ISOTOPES, PLANTS, AND RESERVOIR EFFECTS: CASE STUDY FROM THE CASPIAN STEPPE BRONZE AGE

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ABSTRACT. Bronze Age human and animal bone collagen from several steppe Bronze Age cultures (i.e. Early Catacomb, East and West Manych Catacomb, and Lola cultures) shows large variations in $\delta^{13}C$ and $\delta^{15}N$ values. In general, we observed that the older the sample, the lower the $\delta^{13}C$ and $\delta^{15}N$ values. We hypothesize that more positive values of $\delta^{13}C$ and $\delta^{15}N$ are caused by change in diet and a more arid climate. For ancient sheep during drier periods of the Early Catacomb, East and West Manych Catacomb, and Lola cultures, we observed 2 groups with different C and N isotopic compositions, reflecting consumption of different types of fodder. During periods of aridization, C_4 and C_3 plants with high $\delta^{15}N$ values appeared in the vegetation, also influencing bone collagen values. Human bones show reservoir effects, caused by aquatic diet components. These effects can be quantified by paired dating of human bone and associated terrestrial samples. Reservoir corrections have revised chronologies for the region. Some paired dates do not reveal reservoir effects. This can be explained in 2 alternative ways. One is that the human diet did not include aquatic components; rather, the diet was based on C_3 vegetation with high $\delta^{15}N$ values (13–15‰), and flesh/milk of domesticated animals. An alternative explanation is that humans consumed food from freshwater resources without reservoir effects.

INTRODUCTION

Stable isotope studies (^{13}C, ^{15}N) of archaeological samples play an important role in investigating the subsistence of ancient humans. For the Caspian steppe Bronze Age, stable isotope data help define more precisely the chronology of cultures in the region. This central part of the Eurasian steppe is adjacent to the North Caucasus and the Volga and Don rivers. It is characterized by relatively humid and dry periods lasting several centuries during the Bronze Age (Shishlina et al. 2009).

The relative chronology of the Bronze Age cultures of this region is based on stratigraphy of the main archaeological funerary sites of the region, i.e. kurgans. This chronology is shown in Table 1. Kurgans (tumuli) are architectural constructions that consist of a segment-shaped mound. This mound was built over a primary grave; later, secondary graves were added to the original kurgans. The absolute chronology of these cultures is based on a series of about 250 radiocarbon dates of samples from different materials.

Table 1 Chronology of the relevant Bronze Age Steppe cultures.

Culture	Time interval
Eneolithic	4300–3800 cal BC
Majkop	3500–3000 cal BC
Yamnaya	3000–2500 cal BC
Early Catacomb	2700–2400 cal BC
East Manych Catacomb	2500–2200 cal BC
Lola and Krivaya Luka	2200–2000 cal BC

The ^{14}C database obtained for the cultures listed conflicts with the traditional archaeological chronology (Shishlina 2008). The traditional chronology has to be revised because ^{14}C dates from

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human bones can show an "apparent age" due to the reservoir effect. Thus, ^{14}C dates of most human bones of the Bronze Age cultures are older than expected. The offset observed ranges from 100 to 1100 ^{14}C yr (Shishlina et al. 2009). We assume that in some cases this might be the result of consumption of freshwater components in the diet (in particular the 1100-yr value); in other cases, the cause may be marine food consumption. However, some paired dates do not reveal a reservoir effect.

To study the reliability of ^{14}C dates obtained for the study area, we started to measure $\delta^{13}C$ and $\delta^{15}N$ in human and animal bone collagen (Shishlina et al. 2007, 2009; Shishlina 2008). These stable isotope ratios shed light on the main food products humans consumed during last 10–20 yr of their life, i.e. vegetable food, or mixed diet with vegetable food and meat, the proportion of marine and river/lake products, and the proportion of C_3 and C_4 plants.

It is very difficult, however, to interpret the stable isotope data obtained for human and animal collagen because the $\delta^{13}C$ and $\delta^{15}N$ values are not always the results of changes in main dietary components. Aridization due to climate change caused a decrease in precipitation and subsequent change in vegetation. In addition, processes of water preservation as well as the extraction of ^{15}N-depleted wastes, such as urea, has to be taken into account. These factors can lead to an increase of $\delta^{15}N$ in human and animal collagen in arid areas (Schwarcz et al. 1999). Apart from dietary questions, it is necessary to take into account ecological characteristics of the region in question as well.

