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PALEOECOLOGY, SUBSISTENCE, AND ^{14}C CHRONOLOGY OF THE EURASIAN CASPIAN STEPPE BRONZE AGE

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ABSTRACT. Combined analysis of paleoenvironment, ^{13}C, ^{15}N, and ^{14}C in bone, including paired dating of human bone and terrestrial materials (herbivore bone, wood, charcoal, and textile) has been performed on many samples excavated from Russian kurgan graves. The data can be used for dietary reconstruction, and reservoir corrections for ^{14}C dating of human bone. The latter is essential for an accurate construction of chronologies for the Eneolithic and Bronze Age cultures of the Caspian steppes.

INTRODUCTION

The absolute chronology of Eneolithic–Bronze Age cultures of the Caspian steppes is based on series of radiocarbon age measurements of samples taken from kurgans and graves. Kurgans (tumuli) are architectural constructions. They consist of a segment-shaped mound, encircled by a round or oval ditch. In some cases, the upper part of the mound was made flat. A mound was put up over a primary burial when this burial was roofed. Each kurgan embankment was built over 1 grave, or very seldom over 2 or 3 graves. The first kurgans in the studied area appeared during the Eneolithic Age, and became the main funeral sites across the steppe areas starting from the Yamnaya culture. In some cases, population groups of different cultures used the kurgans of their predecessors. Thus, many secondary graves were added to the original kurgans. The chronological sequence of Bronze Age steppe cultures is traditionally based on the analysis of kurgan stratification.

The absolute chronologies are based on series of calibrated ^{14}C dates. Dates obtained for human bones should be carefully and critically evaluated because of possible reservoir effects, i.e. an offset in ^{14}C from the coeval atmosphere, caused by a diet of fish or mollusks in human bone. For the area of the Caspian steppes, such effects have been identified earlier for the Early Catacomb and East Manych Catacomb cultures (Shishlina et al. 2007; van der Plicht et al. 2007).

The goal of the present project is to study and discuss possible reservoir effects in human bone collagen obtained from other Eneolithic and Bronze Age cultures. Therefore, we obtained paired dates from samples of different materials that are believed, from their context, to be contemporary from the same graves. We also measured the stable isotopes ^{13}C and ^{15}N on the sample bone collagen, and studied relevant paleoclimatic data. The regional paleoclimate revealed frequent and sometimes sharp climatic changes, a succession of relatively humid and dry periods that lasted a few centuries. This led to changes of annual precipitation, resulting in quantitative and qualitative changes of morphological and chemical properties of soils, local vegetation, and water resources available, as well as changes in human exploitation of natural food resources (Shishlina 2008). Climate changes can also result in different stable isotope ratio values as has been observed in ancient Egypt (Thompson et al. 2005).

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Here, we present data from 7 archaeological cultures: the Eneolithic, Steppe Majkop, Yamnaya, Steppe North Caucasus, Early Catacomb, Eastern Manych, and Lola cultures. The people of these cultures were mobile pastoralists who exploited different ecological areas of the Caspian steppes and nearby areas of the Volga River and North Caucasus steppes. The location of the sites is shown in Figure 1.

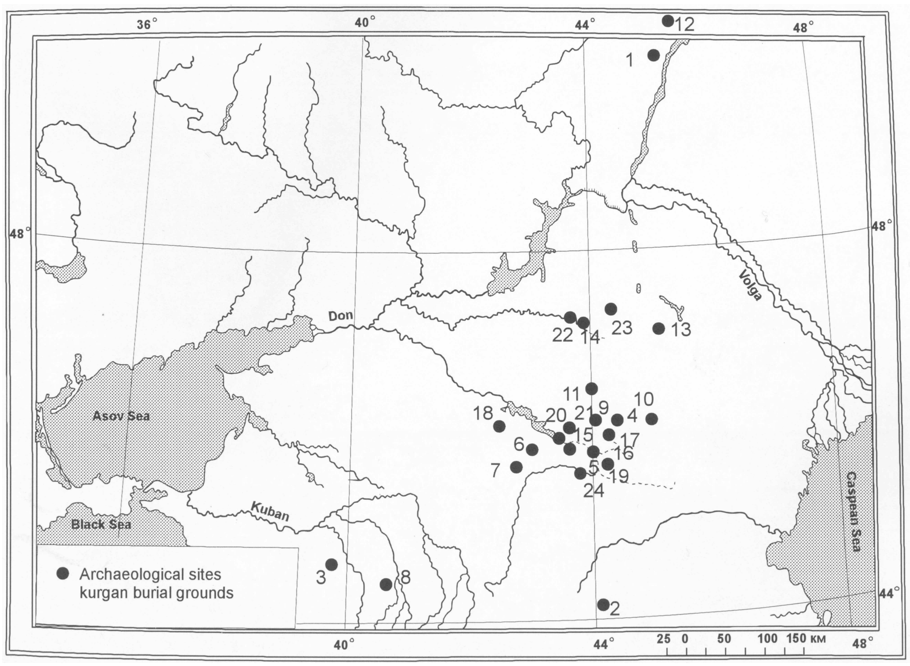

Figure 1 Map showing the sites discussed: 1—Khvalynsk; 2—Nalchik; 3—Myskhako; 4—Mandjikiny-1; 5—Sharakhalsun-6; 6—Aygursky-2; 7—Zolotarevka-1; 8—Novosvobodnaya/Klady; 9—Mu-Sharet-4; 10—Mandjikiny-2; 11—Khar-Zukha; 12—Poludny; 13—Chilgir; 14—Peschany V; 15—Zynda-Tolga-3; 16—Zunda-Tolga-1; 17—Mu-Sharet-1; 18—Baga-Burul; 19—VMLBI,65; 20—Ostrovnoy; 21—Zunda-Tolga-5; 22—Temrta I, III, and V; 23— Yergueni; 24—Chogray IX.

METHODS

The study of soils buried under Bronze Age kurgans yield new data on paleoenvironmental conditions in the Eurasian Caspian steppe areas. We have studied the geochemical characteristics of the soil, as well as pollen and phytoliths. This way, climatic variations are analyzed within the time range of 4300–2300 BC (Demkin et al. 2002a,b; Shishlina 2008).

For fossil bones, collagen was extracted using an improved version of the Longin method (Mook and Streurman 1983). In Groningen, the sample was combusted into CO_2 and purified using an elemental analyzer/mass spectrometer (EA/MS) combination (Aerts-Bijma et al. 2001). The CO_2 is collected cryogenically for off-line graphite production. The graphite powder is pressed into targets which are placed in the sample carousel of the AMS. The AMS measures the isotopic ratios $^{14}C/^{12}C$ and $^{13}C/^{12}C$ of the graphite (van der Plicht et al. 2000). From these measured isotopic ratios, the ^{14}C activities are calculated, including the correction for isotopic fractionation. From this, the conventional ^{14}C dates are calculated, which are reported in BP. In addition, the EA/MS also provides the $\delta^{13}C$ and $\delta^{15}N$ stable isotope ratios.

Conventional ^{14}C dates were obtained at the Institute of Geography of the Russian Academy of Sciences using liquid scintillation. Stable isotope ratios were also measured at the Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, on a DELTA Plus XP (Thermo-Finnigan) isotope mass spectrometer linked with an element analyzer, Flash EA 1112. Additional stable isotope measurements have been done in Oxford. Dietary components obtained from previous research are used as well (Shishlina et al. 2007; Shishlina 2008).

A variety of carbon-containing samples (i.e. terrestrial wood, seeds, river shells and fish bones, bones of humans, and domesticated animals obtained from the same context, i.e. the grave) were used for paired ^{14}C dating. The ^{14}C dates are calibrated using the CALIB program and the IntCal04 data set (Reimer et al. 2004).

