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Isotopic evidence of Bronze Age diet and subsistence practices in the southeastern Carpathian Bend area, Romania

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ABSTRACT

Human and faunal osteological material from the southeastern Carpathian Bend area, Romania, was analysed for $\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$ to reconstruct the dietary practices of the Middle Bronze Age Monteoru culture. As a secondary objective, the extent of intraskeletal variation in stable isotope values was investigated by comparing skeletal elements with differing collagen turnover rates. The intraskeletal isotope results revealed a pattern where cortical bone samples produced statistically lower $\delta^{13}C$ values compared to trabecular bone samples, highlighting the necessity for more systematic research to understand how stable isotopes are incorporated into bone collagen of various skeletal elements. Diet in the Monteoru culture was shown to be exclusively or predominantly terrestrial in origin with no detectable input of C_4 or marine resources. Differences in average $\delta^{13}C$ and $\delta^{15}N$ values between the two sites included in the study (representing distinct phases of the culture) suggest a shift in dietary preferences from a more meat-based economy to a more dairy- and plant-based economy. The dissimilar contribution of animal foods to overall diet between the two sites was supported by estimates generated by the Bayesian mixing model FRUITS, which also showed that in both sites plant foods accounted for most of the calories consumed. The faunal isotopic data contained a few outliers, suggestive of deliberate movement of livestock, either through long-distance herding or trade. A combined approach using juvenile bone collagen and incrementally sectioned tooth dentine from adults demonstrates that the duration of breastfeeding varied between individuals, but that there were no significant differences in weaning practices between survivors and non-survivors. Sulphur isotopes reflect a population that was relatively homogeneous in its isotopic composition and local in origin, except for the presence of two possible migrants. The $\delta^{13}C$ and $\delta^{15}N$ data from the Carpathian Bend are comparable to those from contemporaneous sites in coastal and inland Greece and Croatia, suggesting a broad uniformity in Bronze Age dietary practices across Southeast Europe. As the first major stable isotope study conducted on osteological material from the Romanian Sub-Carpathians, this thesis provides new insights into the lives of these communities, expands our knowledge of Bronze Age subsistence strategies in Southeast Europe, and establishes a foundation for further isotopic investigations in the region.

DECLARATION

I hereby declare that this thesis was composed by myself, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or professional qualification.

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Ülle Aguraiuja

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. Introduction

1.1. Background

The use of stable isotope analysis in archaeological research has a long and successful history dating back to the pioneering publications by Vogel & van der Merwe (1977) and Tauber (1981). It is based on the principle that the chemical composition of body tissues (such as bone) reflects the isotopic signature of the food consumed with a small isotopic enrichment, summed up by the expression 'you are what you eat (plus a few per mil)' (DeNiro & Epstein 1978). Unlike archaeozoological and archaeobotanical studies, which tend to provide general information on the availability and utilization of dietary resources in the population as a whole, stable isotope analysis allows for quantitative reconstruction of an individual's diet.

Most stable isotope analyses are performed on bone collagen, which has a slow turnover rate. It is generally assumed that collagen isotopically reflects an individual's average diet over a period of years before death, although this is believed to vary depending on the age of the individual and the skeletal element sampled (Hedges *et al.* 2007; Schroeder *et al.* 2009). For example, collagen turnover in trabecular bone (e.g. rib or vertebra) is thought to be more rapid than in cortical bone (e.g. femur shaft). These variations in tissue turnover rates have enabled the reconstruction of lifetime dietary histories by comparing skeletal elements with differing formation periods, e.g. teeth, shafts of long bones, and ribs (e.g. Sealy *et al.* 1995; Schroeder *et al.* 2009; Lamb *et al.* 2014). However, the basis of how carbon and nitrogen are incorporated into bone collagen of various skeletal elements with differing turnover rates, is not well documented.

This thesis originated from the present author's interest in the mechanisms behind human isotopic variability. To explore intraskeletal variation in stable isotope values, a well-preserved and large skeletal assemblage was required. A Bronze Age cemetery from the Monteoru culture, in Romania, provided a suitable collection for analysis. Despite belonging to one of the richest and best known Bronze Age cultures in the region, surprisingly little is known about the dietary practices of these communities.

The poor state of current knowledge has certainly been influenced by the fact that many important discoveries concerning the Monteoru culture were made more than 60 years ago, when analytical techniques were limited and little attention was given to biological remains. In addition, the use of stable isotope analysis is still relatively uncommon in East European archaeology, and the coverage uneven. As this time period and region are greatly underrepresented in palaeodietary studies, there was cause to broaden the scope of the dissertation to include a more detailed reconstruction of the dietary habits and subsistence practices of these people.

1.2. Scope of the study

Palaeodietary studies in Southeast Europe have focused mainly on Mesolithic and Early Neolithic communities along the Lower Danube ('Iron Gates') in Serbia and Romania (Bonsall *et al.* 1997, 2004; Cook *et al.* 2001; Borić *et al.* 2004) and the Dnieper Rapids in central Ukraine (Lillie & Richards 2000; Lillie & Jacobs 2006; Lillie *et al.* 2011), but equivalent research has also been undertaken on the Greek Bronze Age (Triantaphyllou *et al.* 2008; Petroutsa *et al.* 2009; Petroutsa & Manolis 2010; Vika 2011) and the Neolithic Linear Pottery culture in Hungary and along the Danubian corridor (Dürrwächter *et al.* 2006; Nehlich *et al.* 2009; Fraser *et al.* 2013; Hedges *et al.* 2013). Yet there is very little stable isotopic data available for the Bronze Age of the northern Balkans, an area that is dominated by the Carpathian Mountains. Along the eastern flank of this mountain chain is a zone of rolling hills and valleys known as the Sub-Carpathians. During the Bronze Age this region was populated by sedentary farmers who cultivated its fertile soils and exploited its abundant natural resources, including extensive woodlands and plentiful salt deposits.

The human and faunal osteological material that forms the basis of this study originates from two Monteoru culture sites, located near one another, but representing separate phases of the culture – the type site, Sărata Monteoru (ca. 1700–1500 cal BC), and Cârlomăneşti (ca. 2280–1800 cal BC). Both sites have produced evidence for extensive trade contacts across Central and Southeast Europe, yet show some differences in grave constructions that may reflect external influences (Motzoi-Chicideanu 1995, 2011). While the Monteoru culture is not thought to have been

characterised by a high degree of social stratification, the presence of numerous 'rich' graves containing exotic goods (of bronze, gold, glass paste and amber) provides a stark contrast to the generally poor funerary inventories of the majority of the graves (Bârzu 1989).

The osteologically well-preserved Sărata Monteoru cemetery includes many individuals of both sexes and all age-groups, which makes it possible to measure the extent of intraskeletal $\delta^{13}C$ and $\delta^{15}N$ variation in stable isotope values by comparing samples taken from the cortical bone (e.g. femur shaft) and trabecular bone (e.g. rib or vertebra) of the same individual. While this approach has been used to explore, among others, the life histories of mobile communities (e.g. African slaves in colonial regions, see Cox & Sealy 1997; Cox *et al.* 2001; Schroeder *et al.* 2009), the present author is unaware of any previous study that has conducted a systematic investigation of this scale on a prehistoric sedentary population. In addition to identifying potential intraskeletal differences in stable isotope values which could signify a change in diet (or location) during the lifetime of the individual, the present study adds to existing knowledge of how stable isotopes are incorporated into bone collagen of various skeletal elements.

Moreover, variations in stable isotope ratios between individuals of varying age, sex and social status (based on grave goods), and between the two sites, are explored. Attention is also given to childhood dietary practices, such as breastfeeding and weaning, as recorded in bone collagen $\delta^{13}C$ and $\delta^{15}N$ values, complemented by information concerning childhood health and stress obtained through osteological analysis. These data are supplemented by stable isotope ratios from incrementally sampled tooth (first molar) dentine from several adult individuals. Since dentine grows sequentially and does not remodel after deposition (Hillson 1996), this approach provides a direct comparison between early and later childhood diet, while also circumventing the selective mortality bias by including childhood dietary information from individuals who survived into adulthood.

In addition, human $\delta^{34}S$ analyses will provide information about the mobility of the Sărata Monteoru population. Although sulphur isotopes can also be used to distinguish between the consumption of terrestrial and aquatic resources, this was not considered a major objective of this dissertation, given the lack of evidence of freshwater resources in Monteoru culture subsistence, reflected in the absence of fish and shellfish remains and fishing equipment from the sites under study.

1.3. Thesis goals and structure

The primary aim of the thesis is to reconstruct the dietary practices of the Bronze Age Monteoru culture based on stable isotope analyses of animal and human bone (and teeth dentine) collagen from the cemeteries at Sărata Monteoru and Cârlomăneşti. Published data on archaeobotanical and archaeozoological studies conducted on related archaeological material will also be utilized in the discussion on subsistence strategies. In addition, a Bayesian mixing model is used to provide quantitative estimates of the contribution of various food groups and macronutrients to Monteoru diet. The results are reviewed in the wider context of the Bronze Age in Central and Southeast Europe, emphasizing regional similarities and differences – and the underlying causes. A secondary aim is the determination of the extent of intraskeletal isotopic variation among the Sărata Monteoru population. In addition to exploring variation between different skeletal elements, individuals of varying age, and C- and N-isotopes, this study investigates whether the choice of skeletal element sampled affects the conclusions made about the dietary habits of the population.

Other research questions include:

1) Is there any evidence of dietary change during the lifetime of the individual as reflected in intraskeletal isotopic measurements?
2) Are there any differences in $\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$ values between individuals of differing age, sex, social group (based on grave goods), and/or between sites?
3) What animal management strategies can be suggested for the Monteoru communities, based on isotopic variations among domesticated species and/or between the two sites?

4) What evidence do the osteological and isotopic records offer for childhood dietary practices such as breastfeeding and weaning?
5) Are there any potential migrants/outsiders within the studied population as determined by human $\delta^{34}S$ values?

The dissertation is divided into seven chapters, including the Introduction (Chapter 1) and Conclusions (Chapter 7).

Chapter 2 establishes the theoretical framework for this research, providing an overview of the distribution of stable C-, N- and S-isotopes in nature, and in skeletal tissues, covering issues such as isotope routing and bone turnover.

Chapter 3 reviews the history of palaeodietary research in Central and Southeast Europe, based on published isotopic, archaeozoological and archaeobotanical data, and provides a comparative framework for the subsequent discussion of the isotopic evidence from Bronze Age Romania.

Chapter 4 outlines the archaeological background of the osteological material that forms the basis of the stable isotope study. A general overview of the Romanian Bronze Age and the Monteoru culture is presented, including accounts of the two archaeological sites under investigation – Sărata Monteoru and Cârlomăneşti.

Chapter 5 provides details of the human and animal bone remains used for stable isotope analysis, including anthropological determinations and species identifications, together with a description of the various methodologies employed. The sampling procedures and subsequent treatment and analysis of bone and tooth samples are elaborated upon.

The results of the stable isotope analysis of Monteoru skeletal material are presented and discussed in Chapter 6, in relation to the main research questions, highlighting their implications for the study of human diet and subsistence in the Bronze Age of Southeast Europe and palaeodietary research in general.

The final chapter (Chapter 7) presents the conclusions of the study, and outlines possible directions for future research. The need for more isotopic and radiocarbon data from areas in and around the Sub-Carpathians is highlighted.

The number and range of stable isotope analyses conducted for this study was dictated by the time and financial constraints associated with a PhD project. As such, the present author acknowledges that the conclusions reached may be limited by the relatively modest number of analyses. Furthermore, owing to the generally poor state of stable isotope research in Eastern Europe, the lack of sufficient comparative data from the immediately adjacent areas prompted the inclusion of evidence from a much wider region (Central and Southeast Europe) in order to set the results of the Monteoru isotope analyses in a broader geographical context. While the wider territory covers a vast range of habitats and cultures, not all of which are directly comparable to the Romanian Sub-Carpathians, in the absence of more suitable comparative data, these must be considered as the closest possible alternatives.

Nevertheless, as the first study of its kind carried out on archaeological material from the Romanian Bronze Age, it stands as a substantial contribution to knowledge of dietary practices in Bronze Age Europe, while at the same time establishing the foundation for further stable isotope investigations within this specific region and period. Finally, the execution and completion of this PhD project has fulfilled the present author's personal objective to obtain the theoretical knowledge and the practical experience necessary to continue work as an independent researcher in the field of palaeodietary studies.

2. Stable isotope analysis for palaeodietary reconstruction

This chapter will cover the principles of applying stable isotope analysis in archaeological research and will provide an overview of the three main isotope systems (carbon, nitrogen and sulphur) included in the present dissertation. It will also address issues concerning the interpretation of stable isotope values from human skeletal material, such as isotope routing and inter- and intra-individual variation. In addition, the concept of bone turnover and its effect on stable isotope values will be discussed in some detail.

2.1. Stable isotope ecology

2.1.1. Background and definitions

Isotopes are atoms of the same element which share an equal number of protons and electrons but have a different number of neutrons. Hoefs (2009) provides a good introduction to the basics of stable isotopes. The term 'isotope' originates from the Greek '*isos*' ('equal') and '*topos*' ('place'), referring to the identical position that isotopes of the same element occupy in the periodic table. Depending on their rate of decay, isotopes can be classified as stable or unstable (radioactive). However, even the so-called stable isotopes experience decay, although the decay rate is too slow to have any significance over the archaeological time scale.

There are approximately 300 stable isotopes recognized across the elements, most important of these for palaeodietary research are carbon (C), nitrogen (N) and sulphur (S). Most elements have two or more isotopes, one of which is generally abundant in nature, whereas the others are present in only minuscule amounts (Hoefs 2009:1). For example, carbon has two stable isotopes, the common ^{12}C and the rarer ^{13}C. The relative abundances of these isotopes can vary greatly in nature and they are present in both organic and inorganic compounds, being absorbed or ingested from the environment or synthesized by organisms (Porcelli & Baskaran 2011:11; Schwarcz & Schoeninger 2011:725). This enables the use of stable isotopes as tracers since the

tissues of plants and animals reveal the environmental isotope ratios present during their lifetime (Schwarcz & Schoeninger 2011:725).

The chemical properties of an element are determined by the number and position of its electrons orbiting the nucleus, which results in all isotopes of a given element behaving similarly in chemical reactions (Schoeninger & Moore 1992:253). However, isotopes differ by their atomic mass (which is governed by the number of neutrons and protons), leading to differences in bonding and kinetics (Porcelli & Baskaran 2011:12). Molecules containing the heavier isotope (^{13}C in the case of carbon) form relatively stable chemical bonds and a greater amount of energy is needed to break these bonds; on the other hand, the bonds between lighter isotopes (^{12}C) are weaker and easier to break, i.e. lighter isotopes react more effectively in chemical reactions (and are consequently more abundant in nature) as compared to heavier isotopes (Schoeninger & Moore 1992:253).

For example, during the transfer of carbon from the ocean to the atmosphere, the bonds between ^{12}C molecules break and form more rapidly than bonds containing ^{13}C. This results in the $^{13}C/^{12}C$ ratio being lower in atmospheric CO_2 than in the ocean, i.e. there is relatively more ^{13}C than ^{12}C in ocean water (Schoeninger & Moore 1992:253). This process of mass-dependent effects causing heavier isotopes to make more permanent bonds and accumulate into one compound or substance (becoming thus enriched with a certain isotope) is also known as isotopic fractionation (Hoefs 2009:5).

The amount of fractionation is usually small and can only be measured through mass spectrometry. The studied material (e.g. collagen) is combusted to produce gases such as CO_2 and N_2, and the instrument detects the exact amount of each isotope in the gas (Peterson & Fry 1987:294; Schoeninger & Moore 1992:253). The analysed gas is then compared with an international standard value and expressed in delta notation, defined as $\delta = (R_{sample}/R_{standard} - 1) \times 1000‰$, where R is the rare to abundant isotope ratio, for example $^{13}C/^{12}C$ in the case of carbon. Traditionally, the standard for nitrogen is atmospheric N_2, while the standard for carbon is a marine limestone called PDB (PeeDee Belemnite) Carbonate, and that of sulphur is troilite (a rare sulphide mineral)

from the Canyon Diablo meteorite (referred to as CDT or Vienna-CDT) (Hoefs 2009). Delta (δ) values are expressed in per mil (‰); a positive δ value indicates that a sample is enriched compared to the standard, i.e. it has more heavy isotopes than the standard (Peterson & Fry 1987:294). Most organisms contain less ^{13}C than PDB, thus their $^{13}C/^{12}C$ ratios ($\delta^{13}C$) are usually negative (Schoeninger & Moore 1992:254).

2.1.2. Carbon

Almost 98.89% of all carbon in the world exists in the form of its lightest isotope, ^{12}C (West *et al.* 2006:409). The source of all terrestrial carbon is atmospheric CO_2, which has a modern $\delta^{13}C$ value of about -7‰. This figure has steadily changed since the introduction of fossil fuels; in prehistory it was likely closer to -6‰ (Marino & McElroy 1991:131). Atmospheric carbon and carbon in the ocean enters biological systems mainly through photosynthesis of green plants and chemosynthesis of deep sea organisms and bacteria (Schoeninger & Moore 1992:255). The lighter isotope ^{12}C enters organisms faster than the heavier ^{13}C, leaving the plant with more ^{12}C than in the atmosphere. Owing to this fractionation process, there is less ^{13}C in plants than in the atmosphere and thus $\delta^{13}C$ values of plants can be almost 20–30‰ lower (Schoeninger & Moore 1992:255).

Plant $\delta^{13}C$ values are determined by their specific photosynthetic pathway – there are three such pathways, referred to as the C_3, C_4 and CAM pathways (Schoeninger & Moore 1992:255). The great majority of temperate plants have C_3 photosynthesis, including all woody trees, and most common cereals, fruits and vegetables; C_3 plants predominate in higher latitudes, temperate climates and in forests and mountains (Ambrose & DeNiro 1986:396; Sealy 2001:270). These plants have $\delta^{13}C$ values between -20‰ and -34‰ (on average -26‰) (Schoeninger & Moore 1992:256). Closer to the equator, C_4 and CAM type plants dominate since they are better adapted to warm and arid conditions (Ambrose & DeNiro 1986:396). C_4 plants include several tropical grasses, including domesticated forms such as maize, millet and sugar cane. They have $\delta^{13}C$ values between -9‰ and -16‰ (on average -12‰) (Schoeninger & Moore 1992:256). CAM plants can alternate between C_3 and C_4 pathways and accordingly can present $\delta^{13}C$ values depending on the specific photosynthesis process

used. However, CAM plants include very few species that are used for human consumption (mainly succulents, e.g. cacti), thus they have little importance in discussions of palaeodiet (Schoeninger & Moore 1992:256; Sealy 2001:271).

Animals obtain their carbon differently from plants, i.e. not through their respiratory system (CO_2) but through ingested food and thus $\delta^{13}C$ values of herbivores are directly influenced by those of the plants they consume. Large herbivores that mainly eat C_3 plants have average $\delta^{13}C$ values around -21‰ (compared to the -26‰ characteristic for plants that make up their main food source) (Sealy 2001:271). Savannah animals eating tropical (C_4) grasses are known to produce average $\delta^{13}C$ values around -8‰ (Vogel 1978a; Ambrose & DeNiro 1986). The diet-to-collagen shift (the difference between the $\delta^{13}C$ value of a food source and the bone collagen of the organism that feeds on it) is usually reported as about -5‰ between plants and herbivores that consume them, although it is thought to be less pronounced in smaller animals (between -1‰ and -3‰) (DeNiro & Epstein 1978; Vogel 1978a; Ambrose & Norr 1993; Tieszen & Fagre 1993). In carnivorous animals, the $\delta^{13}C$ is usually very similar to their direct food source, although a small fractionation of up to +1‰ per trophic level has been documented (DeNiro & Epstein 1978; Schoeninger & DeNiro 1984; Lee-Thorp *et al.* 1989; Fizet *et al.* 1995; van Klinken *et al.* 2000; McCutchan *et al.* 2003).

Marine organisms constitute a separate system, because they utilize carbon from various sources and there is a constant exchange and fractionation of carbon ions and compounds in the ocean (Sealy 2001:271). Seagrasses have $\delta^{13}C$ values similar to C_4 plants, but plankton are isotopically closer to C_3 plants (Schoeninger & Moore 1992:256). Generally, the values become more homogeneous the higher up the marine food chain (Sealy 2001:271). In waters with moderate temperatures, the average $\delta^{13}C$ for marine fish is -12‰ (Schoeninger & DeNiro 1984:632). Freshwater fish and their consumers can have more varied values and are generally more negative than marine fish, ranging in their $\delta^{13}C$ from -12‰ to -26‰ (Schoeninger & DeNiro 1984:632). Hedges & Reynard (2007) concluded that due to the wide potential overlap with both

marine and terrestrial ecosystems, there is presently no independent isotopic measure of freshwater resource consumption.

Carbon isotope ratios in organisms can sometimes be affected by the canopy effect – a phenomenon where foliage closer to the ground level in closed forests is more depleted in ^{13}C than foliage exposed to the free atmosphere either at the top of the canopy or in open clearings (Vogel 1978b; van der Merwe & Medina 1991). In addition to a vertical gradient, the canopy effect has also been shown to be present as a horizontal gradient evidenced in decreasing $\delta^{13}C$ values for forest clearing plants at the edge of the forest (-33.2‰) compared to those in the centre of the field (-28.5‰) (van der Merwe & Medina 1991:256). The canopy effect is believed to be caused either by the decomposition of leaf litter on the forest floor, which results in the photosynthetic recycling of ^{13}C depleted CO_2 in plants, or because of insufficient sunlight exposure below the canopy (Vogel 1978b; Ehleringer *et al.* 1987; van der Merwe & Medina 1991), although France (1996) concedes that the isotopic effect in the tissues of forest dwellers would be the same regardless of the exact cause.

All dense forests are believed to experience the canopy effect but forests with higher CO_2 production (such as rainforests) have more negative values across the scale (van der Merwe & Medina 1991:255). For example, Amazonian forests can have $\delta^{13}C$ values as low as -37‰ in ground litter (van der Merwe & Medina 1991; Medina & Minchin 1980). However, in temperate Bavarian forests Vogel (1978b) found the $\delta^{13}C$ values in the upper canopy and ground fresh litter to be -28‰, while forest floor litter was only -31.5‰. In Canadian boreal forests the ground flora was about 2‰ enriched compared to the upper canopy vegetation, leading France (1996) to conclude that in boreal and temperate forests the canopy effect may not be significant enough to adequately distinguish between open and closed habitats.

In addition to the canopy effect, plant $\delta^{13}C$ values seem to be affected by environmental conditions such as water availability and temperature. Modern eastern Mediterranean plants showed an increase in their $\delta^{13}C$ values during the dry season as a response to drought stress (Hartman & Danin 2010). Van Klinken and colleagues

also demonstrated that plant $\delta^{13}C$ values in Holocene Europe became more positive with decreasing latitude, following a north-west to south-east gradient (van Klinken *et al.* 1994, 2000). The difference between northern and southern data was on average 2‰ and the trend was shown to correlate with regional climatic variations such as average July temperature and hours of sunshine. Climatic influences on stable isotope ratios should be taken into account when interpreting data, since these will be carried over to animal and human consumers and may obscure the actual dietary signal.

2.1.3. Nitrogen

Like carbon, nitrogen also exists in the form of two stable isotopes – ^{15}N and ^{14}N. The lighter isotope is also the most abundant one, accounting for 99.63% of the world's nitrogen (West *et al.* 2006:409). The majority of Earth's nitrogen is bound as N_2 gas in the atmosphere or dissolved into the oceans (Hoefs 2009:54). It enters biological organisms mainly through nitrates in the soil or the activity of microorganisms (Schoeninger & Moore 1992:256; Schwarcz & Schoeninger 2011:730). Plant $^{15}N/^{14}N$ ratios ($\delta^{15}N$) can be very varied, depending on the specific environment and the source of the nitrogen, but generally fall between -2‰ and +2‰ for most terrestrial plants that obtain nitrogen directly from the atmosphere (Peterson & Fry 1987:306; Schoeninger & Moore 1992:256). Legumes are known to have slightly lower $\delta^{15}N$ values since they obtain their nitrogen through nitrogen-fixing bacteria (Ambrose & DeNiro 1986:396; Schwarcz & Schoeninger 2011:730).

With every trophic level up the food chain there is a stepwise enrichment of ^{15}N in consumer tissues relative to their diet (Schoeninger & DeNiro 1984:631). This enrichment occurs during metabolism and leads to a more positive $^{15}N/^{14}N$ ratio compared to the food source (Peterson & Fry 1987:305; Schoeninger & Moore 1992:258). The process is the same for plants and herbivores, herbivores and carnivores, and humans and their respective food source, resulting in organisms at the top of the food chain having the highest $\delta^{15}N$ values, up to +20‰ (Schoeninger & DeNiro 1984). The same applies to breastfed infants, who 'feed' on their mothers (Fuller *et al.* 2006).

Ecological studies and controlled feeding experiments on various animals have shown that the enrichment per trophic level ($\Delta^{15}N_{diet–body}$) for collagen is between +1‰ and +6‰, traditionally set as +3‰ or +4‰ on average (DeNiro & Epstein 1981; Minagawa & Wada 1984; Schoeninger & DeNiro 1984; Ambrose & DeNiro 1986; McCutchan *et al.* 2003; Sponheimer *et al.* 2003). Some authors (e.g. Sponheimer *et al.* 2003) have suggested that high protein diets (such as those in carnivores) result in larger ^{15}N enrichments (hence higher $\delta^{15}N$ values), whereas others (e.g. Robbins *et al.* 2005) have claimed the opposite.

Marine organisms comprise a separate nitrogen cycle and thus cannot be directly compared with the terrestrial food chain. Fish and their consumers can have significantly higher $\delta^{15}N$ values than purely terrestrial feeders since their original nitrogen source is different but also because of the greater number of trophic levels in the marine food chain (Schoeninger & DeNiro 1984:631; Sealy 2001:272; Schwarcz & Schoeninger 2011:732). Without knowing whether the diet has a predominantly marine or terrestrial origin, it may be impossible to distinguish between low and high trophic level resources. For example, lower trophic level marine organisms, such as molluscs, can be isotopically indistinguishable from terrestrial animals in their $\delta^{15}N$ values (Schoeninger & DeNiro 1984:626; Sealy *et al.* 1987:2709).

As with carbon, environmental conditions also affect $\delta^{15}N$ values, which tend to increase with lower moisture (Hedges *et al.* 2004:961). A trend between $\delta^{15}N$ values of African animals and annual rainfall is reflected in herbivorous animals from arid regions having significantly higher $\delta^{15}N$ values (+10‰ or more) than those from more humid ones, even among representatives of the same species (e.g. Heaton *et al.* 1986; Sealy *et al.* 1987). Fizet *et al.* (1995) documented elevated nitrogen values for various Late Pleistocene mammals (both herbivores and carnivores) from Marillac cave, France. All the animals with high $\delta^{15}N$ originated from one layer, which was associated with a colder and more arid phase. However, there has been much debate about whether the high $\delta^{15}N$ values were caused by higher soil (and/or plant) $\delta^{15}N$ values due to environmental conditions or by an individual metabolic response to water stress.

Soil nitrogen fixation is believed to be restricted in warm and arid conditions (Ambrose & DeNiro 1986:402; Ambrose 1991:296), and Heaton (1987) associated high ^{15}N contents of plants in saline and arid environments with the influences of these conditions on the isotopic composition of nitrogen in the soil (i.e. not in plants directly). A general geographical trend in global soil $\delta^{15}N$ values has even been recognized, which seem to decrease with increasing annual precipitation and decreasing mean annual temperature (Amundson *et al.* 2003).

On the other hand, Sealy *et al.* (1987) documented high $\delta^{15}N$ values in animals from areas with very low rainfall, even though the results were not mirrored in plant isotope values from the same regions. The authors suggested that high nitrogen values must therefore be caused by metabolic processes within the animals themselves – water stress (dehydration) leads to increased concentration of ^{14}N enriched urea in urine in order to reduce the loss of valuable water as urine. Ambrose & DeNiro (1986) also showed that drought-tolerant (i.e. more accustomed to water stress) African animals had $\delta^{15}N$ values on average +2‰ to +4‰ higher than obligate drinkers from the same environment. However, this theory has not been substantiated by more recent research.

For example, Ambrose (2000) found no relationship between water or heat stress and $\delta^{15}N$ values in a controlled feeding study of rats. When Hartman & Danin (2010) investigated plant isotope values from the arid eastern Mediterranean, they concluded that $\delta^{15}N$ values correlate well with overall water availability in the soil, but showed no change during seasonal drought periods. A similar conclusion was reached by Hartman (2011) who examined the horn keratin of desert adapted bovids. He found that rather than being determined by individual heat and water stress, the high $\delta^{15}N$ values of herbivore tissues were likely caused by the denitrification process in the soil that directly affected the isotopic values of consumed plants. Even though the results of these experiments may not be directly applicable to humans, it seems that the main factor responsible for high plant and herbivore $\delta^{15}N$ values in arid conditions is the soil itself.

For humans, research conducted by Fuller *et al.* (2004, 2005) demonstrated that the nitrogen balance in the body does indeed affect individual tissue $\delta^{15}N$ values, though not because of water conservation. In healthy adults there is a nitrogen equilibrium, where the same amount of nitrogen is ingested and excreted (Katzenberg & Lovell 1999:321). On occasions where no new nitrogen is being assimilated by the body (i.e. a negative nitrogen balance, such as occurs during fasting, starvation or in protein-deficient diets), nitrogen has to be recycled from available tissues (Fuller *et al.* 2005). Since the re-used nitrogen has already been enriched in ^{15}N relative to diet, individuals under nutritional stress have significantly increased $\delta^{15}N$ values. However, during positive nitrogen balance (e.g. growth or pregnancy) $\delta^{15}N$ values decrease since the production of new tissues leads to more nitrogen being ingested than excreted (Katzenberg & Lovell 1999; Fuller *et al.* 2004).

2.1.4. Sulphur

Sulphur has four stable isotopes – ^{32}S, ^{33}S, ^{34}S and ^{36}S, the lightest of them being the most abundant in nature (94.93%) (Hoefs 2009:71). Sulphur is leached from the bedrock into ground and stream water and incorporated into tissues of plants, although sulphur isotope ratios can also be influenced by atmospheric sulphur deposition and microbial processes in the soil (Krouse *et al.* 1984:322; Richards *et al.* 2003:37; Nehlich *et al.* 2011:4965). The sulphur isotopic composition of plants ranges widely due to the many chemical forms in which the element can exist in the soil, but also because many plants take up sulphur from a combination of sources, e.g. some trees obtain it from the air via needles or leaves as well from the soil via roots (Krouse *et al.* 1984:322; Trust & Fry 1992:1108). Generally, plant $\delta^{34}S$ ($^{34}S/^{32}S$) values are similar to local soil values (a small fractionation of -1‰ has been reported between plants and their sulphate source), ranging between -22‰ to +22‰ (Krouse *et al.* 1984; Peterson & Fry 1987; Peterson & Howarth 1987; Trust & Fry 1992).

In fauna, sulphur is obtained through the consumption of plant or animal protein and will reflect diet $\delta^{34}S$ values, with a small trophic level shift (Peterson & Howarth 1987; Richards *et al.* 2003). The size of this shift can vary – McCutchan *et al.* (2003) found $\Delta\delta^{34}S_{diet-body}$ to mostly lie between -2.5‰ and +2.5‰, although the average amount of

fractionation was shown to be only +0.5‰. The authors also demonstrated that the trophic shift for $\delta^{34}S$ was influenced by the protein content of the diet, i.e. the higher the protein content, the larger the shift (McCutchan *et al.* 2003:381). Human and animal bone collagen $\delta^{34}S$ values from Holocene Europe have usually been reported to be around 0‰ to +22‰ (Richards *et al.* 2001; Privat *et al.* 2007; Fornander *et al.* 2008; Vika 2009; Nehlich *et al.* 2010).

Sulphate in the ocean has a rather uniform value, around +21‰ (Rees *et al*. 1978). Because of its relative consistency compared to terrestrial sulphate sources, the consumption of marine resources has become quite straightforward to identify based on consumer $\delta^{34}S$ values. For example, Leakey *et al.* (2008) were able to successfully differentiate between coastal and estuarine fish in the U.K. However, $\delta^{34}S$ values characteristic of ocean sulphate may not always reflect marine consumption, but rather the proximity of the food source to the ocean (Richards *et al.* 2003:39). This phenomenon, known as the sea-spray effect, can cause coastal soil $\delta^{34}S$ values to be similar to those of the ocean, and can extend from a few kilometres inland to covering whole islands (Wadleigh *et al.* 1994).

Compared to the marine system, freshwater fish are generally thought to have lower $\delta^{34}S$ values, around -5‰ to +10‰, but have been reported from anywhere between -20‰ and +20‰ (Ivanov 1983; Peterson & Fry 1987; Nehlich *et al.* 2010, 2011). This implies a significant degree of potential overlap in $\delta^{34}S$ values of freshwater and terrestrial resources, although the exact values of the respective ecosystems are dependent on the local geology and hydrology at any given site (Privat *et al.* 2007:1202). Indeed, Hu *et al.* (2009) and Nehlich *et al.* (2010) witnessed significant differences between $\delta^{34}S$ values of local fish and herbivores, and were able to distinguish their consumption in human diet, whereas Privat *et al.* (2007), after discovering that the local freshwater and terrestrial ranges completely overlapped, concluded that $\delta^{34}S$ values could not be used as a reliable indicator of freshwater resource consumption.

2.2. Skeletal tissues and isotope routing

Stable isotope analyses can be performed on virtually every biological tissue, but the focus of this chapter will now shift exclusively to skeletal tissue (bones and teeth) as the best-preserved in the archaeological record. Bone is a mineralized connective tissue, a composite material consisting of an organic and an inorganic (mineral) part. The organic part accounts for about 30% of the dry-weight of bone, which also includes water (5–10%) and non-collagenous proteins (about 2%) (Klepinger 1984:75). Much of the organic component is collagen, a long fibrous protein, which is formed of various amino acids (Krueger & Sullivan 1984:210). Collagen fibres deposited in parallel bundles make up the cellular organic matrix of bone and provide nucleation centres for initiating mineralization of new bone (Martin & Armelagos 1985:534–535). The mineral portion consists of small crystals of calcium hydroxyapatite embedded in the collagen fibre matrix and this comprises most of the dry-weight of bone (about 70%) (Aitken 1984:6; Mays 2010:1).

Unlike bones, teeth are considered metabolically inert. Dental tissues do not experience turnover because they lack a blood supply and cannot reshape themselves once formed nor repair themselves after disease or injury (Mays 2010:11). In regard to the research focus of this thesis, this also means that teeth retain the (isotopic) composition they obtained during initial growth. Teeth consist of three hard tissues – enamel, dentine and cementum. Mays (2010) gives a good overview of all of them. The tissue covering the teeth – enamel – is mostly inorganic matter, with a chemical composition similar to bone mineral (hydroxyapatite). Cementum covers the roots of the teeth and has a similar composition to enamel, although it continues to be formed throughout life, increasing in thickness with age. Dentine consists of about 75% inorganic materials (mainly hydroxyapatite) along with an organic portion (mainly collagen). Despite having an organic component, tooth dentine does not turn over during life (Richards *et al.* 2002:209). However, small quantities of secondary and tertiary dentine are added later in life, thus creating a potentially mixed signal of both childhood and adult diet (Jørkov *et al.* 2009:199).

There is a noteworthy difference between the mineral and organic components in terms of how the carbon isotopic composition mirrors the individual's diet. It has been well established that $\delta^{13}C$ values of bone (and teeth dentine) collagen reflect mainly the protein portion of the diet (with approximately one quarter contribution from carbohydrates and lipids) whereas those of the mineral phase (bone apatite and teeth enamel) reflect the whole diet (Krueger & Sullivan 1984; Lee-Thorp *et al.* 1989; Ambrose & Norr 1993; Tieszen & Fagre 1993; Jim *et al.* 2006; Fernandes *et al.* 2012). Since nitrogen is mainly ingested in the form of protein, $\delta^{15}N$ values in collagen only reflect the protein component of the diet (van Klinken *et al.* 2000; Hedges *et al.* 2004); the same applies to $\delta^{34}S$ (Hu *et al.* 2009; Nehlich *et al.* 2011).

The fact that stable isotope ratios in collagen mainly reflect the origin of dietary protein can lead to the under-representation of the non-protein components (carbohydrates and lipids) of diet (Ambrose & Norr 1993; Tieszen & Fagre 1993). Another issue is related to differences between animal and plant protein. For example, compared to animal flesh, plants are generally low in protein, suggesting that large amounts of plants need to be consumed to have a significant effect on the isotope ratios, and vice versa – even a small proportion of animal protein in diet will have a strong effect on consumer tissue isotope values (van Klinken *et al.* 2000:51). This will not be a major concern if herbivores and humans consume the same plants, but may complicate the interpretation of human isotopic data on occasions where plant and animal protein have different isotopic compositions.

2.3. Intraskeletal variation in bone stable isotope ratios

Isotope analysis of human skeletal remains is commonly conducted on a single piece of bone, often from the rib or extracted from the middle of the femur. In rarer cases, two or more locations of the same skeleton are sampled. In such cases, intraskeletal variations in stable isotope ratios have sometimes been documented and are thought to be caused by differences in the bone turnover rate of the skeleton. By understanding how the bone turnover rate can affect stable isotope ratios, a more detailed reconstruction of past diets may be achieved.

2.3.1. Basics of bone remodelling

Bone is a living tissue existing in a state of continuous renewal. During childhood, the skeleton achieves its shape and size through the removal of bone from one site and deposition at another – a process called modelling (Manolagos 2000:116). In a growing individual the deposition of new bone is always slightly greater than the removal of old bone (Frost 1964:326; Manolagos 2000:116). When skeletal growth is complete, this process of modelling continues in adults in a similar manner but with some fundamental differences.

In adulthood, bone is still being removed and deposited but both events happen at the same location (Manolagos 2000:116). The purpose of adult modelling or simply 'remodelling' is not to change the shape or size of the bone, but to maintain the structural integrity of the skeleton (Aitken 1984:9). This allows the bone to repair itself after a disease or injury and to adapt its form according to mechanical forces such as weight bearing or muscular tension (Mays 2010:5). This periodic replacement of old bone with new is responsible for the complete regeneration of the adult skeleton occurring over a somewhat vague period of time, the length of which will be discussed in more detail below.

Remodelling is executed through three basic types of bone cells. Osteoclasts are responsible for bone resorption, osteoblasts for bone formation, and osteocytes for the maintenance of bone (Mays 2010:7). The process of bone remodelling starts on an existing bone surface with the necessary cells arising from marrow tissue adjacent to bone (but not from the bone itself) (Parfitt 1994:274). Osteoclasts are the first cells to arrive at any given location and start bone resorption (Parfitt 1994:274). They adhere to bone and remove it by acidification (which liberates the mineral phase) and proteolytic digestion (a process whereby proteins are broken down into individual amino acids resulting in the destruction of the organic matrix) (Aitken 1984:8; Manolagos 2000:116).

After resorption has ceased, osteoblasts follow and commence new bone deposition at the same location (Parfitt 1994:274). They cover the area and begin secreting osteoid (which includes several specific proteins and comprises the organic matrix of the new bone) that eventually mineralizes into mature bone (Aitken 1984:9; Manolagos 2000:116). During the process of mineralization the organic phase stays the same while the amount of mineral per bone packet increases (Goldman *et al.* 2003:244). Packets of new bone calcify over time, so that the most recently deposited bone will be less mineralized than bone deposited months or years earlier (Goldman *et al.* 2003:244). This means that bone areas with a different state of mineralization or age exist together at any given time (Bell *et al.* 2001:67).

2.3.2. Estimating bone turnover rates

Few precise data are available on bone turnover rates, mostly due to difficulties associated with studying it in living individuals. Controlled diet-switch experiments have been used to observe how the isotopic composition of body tissues changes over time after a shift to an isotopically distinct diet (e.g. Tieszen *et al.* 1983; Hobson & Clark 1992; Sponheimer *et al.* 2006). However, these experiments are conducted on animals (mostly small ones) and thus are not directly applicable to humans owing to differences in size, morphology and physiology.

Another method includes ingesting organic labelled tracers which are then synthesized into newly forming bone (Frost *et al.* 1960). The bone material is later retrieved either during biopsy, amputation or autopsy, depending on the specific case, which allows the amount of bone formed since the deposition of the tracer to be measured (Kimmel & Jee 1982:32). Traditionally, tetracycline, a type of antibiotic, has been used to assess the formation rate of the mineral portion of bone (e.g. Frost *et al.* 1960; Marshall 1973; Kimmel & Jee 1982; Eriksen 1986), whereas isotopically labelled amino acids have enabled the direct study of organic (collagen) synthesis rates (e.g. Scrimgeour *et al.* 1993; Bailey *et al.* 1999; Babraj *et al.* 2002, 2005). However, since this method requires a piece of bone from a living (or a recently deceased) person, there are strict limits to the information that can be gathered by this technique.

Perhaps the most relevant method for estimating bone turnover rates – at least regarding intraskeletal stable isotope values – is bomb radiocarbon, since it can offer data about element-specific turnover on a temporally much greater scale (spanning the whole lifetime of an individual). Due to above ground nuclear testing, amounts of ^{14}C in atmospheric CO_2 in the Northern Hemisphere increased dramatically, with a significant spike between 1955 and 1963, reaching levels almost twice that of 1890 (Libby *et al.* 1964:1170; Hodgins 2009:vii). The higher-than-normal levels of ^{14}C assimilated in plant material through photosynthesis were subsequently incorporated into human tissues through diet (Stenhouse & Baxter 1979:324). Since 1964, atmospheric radiocarbon levels have fallen slowly, but all living organisms alive during the middle of the last century have traces of this bomb radiocarbon in their tissues (Hodgins 2009:x).

The first bomb-carbon studies done by Libby *et al.* (1964) and Stenhouse & Baxter (1977, 1979) focused on determining the amount of human radiation burden caused by the fallout from the nuclear bomb testing. In modern forensics, this method is often used to determine the age at death of individuals who lived and/or died during the bomb-peak period or, conversely, to determine tissue turnover rates from individuals with known dates of birth and death (e.g. Geyh 2001; Wild *et al.* 2000; Ubelaker *et al.* 2006; Hedges *et al.* 2007; Hodgins 2009; Ubelaker & Parra 2011). The extent to which the peak levels of the bomb-pulse are still visible in bone collagen today can be used to determine the degree of bone turnover (Hedges *et al.* 2007:808).

2.3.3. Bone turnover rate in the human skeleton

In stable isotope studies it is generally assumed that the overall bone collagen turnover rate is equivalent to the elemental (e.g. carbon) turnover rate in collagen (Hedges *et al.* 2007:809). Incorporation rates of $\delta^{13}C$ and $\delta^{15}N$ into the bone protein pool have been shown to be identical by Scrimgeour *et al.* (1993), so it is likely that the same also applies to S-isotopes. In terms of bone mineral versus bone collagen, some researchers (e.g. Harkness & Walton 1972; Tsutaya & Yoneda 2013) have argued that the bone mineralization process is slower than the synthesis of the organic matrix, whereas others have promoted the opposite view that collagen has a slower turnover rate than

apatite (Hodgins 2009). Since bone is a composite material and the turnover of the organic and the inorganic components is inevitably linked, it seems probable that there are no *significant* differences between collagen and apatite turnover rates, as was also suggested by Hedges *et al.* (2007).

Concerning the whole skeleton, the predominant practice has been to set the average turnover rate of an adult individual as 10% per year, which implies that the isotopic composition of the whole skeleton would be completely renewed in about 10 years (e.g. Libby *et al.* 1964; Frost 1969; Parfitt 1994; Manolagos 2000; Martin & Rodan 2001). However, other authors (e.g. Bryant & Loutit 1964; Stenhouse & Baxter 1979; Wild *et al.* 2000; Hedges *et al.* 2007) suggest a much longer period for complete replacement, at least 20–30 years. Nevertheless, the average turnover rate for the whole skeleton may be a gross approximation, as it has been documented that the turnover rate of specific skeletal elements is dependent on their type, function and location.

In terms of structural composition, bone can be divided into two categories: cortical (also called 'compact' or 'dense') and trabecular ('cancellous' or 'spongy') bone. Cortical bone roughly comprises the outer layer of all bones and is thickest in the shafts of long bones (diaphyses) (Mays 2010:2–4). Trabecular bone, which has a honeycomb-like structure, can be found within the ends of long bones (epiphyses) and in the interior of flat and irregular bones such as ribs, vertebrae and the pelvis. In the growing skeleton, trabecular bone is the main site of red blood cell production and its large surface area facilitates the exchange of minerals to and from bone (Aitken 1984:6; Mays 2010:2–4). Cortical and trabecular bone are quite similar in their chemical composition (Aitken 1984:6), although the reason for remodelling varies for each. In cortical bone, which acts mainly as a load-bearing structure, the repair of fatigue damage is the most important result of remodelling; in trabecular bone remodelling is necessary for maintaining the calcium balance in the body (Parfitt 1994).

Most authors (e.g. Bauer 1964; Aitken 1984; Manolagos & Jilka 1995; Manolagos 2000; Schroeder *et al.* 2009) agree that bone turnover is more rapid in trabecular bone than in cortical bone, and this is believed to be due to the greater surface area available for metabolic activity in the former (Epker & Frost 1965:133; Aitken 1984:10; Parfitt 2002:808). Various estimates have set the ratio of the turnover rate of cortical and trabecular bone in an adult human to be anywhere between 3 and 10 (Bauer 1964; Bryant & Loutit 1964; Rivera 1965; Marshall 1973; Snyder 1975). The annual turnover rate for cortical bone has been reported from 1% to 5% (with a minimum replacement period of 20 years), and for trabecular bone from 8% to 25% (with a minimum replacement period of a few years) (Bryant & Loutit 1964; Rivera 1965; Marshall 1973; Snyder 1975; Manolagos & Jilka 1995; Manolagos 2000; Hedges *et al.* 2007).

Ubelaker *et al.* (2006) and Ubelaker & Parra (2011) used the bomb radiocarbon method to compare the known age at death of individuals to the ^{14}C content of their cortical (femur shaft) and trabecular (vertebra) bone. In three adults the cortical bone radiocarbon levels lagged atmospheric ^{14}C levels at the time of death by at least 11 years, while trabecular bone lag was minimal, only about a couple of years (Ubelaker & Parra 2011:105). Trabecular bone collagen from a woman who had died in 1959 contained significant amounts of bomb-carbon, yet her cortical bone had almost no trace of post-1954 carbon (Ubelaker *et al.* 2006:486).

Turnover is also believed to be slightly faster in central (axial) bones than in peripheral bones, and this applies to both trabecular and cortical areas (Parfitt 2001:435, 2002:808). Some researchers have even argued that skeletal elements that receive more loading (the primary weight bearing bones such as the femur and tibia) have higher turnover rates due to accumulating microdamage that triggers remodelling (Cho *et al.* 2006; Peck & Stout 2007; Cho & Stout 2011), yet Li & Klein (1990) believed the rate of bone turnover is most likely independent of whether the bone is weight bearing or not.

Several authors (e.g. Balena *et al.* 1992; Pfeiffer *et al.* 1995; Hedges *et al.* 2007) agreed that endosteal (inner) bone turnover is much faster than periosteal (outer), suggesting that both sides will have formed at relatively different ages. In terms of left *vs* right side of the skeleton, no noticeable differences in either turnover rates or stable isotope values have been documented between the two (e.g. Cho *et al.* 2006:215), indicating that there is no difference between which side is sampled for analysis.

In terms of specific skeletal elements, the highest turnover rates for the whole body are reported for vertebrae (especially lumbar), followed by the ilium (trabecular regions) and ribs (Bryant & Loutit 1964:464; Frost 1969:217; Parfitt 2002:808). Even though femur shafts are typically sampled for stable isotope analysis, several studies have demonstrated that tibial shafts have slower turnover rates than femoral shafts (e.g. Bryant & Loutit 1964; Marshall 1973; Snyder 1975). The calvarium (skull cap) is also thought to have a relatively slow turnover rate, since it is composed of very thick and dense cortical bone (Bryant & Loutit 1964:464; Sillen & Kavanagh 1982:174; Li & Klein 1990:99). According to Jørkov *et al.* (2009), the petrous part of the temporal bone in the skull, one of the sturdiest bones in the human skeleton, does not undergo any further remodelling after the age of 2 years, implying an extremely long turnover period.

2.3.4. Age-related variations in bone turnover rates

The previous section focused on bone turnover rates in adult humans, yet in a growing skeleton the situation is more complicated. In growing individuals, the amount of somatic growth must be taken into account when looking at elemental incorporation rates, since this speeds up the turnover rate (Bosley *et al.* 2002:234). Growth is a determining factor influencing the rate of new protein incorporation from diet (Martínez del Rio *et al.* 2009:94) and collagen synthesis is shown to be significantly higher in actively growing animals than in those that have stopped growing (Sukumar & Ramesh 1992:538).

Bone turnover is highest during infancy. Data from Ubelaker *et al.* (2006) imply a bone collagen turnover rate close to 100%/yr for newborns and infants, based on bomb

radiocarbon dating of human remains. Bryant & Loutit (1964) estimated a rate of bone mineral replacement of 100–200% during the first year of life, indicating that bone and diet are in equilibrium and any changes to the composition of bone would be evident in a matter of weeks. Richards *et al.* (2002) discovered that $\delta^{13}C$ and $\delta^{15}N$ values of newborns increase significantly at about 40 weeks after birth, suggesting that 40 weeks (280 days/9 months) is enough time for the collagen in ribs to equilibrate to the new dietary signal obtained from breastfeeding. A model constructed by Tsutaya & Yoneda (2013), that calculated bone collagen turnover rates from trabecular bones of children with a known age at death, indicated that a 31-week period (from birth) is necessary for post-birth dietary $\delta^{15}N$ signal to be fully reflected in (trabecular) bone collagen.

As age increases, bone turnover rates start to slow down. The model by Tsutaya & Yoneda (2013) estimated that annual trabecular bone collagen turnover rates fall from 150% at birth to 100% after the age of 2, to 50% at the age of 7, to 25% at the age of 16 and to 10–12% at the age of 20. During childhood, the differences between turnover rates of cortical and trabecular bone seem to be smaller, compared to adults. For example, Ubelaker & Parra (2011) used the bomb radiocarbon method to compare the known age at death of individuals to the ^{14}C content of their cortical (femur shaft) and trabecular (vertebra) bone and found that in a 16-year-old individual, trabecular and cortical bone had similar radiocarbon levels which displayed only a minimal lag (about a couple of years) from the atmospheric ^{14}C at time of death, indicating that both bone types have relatively fast turnover during adolescence.

While skeletal growth is still ongoing after puberty, bone collagen turnover rates decrease in correlation with the decelerating growth rate (Szulc *et al.* 2000:286). When Hedges *et al.* (2007) measured the ^{14}C content of human femoral mid-shaft collagen, they predicted a turnover rate of 10–30%/yr at age 10–15, but also claimed that male collagen turnover rate is much greater than for females during adolescence (up to two times). They also admitted that collagen turnover rates in adolescents may be dependent on the geometrical growth pattern of the bone and influenced by differences in growth rates between girls and boys.

Pritchett (1991) suggested that areas with more active growth reflect a more recent collagen pool than areas with slower growth. He identified the ends of long bones as areas with active growth and differentiated between the proximal and distal ends of long bones since they grow at different rates. Several other authors (e.g. Schurr 1997, 1998; Richards *et al.* 1998; Waters-Rist *et al.* 2011) have used this approach to detect childhood dietary change from stable isotope values. Schurr (1997, 1998), who studied weaning practices among prehistoric and historic North Americans, sampled the metaphyses of long bones of children to obtain stable isotope values from the time closest to death (i.e. the area with the fastest bone turnover). Waters-Rist *et al.* (2011) also investigated the effects of breastfeeding and weaning on stable C- and N-isotope values and sampled three different growth areas of the humerus – proximal metaphysis, diaphysis and distal metaphysis. They based their methodology on the data provided by Pritchett (1991), who proposed that in the humerus, much of the growth (and thus the fastest turnover) is exhibited in the proximal end. While Waters-Rist *et al.* (2011) documented notable variations in $\delta^{15}N$ values between the different areas of the long bone due to breastfeeding and weaning, no equivalent differences were evident among the $\delta^{13}C$ values.

A similar approach was used by Richards *et al.* (1998) who studied Roman Age burials from Britain. In the case of a burial of a child, who was believed to have migrated to Britain from Greece shortly before death, samples from two areas of the cortical bone of the femur were taken – one from the proximal end of the diaphysis and the other from the middle of the femur. According to Richards *et al.* (1998), in a growing femur new bone is laid down at the end of the shaft and added circumferentially, so that bone from the end of the diaphysis should reflect the child's most recent diet, compared to the middle of the shaft. They reported variations between the two skeletal sites for both C- and N-isotope values – a difference of almost 1‰ for $\delta^{13}C$ and 1.6‰ for $\delta^{15}N$, which they attributed to a change in geography and diet.

Perhaps the most important characteristic of adolescent bone turnover is the long-lasting imprint it leaves later, i.e. adult, collagen content. This is not surprising, considering that the main uptake of carbon occurs between birth and the end of puberty

(Geyh 2001:725). Martínez del Rio *et al.* (2009) argued that diet ingested during growth can make it hard to detect dietary contributions after the individual is fully grown. According to Hedges *et al.* (2007), human femoral (cortical) bone collagen reflects an individual's diet over a remarkably long period, including a substantial portion of collagen synthesized during adolescence. A 35-year-old individual could have anywhere from 20–25% up to 40–50% (depending on the specific turnover rate) of their mid-shaft femoral collagen synthesized prior to the age of 20 years (Hedges *et al.* 2007:815).

Frost (1964) claimed that bone turnover does not decrease linearly, arguing that a minimum in bone remodelling activity is reached at age 35. Studies done using the bomb radiocarbon method seem to indicate that bone turnover in mature individuals is almost negligible. Hodgins (2009), while studying the uptake of bomb radiocarbon in bone (tibia) collagen, found that two individuals born in 1917 and 1924 (both died in 2006) barely showed signs of elevated ^{14}C levels, indicating that they did not generate much new collagen after 1955, when atmospheric radiocarbon levels spiked. This means that at the respective ages of 89 and 82 years, the majority of their tibial bone collagen at death originated from a diet consumed when they were less than 38 and 31 years old, respectively. This fits well with the data reported above about collagen formed during adolescence contributing greatly to adult bone composition (Hedges *et al.* 2007:815).

Ubelaker *et al.* (2006) also used the bomb radiocarbon method to compare the ^{14}C levels of different individuals and calculated the average formation time of bone collagen (both from cortical femur and trabecular vertebra) from a 70-year-old individual (born in 1925) as between 1950 and 1963, predating death by more than 30 years. The authors concluded that very little new protein was incorporated into both cortical and trabecular bone collagen during the last four decades of that individual's life, and stressed age as an important factor governing bone turnover rates (Ubelaker *et al.* 2006:487). Geyh (2001) suggested that due to the extremely slow bone turnover rate in mature individuals, about 32 years should be subtracted from the ^{14}C age of bone collagen of a person who died at the age of 65 years.

2.3.5. Extent of natural variation and analytical precision

Earlier sections of this chapter have demonstrated clear differences in bone turnover rates among different skeletal elements and individuals of differing ages. However, differences in the bone turnover rate between individuals and different skeletal elements do not in themselves result in intraskeletal variation in stable isotope ratios. Therefore, individuals with a constant diet and/or domicile throughout the greater part of their life are not normally expected to exhibit variations in bone collagen isotopic composition, either on the populational or the intraskeletal level (Sillen & Kavanagh 1982:78; Chisholm 1989:19).

Controlled feeding experiments with animals raised on identical diets and in identical conditions have produced very homogeneous stable isotope ratios. Jim *et al.* (2006) found that interindividual bone collagen $\delta^{13}C$ values in laboratory rats only differed between 0.3‰ and 0.7‰. DeNiro & Schoeninger (1983) obtained similar results and proposed differences in the order of 1‰ or less (for both $\delta^{13}C$ and $\delta^{15}N$) to be classified as natural variation – i.e. not caused by dietary or external factors. For humans, Lovell *et al.* (1986) measured a standard deviation of only ±0.3‰ (for $\delta^{13}C$) among a group of prehistoric individuals, while Hedges *et al.* (2008) observed similar values for both C (±0.2‰) and N (±0.4‰) among Neolithic adults from Britain. On the other hand, Cox *et al.* (2001) considered differences in stable isotope values of 2‰ or more to be caused by external factors and everything below it they attribute to normal physiological variation. However, Cox *et al.* (2001) seem to have based their variation baseline on the data supplied by DeNiro & Schoeninger (1983).

Hedges *et al.* (2007) claimed that variations in collagen turnover rates between individuals can differ by up to two times for mid-shaft femora in a normal population, as was also demonstrated in various bomb radiocarbon studies (e.g. Geyh 2001; Ubelaker *et al.* 2006). When Hodgins (2009) compared the uptake of radioactive ^{14}C caused by the atomic bomb testing in the 1950s and 1960s, he also discovered that two individuals born in the same year had very different levels of ^{14}C in their bone (tibia) collagen, indicating a great degree of individual variation. However, individual

differences in bone turnover rates likely have no effect on isotope ratios if all the individuals have consumed food with a similar isotopic composition.

Indeed, when other external factors are accounted for, no marked variations are usually observed in stable isotope ratios across skeletal elements of the same individual. Controlled feeding experiments produced no differences between stable isotope ratios of various skeletal elements of the same animal (DeNiro & Schoeninger 1983:201; Jim *et al.* 2006:1057; Warinner & Tuross 2009:1694). Bonsall *et al.* (1997) found no significant variations among the $\delta^{13}C$ and $\delta^{15}N$ values obtained from different parts of a femur shaft or from the femur, humerus, tibia and rib bone from the same skeleton. Katzenberg & Lovell (1999) compared stable isotope values from three sites of the same bone and found very small differences – 0.2‰ to 0.7‰ for $\delta^{13}C$, and 0.3‰ to 0.4‰ for $\delta^{15}N$; while Warinner & Tuross (2009) examined $\delta^{13}C$ values of the mandible and humerus of a pig raised on a fixed diet and found the results to be almost identical.

These differences are well within the range of the analytical measurement error, which raises the question of whether the concept of 'natural variation' is even appropriate or whether all differences smaller than 1‰ can be explained by the limitations of the equipment's precision. To be fully distinguishable from differences caused by measurement error, variations between the stable isotope values from different skeletal elements should be at least ±1‰ for both $\delta^{13}C$ and $\delta^{15}N$ (and slightly more for $\delta^{34}S$). This benchmark will also be used when discussing the results of the present study.

2.3.6. Applying differences in bone turnover rates to stable isotope investigations of archaeological human remains: examples from case studies

The following overview includes various archaeological case studies that have utilized stable isotope analysis on two or more skeletal locations from the same individual. In some occasions, this was coupled with sampling a tooth in order to obtain a complementary isotopic signal from childhood (since teeth do not remodel after formation). This selection will serve to illustrate both the potential and the limitations of this approach to palaeodietary studies.

One of the first papers that attempted to reconstruct a more detailed life history of individuals based on stable isotope ratios of different calcified tissues was conducted by Sealy, Armstrong & Schrire (1995). They sampled a tooth formed in early childhood, a third molar formed during later childhood, the shaft of a long bone and a rib bone from five prehistoric and historic human skeletons from South Africa. While the authors managed to identify differences between childhood and adult diet as evident in variations between teeth dentine and bone collagen stable isotope ratios, the differences between ribs and long bones were small. However, in two cases they recorded variations of up to 2‰ for both C- and N-isotopes between the long bone and rib of the same individual. The differences were attributed to a change of domicile during life (possibly accompanied by a diet change), which was also supported by $^{87}Sr/^{86}Sr$ data.

The analysis by Sealy *et al.* (1995) is complemented by two similar studies done by Cox & Sealy (1997) and Cox *et al.* (2001), which both investigated stable isotope ratios of historical skeletons from South Africa. Cox & Sealy (1997) sampled a tooth formed in early childhood, cortical bone and trabecular bone (the same bone was not available in all cases) from eight individuals (one adult and seven non-adults between the ages of 10–21 years), thought to be slaves brought from Mozambique. For all skeletons $\delta^{13}C$ values became more depleted during life, indicating a change from a typically tropical C_4 plant diet to a more C_3 plant dominated diet during the late stages of their lives. While teeth dentine and cortical bone C- and N-isotope values were similar, all individuals had significantly different values for trabecular bone. The average $\delta^{13}C$ value for cortical bone was -12.2‰, compared to -16.2‰ for trabecular bone. Even among specific individuals, trabecular bone stable isotope values varied greatly. For one individual (approx. 12 years old), samples from four different trabecular bone sites – rib, trabecular bone of femur, palatine and occipital bone – were obtained, with the corresponding $\delta^{13}C$ values of -20.1‰, -15.3‰, -15.3‰ and -12.2‰, compared to only -7.9‰ for cortical femur.

In an analogous study by Cox *et al*. (2001) investigating human skeletons from a colonial cemetery in Cape Town, both the research technique and the outcomes of the

stable isotope analyses were similar, indicating a change in diet during their lifetimes as evident in differences between stable isotope ratios of teeth, cortical and trabecular bone. Yet it is important to point out that the case studies presented thus far employed a well-thought-out strategy to obtain the observed results – isotope analyses on multiple skeletal elements were only done on those individuals who were thought to be non-locals based on evidence obtained from other sources (archaeological, osteological, but also preliminary isotope analyses), so that positive results were expected.

The paper by Schroeder *et al.* (2009) follows a similar pattern: stable isotope values of rib and femur bone collagen and teeth dentine collagen from the residents of 17th to 19th century Barbados were compared in order to detect possible migrants. In several cases it was possible to distinguish potential newcomers – most likely imported slaves from Africa – due to differences between teeth and bone stable isotope values. In a couple of instances even variations greater than 2‰ between (trabecular) rib and (cortical) femur bone were detected, which enabled the authors to more precisely pinpoint how much time had passed since the migration event (which involved a change from a C_4 to C_3 plant-based diet) had occurred. However, for individuals who were presumed to have lived in the same place throughout their lives, i.e. their teeth and bone isotope values were very similar, the differences between ribs and femurs did not exceed 1.2‰ for $\delta^{13}C$ and 0.8‰ for $\delta^{15}N$.

When studying immobile, static communities, differences in isotope values among skeletal elements are more rarely observed. Jay *et al.* (2013) investigated C-, N- and S-isotopes of the residents of a British Iron Age community and compared rib, humerus and tooth dentine collagen from the same individual to obtain timing differences between the formation periods of the collagen. While they were successful in demonstrating that some individuals had moved around between their childhood and death, as was evident in noticeable variations between the stable isotope values of teeth and bones, the differences between the rib and the humerus were minimal – 0.5‰ or less for both $\delta^{13}C$ and $\delta^{15}N$.

Similar results were obtained by Jørkov *et al.* (2009), who reported differences in C- and N-isotope values between tooth dentine and the petrous bone in the skull (which were claimed to represent the early childhood dietary signal) compared to the other bones (representing adult diet), yet not between rib and femur of the same individuals. Hedges *et al.* (2008) compared trabecular (femoral head) and cortical (mid-shaft) collagen from the same femur of 15 adults, but found the variations to be small for both $\delta^{13}C$ and $\delta^{15}N$ (on average only 0.2‰), although they detected slightly greater differences among the respective values from sub-adults.

In the case of children and adolescents, not many studies have been done that compare isotope ratios from different parts of the skeleton. To some extent, this is certainly caused by the more fragile nature of juvenile bones and their frequent under-representation in skeletal assemblages. However, in a paper by Waters-Rist *et al.* (2011), stable C- and N-isotope values from a long bone shaft (mostly humerus, but femora, tibiae and ulnae were also used) were compared to measurements done on both the distal and the proximal metaphysis of the same bone in children under the age of 10 to more precisely pinpoint the start and end of weaning. Instead of just determining whether a child at a certain age was being breastfed or weaned, as is usually done when just one skeletal site is sampled, they were able to more precisely determine the time when weaning commenced or ended, by comparing the nitrogen isotope values of the shaft and the metaphysis. They also successfully demonstrated that the diaphysis was the slowest part of the long bone to reflect dietary changes.

In summary, intraskeletal stable isotope analysis can offer a wealth of new information about the life histories and dietary practices of past people, although there are factors that need to be considered before applying this approach to an archaeological population. This method has been shown to work well for juvenile individuals that exhibit much faster turnover rates, so that changes in their diets become evident in their bone collagen composition in a significantly shorter time, when compared to adults. This has important implications for studying infant feeding practices in more detail in situations where no teeth are available to sample. Intraskeletal sampling of both trabecular and cortical bone can also identify migrants or non-locals, on the

condition that the relocation occurred a sufficient number of years before death, and that the isotopic composition of the diet between the two locales was sufficiently dissimilar to be distinguishable from measurement error. However, even if intraskeletal variation is shown to be negligible, it can still be regarded as an indicator of a stable community with homogeneous dietary practices.