The goals of the present research are

(i) to discuss the results of the main components of the human diet and animal food based on measurements of stable isotope ratios ($\delta^{13}C$ and $\delta^{15}N$);

(ii) to study additional archaeological plant samples obtained from the same context, i.e. burial, from which human and animal bone collagen has been analyzed and ^{14}C dated;

(iii) to analyze results of paired (with and without reservoir effects) dates using the background of additional diet and plant information.

MATERIALS AND METHODS

We collected samples from kurgan burial grounds located in the Caspian steppe, the Lower Volga and Don regions, and the North Caucasus. A map of the studied region is shown in Figure 1.

Most stable isotope ratio measurements were made in the Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, Moscow, using the isotope mass spectrometer DELTA-plus XP (Thermo Finnigan), linked with a Flash EA element analyzer. Each sample has been measured in triplicate with an analytical error for $\delta^{13}C$ of ±0.2‰ and ±0.2–0.3‰ for $\delta^{15}N$. A subset of the measurements were made at the universities of Oxford and Groningen.

Phytoliths of plant samples were analyzed at State Moscow University (Bobrov 2002; Shishlina 2008). Conventional ^{14}C dates were measured at the Institute of Geography of the Russian Academy of Sciences, Moscow, using liquid scintillation (laboratory code IGAN). Accelerator mass spectrometry (AMS) dates were obtained at Groningen University (laboratory code GrA) and at Oxford University (laboratory code OxA). For bone samples, collagen was extracted using the method of Longin (1971).

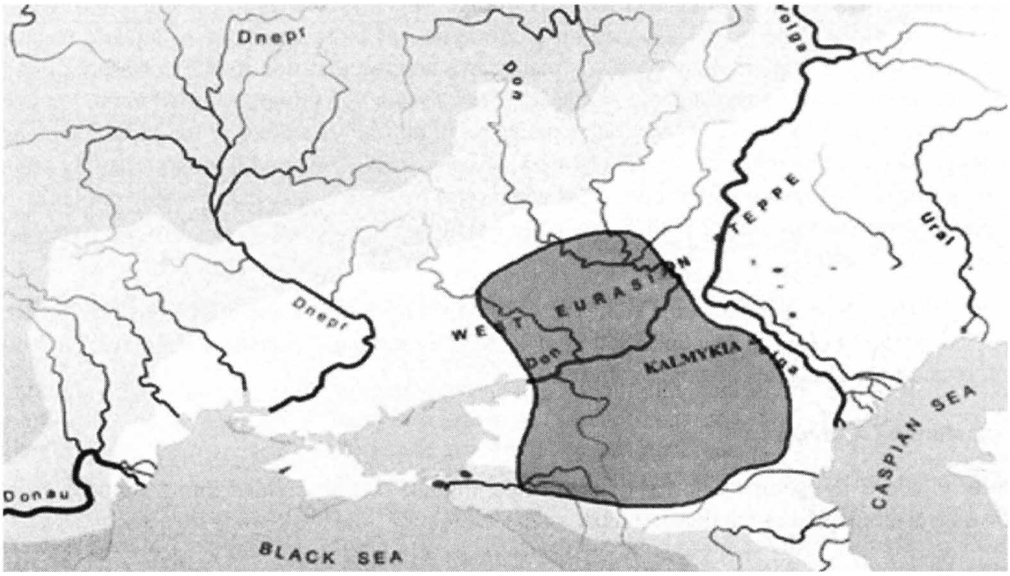

Figure 1 Location of studied area within the Caspian steppe

RESULTS

In the last few years, we have analyzed the following archaeological remains: 90 human, 60 animal, 4 fish, 1 dolphin, and 17 archaeological plants obtained from burials. Some data have been previously published (Shishlina et al. 2007, 2009).

Humans

Data obtained for humans with a mixed and multicomponent diet system show large variations and form the basis for discussing 3 diet system models. The average values are representative for our measured data and are shown in Table 2 for bone collagen isotopic values. For the time periods of the cultures, we refer to Table 1.

Table 2 Isotope ratios in bone collagen for 3 diet groups of steppe population.

Model	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Model 1: Flesh/milk of herbivore animals, wild C_3 plants Eneolithic, Majkop cultures	–21 to –19	+9 to +11
Model 2: Flesh/milk of herbivore animals, river and lake aquatic products, wild C_3 plants Eneolithic, Majkop, Yamnaya, Catacomb, Lola, Krivaya Luka cultures	–21 to –17	+11 to +15
Model 3: marine products are predominant Yamnaya, Early Catacomb, East Manych Catacomb cultures	–17 to –15	+15 to +18

Model 1 is characterized by average values of $\delta^{13}C$ from –21 to –19‰ and $\delta^{15}N$ from +9 to +11‰. We believe that some individuals of the Eneolithic and Majkop cultures consumed mostly vegetable food, which caused a reduction in the values of $\delta^{13}C$ and $\delta^{15}N$.