RESULTS AND DISCUSSION

The Paleoenvironment

Paleoclimatic investigations based on analyses of soils buried under Bronze Age kurgans (Kremenetsky 1997:32–3; Ivanov and Demkin 1999; Demkin et al. 2002a:118–22, 2002b; Shishlina 2008) resulted in the establishment of distinct climatic periods during the time interval 4300–2000 BC. Periods of relatively humid and dry periods lasted for several centuries, during which slight variations in the groundwater level may have caused changes in vegetation, soil, and fauna. Our investigations resulted in the establishment of a succession of climatic periods, summarized in Table 1.

Table 1 Climatic changes in the Caspian steppes during time interval 4300–2000 BC.

Time interval	Climatic characteristics	Culture
4300–3800 cal BC	Favorable climatic conditions with a prevailing grassland and steppe landscape, spread of mixed forests in the ravines, and an average annual precipitation rate of 400–420 mm; dry steppe with zonal type of vegetation (predominance of C_3 plants); abundant with freshwater lakes and rivers.	Eneolithic
3800–3000 cal BC	Favorable climatic conditions of mixed gramineous steppe plants and increased humidity with 400–500 mm annual precipitation.	Steppe Majkop
3000–2600 cal BC	Favorable climatic period, which was humid and warm, an average annual precipitation rate of around 400 mm, predominance of mixed grass steppes; at the end of the first half of the 3rd millennium BC, a process of gradual aridization began.	Yamnaya
2600–2300 cal BC	Abrupt aridization; summer temperature increased and winter temperature became lower, and the amount of precipitation decreased; dry steppes were replaced with semi-desert landscapes, characterized by wormwood and fescue corresponding to a very dry climate; the forest area over ravines was reduced; the annual precipitation was 40–60 mm lower than today, and 140–160 lower than it was during the previous period.	Late Yamnaya, Steppe North Caucasus, Early Catacomb, and Early East Manych Catacomb
2300–2000 cal BC	Continuation of the aridization, predominance of semi-desert landscapes, further reduction of forest areas.	East Manych Catacomb and Lola

Stable Isotope Measurements

We measured the stable isotope ratios $\delta^{13}C$ and $\delta^{15}N$ in human and animal bones representing cultures exploiting the same ecological niches during different ecological conditions. These isotope ratios indicate the main components of the diet. It is most instructive to present the data for each culture separately.

The Eneolithic cultures (4300–3800 cal BC) were the first to develop a pastoral economy. We measured the stable isotopes $\delta^{13}C$ and $\delta^{15}N$ for the human bones that were previously dated by ^{14}C, as well as for domesticated animals and a dolphin obtained from the Eneolithic sites. These stable isotope data are shown in Table 2, and plotted in Figure 2. The data show that the Eneolithic populations had a diet based on river products. This is confirmed by catfish (*Silurus glanis*) bones and special fishing tools (hooks and harpoons) found at Eneolithic sites (Agapov et al. 1990).

Table 2 Stable isotope ratios for human and animal bones from the Eneolithic cultures.

Kurgan/grave/sample	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Khvalynsk II		
g.10, human	–20.34	+13.96
g.10, domesticated cow	–20.04	+7.51
g.18, human	–22.36	+13.58
g.24, human	–20.24	+13.76
g.34, human	–20.58	+10.26
g. 35, human	–21.92	+13.79
Khvalynsk I		
g.127, animal?	–20.77	+14.57
g.147, sheep (ring)	–17.86	+11.69
Nalchik		
g.86, male adult	–20.75	+8.97
Myskhako		
Dolphin, level	–13.58	+9.20
Domesticated cow, level	–19.65	+7.92

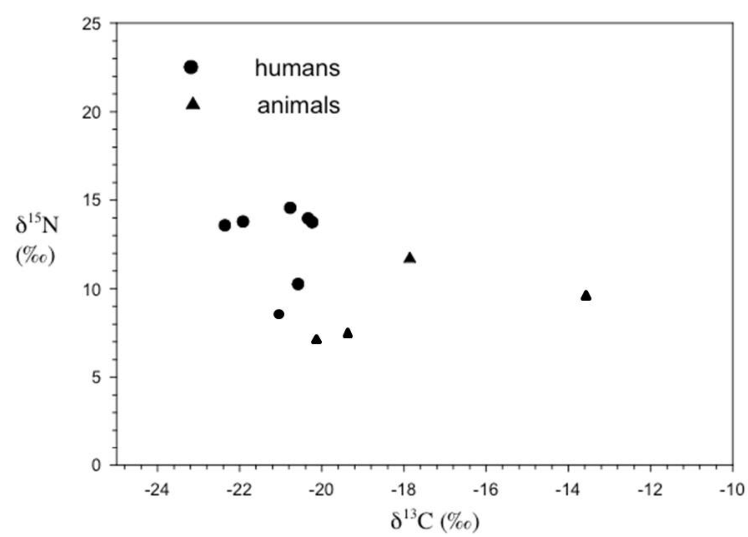

Figure 2 Stable isotope ratios $\delta^{13}C$ (horizontal) and $\delta^{15}N$ (vertical) for human bone samples from the Khvalynsk and Nalchik cemeteries and Myskhako settlements samples.

The Steppe Majkop population (3800–3000 cal BC) penetrated into the open steppe under favorable conditions. They are considered to be agriculturalists and pastoralists (Munchaev 1975). The stable isotope ratios $\delta^{13}C$ and $\delta^{15}N$ for human and animal bones were measured (Table 3, Figure 3). The new data indicate that river products were the main dietary components of people who occupied steppe ecological areas at that time. They also gathered wild steppe gramineous C_3 plants (Shishlina 2008).

Table 3 Stable isotope ratio measurements for human and animal bones from the Majkop culture.

Kurgan/grave/sample	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Mandjikiny-1		
k. 14, g. 13, male 45–55	–18.80	+11.64
Sharakhalsun-6		
k. 5, g. 7, child	–16.77	+15.23
k. 2, g. 17, child	–18.35	+13.49
Aygursky-2		
k. 17, g. 6, human	–18.53	+15.90
Zolotarevka-1		
k. 22, g. 11, human	–18.57	+14.16
Novosvobodnaya/Klady		
k. 2, deer teeth	–22.92	+6.92
k. 2, deer teeth	–22.10	+4.01

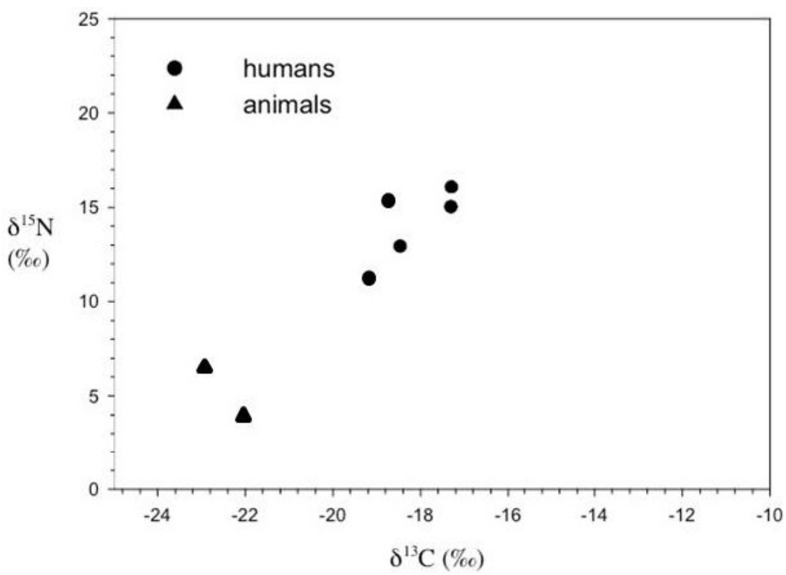

Figure 3 Stable isotope ratios $\delta^{13}C$ (horizontal) and $\delta^{15}N$ (vertical) for the Majkop culture