3. History of palaeodietary research in Central and Southeast Europe

As the focus of this dissertation is on reconstructing Bronze Age diets in the Romanian Carpathians, an understanding of the broader trends in dietary habits in and around this region is necessary for interpreting the results of the stable isotope analysis and for evaluating any possible changes in subsistence practices through time. This chapter reviews published data from various sources (stable isotope, archaeozoological and archaeobotanical evidence) to create a reference base for the subsequent discussion of the results of this dissertation.

3.1. Isotopic evidence of human palaeodiets

There is very little published isotopic data available for Romania and no immediately comparable datasets for the Carpathians. This necessitates expanding the study area to include regions where more isotopic research has been undertaken – the southern Balkans, Central Europe and the Pontic steppes around the Black Sea. With the inclusion of territories where the prehistoric climate and environment were not identical to the Romanian Carpathians, it is also necessary to evaluate the appropriateness of using these data to make generalisations about the wider dietary history of the northern Balkans.

Southeast Europe is generally defined as including the modern territories of Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Greece, Kosovo, Moldova, Macedonia, Montenegro, Romania and Serbia. Isotopic studies have been conducted in only a few of these countries. However, Southeast Europe encompasses two major environmental zones – the warmer Mediterranean, and a more temperate continental region (Figure 1). Romania mainly falls into the latter division. For comparative purposes, studies done in continental areas further north than the Balkan Peninsula, in Central Europe, have also been included in the following analysis (including Austria, Hungary, Slovakia, Slovenia, Poland, Germany and the Czech Republic).

Figure 1 also reveals a third major environmental zone very close to the Carpathians – the steppe region immediately to the east, stretching along the Black Sea coast in Ukraine to the Caucasus in southern Russia. While these areas are environmentally different from the Carpathians, the cultural influences and trade contacts between these two regions have been well documented (see Chapter 4, Archaeological Background). Studies from this area have been included to detect possible similarities and differences with the nearby Carpathians.

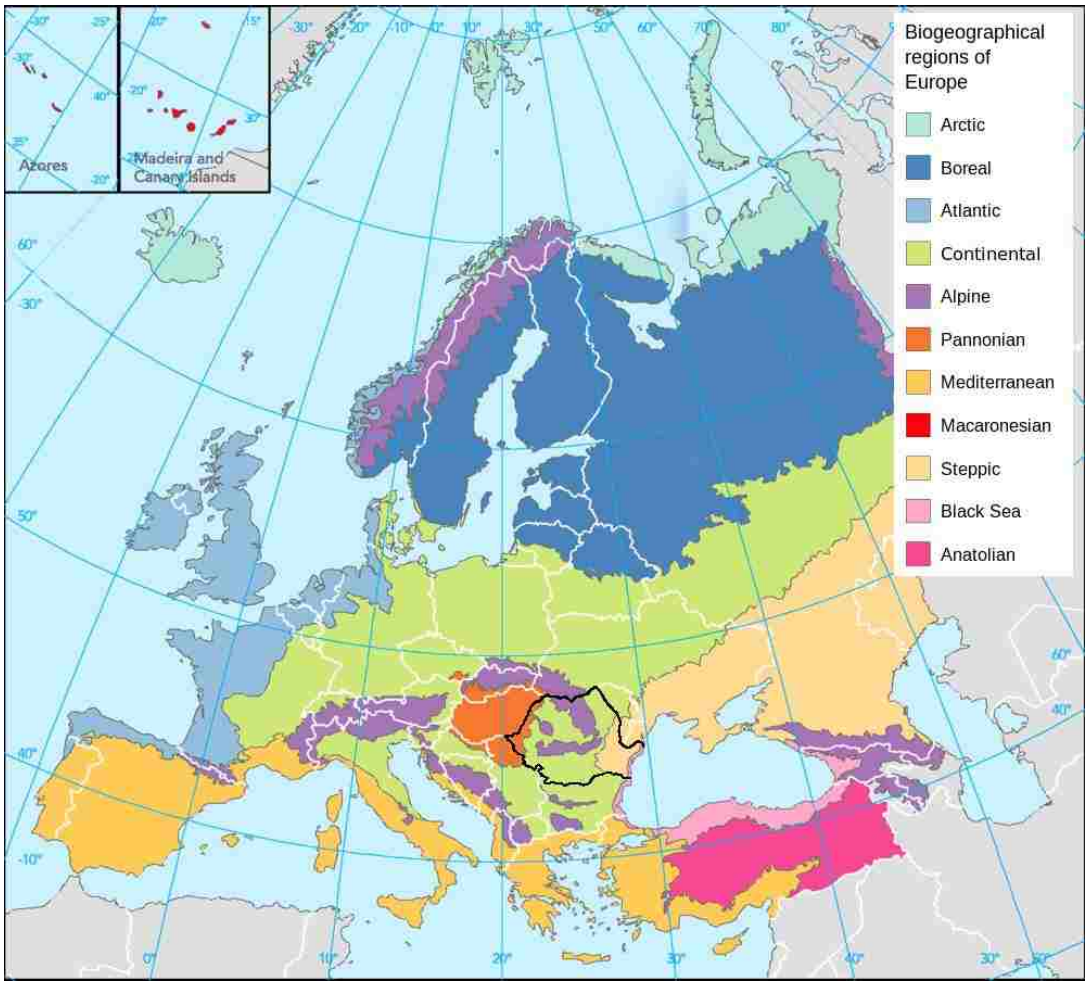


Figure 1. Biogeographical map of Europe. Territory of present-day Romania in black outline (map by European Environment Agency used under Creative Commons Attribution-Share Alike 3.0 Unported licence, modified by Ü. Aguraiuja)

While this chapter is mainly concerned with isotopic dietary studies conducted in Central and Southeast Europe, later in the discussion the Bronze Age data will be reviewed in the wider Eurasian context, prompting the inclusion of data from Western European and Western Asian sites. A full list of sites and studies with comparable

isotopic data, in addition to a brief overview of the methodology used in compiling this dataset, is provided in Appendix 1.

3.1.1. Mesolithic–Early Neolithic (ca. 9000–5000 BC)

For the Balkan Peninsula, the Iron Gates region of the Danube River on the Romania–Serbia border has offered abundant evidence of Mesolithic occupation and has resulted in palaeodietary studies of some of the best researched sites, such as Vlasac, Lepenski Vir and Schela Cladovei. Bonsall *et al.* (1997) were the first to investigate Mesolithic and Early Neolithic diet at the three sites mentioned above using carbon and nitrogen stable isotope analysis. Mesolithic individuals from Vlasac and Schela Cladovei have similar average values, around -19‰ for $\delta^{13}C$ and +15‰ for $\delta^{15}N$, which the authors interpreted as reflecting diets consisting mainly of riverine resources combined with some terrestrial protein (Bonsall *et al.* 1997:85).

At Lepenski Vir, most of the burials belong to the period of transition from the Mesolithic to the Early Neolithic, ca. 6300–5800 cal BC, and fall into two distinct groups distinguished mainly by their $\delta^{15}N$ values, with a cut-off point around +13‰. Bonsall *et al.* (1997) suggested this represents a dietary shift at the beginning of the Neolithic reflecting a change from a subsistence strategy focusing mainly on aquatic resources to a broad spectrum economy that included more protein from terrestrial resources.

The work conducted on the Iron Gates material was later expanded by Cook *et al.* (2001), Bonsall *et al.* (2004) and Borić *et al.* (2004). Despite minor discrepancies between those studies, they have produced similar average results for the same sites, thus they will not be reviewed here separately. Nehlich *et al.* (2010) investigated C-, N- and S-isotopes in the Danube Gorges and in addition to Lepenski Vir and Vlasac presented data from the Mesolithic sites of Padina and Hajdučka Vodenica. Their C- and N-isotope data for Mesolithic individuals from Lepenski Vir and Vlasac were comparable to the values reported by previous researchers, and so will not be examined separately. The average isotope values from Padina and Hajdučka Vodenica cluster in the same range, around -19‰ for $\delta^{13}C$ and +15‰ for $\delta^{15}N$.

Figure 2 presents the average $\delta^{13}C$ and $\delta^{15}N$ values for Mesolithic–Early Neolithic sites in the study region. The Iron Gates data are tightly clustered and – despite the limited dataset – seem to be distinct from results obtained from other areas. Markedly different are the average isotope data from two Mesolithic sites in coastal Croatia (pooled into one datapoint due to the small number of analysed individuals), which seem to reflect a more balanced diet of both marine and terrestrial protein (Lightfoot *et al.* 2011). The relatively low $\delta^{13}C$ and $\delta^{15}N$ values suggest only a small marine resource component in the diet, in comparison to those documented for some Mesolithic communities on the Atlantic coast of Europe (e.g. Richards & Hedges 1999).

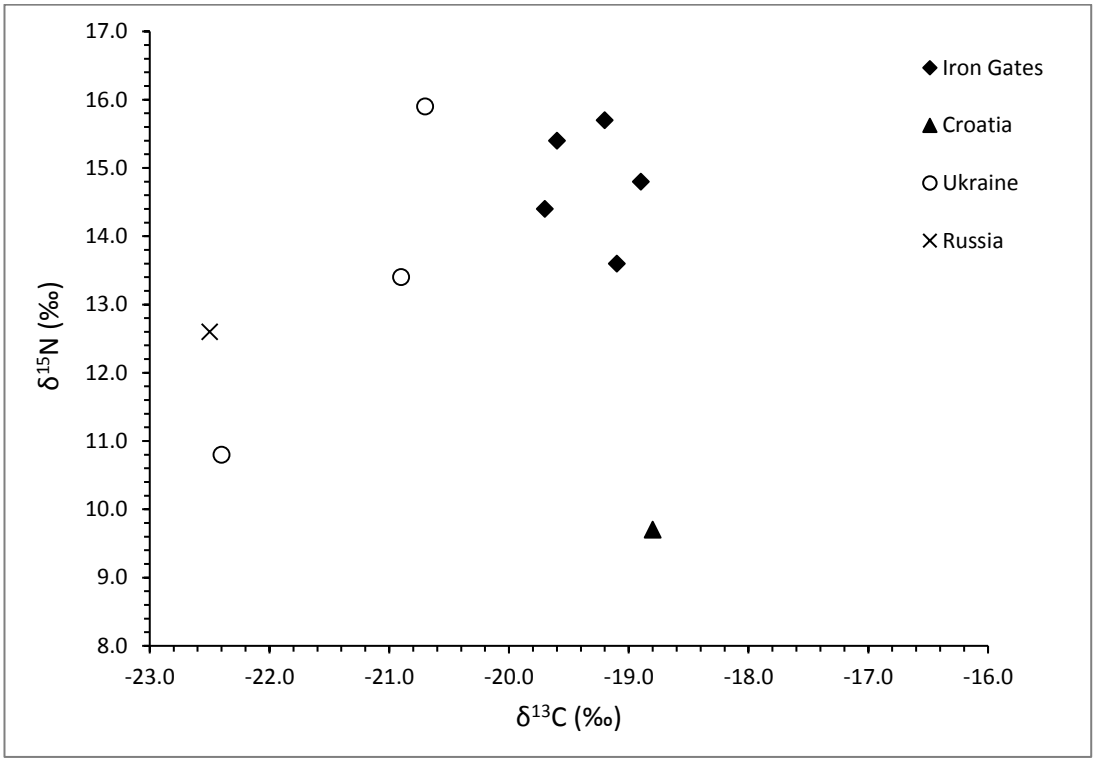


Figure 2. Average $\delta^{13}C$ and $\delta^{15}N$ values from published stable isotope studies of Mesolithic–Early Neolithic sites in Central and Southeast Europe (see Appendix 1 for references)

While the differences in average isotope values between the Iron Gates and Croatian sites may be explained by the geographical location (inland *vs* coastal), data from Mesolithic sites in central Ukraine (near the Dnieper River) should be more comparable. Two of the three Ukrainian studies included human burials dated firmly to the Mesolithic period, and both revealed a diet where terrestrial protein and freshwater fish were important (Richards *et al.* 2001; Lillie & Jacobs 2006). The mean

$\delta^{15}N$ values from these two sites are comparable to those from the Iron Gates, although the $\delta^{13}C$ values are somewhat lower. The third data point from Ukraine is from the same region but the material is dated to the Mesolithic–Neolithic transition (ca. 7000–4700 cal BC) (Lillie & Richards 2000). The isotope values from this study (on average -22.4‰ for $\delta^{13}C$ and +10.8‰ for $\delta^{15}N$) were interpreted by the authors as indicative of mainly terrestrial resource consumption with minor contributions from freshwater fish.

Finally, the Mesolithic site of Zamost near present-day Moscow, in Russia, is spatially further away from the main study region, but shares a similar environmental setting (continental, temperate climate; mixed coniferous and broad-leaved forests) to the Iron Gates (Iacumin *et al.* 2004). This is reflected in the average isotope values for this site, which again are indicative of a reliance on freshwater resources.

3.1.2. Neolithic–Eneolithic (ca. 5000–3000 BC)

Published isotope studies on material dating to this phase are much more abundant in the study region compared to the Mesolithic, although for Romania the data are sparse, originating again from the banks of the Danube. Some Early Neolithic sites were already covered in the previous section and indicate that freshwater resource consumption was still common at the beginning of the Neolithic. A group of Neolithic humans from Vinča-Belo Brdo upriver from the Iron Gates have average $\delta^{13}C$ and $\delta^{15}N$ values of -20.7‰ and +11.5‰, respectively (Nehlich *et al.* 2010). Bonsall *et al.* (2004) also produced stable isotope values (-19.5‰ for $\delta^{13}C$ and +10.5‰ for $\delta^{15}N$) for one Lepenski Vir burial dated to the Eneolithic, which shows the consumption of significantly lower trophic level protein compared to preceding periods.

Since farming reached the northern Balkans in the 7^{th}–6^{th} millennium BC (Gronenborn & Dolukhanov 2015:198), the reorientation to more plant-based diets in this period is to be expected. Figure 3 displays the Iron Gates stable isotope data against average values from other Neolithic–Eneolithic sites in the study region. The data form two clusters, one with lower $\delta^{15}N$ but quite consistent $\delta^{13}C$, and the other with higher $\delta^{15}N$ but more diverse $\delta^{13}C$ (probably reflecting a significant input from freshwater

resources). The more easterly sites fall into the second group, while Central European sites are more similar to the average isotope values from the rest of the Balkan Peninsula.

Data from Bulgaria (Honch *et al.* 2006; Gerling 2014) and Croatia (Lightfoot *et al.* 2011) are mostly from sites near the modern coastline, yet show no clear marine signal and are similar to isotope values from the inland region of Iron Gates (and from inland sites in Croatia), reflecting a dominantly terrestrial diet based on C_3 plants, C_3 plant consumers and products derived from them.

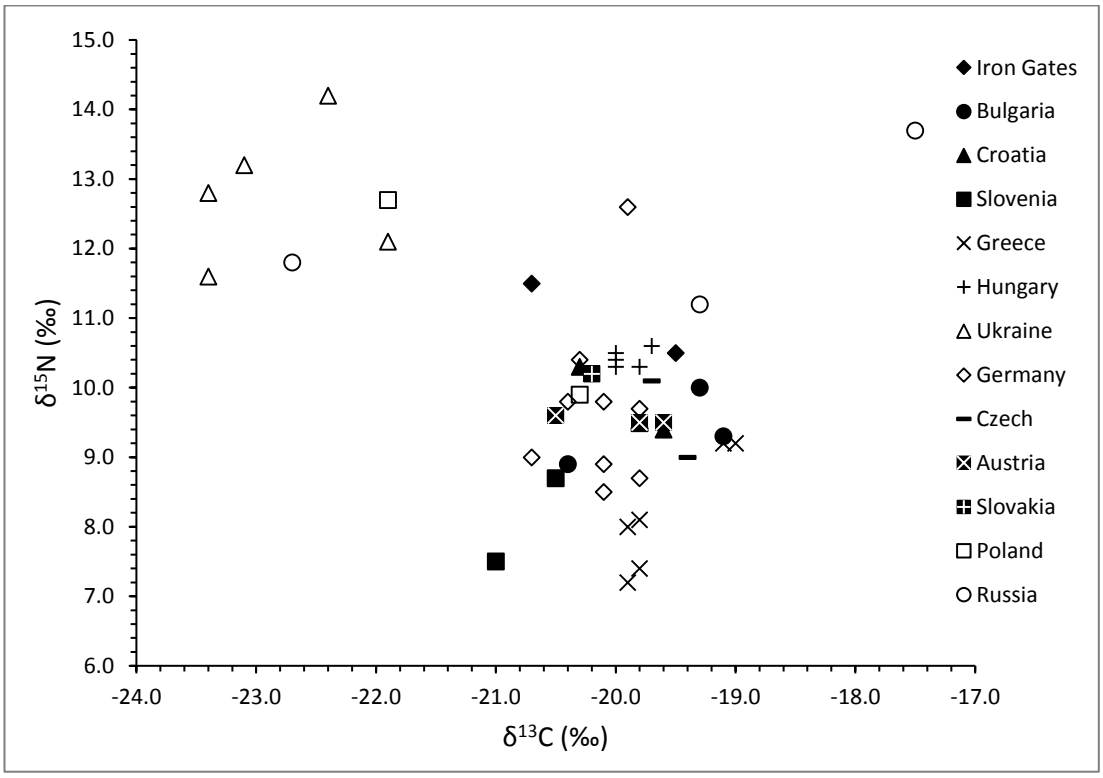


Figure 3. Average $\delta^{13}C$ and $\delta^{15}N$ values from published stable isotope studies of Neolithic–Eneolithic sites in Central and Southeast Europe (see Appendix 1 for references)

In a study of various Late Neolithic–Eneolithic sites in the Great Hungarian Plain (west of the Carpathians), Hoekman-Sites & Giblin (2012) interpreted the average values (around -20‰ for $\delta^{13}C$ and +10.5‰ for $\delta^{15}N$) as indicative of high terrestrial protein consumption; however, based on high $\delta^{15}N$ values of domesticated animals from the same site, they also proposed the possible reliance on manured cereals. Very similar values were obtained by Whittle *et al.* (2013a) for several Neolithic sites in Hungary.

In nearby Slovenia, there have been two stable isotope studies conducted on the Neolithic site of Ajdovska Cave (Ogrinc & Budja 2005; Bonsall *et al.* 2007) that produced somewhat different results, thus the two datasets are presented separately in Figure 3. While the average values for both studies were generally in agreement, the authors disagreed on the interpretation of the isotope values. Ogrinc & Budja (2005) argued that the isotope data reflect a significant reliance on domesticated animal protein, whereas Bonsall *et al.* (2007) suggested that cereals and pulses may have been more dominant in the diet, supporting this with the abundant presence of caries on the teeth of the individuals analysed.

Several Neolithic sites from both inland and coastal Greece stand out for their notably low average $\delta^{15}N$ values (Papathanasiou 2003) but are generally comparable to other Balkan sites. Schulting (2015) proposed that the Neolithic Mediterranean diet may have relied less on animal protein, or, alternatively, that the greater consumption of legumes could have lowered the $\delta^{15}N$ values while the amount of animal protein consumed remained more or less the same.

As mentioned earlier, studies conducted on archaeological material from Central Europe have produced stable isotope data similar to those from Balkan sites. Most of the analysed material is associated with the Linear Pottery culture (or LBK) which covers a vast area of the temperate European loess belt and is associated with an economy based on farming (mainly wheat, barley, legumes) and herding (cattle, sheep/goat, pig) (Oelze *et al.* 2011:273; Gronenborn & Dolukhanov 2015:200). Some isotope studies (e.g. Dürrwächter *et al.* 2006; Nehlich *et al.* 2009; Oelze *et al.* 2011) have proposed a heavy reliance on domesticated animals and their products for LBK people; however, Fraser *et al.* (2013) demonstrated that cereals from the LBK site of Vaihingen in southwest Germany had high $\delta^{15}N$ values suggestive of manuring and concluded that the relatively high human $\delta^{15}N$ values from other LBK sites may have been incorrectly interpreted as being indicative of high protein (meat) consumption, and that in reality, the importance of cereal and plant foods in LBK diets may have been underestimated in previous isotopic studies.

In a comprehensive study of LBK diet which included sites from Germany, Hungary, Austria, the Czech Republic and Slovakia, Hedges *et al.* (2013) documented a general dietary consistency throughout the LBK area (human values on average around -20‰ for $\delta^{13}C$ and +9.5‰ for $\delta^{15}N$). However, the eastern sites (in the Danube catchment) had on average slightly higher $\delta^{13}C$ and lower $\Delta^{15}N_{human–herbivore}$ (i.e. the difference between average human $\delta^{15}N$ and herbivore $\delta^{15}N$ values) as compared to the western LBK sites. The authors explained the shift in $\delta^{13}C$ values from west to east in terms of climatic conditions (the response of plants to moisture and sunshine availability) and the lower $\Delta^{15}N_{human–herbivore}$ with the eastern LBK populations consuming less animal protein (and more plant foodstuffs) (Hedges *et al.* 2013:351,354).

The only exception in the Central European data can be seen at the site of Ostorf, northern Germany, which produced a much higher average $\delta^{15}N$ (+12.6‰) indicative of large proportions of fish and terrestrial meat consumption (Fernandes *et al.* 2015). Unlike other German sites, Ostorf is associated with the Funnel Beaker culture (not LBK) – a mixed farming economy where hunting and gathering played an equally important role in subsistence (Midgley 1992). The two data points from neighbouring Poland are both from cultures associated with transitional economies (i.e. in-between hunter-gatherers and sedentary farmers). Four individuals from an early Corded Ware culture site of Zabie near the Baltic Sea coast showed reliance on high trophic level protein and possibly also freshwater resources (Pospieszny 2015), whereas $\delta^{13}C$ and $\delta^{15}N$ values (-20.3‰ and +9.9‰, respectively) for one individual from eastern Poland (Globular Amphora culture) are indistinguishable from LBK humans (Kozłowski *et al.* 2014).

Concerning the area east of the Carpathians, sites from Ukraine and Russia are clearly distinct from the Balkan data (although it must be noted that 'Neolithic' contexts in these areas are mostly defined by the presence of pottery rather than subsistence economy [Schulting 2015:371]). Several sites from central Ukraine, near the Dnieper River, have been analysed for stable isotopes and they have all demonstrated that the Neolithic–Eneolithic diet in this region was primarily supported by freshwater

resources as evidenced by extremely low $\delta^{13}C$ and high $\delta^{15}N$ values (Richards *et al.* 2001; Lillie *et al.* 2011).

The Neolithic site of Spas-Klepiki, near present-day Moscow, displayed average isotope values similar to Ukrainian sites, with an equally high reliance on aquatic protein (Iacumin *et al.* 2004). Different results were obtained from southern Russia, in the Caucasus (between the Black and the Caspian Sea). Comparison between Eneolithic sites in the forest-steppe (on average -19.3‰ for $\delta^{13}C$ and +11.2‰ for $\delta^{15}N$) and in the drier grass-steppe (on average -17.5‰ for $\delta^{13}C$ and +13.7‰ for $\delta^{15}N$) revealed that region-specific flora and climate were likely the main cause of variations, e.g. the grass-steppe contained wild C_4 plants (which would account for the more positive $\delta^{13}C$ values of animals and humans from this region), whereas the arid environment may have been responsible for elevated $\delta^{15}N$ values (Hollund *et al.* 2010). For the sites located in a more temperate, forested environment, the average isotope results were indeed quite similar to those obtained from the Iron Gates and the Hungarian Plain.

3.1.3. Bronze Age (ca. 3000–1000 BC)

Most isotopic dietary studies on Bronze Age material in the study region have been conducted on sites from Greece, with data also available from Croatia, Bulgaria and areas further north and east. There are no comparable data from Romania. Figure 4 illustrates a clearly different pattern in average isotope values as compared to the Neolithic–Eneolithic period in Figure 3. Average $\delta^{13}C$ values for Bronze Age sites do not fall below -21‰, whereas for the first time since the beginning of the Holocene, they go up to -16‰, indicating a possible shift in dietary practices. The variation in average $\delta^{15}N$ values, however, is of the same magnitude as in the preceding Neolithic period.

In Bulgaria, there are isotopic data from two Bronze Age sites from the Yamnaya and Catacomb culture area (Gerling 2014). These cultures are known to have close contacts with the inhabitants of the Bronze Age Sub-Carpathians through trade and cultural influences (see Chapter 4, Archaeological Background). Gerling (2014) identified the

importance of C_4 plant contribution in the average $\delta^{13}C$ values for both sites (ca. -17‰ and -18.2‰), while also claiming that marine input can be considered improbable due to the geographical location of the sites. Gerling also suggested the cultivation of millet as the probable cause of the observed isotope values. For comparison, data by the same author from a slightly earlier (Eneolithic) site of Smyadovo nearby had an average $\delta^{13}C$ of -20.5‰, indicating that C_4 plant influence had increased over time (Gerling 2014).

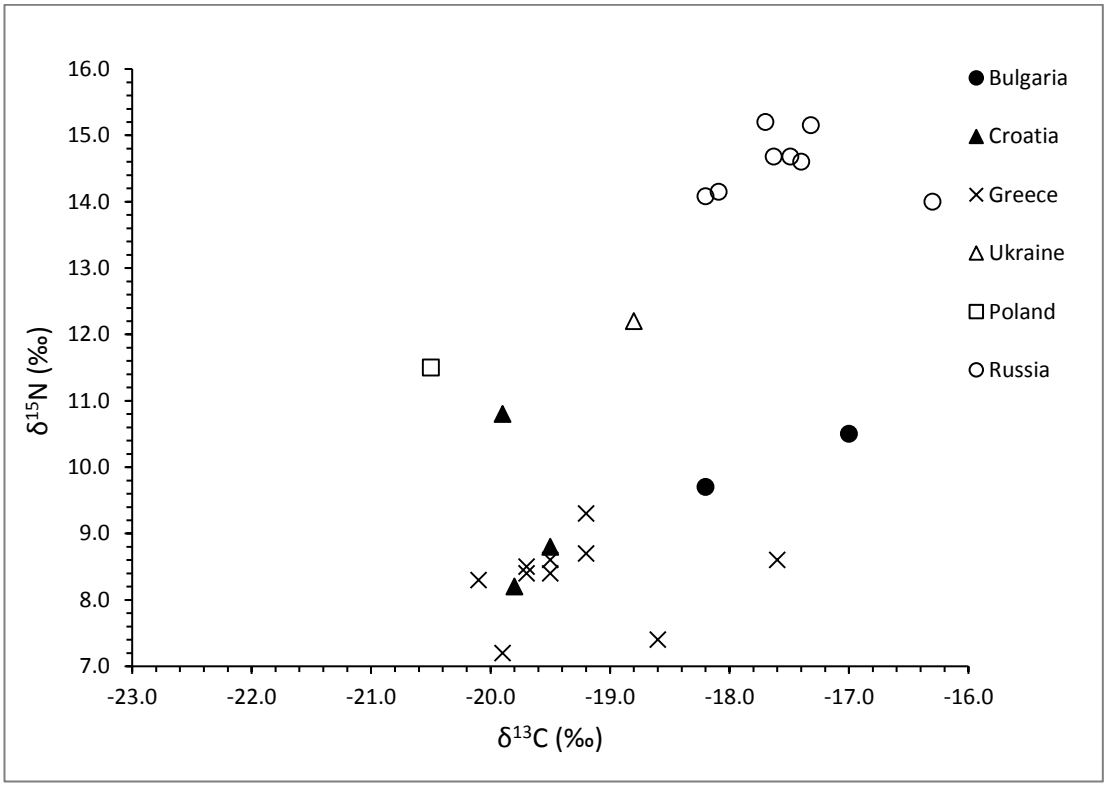


Figure 4. Average $\delta^{13}C$ and $\delta^{15}N$ values from published stable isotope studies of Bronze Age sites in Central and Southeast Europe (see Appendix 1 for references)

There are stable isotope data from various sites in Bronze Age Croatia, which are here conveyed as three data points. Nine sites from the coastal region (dated to ca. 2000–1000 BC) had very similar average values, expressed together as -19.4‰ for $\delta^{13}C$ and +8.8‰ for $\delta^{15}N$ (Lightfoot *et al.* 2015). Another coastal site, dated slightly later (ca. 1500–600 BC), also had similar mean values (-19.8‰ and +8.2‰, respectively) (Lightfoot *et al.* 2012). However, the inland site of Ilok Dvor knezova Iločkih (2200–1600 BC), located near the Danube River, differed with a much more positive average $\delta^{15}N$ (+10.8‰) (Lightfoot *et al.* 2015). Interestingly, the $\delta^{13}C$ and $\delta^{15}N$ values for the

two individuals from Ilok are almost identical to those obtained from a human burial from another Danubian site (Lepenski Vir), radiocarbon dated to the Eneolithic (Bonsall *et al.* 2004). Finally, Lightfoot *et al.* (2015) also noted minor C_4 (or marine resource) consumption for several individuals in both coastal and inland sites in Croatia, and believe the C_4 food consumed was almost certainly millet.

The Greek data are relatively homogeneous, characterised by relatively low $\delta^{15}N$ values, and $\delta^{13}C$ values roughly between -18‰ and -20‰ (Triantaphyllou 2001; Triantaphyllou *et al.* 2008; Petroutsa *et al.* 2009; Petroutsa & Manolis 2010; Vika 2011) – typical for farming-herding communities in a temperate climate. Even for coastal sites or those from the island of Crete, there was no clear marine resource signal. Triantaphyllou (2001) reported possible C_4 plant (millet) consumption in Late Bronze Age Ryhmnio, northern Greece, as expressed in average isotope values of -17.6‰ for $\delta^{13}C$ and +8.6‰ for $\delta^{15}N$. Petroutsa & Manolis (2010) also found several individuals from the sites of Aghia Triada and Almyri that show isotopically significant reliance on C_4 plants.

Like results for the Neolithic–Eneolithic group, sites further north and/or east of the Carpathians stand out by their higher average $\delta^{15}N$ values. An Únětice culture site from Poland had on average lower $\delta^{13}C$ (-20.5‰) and higher $\delta^{15}N$ (+11.5‰) than any other site from the Balkan Peninsula (Pokutta & Howcroft 2013). In central Ukraine, four Bronze Age sites from the North Pontic steppe region produced an average value of -18.8‰ for $\delta^{13}C$ and +12.2 for $\delta^{15}N$ (Gerling 2014). The author associated the high $\delta^{13}C$ and $\delta^{15}N$ values with C_4 plant consumption (either wild or domesticated) and aridity, respectively. Compared to studies conducted in the same region for earlier sites (e.g. Lillie *et al.* 2011), there was a significant increase in $\delta^{13}C$ values (around -23‰ for Mesolithic sites) through time.

The Russian data are from the Pontic–Caspian steppe near the Caucasus which was inhabited by nomadic herders associated with the Yamnaya, Catacomb and Kurgan cultures (Iacumin *et al.* 2004; Shishlina *et al.* 2007, 2009). All the sites have significantly enriched $\delta^{15}N$ values and some also have moderately enriched $\delta^{13}C$ which

the authors interpreted as reflecting a continued reliance on wild resources (including freshwater fish), but also consumption of herbivores consuming wild C_4 grasses. Of all the Bronze Age data, the Russian sites are the only ones not to display any significant influence of domesticated species in diets.

3.1.4. Iron Age (ca. 1000–1 BC)

For the period following the Bronze Age up until the end of the 1st millennium BC, average stable isotope data for sites are summarized in Figure 5. For the immediate Balkan region, there is information from Croatia, Bulgaria and Greece. A Greek colonial site of Apollonia on the coast of the Black Sea, in Bulgaria, has evidence of a mixed diet of terrestrial C_3 resources supplemented by marine and/or C_4 foodstuffs (Keenleyside *et al.* 2006).

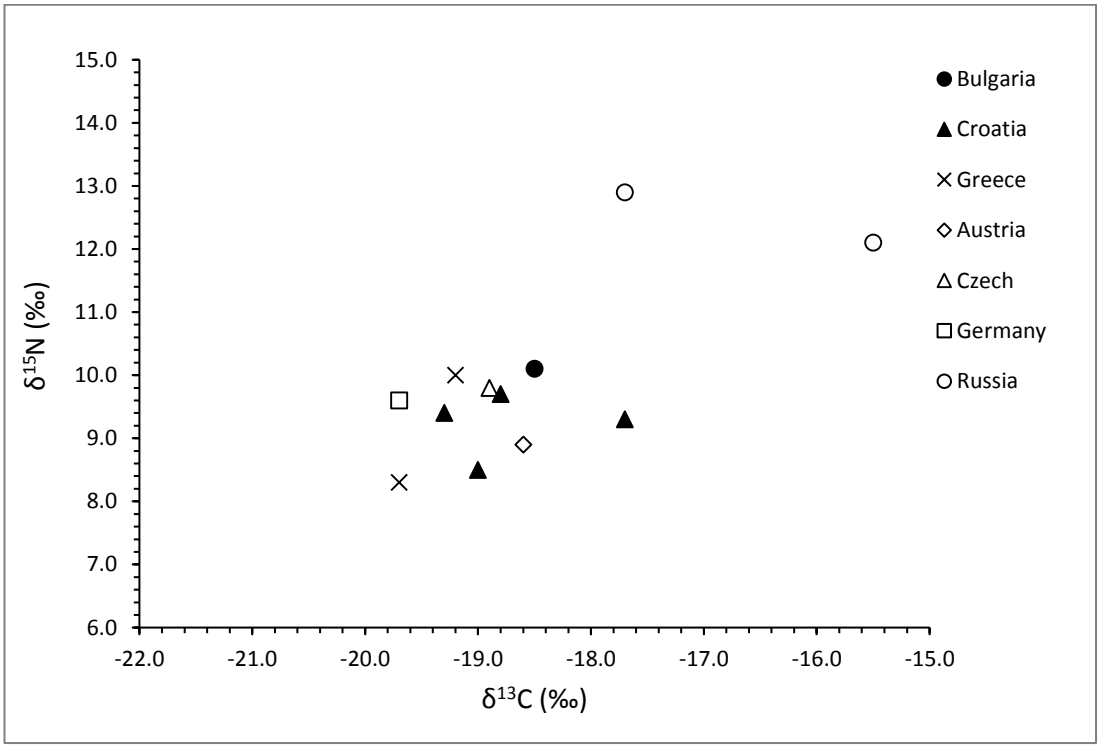


Figure 5. Average $\delta^{13}C$ and $\delta^{15}N$ values from published stable isotope studies of Iron Age sites in Central and Southeast Europe (see Appendix 1 for references)

Four sites in Iron Age Croatia are quite homogeneous and similar to the Bulgarian results (Lightfoot *et al.* 2012, 2015). Interestingly, average $\delta^{13}C$ results are more negative for the three coastal sites, indicating that marine resources were of little

importance. The highest average $\delta^{13}C$ (-17.7‰) is from an inland site, near the Croatia–Serbia border, and suggests notable amounts of C_4 plant consumption. While both Keenleyside *et al.* (2006) and Lightfoot *et al.* (2015) agree that millet was likely grown in Iron Age Bulgaria and Croatia, they conclude that it was probably of secondary importance in diet.

In Greece, there are data from two sites located near the coast, one from the Early Iron Age (Papathanasiou *et al.* 2013), and the other from the Classical–Hellenistic period (Vika 2011). Neither showed a strong influence of marine or C_4 resources. However, Vika (2011) associated the slightly higher $\delta^{15}N$ (+10‰) of the Classical–Hellenistic site of Thebes with increased consumption of animal protein, although intensive manuring was also suggested as an alternative explanation for the enriched N-isotope values.

Oelze *et al*. (2012b) investigated the diets of individuals from the Magdalenenberg burial site (Hallstatt culture) in southern Germany and found an entirely terrestrial, C_3 plant dominated isotopic signal. Le Huray & Schutkowski (2005) compared several Early Iron Age Hallstatt sites from Austria to Late Iron Age La Tène Culture sites from the neighbouring Czech Republic and observed several individuals from both regions/sub-periods with $\delta^{13}C$ values less negative than -18‰ (up to -14.8‰) which the authors interpreted in terms of C_4 plant (millet) consumption. However, the average values for all sites were entirely comparable with the Balkan and German data.

Finally, there is isotopic evidence for Iron Age diets in the Pontic steppe and Caucasus area from southern Russia (Iacumin *et al.* 2004). A site on the coast of the Black Sea and another near the Caucasus Mountains are clearly outliers in the otherwise homogeneous Iron Age group, as can be seen in Figure 5. They have very high $\delta^{15}N$ and relatively enriched $\delta^{13}C$ values, which the authors explained as reflecting aridity and the consumption of wild C_4 plants (in the Caucasus site), and the possible consumption of marine resources (in the Black Sea site).

3.1.5. Roman–Medieval (ca. AD 1–1400)

Completing the overview of isotopic dietary studies conducted in this region, sites from the 1st millennium AD up until the Medieval period are included as one group because of their general similarity and the small amount of data (Figure 6). Compared to any other temporal group, there is the least amount of variation in both $\delta^{13}C$ and $\delta^{15}N$ average values for historic sites (excluding one outlier).

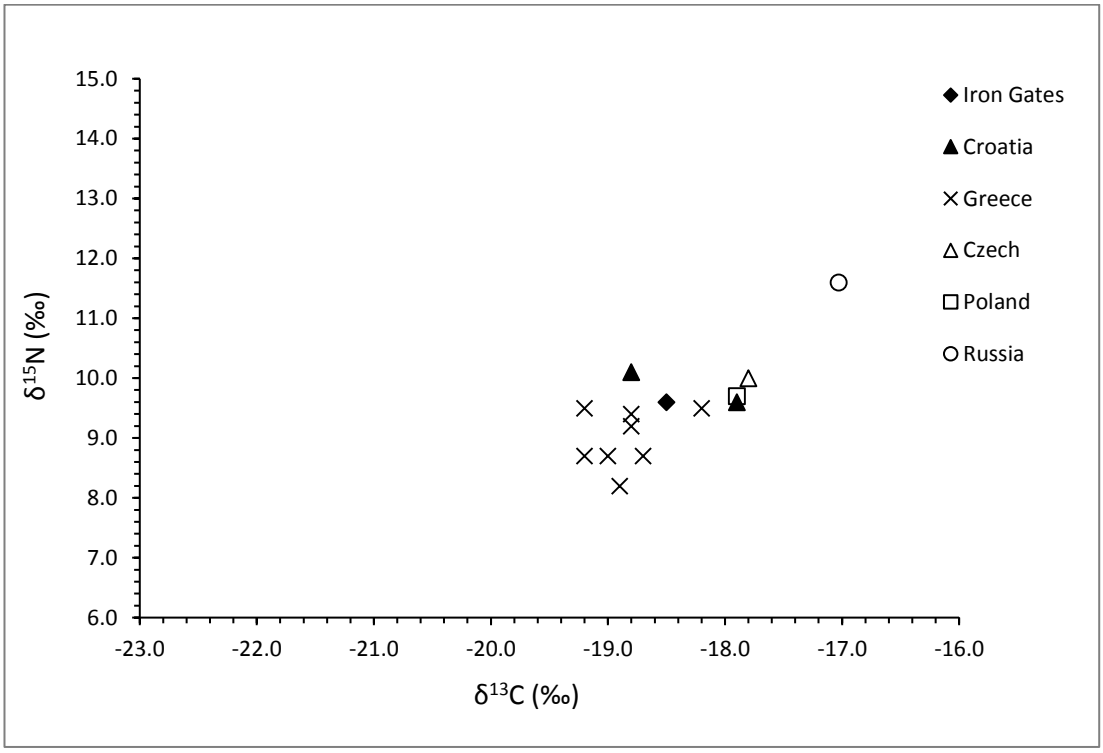


Figure 6. Average $\delta^{13}C$ and $\delta^{15}N$ values from published stable isotope studies of Roman–Medieval sites in Central and Southeast Europe (see Appendix 1 for references)

Whilst re-examining the Mesolithic–Neolithic diet of the Iron Gates, Bonsall *et al.* (2004) radiocarbon dated four individuals from Lepenski Vir to the Roman and Medieval period (ca. 300–1500 cal AD). The four individuals had very similar isotope values, averaging around -18.5‰ for $\delta^{13}C$ and +9.6‰ for $\delta^{15}N$ which were taken as evidence for a mainly terrestrial, C_3 plant-based diet with minor amounts of direct or indirect C_4 plant (millet) consumption (Bonsall *et al.* 2004:299). In Croatia, Lightfoot *et al.* (2012) examined both Roman/Late Antique and Early Medieval coastal sites and found very consistent isotope values. The isotopic signal was in agreement with a diet primarily based on C_3 plants and terrestrial protein, supported by minor amounts of

marine or C_4 resources; there was no indication of a substantial dietary shift occurring between the two time periods.

Bourbou *et al.* (2011) and Bourbou & Richards (2007) have offered data for several Greek Byzantine sites from the 6th–15th centuries AD which have produced results similar to those obtained from contemporaneous sites in the Iron Gates and Croatia. All the Greek sites from this period fall between -18.2‰ and -19.2‰ for $\delta^{13}C$ and between +8.2‰ and +9.5‰ for $\delta^{15}N$, reflecting a mainly terrestrial, C_3 plant-based diet, supplemented with minor amounts of fish (in coastal sites) and/or millet (in inland sites). Bourbou *et al.* (2011) also admitted that the importance of marine/C_4 resources in individual Greek Byzantine diets demonstrated notable variation.

For Central Europe, a 2nd century AD cemetery from Poland produced average isotope values that were interpreted as reflecting a mainly terrestrial diet supported by marine or anadromous fish and C_4 plants (millet) (Reitsema & Kozłowski 2013). Bone carbonate analysis of the same material suggested that millet contributed between 0% and 35% to overall diet, depending on the individual (Reitsema & Kozłowski 2013:12). In the nearby Czech Republic, Kostelisko cemetery (dated to ca. AD 800–900) offered almost identical average values (-17.8‰ for $\delta^{13}C$ and +10.0‰ for $\delta^{15}N$) (Halffman & Velemínský 2015). The authors suggested minor millet consumption (between 13–30% of dietary protein) as the most reasonable explanation for the slightly elevated $\delta^{13}C$ values.

The dataset from the Russian Caucasus is (again) an outlier. Three individuals dated to the Medieval period averaged -17.0‰ for $\delta^{13}C$ and +11.6‰ for $\delta^{15}N$ which are the highest values among all sites in this group (Iacumin *et al.* 2004). Analogous to previous isotope data from this region, the results were interpreted as being influenced by the steppe environment (i.e. aridity and the presence of wild C_4 plants).

3.1.6. Subsistence practices through time

The foregoing review shows that various regions in Central and Southeast Europe have produced similar average isotope values for each period. The only exception is the area

to the east of the Carpathians, covering the Pontic steppes and the Caucasus. Excluding the Mesolithic period, the Russian data are consistently outliers, being often positioned in the high $\delta^{13}C$ and high $\delta^{15}N$ area of the graphs (see Figures 2–6). These differences are likely caused by both environmental (open, dry grassland and steppe environment with wild C_4 plants) and cultural (more nomadic way of life, greater reliance on wild resources even after the advent of the Neolithic Revolution) factors.

For these reasons, the Russian data are henceforth excluded from the discussion of temporal and regional trends in the isotopic dietary history of Central and Southeast Europe. Data from Ukraine, which is both geographically closer and displays fewer outliers, has been kept in the discussion. Chronologically the most recent isotope values for the Ukrainian territory are from the Bronze Age and these results do show the realignment from wild resources (both aquatic and terrestrial) to a more 'Neolithic' isotopic signal evidenced elsewhere in the Balkan Peninsula.

Figure 7 displays all the previously mentioned data (excluding those from Russia) obtained from Holocene material in Central and Southeast Europe. Geographically, the closest sites to the Carpathians are near the Black Sea coast in Bulgaria, and in the Iron Gates region on the Serbia–Romania border. Most of the Iron Gates sites stand out in the graph, which is caused by most of the data originating from Mesolithic–Early Neolithic contexts where diet was significantly different. The same applies to Neolithic Ukrainian sites, which are also distinct because of a strong reliance on freshwater resources. The notable difference in average $\delta^{13}C$ values between the Ukrainian and Iron Gates sites may be explained by variability in isotope values of freshwater organisms – either species specific or due to environmental factors.

Except for six individuals from Croatia (who display a mixed diet of terrestrial and marine protein), there are no other comparable Mesolithic data from the rest of the Balkans. However, the limited Iron Gates data from later periods plot in the same range as nearby areas such as Hungary and Bulgaria, but also Croatia, Greece, Germany, the Czech Republic, Slovakia and Austria, indicating that at least from the Eneolithic

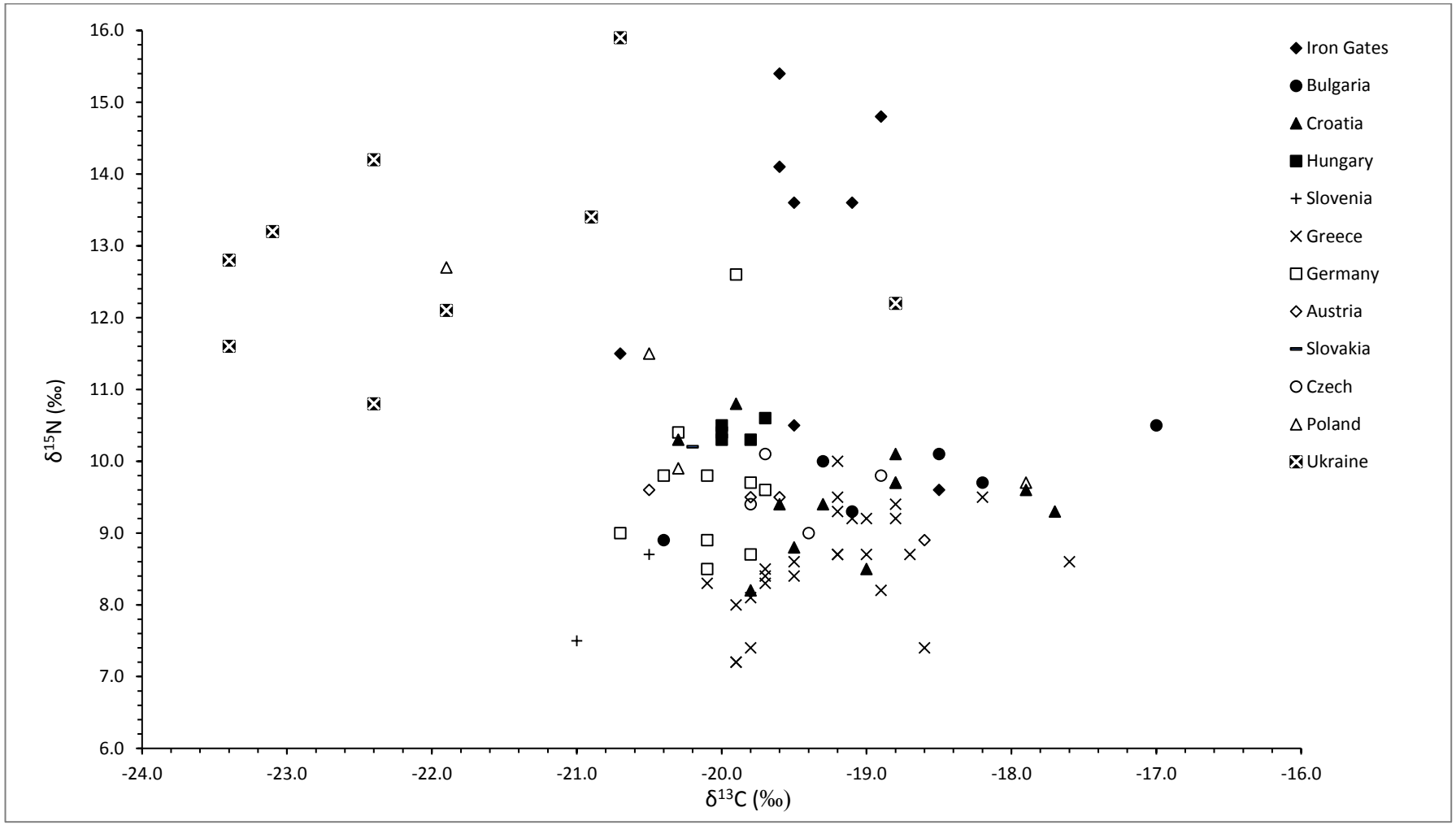


Figure 7. Average $\delta^{13}C$ and $\delta^{15}N$ values from published stable isotope studies of Holocene sites in Central and Southeast Europe, divided by regions (modern countries) (see Appendix 1 for references)

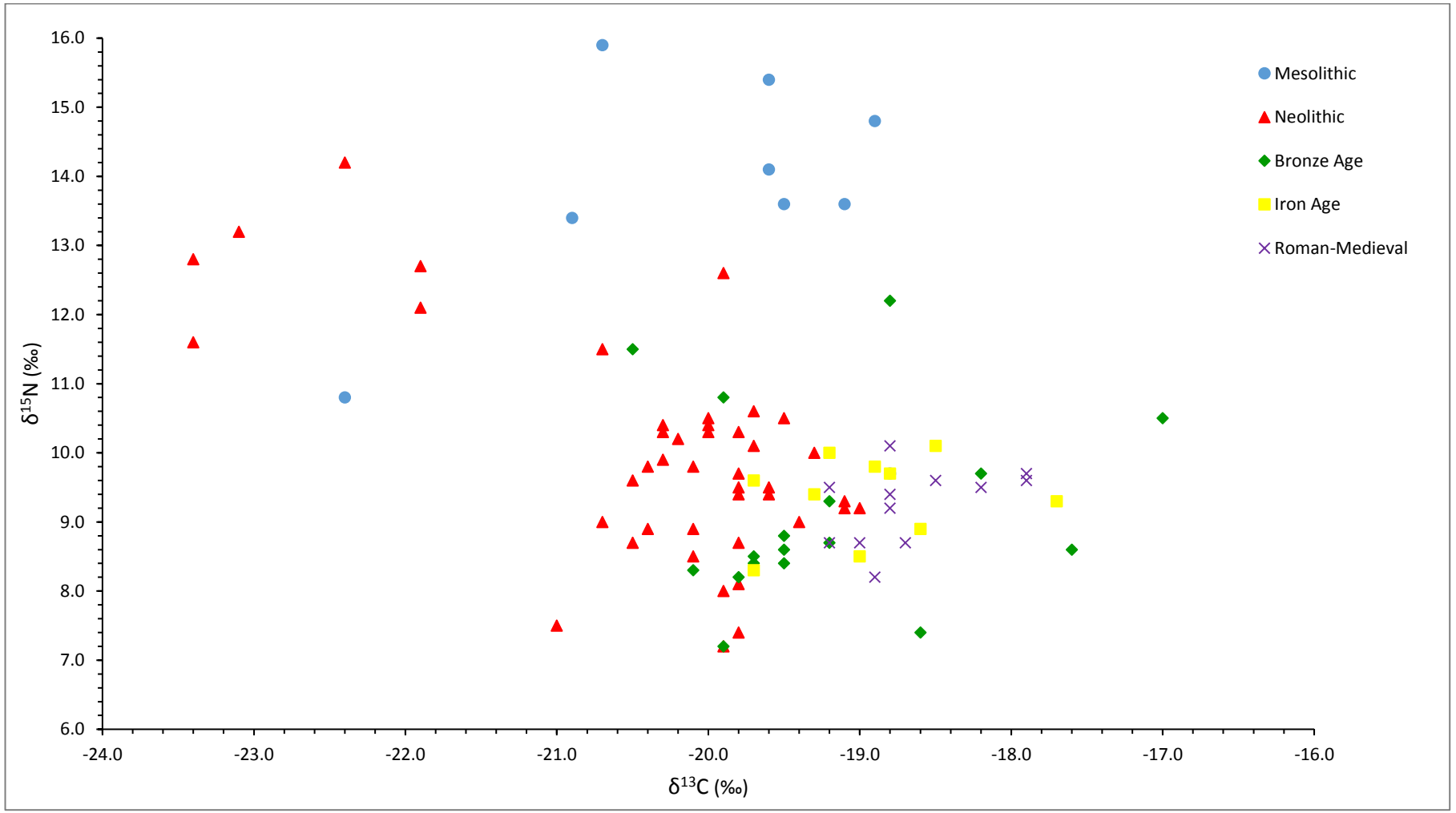


Figure 8. Average $\delta^{13}C$ and $\delta^{15}N$ values from published stable isotope studies of Holocene sites in Central and Southeast Europe, divided by time periods (see Appendix 1 for references)

onwards, this region shared uniform dietary practices. This in turn implies that the Mesolithic in those areas (at least in inland regions with large rivers and lakes) may have followed a similar pattern as in Iron Gates, i.e. characterised by the consumption of mainly freshwater and terrestrial protein.

In addition to the Mesolithic Iron Gates sites, some northern and eastern data points (one from Germany, two from Poland and most of the Ukrainian data) stand out from the main group by their higher average $\delta^{15}N$ values, indicating a greater reliance on high-trophic level protein. However, comparing this with the distribution of sites based on time periods (Figure 8), it becomes clear that almost all sites (with only two exceptions, one from Poland and one from Ukraine) with an average $\delta^{15}N$ over +11‰ are either from the Mesolithic or Neolithic periods, where the emphasis on animal protein can be expected.

The average isotope data from Neolithic sites can be characterised by significant variability in both $\delta^{13}C$ and $\delta^{15}N$ values. Most of the Balkan and Central European Neolithic $\delta^{13}C$ values cluster between -19‰ and -21‰ which is a characteristic signal for farming-herding communities relying mainly on C_3 plants and their consumers. The $\delta^{13}C$ values between -22‰ and -24‰ are found in Ukrainian and Polish sites, and can either be caused by the consumption of aquatic resources, or plants and animals affected by the canopy effect, which has been shown to decrease $\delta^{13}C$ values (see section 2.1.2.). These sites are also significantly more enriched in $\delta^{15}N$, which can either be due to environmental differences (e.g. aridity in the steppe region), or more often, because the Neolithic way of life reached these areas much later, resulting in the longer continuation of Mesolithic subsistence practices heavily reliant on higher trophic level protein.

The Neolithic in Central Europe and the northern Balkans was unified in the LBK culture tradition, which shared relatively homogeneous dietary practices. However, there is considerable variation in average $\delta^{15}N$ values of Balkan and Central European sites, which could have been caused by differential exploitation of animal *vs* plant protein between southern and northern regions, or by differing levels of manuring

altering the $\delta^{15}N$ values of crops. It must also be noted that even in coastal sites near the Mediterranean and the Black Sea, the isotopic evidence for marine resource consumption was negligible during the Neolithic period.

The succeeding Bronze Age shows an overlap with the Neolithic in average $\delta^{15}N$ values, its wide range being similarly explicable by either manuring or differing contributions of meat *vs* plants in diet. In comparison, the range of average $\delta^{13}C$ values has shifted considerably to more positive (even excluding the outlying Ukrainian data), being most likely caused by the supplementary contribution to diets of C_4 plants, such as millet. This trend continued into the Iron Age and Roman–Medieval period, where most sites included in this analysis demonstrated small yet isotopically detectable contributions of C_4 plants to individual diets (up to 35% in some individuals).

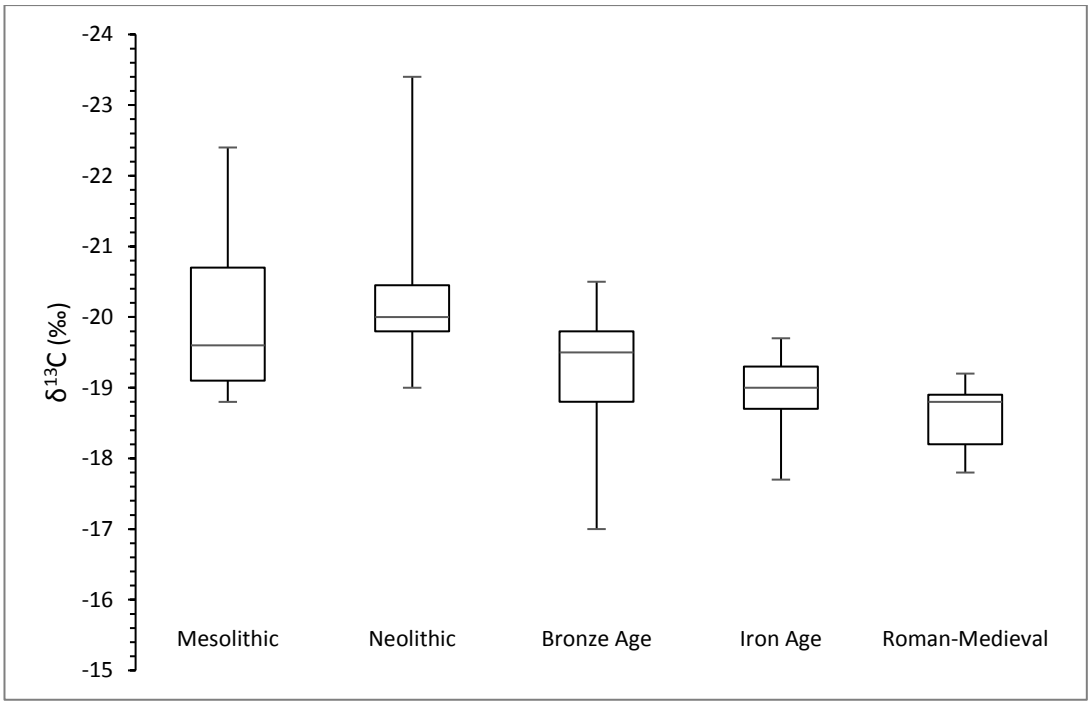


Figure 9. Box plot depicting quartile values with whiskers representing minimum and maximum range of average $\delta^{13}C$ values from published stable isotope studies of Holocene sites in Central and Southeast Europe (see Appendix 1 for references)

This is especially clear in Figure 9 which demonstrates the quartile values (boxes) and minimum and maximum ranges (whiskers) of the average $\delta^{13}C$ values from the five main time periods. In addition to the average $\delta^{13}C$ values undergoing a gradual rise from the Neolithic onwards, the Iron Age and Roman–Medieval data are much more

concentrated and less varied compared to the earlier periods. A non-parametrical Kruskal–Wallis H test indicated statistically significantly different average $\delta^{13}C$ values between the temporal groups (H=44.068, d.f.=4, p<0.001). Pairwise comparisons performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons revealed the differences in $\delta^{13}C$ values to lie between the Mesolithic–Roman/Medieval (p=0.033), Neolithic–Bronze Age (p=0.007), Neolithic–Iron Age (p<0.001) and Neolithic–Roman/Medieval (p<0.001).

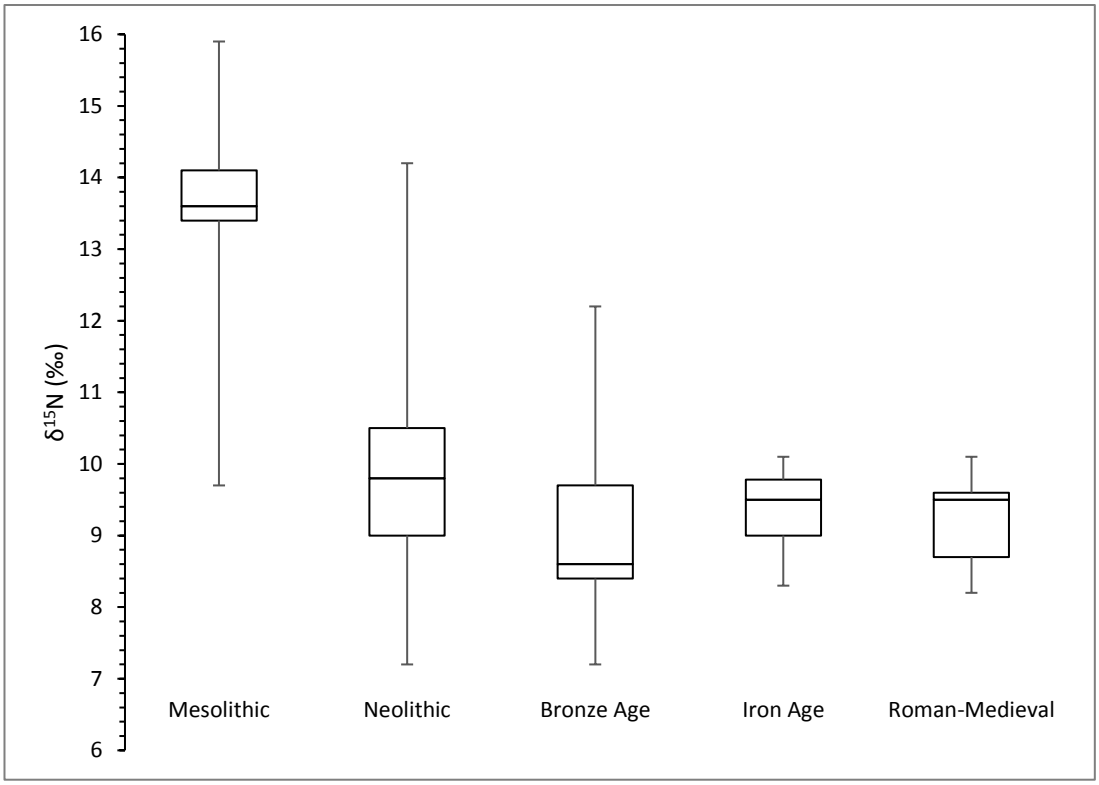


Figure 10. Box plot depicting quartile values with whiskers representing minimum and maximum range of average $\delta^{15}N$ values from published stable isotope studies of Holocene sites in Central and Southeast Europe (see Appendix 1 for references)

Figure 10 shows a similar pattern for average $\delta^{15}N$ values – the range is quite wide for the Mesolithic to Bronze Age periods, but becomes smaller (and almost identical) for the two later periods. While the Kruskal–Wallis H test indicated statistically significant differences between the temporal groups (H=24.343, d.f.=4, p<0.001), post hoc analyses demonstrated the differences to occur between the Mesolithic and all other time periods (Mesolithic–Neolithic p=0.006, Mesolithic–Bronze Age p<0.001, Mesolithic–Iron Age p=0.005, Mesolithic–Roman/Medieval p=0.001), but not between any other group combination.

The possible causes behind the wide variation of average $\delta^{15}N$ values in earlier periods may relate to varying subsistence strategies, which took advantage of specific environmental conditions, or the irregular use of manured plants as either direct food or animal fodder in the Neolithic and Bronze Age. As societies became more complex from the Iron Age onwards, it is reasonable to assume that a degree of uniformity in agricultural practices spread among the new domains, which could explain the small variation in both $\delta^{13}C$ and $\delta^{15}N$ values across Central and Southeast Europe (although this may also be a result of the small amount of comparable data available from late-prehistoric and historic periods in this region).

3.1.7. Variability of Bronze Age subsistence practices in Eurasia

The remarkably wide variation in average isotope values from Bronze Age sites in Central and Southeast Europe, seems, however, more focused when compared to data from contemporary sites in Northern and Western Europe and Western Asia (Figure 11). In addition to studies covered earlier, this also includes data from the United Kingdom, Sweden, Spain, Portugal, Lithuania, Italy, Jordan, Georgia, Kazakhstan, and several sites in southern Siberia (Russia). All these Bronze Age sites were occupied by people who were familiar with agriculture and animal husbandry, although the importance of herding was likely greater in steppe cultures and areas where the 'Neolithic package' arrived later.

The Bronze Age Eurasian data can be broadly divided into three regions which share both environmental and cultural characteristics: North and West Europe (NWE), East Europe and West Asia (EEWA), and Southeast Europe and Mediterranean (SEM). The Kruskal–Wallis H test indicated statistically significant differences for both $\delta^{13}C$ and $\delta^{15}N$ between the three regions ($H=19.184$, d.f.=2, $p<0.001$; $H=33.657$, d.f.=2, $p<0.001$). Pairwise comparisons showed the differences to lie between NWE–SEM ($p=0.019$) and NWE–EEWA ($p<0.001$) for $\delta^{13}C$, and between SEM–EEWA ($p<0.001$) for $\delta^{15}N$.

Northern and Western Europe include sites that have on average low $\delta^{13}C$ and moderately high $\delta^{15}N$ values, although statistically only the former is significantly

different compared to the other two regions. This observation may be influenced by climate-induced variation in plant and bone collagen $\delta^{13}C$ values in Holocene Europe, which results in terrestrial endpoints being 1–2‰ lower in Northern Europe compared to the south (van Klinken *et al.* 2000:43). While statistically non-significant (p=0.061), the relatively higher average $\delta^{15}N$ values in contrast with data obtained from Southeast European studies have been associated with either a greater reliance on animal protein, the consumption of manured plants, or a combination of the two (e.g. diet consisting primarily of animal protein *and* manured plants, or of livestock foddered on manured fields).