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Model 2 fits most data and is characterized by average values of $\delta^{13}C$ from –21 to –17‰ and $\delta^{15}N$ from +11 to +15‰. The model is based on consumption of large quantities of aquatic resources (fish, mollusks, water plants) and wild C_3 plants. We assume that this model corresponds to the steppe environment of Bronze Age mobile pastoralists. Population groups of the Majkop, Yamnaya, Catacomb, Lola, and Krivaya Luka cultures made use of all food resources of the exploited areas of the Volga, Don, Caspian steppe, and the North Caucasus areas. This model is supported by archaeological finds of freshwater (from both lakes and rivers) fish bones and scales, edible mollusks, and C_3 plants obtained through phytolith and pollen analyses uncovered in the Bronze Age graves (Shishlina et al. 2009).

Model 3 is characterized by average values of $\delta^{13}C$ from –17 to –15‰ and $\delta^{15}N$ from +15 to +18‰. Such values might indicate the consumption of seafood by some individuals of Yamnaya, Early Catacomb, and East Manych Catacomb cultures.

Domesticated Animals

The $\delta^{13}C$ and $\delta^{15}N$ isotope data for domesticated animals can be divided into 2 groups. Table 3 shows the average values for these groups.

Table 3 Isotope ratios in bone collagen for 2 groups of steppe domesticated animals.

Model	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Model 1: Pastures with predominance of C_3 vegetation Eneolithic, Majkop, Yamnaya, Catacomb, Lola cultures	–23 to –18	+4 to +13
Model 2: Pastures with predominance of C_3 plants, mixed C_3 and C_4 vegetation Yamnaya, Catacomb, Lola cultures	–17 to –14	+11 to +13

Model 1 for domesticated animal food ($\delta^{13}C$ from –23 to –18‰ and $\delta^{15}N$ from +4 to +13‰) is based on the use of pastures with a predominance of C_3 plants (period of mild and humid climate of Eneolithic, Steppe Majkop and Yamnaya cultures; it is assumed that such pastures existed in some areas during the Catacomb and Lola cultures as well).

Model 2 of domesticated animal food ($\delta^{13}C$ from –17 to –14‰ and $\delta^{15}N$ from +11 to +13‰) is based on the use of pastures with mixed C_3 and C_4 plants.

Archaeological Plants

An additional isotope study of archaeological Bronze Age plants was conducted. The theoretical average $\delta^{13}C$ value of C_3 plants that are predominant in the steppe zone is around –26‰, while the average $\delta^{13}C$ value of C_4 plants is around –12‰. Table 4 shows the stable isotope data obtained for archaeological samples of reed, some seeds, and gramineous plants obtained from graves from which animal and human bone samples have been dated. All samples correspond to C_3 plants.

It is interesting to note that 3 reed samples from the East Manych Catacomb culture samples show very high $\delta^{15}N$ values, compared to those from Early Catacomb reed samples. Some other C_3 plants show elevated ^{15}N values as well.

Paired Radiocarbon Dates

We continued dating sample pairs of different materials (with and without reservoir effects) obtained from the same archaeological context. Earlier results have been published (Shishlina et al.

Table 4 Stable isotope ratios of archaeological plants of the Bronze Age.

Site name	Sample	Species	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Yamnaya culture: 3000–2500 cal BC				
Mu-Sharet 1	kurgan 5, grave 3	seeds of Amaranths	–26.5	+6.4
East Manych, Left Bank, III	kurgan 29, grave 8	plant mat, reed?	–24.3	+15.6
Early Catacomb culture: 2700–2400 cal BC				
Mandjikiny 1	kurgan 14, grave 6	seeds (*Lithosperpum officinale*)	–26.6	+13.0
Mandjikiny 1	kurgan 14, grave 6	plant mat, gramineous plants	–24.6	+13.9
Temrta I	kurgan 1, grave 2	plant mat, reed?	–25.2	+1.9
Temrta I	kurgan 1, grave 2	plant mat, reed	–28.6	+4.6
Ulan IV	kurgan 3, grave 14	plant mat, reed	–25.9	+6.5
Ulan IV	kurgan 3, grave 15	plant mat, reed	–25.4	+13.0
Ulan IV	kurgan 3, grave 15	plant mat, reed	–25.4	+10.3
Steppe North Caucasus culture: 2700–2400 cal BC				
Kislovodsk	tomb 3	*Celtis caucasica* Willd fruit stones	–19.6	+1.5
East Manych, Left Bank, III	kurgan 12, grave 13	reed?	–24.0	+11.8
East Manych and West Manych Catacomb cultures: 2500–2200 cal BC				
Mandjikiny 1	kurgan 14, grave 1	reed	–23.9	+17.4
Mandjikiny 1	kurgan 14, grave 1	plant mat, stem of reed	–25.7	+21.1
Yergueni	kurgan 10, grave 2	reed	–25.4	+19.1
Shakhaevskaya	kurgan 4, grave 35	gramineous plants from the pot	–27.2	+5.6
Shakhaevskaya	kurgan 4, grave 32	seeds (*Lithospermum officinale*)	–22.6	+9.6
Sharakhalsun-6	kurgan 3, grave 4	plant mat, reed stem	–28.0	+11.9
Lola culture: 2200–2000 cal BC				
Ostrovnoy	kurgan 3, grave 39	seeds of winter-cress	–22.6	+10.7