The Yamnaya culture population (3000–2450 cal BC) occupied various ecological areas, exploiting all food resources. Stable isotope data obtained for human and animal bones (Table 4, Figure 4) suggest that river products were a major food source for this population, male and female alike. This conclusion is confirmed by finds of river fish bones and shells of edible mollusks (like pearl oysters) in the Yamnaya burials Krivaya Luka IX and XXI. During more humid conditions, the steppe rivers were apparently abundant with fish. Fish were caught with nets; mats in the form of a knotless net were found in some graves. Ethnographic data show that woven mats were used to catch fish (Rybina 2003); similar items have been identified in the collection of mats coming from Yamnaya graves we have studied (Shishlina 2008). Shells of river mollusks and bird eggs were collected for food as well as many edible C_3 plants (Shishlina 2008), i.e. wild steppe C_3 gramineous plants (*Hordeum*), *Poaceae*, *Fabaceae*, and *Ephedra.*

Table 4 Stable isotope ratio measurements for human and animal bones from the Yamnaya culture.

Kurgan/grave/sample	δ^{13}C (‰)	δ^{15}N (‰)
Mu-Sharet-4: k. 12, g. 1, male 17–20	–18.08	+14.31
Mandjikiny-2: k. 11, g. 2, male 35–45	–17.57	+15.29
Mandjikiny-2: k. 11, g. 3, females 45–50	–16.62	+18.09
Mandjikiny-1: k. 14, g. 12, male 17–25	–18.61	+14.13
Mandjikiny-1: k. 14, g. 10, male 20–25	–18.16	+14.00
Mu-Sharet-4: k. 11, g. 3, female 14–17	–16.55	+15.36
Khar-Zukha: k. 2, g. 3, female 20	–16.08	+13.74
Poludny: k. 2, g. 7, male 45	–17.41	+15.05
Chilgir: k. 2, g. 3, male *maturus*	–15.43	+17.68
Peschany V: k. 1, g. 3, male 30–40	–18.89	+13.22
Grachevka: k. 5, g. 2, juveniles	–19.03	+10.59
Mu-Sharet-4: k. 1, g. 3, sheep	–18.80	+7.23
Zynda-Tolga-3: k. 1, g. 4, sheep	–23.59	+11.80

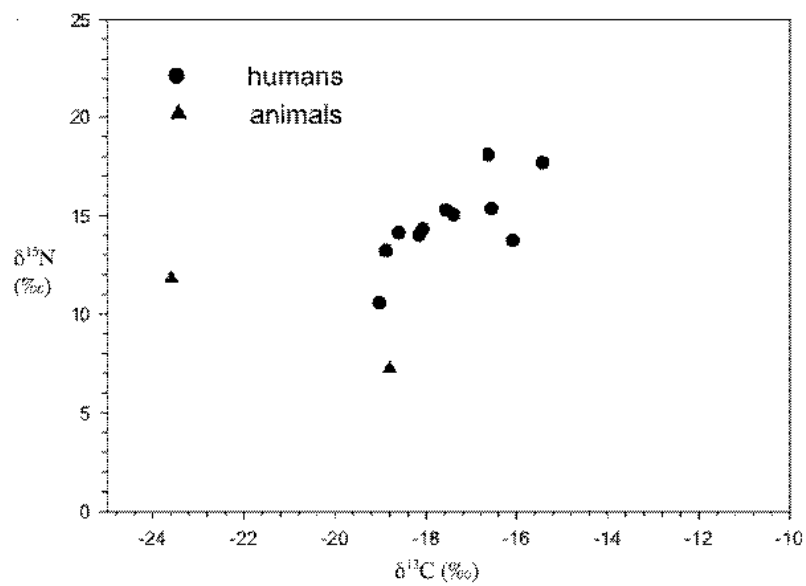

Figure 4 Stable isotope ratios δ^{13}C (horizontal) and δ^{15}N (vertical) for the Yamnaya culture

The Steppe North Caucasus population (2500–2300 BC) began to penetrate the Caspian steppes from the North Caucasus region during a period of climatic deterioration. It led to a reduction in the number of potential winter and summer grasslands, arable lands, and lands suitable for growing vegetables on the steppe, piedmont, and coastline areas of the North Caucasus (Gey 1989). In the end, it caused the North Caucasus inhabitants to ameliorate their economic problems by exploiting regions in the north.

New measurements of stable isotope ratios in human bone collagen showed that river products such as fish and mollusks were important elements of the diet system of the Steppe North Caucasus population (Table 5, Figure 5). Food and economic resources were provided by fishing, e.g. trout from the Konstantinovskoye plateau (Markovin 1994) and carp from North Caucasus found in graves of the Kuban region (Nechitailo 1979) as well as by gathering wild plants and root crops (Shishlina 2008).

Table 5 Stable isotope ratio measurements for human and animal bones, and shells from the Steppe North Caucasus culture.

Kurgan/grave/sample	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Zunda-Tolga-1: k. 1, g. 11, male 15–17	−18.40	+12.28
Zunda-Tolga-1: k. 1, g. 11, ring made of ungulate bone	−18.19	+8.25
Mandjikiny-2: k. 7, g. 2, male 30–40	−17.77	+16.03
Mu-Sharet-1: k. 6, g. 4, ring made of ungulate bone (sheep)	−16.52	+11.38
Mu-Sharet-1: k. 6, g. 4, ring made of ungulate bone (sheep)	−20.25	+13.06
Mu-Sharet-1: k. 6, g. 4, *Unio* shell	−8.46	n/a

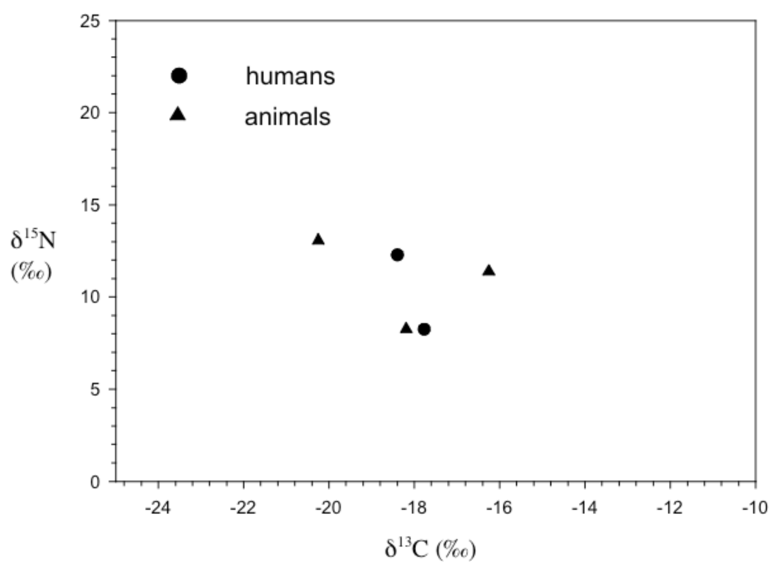

Figure 5 Stable isotope ratios $\delta^{13}C$ (horizontal) and $\delta^{15}N$ (vertical) for Steppe North Caucasus culture.