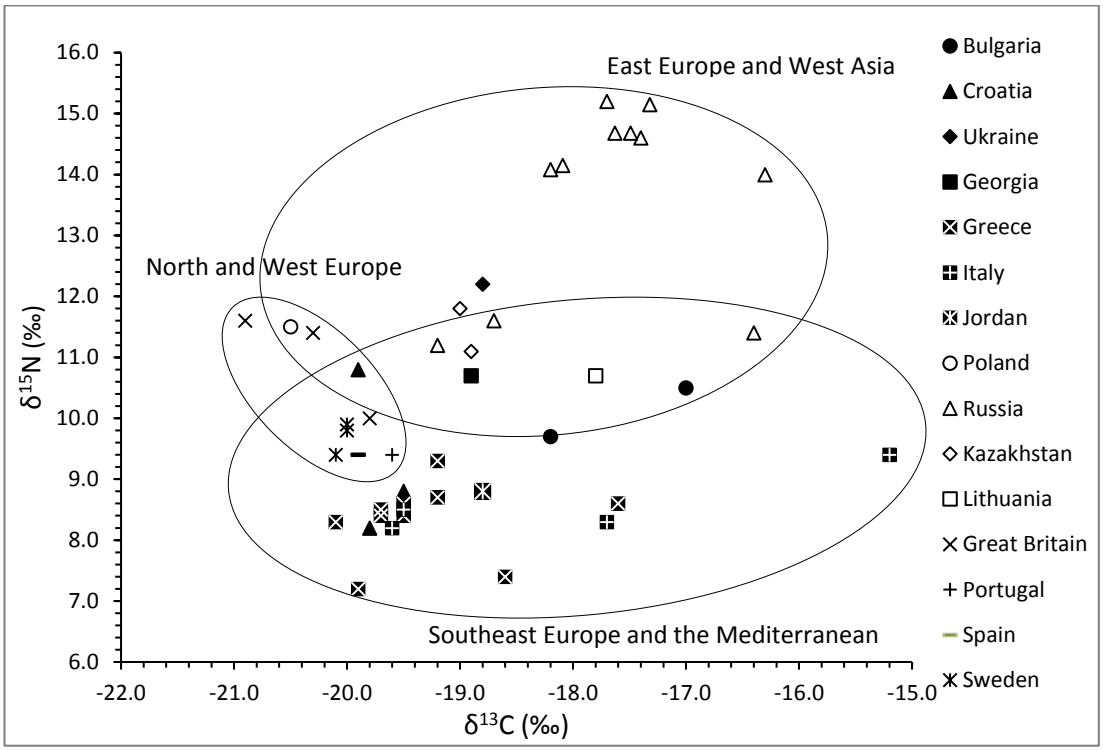


Figure 11. Average $\delta^{13}C$ and $\delta^{15}N$ values from published stable isotope studies of Bronze Age sites in Europe and Western Asia (see Appendix 1 for references)

In England, especially, dairying was an important part of the Bronze Age economy and cereals only became dominant from the Iron Age onwards (Lightfoot *et al.* 2009:303). Both wild and domesticated animal remains were also abundant in the Eton Rowing Lake site in central England, where Bronze Age cattle had an average $\delta^{15}N$ value of +8.2‰ (compared to +5.1‰ for Neolithic cattle from the same sites), which the authors believed was due to intensive manuring (Stevens *et al.* 2012:175).

The second group (East Europe and West Asia) can be described as containing information from East European and West Asian Bronze Age sites and is characterised by high $\delta^{15}N$ values and a broad range of $\delta^{13}C$ values. Most sites in this cluster originate from steppe or forest-steppe environments where aridity, high reliance on animal (and fish) protein and C_4 plants (both wild and domesticated species) have likely influenced the human isotope values. In addition to sites from Kazakhstan and southern Siberia, millet cultivation was also proposed in the Lithuanian study, based on recovered palaeobotanical remains and the slightly enriched $\delta^{13}C$ values (Antanaitis & Ogrinc 2000). Along with Poland, Lithuania does not belong to the steppe environment and as such it is not surprising that the data plot on the fringes of the second cluster, being more similar to other temperate European sites.

The final cluster (Southeast Europe and the Mediterranean) includes additional data from four Bronze Age sites in Italy (Tafuri *et al*. 2009) and one in Jordan (Sandias & Müldner 2015), and can be characterised by low to moderate $\delta^{15}N$ values and a broad variation in $\delta^{13}C$ values comparable to that observed in eastern regions. Several sites in Italy, Greece and Bulgaria display notable contributions from C_4 plants, which in the context of prehistoric Europe, can only be millet. Despite many of the sites in this group being located close to the sea, the isotopic evidence does not support any significant reliance on marine resources during the Bronze Age. The low average $\delta^{15}N$ values in some sites (especially in Greece and Italy) most likely reflects a greater reliance on cereals and/or legumes.

In conclusion, the isotopic evidence for diet in Bronze Age Eurasia has demonstrated a wide variation in $\delta^{13}C$ and $\delta^{15}N$ values, largely influenced by environmental and cultural differences. However, even within the otherwise compact region of Southeast Europe, the isotope values reconstruct a situation where there seems to have been considerable variation (both intra- and intersite) in subsistence practices, e.g. how and what plants were grown and animals kept, and the varying proportions of plant *vs* animal protein in diets. In the following sections, complementary lines of evidence from archaeozoology and archaeobotany will be utilized to reconstruct a more detailed understanding of subsistence preferences in and around prehistoric Romania.

3.2. Archaeozoological and archaeobotanical evidence for human subsistence

The previous section demonstrated that certain regions of Central and Southeast Europe shared a quite uniform isotopic pattern in relation to dietary trends throughout the Holocene. However, stable isotope analysis can only inform us on the general types of food eaten; it is unable to detect more nuanced variations in diet, e.g. to differentiate between cereals and fruits/vegetables, or milk products and meat. For a more thorough reconstruction of palaeodiet in the study region, archaeozoological and archaeobotanical evidence also must be considered. Since the focus of this thesis is on stable isotope evidence of diet, other lines of evidence will be considered here in less detail and only for the prehistoric period.

3.2.1. Animal exploitation

The previous section demonstrated that Mesolithic and Early Neolithic diets in Central and Southeast Europe were characterised by heavy reliance on wild resources and high-protein foods. Archaeozoological evidence from various Mesolithic sites in the Iron Gates region has revealed that red deer and boar were the most common hunted mammals, with brown bear, beaver, wild birds and various species of fish (especially carp, catfish and sturgeon) also frequently exploited (Bonsall *et al.* 1997:57). Dog was the only domesticated animal in the Mesolithic (Bonsall *et al.* 1997:57).

The traditional 'Neolithic package' of cattle, pig, goat and sheep originates from the Near East and first reached Greece and southeast Balkans around 6500 cal BC, arriving at the territory of present-day Romania with the Starčevo/Körös/Criş farming cultures by 6000 cal BC (Biagi *et al.* 2005; Manning *et al.* 2013). In the Early Neolithic, the amount of domesticated animal bones in assemblages from Southeast Europe slowly increases (with sheep/goat being the dominant species), although hunting and fishing are still an important part of the subsistence strategy (Arnold & Greenfield 2006:26; Bartosiewicz & Lillie 2015:414). Regional variations between Greek and northern Balkan Early Neolithic sites are reflected in the former being completely dominated by caprines (accounting for about 78% of the faunal spectrum), whereas the latter

exhibit proportionally much more cattle remains (caprine bones are still the most abundant yet cattle meat yield would have equalled or surpassed that from sheep and goats) (Manning *et al.* 2013).

Bogaard (2004) has theorized that small-scale, intensive livestock management (in connection with intensive garden cultivation) was implemented by the first farmers in the Pannonian Plain, and the practice was generally meat-orientated and did not include intensive dairying or wool production. However, the presence of ruminant fats (milk residues) detected on sherds from Early Neolithic contexts in Hungary and Romania (Craig *et al.* 2005; Evershed *et al.* 2008) has indicated that small-scale dairying was not unknown to the first farmers in Europe.

From the Balkans, farming spread through the Danube valley and the Pannonian Plain further north and west, as evidenced by the first appearance of domesticated animals in Central Europe in the middle of the 6th millennium BC (Manning *et al.* 2013; Bartosiewicz & Lillie 2015). This expansion is associated with the Linear Pottery culture (LBK), which originated in the area of present-day Hungary, Slovakia and Austria (historically referred to as Transdanubia) at around 5600–5500 cal BC (Whittle 1990:297). Compared to southern Balkans, LBK sites have displayed a much greater reliance on cattle (and pig) (Bartosiewicz & Lillie 2015:414) – a change which has sometimes been associated with the increased importance of cattle as a form of wealth and property (e.g. Manning *et al.* 2013:250). Hunting and fishing were still important throughout the region, with the increase of aurochs and wild pig remains sometimes taken as evidence for local domestication (Arnold & Greenfield 2006:27; Bartosiewicz & Lillie 2015:414).

The Late Neolithic–Eneolithic sees the emergence of intensive secondary products exploitation (milk and wool production, use of animal traction) in the region (Bartosiewicz & Lillie 2015:416). As was mentioned above, chemical analyses have demonstrated that this was preceded by small-scale dairying in the Early Neolithic, possibly involving goats, as has been suggested by Greenfield & Arnold (2015). They investigated mortality profiles (based on tooth eruption and wear data) of domesticated

animals in various Balkan sites from the Neolithic to the Iron Age and argued that goats may have been exploited for milk more intensively and longer (from the Early Neolithic onwards) compared to other domesticates. Cattle and sheep, however, showed evidence of secondary products exploitation becoming more intensive only after the Neolithic period (Greenfield & Arnold 2015:810).

By the beginning of the Bronze Age all main domesticated animals were exploited for both their primary and secondary products (Greenfield & Arnold 2015:809). According to Harding (2000:142), Bronze Age economies in temperate Europe were cattle-dependent, although ovicaprids were still predominant in the Mediterranean region. Bartosiewicz (2013), in his study of more than 200 Bronze Age animal bone assemblages across Europe, also found that nearly half of the bones from a typical settlement belonged to cattle (although he pointed out that cattle are often over-represented due to intensive butchering and natural fragmentation of large bones). Caprines accounted for a quarter of a typical assemblage, with a fifth belonging to pigs and the remainder to horse, dog and game (Bartosiewicz 2013:331–332). Domesticated horses, which first appear in archaeozoological assemblages during the Early Bronze Age, were usually not kept for their meat but had great social and military importance (Arnold & Greenfield 2006:30; Bartosiewicz 2013:336).

Wild species are rare in the Bronze Age and disappear almost completely by the Iron Age (Arnold & Greenfield 2006:30; Bartosiewicz 2013:341). For example, the relative abundance of wild mammals in bone assemblages from the Romanian Carpathians decreased from 40% in the Neolithic to 6% in the Eneolithic and 1% in the Late Bronze Age (Becker 1999:98). However, bones from red deer, roe deer, aurochs and boar are often found in most Bronze Age sites in the Carpathians and the Hungarian Plain, indicating that there was no decline in wild animal diversity (Becker 1999:98; Harding 2000:136). Despite the lack of water sieving in many sites, which has made it difficult to collect bird bones, there is evidence for the exploitation of waterfowl, goose and hens (Bartosiewicz 2013:339).

Specialist transhumant pastoralism (the seasonal movement of flocks between summer and winter pastures) has also been suggested by several authors (e.g. Gyulai 1993; Arnold & Greenfield 2006) to have been practised in Bronze Age Southeast Europe. A change in settlement patterns to smaller, more dispersed communities during the Bronze Age has been taken as an indication of increased mobility of the population across the landscape, and with it the opportunistic movement of herds (Arnold & Greenfield 2006:32). Transhumance has been a significant part of the Balkan economy in history, and it is still practised in the Romanian Carpathians today as a common strategy in livestock production for overcoming temporal and spatial shortages in fodder and forage (Arnold & Greenfield 2006:8; Huband *et al.* 2010:56; Juler 2014:1).

Written evidence of transhumance in Romania goes back to the 14th century AD (Juler 2014:4). However, many authors highlight the difficulty of finding archaeological evidence for it in prehistory (e.g. Becker 1999:102; Bartosiewicz 2013:336), although this has not discouraged attempts at achieving this. Arnold & Greenfield (2006) studied harvest profiles (based on tooth wear and eruption) of domesticated animals from prehistoric sites in central Balkans and claimed that their evidence supports the presence of transhumant movement of sheep and goat herds from the Early/Middle Bronze Age, and of cattle herds from the Late Bronze Age onwards (although their evidence was mixed, i.e. it was stronger for some sites than others). In her study of animal slaughter waste from Eneolithic–Early Bronze Age Coţofeni culture sites in western Romania, Becker (1999) suggested that the lack of ribs and vertebrae can be explained with joints of dried or smoked meat being carried away and consumed elsewhere, possibly given to mobile herders.

On the other hand, Harding (2000) disclaimed the existence of specialised transhumant pastoralism in Bronze Age Europe, arguing that flocks were probably still quite small and forest cover too extensive. Alternatively, a low-intensity, short-distance form of transhumance may have existed in Southeast Europe in prehistory. Arnold & Greenfield (2006) contended that in sub-montane and low-altitude settlements in temperate regions there would be less incentive for long-distance transhumance as sufficient water and graze would be available year long. Instead, they suggested a more

localised herding strategy from a village base between swamplands and marshes (which thaw quicker) in the winter and hills in the summer (Arnold & Greenfield 2006:9). Modern Romanian herders also practise a low-intensity form of transhumance called pendulation, where livestock spend the summer months grazing in or near hills but are kept in villages during winter and fed on hay (Huband *et al.* 2010:56).

3.2.2. Plant cultivation

Before the advent of farming, Mesolithic hunter-gatherers, such as those in the Danube catchment area, exploited a wide range of habitats and wild plant resources, e.g. cornelian cherries, various berries, fruits (plums, cherries), nuts (acorns) and seeds (Marinova *et al.* 2013:472). However, the beginning of plant cultivation in Central and Southeast Europe is linked to the spread of the 'Neolithic Revolution' from the Near East, and included the crop package of eight founder species: emmer, einkorn, hulled barley, lentil, pea, chick pea, bitter vetch and flax (Colledge & Conolly 2007:26). These founder crops reached Greece in the Early Neolithic at about 7000–6000 cal BC, and arrived in the northern Balkans slightly later (6000–5500 cal BC) with the Starčevo/Körös/Criş farming cultures (Colledge & Conolly 2007:29).

Early Neolithic sites in Greece and Bulgaria have demonstrated similar crop diversity as in southwest Asia – because of their comparable climate, new crops were easily assimilated and exploited by the first farmers of Europe (Colledge & Conolly 2007:34). Conversely, Colledge & Conolly (2007) argued that archaeobotanical data from sites further north (associated with the Starčevo/Körös/Criş cultures) have revealed a decrease in crop diversity, which could be partly explained by the reduction in the range of pulses used (only lentil and pea were of significant importance in the Early Neolithic of northern Balkans) and a change towards crops better suited for a more continental environment.

Emmer, einkorn and barley were the most common crops grown across the study area during the Neolithic, with legumes and flax also frequently identified in archaeobotanical assemblages but never in any great quantities (Cârciumaru 1996:194–195; Monah 2007:117; Reed 2013:27, 35). Bogaard (2004, 2015) has

theorized on the agricultural mode in the Pannonian Plain in the Neolithic, suggesting that intensive garden cultivation was likely practised, supported by small-scale livestock management where animals were kept close to the settlements and provided manure for the fields. The situation was likely similar for the rest of the study area, with one of the exceptions being the Dnieper river region in Ukraine, where cereal cultivation only became prominent from the Eneolithic onwards (Lillie *et al.* 2011:65).

By the Late Neolithic, new crop species such as bread, durum and club wheat, spelt and broomcorn millet started to become more frequent among archaeobotanical material in the northern part of the Balkans (Cârciumaru 1996:195; Monah 2007:115; Reed 2013:35). Eneolithic sites generally display a similar range in cultivated plants as in the Late Neolithic, with the addition of the first identification of foxtail millet and rye in archaeobotanical assemblages from Serbia, Croatia and Romania (Cârciumaru 1996:195; Reed 2013:28). In Romania, there is also evidence of fruit collection in the form of plum seeds found in a pot together with charred grains of barley (Cârciumaru 1996:196).

A certain continuity of the Neolithic agricultural system (small-scale, intensive cultivation) has been proposed up until the Middle Bronze Age, followed by a marked change and an increase in both species diversity and cultivation intensity in the Late Bronze Age (Harding 2000:144; Reed 2013:181; Stika & Heiss 2013:350). The intensification of farming from the Bronze Age onwards is also evident in pollen diagrams from and around the Carpathians, which demonstrate the opening up of the primeval forests and the advancement of grasslands at lowland areas at around 1200–1000 cal BC; more mountainous areas probably retained their natural forests up until at least AD 1000 (Feurdean *et al.* 2013).

Throughout the Bronze Age in Europe, species of wheat (dominated by einkorn and emmer) and barley were still the most common crops grown, usually supplemented by legumes (mainly lentil, pea, bitter vetch, grass pea, broad bean and chickpea) and wild plants (fruits and berries) (Harding 2000:143; Reed 2013:31). Rye and oats – although quite rare – have been reported from Bronze Age assemblages from Croatia, Slovakia,

Hungary and Romania (Cârciumaru 1996:197; Harding 2000:149; Reed 2013:57). Millet cultivation sees a significant increase by the Late Bronze Age throughout Central and Southeast Europe (Gyulai 1993:27; Reed 2013:153; Stika & Heiss 2013:351). Fruit cultivation is represented by botanical remains of fig and grape (Reed 2013:58; Stika & Heiss 2013:352, 356).

Of special importance in the discussion concerning palaeodiet is the significance of millet, the only commonly cultivated C_4 plant in Bronze Age Europe, and consequently the only food crop that can be theoretically identified through stable isotope analysis in this context. It is not surprising then that the presence or absence of C_4 resource consumption is mentioned in most isotope studies of Bronze Age and later sites from Central and Southeast Europe, which taken together suggested that millet was commonly grown and consumed in differing proportions, although it was of secondary importance in human diets (Tafuri *et al.* 2009; Petroutsa & Manolis 2010; Lightfoot *et al.* 2013, 2015; Gerling 2014).

The two common species of millet – broomcorn and foxtail millet – originate from Asia, whence they spread to Europe separately from other domesticated cereals (Zohary & Hopf 2000:83; Stika & Heiss 2013:362). Remains of broomcorn millet have been reported from several Neolithic and Eneolithic sites in Central and Southeast Europe (Monah 2007:115; Hunt *et al.* 2008:14), but many authors concede that millet only becomes prominent in this region during the Bronze Age (Gyulai 1993:27; Zohary & Hopf 2000:83; Stika & Heiss 2013:358).

This is supported by recent research by Motuzaite-Matuzeviciute *et al.* (2013) who directly dated millet grains attributed to Neolithic sites in the study region and found that none of them were older than ca. 1600 cal BC (Middle Bronze Age). The oldest dated millet grain from Romania (archaeologically associated with a 6th millennium BC Neolithic culture) was from the Late Bronze Age (1434–1268 cal BC); depositional issues were cited as one of the possible explanations for its presence in a Neolithic context (Motuzaite-Matuzeviciute *et al.* 2013:1080).

4. Archaeological background

This chapter provides an overview of the historical and archaeological background of the osteological material used for stable isotope analysis. First, an introduction to the Romanian Bronze Age and the Monteoru culture will be presented, including information about the research history, chronology and the main characteristics of this period. Then, the focus will shift to the two archaeological sites where the osteological material originates – Sărata Monteoru and Cârlomăneşti – covering their chronology, burial customs, and socio-economic implications based on their material culture.

4.1. Introduction

The Monteoru culture has been referred to as one of the most important and best researched Bronze Age cultures in Romanian prehistory and one of the richest Bronze Age cultures in Southeast Europe (Nestor 1933:94–100; Vulpe 1995:9; Motzoi-Chicideanu 2011:369). However, it is still relatively unknown in Western Europe, largely due to the language barrier. While this has started to change in recent years, most published sources on the Monteoru culture are still in Romanian, and much less frequently in French or English.

The Monteoru culture was first defined by I. Nestor in his 1933 work, '*Der Stand der Vorgeschichtsforschung in Rumänien*'. A good overview of the culture in English is provided in M. Gimbutas' monograph '*Bronze Age Cultures of Central and Eastern Europe*' (1965). While her coverage is outdated in several respects (e.g. chronology), it provides a useful introduction to the material culture of the Monteoru people with detailed descriptions and drawings of the various categories of artefacts. A summary of the Monteoru culture, including its research history, relative chronology and material culture, is also offered by I. Motzoi-Chicideanu (1995), in German.

A more recent account can be found in '*The Oxford Handbook of the European Bronze Age*' (2013), where the chapter by N. Boroffka discussing the Bronze Age in Romania, Moldova and Bulgaria, also briefly covers the Monteoru culture. According to Boroffka (2013:881), many archaeological cultures in Romania are poorly defined and

often only differentiated by pottery decoration styles, a problem at least partially caused by selective publication of materials, which has prevented more complex analyses and comparisons between sites.

The archaeology, stratigraphy and periodization of the Monteoru culture and its eponymous site Sărata Monteoru has been covered by E. Zaharia (1987, 1990, 1991, 1993, 2000). Additionally, I. Motzoi-Chicideanu (2011) has produced a thorough study on the Bronze Age burial customs in the Middle and Lower Danube, which includes information on all documented Monteoru period cemeteries. Several authors (e.g. Vulpe 2001; Motzoi-Chicideanu 2003b) have attempted to establish an absolute chronology for the Monteoru culture – a process now significantly aided by new radiocarbon dates (Frînculeasa 2014; Motzoi-Chicideanu & Chicideanu-Şandor in press).

Information about the Monteoru culture and its various archaeological sites can also be found in more specialised research articles, increasingly published in English. C. Becker's (1999) study on the archaeozoological material of the Bronze Age Monteoru and Coţofeni cultures is a useful source of information on the broader ecological and economic developments in Romanian prehistory. In addition, N. Palincaş (2010, 2013a, 2013b) has theorized on the cultural and ritual aspects of the Monteoru culture based on archaeological and osteological remains, focusing on the sun cult, the status of women, and the symbolic use of animals.

4.2. Bronze Age in Romania

In order to place the Monteoru culture in the wider context of the European Bronze Age, a brief overview of this period in the territory of present-day Romania will be presented, based mainly on N. Boroffka's (2013) review. He divides the Romanian Bronze Age into three periods: Early (ca. 3000/2500 – 2000/1900 BC), Middle (ca. 2000/1900 – 1500/1400 BC) and Late (ca. 1500/1400 – 1200/1100 BC).

According to Boroffka (2013:885), the **Early Bronze Age (EBA)** has some notable similarities and differences with the preceding Eneolithic period. Copper is still the

dominant material among metal finds, but new styles and distinctive shapes in pottery separate it from the earlier phase. Copper, gold and silver were widely available in western Romania but had to be imported in the region to the east of the Carpathians. Remarkable metal finds across the territory – mostly found as hoards or isolated finds – testify to the presence of extensive trade networks in high-status goods. Metal artefacts from settlements and graves include flat axes, leaf-shaped daggers, pins, spiral pendants and gold, silver and copper/bronze lock rings (*Lockenringe*). EBA burials are mostly represented by inhumations in small groups, sometimes covered with earthen mounds (in western Transylvania) or inside stone slab cists (in eastern Transylvania, Moldova and southern Romania).

For the **Middle Bronze Age (MBA)**, Boroffka (2013:885) emphasizes the increase in regional differences, especially in pottery shapes and decoration styles, which become the main distinguishing feature of the various MBA cultures. Pottery decoration is generally incised and can be characterised as spiral-meandroid (e.g. zigzags and circles filled with concentric lines). A diverse range of drinking or ceremonial vessels such as those of the *kantharos* or *askos* type are interpreted as reflecting a change in social customs. The first appearance of tin-bronze in the region occurs during the MBA (Boroffka 2013:888). Tin deposits were locally abundant (mostly in Transylvania) but foreign goods are also still present and reflect long-distance contacts with the steppes in the east, Central Europe in the west and Mycenaean Greece. Examples of metal finds include swords and daggers with riveted grips and decorated with spiral motifs, socketed spearheads, metal knives and sickles, pins, pendants and lock rings. The generally large size of the cemeteries (up to hundreds of graves) and a wide variety of burial customs is typical for the Romanian MBA (Motzoi-Chicideanu 2011; Boroffka 2013). The dead were deposited as crouched inhumations, simple cremations in urns, more complex urn burials with grave goods, in stone cists or catacombs, or under earthen mounds.

During the **Late Bronze Age (LBA)** the western, eastern and southern regions continued their local development, while their differences became even more accentuated owing to influences from neighbouring areas to the west, east and south

(Boroffka 2013:889–890). The western channelled pottery group had close relations with the Urnfield culture in Central Europe and practised cremation burials in urns, whereas the southeastern Noua group sustained its tradition of crouched inhumations while demonstrating connections with the steppe region visible in pottery and metal objects. Boroffka (2013:890) also mentions the decreasing diversity in pottery forms, the continued presence of long-distance trade in luxury goods and the increase in local metallurgy as some of the characteristics of the LBA. The workmanship of local smiths is evident in numerous bronze hoards, sometimes containing up to 1000kg of metal (Boroffka 2013:894).

4.3. Monteoru culture

4.3.1. Overview of culture

The Monteoru culture flourished during the MBA in the area of present-day eastern Romania (Figure 12). The high peaks of the Carpathian Mountains and the vast plains to the east and south acted as natural boundaries to the Monteoru people who occupied the hilly region in between, often referred to as the Sub-Carpathians (Zaharia 2000:102). The landscape can be characterised by deciduous forests, low hills and numerous valleys, which comprise the catchment area of the River Siret (Becker 2000:66). The abundant river valleys and passes also make the Carpathians relatively easy to cross, which benefited long-distance exchange between Monteoru settlements and the communities living on the other side of the Carpathian ridge (Becker 2000:66). The present climate in the region is continental, with hot summers and cold winters, average annual precipitation of 650mm and average annual temperature about 9°C (Becker 2000:66; Rădoane 2001:113, 143).

The Monteoru culture seems to have been located at the centre of various transport networks, expressed in both foreign cultural influences (as evidenced in burial customs) and exotic goods. These trade contacts extended to Transylvania (via easily accessible mountain passes), to the Black Sea and even to the sphere of influence of Mycenaean Greece (Motzoi-Chicideanu 1995). Besides foreign imports, one of the main characteristics of the Monteoru culture was its rich ceramic inventory, including

vessels of various shapes and sizes, such as two-handled cups of the *kantharos* type, *askos* cups, mugs, drink-offering vessels, storage jars and bowls (Zaharia 1990, 1991). Ceramic decoration was incised and usually included horizontal lines, zigzag motifs and sun patterns (Zaharia 2000).

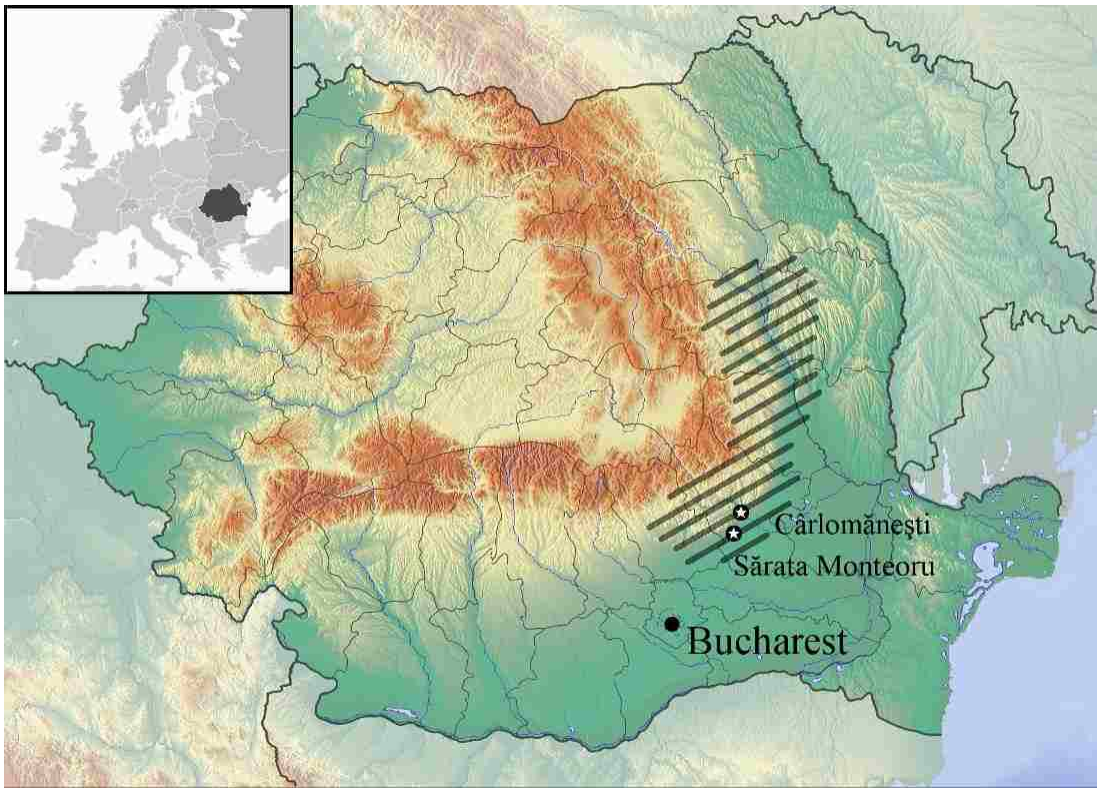


Figure 12. Map of Romania showing the area of the Monteoru culture and the locations of Sărata Monteoru and Cârlomăneşti ('Location map of Romania' by Wikimedia Commons user Dr Brains used under GNU Free Documentation Licence 1.2, modified by Ü. Aguraiuja)

Almost all forms of bronze objects from the Monteoru culture are either western or eastern in origin – unlike other parts of Romania, this region does not have any natural copper deposits (Gimbutas 1965:228; Motzoi-Chicideanu 2011:370). There is some evidence for local bronze metallurgy in the Monteoru culture – in the form of several moulds for shaft-hole axes from the site of Sărata Monteoru (Gimbutas 1965:228) and Năeni Zănoaga *Cetatea 2* (Motzoi-Chicideanu & Şandor-Chicideanu 1999:64–72) – but the raw materials were likely imported from Transylvania. Bronze objects are most often found in graves or hoards, although the latter only occur on the periphery of the Monteoru culture area (Motzoi-Chicideanu 2004:78). The region also has abundant salt deposits, with many Monteoru sites being located near saltwater streams – a detail

sometimes revealed in toponymic origins (e.g. ‘Sărata’ means ‘salty’ in Romanian) (Motzoi-Chicideanu 2011:370). Salt may have played an important part in the extensive trade network of the Monteoru communities, possibly being traded for western metal (Gimbutas 1965:230).

Monteoru settlements were commonly located on higher ground, on naturally protected hilltops and river banks, and often artificially fortified (Zaharia 2000:102). Sites are located quite close to each other, sometimes only 5−10km apart in the most intensively researched areas (Florescu 1985:23). The settlements were often long-lived, as expressed in their multi-layered stratigraphy, and had a surface area around 1−2ha (Florescu & Buzdugan 1962:301). However, dwellings were usually sparsely dispersed around the hill or plateau, indicating that population density inside the settlements was likely low (Zaharia 2000:102). It must be noted that information on the structure of settlement sites and individual houses is rare owing to a lack of properly documented and/or published excavations (Boroffka 2013:885). Nevertheless, available evidence suggests that some buildings had stone foundations (made from rocks collected from nearby rivers), wooden constructions with wattle-and-daub walls, and a round or oval fireplace inside (Zaharia 2000:102; Boroffka 2013:888).

Monteoru communities were well adapted to exploit the specific flora, fauna and climate of the Sub-Carpathian hills (Zaharia 2000:102). Archaeozoological analyses suggest that people focused on breeding domesticated animals such as cattle, sheep, goat and pig, but also exploited wild resources from the surrounding woodlands (Becker 1999, 2000). Many Monteoru settlements (including Sărata Monteoru) were located near fertile black earth (chernozem) soils and have produced archaeobotanical evidence for the presence of barley, emmer, einkorn, spelt, bread and durum wheat, rye, bitter vetch, pea and gold-of-pleasure (Cârciumaru 1983:353−363, 1996:197–198).

In his comprehensive study of Romanian Bronze Age burial customs, Motzoi-Chicideanu (2011) described the cemeteries and funerary practices of the Monteoru

culture in detail. He listed 60 known funerary sites, of which 25 are cemeteries (the rest being mainly isolated finds). Inhumation was the dominant funeral rite (ca. 93% of studied graves), whereas cremations – documented as a secondary custom – may have originated from close contacts with other cultures or belonged to migrants. The cemeteries were usually located close to the settlements and in continuous areas either on the slopes of the settlement or on a separate plateau. Many cemeteries seem to have been carefully planned and used over hundreds of years, while the inhabitants gradually made use of the area immediately surrounding the settlement without disturbing previous burials. Graves are commonly simple pits or have stone constructions (e.g. communal and individual stone rings, stone cists, catacombs). The last mentioned are traditionally interpreted as reflecting an eastern influence. Funerary inventories consisted of various ceramic vessels, gold, silver and bronze ornaments, stone axes, and bone artefacts.

4.3.2. Chronology

The chronology of the Monteoru culture has long been a source of debate. It was initially constructed based on stratigraphic observations, the presence of imported goods and changes in pottery styles, but new radiocarbon data have given cause to reassess the existing system.

The conventional chronology divides the Monteoru culture into periods or phases based largely on the stratigraphy of the Sărata Monteoru settlement site. This stratigraphic periodization was later applied to other Monteoru sites, and the layers became synonymous with the various subphases of the Monteoru culture (Zaharia 1987, 1990, 1991, 1993; Motzoi-Chicideanu 2011). However, this long-established system has attracted a great deal of criticism. Not all the excavated Monteoru sites have been properly analysed or even published, which means that limited evidence has been used to create an overarching chronology (Motzoi-Chicideanu & Chicideanu-Şandor in press). Motzoi-Chicideanu (2011:370) also criticized the system for paying too little attention to the actual contents of layers and the chronology of individual sites, and focusing too heavily on the visual characteristics of ceramic vessels. He even suggested referring to the layers not as periods or phases, but as ceramic styles.

Traditionally, 13 habitation levels were recognised in the Bronze Age deposits of the Sărata-Monteoru settlement site, each thought to correspond to a phase of evolution in the Monteoru culture and named after the designations of the layers: Ic4 (with three levels), Ic3 (with three levels), Ic2 (with two levels), Ic1, Ib, Ia, IIa, IIb (with one level each) (Zaharia 2000). Moreover, a 'proto Monteoru' level of Zănoaga I is often added at the beginning of the sequence, and a transitional period with elements from the succeeding Noua culture at the end (Table 1) (Motzoi-Chicideanu & Şandor-Chicideanu 1999).

Table 1. Relative chronology of the Monteoru culture with the traditional designation of phases/periods and the defining characteristics of ceramics (after Zaharia 1993, 2000; Motzoi-Chicideanu 2003b; Motzoi-Chicideanu & Chicideanu-Şandor, in press)

Phase	Spread	Defining characteristics of ceramics
Zănoaga I	Only in the site of Năeni-Zănoaga	Undecorated pottery. Vessel types include single-handled cups, conical bowls, small amphorae and large storage vessels
Ic4	Southern range of the Monteoru area	Initially undecorated pottery, then incised decoration (horizontal grooves, zigzags, concentric lines). First appearance of the double-handled *Kantharos* cup – a typical feature of classical Monteoru pottery
Ic3	All Monteoru area	Incised decoration, geometrical motifs. New ceramic vessel types include *askos* cups and globular vessels with an everted rim
Ic2	Restricted spread, only in a few sites	Relief decoration, omega motif. *Kantharos* cups dominate
Ic1	Only in the site of Sărata Monteoru	Incised decoration, motifs same as in preceding phases
Ib	Only in the site of Sărata Monteoru	Incised decoration, a new element is wavy lines forming connected wreaths or spirals
Ia	All Monteoru area	Incised decoration, horizontal lines
IIa	All Monteoru area	Incised decoration, geometrical motifs
IIb	Restricted spread, only in a few sites	Decoration like IIa, but a new element is knobs
Monteoru–Noua	Monteoru–Noua area overlap	Influences of IIb and Noua style

The origin of the Monteoru culture is still a much debated and poorly understood topic. Gimbutas (1965:220) proposed that the roots of the Monteoru culture lay in the Kurgan culture, whom she believed to be the proto Indo-Europeans. A more recent view envisages the origins of the Monteoru culture in the plains to the south (Motzoi-Chicideanu 2011:370). The first manifestation of the Monteoru culture can already be seen in the EBA, in the so-called Monteoru–Zănoaga phase documented in the levels

of Zănoaga Ia–Ib at the site of Năeni-Zănoaga (Motzoi-Chicideanu 2003b:49; Motzoi-Chicideanu & Chicideanu-Şandor in press).

The early stage of the Monteoru culture, phase Ic4, is only known from the area south of the Carpathians, followed by phase Ic3, which traditionally is considered as the beginning of the classical Monteoru culture (Zaharia 2000:103). However, it has been suggested by Motzoi-Chicideanu & Chicideanu-Şandor (in press) that the pottery styles Ic4 and Ic3 are not sufficiently well defined or distinctive enough to be treated as separate phases.

Phases Ic2, Ic1 and Ib are all quite restricted in their extent throughout the Monteoru culture area (Zaharia 2000:103; Motzoi-Chicideanu 2003b:50). They are distinguished by differences in ceramic decoration style, but the latter two 'phases' have only been found at Sărata Monteoru, suggesting they were merely local manifestations (Zaharia 1993; Motzoi-Chicideanu & Chicideanu-Şandor in press).

The next phase Ia is considered to be both rich in content and widespread, and is commonly regarded as one of the longest phases of the Monteoru culture (Zaharia 2000:104; Motzoi-Chicideanu 2003b:50). Mycenaean ornaments on bone cheekpieces, glass and amber beads, and gold, silver and bronze items associated with this layer are testament to extensive trade contacts across Europe (Gimbutas 1965:225; Zaharia 2000:104).

The beginning of phase IIa can be characterised by changes in society reflected, among other things, in the strengthening of the Sărata Monteoru settlement site with a defensive moat, and an increase in metallurgical activities (Zaharia 2000:104). Extensive trade contacts continued to be important, reflected in the presence of amber and glass paste beads in cemeteries of this phase (including Sărata Monteoru cemetery no. 4) (Bârzu 1989). The following phase IIb is not as well represented in the archaeological material and was likely short (Oancea 1981). Typical IIb pottery is often found mixed with elements from the succeeding LBA Noua culture – this is sometimes considered as a transitional phase between the two cultures and effectively

marks the end of the Monteoru culture and the beginning of the LBA in the Sub-Carpathians (Zaharia 2000:103–104, Motzoi-Chicideanu 2003b:51).

Many attempts have been made over the years to set the Monteoru culture in the wider chronological framework of the European Bronze Age. Nestor (1960) placed the Monteoru culture between 1800 and 1300 BC, while Gimbutas (1965) set it around 2000–1300 BC. More recent estimates include 2300–1500 BC (Vulpe 2001), 2500–1600 BC (Motzoi-Chicideanu 2003b) and 2000–1500 BC (Boroffka 2013). Recent research has now produced more than 35 single-entity ^{14}C dates from various Monteoru sites (M. Constantinescu 2015, pers. comm.; Motzoi-Chicideanu & Chicideanu-Şandor in press), which seem to confirm the overall time range proposed by Vulpe (2001), yet the exact temporal position and relationship of the different ceramic phases/styles is more complicated, as can be seen from Table 2.

Table 2. Published radiocarbon dates (and their sources) associated with Monteoru culture phases/periods

Phase	Associated radiocarbon date range	Source
Zănoaga I	2300–2000 cal BC	M. Constantinescu (pers. comm.)
Ic4	2200–1800 cal BC	Motzoi-Chicideanu & Chicideanu-Şandor (in press); M. Constantinescu (pers. comm.)
Ic3	2280–1800 cal BC	Motzoi-Chicideanu (2003b); Motzoi-Chicideanu & Chicideanu-Şandor (in press); M. Constantinescu (pers. comm.)
Ic2	2200–1960 cal BC	Motzoi-Chicideanu & Chicideanu-Şandor (in press); M. Constantinescu (pers. comm.)
Ic1	N/A	N/A
Ib	N/A	N/A
Ia	1880–1680 cal BC	Vasilescu (2013)
IIa	1750–1500 cal BC	M. Constantinescu (pers. comm.)
IIb	1750–1540 cal BC	Motzoi-Chicideanu *et al.* (2012b); Motzoi-Chicideanu & Chicideanu-Şandor (in press)
Monteoru–Noua	1500–1100 cal BC	Frînculeasa (2014)

In the light of the new radiocarbon data, Motzoi-Chicideanu & Chicideanu-Şandor (in press) proposed a revised chronology for the Monteoru culture. They suggested phases Ic4 and Ic3 should be treated as a single entity, dated between 2200 and 1800 cal BC.

Phase Ic2 has only two associated radiocarbon dates, similar to those from earlier phases. Radiocarbon dates for phases Ia and IIa are similar to those for Ic4–Ic2. This contradicts the classical viewpoint, which considers phase Ia as one of the most extensive Monteoru periods. It is also unclear where the intermediate phases Ic1 and Ib (said to have been the most restricted in their spread and duration, see above) are positioned in the absolute chronology and whether they should be dismissed altogether as separate phases. Motzoi-Chicideanu & Chicideanu-Şandor (in press) considered the end of the classical Monteoru culture to have occurred around 1500 cal BC, and the radiocarbon dates by Frînculeasa (2014) from the Monteoru culture cemetery at Câmpina (1500−1100 cal BC) overlapping with those from classical Noua culture (1600–1100 cal BC) likely represented the transitional Monteoru-Noua phase.

The new radiocarbon data go some way toward clarifying the existing chronology, but further obscure the prevailing periodization. It seems likely that instead of a simple, linear evolution of pottery styles, there was considerable overlap between the different decoration techniques and motifs throughout the duration of the Monteoru culture. Henceforth, to avoid further confusion, the present author will use, where appropriate, the terms 'Early' (Ic4/Ic3/Ic2 – ca. 2200−1800 cal BC), 'Middle' (Ic1/Ib/Ia – ca. 1800–1700 cal BC) and 'Late' (IIa/IIb – ca. 1700−1500 cal BC) Monteoru.

4.4. Sărata Monteoru

4.4.1. Introduction and research history

The archaeological site that gave its name to the Monteoru culture is located 16km northeast of the city of Buzău, in the hilly zone of the Sub-Carpathians (Figures 13 and 14). Because of its deep stratification and early discovery in the 19th century, it has been studied extensively and is regarded as one of the most important sites of the Monteoru culture. The settlement site – usually referred to as the *Cetăţuia* (meaning 'Citadel' or 'Fortress' in Romanian) – is situated on top of a natural hill and has thirteen occupation layers corresponding to the classical phases of the Monteoru culture, from Ic4 to IIb (Zaharia 1987:24; Bârzu 1989:40). The archaeological complex also includes the funeral area surrounding the settlement which was divided

into four (no. 1–4) cemeteries (Bârzu 1989:40). The lack of properly published excavation reports and of simultaneous fieldwork on both the settlement and the cemeteries has meant that the exact relationship between the two areas is still poorly understood (Motzoi-Chicideanu 2011:428).

Figure 13. Modern view from the Citadel (Cetăţuia) hill toward the north; the village of Sărata Monteoru below. Photo by M. Constantinescu

The site was initially discovered in the second half of the 19th century by a German architect, E. Honzik, who came across some graves while building baths in the nearby village of the same name (Gimbutas 1965:219; Zaharia 1987:21). The first excavations were conducted in 1917–1918 by another German, archaeologist, H. Schmidt, who located two cemeteries (Zaharia 1987:21). Systematic fieldwork continued after the First World War, led by I. Andriesescu in 1926–1927 and by I. Nestor in 1937–1939 (Maximilian 1962:10; Gimbutas 1965:219). Research resumed after the Second World War until 1958 under the direction of I. Nestor and E. Zaharia (Nestor & Zaharia 1954; Zaharia 1987, 1990, 1991, 1993). In 1994 research continued on the adjacent hill of Poiana Scoruşului, led by E. Zaharia and I. Motzoi-Chicideanu and further excavations on the settlement site were also undertaken in 2007 and 2008 (Motzoi-Chicideanu 2003a).

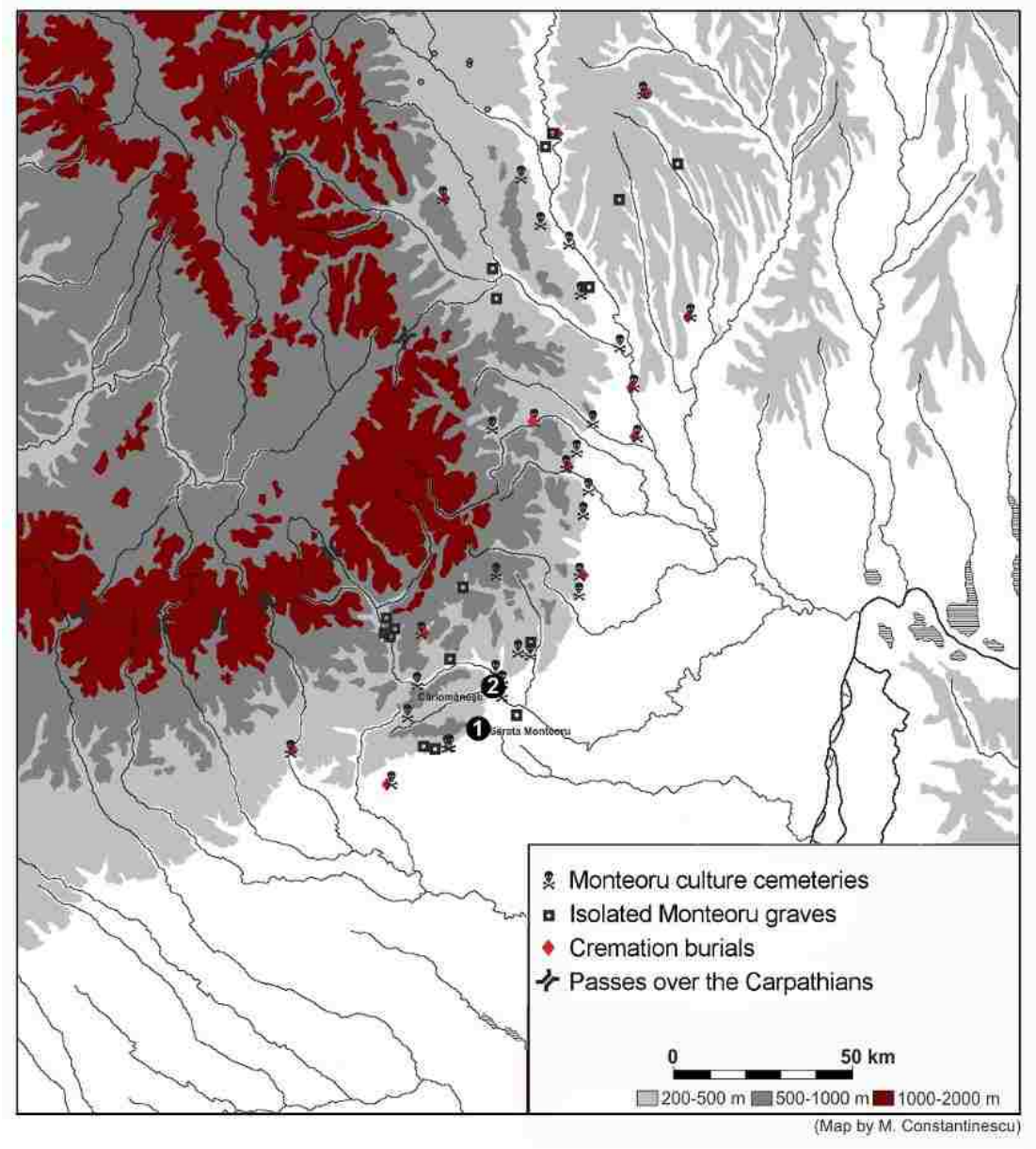


Figure 14. Map of Monteoru culture burial finds and the geographical locations of Sărata Monteoru (1) and Cârlomăneşti (2). By M. Constantinescu

First discoveries at the largest cemetery (no. 4) were made during the field campaign of 1926−1927, with more graves discovered in 1938−1939. Most of the burials were uncovered during further research on the site in 1949, 1950 and 1952 led by I. Nestor and E. Zaharia (Bârzu 1989:39). Some graves were also discovered by chance in 1954 and 1958 (Bârzu 1989:39). Only two of the four cemeteries are published: no. 3 (Comşa 1981) and no. 4 (Bârzu 1989).

4.4.2. Sărata Monteoru archaeological complex

The site owes its name to the small Sărata River which flows at the foot of the *Cetăţuia* (Citadel) hill. Evidence for human occupation in this area spans from the Neolithic to the 12th–13th century AD (Zaharia 1973:17). Sărata Monteoru seemed to have enjoyed a dominant location as it was situated at the centre of connections between Moldavia (east Romania and Moldova), Transylvania (west Romania) and Wallachia (south Romania) (Becker 2000:80). The surrounding area is covered with dense deciduous forests and crossed by streams which swell during downpours (Becker 2000:79).

The surrounding hills and plateaus encompass several archaeological complexes (Figure 15). In addition to the Citadel, a separate settlement of Dealul Leagănului (now destroyed) was located on a nearby hill several hundred metres to the northeast, and an Early Monteoru ritual complex called Poiana Scoruşului ca. 150m southeast of the Citadel (Comşa 1981:111; Motzoi-Chicideanu 2011:429). The sites of Citadel and Poiana Scoruşului are connected by a narrow ridge referred to as 'Col' that was fortified with a defensive moat during Late Monteoru (phase IIa) to allow for control over visitors to and from the settlement (Motzoi-Chicideanu 2003a:363).

The unique ritual complex at the nearby plateau of Poiana Scoruşului had a stone foundation made from rocks collected from the Sărata river and above it a wooden construction with walls made of wattle-and-daub (Motzoi-Chicideanu 2003a:366). Inside were cremated human bones (some still in anatomical positions), burned animal bones and deliberately broken pottery decorated in the Early Monteoru style Ic4–Ic3 (Motzoi-Chicideanu 2003a:363). The structure seems to have been set on fire, after which the walls were caved in and a thick layer of clay was deposited above the rubble (Motzoi-Chicideanu 2003a:367). The complex was initially interpreted as a collective funeral pyre (Nestor & Zaharia 1954), but Motzoi-Chicideanu (2003a:368, 2011:429) believed it was rather a type of burial house or monument designed for a person of high social rank. He also argued that building the structure would have required large-scale social organisation by the Sărata Monteoru community, as the stones and the clay

were probably brought up to the plateau from the river valley below (Motzoi-Chicideanu 2003a:368).

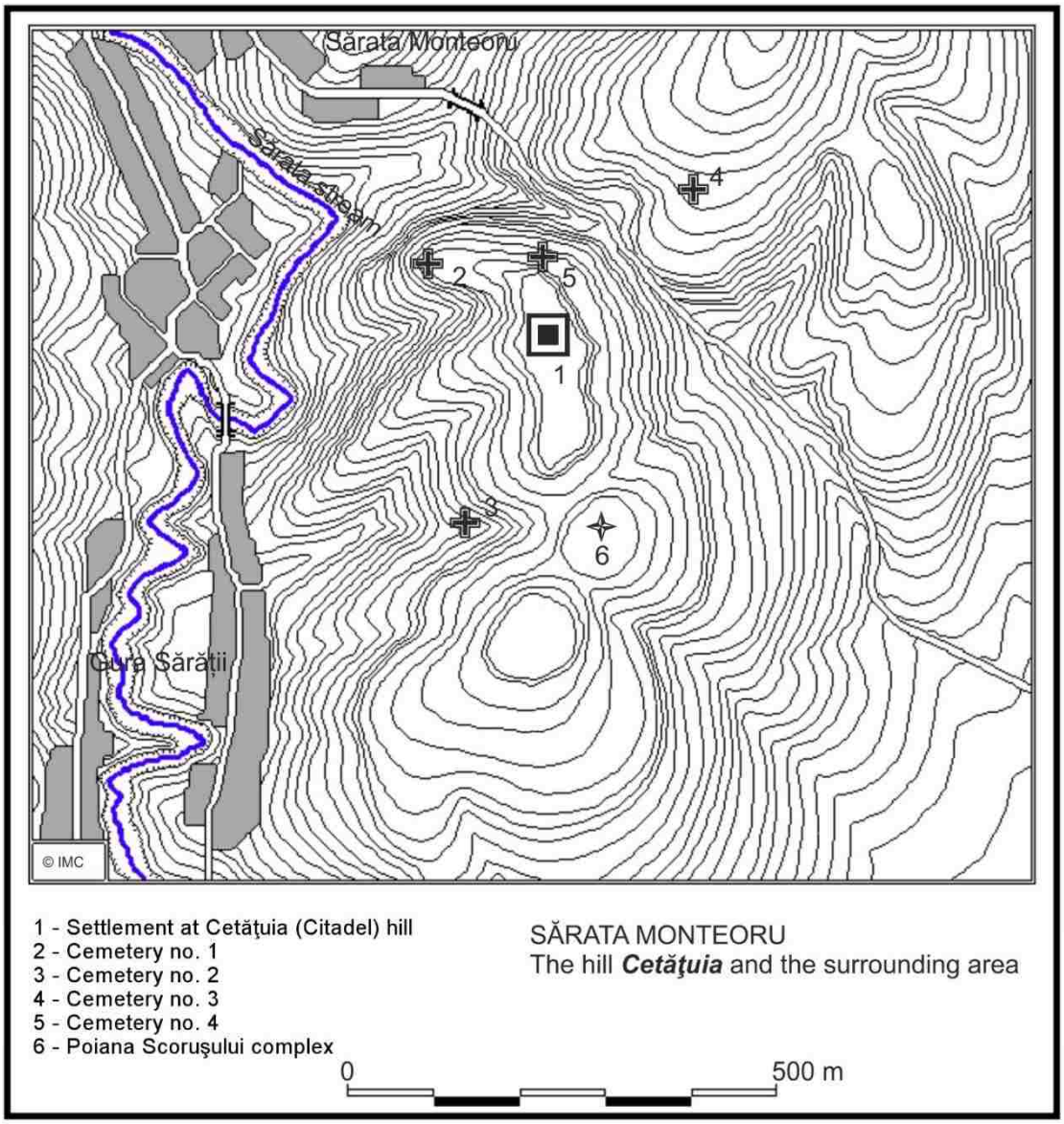


Figure 15. Topographical map of Sărata Monteoru archaeological complex. After Motzoi-Chicideanu (2011, pl. 177)

4.4.3. Cemeteries

The funerary complex at Sărata Monteoru is divided into four cemeteries, three of which (no. 1, 2 and 4) are located on the slopes of the Citadel hill (see Fig. 15) (Motzoi-Chicideanu 2003a:363). Cemetery no. 3, situated on an adjacent slope northeast of the Citadel, is believed to have been associated with the now destroyed settlement of

Dealul Leagănului (Comşa 1981:111; Motzoi-Chicideanu 2011:429). The cemeteries have traditionally been assigned to a phase (ranging from Ia to IIb) based on decoration styles on pottery found as grave goods, covering mainly the Middle and Late Monteoru periods (but see discussion below about the relationship between these different cemeteries). Leaving aside the ritual complex at Poiana Scoruşului, no cemetery has yet been found that corresponds to the earlier period of occupation at the Citadel.

Cemetery no. 1 has never been published but based on information retrieved from the original excavation diaries it consisted of 101 graves (roughly evenly divided between those of adults and juveniles), including 6 cremation burials (as reported by Palincaş 2013b:45). The cemetery is usually assigned to the Late Monteoru period (Bârzu 1989:40; Palincaş 2013b:45; Motzoi-Chicideanu & Chicideanu-Şandor in press). The osteological material from this area was lost during the Second World War (Palincaş 2013b:45). This, coupled with the lack of published reports, means that little more is known about this cemetery.

Cemetery no. 2, assigned to the Middle Monteoru period (phase Ia) and containing approximately 100 graves, is also unpublished (Bârzu 1989:40).

Excavations of **cemetery no. 3** revealed 14 graves, and while a report has been published, no anthropological analysis was conducted on the osteological material (Comşa 1981). Various researchers place cemetery no. 3 either in the Middle (phase Ia) or Late (phase IIa–IIb) Monteoru period (Bârzu 1989:39; Motzoi-Chicideanu & Chicideanu-Şandor in press).

Cemetery no. 4 is the largest and best researched of the cemeteries (Maximilian 1962; Bârzu 1989, 1994) and its osteological material forms the core of this dissertation. It lies on the northern slope of the Citadel hill (Figure 16) and has in total 147 documented graves excavated between 1949 and 1952 (Bârzu 1989:40, 1994:65; Palincaş 2010:300). It is commonly assigned to phase IIa based on ceramic decorations (Bârzu 1989:39; 1994:65), and four radiocarbon samples from this cemetery all fall

within the Late Monteoru period (ca. 1700–1500 cal BC) (M. Constantinescu 2015, pers. comm.).

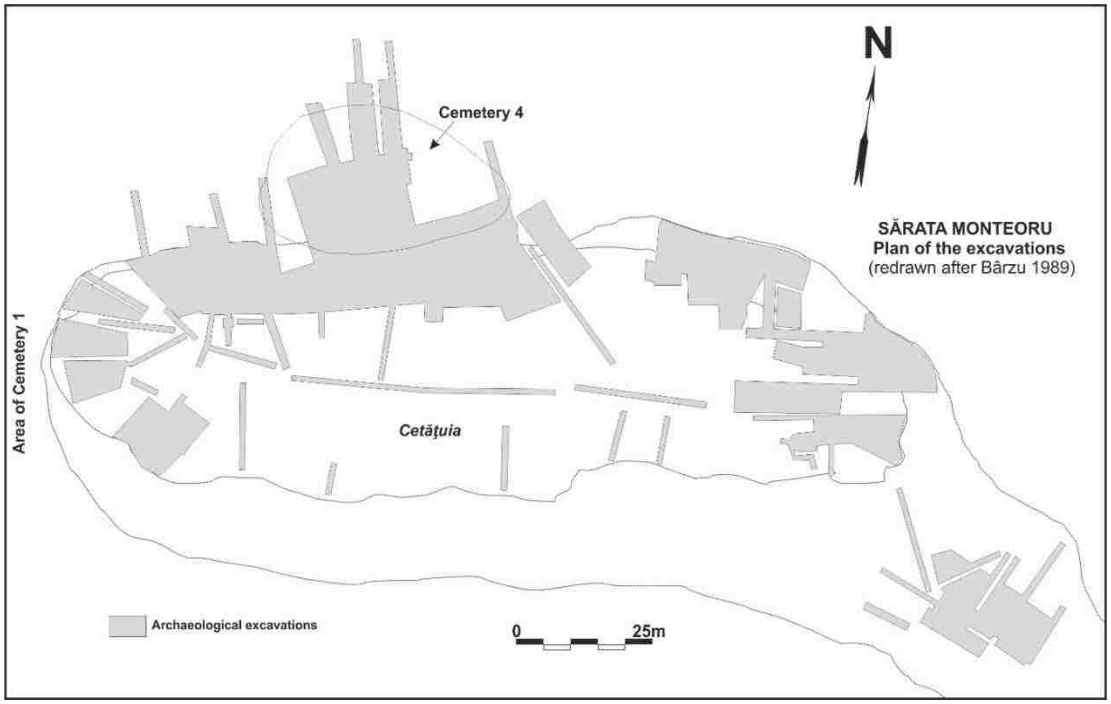


Figure 16. Plan of the excavations at Citadel hill with the location of cemetery no. 4 to the north. By M. Constantinescu

The relationship between cemeteries no. 1, 2 and 4 is ambiguous and is unlikely to be resolved soon owing to the poor state of research of the other cemeteries. While Bârzu (1989:39) claimed that all the cemeteries were distinct areas, Motzoi-Chicideanu (2003a:363, 2011:429) suggested they formed a single, large funerary zone which only appears fragmented because of the incomplete nature of the archaeological excavations. The number of burials and the extent of the cemeteries seems to indicate a long and continuous duration, with new areas taken into use when older ones filled up (Motzoi-Chicideanu & Chicideanu-Şandor in press). The range of ceramic styles that can be found in cemeteries no. 1, 2 and 4 extends from phase Ia to IIb, which, according to the revised (absolute) chronology, only covers a period of about 300 years. Their exact relationship can only be resolved either by new excavations or radiocarbon dates from cemetery no. 2. Therefore, cemetery no. 4 will be treated here as a separate complex.

4.4.4. Cemetery no. 4

The following discussion focuses exclusively on cemetery no. 4 as the best published and researched of the four cemeteries, but also as the source of the osteological material used for stable isotope analysis in this dissertation. The original published account of this cemetery is by Bârzu (1989, 1994), although anthropological observations for many graves were also reported by Maximilian (1962). Bârzu's work contains various mistakes and omissions, including the absence of several burials, discrepancies between drawings and descriptions, and questionable anthropological determinations (as reported by Palincaş [2010:300] and Motzoi-Chicideanu [2011:401]). It is unclear whether the mistakes were made by the original investigators or during the publication process; since the original excavation reports are unavailable and a considerable amount of time has passed since, a critical reading of Bârzu's account is necessary.

As mentioned earlier, phase IIa at Sărata Monteoru – with which cemetery no. 4 is associated, based on pottery style – witnessed an increase in local metallurgical activity, a prosperous long-distance exchange system and the construction of a defensive moat on one side of the Citadel (Bârzu 1989; Zaharia 2000). Unlike cemeteries no. 1, 2 and 3, which were built on low, natural terraces, cemetery no. 4 was situated on the least accessible slope of the Citadel hill (Bârzu 1989:40), perhaps suggesting that the inhabitants had run out of room on the other banks and turned to this area last. Many grave pits were reinforced with stones (likely brought from the nearby stream) or constructed as catacombs that some researchers believe were meant to counteract landslides (Bârzu 1989:40). However, catacomb-graves are also found in other Monteoru cemeteries, such as in Cârlomăneşti where the burials are situated on a plateau instead of a hill slope – there, they are associated with eastern influences (Motzoi-Chicideanu 2011:396; Motzoi-Chicideanu *et al.* 2012a:48). The depth of the graves ranges from 0.40 to 2.25m and may be correlated with the inclination of the hillside (Bârzu 1989:42; Motzoi-Chicideanu 2011:403).

While the graves seem to be placed at random within the cemetery, there are some indications of groups of graves being located close to one another in the central area, which some researchers (e.g. Motzoi-Chicideanu 2011:405) believe was meant to express family or clan relations (see Figure 17 for a plan of the cemetery). A different type of communal relationship is apparent in the mother–child bond as represented by five double graves – often the adult and child were buried in an embracing position which is considered unique in the Monteoru area (Bârzu 1989:50; Palincaş 2010:303).

