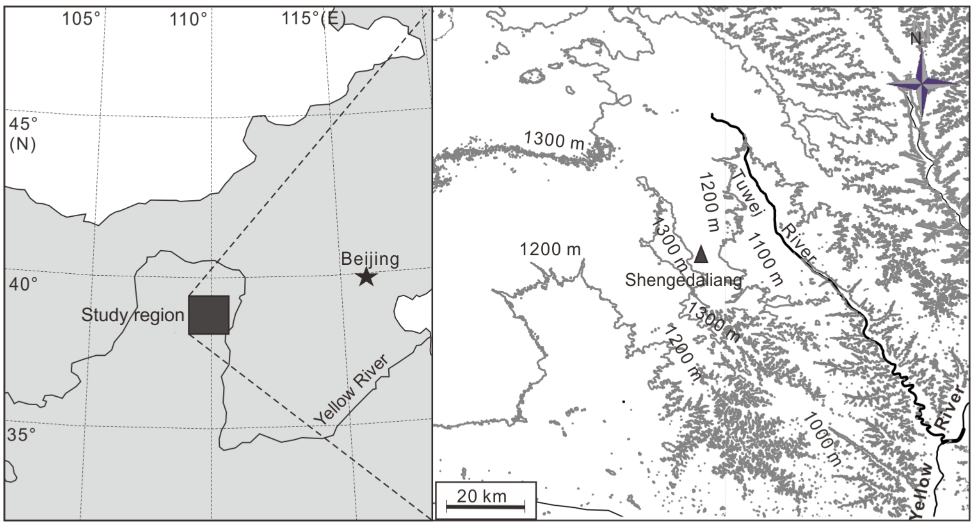

Figure 1 Geography of Shengedaliang site and study region.

this contained: 3 pots, 1 jar, 1 basin, and 1 tripod Jia. In grave M8 a dead pig and a couple of stone tools were found to the right of the burial. Apart from these graves, no additional grave goods were found, which could be an indication of social differentiation in this community (Shaanxi Provincial Academy of Archaeology et al., 2016). The archaeologists suggest that the Shengedaliang site is related to the Yongxingdian-Dakou II culture based on pottery typology research. AMS radiocarbon dating of M7 male indicates an age of 3,825–3,615 cal yr BP (2σ), which is in accordance with the typology research (Personal communication with Dr. Yan Wu from IVPP).

2.2 Samples and methods

28 human bones belonging to 25 graves and 1 trash pits, 1 dog, 7 pigs, 6 cattle and 11 sheep/goats were selected for this study (Table 1). Small fragments of long bones and ribs were sampled. It has been demonstrated that there are differences in the turnover rates between different bones. For example, femoral and humeral turnover rates for adults are more than 10 years, while those of ribs represent only 2–5 years (Cox and Sealy, 1997). Despite of two ribs, most of our samples were from long bones, the isotopic data of our samples thus would not show a strong bias towards population paleodiet of Shengedaliang.

Collagen was isolated using the protocol described by Jay et al. (2008) with some modifications. ~1 g bones were mechanically cleaned and demineralised in 0.5 mol L^{-1} HCl at 5°C. Afterwards, the remains were washed into neutrality with deionised H_2O and immersed in 0.0125 mol L^{-1} NaOH at room temperature for 20 h. The remains were washed again into neutrality and plunged into HCl solution (pH=3) at 70°C for 48 h to make the bone gelatinised. After the filtration, the solution was frozen and freeze-dried to get the collagen. The collagen yield (%) was calculated as the collagen weight divided by the bone weight.

The purified collagen was measured at the Archaeological Isotope Lab of the University of Chinese Academy of Sciences using an Isoprime 100 IRMS coupled with the Elementar Vario PYRO cube. The stable isotope ratios were analyzed relative to internationally defined standards for carbon (Vienna Pee Dee Belemnite, VPDB) and nitrogen (Ambient Inhalable Reservoir, AIR). The analytical precision for δ^{13}C was less than ±0.1‰ and for δ^{15}N was less than ±0.2‰. The element contents and isotope data of humans and animals are shown in Table 1.

3. Results and discussion

Stable carbon (δ^{13}C) and nitrogen (δ^{15}N) isotope ratios of bone collagen has become a routine method for investigating human and animal diets, for a detailed review to see (Cai and Qiu, 1984; Zhang et al., 2003; Hu and Wang, 2005). The %C (36.8–47.7%), %N (14.4–17.5%) and C:N (3.1–3.5) were within the acceptable limits for samples of collagen that are well preserved (DeNiro, 1985; Ambrose, 1990; van Klinken, 1999).

Based on ecological studies, the natural vegetation in northern China is predominated by C_3 plants, and the abundance of C_4 plants is insignificant (Tieszen et al., 1999; Gu et al., 2003; Liu et al., 2011). However, two typical C_4 grains, foxtail and broomcorn millet, were cultivated as important staple foods since middle Neolithic in northern China. As a result, stable carbon isotope values are great helpful for evaluating the importance of millets and millet related food to human diet. Previous studies have shown that δ^{13}C in modern C_3 plants is around –26.5‰ (O'Leary, 1981; Wang G A et al., 2003, 2005), while that of foxtail and broomcorn millet is around –12.5‰ (Yang et al., 2011). Thus, humans consuming an exclusive C_3 plant-related or millet diet would have δ^{13}C values around –20.0‰ or –6.0‰ respectively, assuming the standard fractionation factor of +5‰ from plants to bone collagen (van der Merwe and Vogel, 1978; Lee-Thorp et al., 1989) and a value of +1.5‰ resulted from the fossil fuel effect (Marino and McElroy, 1991).