The Early Catacomb culture population (2600–2350 BC) was also spread out in the studied area during the initial period of climate aridization. The Early Catacomb people were seasonal pastoralists. They were part of the peoples migrating out of southern part of the North Caucasus piedmont area, the Taman Peninsula, the Asov Sea steppes, and the Don River valleys (Shishlina 2008). They made use of all the food resources of the occupied areas, including edible C_3 plants, aquatic resources, as well as domesticated and wild animals (Shishlina 2008). Some C_4 plants are present in the vessel residues as well as in the pastures (identified in the soils buried under kurgans). We show here a large series of $\delta^{13}C$ and $\delta^{15}N$ measurements on human and animal bone (see Figure 6). Part of these data were published before (Shishlina et al. 2007; Shishlina 2008).

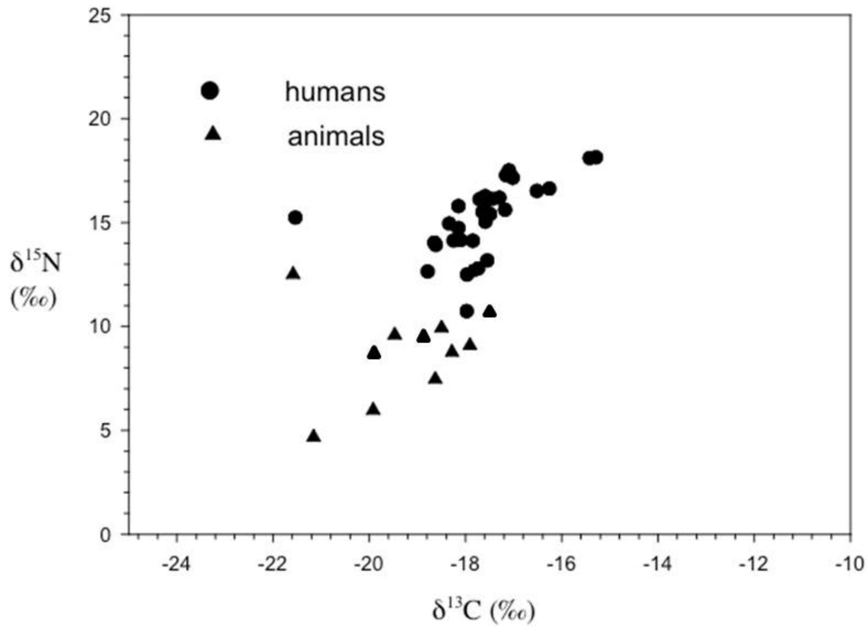

Figure 6 Stable isotope ratios $\delta^{13}C$ (horizontal) and $\delta^{15}N$ (vertical) for the Early Catacomb culture

The Eastern Manych Catacomb culture population (2500–2000 cal BC) lived across the entire Caspian steppes during unfavorable environmental conditions. Aridization affected many Eurasian regions and led to severe climatic disasters, a change in landscapes, and changes in the hydrological network and vegetation, all affecting human activities. Many rivers and lakes became dry during the summer. Aridization that occurred on the Sarpa and Caspian plains caused a drop in groundwater levels and mineralization (Ivanov and Demkin 1999).

The stable isotope ratios of human and animal bone collagen show that all individuals had a diet based largely (at least for protein) on river and lake food (Shishlina et al. 2007) (shown in Table 6 and Figure 7). They also consumed many C_3 wild steppe plants. Some C_4 plants, belonging to *Atriplix*, *Chenopodiaceae*, *Rumex*, and *Polygonaceae*, were also identified in vessel residues and in stomach remains (Shishlina 2008: Table 30).

Table 6 Stable isotope ratio measurements for human and animal bones from the East Manych Catacomb culture.

Kurgan/grave/sex/age	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Baga-Burul		
k. 5, g. 11, female 25–35	–16.94	+15.82
k. 5, g. 21, male <45	–17.86	+14.20
k. 5, ritual place 4, horse	–20.65	+6.22
k. 5, ritual place 4, cow	–16.65	+9.92
k. 5, ritual place 15, sheep	–19.35	+8.28
k. 1, g. 3, cow	–19.19	+9.20
k. 1, g. 3, sheep	–19.39	+7.39
k. 5, g. 12, sheep	–16.6	+10.72
k. 5, g. 8, sheep	–17.44	+9.20

Table 6 Stable isotope ratio measurements for human and animal bones from the East Manych Catacomb culture. *(Continued)*

Kurgan/grave/sex/age	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Ostrovnoy		
k. 3, g. 10, male 35	–17.69	+12.77
k. 3, g. 39, female 20–30	–17.30	+16.08
k. 3, g. 38, sheep	–19.21	+6.65
k. 3, g. 9, sheep	–17.77	+6.43
k. 3, g. 9, sheep	–18.11	+7.64
k. 6, g. 8, sheep	–19.50	+8.18
k. 6, g. 8, sheep	–18.20	+7.54
VMLBI,65		
k. 43, g.1, sheep	–19.92	+9.74
Zunda-Tolga-1		
k. 9, g. 1, male 50	–16.98	+14.19
k. 10, g. 2, female 50–60	–16.58	+16.31
k. 10, g. 3, male 35	–19.35	+14.15
k. 8, g. 1, sheep	–16.74	+11.60
k. 9, g. 1, sheep	–17.38	+9.70
k. 10, g. 3, sheep	–18.83	+5.13
Zunda-Tolga-5		
k. 1, g. 5 male 50–60	–18.65	+14.03
Chilgir		
k. 1, g. 4, female <45	–17.24	+15.71
k. 1, g. 4, sheep	–15.53	+12.01
k. 2, g. 5, sheep	–21.58	+9.22
k. 3, ritual place B, cow	–16.18	+11.99
Temrta V		
k. 1, g. 4, female 25–35	–17.76	+9.45
k. 1, g. 4, sheep	–16.06	+10.16
Temrta III		
k. 1, g. 6		
human 25–30	–15.44	+18.65
Peschany-V		
k. 1, g. 6, male 30–35	–16.09	+16.14
k. 5, g. 5, male 50–60	–17. 58	+15.23
Yergueni		
k. 6, g. 3, sheep	–14.27	+12.76
k. 6, g. 2, sheep	–15.59	+12.02
k. 6, g. 5, sheep	–16.28	+13.12
k. 6, g. 10, sheep	–15.96	+10.36
Mandjikiny-I		
k. 10, g. 2, female 45–40	–16.78	+17.25
k. 14, g. 1, male 30–35	–16.59	+17.69
k. 14, g. 1, sheep	–16.37	+10.33
k. 14, ritual place 21, astragal of the sheep	–24.17	+10.39
Chogray IX		
k. 14, g. 8, adult	–17.75	+14.54
k. 8, g. 2, adult	–17.93	+15.44

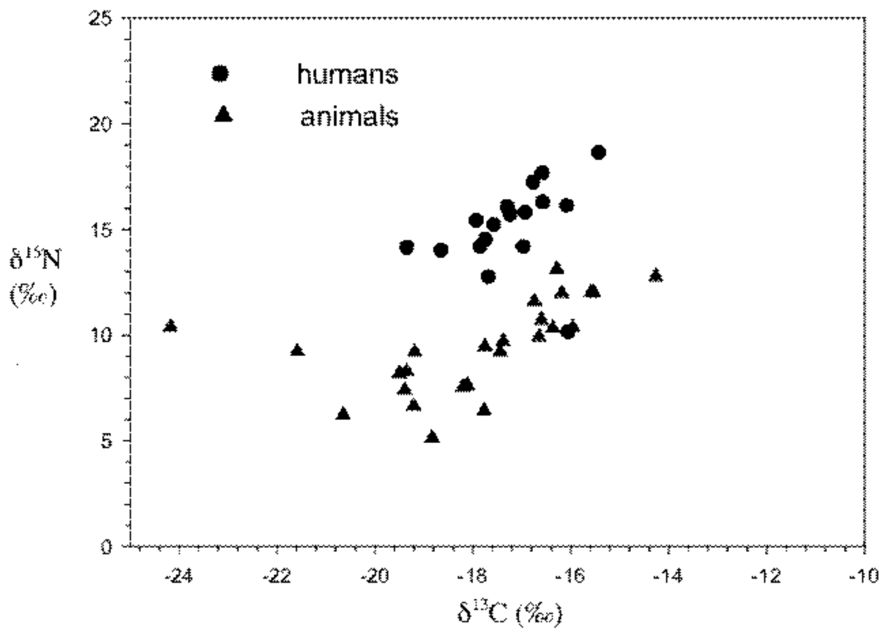

Figure 7 Stable isotope ratios $\delta^{13}C$ (horizontal) and $\delta^{15}N$ (vertical) for the East Manych Catacomb culture