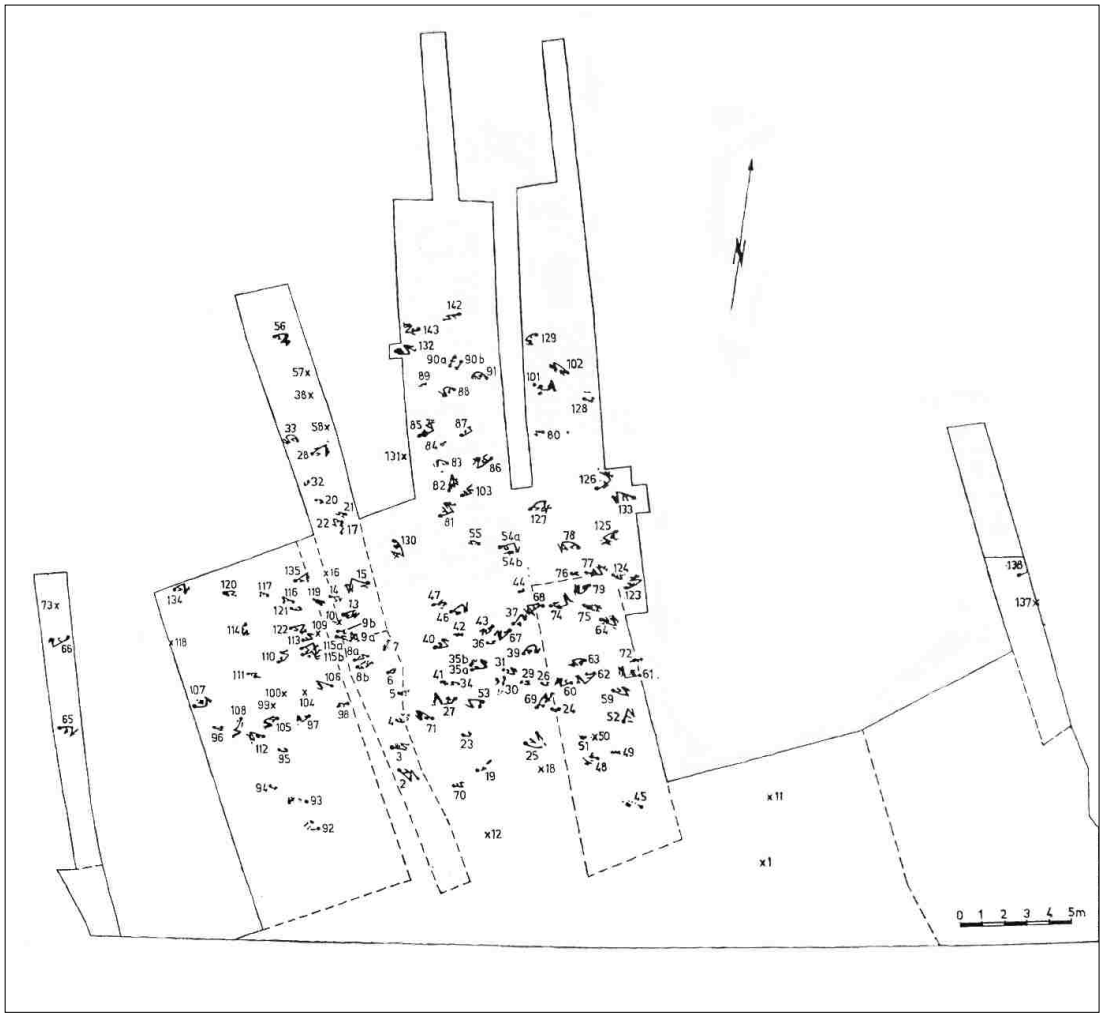


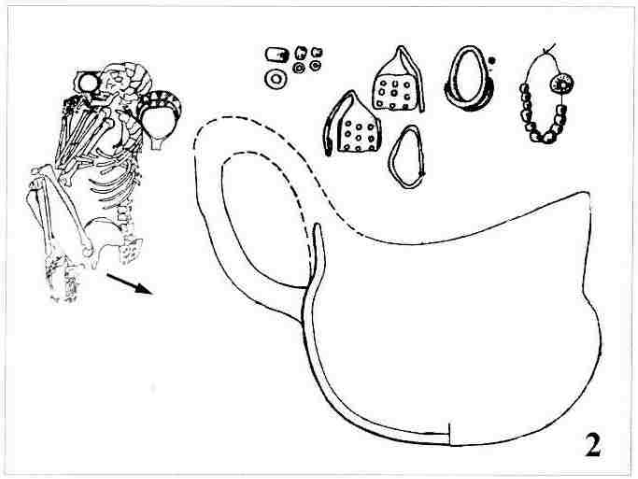
Figure 17. Plan of cemetery no. 4 with the location of individual burials. After L. Bârzu (1989)

Cremation was usually practised as an additional rite in contemporaneous Monteoru cemeteries but it is absent from cemetery no. 4 where inhumation was universal (Bârzu 1989:40). The deceased were generally deposited in the grave individually (although double burials of adult/child or child/child were common), in a crouched position lying

either on the right or left side, with arms bent at the elbow and hands near the face, and the head usually orientated to the west or east (Bârzu 1989:40). More than half of the graves have no grave goods at all; where burial goods are present, they mostly comprise one or several ceramic vessels, more rarely personal adornments and garment pieces, and artefacts made of metal, bone and stone (Bârzu 1989:40–46). Figure 18 shows some examples of typical burials and grave goods at cemetery no. 4.

Ceramics are the most common item deposited in the graves, and often the only one. In total, 44 ceramic vessels from 33 different graves have been recovered from cemetery no. 4 (Bârzu 1989:44). In most cases (24 out of 33) only one vessel per burial was deposited, the maximum number being four per burial (Bârzu 1989:40, 44). The vessels were often large, with a conical lower part and a short cylindrical neck, and either with one or two handles (Gimbutas 1965:220; Bârzu 1989:44). Cups with very distinctive forms are sometimes associated with uncommon or rich burial inventories (Bârzu 1989:44). Vessels were often positioned near the head or in front of the mouth, sometimes even between the hands, which has led some researchers (e.g. Bârzu 1989:45) to suggest that they may have contained a drink, although it should be noted that ceramic vessels were also common in children's graves (Palincaş 2010:307). Decoration was usually incised and included geometric motifs; some cups had no decoration at all but were instead sturdier in their design (Bârzu 1989:45). The firing process was irregular, even on the same vessel, as evidenced by variations in colour (Bârzu 1989:45).

Another important feature of Sărata Monteoru burials are glass paste beads. They were also found in the Monteoru cemeteries at Poiana and Cândeşti where they were associated with the same ceramic style (IIa) as in cemetery no. 4 (Bârzu 1989), or at Cârlomăneşti, where they were accompanied by pottery decorated in the Ic3 style (M. Constantinescu 2015, pers. comm.). Glass paste beads are documented from eight graves at cemetery no. 4 and the largest number from a single grave is 417, which is unusual in the Romanian Carpathian region (Bârzu 1989:50; Motzoi-Chicideanu 2011:425).



Sărata Monteoru
cemetery no. 4
1 - Grave 35a-b
2 - Grave 122
(After L. Bârzu 1989)

Figure 18. Examples of some of the burials and grave goods at cemetery no. 4. Modified from Motzoi-Chicideanu (2011, pl. 203)

These glass paste beads were originally believed to be made of faïence and were thus taken as an indicator for close trade contacts between the Monteoru culture and the Mycenaean area (Zaharia 1973; Gimbutas 1965; Motzoi-Chicideanu 2011). Bârzu (1989:47) conceded that they were in fact made of glass and not faïence, yet still maintained that the beads were Mycenaean in origin, probably made from glass imported from Egypt. According to more recent opinions, the glass was produced in Central Europe and reflects both the development of local metallurgy and the existence of regional trade routes (Motzoi-Chicideanu 2011:425; Motzoi-Chicideanu & Chicideanu-Şandor in press). Glass as a material appears in Europe already in the Early Bronze Age (Henderson 2013:493), so its local production is feasible. Glass beads have been found in other Bronze Age contexts further north in Europe, including Britain and Ireland, and they likely had a high social value (Henderson 2013:493).

In addition to glass, amber beads have been found at cemetery no. 4 (Bârzu 1989:47). They are also known from the Monteoru cemeteries at Cândeşti, Pietroasa Micã, Câmpina and Cârlomăneşti where they are believed to be local in origin (Motzoi-Chicideanu 2011:424; Frînculeasa 2014:145–168). However, Motzoi-Chicideanu (2011:424) argued that Sărata Monteoru amber originates from the Baltic area and was likely obtained through long-distance trade. Amber finds are generally scarce in the Monteoru culture: only five amber beads from four different graves have been documented from cemetery no. 4, two of which are from graves that contained other rare materials such as glass beads and bronze objects (Bârzu 1989:47). This may indicate that amber, in addition to glass, was considered a high status good at Sărata Monteoru.

Another type of grave good is bone artefacts. A characteristic item is a circular bone buckle with a large central, and sometimes small lateral, hole (Boroffka 2013:888). A perforated boar tusk, which was probably worn as a pendant or bracelet was found in one of the graves (Bârzu 1989:50). A bridle cheekpiece made of bone and decorated with a Mycenaean–Minoan influenced spiral motif – found in cemetery no. 2 at Sărata Monteoru – has important implications for both the presence of domesticated horses and long-distance trade at Sărata Monteoru (Gimbutas 1965:61).

Bronze, copper and gold items are mostly manifested as decorative goods, such as neck ornaments (collars), spiral rings, tubular beads, bracelets, pins and lock rings, and usually appear in female graves, less often in those of children (Bârzu 1989:44; Motzoi-Chicideanu 2011:424). As gold and bronze were not available in the Monteoru culture area, they must have been acquired through contacts with neighbouring regions (Bârzu 1989:44). As in other Monteoru cemeteries, weapons are scarce in Sărata Monteoru cemetery no. 4. An antler mace, a bone arrowhead and a stone axe were the only weapons found in the graves (Bârzu 1989:50–51).

4.4.5. Social implications of grave goods

Traditionally, grave goods have been used to draw assumptions about the social system of the community under study. The abundance of grave goods in Sărata Monteoru burials is generally low: 86 graves out of 147 (58%) have no inventory at all, and only 13 of the other 61 burials have a remarkable or 'rich' inventory (Bârzu 1989:50). Bârzu (1989:46, 50) did not believe this society was characterised by a high degree of social inequality, but she went on to propose that social rank may have been hereditary and was expressed through certain kinds of burial goods (jewellery and clothing accessories). She supported this argument with reference to 20 relatively rich child burials, and the fact that one of the three weapons discovered at cemetery no. 4 – a bone arrowhead – was found in the grave of a 1–2-year-old child.

In addition to rich child burials, most of the items that would have been considered as valuable goods (e.g. amber, glass paste beads, gold and bronze ornaments) were usually found in female graves (Bârzu 1989:50). Two of the richest graves in the cemetery belonged to women: no. 35 is a double burial of an adult female and a child containing four ceramic vessels (the highest number found in any grave), two lock rings (one of gold, the other of bronze), a bronze spiral, and beads made of glass paste, amber and bronze; grave no. 142 contained two ceramic vessels, a bronze buckle ring and 417 glass paste beads which adorned either a shroud or a garment (Bârzu 1989:50).

Bârzu (1989:50, 1994:68) suggested that rare and imported items represent social rank and were controlled by women. She also highlighted the mother–child bond

represented in double burials as the primary social relationship and proposed that the high status of women was transmitted to their children with their property, which would explain the richness of child graves (Bârzu 1989:50). Similarly, Palincaş (2010:306) argued that foreign goods marked women's command of long-distance trade and children may have been buried with these items as a sign of their close relationship with their mothers.

The fact that among the burials with grave goods, only eight belong to males (the rest being associated with female and child burials) may support the theory of the privileged status of women in Sărata Monteoru or may just be a consequence of the incomplete nature of the archaeological excavations. As Palincaş (2010:307) observed, while generally many more graves of women and children are richer than those of men, the richest male grave (no. 122) is just as 'wealthy' as the richest female grave (no. 35).

Despite her argument for the higher social ranking of women, Bârzu (1994:68) also claimed that men were likely the real leaders of the community, which she supported with the presence of four unique artefacts with a 'symbolic value' found in male graves: the antler mace and stone axe mentioned above, a bronze ring decorated with a double spiral, and a perforated boar tusk worn as a pendant. The subjects of these burials were referred to as the 'political and military leaders of their community' by Bârzu (1994:68). However, as Palincaş (2010:296, 306) observed, the lack of weaponry in the cemetery does not support the idea of male political leadership or high status for warriors. The three weapons are quite modest and only two of them are associated with adult males, the third buried with a young child (Bârzu 1994:69; Palincaş 2010:306).

Since weapons are rare in Monteoru cemeteries, Motzoi-Chicideanu (2004:62; 2011:426) suggested that their absence from graves does not reflect everyday life but only funeral customs. After all, while personal adornments and garment pieces made of metal or rare materials are common in graves, they are rarely found in settlements or hoards, whereas the opposite is true for weapons (Motzoi-Chicideanu 2011:427).

Finally, it is important to make the distinction between what we as modern researchers consider a rich grave (e.g. jewellery and clothing decorations) and what might have just been a part of the female (funeral) costume. Without knowing the significance of the decorative pieces, the present author would defer assigning social meaning to various items found in male and female graves.

Interestingly, a contradiction seems to exist between the generally poor funerary inventory of most graves and the apparent prosperity of the settlement achieved through trade contacts and represented by rare imported items (Bârzu 1989:44). It has even been claimed that control over the Carpathian passes that linked various European areas through trade routes, allowed the Monteoru communities to thrive and possess the largest number of imported objects in the whole of the Romanian Bronze Age (Palincaş 2010:301). The question remains whether these imported items were controlled by a select few or whether this is another example of funeral customs not reflecting the actual importance of the deceased.

Finally, researchers have also tried to deduce more general ritualistic behaviour from Monteoru material culture. Two cults are proposed to have been practised by the Monteoru people: the sun cult (inferred from solar symbols on pottery) and the fertility cult (inferred from gynomorphic vessels and depictions of animals on pottery) (Florescu 1979; Palincaş 2010). Palincaş (2010:308) saw the two cults as combined into one, and by associating the female gender with the sun, claimed to have further proof for the exalted status of women in Monteoru culture.

4.4.6. Archaeozoological evidence

Only a small fraction of the archaeozoological material from Sărata Monteoru has been analysed, summarised in C. Becker's work on the archaeozoology of the prehistoric Carpathians (1999, 2000). Becker presented data on various sites from the Monteoru culture and the preceding Coțofeni culture. For Sărata Monteoru specifically, she examined a collection of animal bones (n=475) from an Early Monteoru layer at the Citadel settlement, collected during the 1994 excavation campaign. In her analysis she also referred to S. Haimovici's (1994) report on a sample of 511 bone fragments from

a larger collection from the 1948–1952 excavations at Sărata Monteoru, although those bones lack a reliable chronological context (Becker 2000:79).

The animal bone fragments analysed came from an artificial depression filled with pottery sherds (decorated in the Early Monteoru style Ic3) and bone fragments, and sealed by a layer of bricks (Becker 2000:79). As Becker (1999:97, 2000:67) emphasised, this selection was collected for radiocarbon dating (thus focusing on larger and/or more compact bones) and is not necessarily representative of the whole osteological material collected during that campaign. However, despite the random selection and the relatively small sample size, the material has features that are typical of slaughter and consumption refuse, with parts of the skull and elements of the feet being more common than meat-bearing sections of the vertebrae, ribs and limbs (Becker 1999:97, 2000:79).

Becker's (1999, 2000) data show that 99% of the bones (by weight) belong to domesticates (91% by number of identifiable bone fragments). Cattle were the largest supplier of meat based on bone weight (74%), but caprine bones equaled those of cattle based on number of identifiable fragments (44.9% for caprines vs 43.2% for cattle). Domestic pigs and dogs were also represented, though in smaller quantities. No horse bones were identified in the collection, but Becker (2000:81) considered this to be influenced by the small sample size since horse was already domesticated in the Carpathians during this period. Only a few bones were carbonized, four bones (vertebra from sheep, cattle and dog) had cut marks, five bones had been gnawed by dogs, and two bones swallowed and excreted by dogs (Becker 2000:81).

Wild animal bones were few and restricted in their species diversity – only single finds from roe deer (*Capreolus capreolus*) and fox (*Vulpes vulpes*), to which Becker added undated finds of beaver (*Castor*) and bear (*Ursus*) from Haimovici (1994). As evidenced in other contemporaneous Monteoru sites, this region had a rich wildlife, which led Becker (2000:80) to think that the small sample from Sărata Monteoru does not accurately reflect the hunting activities of the local people. However, compared to the preceding Coțofeni culture, the proportion of wild animal bones had significantly

decreased in the slaughter waste of Monteoru sites, a trend that continued into the LBA (Becker 1999:97).

No fish bones were identified among the faunal material from Sărata Monteoru. This could be the result of the small sample size or inadequate recovery techniques; however, a similar pattern was apparent among the material from another Monteoru period site (Năeni-Zănoaga) investigated by Becker (1999, 2000). Even in the preceding Eneolithic/Early Bronze Age Coțofeni culture, the only freshwater species present in significant quantities was shells from the river mussel (*Unio pictorum)* (Becker 2000:73). Certainly, the abundant rivers and streams of the surrounding landscape would have offered plenty of freshwater resources for consumption, yet the present data seem to imply that fishing did not play an important part in the economy of the inhabitants of the Carpathians during the Bronze Age.

Animal bones are also found in Monteoru graves and have sometimes been treated as a separate category of funerary inventory (Motzoi-Chicideanu 2011:427). Leg bones of caprines, phalanges of horse and cattle, and skull elements from caprines and bovids have been found in Monteoru period cemeteries such as Năeni Colarea and Pietroasa Micã (Motzoi-Chicideanu 2011:427). Although not previously documented or published elsewhere, the present author identified 23 animal bone fragments among the human skeletal material from 16 different graves at cemetery no. 4, belonging to sheep/goat, cattle, pig, horse and dog, including three articulated bones from the heel area of a sheep or goat.

Animals that are abundant in deposits from settlement sites (e.g. cattle, sheep/goat, pig) also occur in graves and are traditionally considered as food offerings (Palincaş 2013b:61). Palincaş (2013b:62–64) observed that in Sărata Monteoru cemetery no. 4 animal bones were more often present in graves belonging to children and/or with a rich funerary inventory, although her analysis was mostly concerned with modified artefacts (bone tubes and weapons, perforated shells and teeth) and did not take into account the undocumented animal bones the present author identified among the human burials.

Regarding the aforementioned animal bones from Sărata Monteoru cemetery no. 4, in 10 cases out of 15 (one grave is not reported by Bârzu [1989] and thus no information about its grave inventory is available) they were associated with burials without any grave goods, and in only 2 cases could the burial inventory be described as rich. On the other hand, animal bone finds were associated with child burials in 11 cases, the rest were from adult graves and one from a double burial of an adult and child. None of the adult burials had a remarkable burial inventory. However, it should be noted that these animal bones lack a properly documented context and are only associated with the burials because the bones were found in the same container where the human remains were stored. They were likely misidentified as human bones during recovery or post-excavation.

4.5. Cârlomăneşti

The Monteoru site of Cârlomăneşti is located ca. 12km north-east from Sărata-Monteoru (Figure 12), in a similar environmental setting in the foothills of the Sub-Carpathians. As at Sărata Monteoru, the settlement site at Cârlomăneşti is located on a hill, also referred to as *Cetăţuia* ('Citadel'), on the right bank of the Nişcov River. Between 400 and 500m from the settlement, on an adjacent hill known as the La Arman plateau, lies the cemetery (Figure 19) (Motzoi-Chicideanu 2011:396; Motzoi-Chicideanu *et al.* 2012a:47). The cemetery is partly under the present-day village of Cârlomăneşti and partly under agricultural land, which has significantly hindered attempts to fully research the complex, and has led to the destruction of some of the graves (Motzoi-Chicideanu *et al.* 2007:1; Motzoi-Chicideanu *et al.* 2012a:47).

The settlement site at Citadel hill was investigated between 1972 and 1981, during which time one grave belonging to Late Monteoru (phase IIa) was discovered inside the settlement (Oancea *et al.* 1976). The cemetery remained unknown until local villagers who found pottery and human bones on their land brought it to the attention of archaeologists (Motzoi-Chicideanu *et al*. 2007). Excavations at the southern part of the cemetery started in 2001 and resumed in 2003–2004, uncovering 24 burials (Motzoi-Chicideanu *et al*. 2007). Further investigations in 2008–2009 and 2011–2012 added another 44 graves from the western edge of the cemetery (Motzoi-Chicideanu

et al. 2012a). Finally, excavations from 2013–2014 increased the number of graves to 105 (M. Constantinescu 2015, pers. comm.), although these have not yet been published. The human burials from Cârlomăneşti have also been analysed for osteological data (M. Constantinescu 2015, pers. comm.).

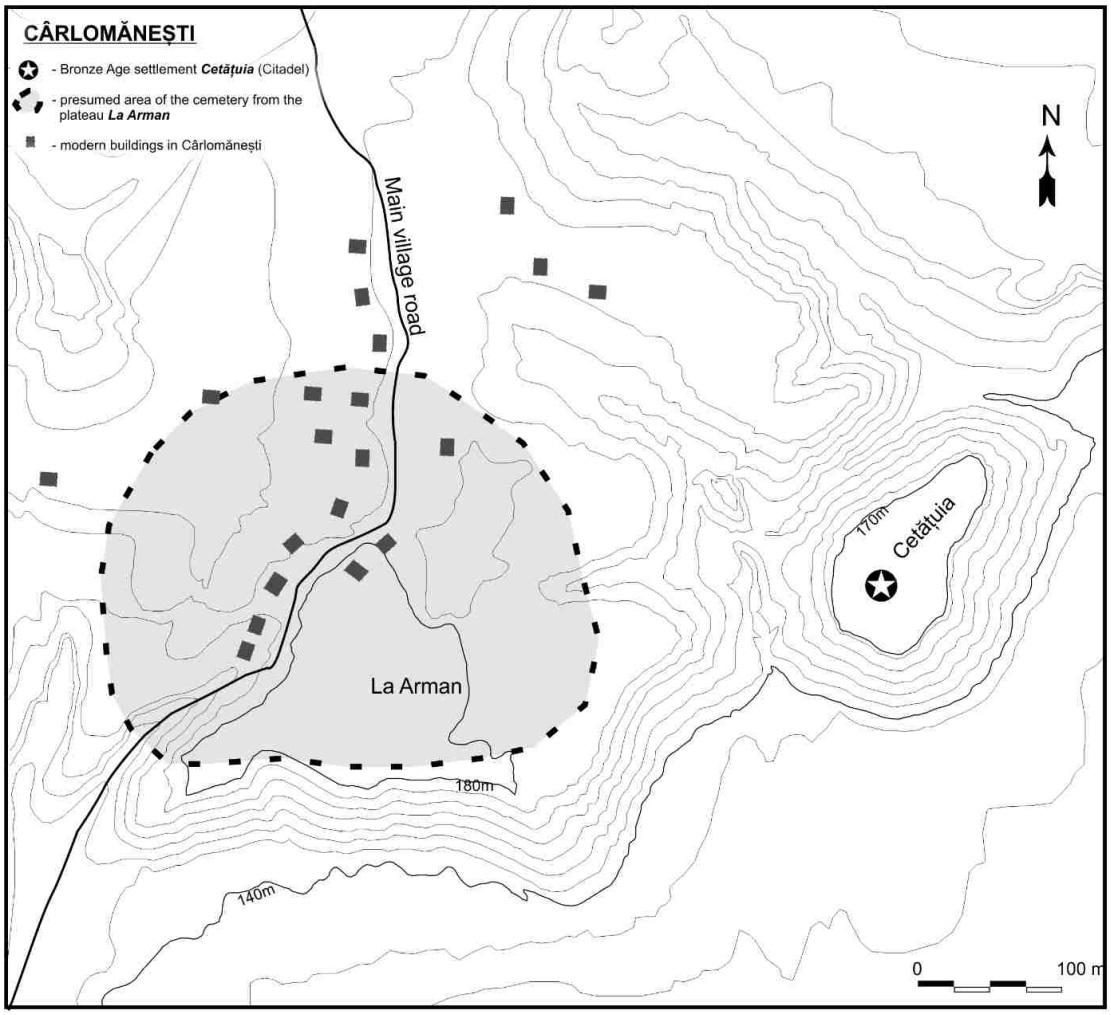


Figure 19. Topographical map of the Cârlomăneşti archaeological complex. By M. Constantinescu

The relationship between the settlement and the cemetery at La Arman is uncertain. Most of the pottery from graves is decorated in style Ic3 (Early Monteoru), although there are some in style Ic1 and Ib (Middle Monteoru) (Motzoi-Chicideanu *et al.* 2012a:50). Radiocarbon dates from 14 burials in the cemetery range between 2280 and 1800 cal BC (M. Constantinescu 2015, pers. comm.). Only one radiocarbon date is currently available for the settlement at Citadel hill – an animal bone associated with Late Monteoru phase IIb was dated to 1640–1530 cal BC (confidence interval of 95%)

(Motzoi-Chicideanu *et al.* 2012b). Interestingly, the cemetery is overlain and often disturbed by Late Monteoru material containing burnt adobe, animal bones and pottery decorated in the IIb style, indicating that the cemetery was likely out of use before the end of the culture (Motzoi-Chicideanu 2011:396). It is even suggested that the cemetery may have belonged to another, bigger settlement site, situated close-by but not yet identified in the field (Motzoi-Chicideanu *et al.* 2012a:50).

The cemetery at Cârlomăneşti is believed to have covered quite a large area, as evidenced by the presence of burials on different sides of the La Arman plateau (Motzoi-Chicideanu *et al.* 2012a:50). Of the 68 published graves, 38 are collective burials with 2–4 individuals (Motzoi-Chicideanu *et al.* 2012a:47). These are interpreted as belonging to families or clans, although they seem to cover a relatively short time span based on ceramic style and radiocarbon dates (Motzoi-Chicideanu *et al.* 2012a:48–50; M. Constantinescu 2015, pers. comm.). Most collective graves appear to follow the same pattern: the initial burial was exhumed, new remains interred, and then the old one re-deposited, sometimes by distributing the original bones among the stone filling (Motzoi-Chicideanu *et al.* 2012a:48). In some cases, adult remains were found in association with disarticulated teeth or fragmented bones belonging to young children.

Most of the graves had some sort of stone structure (e.g. stone cists, catacombs), mainly composed of river stones, limestones or conglomerate boulders, in rare cases with signs of burning (Motzoi-Chicideanu 2011:396–397; Motzoi-Chicideanu *et al.* 2012a:48). The quantity of stones in graves varies from just a few boulders to the entire body being covered. Stones were also found underneath the skeleton and lining the grave pit. While the practice of placing stones underneath or immediately around the body is also known from other Monteoru cemeteries, including Sărata Monteoru, the method of filling the whole grave pit with stones is only known from one other case at Cândeşti (Motzoi-Chicideanu 2011:397). In addition to bones from an earlier burial, pottery (both fragments and whole vessels) was also sometimes found among the stone filling (Motzoi-Chicideanu *et al.* 2012a:48).

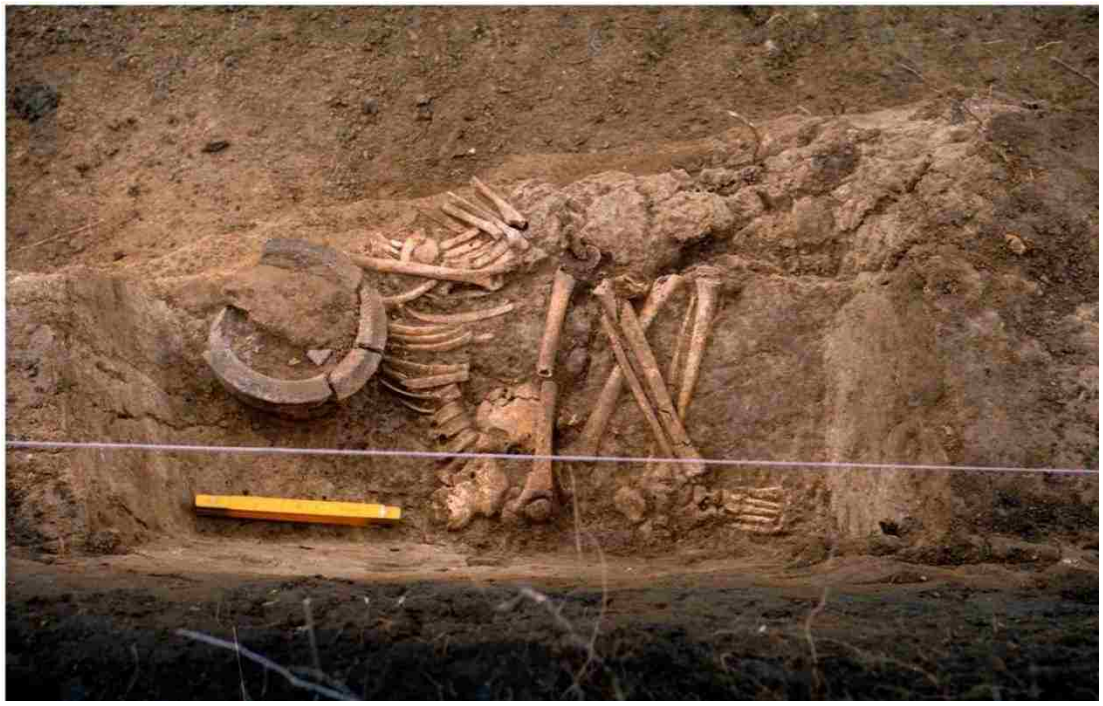


Figure 20. Grave no. 2 at Cârlomăneşti. Photo by M. Constantinescu

Two special types of graves were occasionally found at Cârlomăneşti: cenotaph graves (with stone structures similar to those in other graves, but without any osteological remains) and catacomb graves (Motzoi-Chicideanu 2011:396; Motzoi-Chicideanu *et al.* 2012a:48–49). As mentioned above, catacomb graves are also found in Sărata Monteoru and are believed to have arrived in the Monteoru area from the eastern cultures of Katakombnaja and Mnogovalikovaja (Motzoi-Chicideanu *et al.* 2012a:49). In addition, grave pits with two steps (see Figure 20) have been discovered from the southern part of the presumed area of the cemetery – a phenomenon thus far known only from one other Monteoru cemetery (Cândeşti) but quite common in the Bronze Age Yamnaya and Mnogovalikovaja cultures to the east (Motzoi-Chicideanu *et al.* 2007:10; Motzoi-Chicideanu 2011:397).

Generally, the dead were buried horizontally, in a crouched position lying either on the left or right side, with the head toward the W–SW (Motzoi-Chicideanu 2011:396, 398). Burial pits were commonly rectangular in plan, more rarely circular, and quite shallow, ranging from 0.40 to 1.40m deep (Motzoi-Chicideanu 2011:397; Motzoi-Chicideanu *et al.* 2012a:48). The dominant rite was inhumation, although cremations accounted for 4% of burials (Motzoi-Chicideanu 2011:396). In two cremation graves

burnt bones were deposited in a circular, shallow pit (Motzoi-Chicideanu *et al.* 2012a:48).

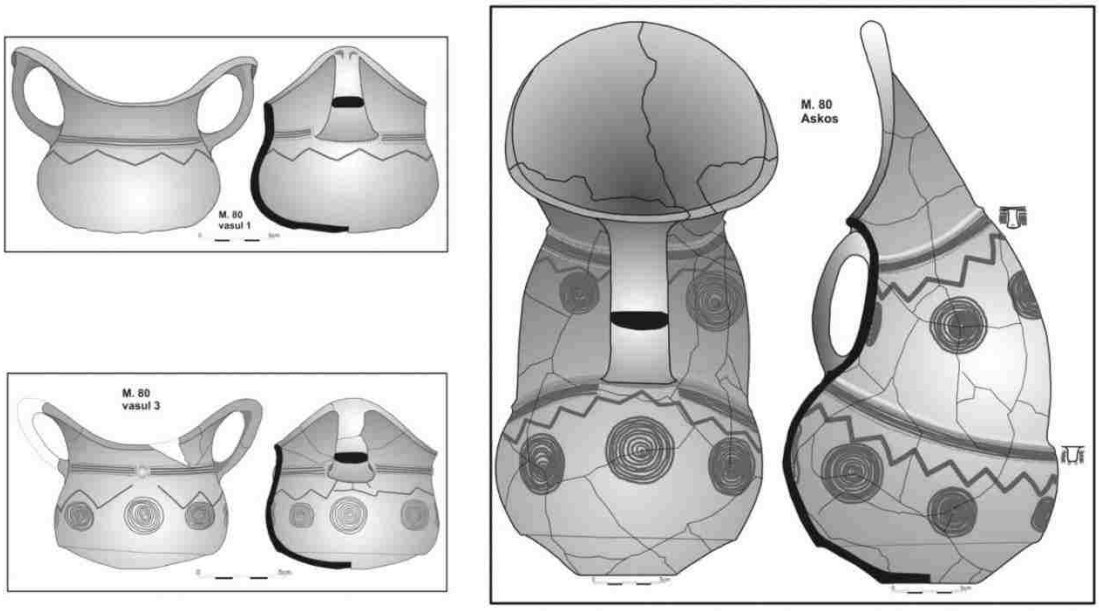


Figure 21. Ceramic vessels from grave no. 80 at Cârlomăneşti. By M. Constantinescu

As at Sărata Monteoru, the most common grave goods were ceramic vessels (Figure 21) (Motzoi-Chicideanu *et al.* 2012a:50). The two-handled *kantharos* cup is the most frequent type, while *askos* and *pyxis* type cups were also popular. Interestingly, common domestic pots are missing from graves. Garment pieces and jewellery are less frequent, being represented by gold and silver lock rings, bronze ornaments, pendants, bracelets and clay beads (Motzoi-Chicideanu *et al.* 2012a:50). Other finds include animal bones and one weapon – a sandstone axe.

5. Materials and methods

This chapter provides an overview of the osteological material that forms the basis of the current study, specifically the human and animal bones from Sărata Monteoru cemetery no. 4 and Cârlomăneşti. Detailed anthropological information on the human bone material (determination of sex, age-at-death and pathological conditions) and species identifications of the animal remains will be presented. Sample selection and the analytical procedure involved in stable isotope analysis will also be outlined, together with a brief account of the various statistical methods used in data analysis.

5.1. Osteological analysis

5.1.1. Sărata Monteoru cemetery no. 4

The first osteological examination of the human remains from cemetery no. 4 was published by C. Maximilian (1962). Despite offering an interesting insight into the Sărata Monteoru population, Maximilian's work is out of date, and fails to conform to some of the modern research practices in osteology. For example, his research focused too heavily on craniometrics and tended to overlook pathological conditions on skeletons (except for skeletal trauma). His analysis also included burials from cemetery no. 2; however, no distinction was made between the different burial areas when discussing the demography and health of the Sărata Monteoru population. Furthermore, Maximilian's monograph offered almost no information about the juvenile burials at cemetery no. 4.

The other source of anthropological data for cemetery no. 4 was compiled by L. Bârzu (1989, 1994) based on original field notes. Bârzu's osteological determinations (sex and age-at-death) are mostly in agreement with those of Maximilian, although there is no indication of whether the data were taken directly from Maximilian's study or analysed by Bârzu herself (or by a third party). The mistakes and omissions in Bârzu's work were mentioned in Chapter 4.4.4. Despite these obvious shortcomings, this is the only published account of the archaeological research conducted at cemetery no. 4,

and as such it is an invaluable source of information on burial practices and grave goods.

Owing to the time and resource constraints associated with a PhD project, a complete anthropological analysis of cemetery no. 4 was not an objective of this dissertation. However, the present author examined all the individuals selected for stable isotope analysis following standard procedures outlined in Ferembach *et al.* (1980), Buikstra & Ubelaker (1994) and Brickley & McKinley (2004). This included sex and age-at-death determination, osteological measurements, and diagnosis of pathological conditions. The author's own findings are preferred to those of previous investigators. A complete overview of the burials from Sărata Monteoru sampled for this study is presented in Appendix 2, containing osteological observations by the current author and information about grave structures, body positions and funerary inventory by Bârzu (1989). A selection of photographs (taken by the present author) of pathological conditions, skeletal changes and noteworthy finds recorded during the analysis of the human remains is provided in Appendix 3.

5.1.1.1. Overview of the material

At the time of investigation, the osteological material from cemetery no. 4 was held at the 'Francisc I. Rainer' Institute of Anthropology in Bucharest, Romania. Over the past 60 years the collection has been in a neglected state and has only recently been re-organised, re-labelled and stored in more suitable containers. In several boxes the present author observed additional human bones or bone fragments (frequently partially articulated and belonging to infants or children), which were clearly not part of the main skeleton. Their context was often unclear; depending on the anatomical connections and the exact number of additional bones, possible scenarios include remnants of a badly preserved extra burial, a secondary burial (post-mortem manipulation), or accidental inclusion of osteological material from a nearby grave. However, when selecting individual burials for stable isotope analysis, every care was taken to ensure that bone samples originated from complete skeletons, i.e. not from potentially mixed material.

In total, 59 individuals from 57 graves (two graves each contained two individuals) at Sărata Monteoru cemetery no. 4 were selected for stable isotope analysis (Table 3). The selection includes 17 juveniles, 13 adolescents and 29 adults. For juveniles (here defined as between the ages 0–12 years), age-at-death was determined as accurately as possible based on tooth eruption stages, ossification of the skeleton, and long-bone measurements. In this context, adolescents are distinguished as having reached sexual maturity (e.g. sex-specific skeletal features, such as the pelvic region, are well defined), but not yet skeletal maturity (i.e. epiphyseal fusion has not been completed). The process of epiphyseal fusion allows for relatively accurate age determination in adolescents. However, once skeletal growth has stopped, the appearance of subsequent degenerative changes in the skeleton is much more individually timed and harder to interpret, as individuals of the same chronological age can show different degrees of development (White & Folkens 2005:363). For adults, the present author has adapted the concept of biological stages of human skeletal development as outlined by Roksandic & Armstrong (2011). To some extent these divisions are subjective, but they are useful for classification purposes.

This approach divides adulthood into four stages experienced by all humans: young adult, fully adult, mature adult and senile adult. The stages reflect 'progressive changes in the experience of the quality of life', while at the same time acknowledging the limitations of aging adult skeletal remains (Roksandic & Armstrong 2011:343–345). The four adult stages can be described as follows: a) young adult – skeletal maturity is reached; closure of all long-bone epiphyses except the medial clavicle; epiphyseal lines are still visible and secondary fusing locations such as the iliac crest are still open; b) fully adult – epiphyseal lines have obliterated and the two superior sacral segments have closed; c) mature adult – appearance of degenerative changes in the skeleton (although these can also be caused by pathology or life-style choices); 4) senile adult – severe degenerative changes in the axial skeleton; obliteration of cranial sutures.

The stages were allocated as follows: 9 young adults, 6 fully adults, 7 mature adults and 7 fully/mature adults (i.e. individuals whose remains did not allow for a differentiation between fully and mature adult). The present author did not identify the

senile adult stage among the remains analysed, although as Roksandic & Armstrong (2011:344) observed, distinguishing between the mature and senile stages can be difficult, especially with incomplete preservation, which was sometimes the case for the Sărata Monteoru burials.

Table 3. Individuals from Sărata Monteoru cemetery no. 4 selected for stable isotope analysis

Burial No.	Age (years)	Sex	Grave goods	Burial No.	Age (stage)	Sex	Grave goods
75b	1–2	N/A	No	13	Young adult	F	No
90b	1–2	N/A	No	53	Young adult	F	No
24	1.5–2	N/A	No	68	Young adult	M	Few
35b	1.5–2	N/A	Rich	81	Young adult	?	Few
50	1–3	N/A	Few	101	Young adult	F	Few
117	2–3	N/A	No	105	Young adult	F	Rich
80	2–4	N/A	Few	107	Young adult	F	Rich
124	2–4	N/A	No	122	Young adult	F	Rich
116	3–5	N/A	No	130	Young adult	F	No
119	5–6	N/A	Few	62	Fully adult	M	No
41	7–9	N/A	No	66	Fully adult	?	No
72	7–9	N/A	Rich	71	Fully adult	M	Rich
88	7–9	N/A	Rich	75a	Fully adult	F	No
70	8–10	N/A	No	85	Fully adult	F	No
120	9–10	N/A	No	106	Fully adult	F	No
12	9–11	N/A	Rich	77	Mature adult	M	Few
128	8–12	N/A	No	78	Mature adult	M	Few
69	15–17	?	Few	79	Mature adult	M	No
82	15–17	?	Few	115a	Mature adult	F	No
102	15–17	?	No	126	Mature adult	M	No
46	16–18	?	N/A	127	Mature adult	M	No
35a	17–19	F	Rich	135	Mature adult	F	No
40	17–19	F	Rich	48	Fully/Mature adult	?	Few
61	17–19	F	No	54a	Fully/Mature adult	F	No
123	17–19	M	No	64	Fully/Mature adult	F	No
125	17–19	F	Rich	65	Fully/Mature adult	?	No
133	17–19	F	Rich	74	Fully/Mature adult	F	No
86	18–20	M	No	108	Fully/Mature adult	M	No
112	18–20	M	No	134	Fully/Mature adult	F	No
63	19–21	F	Rich				

Out of 34 assessable individuals (with fully developed and well-preserved diagnostic anatomical features) the present author identified 22 females and 12 males. Since the selection for stable isotope analysis was made primarily based on preservational

criteria, the ratio between males and females does not necessarily reflect the actual gender balance of the Sărata Monteoru population.

Individuals with varying amounts of grave goods were included in the selection in order to observe whether any differences would emerge in the isotopic composition of their tissues. One grave is lacking information on grave goods since its description was missing from Bârzu (1989). Of the remaining 56 graves, 33 (59%) had no funerary inventory at all, 11 (20%) had 'few' grave goods (consisting of either only ceramic vessels or a single artefact) and another 12 (21%) could be characterised as having a 'rich' inventory (consisting of two or more artefacts, at least one of which was made from a material other than ceramics).

It must be recognized that distinguishing burials based on the number of grave goods may be arbitrary. The quantity of grave goods and their value to the deceased or to the people who buried them may have been unrelated either to wealth or the status of the individual (Porčić & Stefanović 2009:265). The allocation of grave goods among these selected burials mirrors the general observations made by Bârzu (1989). Child and female graves were more likely to contain a funerary inventory than those of adult males, while burials of infants and older adults often lacked grave goods.

5.1.1.2. Palaeodemography

Both Maximilian (1962) and Bârzu (1994) conducted a palaeodemographical analysis of the osteological material from Sărata Monteoru. This offers some insight into the possible population dynamics of the community, although, again, requires a critical approach: the area associated with cemetery no. 4 has not been completely excavated, and it is not clear whether it comprised a unitary burial area with the other 'cemeteries' or not. If the 'cemeteries' were part of a single burial area, then the material studied from cemetery no. 4 would not necessarily be representative of the Sărata Monteoru population as a whole. It is also evident that the number of individuals buried in the area known as cemetery no. 4 was likely much greater than reported by either Maximilian or Bârzu, based on the undocumented partial remains identified among the collection by the present author.

Maximilian's results (which also included burials from other areas at Sărata Monteoru, mainly from cemetery no. 2) demonstrated that child (defined by Maximilian as below 14 years old) mortality was around 30%; however, based on notes from previous fieldwork seasons, he argued that the actual figure was likely much higher, up to 40% (Maximilian 1962:91). Average life expectancy at birth was calculated as 22 years. Among adults (aged 20 and above) there was a relatively even distribution of males and females. However, female deaths were more prevalent in the younger age group (20–30 years) – a common characteristic of prehistoric societies hinting at possible complications associated with childbirth and/or pregnancy. Maximilian also concluded that despite more female deaths in the younger adult stage, women tended to live longer than men, and may have experienced better physical health.

Bârzu's data are somewhat different because her analysis only contained burials from cemetery no. 4. Children between the ages of 0–14 years accounted for about 48% of deaths; among this age group, 35% could be considered as representing infants (0–4 years) (Bârzu 1994:66). This figure is significantly greater than that reported by Maximilian. The dissimilarities are also evident in average life expectancy, which Bârzu estimated to be between 21 and 30 years.

In addition, only seven individuals over the age of 40 were reported by Bârzu, including one over 60. This corresponds well with the lack of individuals belonging to the 'senile adult' stage among those analysed by the present author. Yet there seems to be a palaeodemographic trend in archaeological populations where mortality peaks between 30 and 45 years of age accompanied by an absence of older individuals – a pattern not visible in historical hunter-gatherer societies (Roksandic & Armstrong 2011:338). This signifies that the lack of older individuals does not necessarily reflect the actual demographics of the population, but rather the methodological tendency to underestimate age in over 50-year-olds.

Since the present author did not re-analyse the entire cemetery, no new palaeodemographic data can be added at this point, nor can any previous results be confirmed or disproved. Nevertheless, the available data seem to follow an anticipated

pattern for a prehistoric population displaying a high rate of infant and child mortality, and the prevalence of female deaths at the younger adult stage.

5.1.1.3. Implications for health and diet

Information concerning skeletal and dental pathologies offers valuable insight into the health and diet of both the individual and the population as a whole. For example, the introduction of cereal agriculture and a diet rich in carbohydrates and starches has been linked to an increase in dental caries, whereas protein-rich diets (e.g. among hunter-gatherer groups) are often associated with an absence of caries (Larsen 1983; Hillson 1996). Maximilian (1962:143) claimed that the Sărata Monteoru population had a low frequency of dental caries, although he did not produce any figures to support this observation. The present author detected dental caries in 4 (12%) out of 33 individuals selected for stable isotope analysis (see Appendix 2 for descriptions of pathological conditions documented by the author). In each individual, only one or two teeth were affected, and all four cases were associated with adults. The percentage of individuals affected by caries is similar to that obtained for Bronze Age populations in Britain (15%) by Roberts & Cox (2007). According to Hillson (1996), similar caries rates are also found in populations that rely on a combination of pastoralism, agriculture and fishing.

Furthermore, the present author documented the occurrence of dental calculus (mineralized plaque, identified in 9 out of 33 cases), which had a higher prevalence (27%) than caries. The occurrence and amount of calculus can be affected by poor oral hygiene and/or carbohydrate consumption (Hillson 1996:259). Based on these limited data from a random selection from cemetery no. 4, it can be suggested that the oral health of the population was moderately good, and that they consumed a mixed diet including (but not limited to) carbohydrate-rich plant foods.

Linear enamel hypoplasia (LEH) – a defect of the hard dental tissue – affected 4 out of 33 individuals, all of them adults. Evidence of LEH indicates generalised stress (e.g. associated with nutritional deficiencies or disease) occurring during the period of tooth growth. The location of the stress lines on the enamel of these four individuals implied

that they would have formed around the age of 2–4 years, possibly coinciding with weaning. However, for two of the four individuals, physiological disruption continued beyond that (up to 5–7 years of age). Another stress indicator – cribra orbitalia (porosity of the orbital roof) – was documented in one child (2–4 years old) and one young adult. While this condition is usually associated with nutritional deficiencies, such as iron deficiency anaemia, it could also be caused by infectious diseases or poor sanitation (Ortner 2003:102; Walker *et al.* 2009:114).

Degenerative changes of the skeleton associated with osteoarthritis were present in a third of the adults (mostly those belonging to the mature adult stage), and were typically represented by lumbar osteophytes and eburnation of the tarsal bones. Although sometimes associated with pathological conditions or increased mechanical loading, these features are usually part of the normal ageing process (White & Folkens 2000:398). Additionally, the present author observed robust, mechanically altered long-bones with well-developed muscle attachments on more than half of the adult individuals. Males were more likely to display well-developed lower limbs, whereas twice as many females demonstrated similar features on upper limbs, especially humeri. It seems likely that regular physical activity as expressed in strenuous and repetitive activities and high mobility levels were an important part of the everyday life of the Sărata Monteoru community.

Periosteal new bone formation (inflammation of the periosteum, also known as 'periostitis') on the surface of long-bone diaphyses had a prevalence of 38% among the whole group selected for isotope analysis (with more than half of the juvenile individuals affected). Femora and tibiae were the most common skeletal elements to display the pathology, usually interpreted as a sign of nonspecific infections (Ortner 2003:206). Abnormal bone porosity on the skull (mostly on the temporal, frontal, occipital, zygomatic and mandible) was also frequent (13 out of 37 observable cases), indicating metabolic stress and/or nutritional deficiencies. In two cases (both juveniles 2–4 years old) the combination of abnormal bone porosity with periosteal new bone formation on various cranial and postcranial locations was strongly indicative of

chronic vitamin C deficiency, judged on criteria first established by Ortner & Ericksen (1997) for diagnosing scurvy in skeletal remains.

Vitamin C deficiency is caused by a prolonged (anywhere from 4–10 months) inadequate intake of ascorbic acid (Ortner & Ericksen 1997:213). It can leave the affected individual susceptible to infections, is fatal if left untreated, and is often accompanied by other nutritional deficiencies such as vitamin D deficiency and anaemia (Crist & Sorg 2014:96; Stark 2014:18). Scorbutic lesions, like those evidenced in the two individuals from cemetery no. 4, are expected to occur both in the chronic deficiency stage as well as in the healing phase (Stark 2014:23; Mays 2014:56).

While chronic vitamin C deficiency was most likely rare in prehistoric temperate Europe, these examples are from children 2–4 years old, indicating that the disease may have been related to weaning practices, as suggested by Bourbou (2014) and Mays (2014). If the food used for weaning was devoid of vitamin C (e.g. cereal-based foods such as gruel) or heated (leading to loss of nutrients), it would have had a detrimental effect on the health of young children, who were already susceptible to ailments due to being deprived of the beneficial influences of maternal milk.

5.1.2. Cârlomăneşti

The osteological material from Cârlomăneşti cemetery was recently analysed by Dr Mihai Constantinescu of the 'Francisc I. Rainer' Institute of Anthropology in Bucharest, and the unpublished data are used here with his permission. Ten individuals were chosen from the collection to provide a comparative source of isotopic data for Sărata Monteoru. The selected burials represent various age, sex and social (based on grave goods) groups, and are outlined in Table 4. The classification of grave inventories between 'Few' and 'Rich' follows the same principles as were set out above for Sărata Monteoru.

Six out of the ten burials have been radiocarbon dated. The results fall broadly into two chronological groups – ca. 2200–2000 cal BC and ca. 2000–1800 cal BC (M.

Constantinescu 2015, pers. comm.). These six graves originate from various locations of the burial area (both the southern and the western edge of the plateau), however, there does not seem to be a clear relationship between the radiocarbon data and the location of the graves. A detailed description of the selected individuals is presented in Appendix 4, including information on grave structures, body positions and funerary inventories from Motzoi-Chicideanu *et al.* (2007), Motzoi-Chicideanu *et al.* (2012a) and M. Constantinescu (2015, pers. comm.).

Table 4. Individuals from Cârlomăneşti selected for stable isotope analysis

Burial No.	Age (years)	Age (stage)	Sex	Grave goods
58	8–9	Juvenile	N/A	Few
105a	8–9	Juvenile	N/A	Few
51	9–13	Juvenile	N/A	Rich
24	10–12	Juvenile	N/A	Few
2	13–15	Adolescent	?	Few
1	21–28	Young adult	F	Rich
103	30–38	Mature adult	F	Few
5	30–40	Mature adult	M	Few
80a	30–40	Mature adult	F	Rich
19	45	Mature adult	F	Few

Owing to the relatively recent investigation (between 2001 and 2014) of the cemetery at Cârlomăneşti, no published account of the whole excavated area or the osteological material is currently available. Consequently, no comments can be offered on the palaeodemography, burial customs or health of the buried individuals. In addition, the general state of preservation of the Cârlomăneşti burials was often unsatisfactory, limiting the amount of information that might be gathered from osteological analysis, especially regarding pathological conditions (M. Constantinescu 2015, pers. comm.).

5.1.3. Archaeozoological material

The inclusion of associated faunal remains into isotopic dietary studies has become a common practice. For Sărata Monteoru the choice was limited – while abundant faunal material was recovered throughout the many excavation seasons at the Sărata Monteoru archaeological complex, almost all of these remains are today either reburied, or their current whereabouts unknown. Thus, the only available archaeozoological material consists of undocumented finds from the graves of

cemetery no. 4, identified by the present author. These are assumed to relate with the burial activity (e.g. grave goods or remains of feasting) but it is possible they are derived from earlier or later human activity in this area.

The material from Sărata Monteoru is supplemented with faunal remains from Monteoru-era layers at the Cârlomăneşti settlement site. This collection has not been systematically sorted or organized, and the archaeozoological material lacks a direct association with the burials from the nearby cemetery. However, these faunal remains should be a suitable proxy for the types of animal protein consumed by the individuals buried in the Cârlomăneşti cemetery.

19 bones or bone fragments from cemetery no. 4 at Sărata Monteoru, and 39 from Cârlomăneşti were selected for stable isotope analysis, including the main domesticates cattle, horse, pig, sheep/goat and dog (Table 5). Wild animals were represented by a cervid (most likely a red deer) and a hare. A detailed list of the archaeozoological material sampled for isotopic analysis is provided in Appendix 5.

Table 5. Animal bones from Sărata Monteoru cemetery no. 4 and Cârlomăneşti settlement site selected for stable isotope analysis

Genus	Sărata Monteoru	Cârlomăneşti
Bos	5	10
Equus	1	3
Sus	5	8
Ovis/Capra	7	8
Ovis	N/A	1
Canis	1	7
Cervus	N/A	1
Lepus	N/A	1
Total	19	39

The identification of the faunal remains was made by the present author based on E. Schmid's (1972) '*Atlas of Animal Bones*'. Prof. László Bartosiewicz (at the time a member of staff of University of Edinburgh) helped with the identification of some skeletal elements. Species-level identification was not always achievable; for example, some of the canid bones could belong to a wolf. However, since wild mammals

account for only a small proportion of Monteoru faunal deposits, it seems more likely that most canid remains represent domesticated dogs.

5.2. Stable isotope analysis

5.2.1. Sampling procedure

For the majority of human burials, a rib bone was preferentially sampled because of its ready availability among skeletal remains and its non-vital diagnostic value in anthropological analysis (sternal rib ends were avoided, as these can be used in age assessment). Since Crowder & Rosella (2007:274) demonstrated that there are no histological differences between the 3rd–8th ribs, any suitable rib fragment within that range was considered.

For Sărata Monteoru cemetery no. 4, a subset of related skeletal elements (from both adults and sub-adults) was sampled to observe any potential differences between short-term and long-term dietary signals as expressed in the isotopic composition of trabecular *vs* cortical bone. In 25 cases the rib bone was complemented with a sample from the femur shaft of the same individual. Among these, in 16 occasions, a third location (either from the vertebra, calvarium of the skull, or femoral proximal epiphysis) was also sampled. Finally, in 2 cases multiple samples were taken from well-preserved (adult) skeletons, including from the rib, femoral diaphysis (shaft), calvarium, lumbar vertebra and metacarpal to evaluate the degree of intraskeletal variation.

For animal bones, the sample selection was determined by species representation; all bone fragments are from specimens that were identifiable to at least genus level. Concerning the samples from Cârlomăneşti, it is possible – though highly unlikely – that some bone fragments originate from the same animal. All skeletal elements were described and photographed prior to sampling.

5.2.2. Chemical pre-treatment

All bone samples were prepared in the University of Edinburgh Bone Chemistry Laboratory by the author. For both human and animal bone samples, pieces of ~1g were cut from larger bone fragments using a Dremel® multi-tool with a diamond cutting disc. Samples were physically cleaned with a sterile surgical blade removing the outer 1mm of the bone. They were then washed in ultrapure (MilliQ™) water in an ultrasonic bath for 20 minutes to remove soil contaminants, and left to dry at 37°C for 48 hours. The dry weight was recorded with a Sartorius precision balance (precision level 0.00001g) and the samples put in 100ml of 0.2–1M (depending on bone structure and preservation) hydrochloric acid. The solution was refreshed every 48 hours until the bones were completely demineralized. This took anywhere from a few days to five weeks.

After decalcification, samples were rinsed three times with ultrapure water and left in 0.2M sodium hydroxide solution for 20 minutes to remove humic acids. Samples were rinsed again three times and treated with 1M HCl for 1 hour to remove any carbonates that may have precipitated during the NaOH wash. Following this, bone fragments were rinsed for a final time and gelatinized at 80°C for approximately 20 hours. The gelatin solution was then filtered using a glass microfiber filter (GF/A filter paper with a particle retention size of 1.6μm) and the insoluble residues discarded. The filtrate was evaporated until about 10ml remained and subsequently freeze-dried using a Christ Alpha 1–2 LD^{Plus} freeze drier at -60°C for 48 hours. The resulting collagen was a white to yellowish substance, often fluffy but sometimes flaky or crystalline in consistency.

5.2.3. Incremental sectioning of tooth dentine

First molars from four young adults from Sărata Monteoru cemetery no. 4 were included in the study in order to examine childhood dietary changes in more detail. All four were also sampled for bone collagen to establish adult diet. The methodology used here was adapted from Eerkens *et al.* (2011) and Beaumont *et al.* (2013), who sectioned the dentine of a permanent first molar into 1–2mm thick slices. Since some

of the bone samples from Sărata Monteoru had low collagen yields, 3mm thick increments were applied to ensure enough material for isotope analysis. All teeth were caries-free and with minimal attrition. Individuals under 25 years old were chosen for analysis to avoid the inclusion of secondary dentine, which forms later in life. It should also be noted that first molars were only acquired from individuals who had at least one other complete first molar (either lower or upper) in order to reduce the loss of osteological information.

Teeth were first manually cleaned and washed with ultrapure water in an ultrasonic bath for 20 minutes. The complete tooth was then left in 100ml of 1M hydrochloric acid until it had become soft but still retained its original shape. Dentine was divided by hand into horizontal transverse sections at ca. 3mm intervals, using a sterile scalpel. Depending on the size of the tooth, this method produced 5–6 increments per individual. The sections were then labelled for identification and put back in 1M HCl until demineralization was complete, after which the methodology followed the procedure outlined above for bone collagen. While this method does not offer as high a level of accuracy as could perhaps be achieved by sectioning the tooth while it is still hard (pre-demineralization), less tissue is lost when cutting with a scalpel when compared to cutting with a diamond wheel.

Permanent first molars begin growing at the time of birth at the dentine-enamel junction (DEJ). The crown is completed by 2.5–3 years at the cementum-enamel junction (CEJ) and the apical root tip closes around 9–10 years (the difference in upper-lower, and left-right first molar growth rates is negligible) (Hillson 1996:123). While Eerkens *et al.* (2011) calculated the formation period of a 1mm dentine section to be about 6.9 months in the crown (1.75mm per year) and 6.4 months in the roots (1.87mm per year), Beaumont *et al.* (2013) applied a slightly different rate of anywhere between 9–12 months for a 1mm section. However, it should be noted that tooth growth rate has been shown to vary both between individuals and within a single tooth (e.g. Dean *et al.* 1993; Liversidge *et al.* 1993).

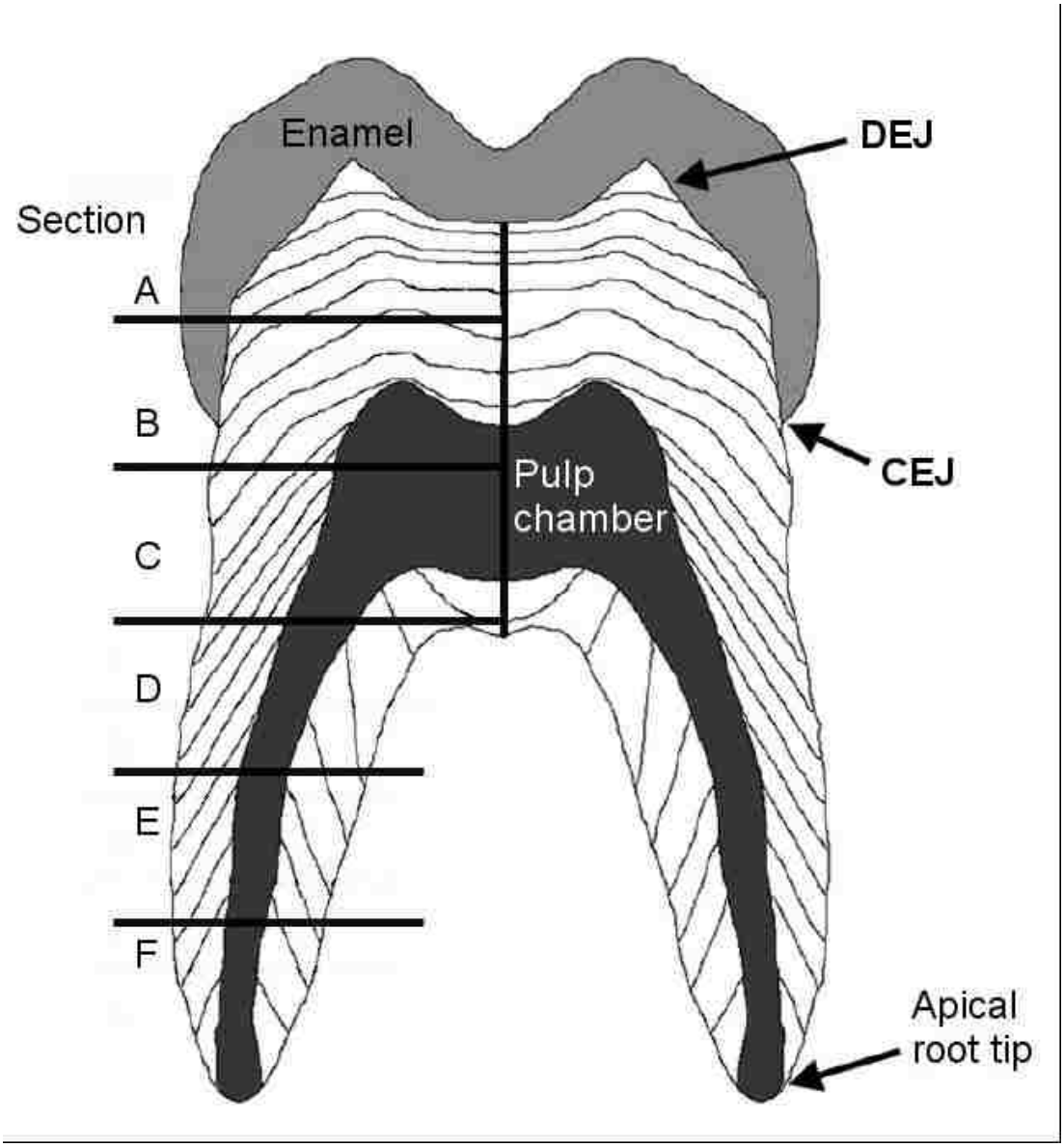


Figure 22. Example of the sampling strategy for incremental sectioning of tooth dentine with six samples from the crown (A) to root tip (F). Dentine is in white, with approximate angles of growth lines. After Eerkens et al. (2011:3104)

Figure 22 shows a hypothetical first molar with dentine growth lines and the proposed sampling strategy consisting of approximately 3mm sections (starting from the crown). The four selected teeth varied in size, but for every individual the DEJ represents age 0. As mentioned above, root closure is completed at 9–10 years, thus a midpoint age of 9.5 years was assigned to the apical root tip for every individual. In the case of 6 microsamples (A to F, or from earliest to latest), each section represents approximately $1/6^{th}$ of 9.5 years, or 1.58 years (approx. 19 months). Each increment is then given a

midpoint age, which for the first section (0–19 months) would be 9.5 months, for the second section (19–38 months) 28.5 months, etc.

This method may not be entirely accurate in assigning age ranges to each section, and each sub-sample could represent a shorter or longer period than estimated here. In addition, since dentine does not form horizontally, the sections will cross the growth lines, especially in the roots. As a result, the increments will provide values that are averaged over the time of growth, including dentine from both the preceding and succeeding sections. This effect will be less pronounced for the beginning and end of a tooth, which only experience one-way averaging (Beaumont & Montgomery 2016:17). Nevertheless, despite these limitations, this strategy greatly increases the time resolution of sampling and offers a more detailed record of childhood dietary changes than could be achieved by only relying on bone collagen data.

5.2.4. IRMS

Isotope-ratio mass spectrometry was used to measure the respective elemental ratios of C-, N- and S-isotopes. Some of the human collagen samples from Sărata Monteoru, including all $\delta^{34}S$ measurements and all dentine samples, were analysed at the Scottish Universities Environmental Research Centre (SUERC) Radiocarbon Laboratory in East Kilbride, Scotland. Results were obtained using a continuous-flow IRMS (Thermo Scientific Delta V Advantage) coupled to a Costech ECS 4010 elemental analyser (EA) fitted with a pneumatic autosampler. Approximately 600μg of collagen for $\delta^{13}C$ and $\delta^{15}N$, and ~10mg for $\delta^{34}S$ were weighed into tin capsules. Results were reported in per mil (‰) relative to the internationally accepted standards VPDB, AIR and VCDT with 1-sigma precisions of ±0.2‰, ±0.3‰ and ±0.6‰ for $\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$, respectively.

For the remaining samples, a Natural Environmental Research Council (NERC) student grant was awarded to the present author (under the supervision of Prof. Clive Bonsall) to conduct the analyses at the NERC Isotope Geosciences Laboratory (NIGL) at Kewyorth, England. Analyses of $\delta^{13}C$ and $\delta^{15}N$ were conducted using Continuous Flow-Elemental Analysis-Isotope Ratio Mass Spectrometry (CF-EA-IRMS)

comprised of an Elemental analyser (Flash/EA) coupled to a Thermo Finnigan Delta^{Plus} XL isotope ratio mass spectrometer via a ConFlo III interface. Collagen carbon and nitrogen isotope ratios are reported in per mil (‰) relative to VPDB and AIR standards, respectively. Approximately 600μg of collagen were weighed into tin capsules for $\delta^{13}C$ and $\delta^{15}N$. Analyses were run in duplicate and the average 1-sigma standard deviation of the duplicates was $\delta^{13}C = \pm 0.06‰$ and $\delta^{15}N = \pm 0.05‰$. The 1-sigma reproducibility for mass spectrometry controls for these analyses were better than ±0.14‰ for $\delta^{13}C$ and ±0.06‰ for $\delta^{15}N$.