3.1 Animal husbandry

The δ^{13}C values of the pigs (n=7) were between –9.5‰ and –7.2‰ and had mean result of –8.4±0.9‰ (Table 1, Figure 2), indicating a typical C_4 plant-based diet (millets). The δ^{13}C value of a single dog (–15.5‰) indicated it subsisted on a mixed C_3/C_4 diet. The cattle (n=6) and sheep/goats (n=11) displayed mean δ^{13}C values of –14.7±1.4‰ and –16.0±0.8‰, respectively. An ANOVA test (P=0.04<0.05) found a significant difference of δ^{13}C values between them and suggested millet byproducts overall were more important to cattle than sheep/goats. When checking isotopic data one by one, however, we found most cattle displayed similar δ^{13}C value to sheep/goats indicative of a diet predominated by C_3 plants with the exception of SGDL23 and SGDL26, which inevitably consumed more C_4 plants. The different diets between the two and other cattle as well as sheep/goats might indicate two different raising practices of herbivore domesticates, namely shelter feeding and free foraging (Chen et al., 2012).

Dog had the highest δ^{15}N value (9.4‰) and the omnivorous pigs ranked the second with an average value of 7.7±0.8‰. This indicates their occasional consumption of animal protein, probably resulting from scavenging kitchen refuses and leftovers (Pechenkina et al., 2005; Guan et al., 2011). The δ^{15}N values of cattle (6.5±0.5‰) and sheep/goats (6.3±1.2‰) were in accordance with a herbivorous diet in temperate regions (Bösl et al., 2006).

Pigs are the typical indigenous domesticate in East Asia,

Table 1 Stable isotope results and details of human and animal bones from the Shengedaliang site

Lab No.	Context	Species	Element	Collagen content	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C (%)	N (%)	C/N
SGDL1	M1	Human	R. radius	10.2%	–7.3	9.1	46.5	16.9	3.2
SGDL2	M2, S	Human	R. ulna	5.1%	–8.5	6.3	44.6	16.3	3.2
SGDL3	M2, N	Human	R. radius	5.3%	–8.7	6.5	45.7	16.7	3.2
SGDL4	M4	Human	L. collarbone	6.1%	–8.9	10.8	46.7	17.2	3.2
SGDL5	M5	Human	R. tibia	3.9%	–8.6	6.2	44.7	16.2	3.2
SGDL6	M6	Human	R. tibia	2.6%	–8.5	10.0	43.8	15.9	3.2
SGDL7	M7, F	Human	Phalange	6.0%	–7.2	9.0	46.6	17.1	3.2
SGDL8	M7, M	Human	Phalange	11.1%	–8.7	9.7	47.7	17.5	3.2
SGDL9	M8	Human	Phalange	6.3%	–8.1	9.7	46.5	16.9	3.2
SGDL10	M9	Human	R. ulna	2.3%	–9.7	9.1	42.0	15.2	3.2
SGDL11	M10	Human	R. radius	2.9%	–10.1	10.7	45.2	16.3	3.2
SGDL12	M12	Human	L. tibia	2.8%	–7.7	9.8	45.5	16.2	3.3
SGDL13	M13	Human	L. collarbone	3.0%	–7.2	7.8	46.7	16.9	3.2
SGDL14	H2	Human	R. radius	2.7%	–7.7	9.3	46.6	17.0	3.2
SGDL15	H24	Dog	L. mandible	1.5%	–15.5	9.4	45.4	16.4	3.2
SGDL16	F1	Pig	R. mandible	2.8%	–7.6	8.2	44.7	16.3	3.2
SGDL17	F1	Pig	R. mandible	4.8%	–9.5	8.5	47.5	16.3	3.4
SGDL18	H22	Pig	L. mandible	2.6%	–7.2	7.5	45.2	16.3	3.2
SGDL19	H3①	Pig	L. mandible	7.6%	–8.6	7.5	46.6	16.9	3.2
SGDL20	H40①	Pig	L. maxilla	9.7%	–9.0	6.2	46.9	17.1	3.2
SGDL21	H2③	Pig	L. ulna	3.0%	–8.8	8.3	42.8	15.4	3.2
SGDL22	H48③	Cattle	Phalange	2.0%	–15.1	6.7	45.8	16.5	3.2
SGDL23	H48③	Cattle	scapula	4.7%	–12.6	6.7	42.7	15.4	3.2
SGDL24	F10	Cattle	Phalange	11.4%	–14.9	6.2	47.0	17.2	3.2
SGDL25	F1	Cattle	L. mandible	7.3%	–15.6	7.1	46.6	17.0	3.2
SGDL26	H22	Cattle	R. mandible	1.6%	–13.6	6.7	44.2	14.8	3.5
SGDL27	H40①	Cattle	R. ulna	4.7%	–16.6	5.7	42.6	15.2	3.3
SGDL28	H48③	Sheep/goat	L. metacarpus	6.6%	–15.7	6.3	46.5	17.0	3.2
SGDL29	F10	Sheep/goat	scapula	12.2%	–17.2	4.2	46.4	16.9	3.2
SGDL30	F10	Sheep/goat	R. radius	16.1%	–14.8	7.0	39.6	14.4	3.2
SGDL31	F10	Sheep/goat	metacarpus	5.5%	–16.0	6.8	43.9	16.0	3.2
SGDL32	F1	Sheep/goat	L. mandible	7.8%	–15.5	7.0	47.6	17.1	3.2
SGDL33	F1	Sheep/goat	L. mandible	7.7%	–15.3	6.8	47.1	17.0	3.2
SGDL34	H22	Sheep/goat	L. mandible	6.6%	–16.1	6.7	45.4	16.2	3.3
SGDL35	H22	Sheep/goat	L. mandible	8.5%	–16.0	7.3	47.3	17.2	3.2
SGDL36	H2③	Sheep/goat	R. tibia	10.3%	–15.1	6.9	47.3	17.2	3.2
SGDL37	H2③	Sheep/goat	R. humerus	6.8%	–17.6	3.6	47.7	17.2	3.2
SGDL38	H40①	Sheep/goat	L. mandible	3.1%	–16.4	6.7	45.2	16.3	3.2
SGDL39	M8	Pig	Rib	4.7%	–7.7	7.4	43.3	15.6	3.2
SGDL40	M14	Human	Rib	6.7%	–7.7	8.9	43.3	16.1	3.1
SGDL41	M15	Human	Phalange	5.6%	–7.7	8.8	42.7	16.0	3.1
SGDL42	M16	Human	Skull	4.2%	–7.5	11.8	43.5	16.1	3.2
SGDL43	M17	Human	Fibula	10.3%	–13.3	8.4	39.3	14.4	3.2
SGDL44	M18	Human	Rib	3.2%	–6.9	7.5	43.2	16.0	3.1
SGDL45	M19	Human	Phalange	5.2%	–6.7	8.2	42.7	15.8	3.2
SGDL46	M20	Human	Phalange	4.5%	–7.4	9.0	42.6	15.9	3.1
SGDL47	M21	Human	Phalange	2.6%	–10.5	10.4	43.8	16.3	3.1
SGDL48	M22	Human	Phalange	3.1%	–7.4	9.6	44.2	16.5	3.1
SGDL49	M23	Human	Phalange	6.4%	–8.0	8.4	44.8	16.6	3.1
SGDL50	M24	Human	Phalange	10.2%	–14.6	7.0	41.4	15.4	3.1
SGDL51	M25	Human	Rib	3.0%	–8.7	8.4	41.7	15.6	3.1
SGDL52	M27	Human	Phalange	5.9%	–7.8	6.8	44.0	16.4	3.1
SGDL53	M28	Human	Phalange	6.0%	–7.2	9.2	44.1	16.4	3.1