2007, 2009). Table 5 shows new results from pairs of terrestrial samples and pairs of human bone collagen and terrestrial samples obtained from the same grave.

Pairs of terrestrial samples show the same ^{14}C age. The ^{14}C age of humans shows the apparent age due to the freshwater reservoir effects and the consumption of aquatic food. However, there are pairs of human and terrestrial herbivore bone and wood that do not show any offset. Such human bones are not subject to reservoir effects.

DISCUSSION

The results of the stable isotope ratio measurements show a very broad range of $\delta^{13}C$ and $\delta^{15}N$ values for Bronze Age cultures of the studied region. The $\delta^{13}C$ and $\delta^{15}N$ values of human and animal bone collagen correlate as shown in Figure 2. The average values demonstrate a similar trend both for animals and humans. In general, the older cultures show the lowest average values of $\delta^{13}C$ and $\delta^{15}N$ (with some exceptions). The difference in stable isotope data between the Eneolithic and steppe Majkop cultures result from the population of these cultures having occupied different environmental niches. The Eneolithic peoples exploited the Piedmont North Caucasus areas, whereas the steppe Majkop groups lived in the open steppe near rivers and lakes.

Table 5 ^{14}C paired samples and stable isotope (^{13}C and ^{15}N) for Bronze Age cultures.

Lab nr	Kurgan/ grave	Sample	^{14}C (BP)	Calibrated range (1 σ, cal BC) [start: end] relative area	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Novosvobodnaya, kurgan 2, Majkop culture						
GrA-24441	k. 2	deer teeth	4270 ± 45	[2924: 2871] 0.90 [2802: 2779] 0.10	–22.10	+4.01
GrA-21334	k. 2	textile fragment (cotton, wool)	4200 ± 60	[2893: 2849] 0.27 [2841: 2841] 0.004 [2813: 2740] 0.47 [2730: 2693] 0.21 [2688: 2679] 0.04	–29.23	—
Mandjikiny-2, Yamnaya culture						
GrA-12690	k. 11, g. 3	wood	4060 ± 50	[2835: 2817] 0.10 [2665: 2644] 0.10 [2639: 2557] 0.52 [2555: 2550] 0.03 [2537: 2491] 0.27	–24.33	n/a
IGAN-2056	k. 11, g. 3	human bone female 45–60	4050 ± 50	[2832: 2820] 0.06 [2657: 2655] 0.01 [2632: 2488] 0.93	–16.62	+18.09
Sukhaya Termista I, Yamnaya culture						
GrA-45036	k. 1, g. 11	bone pin (ungulate bone)	4150 ± 30	[2867: 2836] 0.22 [2816: 2803] 0.08 [2777: 2670] 0.70	–19.91	+5.75
GrA-45038	k. 1, g. 11	human bone female 25–30	4160 ± 30	[2872: 2848] 0.16 [2842: 2841] 0.01 [2813: 2798] 0.11 [2794: 2740] 0.38 [2731: 2693] 0.28 [2688: 2679] 0.06	–15.72	+16.46
GrA-45165	k. 1, g. 10	*Ovis aries*	4390 ± 35	[3081: 3068] 0.11 [3026: 2927] 0.89	–18.96	+7.09
IGAN-4037	k. 1, g. 10	human bone female 35–45	4400 ± 50	[3090: 3042] 0.30 [3039: 2926] 0.70	–17.03	+14.56
Mandjikiny-1, Early Catacomb culture						
IGAN-2403	k. 14, g. 6	human bone male 55–56	4040 ± 70	[2835: 2817] 0.07 [2665: 2644] 0.08 [2639: 2472] 0.85	–17.53	+15.4
GrA-44245	k. 14, g. 6	gramineous plants	4100 ± 35	[2848: 2813] 0.22 [2738: 2731] 0.04 [2693: 2688] 0.02 [2679: 2578] 0.72	–24.61	+13.98
Temrta V, East Manych Catacomb culture						
KIA-31798	k. 1, g. 4	*Ovis aries*	3795 ± 25	[2284: 2247] 0.48 [2234: 2199] 0.44 [2161: 2153] 0.08	–17.76	+9.45
IGAN-3666	k. 1, g. 4	human bone female 30–35	4250 ± 80	[3000: 2994] 0.01 [2928: 2839] 0.44 [2814: 2676] 0.55	–16.06	+10.16
Shakhaevskaya, West Manych Catacomb culture						
Ua-21407	k. 4, g. 32	seeds (*Lithospermum officinale*)	3745 ± 45	[2268: 2260] 0.04 [2206: 2124] 0.65 [2091: 2043] 0.31	–20.7	—
GrA-26902	k. 4, g. 32	pike bones	4390 ± 40	[3084: 3065] 0.14 [3028: 2924] 0.86	–16.54	+14.95