5.2.5. Collagen quality criteria

All samples were subjected to a quality control to determine the integrity of the preserved collagen. One of the main quality indicators is collagen yield, expressed as a percentage of the total bone weight. For example, modern bone contains about 22% collagen by weight, but anywhere above 1% is usually considered acceptable for archaeological bone (van Klinken 1999:689). Here, all samples that produced collagen yields of at least 1% were submitted for stable isotope analysis.

The elemental concentration (%) in collagen is also used as a common method for ascertaining quality. For carbon, values around 30–35 wt % indicate well-preserved, uncontaminated collagen; the respective range for nitrogen is around 11–16 wt %, with values below 10% typically regarded as unreliable (van Klinken 1999:691). Sulphur concentration is generally low in mammalian bone; well-preserved collagen should have around 0.15–0.35 wt % sulphur (Nehlich & Richards 2009:68).

Elemental atomic ratios can be considered as the third quality criterion. C:N ratios between 2.9 to 3.6, as proposed by DeNiro (1985), have commonly been regarded as an indicator for well-preserved collagen. More recently, van Klinken (1999) implemented a much narrower range of 3.1 to 3.5 for assessing collagen quality. Here, the present author has used the range determined by van Klinken (1999), but also accepted values based on DeNiro's (1985) estimations on occasions where other quality indicators were within norms. For sulphur, Nehlich & Richards (2009)

established acceptable limits for atomic C:S and N:S ratios to identify well-preserved collagen as ca. 600±300 and 200±100, respectively.

5.3. Statistical analysis

Statistical analysis was applied to determine whether differences between groups of data were (statistically) significant. A positive result indicated that the outcome was unlikely to be caused by sampling error. Statistical uncertainty was set at 95% (i.e. p-value must be less than 0.05 for the result to be significant). Appropriate statistical tests were chosen (and are here described) based on the Laerd Statistics (2016) online guide. All calculations were made by the present author using the software SPSS Statistics and/or Microsoft Excel.

For data sets with one continuous dependent variable (e.g. stable isotope values) and two or more categorical groups (e.g. male *vs* female) as independent variables, a suitable statistical test was selected depending on whether the comparison was between two groups (Student's t-test, Mann–Whitney U-test) or more than two groups (one-way ANOVA, Kruskal–Wallis H-test). In the event of no outliers and approximately normal distribution of the dependent variable for each group (as assessed by the Shapiro–Wilk test of normality), a parametric test was chosen (Student's t-test, one-way ANOVA); otherwise, the non-parametric alternative was preferred (Mann–Whitney U-test, Kruskal–Wallis H-test).

An important assumption of the above-mentioned parametric tests is homogeneity of variances, as assessed by Levene's test for equality of variances. If the assumption of homogeneity of variances was not met, a modified (Welch) test was applied to produce the results. Were the one-way ANOVA to demonstrate statistically significant differences between three or more groups, a post hoc analysis was carried out, either based on Tukey's test (if the assumption of homogeneity of variances was met) or on Games–Howell's test (if the opposite occurred).

For non-parametric tests, the prerequisite assumption involves the dependent variable having similarly shaped distributions for all groups of the independent variable. In the

event the assumption is met, Mann–Whitney and Kruskal–Wallis tests can be utilized to compare the medians of the dependent variables for the groups of the independent variable. If the assumption is not met, only the mean ranks of the groups (e.g. whether one group has higher or lower values than the other) are compared. The rejection of the null hypothesis for the Kruskal–Wallis test was automatically followed by a post hoc analysis using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. As above, when distributions were not similarly shaped, only the mean ranks (and not the medians) of the groups involved in pairwise comparisons could be assessed.

If the data involved related groups (i.e. the same participants measured on two occasions on the same dependent variable, such as intraskeletal isotopic values), either a paired t-test or its non-parametric alternative (Wilcoxon signed-rank test) was applied to determine whether the differences were statistically significant. The parametric paired t-test was preferred on the conditions that the groups would not contain outliers and that the dependent variable was approximately normally distributed for each group of the independent variable (as assessed by the Shapiro–Wilk test of normality); otherwise, the Wilcoxon signed-rank test was chosen. For the latter, the distribution of the differences between the related groups had to be symmetrical in shape. If this assumption was not met, the sign test was carried out instead.

6. Results and Discussion

This chapter presents the results of stable isotope analyses conducted on osteological material from Sărata Monteoru and Cârlomăneşti, and the interpretation of the data divided into sections on collagen quality, intraskeletal variability, human isotope ratio differences between groups, quantitative diet reconstruction, animal exploitation, childhood dietary practices, and $\delta^{34}S$ isotopes and mobility. The chapter concludes with a regional perspective which attempts to integrate the results of this dissertation into the wider context of the Bronze Age in Central and Southeast Europe.

6.1. Results

The full results of the stable isotope analyses of human and animal bone samples from Sărata Monteoru and Cârlomăneşti, including collagen quality indicators, are presented in Appendix 6. The majority of samples complied with the quality criteria for well-preserved collagen as set out in Chapter 5.2.5. In five cases, the elemental C and N concentrations fell slightly below the accepted range, but since these samples had C:N ratios indicative of well-preserved collagen and the values themselves did not seem abnormal, they were not discarded. In one further instance (sample 25-CRL, horse), %C and %N were significantly below the accepted limits – 16.0 for %C and 5.5 for %N, compared to the acceptable lower margins of 30% and 10%, respectively. This sample's C:N ratio was 3.4, and the $\delta^{13}C$ and $\delta^{15}N$ values themselves did not seem anomalous, nevertheless, it has been excluded from further discussions.

The $\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$ isotope values from human and animal collagen are presented in Tables 6–12. Table 6 displays the results for the 27 individuals from Sărata Monteoru who were tested for intra-individual variability by analysing two or more related skeletal elements. Intraskeletal measurements were taken from the femoral diaphysis (in the following discussion referred to as 'cortical femur'), calvarium ('skull'), vertebra, rib, metacarpal and femoral proximal epiphysis ('trabecular femur'). Unless stated otherwise, 'femur' is used here to refer to cortical bone from the femur shaft.

Table 6. Stable isotope results of intraskeletal $\delta^{13}C$ and $\delta^{15}N$ analyses from Sărata Monteoru human burials along with their contextual information

Burial no.	Age	Sex	Skeletal element	$\delta^{13}C$	$\delta^{15}N$
75b	1–2yr	N/A	Femur	-19.1	10.8
			Rib*	-18.8	11.0
90b	1–2yr	N/A	Femur	-19.8	10.9
			Skull	-19.9	10.8
			Rib*	-19.3	10.0
24	1.5–2yr	N/A	Femur (cortical)	-19.8	10.0
			Femur (trabecular)*	-19.2	9.8
50	1–3yr	N/A	Femur	-19.6	10.7
			Rib	-19.0	10.6
			Vertebra*	-18.8	10.8
117	2–3yr	N/A	Femur (cortical)	-20.7	7.2
			Femur (trabecular)	-19.8	7.4
			Rib*	-20.0	7.7
80	2–4yr	N/A	Femur (cortical)	-20.4	10.6
			Rib	-19.0	10.4
			Femur (trabecular)*	-19.4	10.1
124	2–4yr	N/A	Femur (cortical)	-20.7	8.2
			Rib	-20.4	7.9
			Femur (trabecular)*	-19.9	8.2
116	3–5yr	N/A	Femur	-20.5	8.8
			Rib*	-19.5	8.9
119	5–6yr	N/A	Femur	-20.5	7.9
			Vertebra	-19.9	8.4
			Rib*	-19.7	8.3
88	7–9yr	N/A	Femur	-20.6	7.8
			Rib	-20.0	7.9
			Vertebra*	-19.7	8.6
120	9–10yr	N/A	Femur	-20.3	8.6
			Rib	-20.0	8.6
			Vertebra*	-19.6	8.8
46	16–18yr	N/A	Femur	-20.0	9.2
			Intrafemur	-19.7	9.2
			Skull	-19.9	9.5
			Skull (interlab duplicate)*	-19.8	9.5
			Metacarpal	-19.7	9.3
			Rib	-20.4	9.0
			Vertebra	-19.7	9.2
35a	17–19yr	F	Femur	-20.2	8.2
			Intrafemur	-19.6	8.3
			Rib*	-19.5	8.5
40	17–19yr	F	Femur	-20.6	7.8
			Intrafemur	-20.3	7.9
			Rib*	-19.5	5.8

Table 6. Continued

Burial no.	Age	Sex	Skeletal element	$\delta^{13}C$	$\delta^{15}N$
123	17–19yr	M	Femur	-20.6	7.8
			Rib	-19.6	7.5
			Vertebra*	-19.7	7.9
125	17–19yr	F	Femur	-20.4	8.2
			Rib	-19.8	8.3
133	17–19yr	F	Femur	-20.6	7.7
			Rib	-19.5	8.0
13	Young adult	F	Femur	-19.7	9.8
			Intrafemur	-19.9	9.9
			Skull	-19.9	9.5
			Skull (interlab duplicate)*	-19.9	9.5
			Metacarpal	-19.6	9.5
			Rib	-19.4	9.4
			Vertebra	-19.3	8.6
122	Young adult	F	Femur	-20.6	9.0
			Rib	-20.0	8.8
85	Fully Adult	F	Femur	-20.7	8.0
			Rib	-19.7	8.3
			Vertebra*	-20.0	8.0
106	Fully adult	F	Femur	-20.5	8.4
			Rib*	-19.4	8.6
77	Mature adult	M	Femur	-20.4	7.7
			Rib	-20.2	8.3
			Vertebra*	-19.3	8.9
78	Mature adult	M	Femur	-20.3	7.8
			Vertebra	-19.2	8.7
			Rib*	-19.6	8.3
115a	Mature adult	F	Femur	-20.2	9.7
			Rib	-19.9	9.7
126	Mature adult	M	Femur	-20.4	8.8
			Rib*	-19.5	9.3
127	Mature adult	M	Femur	-20.3	7.9
			Rib	-19.7	8.2
			Vertebra*	-19.2	8.8
134	Fully/Mature adult	F	Femur	-20.6	7.5
			Rib	-20.6	7.5
			Vertebra*	-19.7	8.7

It should be noted that while most of the intraskeletal $\delta^{13}C$ and $\delta^{15}N$ measurements were conducted at SUERC (East Kilbride), some were also analysed at NIGL (Keyworth). The latter are marked with an asterisk in Table 6. Since all the collagen was extracted in the University of Edinburgh Bone Chemistry Laboratory following

the same procedure, there is no difference in the way samples were prepared that could affect the intraskeletal measurements. Interlaboratory variation was tested for two individuals (burials no. 46 and 13) – two separate extractions of collagen from the same bone (skull) sample were analysed in both laboratories. Interlaboratory variation was less than ±0.1‰ for both $\delta^{13}C$ and $\delta^{15}N$, indicating that any significant discrepancies in intraskeletal measurements should not be caused by differences in the IRMS equipment.

Owing to complications during $\delta^{34}S$ analyses involving the performance of the analytical instruments at SUERC, quite a few human bone collagen samples had to be repeated (including new $\delta^{13}C$ and $\delta^{15}N$ measurements). With the exception of a few $\delta^{34}S$ measurements (which were eventually discarded as unreliable), most of the results from the original run were later deemed acceptable by the laboratory technician. For many of those samples there was insufficient material for repeat analyses, which presented the opportunity to analyse another (additional) skeletal element from the same individual.

In four cases the only available bone was from the same femur sample. These samples can be regarded as replicate analyses of the same cortical femur sample using an independent extraction of collagen (referred to as 'intrafemur') measured in the same laboratory. The variation among the intrafemur samples was generally within the 1σ reproducibility for mass spectrometry controls (±0.2‰ for $\delta^{13}C$ and ±0.3‰ for $\delta^{15}N$ for these analyses), except for burial no. 35a, where the difference in $\delta^{13}C$ values between the two femoral samples was 0.6‰, i.e. within error at the 2σ confidence level.

Measuring intra-individual variability in isotope ratios was not initially planned for $\delta^{34}S$, but due to the complications mentioned above, the opportunity was taken to also examine this line of evidence. For 13 individuals from Sărata Monteoru there are $\delta^{34}S$ data from two related skeletal elements (in most cases a cortical femur and a rib). The results are presented in Table 7. All sulphur isotope measurements were conducted at SUERC with a 1σ analytical precision of ±0.6‰.

Table 7. Stable isotope results of intraskeletal $\delta^{34}S$ analyses from Sărata Monteoru human burials along with their contextual information

Burial no.	Age	Sex	Skeletal element	$\delta^{34}S$
90b	1–2yr	N/A	Femur	1.9
			Skull	1.9
50	1–3yr	N/A	Femur	-0.1
			Rib	0.3
117	2–3yr	N/A	Femur (cortical)	2.8
			Femur (trabecular)	2.0
80	2–4yr	N/A	Femur	2.7
			Rib	3.4
124	2–4yr	N/A	Femur	3.2
			Rib	3.3
88	7–9yr	N/A	Femur	2.3
			Rib	1.0
120	9–10yr	N/A	Femur	3.7
			Rib	2.7
35a	17–19yr	F	Femur	3.8
			Intrafemur	4.0
40	17–19yr	F	Femur	3.6
			Intrafemur	3.5
125	17–19yr	F	Femur	3.3
			Rib	2.8
122	Young adult	F	Femur	3.9
			Rib	2.8
127	Mature adult	M	Femur	2.9
			Rib	2.6
134	Fully/Mature adult	F	Femur	3.2
			Rib	2.8

Combined human bone collagen $\delta^{13}C$ and $\delta^{15}N$ values (both for those sampled from only one, and those from multiple skeletal locations) for 59 individuals from Sărata Monteoru are presented in Table 8. For individuals with measurements from two or more skeletal elements, an average value and 1SD are given.

Table 8. Combined stable isotope results of $\delta^{13}C$ and $\delta^{15}N$ analyses from Sărata Monteoru human burials along with their contextual information. For individuals with measurements from two or more skeletal elements, an average value and 1SD are given

Burial no.	Age	Sex	Grave goods	$\delta^{13}C$	SD	$\delta^{15}N$	SD
75b	1–2yr	N/A	No	-19.0	0.2	10.9	0.1
90b	1–2yr	N/A	No	-19.7	0.3	10.6	0.5
24	1.5–2yr	N/A	No	-19.5	0.4	9.9	0.2
35b	1.5–2yr	N/A	Rich	-19.2		11.1	
50	1–3yr	N/A	Few	-19.1	0.4	10.7	0.1
117	2–3yr	N/A	No	-20.2	0.5	7.4	0.2

Table 8. Continued

Burial no.	Age	Sex	Grave goods	$\delta^{13}C$	SD	$\delta^{15}N$	SD
80	2–4yr	N/A	Few	-19.6	0.7	10.4	0.2
124	2–4yr	N/A	No	-20.3	0.4	8.1	0.2
116	3–5yr	N/A	No	-20.0	0.7	8.9	0.1
119	5–6yr	N/A	Few	-20.0	0.4	8.2	0.3
41	7–9yr	N/A	No	-20.1		7.7	
72	7–9yr	N/A	Rich	-20.0		6.9	
88	7–9yr	N/A	Rich	-20.1	0.4	8.1	0.4
70	8–10yr	N/A	No	-19.4		8.5	
120	9–10yr	N/A	No	-20.0	0.4	8.7	0.1
12	9–11yr	N/A	Rich	-19.7		6.3	
128	8–12yr	N/A	No	-19.8		8.5	
69	15–17yr	?	Few	-19.3		8.8	
82	15–17yr	?	Few	-19.5		8.5	
102	15–17yr	?	No	-19.8		8.1	
46	16–18yr	?	N/A	-19.9	0.3	9.3	0.2
35a	17–19yr	F	Rich	-19.7	0.3	8.4	0.2
40	17–19yr	F	Rich	-20.0	0.7	6.8	1.4
61	17–19yr	F	No	-19.4		7.9	
123	17–19yr	M	No	-20.0	0.6	7.7	0.2
125	17–19yr	F	Rich	-20.1	0.4	8.2	0.1
133	17–19yr	F	Rich	-20.0	0.8	7.8	0.2
86	18–20yr	M	No	-19.7		8.5	
112	18–20yr	M	No	-19.3		8.8	
63	19–21yr	F	Rich	-19.9		7.8	
13	Young adult	F	No	-19.7	0.2	9.5	0.4
53	Young adult	F	No	-19.3		8.7	
68	Young adult	M	Few	-19.4		8.9	
81	Young adult	?	Few	-19.4		8.2	
101	Young adult	F	Few	-19.5		8.6	
105	Young adult	F	Rich	-19.7		8.9	
107	Young adult	F	Rich	-19.9		8.8	
122	Young adult	F	Rich	-20.3	0.4	8.9	0.1
130	Young adult	F	No	-20.4		7.8	
62	Fully adult	M	No	-19.4		9.1	
66	Fully adult	?	No	-19.5		8.3	
71	Fully adult	M	Rich	-19.1		8.9	
75a	Fully adult	F	No	-19.2		9.5	
85	Fully adult	F	No	-20.1	0.5	8.1	0.2
106	Fully adult	F	No	-19.9	0.8	8.5	0.2
77	Mature adult	M	Few	-20.0	0.6	8.3	0.6
78	Mature adult	M	Few	-19.7	0.6	8.3	0.5
79	Mature adult	M	No	-19.7		8.6	
115a	Mature adult	F	No	-20.0	0.2	9.7	0.0
126	Mature adult	M	No	-19.9	0.6	9.1	0.3

Table 8. Continued

Burial no.	Age	Sex	Grave goods	$\delta^{13}C$	SD	$\delta^{15}N$	SD
127	Mature adult	M	No	-19.7	0.5	8.3	0.5
135	Mature adult	F	No	-19.3		9.4	
48	Fully/Mature adult	?	Few	-19.7		8.4	
54a	Fully/Mature adult	F	No	-19.7		8.7	
64	Fully/Mature adult	F	No	-19.6		8.8	
65	Fully/Mature adult	?	No	-19.3		9.1	
74	Fully/Mature adult	F	No	-19.0		10.2	
108	Fully/Mature adult	M	No	-19.4		10.4	
134	Fully/Mature adult	F	No	-20.3	0.5	7.9	0.7

Human $\delta^{13}C$ and $\delta^{15}N$ values for 10 individuals from Cârlomăneşti are presented in Table 9 along with their contextual information. No intraskeletal samples were analysed for these individuals.

Table 9. Stable isotope results of $\delta^{13}C$ and $\delta^{15}N$ analyses from Cârlomăneşti human burials along with their contextual information

Burial no.	Age	Sex	Grave goods	$\delta^{13}C$	$\delta^{15}N$
58	8–9yr	N/A	Few	-18.9	9.0
105a	8–9yr	N/A	Few	-19.3	9.4
51	9–13yr	N/A	Rich	-19.2	9.7
24	10–12yr	N/A	Few	-19.5	9.2
2	13–15yr	?	Few	-19.6	9.2
1	Young adult	F	Rich	-19.6	9.7
5	Mature adult	M	Few	-19.4	9.7
19	Mature adult	F	Few	-19.3	10.2
80a	Mature adult	F	Rich	-19.3	10.1
103	Mature adult	F	Few	-19.4	10.0

Combined human S-isotope data are available for 26 individuals from Sărata Monteoru, and these are presented in Table 10 along with corresponding $\delta^{13}C$ and $\delta^{15}N$ values. For individuals with measurements on two skeletal elements, the average $\delta^{34}S$ value and 1SD are given; for $\delta^{13}C$ and $\delta^{15}N$, the mean values are calculated only from the two samples that were also analysed for $\delta^{34}S$, i.e. not from all intraskeletal measurements.

Table 10. Combined stable isotope results of $\delta^{34}S$ analyses from Sărata Monteoru human burials along with their corresponding $\delta^{13}C$ and $\delta^{15}N$ values and contextual information. For individuals with measurements from two skeletal elements, an average value and 1SD are given

Burial no.	Age	Sex	Grave goods	$\delta^{34}S$	SD	$\delta^{13}C$	SD	$\delta^{15}N$	SD
75b	1–2yr	N/A	No	0.7		-19.1		10.8	
90b	1–2yr	N/A	No	1.9	0.0	-19.9	0.1	10.9	0.1
24	1.5–2yr	N/A	No	0.5		-19.8		10.0	
50	1–3yr	N/A	Few	0.1	0.2	-19.3	0.3	10.7	0.1
117	2–3yr	N/A	No	2.4	0.4	-20.3	0.5	7.3	0.1
80	2–4yr	N/A	Few	3.1	0.4	-19.7	0.7	10.5	0.1
124	2–4yr	N/A	No	3.3	0.1	-20.6	0.2	8.1	0.2
116	3–5yr	N/A	No	2.2		-20.5		8.8	
119	5–6yr	N/A	Few	2.1		-19.9		8.4	
88	7–9yr	N/A	Rich	1.7	0.7	-20.3	0.3	7.9	0.1
120	9–10yr	N/A	No	3.2	0.5	-20.2	0.2	8.6	0.0
35a	17–19yr	F	Rich	3.9	0.1	-19.9	0.3	8.3	0.1
40	17–19yr	F	Rich	3.6	0.1	-20.5	0.2	7.9	0.1
123	17–19yr	M	No	0.2		-19.6		7.5	
125	17–19yr	F	Rich	3.1	0.3	-20.1	0.3	8.2	0.1
133	17–19yr	F	Rich	2.3		-19.5		8.0	
122	Young adult	F	No	3.4	0.6	-20.3	0.3	8.9	0.1
130	Young adult	F	No	0.3		-20.4		7.8	
85	Fully adult	F	No	-1.6		-19.7		8.3	
106	Fully adult	F	No	-2.6		-20.5		8.4	
77	Mature adult	M	Few	1.6		-20.2		8.3	
78	Mature adult	M	Few	3.0		-19.2		8.7	
115a	Mature adult	F	No	2.8		-19.9		9.7	
126	Mature adult	M	No	2.4		-20.4		8.8	
127	Mature adult	M	No	2.8	0.2	-20.0	0.3	8.0	0.2
134	Fully/Mature adult	F	No	3.0	0.2	-20.6	0	7.5	0.0

The results of faunal collagen $\delta^{13}C$ and $\delta^{15}N$ analyses from Sărata Monteoru and Cârlomăneşti are presented in Table 11. As mentioned above, one of the faunal samples produced atypical %C and %N values and was thus excluded from the list of samples with acceptable quality. This sample (25-CRL, horse), along with its respective isotope values, is shown in Table 11 for information only (in strikethrough text), although it is not included in subsequent data- or statistical analyses.

Table 11. Stable isotope results of $\delta^{13}C$ and $\delta^{15}N$ analyses from Sărata Monteoru and Cârlomăneşti animal bones along with their contextual information

Sample	Species	$\delta^{13}C$	$\delta^{15}N$	Sample	Species	$\delta^{13}C$	$\delta^{15}N$
Sărata-Monteoru				**Cârlomăneşti**			
8-SM	Bos	-20.0	6.6	22-CRL	Bos	-20.6	6.5
10-SM	Bos	-20.0	6.3	30-CRL	Bos	-20.3	7.7
14-SM	Bos	-20.7	7.8	37-CRL	Bos	-20.2	5.6
15-SM	Bos	-19.5	6.4	46-CRL	Bos	-19.5	5.3
20-SM	Bos	-20.5	6.4	47-CRL	Bos	-20.6	8.2
2-SM	Ovis/Capra	-19.4	6.1	51-CRL	Bos	-20.4	6.1
3-SM	Ovis/Capra	-20.0	5.9	59-CRL	Bos	-19.4	6.1
6-SM	Ovis/Capra	-19.1	6.4	60-CRL	Bos	-20.2	7.0
7-SM	Ovis/Capra	-19.6	5.9	61-CRL	Bos	-20.5	6.1
11-SM	Ovis/Capra	-19.0	5.4	64-CRL	Bos	-19.8	5.5
13-SM	Ovis/Capra	-18.9	5.7	26-CRL	Ovis/Capra	-19.9	6.0
19-SM	Ovis/Capra	-20.2	7.4	39-CRL	Ovis/Capra	-16.4	6.8
21-SM	Equus	-19.9	6.4	40-CRL	Ovis/Capra	-22.1	6.4
4-SM	Sus	-19.9	7.4	48-CRL	Ovis/Capra	-20.3	7.6
5-SM	Sus	-19.1	9.8	53-CRL	Ovis/Capra	-20.6	6.1
9-SM	Sus	-19.5	7.6	55-CRL	Ovis/Capra	-17.1	7.9
16-SM	Canis	-19.2	8.4	65-CRL	Ovis/Capra	-20.5	4.5
				67-CRL	Ovis/Capra	-20.4	4.9
				24-CRL	Ovis	-20.1	5.8
				~~25-CRL~~	~~Equus~~	~~-19.6~~	~~4.8~~
				29-CRL	Equus	-19.5	2.8
				49-CRL	Equus	-20.9	3.2
				31-CRL	Sus	-13.5	6.2
				32-CRL	Sus	-18.5	5.2
				34-CRL	Sus	-19.5	7.9
				36-CRL	Sus	-18.6	6.3
				41-CRL	Sus	-20.6	6.1
				43-CRL	Sus	-20.5	5.8
				57-CRL	Sus	-19.1	6.6
				58-CRL	Sus	-19.4	6.7
				35-CRL	Canis	-20.0	9.8
				44-CRL	Canis	-19.2	9.0
				52-CRL	Canis	-19.5	9.7
				56-CRL	Canis	-19.4	7.9
				62-CRL	Canis	-19.5	8.9
				63-CRL	Canis	-19.0	9.9
				66-CRL	Canis	-19.1	9.8
				33-CRL	Cervus	-20.8	4.3
				45-CRL	Lepus	-19.5	3.0

Concerning incrementally sampled tooth dentine from 4 individuals from Sărata Monteoru, 21 out of 23 slices produced enough collagen for $\delta^{13}C$ and $\delta^{15}N$ analyses. The two increments with insufficient collagen originated from the end of the tooth (i.e. root tip). The results are presented in Table 12, along with contextual information for the sampled individuals and the corresponding bone collagen values reflecting adult diet. For each individual, one sample represents a ca. 3mm increment from the complete tooth. An approximate age range is shown, and reflects the presumed time (in months) taken for the dentine in any particular increment to form. A midpoint age is also calculated, listed both in months and in years.

Table 12. Stable isotope results of $\delta^{13}C$ and $\delta^{15}N$ analyses of incrementally sampled dentine from Sărata Monteoru human burials along with their contextual information

Context	Increment	Approx. age range (months)	Midpoint age (months/years)	$\delta^{13}C$	$\delta^{15}N$
Burial no: 63	0–3mm	0–19	9.5/0.8	-19.7	10.2
Age: 19–21yr	3–6mm	19–38	28.5/2.4	-20.0	8.5
Sex: F	6–9mm	38–57	47.5/4	-20.1	8.5
Grave goods:	9–12mm	57–76	66.5/5.5	-20.2	8.5
Rich	12–15mm	76–95	85.5/7.1	-20.1	8.1
Tooth: M1	15mm–end	95–114	104.5/8.7	-20.1	8.4
			Bone collagen	**-19.9**	**7.8**
Burial no: 81	0–3mm	0–19	9.5/0.8	-19.1	10.3
Age: Young adult	3–6mm	19–38	28.5/2.4	-19.5	8.4
Sex: ?	6–9mm	38–57	47.5/4	-19.6	8.2
Grave goods:	9–12mm	57–76	66.5/5.5	-19.6	8.3
Few	12–15mm	76–95	85.5/7.1	-19.8	8.8
Tooth: M1	~~15mm–end~~	~~95–114~~	~~104.5/8.7~~	N/A	N/A
			Bone collagen	**-19.4**	**8.2**
Burial no: 86	0–3mm	0–19	9.5/0.8	-19.8	9.0
Age: 18–20yr	3–6mm	19–38	28.5/2.4	-20.2	7.9
Sex: M	6–9mm	38–57	47.5/4	-20.2	7.6
Grave goods:	9–12mm	57–76	66.5/5.5	-20.1	7.6
No	12–15mm	76–95	85.5/7.1	-20.2	7.8
Tooth: M1	15mm–end	95–114	104.5/8.7	-20.0	7.9
			Bone collagen	**-19.7**	**8.5**
Burial no: 105	0–3mm	0–23	11.5/1	-18.8	12.4
Age: Young adult	3–6mm	23–46	34.5/2.8	-19.3	10.9
Sex: F	6–9mm	46–69	57.5/4.8	-19.8	9.3
Grave goods:	9–12mm	69–92	80.5/6.7	-19.9	8.9
Rich	~~12mm–end~~	~~92–115~~	~~103.5/8.6~~	N/A	N/A
Tooth: M1			**Bone collagen**	**-19.7**	**8.9**

6.2. Collagen quality

Collagen yield for all samples ranged between 1.1% and 38.6% (average 7.1%) (Table 13). Mean collagen yield was 4.4% for human bone collagen samples, 8.8% for faunal bone collagen, and 18.4% for human dentine collagen. There were statistically significant differences in collagen yields between all these groups (Kruskal–Wallis H test, H=90.877, d.f.=2, $p<0.001$). It is surprising that the animal bones displayed significantly higher collagen yields than human bones, considering that at least some of the bones may have been cooked or processed in some other way before interment. Interestingly, faunal samples from graves (Sărata Monteoru) had significantly lower mean collagen yields (6.0%) compared to animal bones from a settlement area (Cârlomăneşti) (10.0%) (Mann–Whitney U test, U=526, p=0.001).

Table 13. The mean, standard deviation, minimum and maximum values of collagen yields (%) for stable isotope samples analysed for this study

Group	Mean	SD	Min	Max	N
All human bone	4.4	2.6	1.1	14.2	122
Sărata Monteoru human bone	4.2	2.4	1.1	14.2	39
Cârlomăneşti human bone	7.2	2.7	1.5	11.5	10
All animal bone	8.8	4.4	2.0	21.7	55
Sărata Monteoru animal bone	6.0	3.4	2.0	14.6	17
Cârlomăneşti animal bone	10.0	4.3	3.2	21.7	38
All Sărata Monteoru bone	4.4	2.6	1.1	14.6	129
All Cârlomăneşti bone	9.5	4.2	1.5	21.7	48
Sărata Monteoru dentine	18.4	2.7	12.6	38.6	21
All	7.1	5.7	1.1	38.6	198

In addition, Sărata Monteoru bone samples (both human and animal) had significantly lower collagen yields (mean 4.4%) than all Cârlomăneşti samples (mean 9.5%) (U=5505, $p<0.001$). This may be related to the amount of time that has elapsed since the bones were removed from their burial environment – the Sărata Monteoru material was excavated in the early 1950s and has been kept in storage since then, whereas the osteological material from Cârlomăneşti was excavated much more recently and the faunal bones had not even been cleaned (i.e. soil removed) before sampling by the present author. However, it seems more likely that different burial environments (and not storage) resulted in the observed differences in collagen preservation.

Even so, this would not explain the statistically significant differences in collagen yields between human and animal osteological material. Collagen extraction for all samples followed the same procedure (e.g. all included NaOH wash), however, Sărata Monteoru human bones were the first to be processed by the present author, who at that time was still experimenting with the duration of the initial acid wash in order to establish the most appropriate methodology for the material under study. Still, there is only a weak positive correlation (Pearson correlation coefficient r=0.36) between collagen yield and order of processing, suggesting that the differences in yields do indeed reflect significantly better collagen preservation in Cârlomăneşti/faunal samples.

Concerning the Sărata Monteoru tooth samples, the remarkably high collagen yields reported here are influenced by the much smaller weight of the dentine increments compared to bone samples. While the average dry weight of a bone sample before demineralization was slightly over 1g, the average weight of a dentine increment (sectioned once the tooth was already partly demineralized) was 0.13g. Good quality collagen in a quantity sufficient for analysis was produced even from a sample weighing only 0.05g, although another two samples with low weights (0.05g and 0.06g) failed to achieve this. Since most of the 3mm sections produced enough collagen, slightly smaller increments may be sampled in future studies involving archaeological teeth from Sărata Monteoru.

Atomic C:N ratios for all samples fall within a very narrow range, between 3.2 and 3.4, indicating generally good preservation. Mean C:N ratio was 3.3 for all bone samples, independent of site or species, but 3.2 for dentine samples. There was no correlation between C:N ratios and collagen yields. For the $\delta^{34}S$ analyses, atomic C:S and N:S ratios range from 371 to 611 (average 510) and from 112 to 188 (average 157), respectively. These are well within the limits established by Nehlich & Richards (2009), although in the lower range of acceptable values. C:S and N:S ratios showed an almost perfect positive correlation (r=0.99).

Carbon concentration (%C) for all samples ranged from 24.3% to 46.5% with an average of 40.1%; %N had a range of 8.7% to 16.8% (average 14.3%) (Table 14). %C and %N for dentine samples was statistically significantly different from those for bone samples ($p<0.001$ for both variables), although no differences appeared between human and faunal bone elemental concentrations. Dentine samples had on average lower carbon and nitrogen yields, which is somewhat surprising considering that they presented the highest collagen yields. This may be related to fundamental differences between bone collagen and teeth dentine, especially regarding preservation and diagenesis.

Table 14. The mean, standard deviation, minimum and maximum values of Carbon (%C) and Nitrogen (%N) concentrations for stable isotope samples analysed for this study. SM = Sărata Monteoru, CRL = Cârlomăneşti

Group	%C				%N				N
	Mean	SD	Min	Max	Mean	SD	Min	Max	
All human bone	40.4	2.5	28.5	46.5	14.4	0.9	9.9	16.8	122
SM human bone	40.3	2.5	28.5	46.5	14.4	0.9	9.9	16.8	39
CRL human bone	41.9	1.4	38.0	42.9	14.8	0.6	13.3	15.2	10
All animal bone	40.4	3.3	26.2	42.9	14.3	1.2	9.1	15.5	55
SM animal bone	40.3	1.9	34.3	42.7	14.2	0.7	12.1	15.0	17
CRL animal bone	40.4	3.7	26.2	42.9	14.4	1.4	9.1	15.5	38
All SM bone	40.3	2.4	28.5	46.5	14.3	0.9	9.9	16.8	129
All CRL bone	40.7	3.4	26.2	42.9	14.5	1.3	9.1	15.5	48
SM dentine	37.0	4.2	24.3	43.7	13.3	1.6	8.7	15.8	21
All	40.1	3.1	24.3	46.5	14.3	1.1	8.7	16.8	198

In addition, mean %C and %N were statistically significantly different for bone samples from Sărata Monteoru and Cârlomăneşti (for both variables $p=0.001$), emphasising the variation in collagen preservation between the two sites already documented in mean bone collagen yields. Ambrose (1990) suggested that carbon and nitrogen concentration in prehistoric bone collagen declines with decreasing collagen yield, although the relationship is non-linear. Here, while bone %C and %N are almost perfectly correlated ($r=0.98$), there is no significant correlation between elemental concentrations and collagen yields ($r=0.26$ for %C; $r=0.25$ for %N).

For $\delta^{34}S$, %S ranged between 0.18% and 0.27% (mean 0.22%) for all samples. This is in accordance with sulphur levels from well preserved mammalian bone. There is also no correlation between %S and collagen yields, nor between %S and %C or %N.

6.3. Intraskeletal variability

6.3.1. Carbon and Nitrogen

In order to better compare intraskeletal variation between individuals, the results should be examined not as absolute values, but as *per mil* differences in $\Delta^{13}C$ and $\Delta^{15}N$ between related skeletal elements, calculated as follows:

$$\Delta^{13}C_{1\text{-}2} = \delta^{13}C_{\text{skeletal element1}} - \delta^{13}C_{\text{skeletal element2}}$$

$$\Delta^{15}N_{1\text{-}2} = \delta^{15}N_{\text{skeletal element1}} - \delta^{15}N_{\text{skeletal element2}}$$

Table 15 shows the *per mil* differences in intraskeletal $\Delta^{13}C$ and $\Delta^{15}N$ for two well preserved burials with multiple intraskeletal samples: burials no. 13 (upper) and 46 (lower). The Δ values are compared with the 1-sigma standard deviation of the analytical precision of the mass spectrometer used in sample analysis. Only one sample from both individuals was analysed at NIGL ('interlab skull'), and these results were excluded from this table. The average intrafemur difference for these two individuals lies within the 1σ analytical precision (0.3‰ for $\delta^{13}C$ and 0.1‰ for $\delta^{15}N$). For comparisons between 'femur' and other skeletal elements, a mean value of the two intrafemur samples is used.

The two individuals often display very different offsets which can be caused either by measurement error, slight dietary changes during life, or physiological factors (see discussion further below). While variability of the individual Δ values is noticeable, it mostly remains within the 2σ level of measurement error, and the mean differences for the two sets of related data do not exceed 0.5‰ for $\delta^{13}C$ and 0.6‰ for $\delta^{15}N$.

Table 15. Intraskeletal differences ($\Delta^{13}C$ and $\Delta^{15}N$) in bone collagen $\delta^{13}C$ and $\delta^{15}N$ values for related skeletal elements of two individuals from Sărata Monteoru (burial no. 13, top row; burial no. 46, bottom row) compared with analytical precision

Analytical precision (1SD)		**Intrafemur**		**Femur–rib**		**Femur–skull**		**Femur–vertebra**		**Femur–metacarpal**	
$\delta^{13}C$	**$\delta^{15}N$**	**$\Delta^{13}C$**	**$\Delta^{15}N$**	**$\Delta^{13}C$**	**$\Delta^{15}N$**	**$\Delta^{13}C$**	**$\Delta^{15}N$**	**$\Delta^{13}C$**	**$\Delta^{15}N$**	**$\Delta^{13}C$**	**$\Delta^{15}N$**
±0.2	**±0.3**	0.2	0.1	0.4	0.45	0.1	0.35	0.5	1.25	0.2	0.35
		0.3	0.01	0.5	0.2	0.05	0.3	0.15	0.01	0.15	0.1
Mean:		0.3	0.1	0.5	0.3	0.1	0.3	0.3	0.6	0.2	0.2
Rib–skull		**Rib–vertebra**		**Rib–metacarpal**		**Skull–vertebra**		**Skull–metacarpal**		**Vertebra–metacarpal**	
$\Delta^{13}C$	**$\Delta^{15}N$**	**$\Delta^{13}C$**	**$\Delta^{15}N$**	**$\Delta^{13}C$**	**$\Delta^{15}N$**	**$\Delta^{13}C$**	**$\Delta^{15}N$**	**$\Delta^{13}C$**	**$\Delta^{15}N$**	**$\Delta^{13}C$**	**$\Delta^{15}N$**
0.5	0.1	0.1	0.8	0.2	0.1	0.6	0.9	0.3	0.01	0.3	0.9
0.5	0.5	0.7	0.2	0.7	0.3	0.2	0.3	0.2	0.2	0.01	0.1
0.5	0.3	0.4	0.5	0.5	0.2	0.4	0.6	0.3	0.1	0.2	0.5

For the remaining individuals, $\delta^{13}C$ and $\delta^{15}N$ values were compared between two or three related skeletal elements, commonly a rib and cortical femur, supplemented by a sample from a vertebra, skull or trabecular femur. Table 16 shows the $\Delta^{13}C$ and $\Delta^{15}N$ values between related skeletal elements for all burials sampled from two or more locations compared with 1SD of the analytical precision. Since this data set contains samples analysed in two different laboratories, the measurement error has been set as the larger of the two.

When discussing intraskeletal isotope values, there are three main things to consider: measurement error (the amount of variability caused by the analytical precision of IRMS), sampled skeletal element (variability caused by differences in the rate of bone turnover between cortical and trabecular bones), and age of the individual (variability caused by differences in the rate of bone turnover between younger and older individuals).

As stated above, the highest 1SD of the analytical precision for these samples is ±0.2‰ for $\delta^{13}C$ and ±0.3‰ for $\delta^{15}N$. However, in the following discussion, intraskeletal differences up to 2σ analytical precision (±0.4‰ for $\delta^{13}C$; ±0.6‰ for $\delta^{15}N$) will be considered as 'within error'. The 2σ measurement error represents a 95% confidence level that the actual value is within the range of two standard deviations. Thus, any intraskeletal differences outside this range are unlikely to be caused by analytical error.

Table 16. Intraskeletal differences ($\Delta^{13}C$ and $\Delta^{15}N$) in bone collagen $\delta^{13}C$ and $\delta^{15}N$ values for related skeletal elements of burials from Sărata Monteoru compared with analytical precision

Burial no.	Analytical precision (1SD)		Intrafemur		Femur–rib		Femur–vertebra		Femur–skull		Femur–trabecular femur		Skull–rib		Rib–vertebra		Rib–trabecular femur	
	$\delta^{13}C$	$\delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$
75b					0.3	0.2												
90b	**±0.2**	**±0.3**			0.5	0.9			0.1	0.1			0.6	0.8				
24											0.6	0.2						
50					0.6	0.1	0.8	0.1							0.2	0.2		
117					0.7	0.5					0.9	0.2					0.2	0.3
80					1.4	0.2					1.0	0.5					0.4	0.3
124					0.3	0.3					0.8	0.0					0.5	0.3
116					1.0	0.1												
119					0.8	0.4	0.6	0.5							0.2	0.1		
88					0.6	0.1	0.9	0.8							0.3	0.7		
120					0.3	0.0	0.7	0.2							0.4	0.2		
46			0.3	0.0	0.5	0.2	0.2	0.0	0.1	0.3			0.5	0.5	0.7	0.2		
35a			0.6	0.1	0.4	0.2												
40			0.3	0.1	1.0	2.1												
123					1.0	0.3	0.9	0.1							0.1	0.4		
125					0.6	0.1												
133					1.1	0.3												
13			0.2	0.1	0.4	0.5	0.5	1.3	0.1	0.4			0.5	0.1	0.1	0.8		
122					0.6	0.2												
85					1.0	0.3	0.7	0.0							0.3	0.3		
106					1.1	0.2												

Table 16. Continued

Burial no.	Analytical precision (1SD)		Intrafemur		Femur–rib		Femur–vertebra		Femur–skull		Femur–trabecular femur		Skull–rib		Rib–vertebra		Rib–trabecular femur	
	$\delta^{13}C$	$\delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$
77					0.2	0.6	1.1	1.2							0.9	0.6		
78					0.7	0.5	1.1	0.9							0.4	0.4		
115a					0.3	0.0												
126					0.9	0.5												
127					0.6	0.3	1.1	0.9							0.5	0.6		
134					0.0	0.0	0.9	1.2							0.9	1.2		
	Mean:		**0.4**	**0.1**	**0.7**	**0.3**	**0.8**	**0.6**	**0.1**	**0.3**	**0.8**	**0.2**	**0.5**	**0.5**	**0.4**	**0.5**	**0.4**	**0.3**

Previous studies on intra- and inter-individual variation have demonstrated differences in the order of 1‰ or less (for both $\delta^{13}C$ and $\delta^{15}N$) for animals raised on identical diets (DeNiro & Schoeninger 1983; Jim *et al.* 2006; Warinner & Tuross 2009), prehistoric populations with a presumed uniform diet (Lovell *et al.* 1986; Hedges *et al.* 2008), and even for various locations within the same bone (Katzenberg & Lovell 1999). Thus, the present author feels confident in using the 2σ error range as a cut-off point by which meaningful differences between intraskeletal isotope values can be identified.

Considering the mean differences for related skeletal elements shown in Table 16 (final row), it is surprising to observe generally greater Δ values for carbon than for nitrogen. Even though the analytical precision is different for $\delta^{13}C$ and $\delta^{15}N$, and they reflect distinct isotope systems, it is still unexpected that $\Delta^{15}N$ values demonstrate significantly smaller differences, considering the greater error range for $\delta^{15}N$. This difference is statistically significant ($U=1227.5$, $p<0.0001$): the median $\Delta^{13}C$ for all compared pairs is 0.6‰, whereas for $\Delta^{15}N$ it is 0.3‰. To theorize, if all intraskeletal variation observed here were caused by random measurement error, one would expect $\Delta^{15}N$ values to be on average higher or at least statistically similar to the distribution of $\Delta^{13}C$ values. However, this is not the case here.

Using the 2σ error range as a cut-off point, it can be established that the following groups display potentially meaningful differences in intraskeletal $\delta^{13}C$ isotope values: 'femur–rib', 'femur–vertebra' and 'cortical femur–trabecular femur'. Interestingly, all three of these groups comprise cortical–trabecular bone pairs, whereas the groups with either cortical–cortical or trabecular–trabecular pairs (e.g. 'femur–skull', 'rib–vertebra') generally produced smaller average $\Delta^{13}C$ (although most of these groups also contain a limited number of individuals). It should be noted that the $\Delta^{15}N$ data do not follow this pattern, and indeed, do not seem to display any visual trend in $\Delta^{15}N$ values for the skeletal elements compared.

Statistical analyses can be used to compare the 'femur–rib', 'femur–vertebra' and 'rib–vertebra' groups, as all the other groups had only three or four subjects. A statistically significant difference was found for $\Delta^{13}C$ values ($H=10.596$, $d.f.=2$, $p=0.005$) but not

for $\Delta^{15}N$ (H=1.962, d.f.=2, p=0.375). Post hoc analyses revealed that while the groups 'femur–rib' and 'femur–vertebra' do not differ statistically in the distribution of their $\Delta^{13}C$ values, the 'rib–vertebra' group is significantly different from both the 'femur–rib' (p=0.043) and the 'femur–vertebra' (p=0.005) group. This would be expected if the different turnover rates between cortical (e.g. femur) and trabecular (e.g. rib and vertebra) bone had an influence on intraskeletal isotope values. While the $\Delta^{13}C$ differences are generally small, it is statistically unlikely that the observed variability in $\Delta^{13}C$ values between different groups was caused by measurement error alone.

To explore intraskeletal variability further, the direction of the change in intraskeletal measurements should be taken into account. The following graphs (Figures 23 to 26) display both $\Delta^{13}C$ and $\Delta^{15}N$ values for the same groups listed in Table 16, but include the direction of the change between the two skeletal elements. The direction is established by always subtracting the δ value of the second skeletal element (δ_2) from the δ value of the first skeletal element (δ_1). For example, in the group 'femur–rib', femur is δ_1 and rib δ_2; for the group 'rib–vertebra', rib is δ_1 and vertebra is δ_2, etc. All figures also display the range of 2σ analytical precision for both $\delta^{13}C$ (black line) and $\delta^{15}N$ (grey line). All subjects are labelled by their burial number and arranged by age-at-death from youngest (left) to oldest (right).

The comparative group 'femur–rib' (Figure 23) has the largest number of subjects since both the femur and rib were available for all but one of the individuals sampled for intraskeletal measurements. A negative difference indicates that the femur has a more negative δ-value than the rib; a positive difference indicates the opposite. There seems to be a clear pattern in $\Delta^{13}C$ values where femur samples are consistently depleted compared to the ribs. Only in one case is the difference positive. On the other hand, no trend is apparent in the $\Delta^{15}N$ values which generally also display significantly smaller differences between femur–rib pairs. Statistically, it is highly unlikely that the difference between femur–rib $\Delta^{13}C$ and $\Delta^{15}N$ values (shown to be significant based on a Mann–Whitney U-test, U=89, p<0.0001) is caused by random factors such as sample selection or measurement error.

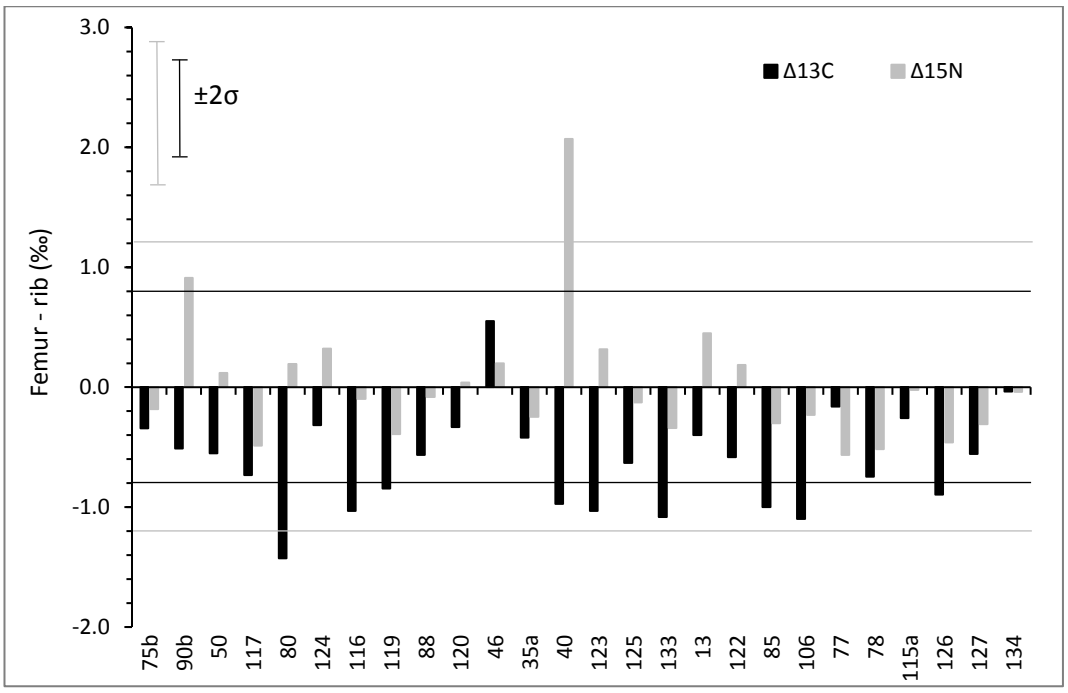


Figure 23. Per mil differences ($\Delta^{13}C$ and $\Delta^{15}N$) in $\delta^{13}C$ and $\delta^{15}N$ values between femur–rib pairs from Sărata Monteoru human burials. Subjects labelled by their burial number and arranged by age-at-death from youngest (left) to oldest (right)

Nine subjects show $\Delta^{13}C$ values around or above the 2σ range for analytical reproducibility, with the most substantial change occurring for a juvenile individual (burial no. 80), whose femur $\delta^{13}C$ is 1.4‰ lower than the rib. Only one subject (adolescent, burial no. 40) has a $\Delta^{15}N$ value beyond the cut-off point of the 2-sigma error range: the femur $\delta^{15}N$ is 2.1‰ greater than the rib. This individual also has a difference of -1‰ between their femoral and rib $\delta^{13}C$ values. None of the other subjects who displayed $\Delta^{13}C$ values greater than the 2σ analytical precision showed an accompanying (significant) change in their nitrogen isotope values.

Figure 24 displays equivalent data for all sampled femur–vertebra pairs. Even though the number of subjects is smaller, one would still expect a pattern similar to the 'femur–rib' group to emerge from the Δ values, if cortical–trabecular bone differences are influencing the data. Indeed, $\Delta^{13}C$ values display a consistent trend for femur samples which are consistently depleted in ^{13}C compared to vertebrae, similar to the pattern observed among femur–rib pairs. Half of the subjects have intraskeletal $\delta^{13}C$ differences around or beyond the 2σ measurement error, and two of them also show a potentially significant difference in their respective $\delta^{15}N$ values (burials no. 77 and

134). However, in contrast to the 'femur–rib' group above, $\Delta^{15}N$ values in this group seem to be distributed less randomly (in a mostly negative direction), and there are no statistically significant differences between femur–vertebra $\Delta^{13}C$ and $\Delta^{15}N$ values (U=46.5, p=0.143).

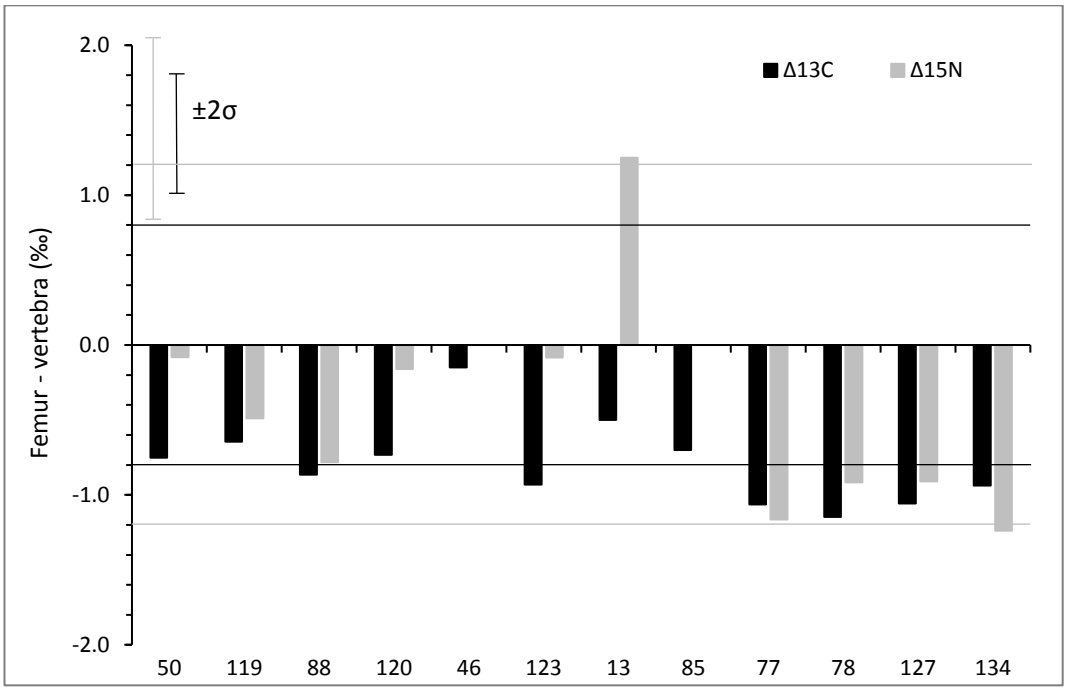


Figure 24. Per mil differences ($\Delta^{13}C$ and $\Delta^{15}N$) in $\delta^{13}C$ and $\delta^{15}N$ values between femur–vertebra pairs from Sărata Monteoru human burials. Subjects labelled by their burial number and arranged by age-at-death from youngest (left) to oldest (right)

The results from 'rib–vertebra' pairs display a pattern quite different from the two previous groups (Figure 25). Nearly all subjects demonstrate intraskeletal differences well within the measurement error, and the directionality of the change also seems randomized. There are no statistical differences in the distribution of rib–vertebra $\Delta^{13}C$ and $\Delta^{15}N$ values (U=75, p=0.887). The remaining skeletal pairs have intraskeletal differences below or very close to the cut-off point of the 2-sigma error range, and/or have too few subjects to identify any trends in the distribution of $\Delta^{13}C$ and $\Delta^{15}N$ values (see Figure 26), hence they are not discussed further here.

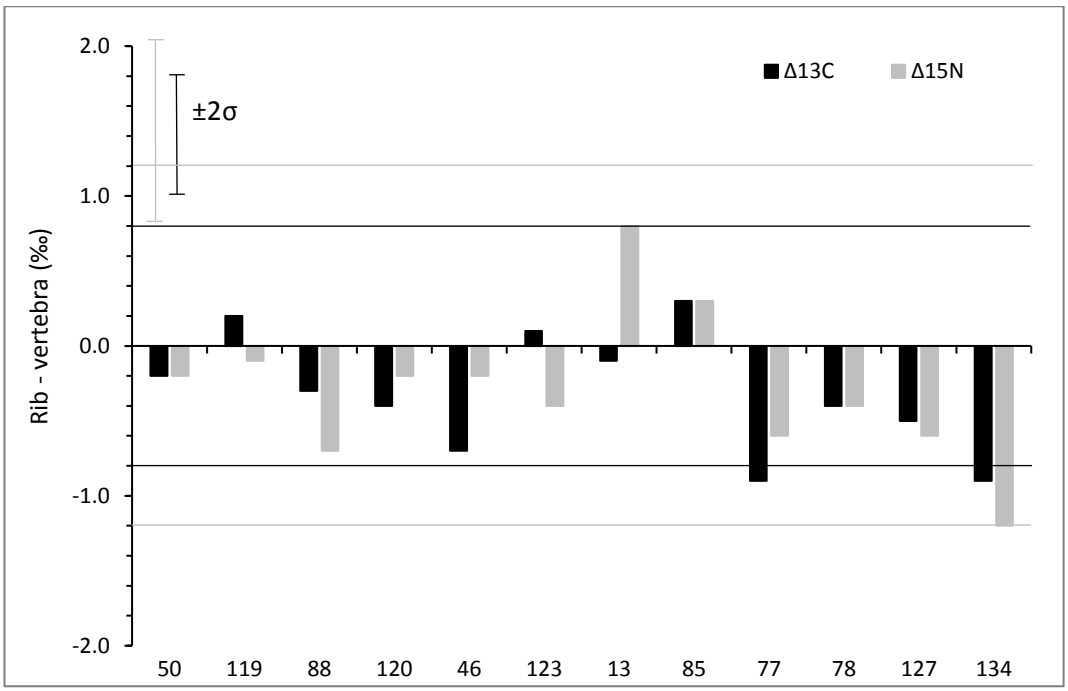


Figure 25. Per mil differences ($\Delta^{13}C$ and $\Delta^{15}N$) in $\delta^{13}C$ and $\delta^{15}N$ values between rib–vertebra pairs from Sărata Monteoru human burials. Subjects labelled by their burial number and arranged by age-at-death from youngest (left) to oldest (right)

The comparisons between skeletal pairs have shown that even though intraskeletal variation is generally within the 2-sigma analytical error, it is often around the outer limits of the error range and sometimes beyond that (mainly for cortical–trabecular bone comparisons), suggesting that at least some of the variability may be caused by factors other than analytical precision. To determine whether there is a third factor influencing intraskeletal isotope values, it is necessary to consider the effect of the individual's age on bone turnover rates.

Evidence presented in Chapter 2 shows that bone turnover in juveniles is much faster than in adults, with the highest rates occurring during the first year of life. This implies that any dietary change should be evident in juvenile bone collagen considerably faster than in adult tissues. In addition, the differences between cortical and trabecular bone turnover rates are believed to be much smaller for younger individuals, suggesting that even in the case of a minor dietary change, trabecular and cortical bone would register the change at a more comparable rate than in adults.

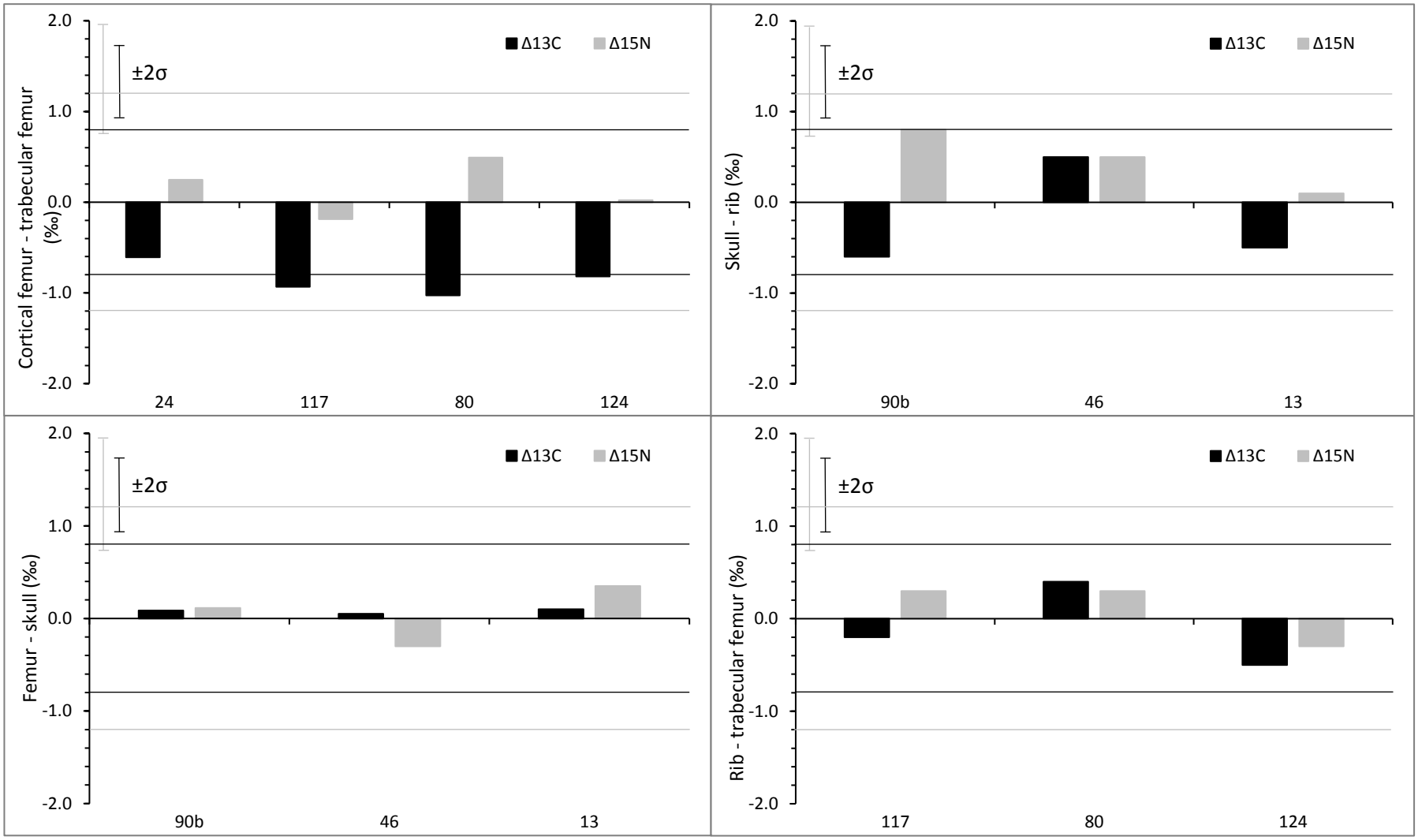


Figure 26. Per mil differences ($\Delta^{13}C$ and $\Delta^{15}N$) in $\delta^{13}C$ and $\delta^{15}N$ values between various skeletal pairs from Sărata Monteoru human burials. Subjects labelled by their burial number and arranged by age-at-death from youngest (left) to oldest (right)

Figure 27 shows the $\delta^{13}C$ values of juvenile individuals for all measured skeletal elements, in addition to the range of 2σ analytical error. All subjects are labelled by their burial number and sorted by their age-at-death from youngest (left) to oldest (right). The graph reflects the observations made earlier concerning cortical samples having consistently lower $\delta^{13}C$ values, and this is also true for individuals who already display ^{13}C enrichment likely caused by breastfeeding. This may imply that the enrichment of trabecular bone over cortical bone seen in $\delta^{13}C$ values is not influenced by diet but may have physiological causes.

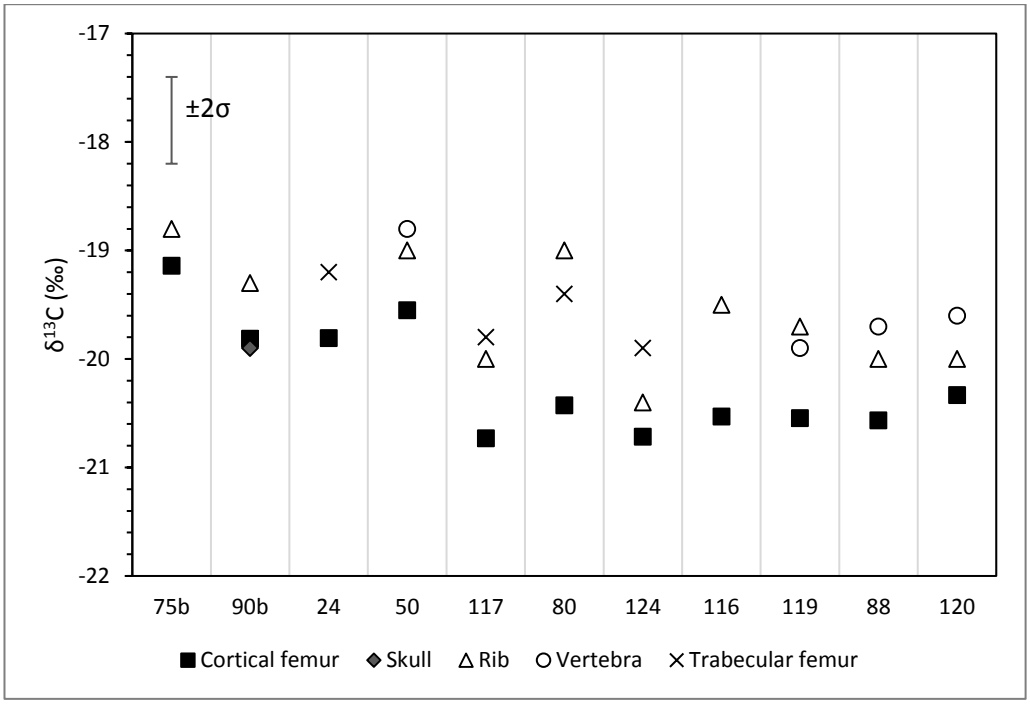


Figure 27. Intraskeletal $\delta^{13}C$ measurements for Sărata Monteoru juvenile (0–12 years) individuals. Subjects labelled by their burial number and arranged by age-at-death from youngest (left) to oldest (right)

Burial no. 80 (2–4 years old) demonstrates the greatest intraskeletal differences in $\delta^{13}C$ values (1.4‰ between femur and rib, and 1.0‰ between cortical femur and trabecular femur). The trabecular skeletal locations (rib and trabecular femur) of this individual show a $\delta^{13}C$ value very similar to burials no. 75b, 90, 24 and 50, who were all under 2 years old and presumably display the breastfeeding effect, whereas the cortical (femur) sample $\delta^{13}C$ is in the range of the older children, who have lower average $\delta^{13}C$ values than the infants. However, if the cortical bone collagen signal reflects a longer period, i.e. than the rib, it should have a *higher* $\delta^{13}C$ value than in trabecular bone (similar to

the other infants in this study); the opposite can be seen here. If the difference between the skeletal elements does indeed reflect a change in dietary isotopic composition associated with breastfeeding and/or weaning, the evidence for this individual would suggest that the difference between cortical and trabecular bone turnover rate in early childhood is either very small, or turnover is actually faster for cortical bone.