The majority of animal bones show a very broad range of $\delta^{13}C$ and $\delta^{15}N$ values. Several sheep (Baga-Burul; Zunda-Tolga-1, Chilgir, Yergueni) show high values of $\delta^{15}N$ (+10.39 to +13.72‰) and also of $\delta^{13}C$ (–14.27 to –16.74‰). This can be explained by arid conditions (Bocherens et al. 2006).

The population of the Lola culture appeared in the steppes during the end of the Eastern Manych Catacomb cultural period. The climate was still severe, leading to the development of a mobile pastoral economy. The stable isotope values for both human and animal fossil bones overlap each other (see Table 7 and Figure 8). Animals show high $\delta^{15}N$ values (+12.30‰) and high $\delta^{13}C$ values (around –16‰).

Table 7 Stable isotope ratio measurements for human and animal bones from the Lola culture.

Kurgan/grave/sex/age	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Ostrovnoy		
k. 3, g. 39, female 20–30	–17.30	+16.08
k. 3, g. 39, sheep	–16.37	+12.30
k. 6, g. 9, sheep blade	–15.83	+4.61
Mandjikiny-1		
k. 9, g. 1, male 35–40	–17.13	+15.03
Temrta-1		
k. 2, g. 8, *Bos taurus* teeth	–18.65	+9.72
k. 2, g. 8, male 40–50	–18.47	+12.94

Radiocarbon Dating

Parallel dating of animal and human bone, as well as wood samples, have been conducted for the studied cultures. The results are shown in Table 8.

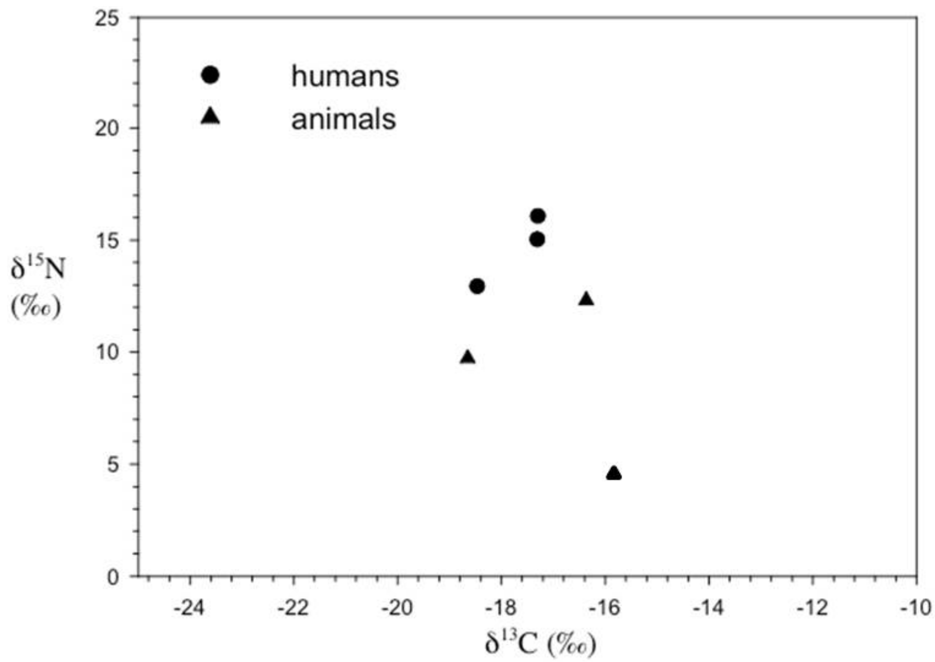

Figure 8 Stable isotope ratios $\delta^{13}C$ (horizontal) and $\delta^{15}N$ (vertical) for the Lola culture

Paired ^{14}C dating of human, sheep, and cow bones from the Eneolithic Khvalynsk graves was used in order to quantify the size of reservoir effect. The human bone from Khvalynsk II, grave 10, is 220 yr older than contemporaneous cow bone from the same grave. The date of a ring made of ungulate bone from Khvalynsk I, grave 147, is the same as for the cow bone. For this grave, the reservoir effect appears to be about 275 yr.

The chronology of the Steppe Majkop culture is so far only based on ^{14}C dates of human bones and 1 bead made of animal bone (Shishlina 2008). Paired dates for the Steppe Majkop culture are not yet available.

Paired dating of Yamnaya culture human bones and wood (*Fraxinus*, *Ulmus*, *Acer*) from the same grave show the reservoir effect for the bones: Mu-Sharet-1, k. 5, g. 3, 195 yr; Mandjikiny-1, k. 14, g. 12, 265 yr; and Mandjikiny-2, k. 11, g. 2, 270 yr.

To investigate the reservoir effect in human bones, paired samples of wood, plant mat, and human bones taken from 4 Steppe North Caucasus burials were dated. Two such pairs have been obtained (see Table 8). The data from Zunda-Tolga-3 show a difference of 90 yr. The difference between ^{14}C dates of shell and animal bone appears larger than 4000 yr, which is obviously impossible and needs to be explained by further investigation.

Table 8 also shows 3 examples of paired ^{14}C dates of terrestrial and human bone samples from the same graves of the Early Catacomb culture. The difference between a pin made from an ungulate bone and human bone is 220 yr (Temrta V, k. 1, g. 2); between human bone and a sheep bone, 490 yr (Temrta V, k. 1, g. 3); and between human bone and sheep, 185 yr (Mandjikiny-1, k. 54, g. 6). The pin came from the primary grave, and the sheep bone from the secondary grave. A fourth paired dating concerns wood and sheep bone from Temrta I.

Table 8 ^{14}C dates and stable isotope (^{13}C and ^{15}N) data for Eneolithic and Bronze Age cultures of the Eurasian steppes.