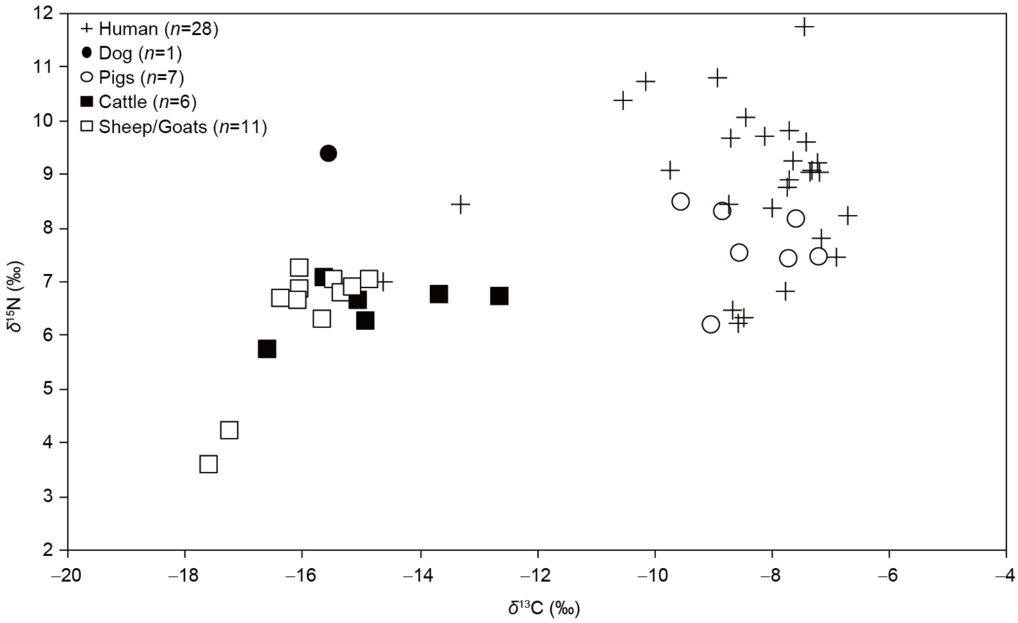

Figure 2 $\delta^{13}C$ and $\delta^{15}N$ values of human and animal bone collagen from the Shengedaliang site.

and were the most important domestic animals in the agriculture communities of China including northern Shaanxi (Yuan and Flad, 2008; Cucchi et al., 2011). Previous studies documented that pigs at Wuzhuanggeliang were foddered primarily with C_4 plant-based food (Guan et al., 2008). In this study, we found similar situation, namely pig raising at Wuzhuanggeliang and Shengedaliang displayed a close relationship to millet farming. In fact, this was very common at Neolithic agriculture communities in Central Plains, for example at the sites of Kangji, Xipo (Pechenkina et al., 2005), Dongying (Chen et al., 2016b), Taosi (Zhang et al., 2007; Chen et al., 2012), Xinzhai (Wu et al., 2007), and Wadian (Chen et al., 2016a). We again demonstrate that millet farming was essential for pig raising at Shengedaliang by providing millet byproducts such as straw and chaff.