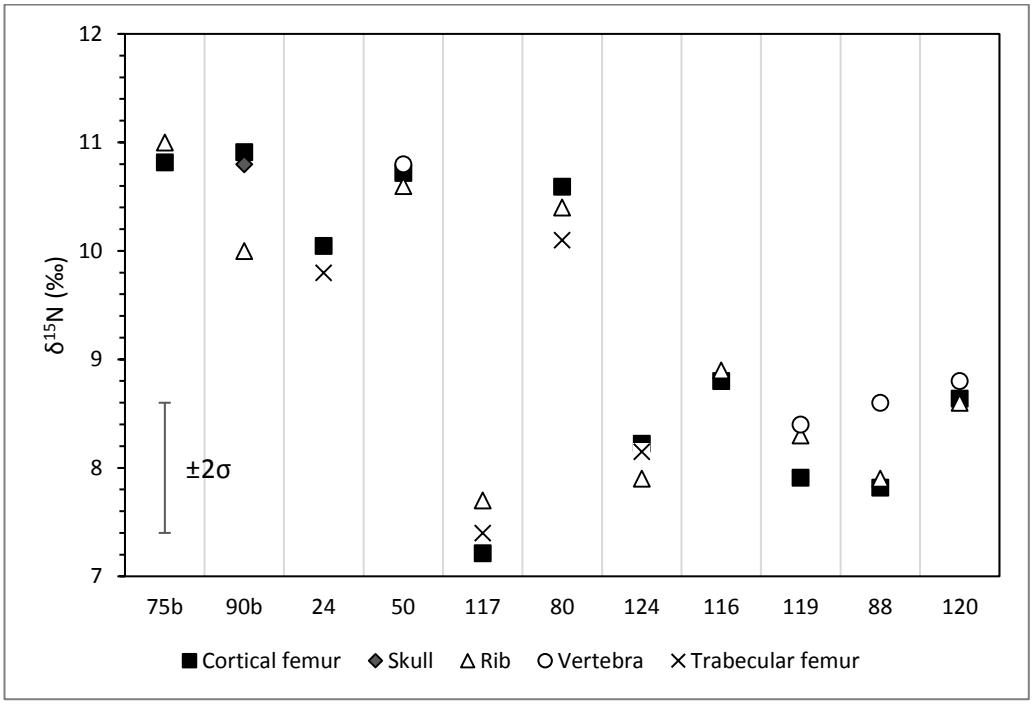


Figure 28. Intraskeletal $\delta^{15}N$ measurements for Sărata Monteoru juvenile (0–12 years) individuals. Subjects labelled by their burial number and arranged by age-at-death from youngest (left) to oldest (right)

It should be noted that the intraskeletal $\delta^{15}N$ values for burial no. 80 show only minimal variability, and are characteristic for an infant still being breastfed (Figure 28). If this individual was still being breastfed but had already been introduced to weaning foods which could have affected the $\delta^{13}C$ composition, it would still not explain why the cortical bone carries a seemingly 'younger' signal. In fact, when Waters-Rist *et al.* (2011) used a similar approach to study breastfeeding and weaning practices in prehistoric Siberia by comparing $\delta^{13}C$ and $\delta^{15}N$ values from long-bone diaphyses (cortical bone) and metaphyses (trabecular bone) of juvenile individuals, they came to the conclusion that the diaphysis is the slowest part of the long-bone to reflect dietary changes, and that bone collagen enriched in ^{15}N (from breastfeeding) was retained in

the diaphysis until the age of 5–6 years (although this varied both individually and between the three sites included in their study).

In the current data set, the lack of a significant change in intraskeletal $\delta^{15}N$ values in very young individuals who were likely breastfed and/or in the process of weaning implies that the differences in early childhood turnover rates between various skeletal elements included in this study may not be large enough to register the changing isotopic signal, and that infant bone turnover is so rapid that individuals around 3–6 years old (see burials no. 124, 116, 119) had already replaced all the collagen that was synthesized when they were being breastfed/weaned (or that the age determinations for these individuals have simply been overestimated).

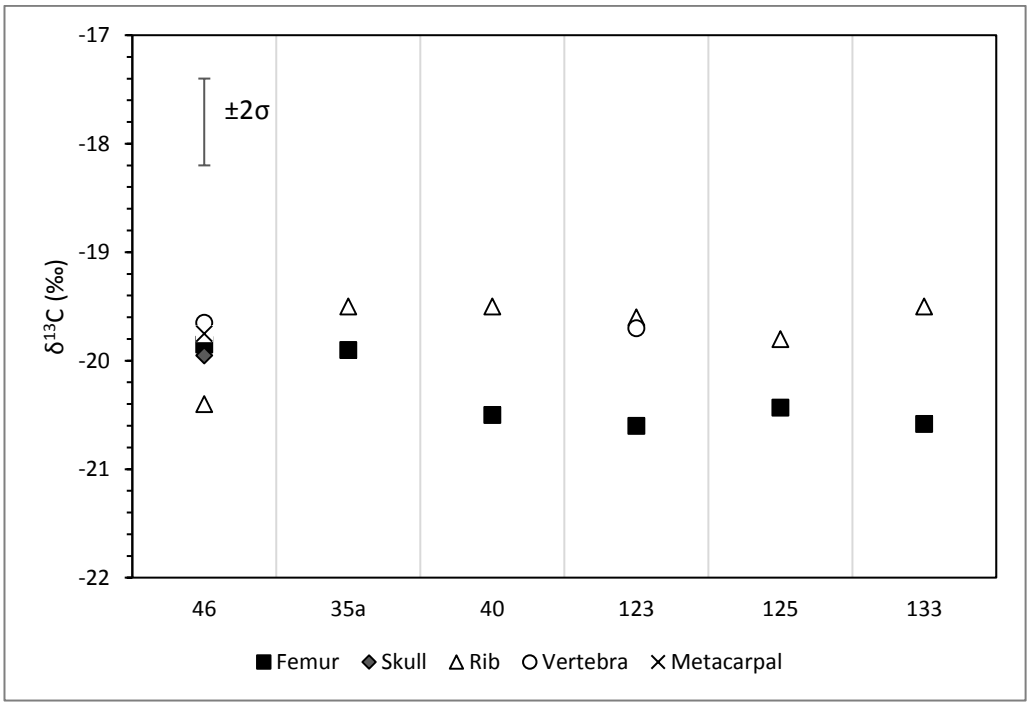


Figure 29. Intraskeletal $\delta^{13}C$ measurements for Sărata Monteoru adolescent (15–21 years) individuals. Subjects labelled by their burial number and arranged by age-at-death from youngest (left) to oldest (right)

Intraskeletal $\delta^{13}C$ and $\delta^{15}N$ values from adolescent individuals (between 15–21 years) are shown in Figures 29 and 30, sorted by age-at-death from left (youngest) to right (oldest). Differences in bone turnover rates between cortical and trabecular skeletal locations should be more pronounced in adolescents compared to juveniles, but the general pattern seen here is not unlike the previous graphs. In most cases, femoral $\delta^{13}C$

is lower than in trabecular samples, and in three individuals (burials no. 40, 123 and 133) the difference between cortical and trabecular bones is at or slightly over 1‰ (Figure 29).

For $\delta^{15}N$, adolescent intraskeletal measurements display very little variation between cortical and trabecular locations, usually within the 1-sigma error range (Figure 30). The one exception is the individual from grave 40 (female, 17–19 years old). Her rib bone has a $\delta^{15}N$ value 2.1‰ lower than the cortical femur, while at the same time the rib $\delta^{13}C$ is enriched 1‰ over the femur. The decrease in rib $\delta^{15}N$ seems to imply a change in diet (or in the isotopic composition of the diet) during the years preceding her death. However, if the observed difference was caused by a change in the trophic level of consumed food, the rib $\delta^{13}C$ should have predictably decreased, not increased. In modern vegans who display on average 2‰ lower $\delta^{15}N$ values than omnivores, $\delta^{13}C$ has either remained similar or decreased compared to those still eating animal products (O'Connell & Hedges 1999; Petzke *et al.* 2005). Alternatively, the increase in $\delta^{13}C$ could also be achieved through the consumption of C_4 plants.

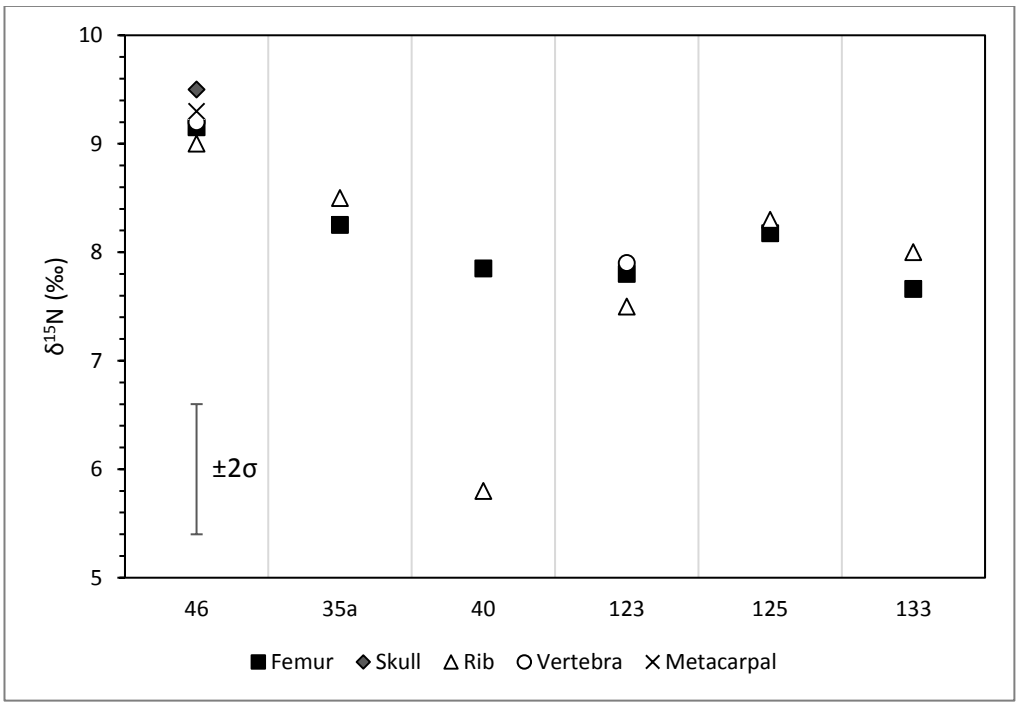


Figure 30. Intraskeletal $\delta^{15}N$ measurements for Sărata Monteoru adolescent (15–21 years) individuals. Subjects labelled by their burial number and arranged by age-at-death from youngest (left) to oldest (right)

Richards *et al.* (1998) saw a reverse trend of rising $\delta^{15}N$ (+1.6‰) and falling $\delta^{13}C$ (-0.9‰) values between the cortical femur and trabecular femur of a young child from Roman England, and suggested migration (to Britain, from an area with a warmer climate – and thus more positive human $\delta^{13}C$ values) as a possible explanation. However, if the pattern observed in burial no. 40 is caused by similar mechanisms (i.e. climate-induced variations in isotopic baseline values), it would seem illogical for the rib $\delta^{15}N$ value (representing time closer to death) to be so different from the average Sărata Monteoru population mean, and the femur value (representing a longer period of time) to reflect the 'local' signal, unless the individual spent time away from Sărata Monteoru during the last few years of life and returned shortly before her death.

Aridity, disease, and metabolic stress are all known to significantly influence human $\delta^{15}N$ values (e.g. Heaton *et al.* 1996; Ambrose 1991; Katzenberg & Lovell 1999; Fuller *et al.* 2005), but these factors usually result in ^{15}N enrichment. The only documented circumstance where $\delta^{15}N$ values are known to decrease is during positive nitrogen balance, such as growth or pregnancy, as shown in isotope analyses of human hair and fingernails (Fuller *et al.* 2004). However, when Nitsch *et al.* (2010) compared $\delta^{15}N$ values of 19th century women, who had died soon after giving birth, they saw no difference from the other adults, concluding that the so-called pregnancy effect seen in hair and nail collagen is not visible in bone collagen due to the slower turnover rate, and that any differences in $\delta^{15}N$ values between males and females must therefore be caused by actual dietary differences.

There is also the possibility that the low rib $\delta^{15}N$ value is the result of contamination. Even though the quality indicators for this sample were within the accepted limits, a $\delta^{15}N$ value of +5.8‰ is uncharacteristically low, even for a human vegan. O'Connell & Hedges (1999) found modern vegans to have mean values of +6.9‰ (minimum +6.3‰) in their hair keratin $\delta^{15}N$, whereas Petzke *et al.* (2005) found it to be on average +6.2‰ (minimum +5.5‰). In addition, human hair has been shown to be on average 0.86‰ lower than bone collagen from the same individual (O'Connell *et al.* 2001), suggesting that the bone collagen values of the modern vegans would be even more positive than those reported for keratin.

Human $\delta^{15}N$ values under +6‰ are rarely encountered in prehistoric European contexts, although low values around that figure have been published for the Mediterranean (e.g. Papathanasiou [2003] for Neolithic Greece), where they have been commonly explained by a greater reliance on legumes. Ogrinc & Budja (2005) also reported several humans from Neolithic Slovenia with $\delta^{15}N$ values below +6‰. However, when these same skeletons were re-analysed for radiocarbon dating by Bonsall *et al.* (2007), none of the samples which had shown low $\delta^{15}N$ values produced collagen of a satisfactory quality, leading the authors to suggest that the original samples (i.e. from Ogrinc & Budja) may have contained non-collagenous contaminants. Whether this could have occurred in the case of the rib sample from burial no. 40 can be tested by re-analysing the same bone, if possible, using the ultrafiltration protocol for improved collagen quality (Bronk Ramsey *et al.* 2004).

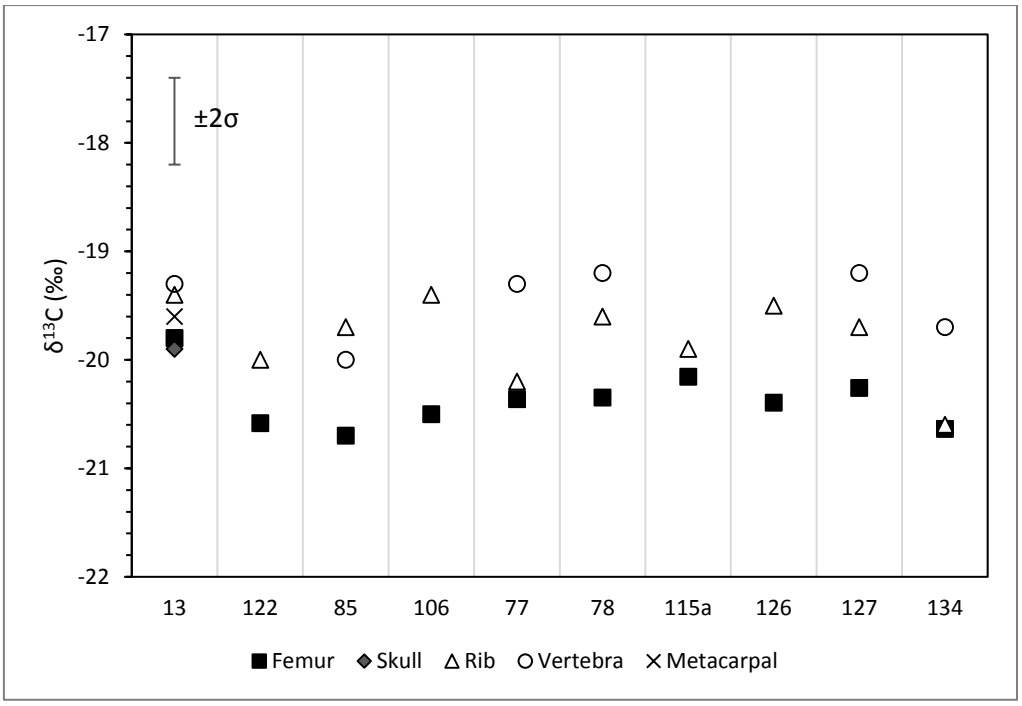


Figure 31. Intraskeletal $\delta^{13}C$ measurements for Sărata Monteoru adult (21+ years) individuals. Subjects labelled by their burial number and arranged by age-at-death from youngest (left) to oldest (right)

Finally, the intraskeletal $\delta^{13}C$ and $\delta^{15}N$ data for adults is presented in Figures 31 and 32. As expected, the $\delta^{13}C$ values display the already familiar trend of being lower in cortical bone samples than in trabecular bone, although in several cases the differences between the two are negligible. $\delta^{15}N$ values show slightly greater variability than was

seen in the adolescent and juvenile groups, and in three subjects the femur–vertebra difference is around 1.2‰ (burials no. 13, 77 and 134), which is the upper limit of the 2-sigma analytical error range for $\delta^{15}N$.

Unlike the previous age groups, in several individuals the rib and femur values are very similar, and it is the vertebra samples that display the greatest difference from cortical samples (for both $\delta^{13}C$ and $\delta^{15}N$). While this could be an effect of sampling bias (e.g. the adult group contains the most individuals that were sampled from the vertebra), it may also imply that the vertebral turnover rate in (some) adults is much greater than in ribs, perhaps reflecting small-scale variations in diet over a shorter period. Vertebral locations sampled for this study contained much more of the honeycomb-like bone tissue than ribs, possibly resulting in this area of the vertebra having a very high turnover rate.

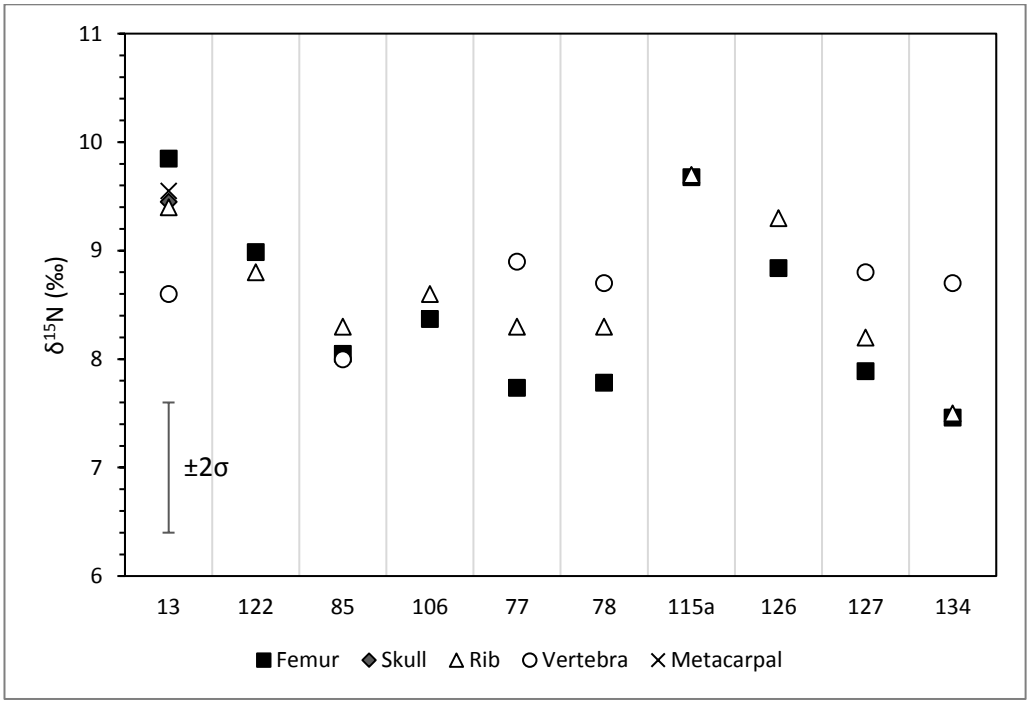


Figure 32. Intraskeletal $\delta^{15}N$ measurements for Sărata Monteoru adult (21+ years) individuals. Subjects labelled by their burial number and arranged by age-at-death from youngest (left) to oldest (right)

It is not clear if the observed variations in rib–vertebra differences are influenced by the age of the individual, i.e. the difference between rib and vertebra turnover rates changing with age. The rib–vertebra differences do seem to be more pronounced in

adults, whereas they usually vary within the 1-sigma error range in the juvenile group. However, there is insufficient evidence to draw a firm conclusion on this. In addition, there is no correlation between age-at-death and Δ values for any of the skeletal pairs (e.g. femur–rib, femur–vertebra, rib–vertebra), suggesting that whatever is causing the variation that exceeds the analytical error range, it does not seem to be influenced by the age of the individual, i.e. by younger individuals having faster bone turnover rates and smaller differences between cortical and trabecular regions, and by older individuals displaying significant differences between cortical and trabecular regions in terms of the time period reflected in bone collagen.

Alternatively, intraskeletal differences may be influenced by individual variations in collagen turnover rates which can differ by up to a factor of two for various skeletal elements and within a population (see Hedges *et al.* 2007; Hodgins 2009). Different rates in, for example, individual vertebral turnover, can theoretically lead to collagen that has formed over a varying period of time, and minor (e.g. seasonal) fluctuations in diet could thus be differently reflected in the isotopic composition of vertebrae between individuals.

However, collagen turnover rates should apply equally to both nitrogen and carbon incorporation, but as noted above, cortical–trabecular $\Delta^{13}C$ values tend to display a very distinct pattern compared to $\Delta^{15}N$. Even taking into account the 2-sigma error range and the lower analytical precision for $\delta^{15}N$, the differences seen in intraskeletal $\Delta^{13}C$ and $\Delta^{15}N$ are statistically very unlikely to be random. Possible explanations for the observed pattern in intraskeletal $\delta^{13}C$ values include minor changes in diet during different stages of life, physiological differences in how carbon and nitrogen are incorporated into bone collagen of various skeletal tissues, or simply 'normal' variation.

A Wilcoxon signed-rank test determined that there was a statistically significant median change in $\delta^{13}C$ values (0.6‰) between associated cortical (-20.4‰) and trabecular (-19.8‰) $\delta^{13}C$ values ($z=3.698$, $p<0.001$); no such change was seen in $\delta^{15}N$ values. The fact that cortical bone $\delta^{13}C$ values are consistently lower than trabecular

bone values, may give credence to the interpretation that a minor dietary change has affected the Sărata Monteoru population. The results seen here could occur if diet in later life (as reflected in trabecular bone locations with a fast turnover) was more enriched in ^{13}C compared to diet in early life (as reflected in cortical bone collagen). Consumption of marine or freshwater resources or higher trophic level protein can affect $\delta^{13}C$ values but are usually accompanied by a complementary change in $\delta^{15}N$ values (something which is not seen in this data set). On the other hand, significant intake of low trophic level aquatic resources (e.g. some shellfish), C_4 plants, or dairy products can all affect $\delta^{13}C$ values without (theoretically) changing the $\delta^{15}N$.

While it is not inconceivable that the Sărata Monteoru population consumed any of these products in slightly differing amounts during their early life, it must be noted that there were no statistically significant differences between cortical–trabecular $\Delta^{13}C$ of adults and adolescents/juveniles. If there was even a minor change between childhood–adolescent–adult diet $\delta^{13}C$, the $\Delta^{13}C$ values should increase with age, due to the changing differences between cortical–trabecular bone turnover rates. Several studies (e.g. Hedges *et al.* 2007; Hodgins 2009) have demonstrated that in mature adults, cortical bone collagen can display lag times up to 30 years and more. The fact that adult and adolescent cortical bone $\delta^{13}C$ values show no differences, suggests that whatever the cause of the observed variability, it does not seem to be influenced by age-related changes in diet.

Another possible explanation of the observed data is that there are physiological differences in how carbon and nitrogen are incorporated into bone collagen, especially with regard to cortical *vs* trabecular bone. While bomb radiocarbon studies have displayed clear differences in bone collagen ^{14}C replacement rates between different skeletal elements, they offer no similar evidence for nitrogen incorporation rates (Ubelaker *et al.* 2006; Hodgins 2009; Ubelaker & Parra 2011). However, studies that have used isotopically labelled amino acids to explore bone collagen protein synthesis rates have shown that incorporation rates of amino acids such as proline and alanine labelled with either ^{13}C or ^{15}N show no differences based on the isotope used, even

when comparing between cortical and trabecular bone (Scrimgeour *et al.* 1993; Babraj *et al.* 2005).

Concerning 'normal' variation, unfortunately, there have been very few systematic studies that assess the range of variation in cortical and trabecular isotope values in prehistoric human populations. Some researchers have obtained intraskeletal measurements for a limited number of individuals, but found the results to show variation much smaller than reported here for cortical–trabecular $\delta^{13}C$ (e.g. Bonsall *et al.* 1997; Jay *et al.* 2013). Others have only looked at intraskeletal $\delta^{15}N$ measurements (e.g. Waters-Rist & Katzenberg 2010). There are also studies in which clear differences were observed in both $\delta^{13}C$ and $\delta^{15}N$ intraskeletal values for a limited number of individuals from historic contexts but these were associated with migrations over long distances (e.g. Sealy *et al.* 1995; Cox & Sealy 1997; Schroeder *et al.* 2009).

When Waters-Rist *et al.* (2011) looked at $\delta^{13}C$ and $\delta^{15}N$ from the diaphysis (cortical bone) and metaphysis (trabecular bone) of juvenile individuals, they sometimes saw intraskeletal $\delta^{13}C$ differences of up to 2‰, but found no trends in either cortical or trabecular values, nor any correlation with age-at-death. Similarly, Cox *et al.* (2001) reported differences up to and slightly over 2‰ between cortical and trabecular locations in individuals from historic South Africa, but attributed these to the influence of a marine diet since both $\delta^{13}C$ and $\delta^{15}N$ became more positive with age.

There are two studies of medieval European material that have systematically compared femur and rib $\delta^{13}C/\delta^{15}N$ values from a considerable number of individuals – 58 adults and subadults from Denmark (Jørkov *et al.* 2009), and 19 adults and adolescents from England (Pollard *et al.* 2012). It should be noted that both studies used a similar method for collagen preparation (although different from that applied in the present study), which included the use of powdered bone and the omission of the NaOH stage. Another study by Hedges *et al.* (2008) compared $\delta^{13}C$ and $\delta^{15}N$ values of cortical femur and trabecular femur from 22 adults and subadults recovered from a Neolithic chambered tomb in England. Their analysis also omitted the NaOH stage, although bone pieces (instead of powdered bone) were used.

Jørkov *et al.* (2009) did not observe any significant variations or trends between femur–rib differences for either $\delta^{13}C$ or $\delta^{15}N$, with an average intraskeletal difference of only around 0.1‰ for both. Hedges *et al.* (2008) reported that cortical and trabecular bone $\delta^{13}C$ and $\delta^{15}N$ values did not vary significantly for the whole group (average difference of 0.1‰ for both C and N), although adults showed slightly greater average differences than subadults (0.2‰ for both C and N). Pollard *et al.* (2012), however, found ribs to have consistently higher $\delta^{15}N$ than femurs (the average difference of 0.6‰ was statistically significant as calculated by the present author based on published data), yet saw no corresponding shift in $\delta^{13}C$ values (which showed differences on average of only 0.1‰). No correlation with age was reported, and the authors were unable to explain the higher rib $\delta^{15}N$ values, other than conceding that the results were unlikely to have happened 'by chance'.

The present author is inclined to agree with Pollard and colleagues' conclusion and to offer a similar verdict on the data observed here. With a few exceptions discussed earlier, the intraskeletal differences seen here are usually not large enough to be confidently interpreted as due to dietary changes. There is also no correlation between intraskeletal differences and age/sex. However, the observed pattern between cortical and trabecular $\delta^{13}C$ values is certainly unusual and statistically speaking very unlikely to have been caused by random sample selection.

The only other viable explanation is variation caused by samples being analysed in two different laboratories, i.e. if the interlaboratory differences were actually greater than that demonstrated by the two test samples. It should be noted that while all the femur samples were analysed at SUERC, some rib samples (n=16) were analysed at SUERC and others (n=34) at NIGL. The NIGL rib samples also include some individuals for which only the rib was sampled. While a Mann–Whitney U test showed statistically significant differences between $\delta^{13}C$ values of ribs from the two labs ($U=399$, $p=0.008$; SUERC ribs mean value -19.8‰, NIGL ribs mean value -19.5‰), no corresponding difference was seen between rib $\delta^{15}N$ values ($U=240$, $p=0.505$). There are thus no systematic differences between the measurements from the two laboratories.

In addition, when comparing Δ values from all cortical–trabecular pairs (mean $\Delta^{13}C$ = -0.65‰, mean $\Delta^{15}N$ = -0.05‰) to Δ values from only pairs where both skeletal elements were analysed in one lab (SUERC) (mean $\Delta^{13}C$ = -0.56‰, mean $\Delta^{15}N$ = -0.01‰), no statistically significant differences emerge between the two groups, for either C (U=396, p=0.292) nor N (U=436.5, p=0.620). Since distinguishing between data received from the two laboratories did not affect the overall trend seen in cortical–trabecular $\Delta^{13}C$ values, interlaboratory differences cannot be regarded as a sufficient explanation.

For the moment, therefore, no explanation can be offered for the observed differences between cortical and trabecular $\delta^{13}C$ values. Further systematic comparisons between cortical and trabecular samples (ideally following a consistent sampling strategy) from various prehistoric populations should show whether the trend seen here only applies to Sărata Monteoru, or occurs more widely. To begin with, the ten Cârlomăneşti individuals represented in this study by rib samples only, could also be analysed from the cortical femur. Improvements in IRMS analytical precision would also increase the prospects of detecting meaningful variations in intraskeletal isotope values.

The current study underlines the importance of consistency in the choice of skeletal element used in dietary studies when comparing individuals or populations. In this regard, the causes of the observed (small, yet consistent) intraskeletal variation in Sărata Monteoru $\delta^{13}C$ values are less relevant than *how* these variations affect the dietary interpretations made for this population. For example, since femur $\delta^{13}C$ values are consistently lower than rib $\delta^{13}C$ values, it follows that a population average $\delta^{13}C$ calculated when only femur values are available will be lower than a population average calculated from only rib samples. For Sărata Monteoru, the population mean $\delta^{13}C$ based on all available samples would be -19.7‰ (±0.4‰), whereas the population mean based on only rib samples (n=50) is -19.6‰ (±0.4‰) and on only femur samples (n=28) -20.3‰ (±0.4‰). The difference between the rib-only and femur-only groups is statistically significant (U=147, p<0.0001); however, the difference is not retained when comparing rib-only and femur-only for $\delta^{15}N$ (mean values for both groups are within 0.1‰ from the whole population mean calculated from all available samples).

It is important to note that on this occasion the rib–femur $\delta^{13}C$ variations do not affect the outcome when comparing the Sărata Monteoru population mean to that of Cârlomăneşti: the differences between the two populations are statistically significant regardless of whether the 'all-samples', rib, or femur $\delta^{13}C$ values are used to calculate the Sărata Monteoru population mean. Nevertheless, this study of intraskeletal variation demonstrates that it *does* matter which bone is sampled for isotope analysis, as this can influence the average values for the population, and hence influence conclusions based on that value. In the following discussions, the 'all-samples' population average is generally used for Sărata Monteoru, unless noted otherwise. In Chapter 6.5 it will be discussed whether using either the 'all-samples', rib, or femur average as the population mean affects the outcome of a mixing model used to quantify the diet of the Sărata Monteoru population.

6.3.2. Sulphur

Intraskeletal $\Delta^{34}S$ measurements are available for 11 individuals from Sărata Monteoru, and are shown in Table 17 along with 1SD analytical precision and intrafemur differences. $\Delta^{34}S$ values are variable, ranging from 0.01‰ to 1.3‰. In three occasions $\Delta^{34}S$ is >1‰, but these variations are not significant when the much greater measurement error for $\delta^{34}S$ is taken into consideration. There is no indication of a significant change in baseline $\delta^{34}S$ values between early (cortical bone) and later (trabecular bone) life that would suggest a change in location or food source.

For 10 individuals, intraskeletal data from one cortical (femur in all 10 cases) and one trabecular (mostly rib, in one case trabecular femur) bone location is plotted for $\Delta^{13}C$, $\Delta^{15}N$, and $\Delta^{34}S$ (Figure 33). The directionality of the change is calculated based on the same principles as outlined above for C and N, i.e. a negative direction indicates that the cortical bone has a lower value compared to the trabecular bone. A 2σ error range for analytical precision is depicted for $\delta^{13}C$ (black line) and $\delta^{15}N$ (grey line); the 2σ error range for $\delta^{34}S$ is not shown as it lies beyond the range of the graph. The individuals are arranged by age-at-death from left (youngest) to right (oldest) ranging from infants to mature adults.

Table 17. Intraskeletal differences ($\Delta^{34}S$) in bone collagen $\delta^{34}S$ values for related skeletal elements of burials from Sărata Monteoru compared with analytical precision

Burial no.	Analytical precision (1SD) $\delta^{34}S$	Intrafemur $\Delta^{34}S$	Femur–rib $\Delta^{34}S$	Femur–skull $\Delta^{34}S$	Femur–trabecular femur $\Delta^{34}S$
90b	**±0.6**			0.0	
50			0.4		
117					0.8
80			0.7		
124			0.1		
88			1.3		
120			1.0		
35a		0.2			
40		0.1			
125			0.5		
122			1.1		
127			0.3		
134			0.4		
	Mean:	0.15	0.64	N/A	N/A

There is no apparent trend in $\Delta^{34}S$ values and no correlation with age or between the $\Delta^{34}S$ and $\Delta^{13}C/\Delta^{15}N$ of the same individual. Burial no. 80 (2–4 years old) has a cortical–trabecular bone difference of -1.4‰ for $\Delta^{13}C$, but the lack of a significant change in the respective $\delta^{34}S$ values indicates that this shift was not caused by migration from an area with different baseline $\delta^{34}S$ values. It is unfortunate that intraskeletal $\delta^{34}S$ data are lacking for the other individual (burial no. 40) with a marked difference between femur–rib $\delta^{15}N$ values, as a significant difference between femur–rib $\delta^{34}S$ values might have indicated a change in residence.

No further conclusions can be drawn from this data set, nor are there many similar studies with which to compare these results. The present author is aware of only one other published study (Jay *et al.* 2013) that analysed human $\delta^{34}S$ values from a cortical and a trabecular bone element. For three individuals, the maximum difference between $\delta^{34}S$ values of a humerus and a rib was 1.7‰, which the authors did not deem significant. The identification of intraskeletal changes in $\delta^{34}S$ values would also benefit from an improvement in the analytical precision associated with S-isotope measurements, as the current error range is far too large to detect minor variations.

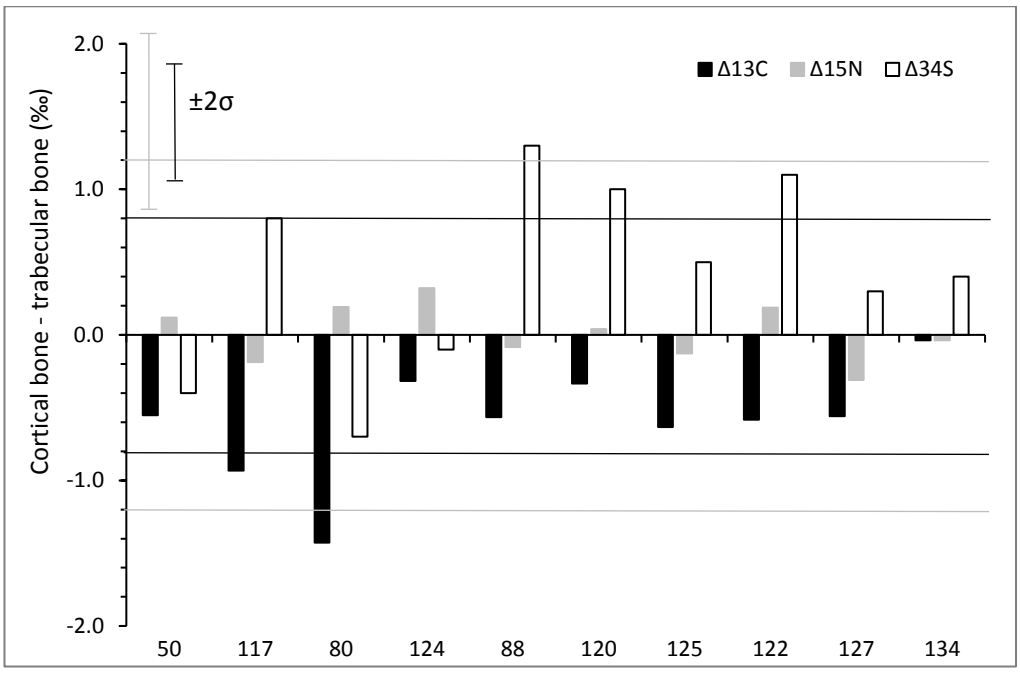


Figure 33. Per mil differences ($\Delta^{13}C$, $\Delta^{15}N$ and $\Delta^{34}S$) in $\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$ values between cortical bone–trabecular bone pairs from Sărata Monteoru human burials. Subjects labelled by their burial number and arranged by age-at-death from youngest (left) to oldest (right)

6.4. Isotope ratio differences between groups

6.4.1. Sărata Monteoru *vs* Cârlomăneşti

These two sites, typical for the Monteoru culture, provided an opportunity to assess the uniformity in dietary practices in the Sub-Carpathians during the Bronze Age. Additionally, the human burials from each site represent distinct time periods as suggested by radiocarbon dating of some of the skeletons: Sărata Monteoru cemetery no. 4 belongs to the late phase of the culture (ca. 1700–1500 cal BC), whereas the human burials from Cârlomăneşti originate from an earlier phase (ca. 2280–1800 cal BC). This allows us to explore the continuity of dietary practices through time, although any conclusions must be made with caution as it may be difficult to differentiate between temporal variations and those caused by site-specific dietary preferences. Nevertheless, the close geographical proximity of the two sites (ca. 12km), and their similar material culture and palaeoecological evidence suggest that any differences in isotope values are likely to reflect temporal changes.

The average isotope values for all Sărata Monteoru (n=59) individuals were -19.7‰ (±0.4‰) for $\delta^{13}C$, and +8.7‰ (±1.0‰) for $\delta^{15}N$. For Cârlomăneşti (n=10) the respective values were -19.3‰ (±0.2‰) and +9.6‰ (±0.4‰) (Figure 34). The mean values for the two sites are statistically significantly different for both $\delta^{13}C$ and $\delta^{15}N$ (Mann–Whitney U test, U=468.5, p=0.003 for $\delta^{13}C$; U=490.5, p=0.001 for $\delta^{15}N$). Unlike Cârlomăneşti, the Sărata Monteoru dataset includes several infants who seem to display the nursing effect ($\delta^{15}N$ values over +10‰), however, this does not significantly affect mean values. Even if individuals under 8 years old are excluded, the differences between the two sites remain statistically significant ($p<0.005$ for both $\delta^{13}C$ and $\delta^{15}N$).

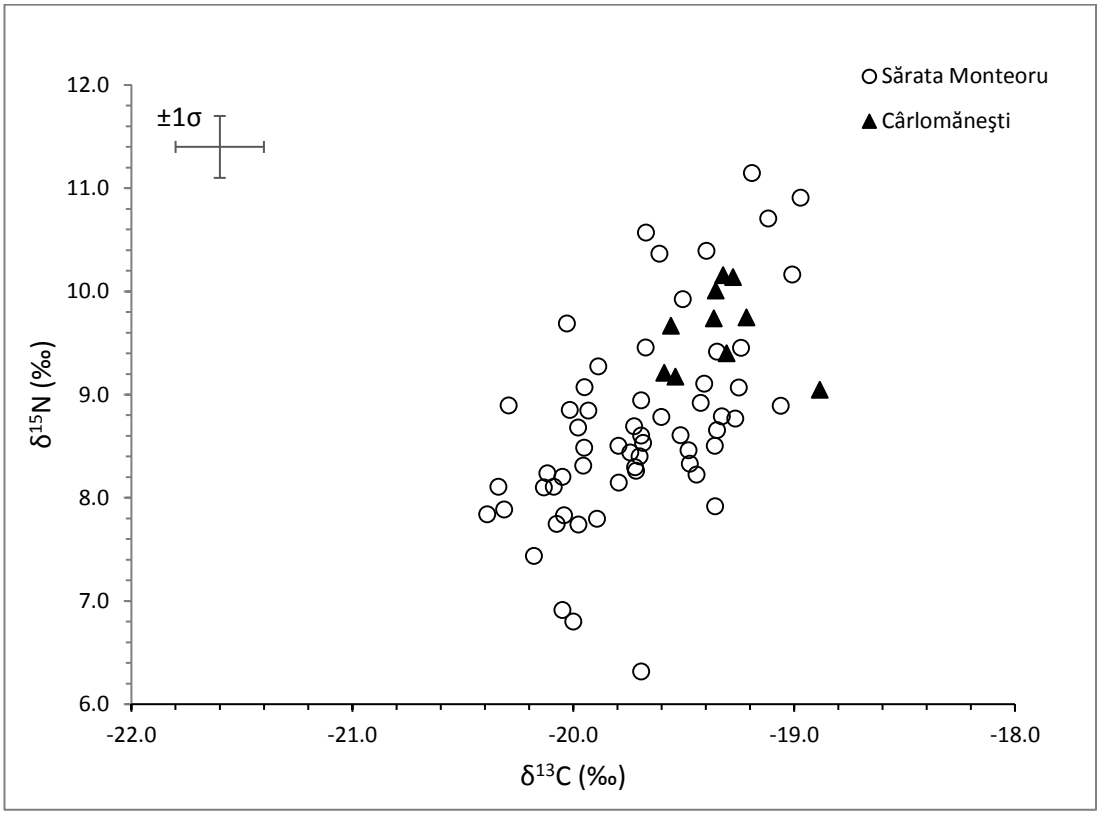


Figure 34. Human bone collagen $\delta^{13}C$ and $\delta^{15}N$ values from Sărata Monteoru and Cârlomăneşti

The Sărata Monteoru population is characterised by lower average $\delta^{13}C$ and $\delta^{15}N$ values compared to Cârlomăneşti. To determine whether the differences are caused by variations in baseline values between the two sites (and/or between time periods), or by actual differences in the proportions of various dietary staples, faunal isotope values from both Sărata Monteoru and Cârlomăneşti should be considered. It should be noted

that Sărata Monteoru animal samples, recovered from graves, are closely associated with the human burials, whereas the Cârlomăneşti faunal material, retrieved from Monteoru-era layers of the nearby settlement, may or may not be contemporaneous with the cemetery at that site.

Because of the similar geographical settings, it is unlikely there would be any significant variations in local baseline isotope values due to environmental factors. This is supported by the observation that while the range of faunal $\delta^{13}C$ and $\delta^{15}N$ values is greater for Cârlomăneşti (n=38) (-13.5‰ to -22.1‰ for $\delta^{13}C$, +2.8‰ to +9.9‰ for $\delta^{15}N$) than for Sărata Monteoru (n=17) (-18.9‰ to -20.7‰ for $\delta^{13}C$, +5.4‰ to +9.8‰ for $\delta^{15}N$), the two ranges overlap and the mean faunal values from the two sites are not statistically different (Cârlomăneşti -19.6‰ [±1.4‰], +6.6‰ [±1.8‰]; Sărata Monteoru -19.7‰ [±0.5‰], +6.8‰ [±1.1‰], for $\delta^{13}C$ and $\delta^{15}N$, respectively) (Figure 35).

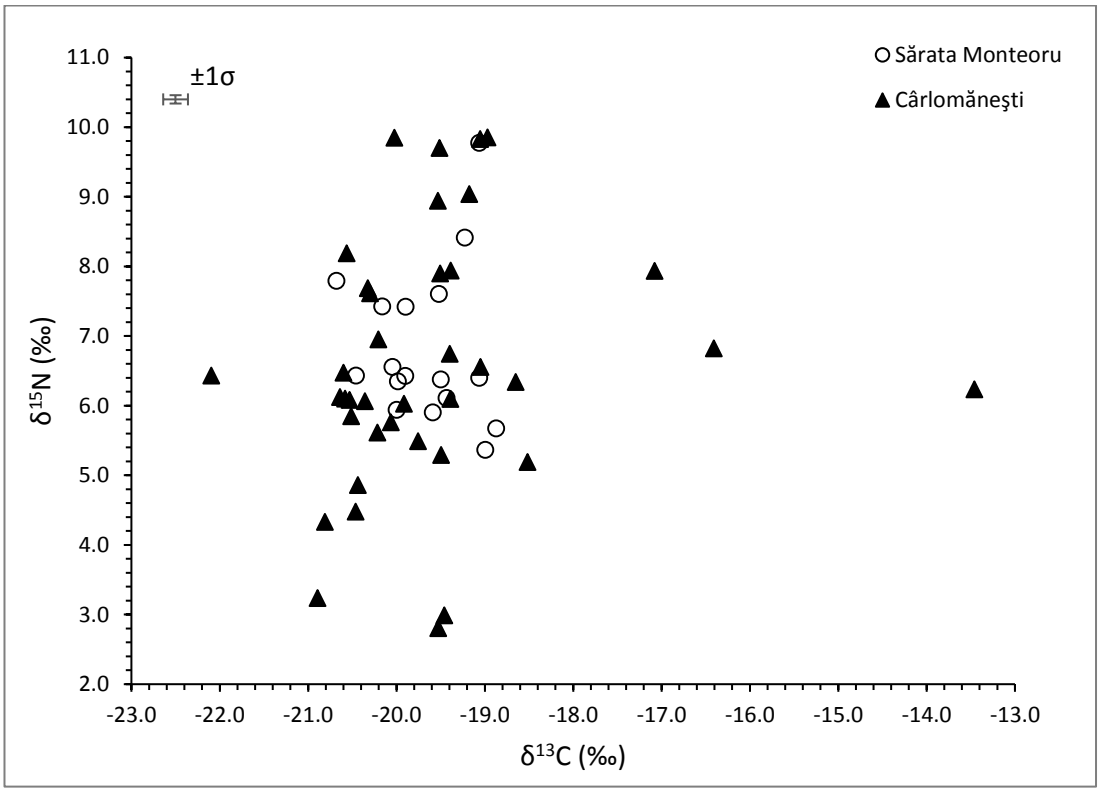


Figure 35. Animal bone collagen $\delta^{13}C$ and $\delta^{15}N$ values from Sărata Monteoru and Cârlomăneşti

However, comparing human and faunal isotope values for each site separately reveals some variations in the animal data. Figures 36 and 37 show human and faunal mean isotope values with a 1SD error range for Sărata Monteoru and Cârlomăneşti, respectively. The average values for humans have been taken to only include adolescent and adult individuals from each site. The human mean values are compared to faunal data from the respective site, with the exception of the deer and hare from Cârlomăneşti: since no wild animal bones were available for sampling from Sărata Monteoru, the Cârlomăneşti specimens were used instead as representatives of the local wild herbivore signal.

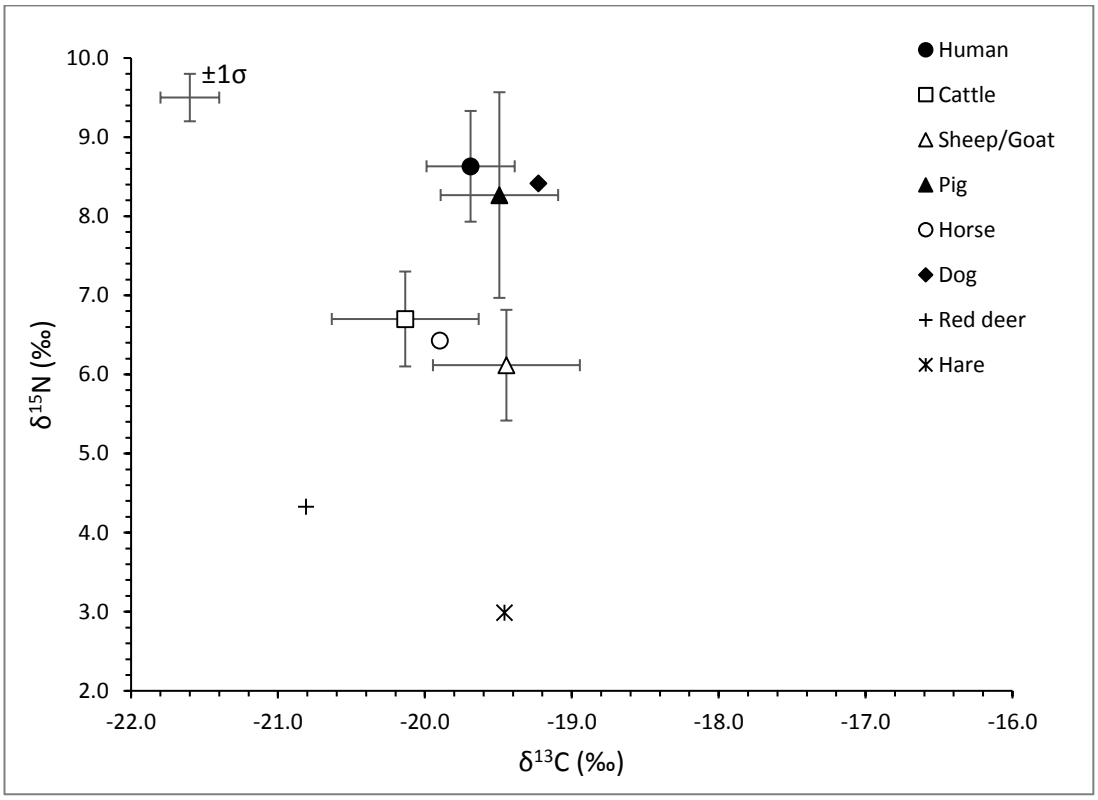


Figure 36. Mean values and 1SD of human (adolescents and adults) and faunal bone collagen δ¹³C and δ¹⁵N from Sărata Monteoru; wild herbivore values are from Cârlomăneşti. Groups with only one subject are presented as individual values

In Sărata Monteoru (Figure 36), the humans have isotope values very similar to those of pigs and (one) dog. Domesticated herbivores show average $\delta^{15}N$ values approximately 2‰ lower than humans, and cattle also have slightly more negative mean $\delta^{13}C$ values compared to humans and other fauna. Comparing the domesticated herbivore (taken here to include cattle and caprines [i.e. goats and sheep]) average $\delta^{15}N$

(+6.4‰ [±0.7‰]) to the human average (+8.6‰ [±0.7‰]) gives a shift of 2.2‰. Even assuming a very conservative 3‰ $\delta^{15}N$ trophic level enrichment, it still follows that there must have been other important sources of dietary protein besides domesticated herbivores and their products. Venison likely made little contribution to dietary protein.

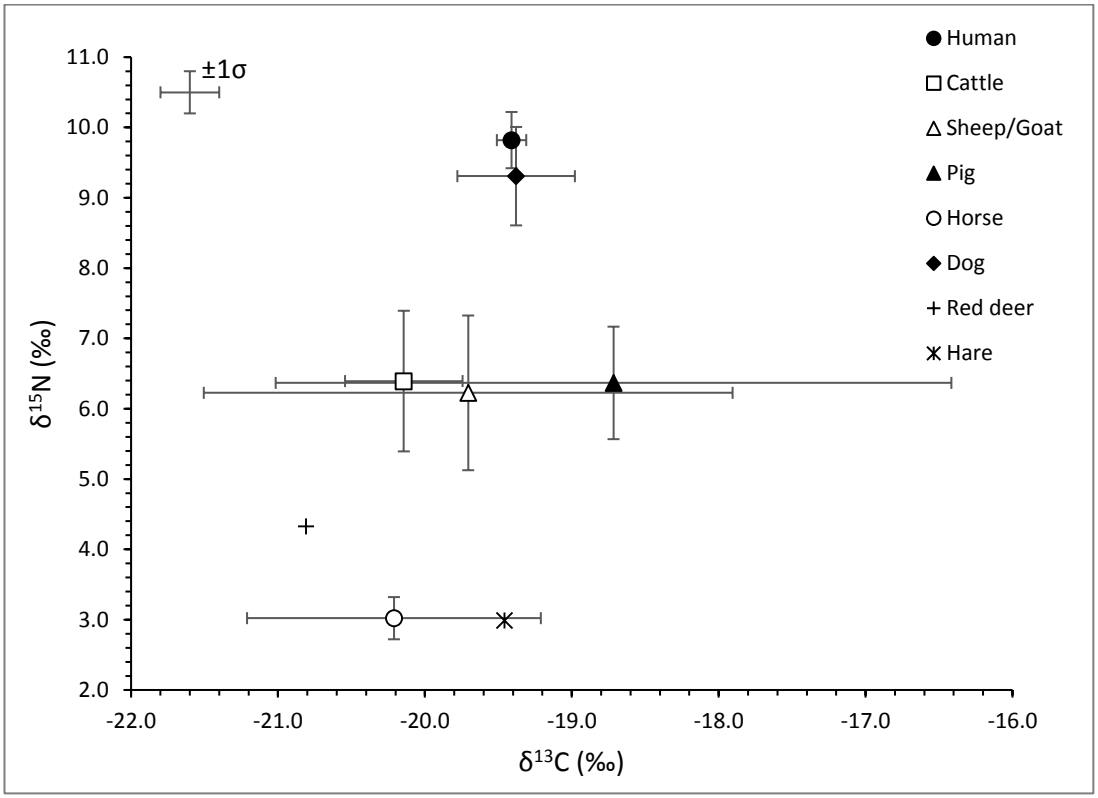


Figure 37. Mean values and 1SD of human (adolescents and adults) and faunal bone collagen $\delta^{13}C$ and $\delta^{15}N$ from Cârlomăneşti. Groups with only one subject are presented as individual values

For Cârlomăneşti (Figure 37), the $\Delta^{15}N$ between domesticated herbivore (+6.3‰ [±1.0‰]) and human (+9.8‰ [±0.4‰]) average isotope values is 3.5‰, significantly greater than for the later period represented at Sărata Monteoru. This implies that domesticated animals and their products likely contributed a notable amount to the overall protein intake, apparently more than in Sărata Monteoru. Humans and dogs again share comparable values for both $\delta^{13}C$ and $\delta^{15}N$. However, significant differences can be seen in pig and horse $\delta^{15}N$ values, which are noticeably lower compared to Sărata Monteoru. At Cârlomăneşti, pigs seem to have been reared on a

(plant-based) diet similar to caprines and cattle. The wide variation in pig and caprine $\delta^{13}C$ values suggests diverse grazing strategies and/or environments.

Based on average isotope values for humans and domesticated fauna, the Early Monteoru Cârlomăneşti community seems to have consumed more animal protein (likely from cattle, caprines and pigs) than the people occupying late-period Sărata Monteoru. This difference can be attributed entirely to the more positive human $\delta^{15}N$ values of Cârlomăneşti, since cattle and caprine average $\delta^{15}N$ values are similar for both sites. The latter observation also implies that differential consumption of cattle and caprines between the two sites cannot be identified based on $\delta^{15}N$ values. Caprines from both sites do have slightly higher average $\delta^{13}C$ values (-19.4‰ for SM, -19.7‰ for CRL) than cattle (-20.1‰ for both sites), but this difference is statistically non-significant. However, based on a 0.5–1‰ human–faunal carbon offset typically associated with a trophic level enrichment, it can be argued that dietary reliance on caprines was smaller in Sărata Monteoru compared to Cârlomăneşti.

As stated above, the difference between the human mean $\delta^{13}C$ values from the two sites is not large (0.4‰), but statistically significant. The slightly lower average $\delta^{13}C$ for Sărata Monteoru is consistent with a reduced intake of animal protein (and corresponding increased reliance on plant foods, since most cultivated crops generally have lower $\delta^{13}C$ values than domesticated animals), and/or may indicate a more important role for dairy products, which have been shown to be slightly more depleted in both ^{13}C and ^{15}N compared to beef (Nardoto *et al.* 2006; Huelsemann *et al.* 2013). The rise in the importance of cattle husbandry during the Carpathian Bronze Age proposed by Becker (1999, 2000) may have increased the amount of milk available for dairy products. It is thus possible that a change in dietary practices between the Early and Late Monteoru periods as represented by the two sites included in this study may have involved a shift from a more meat-based economy to a more dairy- and plant-based economy.

6.4.2. Males *vs* females

The mean values for Sărata Monteoru females (n=22) were -19.8‰ (±0.4‰) for $\delta^{13}C$ and +8.6‰ (±0.8‰) for $\delta^{15}N$. For males from the same site (n=12), the respective values were -19.6‰ (±0.3‰) and +8.7‰ (±0.7‰) (Figure 38). The range in both female and male values was also quite similar, and there were no statistically significant differences in $\delta^{13}C$ or $\delta^{15}N$ related to the sex of the individual, suggesting there were no gender-based restrictions on access to major food sources. The same conclusion was reached when including the individuals from Cârlomăneşti, whose sex could be determined (n=5). Only one adult male individual was represented in Cârlomăneşti, but his $\delta^{13}C$ and $\delta^{15}N$ values fall entirely within the range of the four females from the same site.

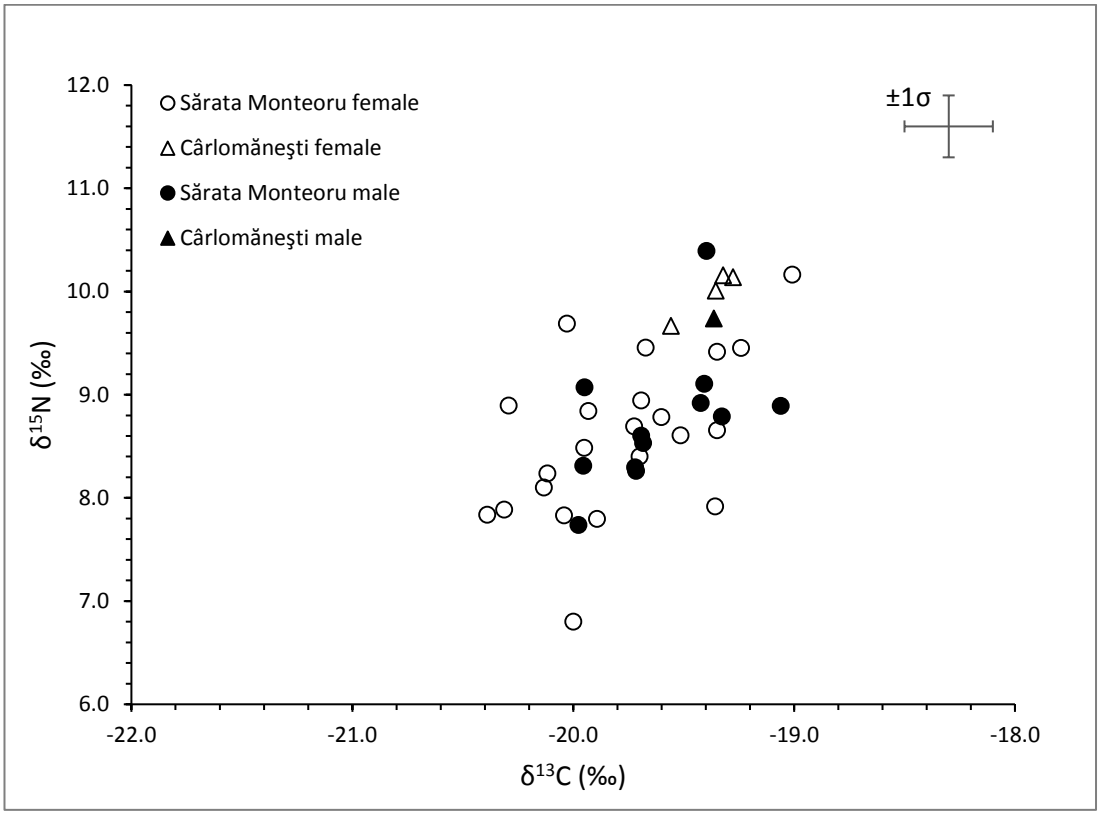


Figure 38. Human bone collagen $\delta^{13}C$ and $\delta^{15}N$ values from Sărata Monteoru and Cârlomăneşti females and males

Both females and males in Sărata Monteoru display a similar degree of variation of ca. 1‰ for $\delta^{13}C$ and ca. 2.5‰ for $\delta^{15}N$, which suggests relative homogeneity between individual diets. Males and females from Cârlomăneşti showed a notably restricted

range in their isotope values, although this could have been caused by the much smaller sample size. Generally, the lack of a clear difference in isotope ratios between males and females is common in Bronze Age populations from Southeast Europe (e.g. Triantaphyllou *et al.* 2008; Petroutsa *et al.* 2009; Vika 2011; Gerling 2014).

6.4.3. Age groups

When examining the Sărata Monteoru human data by age, it seemed appropriate to introduce a fourth age group (’infant’) to the three used earlier (juvenile, adolescent, adult). The infant group includes here individuals between the ages 0–4 years, whereas the older children remain in the juvenile group. The mean $\delta^{13}C$ values for each of the four groups show no statistically significant differences: infants (n=9) -19.6‰ (±0.5‰), juveniles (n=8) -19.9‰ (±0.3‰), adolescents (n=13) -19.7‰ (±0.3‰), and adults (n=29) -19.7‰ (±0.4‰) (Kruskal–Wallis H test, H=4.079, d.f.=3, p=0.253) (Figure 39). However, the $\delta^{15}N$ values between groups differ significantly (H=17.458, d.f.=3, p=0.001): infants +9.8‰ (±1.3‰), juveniles +7.9‰ (±0.8‰), adolescents +8.2‰ (±0.6‰), and adults +8.8‰ (±0.6‰). Post hoc analyses revealed the significant differences to lie between the infant–juvenile (p=0.004), infant–adolescent (p=0.008), and juvenile–adult (p=0.045) groups.

The observation that the infant group has distinctive $\delta^{15}N$ values is hardly surprising; the duration of breastfeeding and weaning, and its impact on childhood isotopic values will be examined in more detail in another section of this chapter. In addition, many juvenile and adolescent individuals display $\delta^{15}N$ values ca. 1‰ lower than the adult mean, which could be interpreted as adults consuming more animal protein than the younger members of the population. However, in this case one would expect a correlation between $\delta^{13}C$ and $\delta^{15}N$ values, which both tend to become more positive with the increase of animal resources consumed. For Sărata Monteoru, the correlation is only a moderate one (r=0.56), suggesting that other factors may have been influencing the adult–juvenile isotopic differences (see Chapter 6.7. for further discussion on this topic).

Additionally, there was no correlation between age (using an estimated midpoint age for adult individuals whose age-at-death was determined by biological stages) and $\delta^{13}C/\delta^{15}N$ values from all Sărata Monteoru burials. It should be noted though that the two (non-infant) individuals with the highest $\delta^{15}N$ values (over +10‰) were both categorised as Fully/Mature adults, displaying a nitrogen isotopic signal similar to those of breastfed infants, i.e. suggestive of feeding on an altogether different trophic level compared to some other members of the community. More precise methods for estimating age-at-death in older adults would perhaps aid in shedding more light on whether this reflects individual dietary preferences, or a tendency for increased animal protein consumption in late adulthood. It is also possible that the elevated $\delta^{15}N$ values of the two adults were influenced by metabolic changes (i.e. physiological stress).