Lab nr	Sample	Kurgan/ grave	^{14}C age (BP)	Calibrated range 1 σ (BC) [start: end] relative area	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Eneolithic culture						
Khvalynsk II: 52°50′N, 48°20′E						
OxA-4311	human bone	g. 10	5790 ± 85	[4763 : 4759] 0.01 [4727 : 4536] 0.99	–20.34	+13.96
GrA-34100	cow bone	g. 10	5570 ± 40	[4448 : 4416] 0.44 [4405 : 4362] 0.56	–20.04	+7.51
OxA-4314	human bone	g. 18	6015 ± 85	[5009 : 4794] 1.0	–22.36	+13.58
OxA-4312	human bone	g. 24	5840 ± 85	[4795 : 4586] 1.0	–20.24	+13.76
OxA-4313	human bone	g. 34	5920 ± 80	[4906 : 4863] 0.18 [4856 : 4709] 0.82	–20.58	+10.26
OxA-4310	human bone	g. 35	6040 ± 80	[5047 : 4835] 0.99 [4812 : 4810] 0.01	–21.92	+13.79
Khvalynsk I: 52°35′N, 47°90′E						
GrA-26899	animal or human bone?	g. 127	5840 ± 40	[4779 : 4683] 0.92 [4633 : 4621] 0.08	–20.77	+14.57
GrA-29178	ring made of ungulate bone	g. 147	5565 ± 40	[4447 : 4417] 0.41 [4403 : 4360] 0.58	–17.86	+11.69
Majkop culture						
East Manych (VMLBIII): 45°34′N, 44°19′E						
GrA-24434	bone bead	k. 17, g. 11	5095 ± 45	[3961 : 3927] 0.30 [3916 : 3916] 0.01 [3877 : 3804] 0.69	–20.95	n/a
Mandjikiny-1: 45°42′32.65″N, 44°42′32.5″E						
GrA-19521	male 45–55	k. 14, g. 13	4950 ± 45	[3773 : 3693] 0.85 [3681 : 3664] 0.15	–18.33	n/a
IGAN-2400	male 45–55	k. 14, g. 13	5199 ± 59	[4220 : 4212] 0.03 [4151 : 4134] 0.06 [4055 : 3952] 0.91	–18.84	+11.65
Stavropol Hills, Sharakchalsun-6: 45°259′N, 43°419′E						
GrA-19258	child	k. 5, g. 7	4710 ± 100	[3632 : 3559] 0.33 [3537 : 3491] 0.22 [3470 : 3373] 0.45	–16.95	n/a
IGAN-2399	child	k. 5, g. 7	5219 ± 94	[4228 : 4199] 0.11 [4171 : 4089] 0.29 [4082 : 3956] 0.60	–16.77	+15.23
IGAN-2517	child	k. 2, g. 17	5297 ± 76	[4234 : 4042] 1.0	–18.35	+13.49
Aygursky-2: 44°38′N, 43°40′E						
GrA-22172	human bone	k. 17, g. 6	4740 ± 60	[3633 : 3555] 0.55 [3539 : 3511] 0.19 [3425 : 3382] 0.26	–18.53	+15.90
Zolotarevka-1: 45°50′N, 42°70′E						
GrA-22174	human bone	k. 22, g. 11	4640 ± 60	[3500 : 3430] 0.82 [3380 : 3363] 0.18	–18.57	+14.16
Yamnaya culture						
Mu-Sharet-1: 45°41′43.6″N, 44°37′1.2″E						
IGAN-2275	woman senilis	k. 5, g. 3	4240 ± 60	[2915 : 2857] 0.47 [2811 : 2749] 0.40 [2723 : 2699] 0.13	n/a	n/a
GrA-17461	wood (*Acer*)	k. 5, g. 3	4045 ± 35	[2620 : 2561] 0.53 [2536 : 2491] 0.47	n/a	n/a
Mandjikiny-1: 45°42′32.65″N, 44°42′32.5″E						
IGAN-2492	man 17–25	k. 14, g. 12	4030 ± 80	[2836 : 2815] 0.07 [2672 : 2468] 0.93	–18.61	+14.13

Table 8 ^{14}C dates and stable isotope (^{13}C and ^{15}N) data for Eneolithic and Bronze Age cultures of the Eurasian steppes. *(Continued)*

Lab nr	Sample	Kurgan/ grave	^{14}C age (BP)	Calibrated range 1 σ (BC) [start: end] relative area	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
IGAN-3228	wood (*Fraxinus*)	k. 14, g. 12	3770 ± 60	[2332 : 2327] 0.01 [2299 : 2031] 0.99	n/a	n/a
Mandjikiny-2: 45°41′28.2″N, 44°40′49.4″E						
IGAN-2058	man 35–45	k. 11, g. 2	4190 ± 50	[2887 : 2850] 0.25 [2813 : 2742] 0.51 [2728 : 2694] 0.22 [2686 : 2680] 0.02	–17.56	+15.29
IGAN-2042	wood	k. 11, g. 2	3920 ± 70	[2546 : 2544] 0.01 [2488 : 2294] 0.99	n/a	n/a
Steppe North Caucasus culture						
Zunda-Tolga-3: 45°42′17.5″N, 44°8′15.5″E						
IGAN-2404	man 15–17	k. 1, g. 11	4140 ± 80	[2872 : 2801] 0.30 [2793 : 2785] 0.03 [2780 : 2621] 0.67	–18.40	+12.2
GrA-32893	ring made of ungulate (sheep) bone	k. 1, g. 11	4050 ± 35	[2827 : 2825] 0.02 [2624 : 2562] 0.57 [2535 : 2492] 0.41	–18.19	+8.25
Mu-Sharet-1: 45°41′43.6″N, 44°37′1.2″E						
GrA-34098	ring made of ungulate bone (sheep)	k. 6, g. 4	4065 ± 40	[2834 : 2817] 0.10 [2663 : 2647] 0.08 [2636 : 2565] 0.57 [2532 : 2495] 0.25	–16.52	+11.38
Gr-32795	*Unio* shell	k. 6, g. 4	8420 ± 40	[7543 : 7478] 1.0	–8.46	n/a
Early Catacomb culture						
Temrta V: 46°32′52.1″N, 43°40′15.2″E						
GrA -30051	pin made of ungulate bone	k. 1, g. 2	4110 ± 45	[2856 : 2812] 0.25 [2747 : 2725] 0.12 [2698 : 2617] 0.48 [2610 : 2581] 0.15	–18.28	+8.75
IGAN-3414	female 17–25	k. 1, g. 2	4333 ± 76	[3088 : 3058] 0.12 [3030 : 2885] 0.88	–17.97	+12.49
IGAN-3318	male 40–50	k. 1, g. 3	4600 ± 80	[3516 : 3398] 0.41 [3384 : 3322] 0.25 [3272 : 3269] 0.01 [3235 : 3171] 0.19 [3162 : 3116] 0.15	–17.74	+12.79
GrA-32893	sheep bone	k. 1, g. 3	4110 ± 35	[2852 : 2812] 0.26 [2744 : 2726] 0.10 [2696 : 2618] 0.52 [2608 : 2598] 0.06 [2594 : 2583] 0.06	–18.60	+8.24
Mandjikiny-2: 45°41′28.2″N, 44°40′49.4″E						
IGAN-2277	female 25–35	k. 54, g. 6	4320 ± 40	[3010 : 2980] 0.28 [2957 : 2952] 0.03 [2940 : 2891] 0.68	–17.58	+15.04
GrA-35809	pin made of ungulate bone	k. 54, g. 6	4135 ± 35	[2862 : 2831] 0.18 [2821 : 2807] 0.09 [2758 : 2718] 0.26 [2707 : 2631] 0.47	–18.77	n/a
Temrta-I: 46°31′15.6″N, 43°36′18.5″E						
IGAN-3433	wood (*Fraxinus*)	k. 1, g. 3	4140 ± 110	[2891 : 2618] 0.94 [2608 : 2598] 0.03 [2594 : 2584] 0.03	–23.14	n/a

Table 8 ^{14}C dates and stable isotope (^{13}C and ^{15}N) data for Eneolithic and Bronze Age cultures of the Eurasian steppes. *(Continued)*