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Table 5 ^{14}C paired samples and stable isotope (^{13}C and ^{15}N) for Bronze Age cultures. *(Continued)*

Lab nr	Kurgan/ grave	Sample	^{14}C (BP)	Calibrated range (1 σ, cal BC) [start: end] relative area	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
GrA-32796	k. 4, g. 32	freshwater river shell *Poludina*	4265 ± 30	[2905: 2883] 1.0	–8.48	—
Temrta 1, Lola culture						
OxA-18387	k. 2, g. 8	*Bos taurus* teeth	3949 ± 32	[2563: 2534] 0.20 [2493: 2437] 0.49 [2420: 2404] 0.11 [2378: 2350] 0.18	–18.65	+9.72
OxA-18388	k. 2, g. 8	human bone male 40–50	3945 ± 31	[2549: 2538] 0.08 [2490: 2449] 0.51 [2446: 2438] 0.05 [2420: 2404] 0.13 [2378: 2350] 0.21	–18.47	+12.94
Temrta I, Early Iron Age						
OxA-18386	k. 2, g. 5	human bone male 25–35	2550 ± 30	[796: 753] 0.67 [685: 668] 0.22 [631: 631] 0.01 [611: 596] 0.10	–17.03	+12.09
OxA-18387	k. 2, g. 5	*Ovis aries*	2540 ± 30	[793: 751] 0.51 [686: 667] 0.23 [637: 621] 0.10 [614: 594] 0.16	–18.80	+7.65

There are also variations in $\delta^{13}C$ and $\delta^{15}N$ values for archaeological plant material. The carbon isotopes show that C_3 plants were dominant in the region. This is in accordance with pollen and phytolith data obtained from the archaeological context (Shishlina 2008) and agrees with the description of vegetation from modern pilot pastures (Novikova 2001). There might be some C_4 plants present, but their proportion was very small.

Some archaeological plants have very high $\delta^{15}N$ values, especially samples that date back to the Early Catacomb, East and West Catacomb, and Lola cultures. Several archaeological sheep bone collagen samples are also marked by very high $\delta^{15}N$ values, especially animals dating back to the period of aridization, i.e. 2300–2200 BC. This was probably caused by including some plants with a high $\delta^{15}N$ value into the animal food, although fractionation within the sheep, when under drought stress, may also be a factor.

The dependence of $\delta^{15}N$ values in human and animal collagen on precipitation was discussed for several arid zones where such an ecological factor causes $\delta^{15}N$ enrichment in plants and soil. Reduced precipitation causes high $\delta^{15}N$ values in herbivores as well (Iacumin et al. 1998; Schwarcz et al. 1999).

Our hypothesis is that values of isotope ratios in humans dating back to different archaeological Bronze Age cultures are determined by a change in diet. People of the Eneolithic and Majkop consumed predominantly terrestrial food. The steppe population of the subsequent periods enhanced their diet using aquatic resources. However, another significant reason for the variation in isotope values of humans and animals as well as in plants of the Yamnaya, Early Catacomb, and East and West Catacomb cultures is climate change, i.e. temperature and precipitation. Paired dates from human and animal bones of Sukhaya Termista I, kurgan 1, grave 11, Yamnaya culture (Table 5), suggest that the female consumed freshwater resources from a system without reservoir effect. The mean annual amount of precipitation for the timeframes corresponding to the archaeological cultures is reconstructed by Demkin et al. (2002), and is shown in Figure 2b.