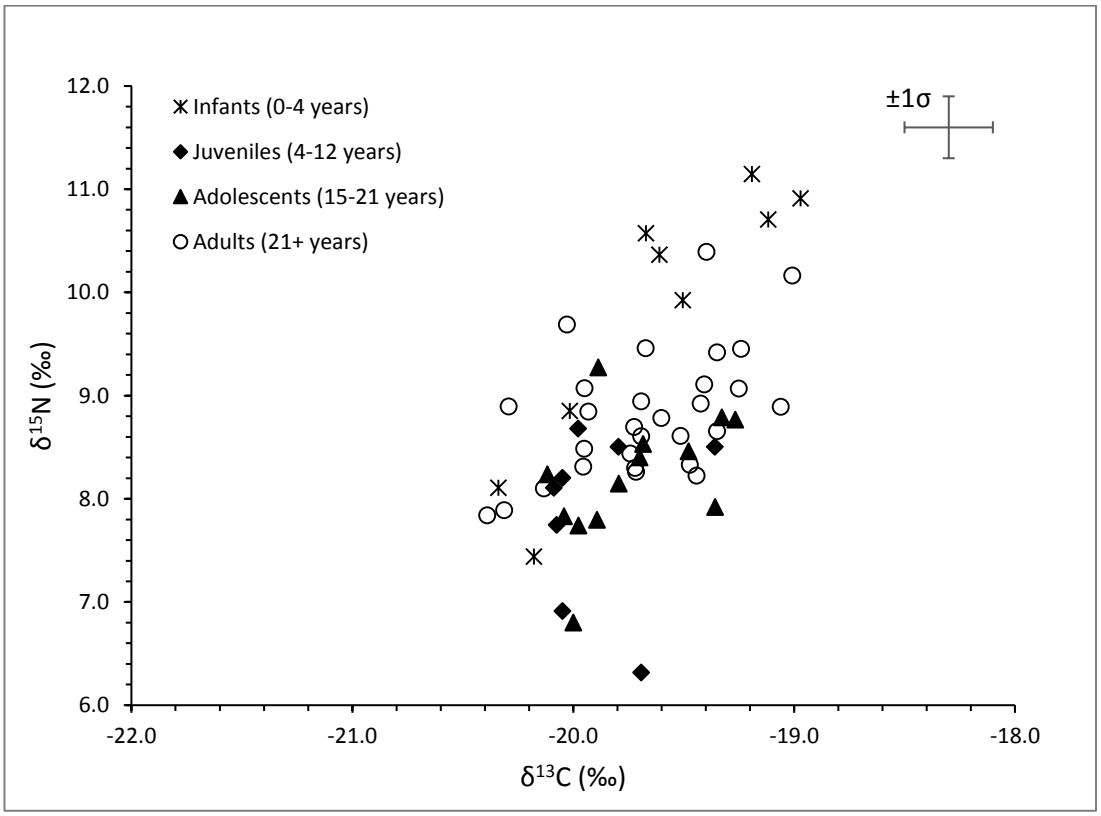


Figure 39. Human bone collagen $\delta^{13}C$ and $\delta^{15}N$ values from Sărata Monteoru by age groups

The Cârlomăneşti sample set was too small to make statistical comparisons between age groups, although the mean values for juveniles (n=5), adolescents (n=1) and adults (n=4) generally follow a similar trend to that seen at Sărata Monteoru, where $\delta^{13}C$ values are quite homogeneous, but adult $\delta^{15}N$ values tend to be slightly higher than in

younger individuals (i.e. juveniles over 8 years old and adolescents) (Figure 40). The respective mean values for the three groups (juveniles, adolescents, adults) are -19.2‰ (±0.3‰), -19.6‰, -19.4‰ (±0.1‰) for $\delta^{13}C$, and +9.3‰ (±0.3‰), +9.2‰, +9.9‰ (±0.2‰) for $\delta^{15}N$.

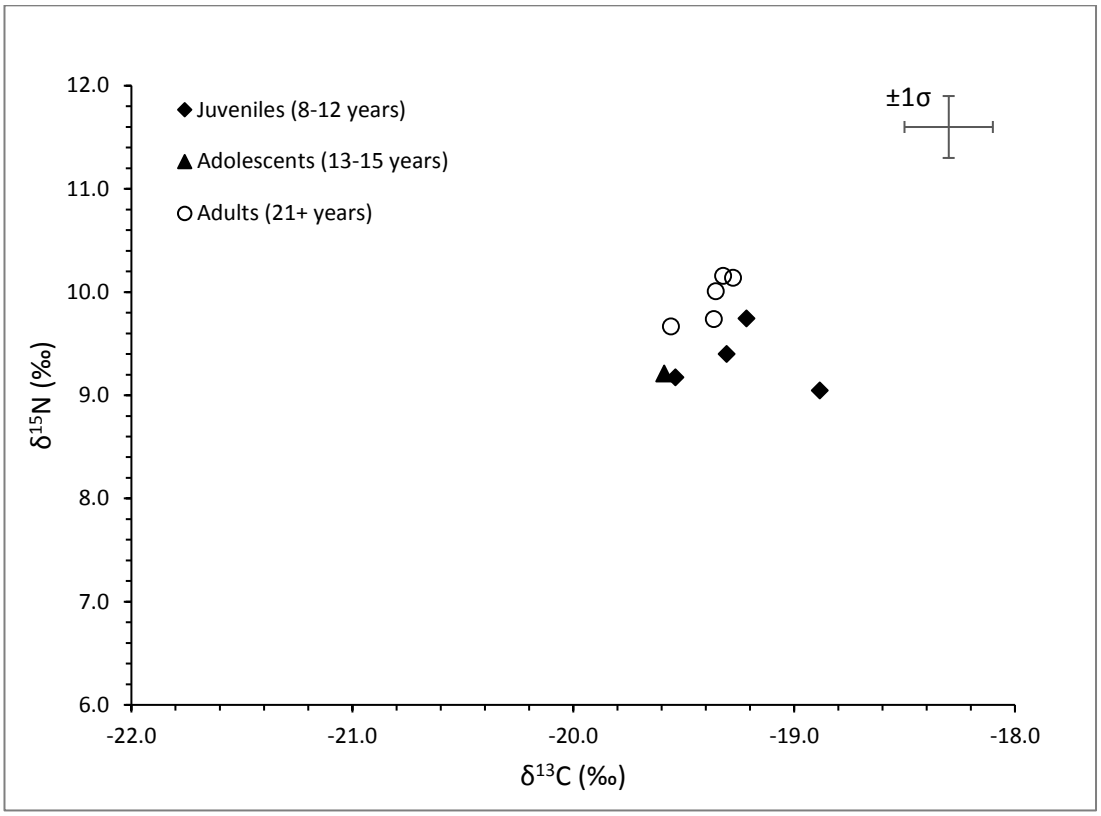


Figure 40. Human bone collagen $\delta^{13}C$ and $\delta^{15}N$ values from Cârlomăneşti by age groups

6.4.4. Grave goods and social status

The quality and quantity of grave goods has traditionally been associated with social status, with a more impressive funerary inventory taken as an indicator for wealth, power, and/or prestige. Figure 41 shows the distribution of human $\delta^{13}C$ and $\delta^{15}N$ values from both sites as grouped based on the presence and number of grave goods. Sărata Monteoru individuals could be divided into two main, and two sub-groups: 'grave goods not present' (mean $\delta^{13}C$ -19.7‰ [±0.4‰], mean $\delta^{15}N$ +8.8‰ [±0.9‰]) and 'grave goods present' (mean $\delta^{13}C$ -19.7‰ [±0.3‰], mean $\delta^{15}N$ +8.5‰ [±1.1‰]); the latter could be further divided into 'few grave goods' (mean $\delta^{13}C$ -19.6‰ [±0.3‰], mean $\delta^{15}N$ +8.8‰ [±0.9‰]) and 'rich grave goods' (mean $\delta^{13}C$ -19.8‰ [±0.4‰],

mean $\delta^{15}N$ +8.2‰ [±1.2‰]). There were no statistically significant differences between those groups ($p>0.05$ for all variables).

A similar conclusion was reached for Cârlomăneşti data: the group 'few grave goods' produced a mean $\delta^{13}C$ of -19.3‰ (±0.2‰) and $\delta^{15}N$ +9.5‰ (±0.4‰), whereas the group 'rich grave goods' had mean values of -19.3‰ (±0.2‰) for $\delta^{13}C$ and +9.9‰ (±0.3‰) for $\delta^{15}N$. The only comparison that produced a statistically significant difference was between combined (Sărata Monteoru and Cârlomăneşti) $\delta^{13}C$ values of the 'few' and 'rich' groups ($U=82$, $p=0.033$), but considering the intersite differences between mean human isotope values, this result may be arbitrary. The lack of a correlation between isotope ratios and the number of grave goods indicates that the members of the community who were buried without grave goods did not consume significantly different diets from those buried with a rich funerary inventory.

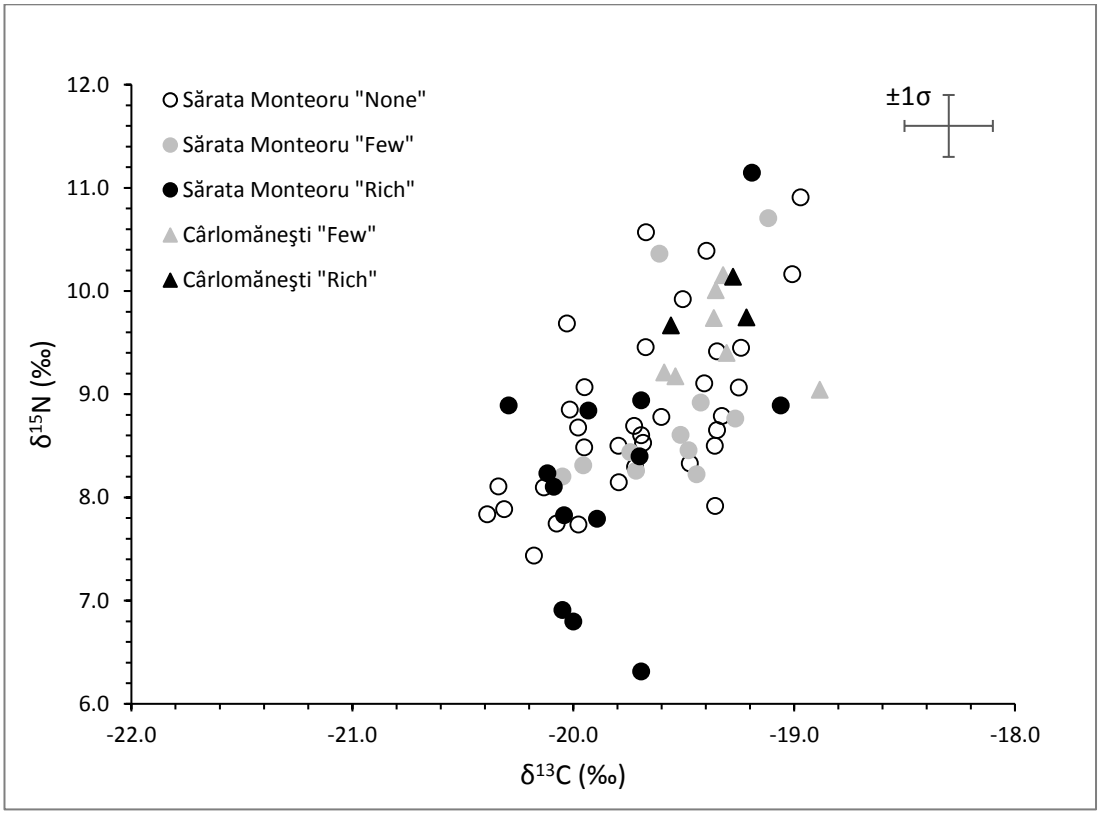


Figure 41. Human bone collagen $\delta^{13}C$ and $\delta^{15}N$ values from Sărata Monteoru and Cârlomăneşti by grave goods

While Bârzu (1989) did not believe that the Monteoru culture was characterised by high social inequality, she did call attention to the fact that most of the valuable and/or

rare items in Sărata Monteoru cemetery no. 4 (e.g. amber, glass paste beads, gold and bronze ornaments) were typically found in female graves. It has also been suggested that these valuable goods represented social rank, and marked women's command of long-distance trade (see Bârzu 1989, 1994; Palincaș 2010), although the possibility that these items were included in the graves because they were part of the female (funeral) costume has not been discussed in the literature. Since there were no statistical differences between stable isotope ratios from either males or females, or between burials with different amounts of grave goods, no connection can be drawn between social status (as reflected in grave goods) and dietary practices.

In addition, two of the three (the third one was not sampled for stable isotopes) male individuals from Sărata Monteoru cemetery no. 4 who were buried with artefacts of 'symbolic value' (burial no. 71 – a mace head made from deer antler; burial no. 77 – a perforated boar tusk worn as a pendant) and identified by Bârzu (1994) as 'political and military leaders of their community' did not produce isotope ratios that stand out in any way from the others. Finally, it should be mentioned that the two adult individuals with the highest $\delta^{15}N$ values (over +10‰) were buried without any grave goods.

6.5. Quantitative diet reconstruction using FRUITS

6.5.1. Modelling parameters

To provide more accurate estimates of the contribution from different food sources to diet among Monteoru communities, the Bayesian mixing model, Food Reconstruction Using Isotopic Transferred Signals (FRUITS, beta 2.1.1) (Fernandes *et al.* 2014), has been applied to the data. The model requires knowledge of the nutrient and isotopic composition of the food groups and their fractions (e.g. protein, carbohydrates, lipids) that would have been available to the population under study, information about diet-to-tissue isotopic offsets, and a sufficient number of dietary proxies in order to make quantitative estimates of diet. In addition, the model also takes into account uncertainties in estimates of isotopic signatures and offsets.

In the current study, two dietary proxies are used ($\delta^{13}C$ and $\delta^{15}N$) to quantify the diet at both Sărata Monteoru and Cârlomăneşti on the population level (i.e. not individually). The population mean (calculated based on adolescents and adults only) is used as the target value, with an uncertainty of ±0.5‰ to account for intra-individual variation in isotope ratios. A weighted model is applied; this accounts for dietary contributions into bone collagen from not only protein, but also from lipids and carbohydrates (here considered together as 'energy'). Although the exact isotopic composition of food fractions is not known, scrambled routing was preferred to direct routing (i.e. where only the protein is regarded as contributing carbon to collagen) in an attempt to provide a more thorough approach to diet reconstruction. For $\delta^{15}N$, all food groups obtain their isotopic signal entirely from the protein fraction (set as 100%). For $\delta^{13}C$, two fractions are considered – protein, accounting for ca. 75% of the isotopic signal, and energy, accounting for ca. 25% of the signal. These estimates are entered into the model with ±5% uncertainty.

First, an overview is necessary of the types of food resources that would have been consumed by the inhabitants of Monteoru settlements. The range of human bone collagen $\delta^{13}C$ values (-19.0‰ to -20.4‰) from Sărata Monteoru and Cârlomăneşti indicates a terrestrial diet that was exclusively or predominantly based on C_3 resources and their consumers. Archaeozoological research has indicated that these communities were focused on breeding cattle, sheep, goat and pig, but also exploited wild resources from the surrounding woodlands to a small extent (Becker 1999, 2000). There is no indication, either in the isotope ratios or in the archaeological record, that fishing or aquatic resources played a significant part in the subsistence economy.

Monteoru settlements were often located near fertile black earth soils and have produced archaeobotanical evidence of barley, various wheat species, rye, and legumes such as bitter vetch, pea and gold-of-pleasure (Cârciumaru 1983, 1996) – all C_3 plants. Although grains of millet, the only C_4 crop commonly cultivated in prehistoric Europe, have not been reported from Monteoru deposits, both broomcorn and foxtail millet are believed to have been known to Bronze Age farmers throughout Southeast Europe (see Gyulai 1993; Zohary & Hopf 2000; Stika & Heiss 2013), and

their consumption is suggested by relatively high $\delta^{13}C$ values of some of the humans from Bronze Age sites in Italy, Greece, Croatia, and Bulgaria (Tafuri *et al.* 2009; Petroutsa & Manolis 2010; Lightfoot *et al.* 2013, 2015; Gerling 2014). It is thus likely that the Monteoru people were not unfamiliar with millet, but the available evidence indicates that it wasn't consumed (either directly or indirectly) in any significant quantities in either earlier period Cârlomăneşti or later at Sărata Monteoru.

Adult human $\delta^{15}N$ values are much more variable than for $\delta^{13}C$, ranging between +6.8‰ and +10.4‰. This suggests some individual variation in the type of protein consumed. In addition, high (around +10‰) adult human $\delta^{15}N$ values from sedentary farming societies could reflect the manuring effect. Based on high (up to 5–6‰) crop $\delta^{15}N$ values, manuring has been proposed to have been spread among Central and Southeast European farmers since the Neolithic (see Bogaard *et al.* 2013; Fraser *et al.* 2013; Bogaard 2015; Vaiglova *et al.* 2014). Reed (2013) and Bogaard (2015) also proposed that manuring spread in tandem with livestock keeping and small-scale intensive agriculture, as animals were often kept close to the settlements and allowed to graze on fallow land. Unfortunately, no plant remains were available for isotope analysis from either Monteoru site, so, two different scenarios are modelled ('manured plants' and 'unmanured plants') to allow for the possibility that elevated plant $\delta^{15}N$ values may have influenced the human N-isotope data.

Based on the evidence presented above, three food groups are considered in the model: animals, cereals and legumes. For animals, the site average values for the most commonly utilized domesticated species (i.e. cattle and goat/sheep) are used. Dairy products were not included as a separate food group for several reasons. Firstly, the precise offset between ruminant meat and milk is not known, although the $\delta^{13}C$ composition of milk protein (casein) is presumably influenced by the content of the animal's diet (Camin *et al.* 2008). Secondly, while it has been shown that dairy products generally have slightly more depleted isotope values for $\delta^{13}C$ and $\delta^{15}N$ than meat products, this difference appears to vary, and is often very small (see Petzke *et al.* 2005; Nardoto *et al.* 2006; Huelsemann *et al.* 2013). Finally, Fernandes *et al. (*2014)

have cautioned against increasing the number of food groups without including additional dietary proxies as this will reduce the accuracy of the estimates.

For plant foods, published isotope values of Neolithic crops from Germany, Hungary and Bulgaria, and from modern fields (Fraser *et al.* 2011, 2013; Bogaard *et al.* 2013; Bogaard 2015) are used as reasonable approximations of average values for cereals and legumes. The modern data are from experimental and 'traditional' fields with no recorded use of chemical fertilizers. For the 'manured plants' scenario, both cereal and legume $\delta^{13}C$ is set as -24‰ ±0.5‰; cereal $\delta^{15}N$ is +5‰ ±1‰ and legume $\delta^{15}N$ +2‰ ±0.5‰. For the 'un-manured plants' scenario, the $\delta^{13}C$ values remain unchanged, but $\delta^{15}N$ for cereal crops has been set as +2‰ ±0.5‰ and for legumes as 0‰ ±0.5‰.

The nutrient content (protein, energy) of the three food groups is expressed as dry weight calorie content (%), and is established from Fernandes *et al.* (2015) for the animal and cereal group, and from Erskine *et al.* (1985), Messina (1999) and Iqbal *et al.* (2006) for the legume group, as follows: animals – 30% protein, 70% energy; cereals – 10% protein, 90% energy; legumes – 25% protein, 75% energy (all estimates have an associated uncertainty of ±2.5%).

The isotopic compositions of food group macronutrients (e.g. cereal $\delta^{13}C_{energy}$) are calculated based on previously reported offsets between macronutrient and collagen isotopic values, summed up in Fernandes *et al.* (2014, 2015). For terrestrial animal meat, the offsets are $\Delta^{13}C_{protein-collagen}$ = -2‰, $\Delta^{13}C_{energy-collagen}$ = -8‰, $\Delta^{15}N_{protein-collagen}$ = +2‰. The large offset between $\delta^{13}C_{energy}$ and $\delta^{13}C_{collagen}$ reflects ^{13}C depletion in lipids, which constitute most of the calories in the energy fraction of meat (Meadows *et al.* 2016:683). For cereal crops and legumes, $\Delta^{13}C_{protein-collagen}$ = -2‰, $\Delta^{13}C_{energy-collagen}$ = +0.5‰. An uncertainty of ±0.5‰ is applied for all estimates.

Finally, the diet-to-collagen isotopic offsets for $\delta^{13}C$ and $\delta^{15}N$ need to be entered into the model. For the former, a value of 4.8‰ ±0.5‰ was calculated by Fernandes *et al.* (2012) based on a comprehensive analysis of data from various published controlled feeding experiments. The situation is less straightforward in the case of $\delta^{15}N$ offset.

Traditionally considered to be on average 3‰ (DeNiro & Epstein 1981; Minagawa & Wada 1984; Schoeninger & DeNiro 1984), more recent studies have suggested the value to be closer to 5–6‰ (Bocherens & Drucker 2003; Hedges & Reynard 2007; O'Connell *et al.* 2012). Hedges & Reynard (2007) also highlighted the fact that using a 3‰ offset would result in many post-agricultural prehistoric societies having more than 60–80% of animal derived protein (from total protein) in diet (compared to 30% seen in modern developing countries), whereas favouring a higher offset (ca. 5‰) would provide more realistic estimates.

The uncertainty surrounding the $\delta^{15}N$ diet-to-collagen offset is reflected in the range of estimates used in various published applications of FRUITS. While some researchers have preferred to use different models, each with a distinct offset (e.g. Pickard *et al.* [2016] applied four offsets, between 3‰ and 6‰; Sayle *et al.* [2016] included two models, one with an offset of 3.5‰ ±0.5‰ and the other with 6‰ ±0.5‰), others have used a single estimate (e.g. 3.6‰ ±1.2‰ [Fernandes *et al.* 2014]; 4.5‰ ±1‰ [Meadows *et al.* 2016]; 5‰ ±1‰ [Tõrv & Meadows 2015]; 5.5‰ ±0.5‰ [Fernandes *et al.* 2015]). Here, the present author acknowledges that the various estimates for $\delta^{15}N$ diet-to-collagen offset seen in the literature may all be appropriate, and has used a consensus value of 5‰ ±1‰ to reflect the more recent research in this field.

6.5.2. Estimates generated by FRUITS

Table 18 provides an overview of the base values used in the FRUITS model, along with their associated uncertainties (±). In total, four different scenarios are modelled, two for each site. Scenarios 1 (Sărata Monteoru) and 3 (Cârlomăneşti) take into account the potential manuring effect on both cereals and legumes, reflected in higher plant $\delta^{15}N$ values; scenarios 2 (Sărata Monteoru) and 4 (Cârlomăneşti) consider unmanured values for plants.

For Sărata Monteoru, both scenarios were run three times to determine whether the estimates were robust to changes in the population mean value as influenced by intraskeletal variation: first using the population average calculated from all

measurements, the second time using the population average calculated only from rib samples, and the third time only from femur samples. The three variables produced average estimates that did not differ by more than ±1%. Since intraskeletal variation had only a marginal effect on model estimates, the results obtained using the all-sample population mean are used in the subsequent discussion, although the estimates from all runs can be seen in Appendix 7.

Table 18. Base values applied in the FRUITS model: consumer value (site average), the different food groups, and their fractions for each dietary proxy (^{13}C, ^{15}N) along with their associated uncertainty (‰). For Cârlomăneşti, values that differ from Sărata Monteoru are shown in bold

	Sărata Monteoru		**Cârlomăneşti**	
	$\delta^{13}C$ (‰)	**$\delta^{15}N$ (‰)**	**$\delta^{13}C$ (‰)**	**$\delta^{15}N$ (‰)**
Consumer	-19.7 ± 0.5	8.6 ± 0.5	**-19.4 ± 0.5**	**9.8 ± 0.5**
Food groups				
Animal	-19.7 ± 0.5	6.4 ± 0.5	**-19.9 ± 0.5**	**6.3 ± 0.5**
Cereal (manured)	-24 ± 0.5	5 ± 0.5	-24 ± 0.5	5 ± 0.5
Cereal (unmanured)	-24 ± 0.5	2 ± 0.5	-24 ± 0.5	2 ± 0.5
Legume (manured)	-24 ± 0.5	2 ± 0.5	-24 ± 0.5	2 ± 0.5
Legume (unmanured)	-24 ± 0.5	0 ± 0.5	-24 ± 0.5	0 ± 0.5
Food values				
Animal protein	-21.7 ± 0.5	8.4 ± 0.5	**-21.9 ± 0.5**	**8.3 ± 0.5**
Animal energy	-27.7 ± 0.5	N/A	**-27.9 ± 0.5**	N/A
Cereal (manured) protein	-26 ± 0.5	5 ± 0.5	-26 ± 0.5	5 ± 0.5
Cereal (manured) energy	-23.5 ± 0.5	N/A	-23.5 ± 0.5	N/A
Cereal (unmanured) protein	-26 ± 0.5	2 ± 0.5	-26 ± 0.5	2 ± 0.5
Cereal (unmanured) energy	-23.5 ± 0.5	N/A	-23.5 ± 0.5	N/A
Legume (manured) protein	-26 ± 0.5	2 ± 0.5	-26 ± 0.5	2 ± 0.5
Legume (manured) energy	-23.5 ± 0.5	N/A	-23.5 ± 0.5	N/A
Legume (unmanured) protein	-26 ± 0.5	0 ± 0.5	-26 ± 0.5	0 ± 0.5
Legume (unmanured) energy	-23.5 ± 0.5	N/A	-23.5 ± 0.5	N/A
Offsets	4.8 ± 0.5	5 ± 1	4.8 ± 0.5	5 ± 1

Table 19 shows the results for each scenario for both Sărata Monteoru and Cârlomăneşti. The generated estimates represent calorie contributions for each food group (Food [%]), the calorie contribution from each food fraction (Fraction [%]), and the calorie contribution of each food group towards an isotopic proxy (either ^{13}C or ^{15}N) (Proxy [%]). The estimates for ^{13}C and ^{15}N differ due to the former including a routed carbon contribution from energy (i.e. carbohydrates and lipids). Estimate uncertainties were mostly between 12% and 25%, which demands caution when interpreting the results. Due to the large error range, most generated values are not

significantly different from each other. Combining the data for Proxy (Food) (%) would reduce the errors to between 10% and 15% (see Table 19).

Table 19. Average estimates generated by FRUITS (%) with a 1-sigma standard deviation for Sărata Monteoru and Cârlomăneşti populations and for both dietary scenarios. The estimates represent calorie contributions for each food group (Food [%]), the calorie contribution from each food fraction (Fraction [%]), and the calorie contribution of each food group towards an isotopic proxy (^{13}C, ^{15}N, and the weighted mean of the two) (Proxy [%])

	Sărata Monteoru		**Cârlomăneşti**	
	Scenario 1 Manured	**Scenario 2** Unmanured	**Scenario 3** Manured	**Scenario 4** Unmanured
Food (%)				
Animal	17 ± 12	27 ± 14	25 ± 16	38 ± 15
Cereal	34 ± 23	37 ± 25	39 ± 25	35 ± 23
Legume	49 ± 20	36 ± 19	36 ± 19	27 ± 16
Fraction (%)				
Protein	21 ± 4	21 ± 4	20 ± 4	22 ± 4
Energy	79 ± 4	79 ± 4	80 ± 4	78 ± 4
Proxy (Food) (%)				
^{13}C (Animal)	19 ± 13	29 ± 14	28 ± 17	42 ± 15
^{13}C (Cereal)	30 ± 22	33 ± 24	35 ± 24	30 ± 21
^{13}C (Legume)	51 ± 20	38 ± 19	37 ± 19	28 ± 16
^{15}N (Animal)	23 ± 15	37 ± 15	35 ± 18	51 ± 14
^{15}N (Cereal)	19 ± 18	22 ± 19	23 ± 20	19 ± 16
^{15}N (Legume)	58 ± 19	41 ± 19	42 ± 19	30 ± 16
Combined ^{13}C+^{15}N				
Animal	21 ± 10	33 ± 10	31 ± 12	47 ± 10
Cereal	23 ± 14	26 ± 15	28 ± 15	23 ± 13
Legume	55 ± 14	40 ± 13	40 ± 13	29 ± 11

It is immediately clear that there are differences in the average estimates for both sites depending on whether values for manured or unmanured plants are used. Unfortunately, without direct isotope data (along with radiocarbon dates) from plant remains from Monteoru settlements, it is impossible to determine whether these communities manured their crops, resulting in higher $\delta^{15}N$ values. Theoretically, herbivore $\delta^{15}N$ values could be used as an indicator for human plant protein isotope values. For both Sărata Monteoru and Cârlomăneşti, the domesticated herbivore mean $\delta^{15}N$ value is around +6.3‰ (compare with adult human average $\delta^{15}N$ of +8.6‰ in SM and +9.8‰ in CRL). Using the lower range of the estimated $\Delta^{15}N_{diet-collagen}$ offset (e.g. 3‰) would lead to herbivore fodder having N-isotope values around 3‰, but applying an offset any higher than that (e.g. 4‰ or 5‰) would result in plants in

Monteoru settlements having $\delta^{15}N$ values characteristic of unmanured plants. Some of the domesticated herbivores do show $\delta^{15}N$ values around +8‰, but apart from the manuring effect, enrichment of this magnitude can also be seen in suckling animals. Regrettably, it is not always possible to determine the age of the animal based on a single bone or bone fragment.

Furthermore, herbivores can only be used as an indicator of human diet if they consumed the same plants. It is thus feasible that humans consumed manured plants, whereas herbivores were eating unmanured fodder from the surrounding area. In conclusion, based on the evidence currently available, it is not possible to securely establish whether plants consumed by Monteoru humans had values characteristic of manured or unmanured plants. Therefore, both scenarios must be taken into consideration when evaluating intersite differences. It should be noted that average estimates between scenarios 2 (Sărata Monteoru, unmanured plants) and 3 (Cârlomăneşti, manured plants) are very similar. While it is possible that the various food groups were consumed in comparable proportions in both sites, this only applies if manuring was practised during the Early Monteoru period, but was discontinued in Late Monteoru a few hundred years later. This, however, seems unlikely.

For both sites, the model predicts that plant foods account for most of the calories consumed, and in most scenarios plant protein also accounts for more than half of total protein intake. Estimates for the cereal food group showed the least variability, suggesting similar contributions for both sites, irrespective of the presence or lack of a manuring effect on plant $\delta^{15}N$ values. Depending on whether manured or unmanured plant $\delta^{15}N$ values are used, the importance of legumes varied within ca. 10% for both sites. Manured values led to greater estimated contributions from legumes to total calorie intake, with scenario 1 (Sărata Monteoru, manured plants) displaying the highest contribution of legumes to both total calorie intake (ca. 49%) and to dietary protein (ca. 58%). Even at Cârlomăneşti, for which the model predicts a lower contribution from legumes, they still account for at least a quarter of total calorie intake, and contribute significantly to dietary protein.

Based on archaeobotanical evidence from Southeast Europe from the Neolithic onwards, the protein-rich legumes were grown on a consistent basis throughout the region, although they are usually reported in smaller numbers compared to remains of wheat and barley (e.g. Gyulai 1993; Cârciumaru 1996; Monah 2007; Reed 2013). According to Bonsall *et al.* (2007), ethnohistorical sources suggest that a typical peasant farming society in Southeast Europe commonly received most of their sustenance from cultivated plants such as cereals, legumes and fruits, with only a modest contribution from dairy products (meat was regarded as luxury). This is in accordance with the model's predictions for the two Monteoru sites.

As suggested earlier from the $\Delta^{15}N_{human–herbivore}$ values for each site, the model has estimated greater reliance on animal foods for Cârlomăneşti – irrespective of whether manured or unmanured scenarios are compared, the contribution of animal-based foods to total calorie intake, total dietary protein and total dietary energy is on average greater for Cârlomăneşti compared to Sărata Monteoru. Considering both manured and unmanured scenarios, for Sărata Monteoru the proportion of animal protein in total dietary protein was estimated as 23–37%, the proportion of animal-derived dietary energy as 19–29%, and the contribution of animal foods to total calorie intake as 17–27%. For Cârlomăneşti, the respective values were 35–51%, 28–42%, and 25–38%. It also appeared that using lower plant $\delta^{15}N$ values, which reflect unmanured crops, led the model to predict ca. 15% greater importance in both sites for animal-based protein at the expense of legume-derived protein.

Estimated protein intake from dietary macronutrients was around 21% for both sites on all scenarios. This value is lower than that reported from ethnographic studies of hunter-gatherer populations, on average around 35% (Cordain *et al.* 2000), and from Early Neolithic hunter-gatherers from Germany (ca. 25%) (Fernandes *et al.* 2015), but higher than in modern Western diets (ca. 15%) (Lands *et al.* 1990). In comparison, the protein intake for Bronze Age burials from Shagara in the forest zone of eastern Russia was estimated as 15–21% by FRUITS, although there, the local subsistence economy included significant numbers of wild animals and fish, in addition to domesticates (Shishlina *et al.* 2016).

As mentioned above, the relatively large uncertainties of the estimates demand cautious interpretation. In addition, the estimates of dietary contributions generated by FRUITS can never be 100% accurate, and the selection of individuals included in this study may not accurately reflect the entire population, or the full range of dietary preferences in the community. However, the evidence presented thus far does suggest slight differences in the way dietary resources were utilized between the two sites, and possibly, also between the Early and Late Monteoru periods. The most likely interpretation of the available data involves a modest decrease in later-period Sărata Monteoru in dependence on animal-derived products and a greater reliance on plant carbohydrates for energy, with legumes increasing in importance as a source of dietary protein over animal protein. This trend is consistent when comparing scenarios 1 and 3 (both sites, manured plants), 2 and 4 (both sites, unmanured plants), 1 and 4 (Sărata Monteoru manured, Cârlomăneşti unmanured), but does not hold in comparisons between scenarios 2 and 3 (Sărata Monteoru unmanured, Cârlomăneşti manured).

The cause of the observed differences between the two sites is a matter of speculation. A significant change in economic activities is unlikely, given the similarities of the palaeoecological and archaeological material recovered from each site. Becker (2000) did not report major differences between Early and Middle Bronze Age faunal assemblages from the Monteoru culture area as represented by the sites of Năeni-Zănoaga and Sărata Monteoru; in both, sheep and goats were slightly more abundant by number of identified specimens although cattle may have provided the most meat by weight. However, available archaeozoological evidence for the Eneolithic and Bronze Age Carpathians does indicate a shift from caprine to cattle husbandry during the Bronze Age, with cattle becoming the dominant species by the Late Bronze Age (Becker 1999, 2000).

As discussed in section 6.4.1., the rise in the importance of cattle husbandry may have increased the amount of milk available for dairy products (or the prominence of dairying may have led to the preferential keeping of cows). Indeed, the maturity of cattle in several middle Danube sites during the second millennium BC has been taken to imply an important role for dairy cows (Barker 1989:109). Additionally, as animals

kept for dairying would be slaughtered less often than those kept for meat, it would presumably reduce the amount of (cattle) meat consumed – and the calories obtained from animal products.

The data set presented here is still relatively small to make firm conclusions about changing dietary practices during the Monteoru culture. More stable isotope data from other sites in the Sub-Carpathian region, spanning from the Eneolithic to the Late Bronze Age, would provide some greater clarity on the question of whether the pattern witnessed here is a true temporal trend or merely reflects site-specific dietary preferences.

6.6. Animal exploitation

Archaeozoological analyses often provide information about the types of fauna bred (and hunted) by human communities, and can sometimes even identify more precise patterns of herd management (e.g. by studying mortality profiles), or the utilization of various parts of the animal (e.g. through the representation of body parts in slaughter waste). This type of evidence is complemented by isotopic data, which offers a way to potentially distinguish between distinct feeding strategies and/or locations as reflected in faunal $\delta^{13}C$ and $\delta^{15}N$ values. Table 20 shows the average isotope values (along with a 1-sigma standard deviation, and minimum and maximum values) for the various animal species sampled from Sărata Monteoru and Cârlomăneşti. Combined faunal $\delta^{13}C$ and $\delta^{15}N$ data from both sites are also plotted by species in Figure 42 to illustrate the variations in intra- and interspecies isotope values.

As noted in an earlier section (6.4.1.), Cârlomăneşti faunal samples displayed a much greater range in isotope values compared to Sărata Monteoru, which may be influenced by the greater sample size, or by the archaeozoological material originating from various Monteoru-era layers of the settlement site (and thus potentially representing a longer period). The presumably narrower range of isotope values for Sărata Monteoru animal bones, recovered from graves, may therefore represent a shorter time range, coinciding with the use of that part of the cemetery. This highlights the need for a

cautious approach when attempting to deduce temporal patterns in animal management strategies from this data set alone.

Table 20. The mean, standard deviation, minimum and maximum $\delta^{13}C$ and $\delta^{15}N$ values for faunal species from Sărata Monteoru (SM) and Cârlomăneşti (CRL)

Species	Site	$\delta^{13}C$	SD	Min	Max	$\delta^{15}N$	SD	Min	Max	N
Cattle	SM	-20.1	0.5	-20.7	-19.5	6.7	0.6	6.3	7.8	5
	CRL	-20.1	0.4	-20.6	-19.4	6.4	1.0	5.3	8.2	10
Sheep/goat	SM	-19.4	0.5	-20.2	-18.9	6.1	0.7	5.4	7.4	7
	CRL	-19.7	1.9	-22.1	-16.4	6.3	1.2	4.5	7.9	8
Sheep	SM	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	CRL	-20.1	N/A	N/A	N/A	5.8	N/A	N/A	N/A	1
Pig	SM	-19.5	0.4	-19.9	-19.1	8.3	1.3	7.4	9.8	3
	CRL	-18.7	2.3	-20.6	-13.5	6.4	0.8	5.2	7.9	8
Horse	SM	-19.9	N/A	N/A	N/A	6.4	N/A	N/A	N/A	1
	CRL	-20.2	1.0	-20.9	-19.5	3.0	0.3	2.8	3.2	2
Dog	SM	-19.2	N/A	N/A	N/A	8.4	N/A	N/A	N/A	1
	CRL	-19.4	0.4	-20.0	-19.0	9.3	0.7	7.9	9.9	7
Cervid	SM	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	CRL	-20.8	N/A	N/A	N/A	4.3	N/A	N/A	N/A	1
Hare	SM	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	CRL	-19.5	N/A	N/A	N/A	3.0	N/A	N/A	N/A	1

The average $\delta^{13}C$ and $\delta^{15}N$ values for faunal groups are as follows: cattle (n=15) -20.1‰ (±0.4‰) for $\delta^{13}C$, +6.5‰ (±0.5‰) for $\delta^{15}N$; caprines (n=16) -19.6‰ (±1.4‰), +6.2‰ (±0.9‰); pig (n=11) -18.9‰ (±1.9‰), +6.9‰ (±1.2‰); horse (n=3) -20.1‰ (±0.7‰), +4.2‰ (±2.0‰); dog (n=8) -19.4‰ (±0.3‰); +9.2‰ (±0.7‰); and wild herbivores (n=2) -20.1‰ (±1.0‰), +3.7‰ (±0.9‰). While there were no statistically significant differences in $\delta^{13}C$ values between these groups, the comparison of $\delta^{15}N$ values produced a positive test result (Kruskal–Wallis H test, H=26.626, d.f.=5, $p<0.0001$). Post hoc analyses showed the significant differences to lie between dogs and all herbivore (both domesticated and wild) taxa.

What follows is a more thorough consideration of the Monteoru faunal isotope data, presented by species. C- and N-isotope values for cattle are very similar between the two sites, occupying a central region of the graph, as seen in Figure 42 (on average around -20.1‰ for $\delta^{13}C$ and +6.5‰ for $\delta^{15}N$). Neither of the sites demonstrates significant variation in cattle $\delta^{13}C$ values (range 1.2‰), but the situation is different for $\delta^{15}N$ values which have a range of almost 3‰. Some of the higher $\delta^{15}N$ may

originate from young animals that were being suckled (and would thus display the nursing effect); the one cattle bone from the Monteoru sample set, which was identified as belonging to an immature individual, had a $\delta^{13}C$ of -20.3‰ and $\delta^{15}N$ of +7.7‰ (compared with the highest cattle $\delta^{15}N$ value of +8.2‰).

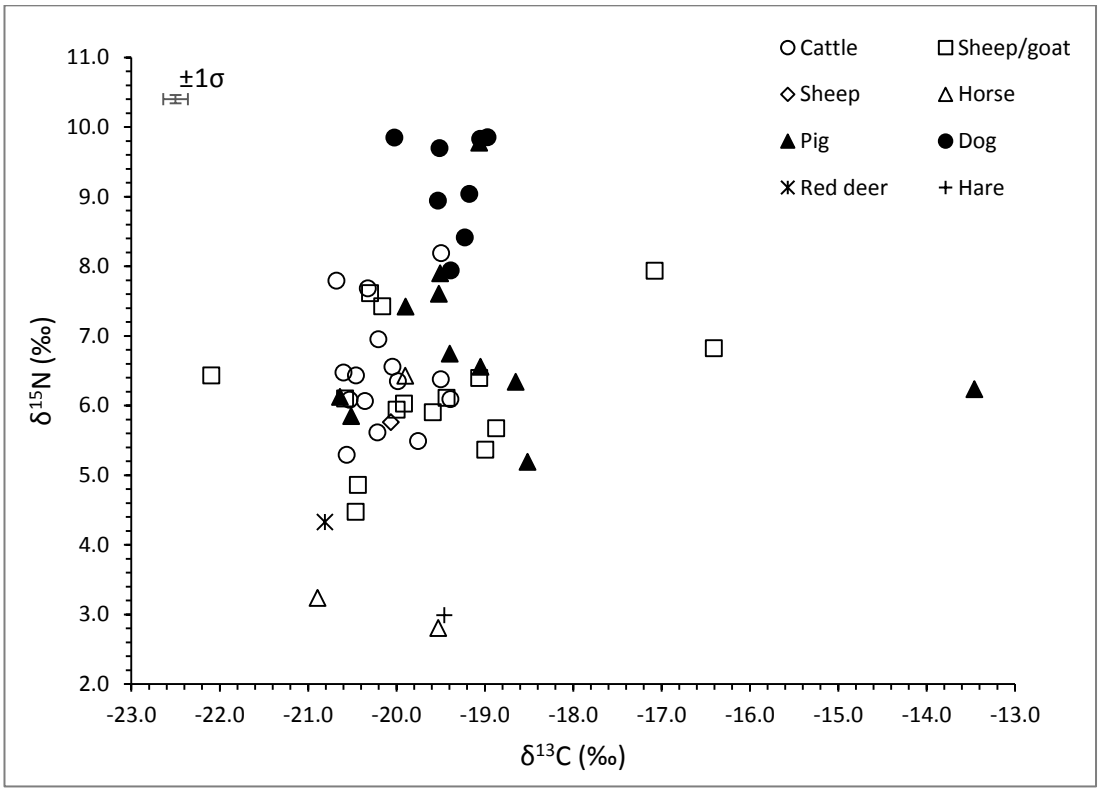


Figure 42. Animal bone collagen $\delta^{13}C$ and $\delta^{15}N$ values from Sărata Monteoru and Cârlomăneşti by species

When Gillis *et al.* (2013) investigated cattle from 5th millennium BC south-east Romania (approx. 125km from Sărata Monteoru), they obtained $\delta^{15}N$ values that varied between +6.3‰ and +9.7‰, and concluded that animals with values over ca. +8‰ were probably suckling (as supported by estimates on the animal's age based on dental wear and development). It is thus possible that at least some of the variation seen in cattle $\delta^{15}N$ values may be caused by the inclusion of young individuals displaying the nursing effect. Another explanation would be a selective consumption of manured plants with elevated $\delta^{15}N$ values. However, it is impossible to differentiate between the two effects based on these data alone.

The variation seen in $\delta^{15}N$ values is not mirrored in $\delta^{13}C$ values, indicating that all cattle grazed in an area with similar plant C-isotope compositions. This is unlike the data gathered by Gillis *et al.* (2013) for Late Eneolithic Romanian cattle, which produced $\delta^{13}C$ values from -14.7‰ to -21.8‰, suggestive of differential access to fodder. The high $\delta^{13}C$ values were explained by the authors in terms of cattle being seasonally herded on nearby marshlands with plentiful wild C_4 plants. However, the site examined by Gillis *et al.* (2013) was situated in a floodplain environment with riparian vegetation, quite different from the Sub-Carpathian hills.

Sheep and goats are here considered together as one group (i.e. caprines). In only one instance was it possible to identify the exact genus of the sample based on anatomical features; this was a sheep with respective C- and N-isotope values of -20.1‰ and +5.8‰. While these values are slightly lower than the caprine averages, one sample is not sufficient to determine whether there were significant isotopic differences between goats and sheep. On average, caprines have slightly lower $\delta^{15}N$ values (+6.2‰) than cattle (+6.5‰), but this difference is not statistically significant. In two instances, it was possible to identify the bone fragment as belonging to an immature animal; these had $\delta^{15}N$ values of +6.1‰ and +7.9‰. The latter also represents the highest measured $\delta^{15}N$ value among all caprines, suggesting that, as with cattle, the variation in N-isotopes to some extent reflects a nursing signal.

However, the caprine $\delta^{13}C$ values differ from those of cattle, ranging from -16.4‰ to -22.1‰. Most of the variation originates from the Cârlomăneşti samples. Two specimens have $\delta^{13}C$ values that reflect a noticeable addition to diet from C_4 resources (-16.4‰ and -17.1‰). Using endpoints of -7.5‰ for a 100% C_4 plant-based diet and -21.5‰ for 0% (i.e. a purely C_3 plant-based diet), the values of the two caprines correspond to 36.5% and 32% C_4 resources in diet, respectively. It bears repeating that none of the Monteoru humans displayed isotopic evidence of either direct or indirect consumption of C_4 plants. It is also unlikely that grazing in a marine-influenced environment (e.g. coastline) can be considered as a possible explanation, although the nearest major body of water (the Black Sea) is not insurmountably far (ca. 180km from Sărata Monteoru). However, Keenleyside *et al.* (2006) did not observe a marine

influence on herbivore values from a Greek colonial settlement by the Black Sea, reporting values on average around -20.6‰ and +5.2‰ for carbon and nitrogen.

Bourbou *et al.* (2011:573) suggested that sheep and goats may be the best indicators for the isotopic baseline, as they would have grazed in areas surrounding the settlements, reflecting both local soil chemistry and plant communities. Indeed, most of the caprines – and all the cattle and humans – had $\delta^{13}C$ values between -19‰ and -21‰. If some of the (local) sheep or goats were grazing further away from the settlements (in an area with C_4 vegetation) on a regular basis, one would expect the slightly enriched $\delta^{13}C$ values to have been transferred along the foodchain and to have also had an influence on human (or dog) isotope values. It thus follows that these animals were either in the minority (i.e. were not consumed regularly) and/or were not part of the 'regular' Monteoru herds.

Considering the latter option, their presence in the Cârlomăneşti assemblage may hint at a type of opportunistic herd movement between winter and summer pastures practised in the Romanian Carpathians even today (see Arnold & Greenfield 2006; Huband *et al.* 2010; Juler 2014). Although several authors (e.g. Harding 2000; Bartosiewicz 2013) have disclaimed the existence of specialised transhumant pastoralism in Bronze Age Europe, Arnold & Greenfield (2006) suggested that a small-scale, localised herding strategy may have existed in the Bronze Age central Balkans, originating from a village base and pendulating between lowland areas and hills depending on seasonal water and pasturage availability.

After all, the fact that most caprines have isotope values similar to the other fauna, does not necessarily mean that the animals were herded in one place, only that they grazed in areas with similar plant isotopic compositions. Additional isotope analyses ($\delta^{13}C$, $\delta^{15}N$, but also $\delta^{34}S$, $\delta^{87}Sr$ and $\delta^{18}O$) for Monteoru culture fauna could shed more light on the question of herd mobility. Alternatively, the two caprines with non-local $\delta^{13}C$ values may have reached the Monteoru culture area in other ways (e.g. through trade or gift exchange), or may instead represent feral caprine forms that roamed freely.

In addition to the two specimens with higher than average $\delta^{13}C$ values discussed above, there is one more outlier in the caprine data set. This animal from Cârlomăneşti has a $\delta^{13}C$ value of -22.1‰, more than 1‰ lower than measured in any other faunal sample from either site. Its $\delta^{15}N$ (+6.4‰) is around the average value for this group. If not a statistical outlier, there are a few possible explanations that can be proposed for its $\delta^{13}C$ value. Firstly, it may have been grazing in a shaded or closed-canopy area, leading to more depleted $\delta^{13}C$ values. Although cattle and pigs are generally considered to be more suited to woodlands than caprines (Hedges *et al.* 2013:360), goats are known to prefer more leafy and woody vegetation than sheep (who favour grassy vegetation in open habitats) (Vaiglova *et al.* 2014:210).

It should be noted though that neither of the two wild herbivores included in the study displayed such negative $\delta^{13}C$ values (minimum -20.8‰). This may support an alternative explanation for the observed isotope data, for example, that the animal was herded in an area with significantly different baseline $\delta^{13}C$ values (see van Klinken *et al.* [2000]), or was a feral animal that roamed freely in denser forests than those in the immediate vicinity of the Monteoru culture area.

In any case, these three caprines are clearly distinct from the rest of the Monteoru fauna (and humans) based on their atypical $\delta^{13}C$ values, indicating that either a small part of the flock was herded far away from the settlements, or that there was movement of livestock over large (beyond the Monteoru culture area) distances through other activities, such as trade. It seems unlikely that the number of feral ruminants would have been so substantial, that this small, random selection would have included three of them.

Average C- and N-isotope values for pigs display notable diversity between the two sites (Sărata Monteoru -19.5‰ and +8.3‰, Cârlomăneşti -18.7‰ and +6.4‰), although the difference is statistically significant only for $\delta^{15}N$ (Mann–Whitney U test, U=2, p=0.048). However, considering that there are data for only three pigs from Sărata Monteoru, the observed intrasite variation may be caused by sample size, and thus does not necessarily reflect differences in livestock management between the

earlier and later Monteoru period. Generally, Sărata Monteoru pigs have isotope values very similar to mean values of humans from the same site. Considering the omnivorous nature of pigs, it is entirely feasible that they were fed largely on domestic refuse, including animal protein.

The similarity of pig and human $\delta^{15}N$ values could be taken to imply that the former did not constitute an important part of the latter's diet – if pigs with elevated $\delta^{15}N$ values had been consumed regularly, the humans should display even higher values. However, since pigs are one of the few domesticated animals that do not provide any secondary products, i.e. were kept only for their meat, alternative explanations should be considered. Bartosiewicz (2013) makes the point that compared to some larger domesticates, pigs were prolific and their stock easily renewable. The Sărata Monteoru pigs (with $\delta^{15}N$ values of +7.4‰, +7.6‰ and +9.8‰) may often have been slaughtered when young, and thus their isotope values could have been influenced by the nursing effect. One of the pig bone fragments was identified as belonging to a young animal, but the $\delta^{15}N$ value of +7.4‰ could reflect either a suckling diet or a more omnivorous diet that included a significant amount of animal protein.

Cârlomăneşti pigs have on average higher $\delta^{13}C$ and lower $\delta^{15}N$ values compared to its neighbouring site, and generally plot close to the range for cattle and caprines, suggesting a predominantly herbivorous diet. There is an outlier in the pig data set (with a $\delta^{13}C$ value of -13.5‰), that will be discussed below. However, removing the outlier would bring the Cârlomăneşti pig average $\delta^{13}C$ very close to that of Sărata Monteoru pig $\delta^{13}C$ values (around -19.5‰). $\delta^{13}C$ values in this range, along with low $\delta^{15}N$ (around +6.5‰), have been interpreted as pigs consuming woodland resources such as fungi and forest fodder in two separate studies on prehistoric English material (Madgwick *et al.* 2012; Stevens *et al.* 2012). Pigs from Neolithic LBK settlements from Central Europe have also displayed isotope values consistent with feeding in forests (Hedges *et al.* 2013). Fornander *et al.* (2008) even suggested that suids with herbivorous diets should be considered as wild or feral, rather than domesticated.

It is entirely plausible that pigs were left to forage in the forests, as was not uncommon in the central Balkan region based on ethnohistorical evidence (see Halpern 1999; Arnold & Greenfield 2006). The higher $\delta^{15}N$ of Sărata Monteoru suids may reflect a different form of pig husbandry, where animals were kept closer to settlements and developed more omnivorous diets through the consumption of household refuse, or the observed data may have been influenced by the inclusion of young animals. However, if all highly positive $\delta^{15}N$ values could be explained by the nursing effect, one would theoretically expect a positive correlation between pig $\delta^{15}N$ and $\delta^{13}C$ values, which both should increase during suckling. Here, the correlation is very weak (r=-0.13), hinting that there may have indeed been real differences in feeding habits between pigs from the two sites.

Concerning the outlier, this Cârlomăneşti pig has the highest $\delta^{13}C$ value (-13.5‰) of any subject, human or faunal, sampled for this project. If this is not a 'rogue' measurement, the carbon isotope value of this specimen was likely affected by C_4 plants (the implications of a marine influence will be considered further below). Since none of the humans have $\delta^{13}C$ values close to this figure, it seems logical to assume that this pig was either a non-local, or represented a minority among the suids. Pigs were not commonly herded over long distances in search of suitable grazing, as was practised with caprines (Arnold & Greenfield 2006). While it is known from ethnohistorical sources that farmers in Serbia sometimes pastured acorn-fed pigs far from their villages if there were no good oak forests in the vicinity (Halpern 1999), it seems unlikely that the Monteoru communities would have had difficulties finding sufficient grazing for their pigs in the surrounding (woodland) landscape.

It is also unlikely that a free-roaming pig would rely entirely on C_4 grasses for sustenance. Even though the human $\delta^{13}C$ values from Monteoru sites do not show evidence for the consumption of C_4 plants, it is not unreasonable to suggest that small quantities of millet may have been grown specifically for animal fodder. However, if this was the case, this pig's diet must have represented an exception rather than the rule. Instead, the animal could have been reared on C_4 (or marine) resources in a different region, and brought to Cârlomăneşti as part of trade activities, or as a gift for

a feast. After all, the Monteoru people had excellent trade relations, extending to Transylvania, the Black Sea, the Baltics, and Mycenaean Greece, as evidenced by the presence of rare and exotic goods found in settlements and cemeteries.

Although the low $\delta^{15}N$ (+6.2‰) of this pig does not indicate the consumption of fish, as an opportunistic feeder it could have ingested fish scraps, including those with high $\delta^{13}C$ and low $\delta^{15}N$ values, such as shellfish. Alternatively, this deviant measurement may have come from a wild boar; wild pigs can move great distances in search of food, and this one may have originated from an area with abundant C_4 vegetation or marine resources. Becker (1999) lends some credence to the idea that wild animals (or their remains) could have been deliberately moved between distant regions, by drawing attention to a set of fallow deer bones (consisting of the skull, antlers, and cervical vertebrae) found at an Early Bronze Age Inner-Carpathian settlement. She describes the find as a trophy brought to the site from further south, as the natural range of the fallow deer never extended so far north.

Only three samples of horse were available from the two sites combined. They have very similar $\delta^{13}C$ values (around -20.1‰), indicative of grazing in a similar environment as most of the other fauna, but display intersite differences in their $\delta^{15}N$ values: Cârlomăneşti horses have isotope values (+2.8‰ and +3.2‰) akin to the wild herbivores, whereas the one from Sărata Monteoru (+6.4‰) is indistinguishable from most of the cattle and caprines. None of the bone fragments were described as originating from immature animals.

The observed data evoke questions about the domestication of the horse in the Carpathian area. Evidence of domesticated horses appears in regional (e.g. Pontic steppes, the Carpathian Basin) archaeozoological assemblages during the Early Bronze Age (Bartosiewicz 2013), and according to Becker (2000), horses were well known to Monteoru people. It thus seems unlikely (although not impossible) that the recorded variation in horse $\delta^{15}N$ would reflect differences between wild and domesticated equids, but may rather be related to whether the animals were grazing

near the settlements alongside other herds (e.g. cattle), or were managed more freely in the surrounding open woodlands.

Dogs were kept already by the Mesolithic hunter-gatherers of the Danube Gorges (Bonsall *et al.* 1997), and their importance in Monteoru communities is reinforced by their constant presence in archaeozoological assemblages from the Carpathians from the Eneolithic onwards (Becker 1999, 2000). Although only one dog bone was available for sampling from Sărata Monteoru, it is complemented by seven more from its neighbouring site. The isotope values of the Sărata Monteoru dog (-19.2‰; +8.4‰) fall within the range of those from Cârlomăneşti (from -19‰ to -20‰ for $\delta^{13}C$, and from +7.9‰ to +9.9‰ for $\delta^{15}N$), thus the results from the two sites are here discussed together.

The range of dog $\delta^{13}C$ values would indicate that they did not consume any aquatic or C_4 plant-based resources, and that their food source had a local isotopic signal. Their high $\delta^{15}N$ values reflect a predominantly carnivorous diet, as is also attested from numerous finds from Monteoru settlements of animal bones (e.g. of cattle, pig, caprines) with canid gnaw marks (Becker 1999, 2000), including three bones from Cârlomăneşti (two caprines and one suid) sampled for the current study. While Becker (2000) reported cut-marks on canid bones from both Sărata Monteoru and another Monteoru culture site (Năeni-Zănoaga), the similarity of dog–human $\delta^{15}N$ values suggests that dog meat was not consumed in significant quantities by humans.

It should be noted that the average $\delta^{15}N$ for all dogs (+9.2‰) is 0.6‰ higher than the average for Sărata Monteoru (adult and adolescent) humans, but also 0.6‰ lower than that of Cârlomăneşti (adult and adolescent) humans. Statistically, the canid and Sărata Monteoru human values are significantly different for both $\delta^{13}C$ and $\delta^{15}N$ (Mann–Whitney U test, U=81, p=0.02; U=92.5, p=0.044, respectively), however, the differences do not hold when comparing dogs and Cârlomăneşti humans ($p>0.1$). This seems to agree with conclusions made in earlier sections (6.4.1. and 6.5.2.) concerning the more carnivorous diet (i.e. with a greater reliance on animal-based products over plant products) of the Cârlomăneşti population as compared to Sărata Monteoru,

although the scarcity of isotope measurements of humans from the former site, and dogs from the latter site makes the inference tentative.

Finally, stable isotope measurements of a deer (-20.8‰, +4.3‰) and a hare (-19.5‰, +3‰) from Cârlomăneşti can be considered to reflect the local baseline values of wild forage. The range of $\delta^{13}C$ values is consistent with that of the humans and most of the fauna. It is noteworthy that neither of the animals displays a canopy effect, and both have relatively high $\delta^{13}C$ values. This could be taken to imply that the landscape around Monteoru settlements was relatively open. However, animals could have been hunted further away from the villages, so their isotopic composition may not necessarily reflect the landscape around the settlement. In addition, hares are usually considered as open country animals, mainly feeding on grasses and herbs.

Today, the immediate surroundings of this area can be characterised as a forest steppe, with a foothill forest belt covering the higher (300–600m) elevations; the modern vegetation consists of patchy forests dominated by oak, hornbeam and beech (Feurdean *et al.* 2013:3). Stevens *et al.* (2006) pointed out that there is a difference between living in a forest, and feeding in a forest. Stevens and colleagues saw no significant differences in modern red deer $\delta^{13}C$ values between open and forested habitats, and even claimed that red deer are known to prefer open thicket sites within forests to dense canopy areas. Thus, the isotopic evidence from the two wild herbivores can not be used to confidently infer the nature of the Bronze Age landscape around the Monteoru settlements.

6.7. Childhood dietary practices

6.7.1. Reconstructing breastfeeding duration and timing of weaning at Sărata Monteoru

Traditionally, the process of weaning in archaeological populations has been reconstructed based on $\delta^{15}N$ (and $\delta^{13}C$) values of bone collagen obtained from individuals who have died at various ages during their childhood (e.g. Katzenberg *et al.* 1993; Schurr 1998; Mays *et al.* 2002; Prowse *et al.* 2008; Pearson *et al.* 2010). However, difficulties associated with precise aging of infant and juvenile skeletons, in

addition to their more fragile nature and frequent under-representation in archaeological assemblages, have led to the development of alternative methods, among them the utilization of dentine microsamples (e.g. Eerkens *et al.* 2011; Henderson *et al.* 2014; Beaumont *et al.* 2015; Beaumont & Montgomery 2016). In the current study, the conventional approach to studying childhood dietary changes is complemented by isotope data from incrementally sectioned dentine of permanent first molars from four individuals at Sărata Monteoru (two adolescents and two young adults).

The inclusion of dentine samples (reflecting collagen formed during the first decade of life) provides an opportunity to test whether isotope ratios from those who died during childhood (as represented by bone collagen) demonstrate the same variations in diet as those that survived into adulthood. This problem reflects the so-called 'Osteological paradox' (see Wood *et al.* 1992), which suggests that juveniles in a cemetery population may not be representative of the whole community, and may have died during childhood because they were at a higher risk for some reason. Furthermore, they may have been breastfed or weaned differently because of that risk.

Although bone and dentine both reflect the organic phase (i.e. collagen), they cannot be compared directly. For example, dentine collagen formed during the 5th year of life may have a very different isotopic composition compared to bone collagen from the same 5-year-old individual. Bone collagen will always show a delayed signal averaged over a certain length of time, and this delay increases with age due to changes in turnover rates. Dentine, however, does not remodel, and reflects collagen deposited during its formation (albeit successive increments may include collagen from both the preceding and succeeding sections due to the non-horizontal growth pattern of dentine). Consequently, dentine should more accurately reflect the true age of weaning, although the differences between bone and dentine isotope ratios would be minimal for infants who experience the fastest turnover.

The combined isotope data from bone and dentine collagen is shown in Figures 43 and 44 for $\delta^{15}N$ and $\delta^{13}C$, respectively, compared with the mean value (and 1SD) of Sărata

Monteoru females. The approximate age, plotted on the x-axis, represents the estimated age of formation for the dentine samples, and the estimated age-at-death for bone samples. As can be seen, the available data for various age ranges have been greatly increased with the inclusion of dentine samples, although it must be taken into account that the latter do not represent unique individuals, but rather diet at certain ages.

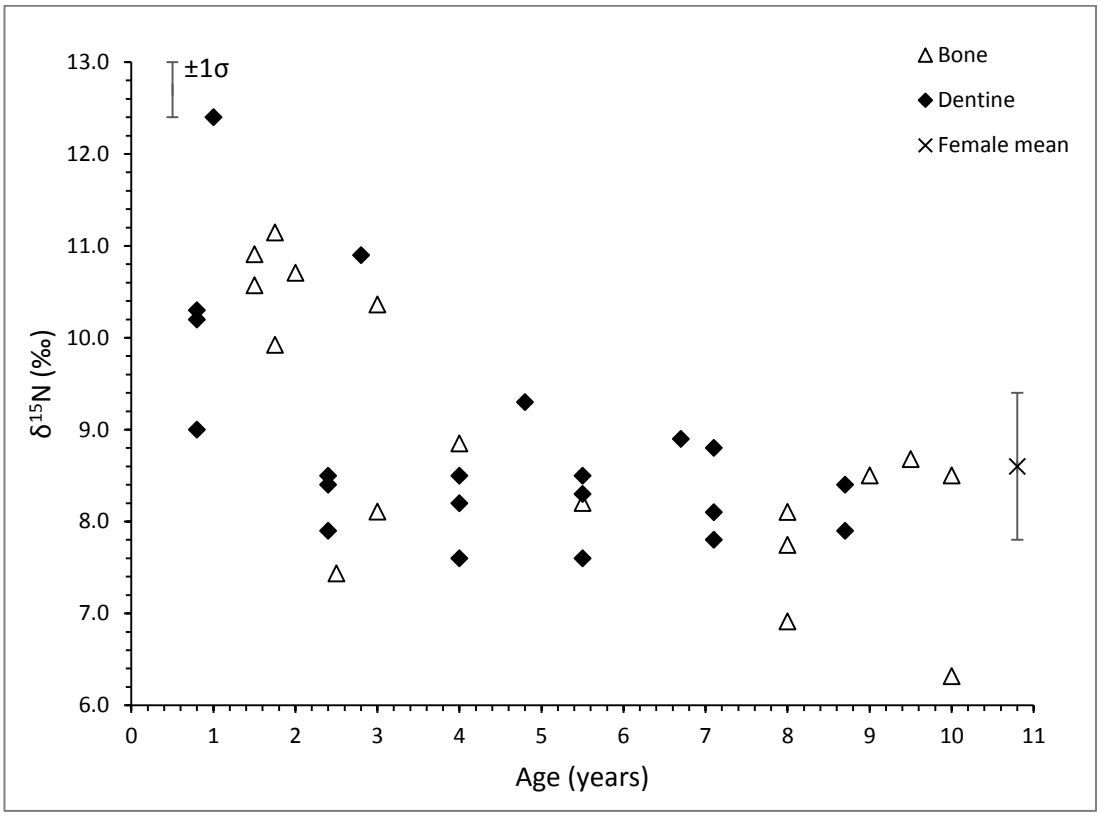


Figure 43. $\delta^{15}N$ values from dentine sections and bone collagen of individuals at Sărata Monteoru plotted against age. The mean value (and 1SD) of Sărata Monteoru females is also shown

There do not seem to be significant differences in the spread of $\delta^{15}N$ values between the two types of tissue (Figure 43). As expected, the earliest measured isotope values from dentine and bone (i.e. below the age of 2 years) are all enriched over the female mean, but the amount of the enrichment varies greatly, from 0.4‰ to 3.8‰. $\delta^{15}N$ values show a substantial decline after the age of 2 years, although in a few occasions the enrichment has continued for a slightly longer period (up to 3 years), and this was seen in both bone and dentine samples. Nitrogen isotope concentrations reach levels similar to those seen in adults by the age of 4 years for all individuals analysed.