Lab nr	Sample	Kurgan/ grave	^{14}C age (BP)	Calibrated range 1 σ (BC) [start: end] relative area	δ^{13}C (‰)	δ^{15}N (‰)
OxA-18352	sheep bone	k. 1, g. 3	4170 ± 30	[2877 : 2851] 0.18 [2813 : 2743] 0.55 [2727 : 2695] 0.24 [2683 : 2681] 0.01	–18.25	+11.29
Eastern Manych Catacomb culture						
Zunda-Tolga-1: 45°34′36″N, 44°19′16″E						
GrA-10045	charcoal from the incense burner	k. 9, g. 1	3910 ± 40	[2468 : 2390] 0.65 [2385 : 2345] 0.34	–	n/a
IGAN-3117	sheep bone	k. 9, g. 1	3920 ± 100	[2569 : 2516] 0.15 [2500 : 2280] 0.78 [2250 : 2230] 0.05 [2219 : 2212] 0.02	–17.38	+9.70
IGAN-2421	female 50–60	k. 10, g. 2	4260 ± 80	[3008 : 2986] 0.06 [2933 : 2849] 0.47 [2813 : 2741] 0.32 [2729 : 2694] 0.13 [2687 : 2679] 0.02	–16.56	+16.31
Bln-5529	male around 35	k. 10, g. 3	3860 ± 30	[2454 : 2419] 0.19 [2405 : 2377] 0.19 [2350 : 2285] 0.54 [2247 : 2234] 0.07	–18.20	+14.15
IGAN-3118	sheep bone	k. 10, g. 3	3810 ± 150	[2468 : 2113] 0.87 [2101 : 2037] 0.19	–18.83	+5.13
Mandjikiny-1: 45°42′32.65″N, 44°42′32.5″E						
IGAN-2493	male 30–35	k. 14, g. 1	4020 ± 110	[2859 : 2809] 0.12 [2752 : 2721] 0.07 [2701 : 2457] 0.76 [2418 : 2407] 0.02 [2375 : 2367] 0.01 [2361 : 2352] 0.02	–16.59	+17.69
IGAN-3229	wood (*Fraxinus*)	k. 14, g. 1	3760 ± 90	[2289 : 2131] 0.87 [2085 : 2054] 0.13	–	–
Temrta V: 46°32′52.1″N, 43°40′15.2″E						
KIA-31798	sheep bone	k. 1, g. 4	3795 ± 25	[2284 : 2247] 0.48 [2234 : 2199] 0.44 [2161 : 2153] 0.08	–16.06	+10.16
IGAN-3507	female 25–35	k.1, g. 4	4610 ± 70	[3633 : 3554] 0.45 [3540 : 3498] 0.23 [3436 : 3378] 0.32	–17.76	+9.45
Chilgir: 45°34′36″N, 44°19′16″E						
IGAN-2652	female ≥45	k. 1, g. 4	4295 ± 40	[3003 : 2992] 0.08 [2929 : 2880] 0.92	–17. 24	+15.71
KIA-31797	sheep bone	k. 1, g. 4	4045 ± 25	[2618 : 2609] 0.08 [2598 : 2594] 0.03 [2583 : 2562] 0.29 [2534 : 2493] 0.60	–15.53	+12.01
Ostrovnoy: 45°44′44.6″N, 44°0.6′53.0″E						
GrA-32895	sheep shoulder blade	k. 3, g. 39	3740 ± 35	[2201 : 2130] 0.70 [2086 : 2050] 0.30	–16.37	+12.30
IGAN-3234	female 20–30	k. 3, g. 39	4820 ± 70	[3693 : 3681] 0.1 [3664 : 3623] 0.33 [3604 : 3523] 0.61	–17.30	+16.08

Table 8 ^{14}C dates and stable isotope (^{13}C and ^{15}N) data for Eneolithic and Bronze Age cultures of the Eurasian steppes. *(Continued)*

Lab nr	Sample	Kurgan/ grave	^{14}C age (BP)	Calibrated range 1 σ (BC) [start: end] relative area	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Lola culture						
Mandjikiny-1: 45°42′32.65″N, 44°42′32.5″E						
IGAN-2278	male 35–40	k. 9, g. 1	3860 ± 40	[2457 : 2418] 0.24 [2408 : 2374] 0.22 [2368 : 2288] 0.54	–17.31	+15.03
IGAN-2227	wood	k. 9, g. 1	3850 ± 60	[2456 : 2418] 0.18 [2407 : 2375] 0.16 [2367 : 2364] 0.01 [2351 : 2274] 0.42 [2256 : 2208] 0.23	n/a	n/a
Temrta-I: 46°31′15.6″N, 43°36′18.5″E						
OxA-18387	*Bos taurus* teeth	k. 2, g. 8	3950 ± 30	[2563 : 2534] 0.20 [2493 : 2437] 0.49 [2420 : 2404] 0.11 [2378 : 2350] 0.18	–18.65	+9.72
OxA-18388	male 40–50	k. 2, g. 8	3945 ± 30	[2549 : 2538] 0.08 [2490 : 2449] 0.51 [2446 : 2438] 0.05 [2420 : 2404] 0.13 [2378 : 2350] 0.21	–18.47	+12.94

Paired samples of charcoal, animal bone, shell, and fish bone, and human bones from the Eastern Manych Catacomb graves, were dated. The results are shown in Table 8 as well. A few of these measurements (IGAN-2421, -3118; Bln-5529) were published earlier (Shishlina et al. 2007; van der Plicht et al. 2007).

Two terrestrial samples from Zunda-Tolga-1, kurgan 9, grave 1, are similar (sheep and charcoal). The situation for kurgan 10 is more complicated. The primary (3) and secondary (2) graves of 2 humans have the same archaeological association (funeral rite), so must date to the same period. However, the difference between the ^{14}C dates is 450 yr. The offset between the sheep from the primary grave and the human from the secondary grave is 400 yr. The stable isotope ratios for the human bones indicate the consumption of riverine food.

The offset between the human bone and *Fraxinus* wood from the Mandjikiny grave is 265 yr. The female from Temrta V, kurgan 1, grave 4, is older than the sheep from the same grave by 815 yr. The sheep shows high $\delta^{15}N$ values (+10.16‰) and heavy $\delta^{13}C$ (–16.06‰). We have a similar situation for the Chilgir grave. Here, the difference between the sheep and human bone is 250 yr.

Paired ^{14}C dating of Lola culture samples was also applied. The offset between the sheep bone and the human bone from the Ostrovnoy kurgan 3 is 1080 yr. This is unrealistically large and needs to be explained by further investigation. ^{14}C dates of wood and human bone samples obtained from Mandjikiny-1 are similar. This is also the case for dates obtained for *Bos taurus* teeth and human bone from Temrta I.

SUMMARY

A series of ^{14}C dates of human bone samples from the Eneolithic Khvalynsk cemetery and similar graves produced an age range of 5500–4700 cal BC (Chernykh et al. 2000; Telegin et al. 2001; Trifonov 2001). However, the ^{14}C dates of the Khvalynsk cemetery were measured on human bones and on river and sea shells (*Dentalium*, *Penctunculus*, *Unio* sp., *Viviparus*, and *Glycymeris*) (Agapov et al. 1990; Kirillova and Popov 2005). A large aquatic component in the diet of the local population is shown by the stable isotope values. Thus, the dates obtained for human bone may show an apparent age of 2–3 centuries due to the reservoir effect; they are older than terrestrial samples, which are not affected by this effect. After applying a reservoir effect correction for the steppe Eneolithic period, the time interval for the Caspian steppe Eneolithic population has now changed to 4300–3800 cal BC.

Comparison of ^{14}C dates of the Steppe Majkop culture ^{14}C dates with 24 ^{14}C dates of the Majkop culture of the North Caucasus (Trifonov 2000, 2004; Shishlina et al. 2003; Korenevsky 2004) suggests that the steppe dates obtained for human bones are close to the North Caucasus dates or older. According to Trifonov (2000, 2004), the age range for the Majkop culture of the North Caucasus is 3600–3000 BC. Unfortunately, stable isotope values for most of the ^{14}C-dated human bones are not available. Therefore, additional ^{14}C dating of bone animal items, deer teeth, and a textile fragment taken from the Majkop graves of the North Caucasus has been performed. The data are shown in Table 9.