Previous studies show that, the two ruminants, cattle and sheep/goats were brought into Yellow River catchment during Longshan period (Yuan et al., 2007). This means that people had began to raise domestic herbivores in grassland in order to improve carrying capacity and land use efficiency, especially in agricultural margin area. The emergence of grassland animal husbandry was essential as the precondition for rising of pastoralism several centuries later in northern China. Isotopic studies at the sites of Dongying (Chen et al., 2016b), Taosi (Zhang et al., 2007; Chen et al., 2012), Wadian (Chen et al., 2016a) show that cattle mainly relied on C_4 plants while sheep/goats foraged on a mix of C_3 and C_4 plants. This situation suggests that the Longshan agriculture communities preferred foddering cattle with millet, possibly millet byproducts, but grazed the sheep/goats in uncultivated areas. It seems that this pattern continued until at least the early Bronze Age based on the paleodiet investigation at Erlitou (Si et al., 2014) and Zhangdeng sites (Hou et al., 2013).

The two cattle with higher $\delta^{13}C$ (SGDL23, SGDL26) clearly displayed their reliance on millet probably under the condition of shelter feeding, while the others had negative $\delta^{13}C$ values and lower than those at Dongying, Taosi, Wadian, and other Longshan period agriculture communities in North China, clearly indicating the predominance of C_3 plants in their diet. We thus propose that a flexible cattle husbandry regime was occurring and that most of the cattle were grazed at the Shengedaliang site. This might correlate with abundant foraging resources in northern Shaanxi. In fact, as recorded in historical document *Shiji*, Dabaodang town belonged to Shangjun County during West Han dynasty, which was one of the most famous bases for raising war-horses.

3.2 Human diet

The humans (n=28) at the Shengedaliang site showed a large variation in $\delta^{13}C$ (from –14.6‰ to –6.7‰) values with a mean of –8.5±1.8‰ (Table 1, Figure 2), indicating that most people consumed millet-based C_4 foods. This situation was very similar to those of other Yangshao and Longshan periods sites in Wei River Valley which were characterized by a millet dominated diet, for example the sites of Jiangzhai ($\delta^{13}C$=–9.9±1.1‰, $\delta^{15}N$=8.6±0.5‰, n=21), Yuhuazhai ($\delta^{13}C$=–8.6±1.4‰, $\delta^{15}N$=9.3±0.7‰ n=25) (Zhang et al., 2010; Guo et al., 2011a), Dongying ($\delta^{13}C$=–8.0±1.3‰, $\delta^{15}N$=9.0±0.3‰, n=5) (Chen et al., 2016b). Meanwhile, two individuals, SGDL43 and SGDL50, clearly ate more C_3 plant-based nutrients than others. Since C_3 cereals such as rice and wheat were rarely discovered from Neolithic sites before and around 4,000 yr BP in northern Shaanxi, the two outliers might be foreigners. After an isotopic comparison with contemporaneous sites of neighboring areas, we found the isotopic signatures of SGDL43 and SGDL50 resembled individuals found at Mogou site (δ^{13}C=–13.9±1.6‰, δ^{15}N=10.2±1.2‰, *n*=37) (Ma et al., 2016) in the upper Yellow River Valley region or people cultivating both rice and millet at the Qinglongquan site (δ^{13}C=–14.5±1.4‰, δ^{15}N=8.9±1.2‰, *n*=25) (Guo et al., 2011b). However, stable strontium and sulfur isotope ratio analysis is necessary to better understand if these individuals were migrants.

The mean δ^{15}N value of the humans was 8.8±1.4‰, and this is slightly higher than the results of the pigs (7.7±0.8‰, *n*=7). This suggests that the humans were not consuming a large amount of animal protein. According to the large range of δ^{15}N values (6.2–11.8‰), it is likely that people had different opportunities in their ability to consume animal products. For instance, δ^{15}N values of the two individuals buried in tomb M2 (6.3‰, 6.5‰) were even lower than the pigs and dogs and nearly identical to the herbivores, which indicates that they were having a vegetarian diet. In contrast, in the individual buried in tomb M16 had a very high δ^{15}N value (11.8‰) revealing a diet with high amount of animal resources.

In order to explore how dietary habits correlated with social status at the Shengedaliang site, the isotopic values of tombs with different funerary treatments were compared, for example: grave goods and tomb size. In terms of grave goods, three categories could be classified: (1) with a sacrificed female and a group of potteries, (2) with a pig and some stone tools, and (3) with no graves goods. Tomb M7 and M8 were categorized into (1) and (2), respectively, while the rest belong to (3). The δ^{13}C values of the M7 male and M8 were –8.7‰ and –8.1‰, respectively, and very close to the mean of the Shengedaliang population (–8.5±1.8‰), while both their δ^{15}N values were 9.7‰, only slightly higher than population (8.8±1.4‰). Moreover, there was little difference between the isotopic values of the male and the sacrificed female in tomb M7. In terms of tomb size, the excavators divided three categories according to tomb width: (1) no less than 2 m, the only M7, (2) 1–2 m, M1 and M2, and (3) less than 1 m, the others. When these tombs were compared, the isotopic values of M7, M1 and M2 showed no clear distinctions from the others. In general, no clearly correlation was isotopically detectable between diet habits and social status accordingly.