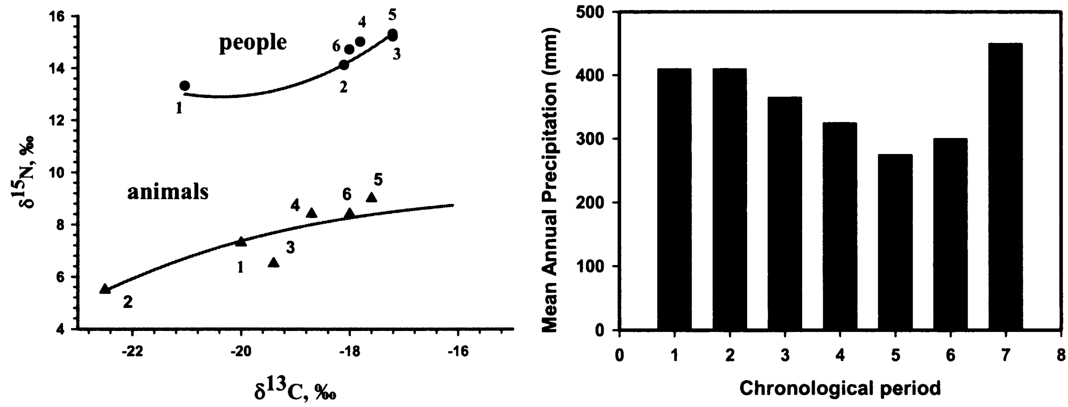

Figure 2 a) Average values of $\delta^{13}C$ and $\delta^{15}N$ for human and animal bone collagen from the studied cultures; b) Mean annual precipitation during these archaeological cultures (Demkin et al. 2002). Legend: 1 – Eneolithic; 2 – Majkop; 3 – Yamnaya; 4 – Early Catacomb; 5 – East Manych Catacomb; 6 – Lola and Krivaya Luka; 7 – modern values.

A high value of $\delta^{15}N$ in archaeological samples obtained from Early Catacomb, East and West Manych Catacomb, and Lola cultures may be a signal of stressed plants suffering from a lack of water during periods of drought. Aridization changed all landscape components, i.e. vegetation, soil, and water resources; dry-steppe and semi-desert species appeared. These produced much less biomass per km^2. The winter precipitation rate decreased, and the intensity of heavy summer showers increased, leading to erosion processes. Climate changes caused a change in vegetation that in turn led to changes of isotope values in animal bone collagen. In addition, human practices may have caused overgrazing by animals, causing degradation of soil and vegetation as well. Animals have a direct impact on vegetation as they eat terrestrial parts of plants, destroy the upper part of soils with their hooves, and leave their droppings (Dinesman and Bold 1992). A substantial part of mineral elements contained in plants that animals eat are returned into the soil via the droppings. Significant amounts of organic matter rich with nitrogen appearing on the soil surface improve soil microbiological activity and vital functions of soil fauna. The impact of animal droppings on soil and plants is determined not only by their amount but also by their chemical composition, physical property, shape, and distribution pattern across the surface. Sheep droppings are especially rich in minerals important for plants. The greatest amount of nitrogen and potassium that gets into pastures is contained in animal urine. Concentrated urine can burn plants and is the main reason for a drastic increase in plant alkalinity. Sheep droppings are distributed across the soil surface evenly and do not have an adverse mechanical impact on plants. By decomposing, mineral elements contained in droppings gradually return to the soil (Masanov 1995). Recent studies have shown the impact of manuring on nitrogen isotope ratios on plants (Bogaard et al. 2007). Degradation of pastures may have led to the appearance of xerophytes and a decline in productivity.

One of the main necessities for Kazakh winter pastures is the availability of reed and cane (Masanov 1995). Apparently, reed and cane were used as winter fodder for domesticated animals in the Bronze Age as well, especially during periods of drought when there were not enough pastures during summer and winter seasons. This could be the main reason for a high value of $\delta^{15}N$ in animal bone collagen in the archaeological samples. Sheep bones with a high level of nitrogen were found in graves that contained several mats made of reed. Some reed samples analyzed show very high $\delta^{15}N$ values.

We assume that water gramineous plants with high $\delta^{15}N$ value can be consumed by humans when there is a shortage of food. Humans also consumed flesh and milk of animals, feeding from plants with high value of $\delta^{15}N$. This could also cause high $\delta^{15}N$ values in human bone collagen. Thus, change in precipitation is reflected in changes in isotope values of all samples analyzed. The average value of $\delta^{13}C$ and $\delta^{15}N$ and precipitation is shown in Table 6.