Table 9 ^{14}C dates and stable isotopes ^{13}C,^{15}N for the Majkop culture of the North Caucasus.

Lab nr	Sample	Kurgan/ grave	^{14}C age (BP)	Calibrated range 1 σ (BC) [start: end] relative area	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Novosvobodnaya/Klady: 44°229′N, 40°449′E						
GrA-21336	Stick made of animal bone	k. 31, sacrifice place	4810 ± 70	[3660 : 2871] 1.0	–21.43	–
GrA- 24441	Deer teeth	k. 2	4270 ± 45	[2924 : 2871] 0.90 [2802 : 2779] 0.10	–22.10	+4.01
GrA-21334	Textile fragment (cotton, wool)	k. 2	4200 ± 60	[2893 : 2849] 0.27 [2841 : 2841] 0.004 [2813 : 2740] 0.47 [2730 : 2693] 0.21 [2688 : 2679] 0.04	–29.23	n/a
Inosemtsevo: 44°69′N, 43°39′E						
GrA-21372	Stick made of animal bone	primary grave	4630 ± 50	[3511 : 3425] 0.76 [3382 : 3355] 0.24	–20.87	–

For the Steppe Majkop culture, the ^{14}C dates obtained for items made of animal bone are 300–400 yr younger than ^{14}C dates of human bones, and are very close to ^{14}C data obtained for animal bone and charcoal (Guamsky Grot; Novosvobodnoye site) (Trifonov 2000). The ^{14}C dates of terrestrial samples obtained from Novosbobodnaya, kurgan 2 (deer teeth and textile), are similar. This shows that the ^{14}C date of the Majkop human bones turns out to be older due to the reservoir effect, caused by a riverine diet of the population. After applying a reservoir effect correction, we suggest a revision of the interval for the Steppe Majkop population to 3800–3000 cal BC.

The data set for the Yamnaya culture includes 35 ^{14}C dates of human bones, wood, charcoal, and vegetable mats, taken from 28 graves (Shishlina 2008). All ^{14}C dates of human bones show an apparent age offset and are older due to the reservoir effect, which is supported by the stable isotope values. An approximate reservoir correction for the regional Yamnaya culture would be 200 yr; thus, the time interval for this culture would now be 3000–2350 cal BC.

New ^{14}C data obtained for the Steppe North Caucasus culture also indicate an apparent age offset for human bone collagen. The ^{14}C age difference between the freshwater shell and animal bone is very large. The time interval of the Steppe North Caucasus culture is based on ^{14}C data of terrestrial samples and is approximately 2500–2300 cal BC. Starting from this period, which coincides with the beginning of the climate deterioration, we observe unusual stable isotope values for domesticated animals. Two samples of sheep bone show relatively high values of $\delta^{15}N$ (+13.06 and +16.03‰); 1 sheep bone shows an unusual $\delta^{13}C$ value (–16.52‰). The reason for such values could be the climate change and the long-distance migrations during which domesticated animals become stressed because of lack of pastures and water resources located in different environmental niches of the steppe and the North Caucasus. C_4 plants began to become dominant in some steppe areas. The $\delta^{13}C$ values indicate an animal diet of mixed C_3 and C_4 components. As for ancient Egypt, the stable isotope values of the faunal samples are vary due to the desert environment, causing high $\delta^{15}N$ values in faunal bone samples and as well as some C_4 input to the animal diet (Thompson et al. 2005).

All ^{14}C data of Early Catacomb human bones show a reservoir effect, and all samples that would not be subject to possible reservoir effects (e.g. animal bone and wood) yield the same ^{14}C age, within error. Paired data sets show a reservoir effect correction of 300–400 yr, resulting in a revised time interval of 2600–2350 cal BC. Some sheep bones show high values of $\delta^{15}N$, which could be caused by a change in pasture vegetation due to climatic deterioration.

A series of ^{14}C dates on human bones, wood, plant remains, and charcoal (at present, 66 samples) has been obtained for the Eastern Manych Catacomb culture. ^{14}C dates of human bones (Zunda-Tolga-1, 2, 3; and Mandjikiny) reveals a chronological problem. This culture appeared much earlier than the Early Catacomb culture population and even Yamnaya culture groups, around 2900/2800 BC. ^{14}C dates for some human bones are significantly older than those obtained for wood and plants, as well as for other human bones. Here, we observed a reservoir effect for human bone, yielding ^{14}C ages that are apparently too old. Also, a sheep bone shows an unusual $\delta^{13}C$ value (–15.53‰). Paleoecological data indicate the change of pasture vegetation and appearance of C_4 plants.

^{14}C dates on human bones obtained from the Lola culture also revealed the reservoir effect in human bone collagen, but sometimes the dates of terrestrial samples and human animal bones are similar. For this culture, however, some animal bones (sheep) show exceptional isotope values, i.e. very high $\delta^{15}N$ and very heavy $\delta^{13}C$.

We conclude that paleoecological, subsistence, and chronological records helped to identify climate changes. Climatic variations led to the change in vegetation pattern as well as in changes in food resources provided by steppe environmental conditions. Ethnobotanical data show that due to the aridization, C_4 plants appeared in vessel residues as well as in the soils buried under the kurgan embankment. They became a dietary component for humans as well as for animals. Stable isotope data also indicate that a large part of the everyday diet of all Eneolithic and Bronze Age groups consisted of aquatic products.

Parallel dates (Table 8) show that in almost all cases, the ^{14}C age for terrestrial samples (animal bone, textile, and wood) obtained from the same graves are similar. Samples of human bones, especially at times of ecological change, always show apparent ages. The size of the reservoir effects observed varies significantly, and can be centuries. It is evident that the chronology of Eneolithic and Bronze Age cultures of the Caspian steppes based on ^{14}C dates of human bones and shells, which are subject to reservoir effects, must be revised.

The range of $\delta^{13}C$ and $\delta^{15}N$ values for animals belonging to cultures whose existence coincided with a milder and cold climate (Eneolithic, Majkop, Yamnaya) differ in $\delta^{13}C$ and $\delta^{15}N$ values for humans of the same cultures. As soon as the aridization of the climate began, the situation changed. Many animal species of the Eneolithic, Majkop, Yamnaya, and some of the Catacomb cultures, have stable isotope ratios characteristic for herbivores. Some sheep (from the Early Catacomb, Steppe North Caucasus, Eastern Manych Catacomb, and Lola cultures) show different $\delta^{15}N$ and $\delta^{13}C$ values. Changes in isotope values in animal bones could be explained by ecological factors, i.e. changes of the vegetation and lack of water resources, but this must be verified. In the future, we intend to measure stable isotope values ($\delta^{15}N$ and $\delta^{13}C$) for modern and prehistoric plant materials from the studied area. New data of contemporary plants show high $\delta^{15}N$ values, which could be the caused by an arid climate. The variation of the isotope values for different animal individuals can be explained by the fact that those species belonged to different family groups of mobile pastoralists, i.e. different herds. They consumed fodder of different pastures located in different ecological environment**s**.

We have shown that combined analysis of ^{13}C, ^{15}N, and ^{14}C in bone, and paired dating of human bone and terrestrial materials can be used for dietary reconstruction. Reservoir corrections for ^{14}C dating of human bone can be derived. This is essential for a correct construction of chronologies for the Eneolithic and Bronze Age cultures of the Caspian steppe.

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