3.3 Subsistence during the late Neolithic and early Bronze Ages in north Shaanxi

Here, subsistent activities were shaped by the local ecological conditions and would change along with the progress of food producing techniques during the Neolithic. Published research shows that millet farming was introduced during early Yangshao period if not earlier, and a remarkable transformation in human adaptations occurred in the following several hundred years, notably from hunting and gathering to farming (Yan, 1991; Han, 2008). Consequently during the Longshan period, grassland animal husbandry began to be an important food-producing way regarding the emergence of domestic ruminants, e.g. cattle and sheep/goats (Ma, 2009; Wang et al., 2014), pointing to diversified subsistent economy consisting of farming, grassland animal husbandry, and hunting and gathering.

Great quantities of stone tools associated agricultural activities from the sites of Zhaimao (Lü, 2002), Xinhua (Wang H et al., 2005), Shimao (Dai, 1977), Huoshiliang (Hu et al., 2008) and Zhukaikou (Inner Mongolian Institute of Cultural Relics and Archaeology and Ordos Museum, 2000), e.g. knives, shovels, etc., indicate that farming was of great importance around 4,000 yr BP. In order to explore the contributions of millet cultivation, grassland animal husbandry, and hunting and gathering to subsistent economy patterns in northern Shaanxi, published isotope data at the regional levels were reviewed for further discussion (Figure 3).

According to previous published isotopic data, the δ^{13}C values of human bones from sites including: Muzhuzhuliang (Chen et al., 2015), Xinhua, Shimao in Shenmu, Zhukaikou in Yijinhuoluo, Dakou in Zhunger (Atahan et al., 2014), as well as Shengedaliang in our study, were consistent with those of contemporaneous sites in the middle Yellow River catchments, such as Dongying (–8.0±1.3‰, *n*=5) (Chen et al., 2016b), Taosi (–6.6±1.0‰, *n*=7) (Zhang et al., 2007), Xinzhai (–9.6±1.4‰, *n*=8) (Wu et al., 2007). This indicates that northern Shaanxi experienced comparable subsistent practices with the millet farmers in the middle Yellow River catchments around 4,000 yr BP, and millets and millet-foddered domesticates formed the major part of human dietary intake.

Farming could provide much more food resources and is more productive than grassland animal husbandry under good climatic conditions (Zhang, 2011). The study of sediments and soils shows there were several soil forming intervals after the last Glacial including a period from 4,400–3,500 yr BP, which was suitable for millet farming in northern Shaanxi (Gao et al., 1993). In fact, a pollen study at the Xinhua site conducted by Wang H et al. (2005) showed a very high *Chenopodiaceae/Artemisia* ratio in samples dating to around 4,000 yr BP indicative of intensified farming activities under good environment and vegetation conditions.

From the above we can see that humans at Shengedaliang, probably with other late Longshan and early Xia period sites in northern Shaanxi Province, adopted a diversified subsistence strategy and acquired nutrients from millet farming, grassland animal husbandry, as well as hunting and gathering. In general, millet farming was of most importance, not only for human consumption but for raising pigs which in turn provided people with meat, while grassland animal husbandry, typically sheep/goats and cattle raising, was relatively unim-

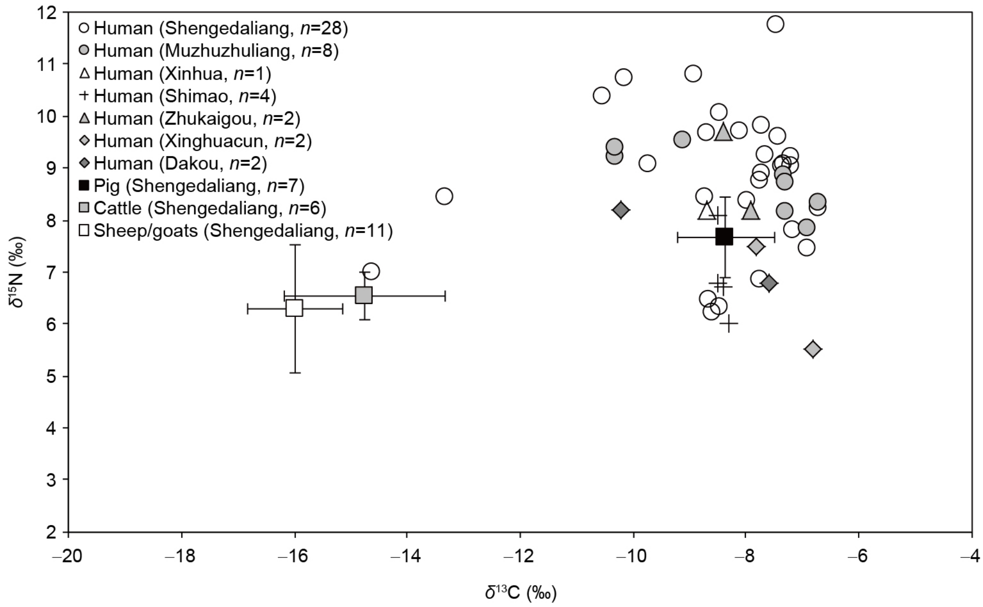

Figure 3 δ^{13}C and δ^{15}N values of human and animal bone collagen of archaeological sites of Longshan and early Xia periods in northern Shaanxi Province and neighboring areas.