Table 6 Average isotope data obtained for humans, animals, and plants available from the cultures in question as well as annual precipitation.

Culture and material	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	Annual precipitation (Demkin et al. 2002)
Eneolithic (4300–3800 cal BC)			
Human	–21.0	+13.3	400–420 mm
Domesticated animal	–20.0	+7.3	
Plants	n/a	n/a	
Steppe Majkop (3500–3000 cal BC)			
Human	–18.1	+14.1	400–420 mm
Domesticated animal	–22.5	+5.5	
Plants	n/a	n/a	
Yamnaya (3000–2500 cal BC)			
Human	–17.2	+15.2	350–380 mm
Domesticated animal	–19.4	+6.5	
Plants	–24.3 (n = 1)	+6.4 (n = 1)	
Early Catacomb (2700–2400 cal BC)			
Human	–17.8	+15.0	350–300 mm
Domesticated animal	–18.7	+8.4	
Plants	–25.9 (n = 8)	–25.9 (n = 8)	
East Manych Catacomb (2500–2200 cal BC)			
Human	–17.2	+15.3	250–300 mm
Domesticated animal	–17.6	+9.0	
Plants	–25.5 (n = 6)	+14.1 (n = 6)	
Lola and Krivaya Luka (2200–2000 cal BC)			
Human	–18.1	+14.7	300 mm
Domesticated animal	–18.0	+8.4	
Plants	–22.6 (n = 1)	+10.72 (n = 1)	

The average values of $\delta^{13}C$ and $\delta^{15}N$ obtained for human and domesticated animal collagen analyzed show a linear correlation with the amount of precipitation. Such changes occurred during 4000–3000 cal BC. This is illustrated in Figures 3 and 4 for animals and humans, respectively.

We also see that changes in precipitation are reflected in the changes in isotope values of plants. There is no linear correlation between isotope values in plants and isotope values in humans and domesticated animals. Separate plant samples obtained from graves were analyzed. Their isotope signal indicates that some steppe plants changed their isotope signal because of the deterioration of climate. It is possible that C_4 plants appeared, although we do not have these in our collection. They were gradually incorporated into the domesticated animal diet, leading to a change in animal isotope values and subsequently in those of humans.

The results of $\delta^{13}C$ and $\delta^{15}N$ stable isotope analyses can be used to interpret the ^{14}C dates (Shishlina et al. 2007, 2009). Consumption of aquatic food components (freshwater and marine) results in

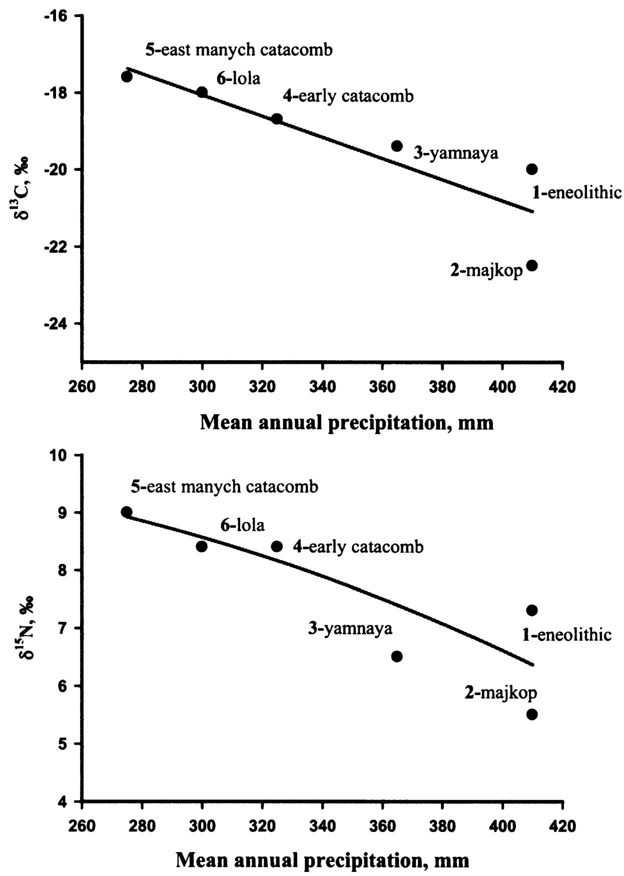

Figure 3 Average values of $\delta^{13}C$ (above) and $\delta^{15}N$ (below) for domesticated animals as well as annual precipitation.

apparent ^{14}C ages of the human bone collagen. This has been demonstrated by comparing paired ^{14}C dates derived from human and terrestrial herbivore bone collagen. Pairs with an offset have been published previously (Shishlina et al. 2009).