portant and simply an accessory subsistent activity producing supplementary animal products. Inherent in millet farming is to meet human's demand for nutrients. Intensive agriculture provided relatively adequate food that allowed population growth, which was documented by densely distributed settlements in northern Shaanxi (State Administration of Cultural Heritage, 1998). This efficient food production was a precondition for redistribution of surplus wealth and labor, which allowed increasing social complexity and division of labor. Under this situation, people could devote more time and energy for public facility construction, trading and exchanges, and even military and political expansion. These were essential prerequisites for the sudden acceleration of the formation of early civilization.

From the Longshan period onwards, northern Shaanxi Province and neighboring areas shared the same material tradition in terms of pottery, stone tools, settlement patterns, and even funerary treatments. Archaeologists propose that the increasing unanimity in archaeological remains implies intimate contacts between populations although they might belong to different alliances. The similarity in foodways was crucial for the formation, maintenance and stability of cultural identity among populations. Millet farming and associated production relationship of intra- and inter-groups in a certain extent was likely a reflection of cultural identity that maintained social relationship in this region. Therefore, cultural habits might encourage people here to continue their food producing ways, primary millet farming, despite of the emergence of grassland animal husbandry before a severe deterioration in climate. After 3,800 yr BP or later, the climate was increasingly worse. The spreading of Mu Us desert indicates a termination of agriculture production, and settled villages and regional centers thus vanished, so did agriculture communities (Wang H et al., 2005). Northern Shaanxi would not experience frequent human activities once again until the rise of the nomadic economy in East Zhou period (Dai and Sun, 1983).

4. Conclusion

In order to explore the reasons for the sudden increase of the social evolution in northern Shaanxi around 4,000 yr BP, human and animal bones from Shengedaliang were sampled and isotopically analyzed in this study. After reconstruction of human diet and animal raising practices at this site, we reviewed the published data and discussed the subsistence economy of this period. As noted, foxtail and broomcorn millets not only were staple foods for humans at Shengedaliang, but also used for fodder for pig raising, possibly in terms of millet chaff and straws. Contrarily, sheep/goats and most cattle relied on wild plants, which indicate that human had already engaged in grassland animal husbandry despite its limited contribution to human diet. After comparison with published data including stable isotopes, zooarchaeology, archaeobotany, etc., we made the conclusion that people in northern Shaanxi mainly depended on millet agriculture although a diversified subsistence was adopted to include millet farming, grassland animal husbandry, as well as hunting and gathering. The intensive millet farming produced adequate food surplus for sustaining population growth, and wealth accumulation, which allowed the culture to flourish and increase in complexity in northern Shaanxi and neighboring areas and more research should be directed to these topics in the future.

Acknowledgements *We thank three referees for constructive criticism of the manuscript. This study was supported by the Knowledge Innovation Fund of the Chinese Academy of Social Sciences, and the National Natural Science Foundation of China (Grant Nos. 41373018 & 41471167).*

References

Ambrose S H. 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. J Archaeol Sci, 17: 431–451

Atahan P, Dodson J, Li X, Zhou X, Chen L, Barry L, Bertuch F. 2014. Temporal trends in millet consumption in northern China. J Archaeol Sci, 50: 171–177

Bösl C, Grupe G, Peters J. 2006. A Late Neolithic vertebrate food web based on stable isotope analyses. Int J Osteoarchaeol, 16: 296–315

Cai L Z, Qiu S H. 1984. Carbon-13 evidence for ancient diets in China (in Chinese). Archaeology, (10): 949–955

Chen X L, Fang Y M, Hu Y W, Hou Y F, Lü P, Yuan J, Song G D, Fuller B T, Richards M P. 2016a. Isotopic reconstruction of the late Longshan Period (ca. 4200–3900 BP) dietary complexity before the onset of state-level societies at the Wadian Site in the Ying River Valley, Central Plains, China. Int J Osteoarchaeol, 26: 808–817

Chen X L, Guo X N, Hu Y W, Wang W L, Wang C S. 2015. Paleodiet analysis of Shengedaliang site in Shenmu, Shaanxi Province (in Chinese). Archaeol Cult Rel, (5): 129–135

Chen X L, Hu S M, Hu Y W, Wang W L, Ma Y Y, Lü P, Wang C S. 2016b. Raising practices of Neolithic livestock evidenced by stable isotope analysis in the Wei River Valley, North China. Int J Osteoarchaeol, 26: 42–52

Chen X L, Yuan J, Hu Y W, He N, Wang C S. 2012. Animal feeding practice at the Taosi site (in Chinese). Archaeology, (9): 75–82

Cox G, Sealy J. 1997. Investigating identity and life histories: Isotopic analysis and historical documentation of slave skeletons found on the Cape Town foreshore, South Africa. Int J Hist Archaeol, 1: 207–224

Cucchi T, Hulme-Beaman A, Yuan J, Dobney K. 2011. Early Neolithic pig domestication at Jiahu, Henan Province, China: Clues from molar shape analyses using geometric morphometric approaches. J Archaeol Sci, 38: 11–22

Dai Y X, Sun J X. 1983. Cultural remains of Huns in Shenmu County (in Chinese). Archaeology, (12): 23–30

Dai Y X. 1977. Archaeological survey on Shimao in Shenmu, Shaanxi Province (in Chinese). Archaeology, (3): 154–157

Deniro M J. 1985. Postmortem preservation and alteration of *in vivo* bone collagen isotope ratios in relation to palaeodietary reconstruction. Nature, 317: 806–809

Gao S Y, Chen W N, Jin H L, Dong G R, Li B S, Yang G S, Liu L Y, Guan Y Z, Sun Z, Jin J. 1993. A preliminary study on the evolution of the deserts in the northwestern margin of China monsoon region during the Holocene (in Chinese). Sci China Ser B, 23: 203–208

Gu Z, Liu Q, Xu B, Han J, Yang S, Ding Z, Liu T. 2003. Climate as the dominant control on C_3 and C_4 plant abundance in the Loess Plateau: Organic carbon isotope evidence from the last glacial-interglacial loess-soil sequences. Chin Sci Bull, 48: 1271–1276

Guan L, Hu Y W, Hu S M, Sun Z Y, Qin Y, Wang C S. 2008. Stable isotope analysis on animal bones from the Wuzhuangguoliang site, Jingbian, Northern Shaanxi (in Chinese). Quat Sci, 28: 1160–1165

Guan L, Hu Y W, Wang C S, Tang Z W, Hu S M, Kan X H. 2011. The application of paleodietary analysis to pig domestication study (in Chinese). Cutl Rel South Chin, (4): 116–124

Guo Y, Hu Y W, Gao Q, Wang C S, Richards M P. 2011a. Stable carbon and nitrogen evidence in human diets based on evidence from the Jiangzhai site, China (in Chinese). Acta Anthropol Sin, 30: 149–157

Guo Y, Hu Y W, Zhu J Y, Zhou M, Wang C S, Richards M P. 2011b. Stable carbon and nitrogen isotope evidence of human and pig diets at the Qinglongquan site, China. Sci China Earth Sci, 54: 519–527

Han J Y. 2007. The expansion of Laohushan culture and its influence on other regions (in Chinese). Cult Rel Cent Chin, (1): 20–26

Han J Y. 2008. Environment and Cultural Development in the Pre-Qin Period in Northwest China (in Chinese). Beijing: Cultural Relics Publishing House

Hou L, Hu Y, Zhao X, Li S, Wei D, Hou Y, Hu B, Lv P, Li T, Song G, Wang C. 2013. Human subsistence strategy at Liuzhuang site, Henan, China during the proto-Shang culture (~2000–1600 BC) by stable isotopic analysis. J Archaeol Sci, 40: 2344–2351

Hu S M, Zhang P C, Yuan M. 2008. A study on the faunal remains from the Huoshiliang Site in Yulin, Shaanxi (in Chinese). Acta Anthropol Sin, 27: 232–248

Hu Y W, Wang C S. 2005. Paleodiet studies of several archaeological sites in China (in Chinese). Agric Archaeol, (3): 49–54

Inner Mongolian Institute of Cultural Relics and Archaeology, Ordos Museum. 2000. Zhukaigou (in Chinese). Beijing: Cultural Relics Publishing House

Jay M, Fuller B T, Richards M P, Knüsel C J, King S S. 2008. Iron Age breastfeeding practices in Britain: Isotopic evidence from Wetwang Slack, East Yorkshire. Am J Phys Anthropol, 136: 327–337

Lee-Thorp J A, Sealy J C, van der Merwe N J. 1989. Stable carbon isotope ratio differences between bone collagen and bone apatite, and their relationship to diet. J Archaeol Sci, 16: 585–599

Liu L, Zhou X, Yu Y Y, Guo Z T. 2011. The natural vegetations on the Chinese Loess Plateau: The evidence of sool organic carbon isotope (in Chinese). Quat Sci, 31: 506–13

Lü Z R. 2002. Prelimary archaeological report on the excavation at Zhaimou in Shenmu county, Shaanxi Province (in Chinese). Archaeol Cult Rel, (3): 3–18

Ma M, Dong G, Jia X, Wang H, Cui Y, Chen F. 2016. Dietary shift after 3600 cal yr BP and its influencing factors in northwestern China: Evidence from stable isotopes. Quat Sci Rev, 145: 57–70

Ma M Z. 2009. The definition and significance of Qijia culture remains in the Hetao area (in Chinese). Rel Museol, (5): 16–24

Marino B D, McElroy M B. 1991. Isotopic composition of atmospheric CO_2 inferred from carbon in C_4 plant cellulose. Nature, 349: 127–131

O'Leary M H. 1981. Carbon isotope fractionation in plants. Phytochemistry, 20: 553–567

Pechenkina E A, Ambrose S H, Xiaolin M, Benfer Jr. R A. 2005. Reconstructing northern Chinese Neolithic subsistence practices by isotopic analysis. J Archaeol Sci, 32: 1176–1189

Si Y, Li Z P, Hu Y W, Yuan J, Wang C S. 2014. Hydrogen and oxygen stable isotopic analysis of animal bone collagen from Erlitou site, Yanshi, Henan Province (in Chinese). Quat Sci, 34: 196–203