In cases where we have an offset between the ^{14}C age of human bone and terrestrial samples and $\delta^{15}N$ values typical for aquatic samples (Table 5), we assume that the human ^{14}C date shows an apparent age and should be corrected (Shishlina et al. 2009).

Stable isotope data obtained for archaeological plant samples suggest that in some cases, in spite of the $\delta^{13}C$ and $\delta^{15}N$ values, the human diet did not include aquatic components. Instead, the diet was based on C_3 plants with very heavy $\delta^{15}N$ values and flesh/milk of domesticated animals. This means that our proposed Model 1 for the human diet system might need some corrections, i.e. the range of $\delta^{15}N$ values in human bone collagen can vary from +12.94 to +15.03‰. In such cases, there is no offset between the ^{14}C age of human bone and terrestrial samples. There is not always a linear relationship between ^{14}C age offset and $\delta^{15}N$ values.

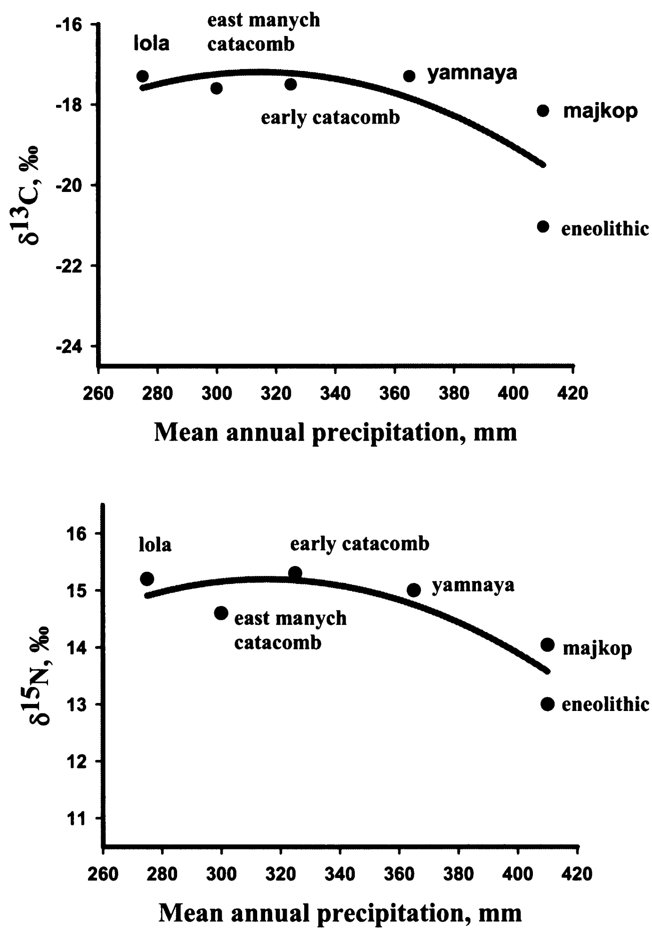

Figure 4 Average values of $\delta^{13}C$ (above) and $\delta^{15}N$ (below) for humans as well as annual precipitation.

CONCLUSION

Our isotope data show a very broad range of $\delta^{13}C$ and $\delta^{15}N$ values for Bronze Age cultures of the Caspian steppe region. Bronze Age human and animal collagen from the steppe show large variations in $\delta^{13}C$ and $\delta^{15}N$ values. In general, we observed that the older the sample, the lower the $\delta^{13}C$ and $\delta^{15}N$ values. We hypothesize that more positive values of $\delta^{13}C$ and $\delta^{15}N$ are caused by change in diet as well as a more arid climate. Our data led us to propose 2 fodder models for domesticated animals and 3 diet models for humans. For ancient sheep during drier periods, we observed 2 groups with different C and N isotopic compositions, reflecting different vegetation pastures. During these times, C_4 plants and C_3 plants with high $\delta^{15}N$ appeared as well in the vegetation, also influencing bone collagen values.

The $\delta^{13}C$ and $\delta^{15}N$ values in animal bones indicate that different pastures were used by local mobile groups. Such pastures could be located in different ecological environments. Different ^{14}C ages of samples from different origins show that many human samples are subject to a reservoir effect. They are thus older than terrestrial samples. The old age of the human bone is caused by a riverine (and in some cases marine) diet of the population. The apparent age offset values vary significantly.

When we do not have the difference in ^{14}C ages of terrestrial and human bone samples, we may assume that the diet of the population did not include riverine and marine products. Isotope variation could be the result of changes in climate and vegetation and in the isotope signal in bone collagen.

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