State Administration of Cultural Heritage. 1998. An Atlas of Chinese Cultural Relics: Shaanxi Volume (in Chinese). Xi'an: Xi'an Map Publishing House

Sun Z Y, Shao J. 2016. Tracing the urn: With east gate of Shimao out wall as the center (in Chinese). Cult Rel, (2): 50–56

Tieszen L L, Ojima D, Chuluun T, Chen Z, Baatar R, Chognii O, Erdenejav G. 1999. Grasslands of Asia and North America:distribution of soil organic carbon and stable isotopes in grasslands of the Mongolian Steppe. In: David E, David F, eds. Proceedings of VI International Rangeland Congress, People and Rangelands-Building the Future. Townsville: VI International Rangeland Congress. 138–139

van der Merwe N J, Vogel J C. 1978. ^{13}C content of human collagen as a measure of prehistoric diet in woodland North America. Nature, 276: 815–816

van Klinken G J. 1999. Bone collagen quality indicators for palaeodietary and radiocarbon measurements. J Archaeol Sci, 26: 687–695

Wang G A, Han J M, Liu D S. 2003. The carbon isotope composition of C_3 herbaceous plants in loess area of northern China. Sci China Ser D-Earth Sci, 46: 1069–1076

Wang G, Han J, Zhou L, Xiong X, Tan M, Wu Z, Peng J. 2006. Carbon isotope ratios of C_4 plants in loess areas of North China. Sci China Ser

D-Earth Sci, 49: 97–102

Wang H, Mo D W, Pan R G, Cao W, Li S C. 2005. Palaeoenvironment study on Xinhua in Shenmu, Shaanxi Province (in Chinese). In: Provincial Institute of Archaeology, Yulin Institute of Heritage Conservation, eds. Xinhua in Shenmu. Beijing: Science Press. 383–396

Wang H, Mo D W, Yuan J. 2014. Relationship between the subsistence and environmental on the Great Wall in northern Shaanxi during the pre-Qin period (in Chinese). Quat Sci, 34: 234–243

Wei J. 2000. On the Yongxingdian Culture (in Chinese). Cult Rel, (9): 64–68

Wu X H, Xiao H D, Wei C Y, Pan Y, Huang Y P, Zhao C Q, Xu X M, Ogrinc N. 2007. Implications for agriculture subsistence and pig husbandry from stable isotope evidence of human and pig diets in Xinzhai, Henan Province (in Chinese). In: Center for Scientific Archaeology of Iinstute of Archaeology, Chinese Academy of Scocial Sciences, eds. Science for Archaeology 2. Beijing: Science Press. 50–58

Xue X X, Li Y X, Yu X F. 2005. Animal remains from the Xinhua site in Shenmu, Shaanxi Province (in Chinese). In: Shaanxi Provincial Institute of Archaeology, Yulin Institute of Heritage Conservation, eds. Xinhua in Shenmu. Beijing: Science Press. 355–367

Yan W M. 1991. On the early archaeological cutlures of the southern central Inner Mongolia (in Chinese). In: Inner Mongolian Institute of Cultural Relics and Archaeology, ed. Corpus of Studies on Early Archaeology Cutlures of the Southern Central Inner Mongolia. Beijing: China Ocean Press. 3–12

Yang Q, Li X, Liu W, Zhou X, Zhao K, Sun N. 2011. Carbon isotope fractionation during low temperature carbonization of foxtail and common millets. Org Geochem, 42: 713–719

Yuan J, Flad R K. 2002. Pig domestication in ancient China. Antiquity, 76: 724–732

Yuan J, Huang Y P, Yang M F, Lü P, Tao Y, Yang J. 2007. Zooarchaeology for the Central Plains during 2500–1500 BC: Examplyfing Taosi, Wangchengguang, Xinzhai and Erlitou sites (in Chinese). In: Center for Scientific Archaeology of Institute of Archaeology, Chinese Academy of Scocial Sciences, ed. Science for Archaeology. Beijing: Science Press. 13–34

Yuan J. 2009a. On the relationship between development of enconomy and formation of Chinese civilization (in Chinese). In: Chinese Ministry of Science and Technology, National Bureau of Cultural Relics, eds. Origin of the Chinese Civilization Project: Technology and Economy 1. Beijing: Science Press. 1–9

Yuan J. 2009b. Rethink the relationship between development of enconomy and formation of Chinese civilization (in Chinese). In: Chinese Ministry of Science and Technology, National Bureau of Cultural Relics, eds. Origin of the Chinese Civilization Project: Technology and Economy 1. Beijing: Science Press. 10–21

Zhang L R. 2011. Agriculture and the origins of civilizations (in Chinese). Archaeology, (5): 61–65

Zhang X L, Qiu S H, Bo G C, Wang J X, Zhong J. 2007. δ^{13}C and δ^{15}N analysis of human bone samples from Erlitou and Taosi sites (in Chinese). In: Center for Scientific Archaeology I-C, eds. Science for Archaeology 2. Beijing: Science Press. 41–48

Zhang X L, Qiu S H, Zhong J, Zhao X P, Sun F X, Cheng L Q, Guo Y Q, Li X W, Ma X L. 2010. Studies on diet of ancient people of the Yangshao cultural sites in the central plains (in Chinese). Acta Anthropol Sin, 29: 197–207

Zhang X L, Wang J X, Xian Z Q, Qiu S H. 2003. A study of acient man's diet (in Chinese). Archaeology, (2): 159–171