Carbon isotope values for dentine and bone also show no visible differences between survivors and non-survivors, nor can it be suggested that dentine values reach the adult range earlier than those from bone (Figure 44). Many of the earliest (youngest) $\delta^{13}C$ measurements from bone and dentine are enriched over the female average, although in several instances the enrichment is minimal and the values fall within the adult range. Like nitrogen, $\delta^{13}C$ values also demonstrate notable variation for samples assigned to earlier age ranges, with the variation becoming smaller as age advances and the $\delta^{13}C$ values settle in the adult range from the age of 3 years onwards.

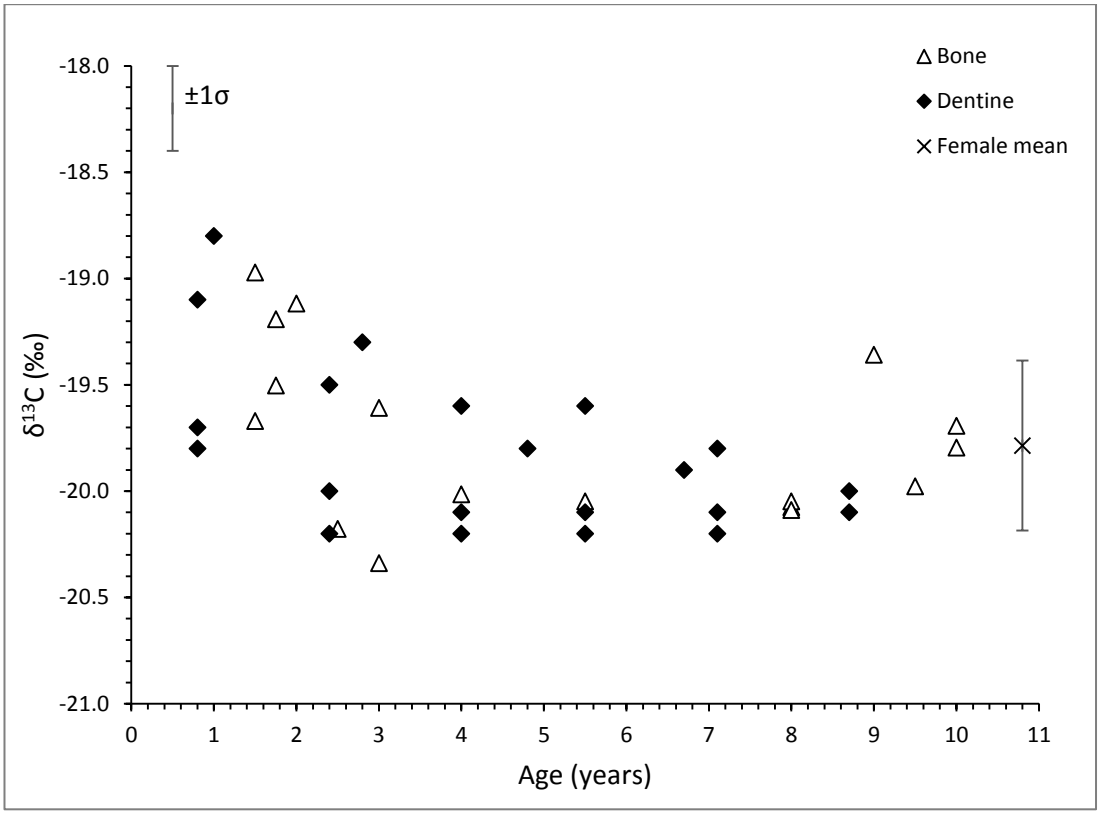


Figure 44. $\delta^{13}C$ values from dentine sections and bone collagen of individuals at Sărata Monteoru plotted against age. The mean value (and 1SD) of Sărata Monteoru females is also shown

Taken together, there is no evidence that bone $\delta^{15}N$ or $\delta^{13}C$ isotope values lag behind dentine in reflecting the adoption of non-breastmilk foods. This observation may be greatly influenced by the fact that the period associated with the most notable childhood dietary changes (i.e. infancy) coincides with the fastest bone turnover rates; the lag between bone and dentine values would be more pronounced as age advances. For example, when Burt (2015) compared isotope data from dentine microsamples and

rib bones, she found that both tissues suggest a similar weaning time. Although the current data set is relatively small, the lack of a notable lag even among the older age groups may be taken to suggest that once weaned, the childhood diet at Sărata Monteoru was fairly homogeneous in its isotopic composition.

In addition, the $\delta^{15}N$ and $\delta^{13}C$ weaning curves produced by dentine increments and bone samples display no variations that could be taken to indicate differential breastfeeding and/or weaning patterns between those individuals who died during childhood and those who survived into adulthood. This outcome is similar to that obtained by Fuller *et al.* (2003) and Burt (2015), but contrasts with the findings of Beaumont *et al.* (2015), who reported differences in $\delta^{15}N$ and $\delta^{13}C$ values between survivors and non-survivors which were manifested in the latter displaying much greater isotopic variation between dentine increments. It should be noted that unlike the current study, Beaumont and colleagues used juvenile teeth (and not juvenile bones) to represent non-survivors, but so did Fuller *et al.* (2003) who observed no significant variations.

At Sărata Monteoru, isotope values associated with an age range of 0–2 years are enriched over the female mean on average 2‰ for $\delta^{15}N$ and 0.5‰ for $\delta^{13}C$. This is in accord with data obtained from modern mother–infant pairs that have shown infants' fingernails and hair to have consistently higher $\delta^{15}N$ (and in most instances $\delta^{13}C$) than their mothers, although the differences are generally smaller than the full trophic level effect (see Fuller *et al.* 2006; de Luca *et al.* 2012). There are several possible explanations for this. For example, Reynard & Tuross (2015) have collected data that suggest maternal milk is lower in $\delta^{15}N$ (by approximately -1‰ to -3.6‰) than maternal collagen, which could (at least partly) explain the small mother–infant trophic offset.

In addition, the first dentine increment (representing the earliest/youngest measurement) will also include some perinatal (i.e. non-breastmilk) collagen, which can slightly lower the $\delta^{15}N$. While the same applies to bone collagen, it is of little consequence in the current study; several researchers (e.g. Richards *et al.* 2002; Tsutaya & Yoneda 2013) have proposed a period of about 40 weeks for the post-birth

dietary $\delta^{15}N$ signal to be fully reflected in bone collagen, but none of the juvenile individuals included in this study were estimated to have been younger than 1 year at time of death. It thus seems unlikely that any of the bone material analysed for this study would include contributions from foetal (i.e. non-breastmilk) collagen.

While direct comparison of mother–infant isotope values is seldom possible in archaeological contexts, two double graves at Sărata Monteoru, consisting of female–child pairs, were included in the present study. Although it cannot be confirmed from available evidence, it seems likely they are instances of mother and child buried together. Burials no. 35a and 35b represent a young female (17–19 years old) and a child 1.5–2 years old. Their respective $\delta^{13}C$ and $\delta^{15}N$ values are -19.7‰ and +8.4‰ (woman), and -19.2‰ and +11.1‰ (child), reflecting an offset of 0.5‰ for $\delta^{13}C$ and 2.7‰ for $\delta^{15}N$. These differences are in the same order as seen in modern comparisons of mother–infant pairs, and suggest the young woman was indeed the mother (or wet nurse) of the child.

The second double grave (burials no. 75a and 75b) consisted of a fully adult female and a child 1–2 years old, with respective $\delta^{13}C$ and $\delta^{15}N$ values of -19.2‰ and +9.5‰ (woman), and -19.0‰ and +10.9‰ (child). The offset between this pair is much smaller than for the first one (0.2‰ for $\delta^{13}C$ and 1.4‰ for $\delta^{15}N$). It is interesting to note that while the isotope values of the two infants (burials no. 35b and 75b) are very similar, the woman from grave 75a has slightly more positive $\delta^{13}C$ and $\delta^{15}N$ values compared to both 35a and the Sărata Monteoru female average. This does not necessarily mean that 75a was not the mother of the child buried in the same grave; it is possible that the introduction of weaning foods (and subsequent decline in intake of breast milk) had already occurred for 75b a significant amount of time before death.

Considering the Sărata Monteoru data set as a whole, the isotopic evidence suggests individual variations in the duration of breastfeeding. In most cases enriched $\delta^{15}N$ values are seen in infants up to the age of 2 years, although for some the enrichment seems to have lasted for shorter (ca. 1 year) or longer (ca. 3 years) periods. Based on the expected decline of $\delta^{13}C$ values from infancy onwards, the introduction of solid

(i.e. non-breastmilk) foods to diet seems to have occurred around the age of 1–2 years, and in some cases could have taken place well before the age of 1. By age 4, all samples show $\delta^{15}N$ and $\delta^{13}C$ values within the adult range, suggesting weaning was completed by that time, if not earlier.

These estimates are somewhat higher than those reported for historical populations. Sellen & Smay (2001) collected ethnographic data from various agricultural, pastoral and hunter-gatherer groups, and demonstrated that weaning foods were first introduced anywhere from 3–6 months (irrespective of the mode of subsistence), whereas breastfeeding had finished before or around the age of 2 years (slightly later for hunter-gatherer groups). From the results obtained for Sărata Monteoru, especially concerning the introduction of non-breastmilk products, it can be suggested that the addition of small quantities of weaning foods to diet may not be visible in the isotopic record if breast milk still accounted for a considerable portion of protein intake.

Ethnographic observations have shown that low trophic level foods such as cereals and legumes are often preferred as weaning foods over animal products (Sellen & Smay 2001). Furthermore, Reynard & Tuross (2015) suggested that since nitrogen isotopes reflect the protein content of the diet, the introduction of low-protein foods (e.g. cereals) during weaning would not initially influence the $\delta^{15}N$ signal until the proportion of high-protein foods (i.e. breast milk) became less prominent. In any case, considering the effects of bone turnover, weaning must have begun before the peak in (bone) $\delta^{15}N$ values occurred. Since even the dentine increments only provide values that are averaged over the time of growth, the true age of the onset of weaning at Sărata Monteoru was likely earlier than that seen in the isotope data.

As mentioned above, there are notable variations in $\delta^{13}C$ and $\delta^{15}N$ values of very young (under 3 years) individuals. The two most likely causes are variations in maternal breast milk values, and inter-individual differences in the duration of exclusive breastfeeding. Unfortunately, as was seen in the comparison of the isotope values of the two female–child pairs, it is difficult to differentiate between the two

scenarios based on this data set alone. However, it may be useful to consider the possible factors influencing the duration of breastfeeding.

The exact length of this practice was probably determined on an individual basis, as is commonly seen in modern societies. Insufficient milk supply, a new pregnancy, illness, the need to return to work, and the idea that weaning should be child-led are some of the factors cited as influencing the decision of nursing among modern women (Sugarman & Kendall-Tackett 1995; Blyth *et al.* 2004). The attitudes of both the mother and the infant toward breastfeeding, in addition to related practical issues, likewise affected prehistoric communities, and these should be taken into consideration when attempting to reconstruct infant feeding strategies.

Furthermore, considering that breast milk provides the infant with valuable nutrients and immunological protection (Goldman *et al.* 1982; Lönnerdal 2000), it is not surprising that weaning would result in the child becoming more susceptible to various pathogens and nutritional deficiencies. Prolonged nursing could have been practised as an attempt to maintain the health of the child during nutritional shortages or even famine. Written accounts from Medieval Europe and Classical Antiquity attest to breastfeeding being commonly considered as beneficial for the child's health (Holman 1998; Winer 2008). While there is no evidence that Bronze Age people would have been aware of these health benefits, nor taken advantage of them intentionally as a strategy to improve the well-being of the infant, it is conceivable that they observed that infants who were breastfed for longer were healthier than those who were weaned earlier.

Still, it seems certain that weaning was a difficult stage of the life of Monteoru children. Among the Sărata Monteoru population there is osteological evidence to indicate that the age of ca. 2–4 years sometimes coincided with physiological stress, as seen in the presence of linear enamel hypoplasia (LEH) on teeth, and skeletal pathologies associated with nutritional deficiencies, including vitamin C deficiency (see Chapter 5 and Appendix 2). Triantaphyllou *et al.* (2008) also reported the presence of LEH among a Greek Middle Bronze Age population, remarking that the enamel

disruptions occurred between the ages of 1 and 5 years. Palaeopathological evidence of vitamin C deficiency was recorded at a Neolithic LBK site in Hungary, where its occurrence (associated with two individuals, aged 1–1.5 years and 2–4 years) was linked to weaning practices (Whittle *et al.* 2013a). A possible connection between vitamin C deficiency and weaning foods was also suggested by Bourbou (2014) and Mays (2014).

The relationship between physiological stress and prolonged breastfeeding is further complicated by the potential effects of non-dietary factors on human $\delta^{15}N$ values. During periods of metabolic stress or starvation, the body is in a state of negative nitrogen balance, which leads to increased $\delta^{15}N$ values (Fuller *et al.* 2005). The more positive $\delta^{15}N$ values of nursing mothers undergoing physiological stress could be transferred to the infant during breastfeeding, and/or the stress experienced by the infant could retain the $\delta^{15}N$ values at elevated levels for a longer period, for example, even after breastfeeding had ceased. Alternatively, a combination of the two factors is possible, i.e. increased $\delta^{15}N$ due to disease or metabolic stress, and increased $\delta^{15}N$ due to prolonged breastfeeding.

It should be noted that the current data set includes bone collagen isotope values for two individuals (aged 2–4 years at death) from Sărata Monteoru who displayed skeletal pathologies strongly indicative of chronic vitamin C deficiency: burial no. 80 (-19.6‰ for $\delta^{13}C$, and +10.4‰ for $\delta^{15}N$) and no. 124 (-20.3‰ for $\delta^{13}C$, and +8.1‰ for $\delta^{15}N$). While neither of them has exceptionally high $\delta^{15}N$, the former (no. 80) displays a $\delta^{15}N$ value that is relatively elevated for its age. If that individual had already been weaned, the high $\delta^{15}N$ could be suggested to reflect the effects of a negative nitrogen balance in the body. However, since physiological stress is not known to affect $\delta^{13}C$ values (see Fuller *et al.* 2005), the fact that C- and N-isotopes show good correlation (i.e. the individual with the more positive $\delta^{15}N$ also has a less negative $\delta^{13}C$) indicates that the observed variation between the two children was more likely caused by differential consumption of breast milk.

Further, it is also possible that some of the observed variation in infant isotope values is a consequence of changes in weaning practices during the ca. 200-year period when the cemetery was in use. After all, breastfeeding duration affects birth spacing, and thus the fertility of the population (Anderson *et al.* 1986). Weaning practices may have been responsive to changes in the overall population dynamics, and the duration of breastfeeding may have increased or decreased depending on demographic circumstances. However, since only four individuals from Sărata Monteoru have been radiocarbon dated, any temporal patterning would be difficult to detect without additional analyses.

6.7.2. Late-childhood diet

In an earlier section (6.4.3.) of this chapter it was shown that there were statistically significant differences in $\delta^{15}N$ values (but not $\delta^{13}C$) between the four Sărata Monteoru age groups, defined here as infants (0–4 years), juveniles (4–12 years), adolescents (15–21 years) and adults (21+ years). Specifically, the differences lie between the infant–juvenile, infant–adolescent, and juvenile–adult groups. Many juvenile and adolescent individuals display $\delta^{15}N$ values ca. 1‰ lower than the adult mean, and the three individuals with the lowest $\delta^{15}N$ (below +7‰) also belong to these two groups. This phenomenon is commonly seen in isotopic dietary studies, where children around the ages of 4–17 years have on average lower $\delta^{15}N$ values (and sometimes also $\delta^{13}C$) compared to adults (e.g. Richards *et al.* 2002; Nitsch *et al.* 2011).

Tsutaya & Yoneda (2013) suggested that low $\delta^{15}N$ values occurring immediately after the peak in the breastfeeding signal may be explained by the consumption of lower trophic-level foods (e.g. cereals) as weaning foods. This scenario was considered above and seems entirely plausible for Sărata Monteoru. Since post-weaned and late-childhood isotope values do not show statistical differences, it can be argued that the weaning diet was similar in its isotopic composition to that consumed by older children and adolescents, but likely included less animal protein than adult diet (as expressed in lower $\delta^{15}N$ values).

An alternative explanation for the observed low $\delta^{15}N$ values of juveniles and adolescents involves the influence of positive nitrogen balance during growth (Katzenberg & Lovell 1999; Fuller *et al.* 2004). However, Waters-Rist & Katzenberg (2010) concluded that the effects of growth (i.e. positive nitrogen balance) are too minor to significantly affect $\delta^{15}N$ values in juvenile bone collagen, and even in infants who experience the fastest growth (and fastest bone turnover rates), the breastfeeding trophic level effect would likely mask any smaller variations in $\delta^{15}N$ values.

6.7.3. Individual weaning trends as recorded in tooth dentine

The data obtained from incrementally sectioned dentine of permanent first molars provides an opportunity to observe a continuous stable isotope record encompassing the first decade of life within one individual. Figure 45 displays these results for all four teeth (from burials no. 63, 81, 86 and 105) plotted against the midpoint of the age range associated with the formation period of the sampled increment. In addition, the isotopic signal from the bone of the same individual (mostly a rib, but in one case a metatarsal) is shown and can be considered to represent diet a few years prior to death.

Burial no. 63 (SM63) is an adolescent (19–21 years) female who has buried with a 'rich' funerary inventory. Her bone collagen $\delta^{13}C$ and $\delta^{15}N$ (-19.9‰, +7.8‰) are from a metatarsal and probably reflect a diet consumed during early adolescence. The bone $\delta^{15}N$ falls at the lower margin of the Sărata Monteoru human range, but is similar to $\delta^{15}N$ values seen in other adolescents (average of +8.2‰). All the dentine samples produced slightly higher $\delta^{15}N$ values than that obtained from bone, suggesting that her adolescent diet may have contained a somewhat greater proportion of low trophic level foods compared to the weaning diet (although the latest dentine increment measurement only differs from the bone by 0.6‰).

The earliest dentine increment has a $\delta^{15}N$ 2.4‰ higher than that obtained from the bone, and the maximum difference in $\delta^{15}N$ values between all dentine samples is 2.1‰. This range is smaller than the full $\delta^{15}N$ trophic shift associated with breastfeeding and may indicate that weaning foods were introduced to diet during the formation period of the first increment (ca. 0–1.5 years) resulting in a decrease in $\delta^{15}N$.

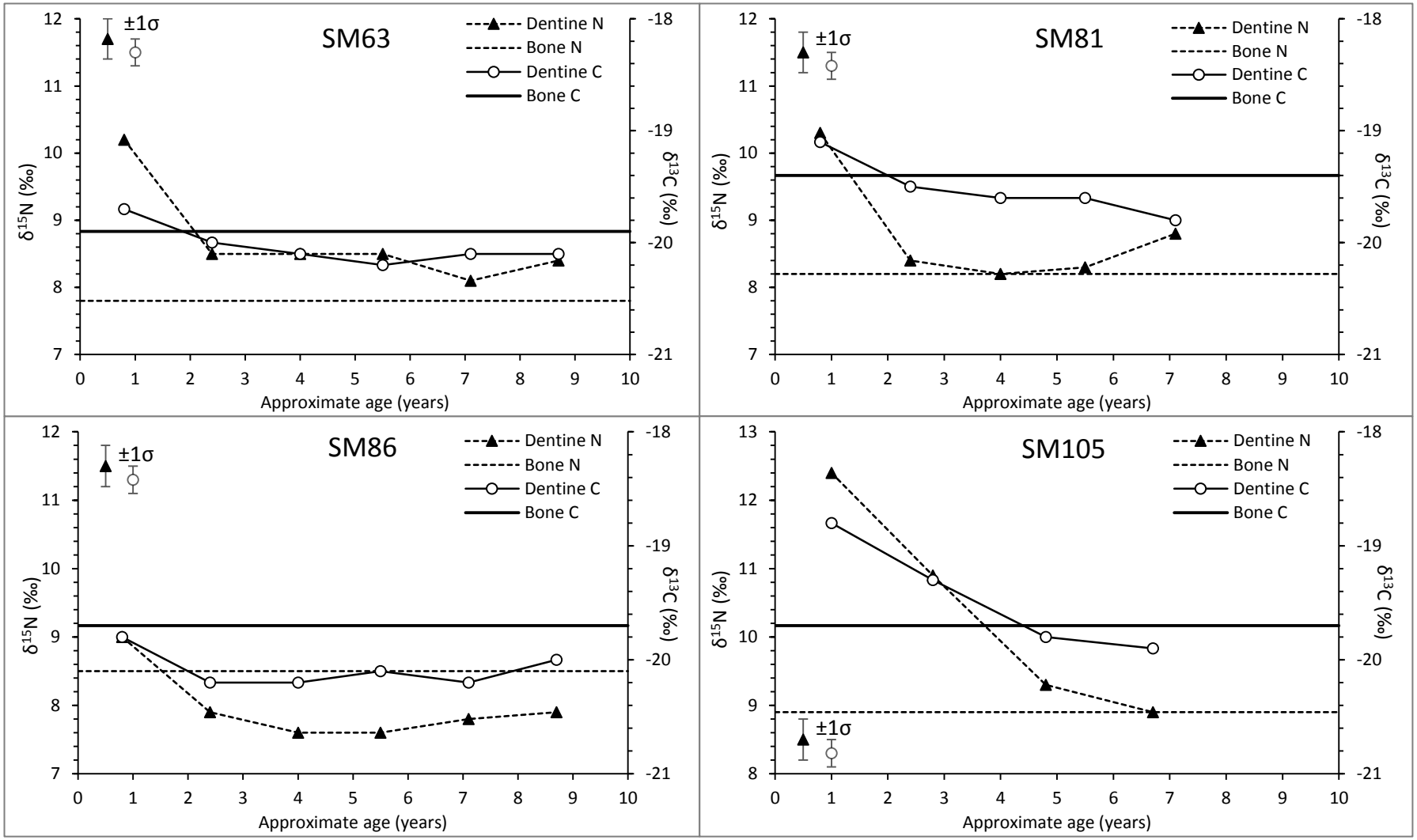


Figure 45. δ¹³C and δ¹⁵N values from incrementally sectioned teeth dentine of four individuals at Sărata Monteoru plotted against age of dentine formation. Associated bone collagen values indicated with the horizontal lines

Alternative explanations of the observed pattern can include the influence of maternal breast milk values and non-dietary (e.g. physiological) factors. While SM63 presented evidence of LEH suggestive of metabolic disruptions occurring between 2–4 years of age, the dentine $\delta^{15}N$ curve showed no corresponding change that could be interpreted as reflecting a stressful episode during this period. By the second increment, $\delta^{15}N$ has declined and the values for the succeeding sections remain at similar levels (i.e. within the analytical error at 1-sigma precision) until tooth formation has completed.

The maximum difference between $\delta^{13}C$ values of dentine increments is only 0.5‰ for SM63, which includes a small decline from the earliest to the latest sections. Generally, these variations are small and do not differ from the bone value by more than 0.3‰. Although infant $\delta^{13}C$ values do not always show a clear pattern of breastfeeding enrichment (e.g. Waters-Rist *et al.* 2011), many studies have demonstrated a simultaneous increase of $\delta^{13}C$ and $\delta^{15}N$ with breastfeeding (e.g. Fuller *et al.* 2003, 2006; de Luca *et al.* 2012). If we assume that a breastfeeding trophic shift in $\delta^{13}C$ of up to 1‰ did indeed occur in this individual, the small difference between the first two dentine sections may indicate that by the end of the formation of the first increment, the diet already contained a significant proportion of non-breastmilk foods.

Burial no. 81 (SM81) is a young adult of undetermined sex buried with 'few' grave goods. The bone collagen (from a rib) of this individual has $\delta^{13}C$ and $\delta^{15}N$ values of -19.4‰ and +8.2‰; the $\delta^{13}C$ is slightly higher than the Sărata Monteoru adult average, and the $\delta^{15}N$ lower. The latest available dentine increment from SM81 has $\delta^{13}C$ and $\delta^{15}N$ isotope values somewhat different from the bone, although the variations remain within analytical error at 1-sigma precision. The similarity of post-weaned dentine values to those from bone collagen suggests that the adolescent diet was similar in its isotopic composition to the weaning diet. The earliest dentine sample has a $\delta^{15}N$ 2.1‰ higher than the rib bone, and the maximum difference in $\delta^{15}N$ values between all dentine increments is also 2.1‰. No pathologies related to childhood ailments were reported for this individual.

SM81 displays a pattern in $\delta^{13}C$ and $\delta^{15}N$ dentine curves similar to those seen in SM63 above, where $\delta^{15}N$ values sharply decline and reach post-weaned levels by the age of ca. 2–3 years, and $\delta^{13}C$ values show a modest decrease between the first two increments (by 0.4‰), followed by negligible variation in post-weaned values. Thus, the possible interpretations of the SM63 isotope data, as described previously, also apply to SM81.

Burial no. 86 (SM86) is an adolescent (18–20 years) male buried without any funerary inventory. Rib bone collagen from this individual provided corresponding $\delta^{13}C$ and $\delta^{15}N$ values of -19.7‰ and +8.5‰, comparable to the Sărata Monteoru adolescent average. SM86 is set apart from the other three because it provides the only example where post-weaned dentine $\delta^{15}N$ values are consistently lower than the bone $\delta^{15}N$ (up to 0.9‰), suggesting that the weaning diet was characterised by greater amounts of low trophic-level foods compared to adolescent diet. It is also interesting that the earliest dentine increment of SM86 has a remarkably low $\delta^{15}N$ (+9‰), and only shows a 0.5‰ enrichment over rib collagen $\delta^{15}N$. While a $\delta^{15}N$ value of +9‰ may seem too low to be considered as reflecting a breastfeeding trophic effect (at least considering the stable isotope values of the females from this site), the maximum $\delta^{15}N$ difference between the first three dentine increments of 1.4‰ does indicate that a shift has occurred in the nitrogen isotope composition during the first four years of life.

If we assume that SM86 was breastfed during infancy, the observed $\delta^{15}N$ value of the earliest increment may result from maternal breast milk with a very low $\delta^{15}N$ compared to most females at Sărata Monteoru. The implications of such a low human $\delta^{15}N$ value were discussed in an earlier section (6.3.1.). Maternal $\delta^{15}N$ values from hair and fingernails have been shown to decrease during pregnancy in response to positive nitrogen balance, but in newborn (breastfed) infants this effect would likely be masked by the more significant ^{15}N enrichment from nursing (Fuller *et al.* 2004, 2006).

However, if the unusually low $\delta^{15}N$ dentine values of SM86 were determined by the isotope values of maternal breast milk alone, one would still expect the weaning curve to have a shape similar to the 'conventional' pattern as seen in SM63 and SM81, where

$\delta^{15}N$ abruptly drops after the age of ca. 2 years. The smaller difference between first and second increment $\delta^{15}N$ values for SM86 also may have occurred if higher-than-usual trophic level resources were used as weaning foods. Yet this explanation seems counterintuitive considering that among the four individuals sampled for incremental dentine, this individual presented the lowest post-weaned $\delta^{15}N$ values suggesting a weaning diet with a much greater reliance on low trophic level foods compared to the others.

Alternatively, if maternal breast milk $\delta^{15}N$ was similar to the average for Sărata Monteoru females, the observed pattern in dentine $\delta^{15}N$ values of SM86 could be taken to suggest an infant feeding strategy consisting of a very early introduction of solid foods (and/or a greater proportion of weaning foods over breast milk) well before the age of 0.8 years (the midpoint age for the formation period of the earliest increment). As in SM63 and SM81, the $\delta^{15}N$ values level out after the age of 2 years, indicating that weaning had been completed by then. The incremental $\delta^{13}C$ values only show a modest decline between the first and second dentine sections (0.4‰), and remain almost unchanged throughout the rest of childhood.

Another possibility to consider is that breast milk may not have always been an available option (e.g. when the mother is unable to nurse due to illness or death, or does not produce sufficient milk), so there may have been a need to resort to natural alternatives, e.g. cow's or goat's milk. SM86 may represent an individual nursed with one of these alternative milk sources (i.e. milk with a lower $\delta^{15}N$ than human breast milk). For example, Fuller *et al.* (2006) found that infants who were fed a combination of breast milk and formula (based on cow's milk) showed an enrichment in their hair $\delta^{15}N$ of only around 1‰ over the mother, whereas another infant who was exclusively formula-fed displayed a 2‰ *decrease* (most likely caused by the low $\delta^{15}N$ of the formula).

Burial no. 105 (SM105) is a young adult female buried with a 'rich' funerary inventory. Her rib bone $\delta^{13}C$ and $\delta^{15}N$ values (-19.7‰ and +8.9‰, respectively) reflect a diet similar to other adults at the site. Likewise, the latest dentine increment has $\delta^{13}C$

and $\delta^{15}N$ values nearly indistinguishable from those obtained from bone collagen, suggesting continuity between late childhood and adolescent diet. Stable isotope data from SM105 display the greatest change between dentine samples (1.1‰ for $\delta^{13}C$ and 3.5‰ for $\delta^{15}N$ between the earliest and latest increments), and, in addition, produce a weaning curve very different from that seen in the other three individuals. It should be noted that fewer dentine sections were produced for SM105 owing to the smaller size of the molar, resulting in the increments reflecting slightly longer formation periods. However, this should not have caused the pattern seen here.

It is noteworthy that the $\delta^{13}C$ and $\delta^{15}N$ values for the earliest increment (-18.8‰ and +12.4‰) are more positive than any values seen among Sărata Monteoru humans, either from dentine or bone collagen (including other breastfed infants). Like SM86, variations in breast milk isotope values could be one explanation for the observed data. If the mother had an unusually high $\delta^{15}N$ value, her infant would have ingested breast milk that was even more enriched in ^{15}N. A scenario whereby SM105 was weaned on foods that had significantly lower $\delta^{15}N$ compared to maternal breast milk, could have thus resulted in the observed greater difference between breastfed and weaned $\delta^{15}N$ values. However, a unique maternal diet would not explain why dentine $\delta^{13}C$ and $\delta^{15}N$ values for the second increment (in SM105 reflecting a formation period with a midpoint age of 2.8 years) are still relatively enriched (0.5‰ and 2‰, respectively) over the post-weaned isotope signal.

The fact that dentine $\delta^{13}C$ and $\delta^{15}N$ values only start to level off after the age of 5 years suggests there were other factors influencing the infant data besides the isotopic composition of breast milk. If (low-protein) weaning foods were introduced to infant diet much later than usual, or if these were consumed in very small quantities during the first years of life, it would result in higher average stable isotope values for the earliest dentine increments (i.e. compared to those individuals who experienced a significant decline in consumption of breast milk – and $\delta^{15}N$ values – already during the formation period of the dentine section), but also lead to the persistence of elevated $\delta^{15}N$ values over a much longer period.

In an earlier section of this chapter (6.7.1.) it was suggested that the duration of breastfeeding could have been influenced by various factors. It should also be emphasized that no pathologies related to childhood ailments were reported for SM105. However, physiological stress (as reflected in associated skeletal pathologies) may not necessarily affect the body's nitrogen balance in a way that is detectable at the current sampling precision – or it may not be distinguishable from the breastfeeding trophic shift – as was seen for SM63, where the occurrence of LEH did not correspond with an apparent change in dentine $\delta^{15}N$ values.

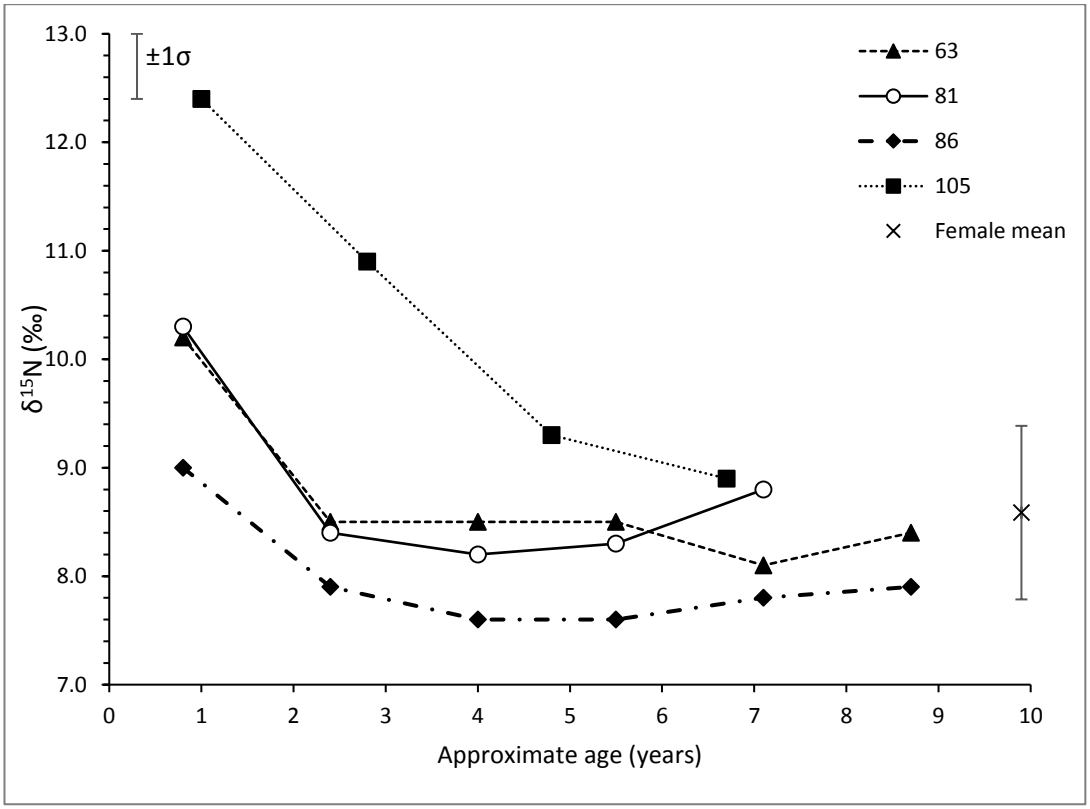


Figure 46. $\delta^{15}N$ values from dentine sections from four individuals at Sărata Monteoru plotted against age of dentine formation. The mean value (and 1SD) of Sărata Monteoru females is also shown

While the possibility that the observed high $\delta^{15}N$ values are influenced by metabolic stress cannot be entirely discounted, it should be pointed out that dentine $\delta^{13}C$ values from SM105 display a nearly identical curve to $\delta^{15}N$. Fuller *et al.* (2005) found that $\delta^{13}C$ in human hair does not display the same pattern of enrichment associated with physiological stress as reported for $\delta^{15}N$. Considering that the $\delta^{13}C$ and $\delta^{15}N$ values of dentine increments for SM105 show a very strong positive correlation (r=0.99), it may

be suggested that a trophic level shift corresponding to a prolonged breastfeeding period is the most likely interpretation of the observed data.

Since the current data set comprises dentine stable isotope values from only four individuals, they cannot be used to make inferences about the Sărata Monteoru population as a whole. They can be compared, however, against one another. N- and C-isotope values from all four individuals are plotted in Figures 46 and 47 along with the mean value (and 1SD) of Sărata Monteoru females. For both $\delta^{15}N$ and $\delta^{13}C$, it should be noted that despite the greater amount of isotopic variability for earlier increments, stable isotope values from later dentine sections are similar and fall entirely within the 1-sigma range of average values for (female) adults.

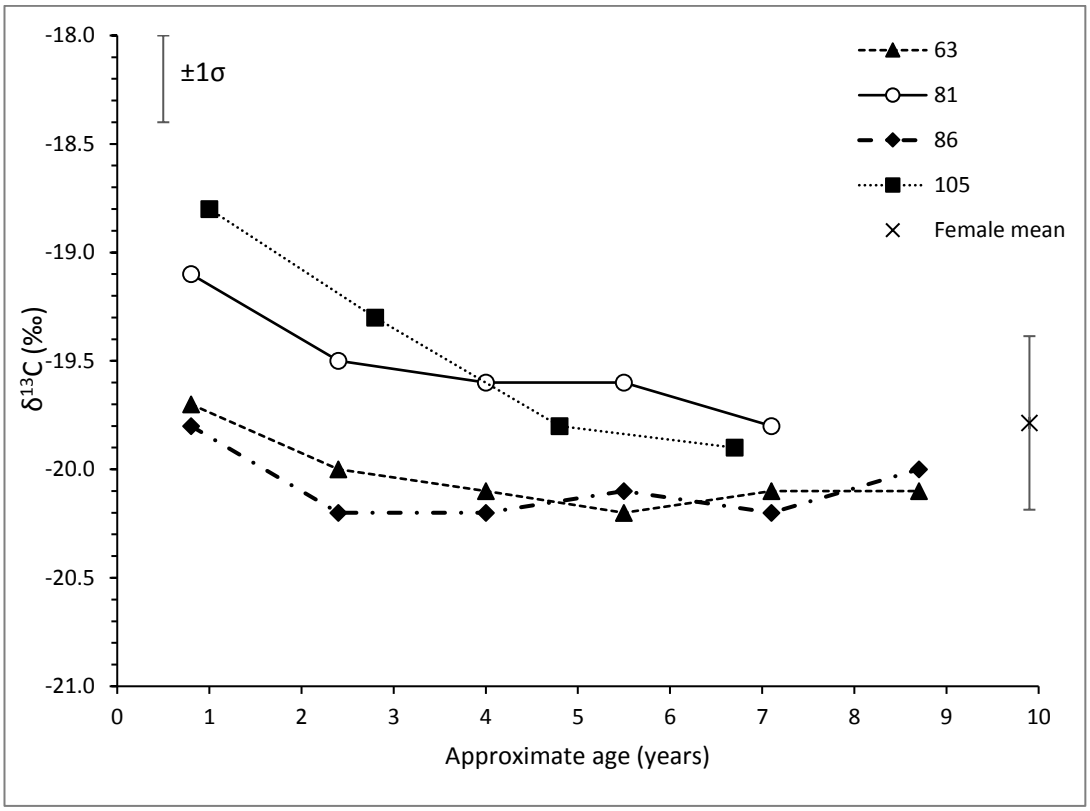


Figure 47. $\delta^{13}C$ values from dentine sections from four individuals at Sărata Monteoru plotted against age of dentine formation. The mean value (and 1SD) of Sărata Monteoru females is also shown

Taken together, all individuals show a strong positive correlation between their dentine $\delta^{13}C$ and $\delta^{15}N$ values (ranging between r=0.79 to r=0.99), supporting the assumptions made above concerning the breastfeeding trophic shift being the most probable factor

governing the observed variations. Variability of this order in individual weaning curves has been reported from other similar studies conducted on incrementally sectioned dentine (e.g. Eerkens *et al.* 2011; Henderson *et al.* 2014; Beaumont *et al.* 2015; Burt 2015; Beaumont & Montgomery 2016), suggesting there was no fixed weaning pattern for the whole population.

6.8. Sulphur isotopes and mobility

Sulphur isotopes were employed in the current study to assess the mobility of the Sărata Monteoru population as represented by 26 individuals of different age groups and sex. One of the advantages of using $\delta^{34}S$ analysis over $\delta^{87}Sr$ and $\delta^{18}O$ to study migration is that the same collagen extraction can be used for $\delta^{34}S$, $\delta^{13}C$ and $\delta^{15}N$ analysis, eliminating the need for extra bone or dental samples (and thus reducing the amount of material destroyed during analytical procedures) where both diet and geographical origin are being investigated.

The $\delta^{34}S$ values for all samples range from -2.6‰ to +3.9‰ with an average of +1.9‰ (±1.6‰) (see Table 7 in Chapter 6.1.). All adults and adolescents analysed for $\delta^{34}S$ could be categorised as either male (n=5) or female (n=10). The mean $\delta^{34}S$ for both sexes are similar (+2.0‰ for males and +1.8‰ for females), but females display a higher standard deviation (±2.3‰) reflecting a wider range (-2.6‰ to +3.9‰) in their $\delta^{34}S$ values compared to males (1SD ±1.3‰, range +0.2‰ to +3‰) (Figure 48). The relatively wide range of the female group is caused by two individuals with the most negative values (-1.6‰ and -2.6‰). Removing the two outliers would result in the female group having an average $\delta^{34}S$ of +2.8‰; however, the difference between the mean $\delta^{34}S$ values of males and females would still be statistically non-significant ($p>0.05$).

In addition, there were no statistically significant differences between mean $\delta^{34}S$ values for juveniles (n=11), adolescents (n=5) and adults (n=10), with respective values of +1.9‰ (±1.9‰), +2.6‰ (±1.5‰), and +1.5‰ (±2.1‰). No correlation between age and $\delta^{34}S$ is evident. Despite the lack of age- or sex-related differences,

the overall range of the $\delta^{34}S$ values (6.5‰, from -2.6‰ to +3.9‰) suggests some variation in the origin of the food sources that contributed to diet.

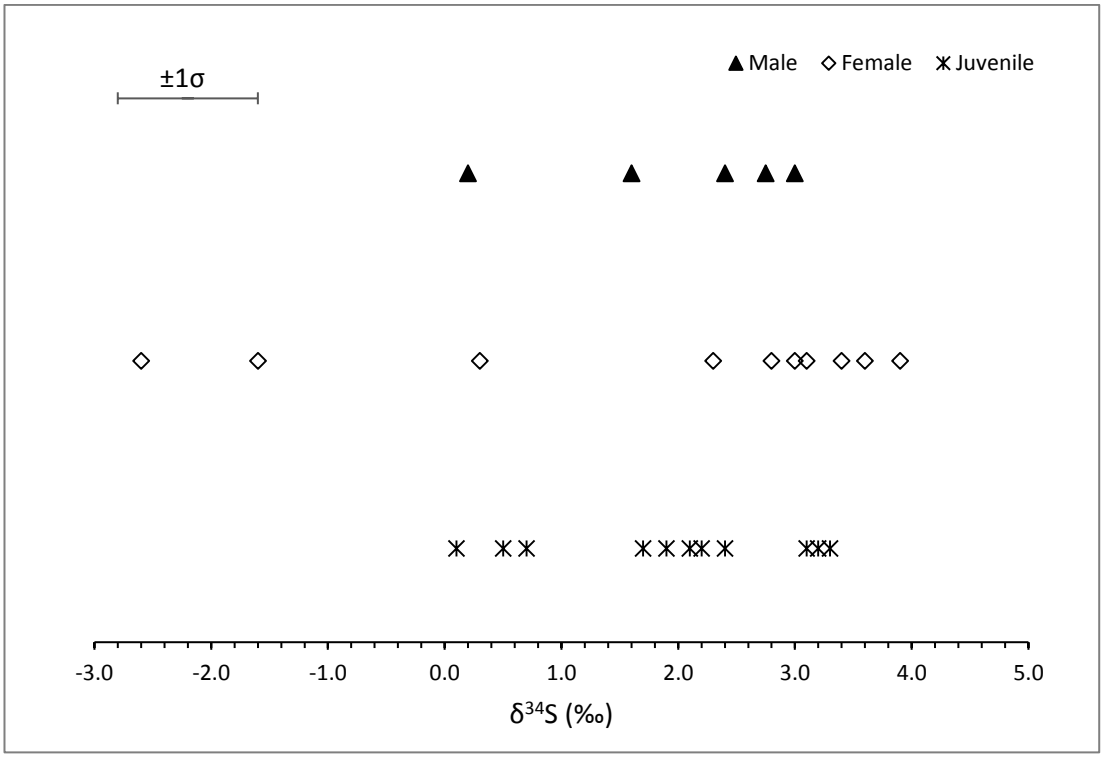


Figure 48. Human bone collagen $\delta^{34}S$ values from Sărata Monteoru

For comparison, when Oelze *et al.* (2012a) reported $\delta^{34}S$ values within a fairly narrow range of 4‰ (1SD of the mean ±0.9‰) for 23 individuals from an Early Bronze Age (ca. 2200–2000 cal BC) cemetery in southern Germany, the results were interpreted as reflecting a homogeneous diet of local origin (supported by $\delta^{87}Sr$ analyses from the same individuals). Another Bronze Age data set (n=11, from a mass grave at Thebes, Greece) displayed a $\delta^{34}S$ range of 6.9‰ (1SD ±1.7‰) (Vika 2009), similar to that of the Sărata Monteoru samples. However, the variation observed by Vika was caused by an outlier; when this was excluded, the $\delta^{34}S$ range was reduced to 2.3‰ (1SD ±0.8‰), indicating individuals with similar origins and/or diets. Although no $\delta^{87}Sr$ analyses were conducted on the Greek material, the local herbivorous fauna had $\delta^{34}S$ values that overlapped with the humans (except for the outlier).

The range of 6.5‰ (1SD ±1.6‰) for Sărata Monteoru is closer to that reported by Oelze *et al.* (2012b) for an Iron Age mass burial from Germany (range 8.6‰, 1SD

±1.5‰). The associated $\delta^{87}Sr$ and $\delta^{18}O$ data for some of these burials indicated significant movement of individuals during childhood. Since no $\delta^{87}Sr$ or $\delta^{18}O$ analyses were conducted on the Sărata Monteoru material, currently there are no additional data that can be used to aid in the interpretation of the $\delta^{34}S$ data. However, removing the two outliers with the most negative $\delta^{34}S$ values from the Sărata Monteoru data set would result in a range of 3.8‰ (1SD ±1.1‰), comparable to some of the populations described above. Thus, it may be suggested that the diet of the majority of the Sărata Monteoru population was relatively homogeneous in its isotopic composition and local in origin, but some individuals did not conform to this pattern.

There are relatively few $\delta^{34}S$ data from continental, temperate Europe, with which to compare the results from Sărata Monteoru. Four humans from Mesolithic and Neolithic Ukraine had $\delta^{34}S$ values between +5.2‰ and +7.9‰ (Richards *et al.* 2001). Bronze and Iron Age burials from Germany have values ranging from -1.9‰ to +6.7‰ (Oelze *et al.* 2012a, 2012b). Humans from various Mesolithic–Neolithic sites along the Danube in the Iron Gates region displayed a wide range of $\delta^{34}S$ values, from +2.3‰ to +12.7‰ (with the higher values thought to be associated with the consumption of aquatic resources) (Nehlich *et al.* 2010). Finally, Bronze Age humans from Thebes, Greece, had $\delta^{34}S$ values between +8.2‰ and +15.1‰, possibly influenced by the 'sea-spray effect' (Vika 2009).

Despite the lack of S-isotope data for associated food remains, the results from Sărata Monteoru humans seem consistent with a largely terrestrial diet, although the $\delta^{34}S$ values are slightly more negative than those reported in other studies (most likely due to differences in the underlying geology). Moreover, the average $\delta^{34}S$ (+1.9‰) for Sărata Monteoru humans does not indicate any input of marine sulphur, or the presence of a 'sea-spray effect', which are known to result in extremely positive (up to +21‰) $\delta^{34}S$ values (Rees *et al.* 1978; Wadleigh *et al.* 1994; Richards *et al.* 2003).

$\delta^{34}S$ values are often used to distinguish between aquatic and terrestrial food webs in cases where the two systems have distinct S-isotope sources (and $\delta^{34}S$ values). However, this approach was not considered for Sărata Monteoru, since no fish (or

other aquatic fauna) remains were available for sampling, and there was no other evidence that freshwater resources were an important part of the Monteoru diet (also supported by $\delta^{13}C$ and $\delta^{15}N$ values). Richards *et al.* (2001) have also cautioned against using modern samples instead of archaeological ones, owing to the possible effects of modern sulphur pollutants. Danube fish in southwest Romania had $\delta^{34}S$ values (ca. +14‰) that were distinct from those of local terrestrial animals (ca. +4‰) (Nehlich *et al.* 2010), but this does not necessarily apply to the Sub-Carpathian region, owing to differences in local bedrock geology. While no faunal $\delta^{34}S$ analyses were conducted as part of the present study, it is interesting to note that terrestrial animals from the Iron Gates sites have S-isotope values similar to those of Sărata Monteoru humans, whose diet was also predominantly terrestrial.

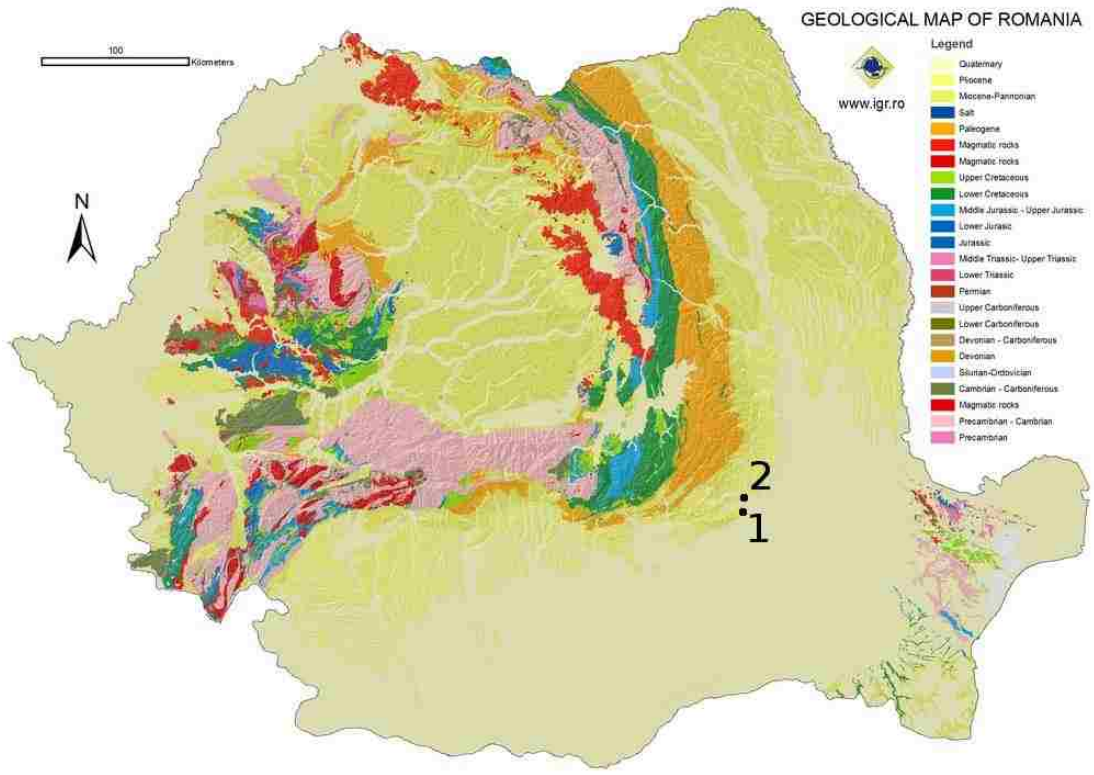


Figure 49. Geological map of Romania with the locations of Sărata Monteoru (1) and Cârlomăneşti (2). From Geological Institute of Romania, www.igr.ro

Although a lack of geological sulphur values from this region undoubtedly hinders drawing firm conclusions on migration based on human $\delta^{34}S$ values, Figure 49 reveals that the Monteoru culture area has a rather uniform surface geology, consisting of Quaternary and Neogene deposits, and surrounded by extensive alluvial plains. Most

of the variation in bedrock geology can be found further to the west, in the Carpathian Mountains and beyond. Privat *et al.* (2007) suggested that areas with relatively uniform surface geology should produce less variation in geological sulphur that is assimilated by terrestrial fauna, and thus result in relatively homogeneous $\delta^{34}S$ values for terrestrial consumers.

Furthermore, most of the territory of the Monteoru culture is comprised of chernozem and luvisol soils, with fluvial soils around the river valleys (Figure 50). Although no $\delta^{34}S$ analyses were conducted on the human bone samples from Cârlomăneşti, considering the proximity of the two sites, and their similar soils and underlying geology, it seems unlikely that the S-isotope values for Monteoru settlements would be significantly different. The full extent of this variation could be determined by further sampling of various Monteoru sites.

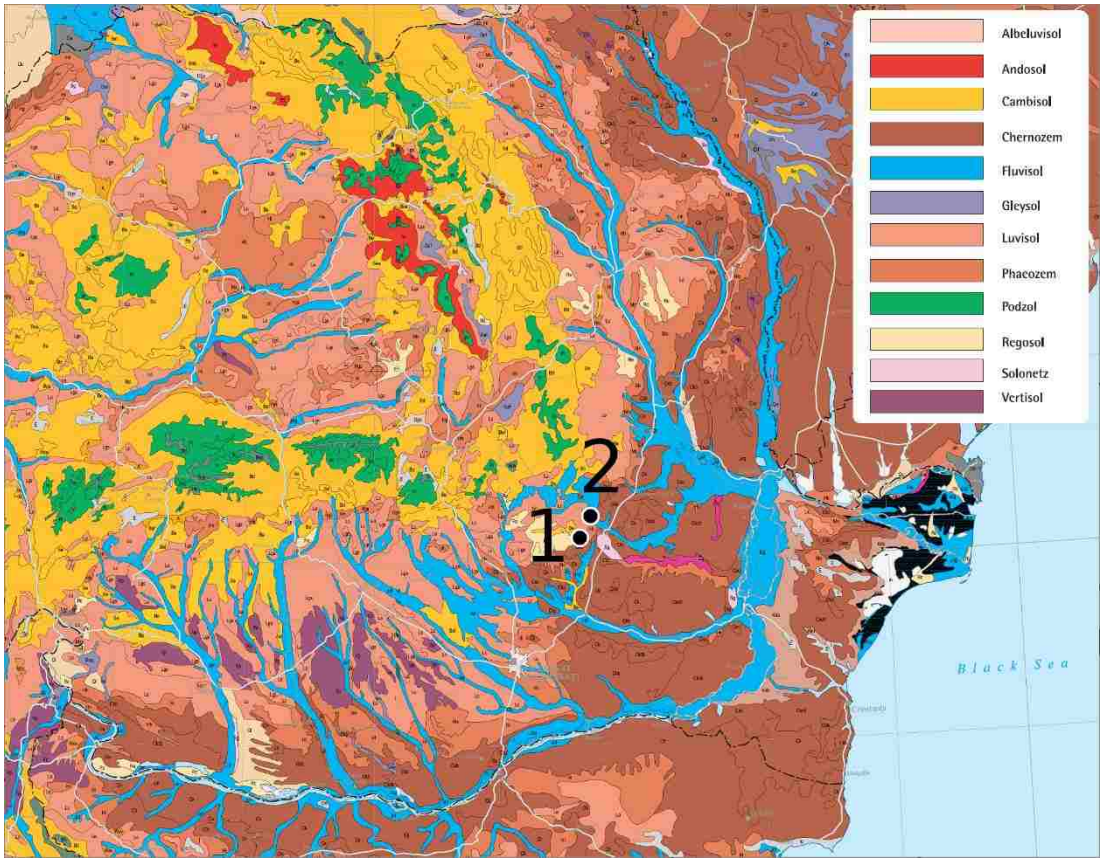


Figure 50. Soil map of Romania with the locations of Sărata Monteoru (1) and Cârlomăneşti (2). Modified from Soil Atlas of Europe (Jones et al. *2005)*

While it is not impossible that the Sub-Carpathian aquatic and terrestrial food webs had very similar $\delta^{34}S$ signatures, and that the consumption of both terrestrial and aquatic resources is reflected in human $\delta^{34}S$ values, this is not supported by other lines of evidence. There is also no correlation between $\delta^{13}C/\delta^{15}N$ and $\delta^{34}S$ values (see Figures 51 and 52), which might be expected if freshwater resources had been consumed. Thus, it is reasonable to assume that the range of $\delta^{34}S$ values exhibited by Sărata Monteoru humans (excluding the outliers) likely represents the (local) terrestrial food web. It also seems likely that the observed variation in $\delta^{34}S$ values is not caused by the consumption of non-terrestrial resources, but by differences in the sulphur source of the (terrestrial) food consumed, reflecting the movement of either humans or their food source (e.g. animals).

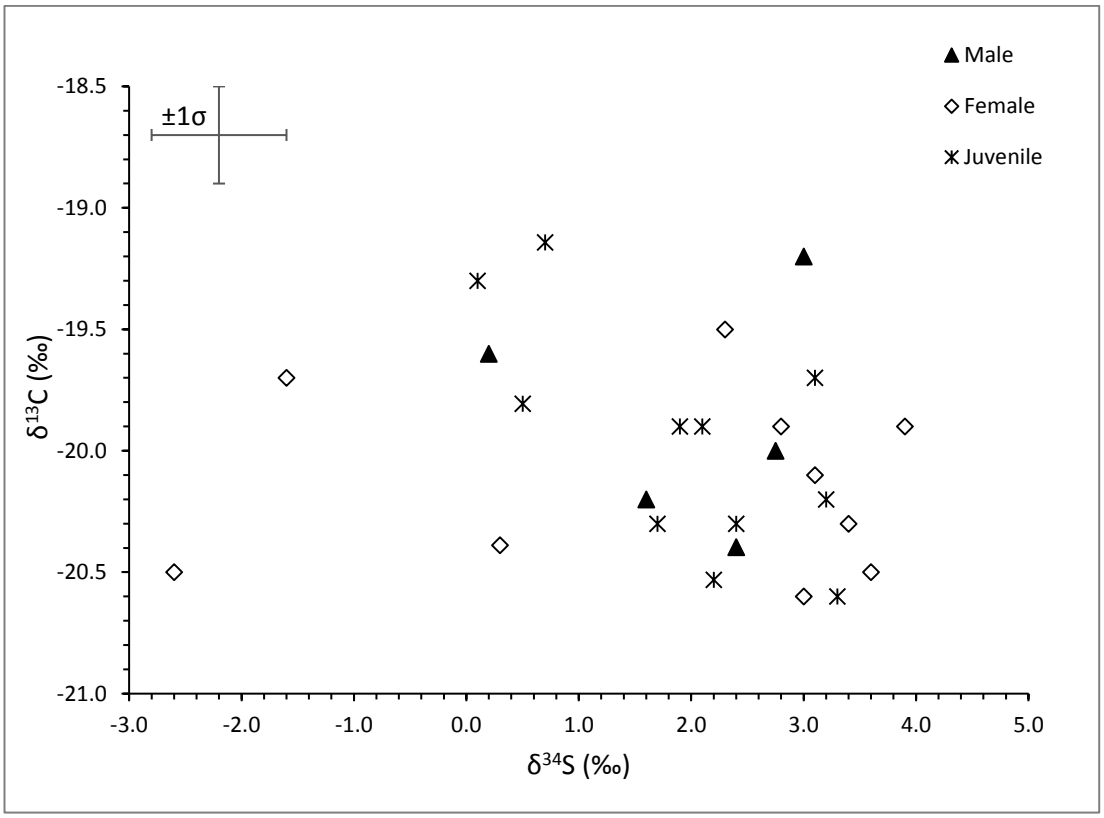


Figure 51. Human bone collagen $\delta^{13}C$ and $\delta^{34}S$ values from Sărata Monteoru

The two individuals mentioned earlier with respective $\delta^{34}S$ values of -1.6‰ and -2.6‰ are visibly distinct from the rest of the group in Figures 51 and 52. Interestingly, both potential outliers (burials no. 85 and 106) are females, assigned to the 'fully adult' age group, and buried without any grave goods. Their $\delta^{13}C$ and $\delta^{15}N$ values are similar

to those of other adults, supporting the view that variation in $\delta^{34}S$ values among the Sărata Monteoru population is less likely to have been caused by dietary differences, and may instead reflect movement between areas with different baseline S-isotope values.

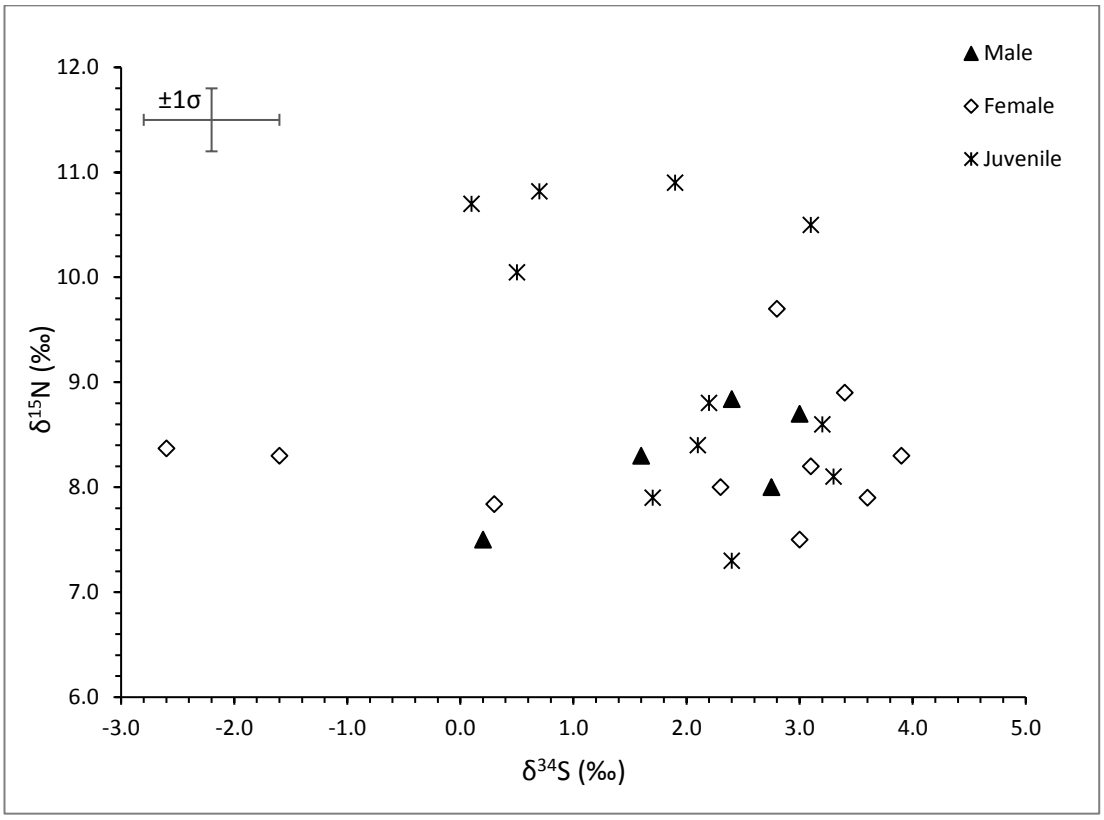


Figure 52. Human bone collagen $\delta^{15}N$ and $\delta^{34}S$ values from Sărata Monteoru

Exogamous practices may be considered a possible explanation for the observed data. Evidence for herd mobility, as suggested by some Monteoru faunal $\delta^{13}C$ values, could also indicate the presence within the community of individuals with more mobile lifestyles. Another possibility is that the extensive trade contacts evidenced by the presence of exotic goods in Monteoru material culture were associated with the movement of people. If representatives of the population were indeed travelling long distances (either for trade or herding), greater variation in their $\delta^{13}C$ and $\delta^{15}N$ values might also be expected. While this was not seen in the respective C- and N-values of the two $\delta^{34}S$ outliers, migration cannot be ruled out if the baseline value of the source area(s) was similar to that of Sărata Monteoru.

In addition, there does not seem to be a clear relationship between the number of grave goods and an individual's $\delta^{34}S$ (Figure 53). There was a tendency for burials with 'rich' grave goods to have slightly higher $\delta^{34}S$ values (on average +2.9‰ [±0.9‰]) than those with 'few' grave goods (+2‰ [±1.2‰]) or no grave goods (+1.6‰ [±1.8‰]), but the differences were statistically non-significant. While it may be speculated that those buried without funerary inventory were outsiders (e.g. not born into the community), this is not supported by the $\delta^{34}S$ signatures of burials without any grave goods, which span more or less the whole range of the reported $\delta^{34}S$ values from Sărata Monteoru.

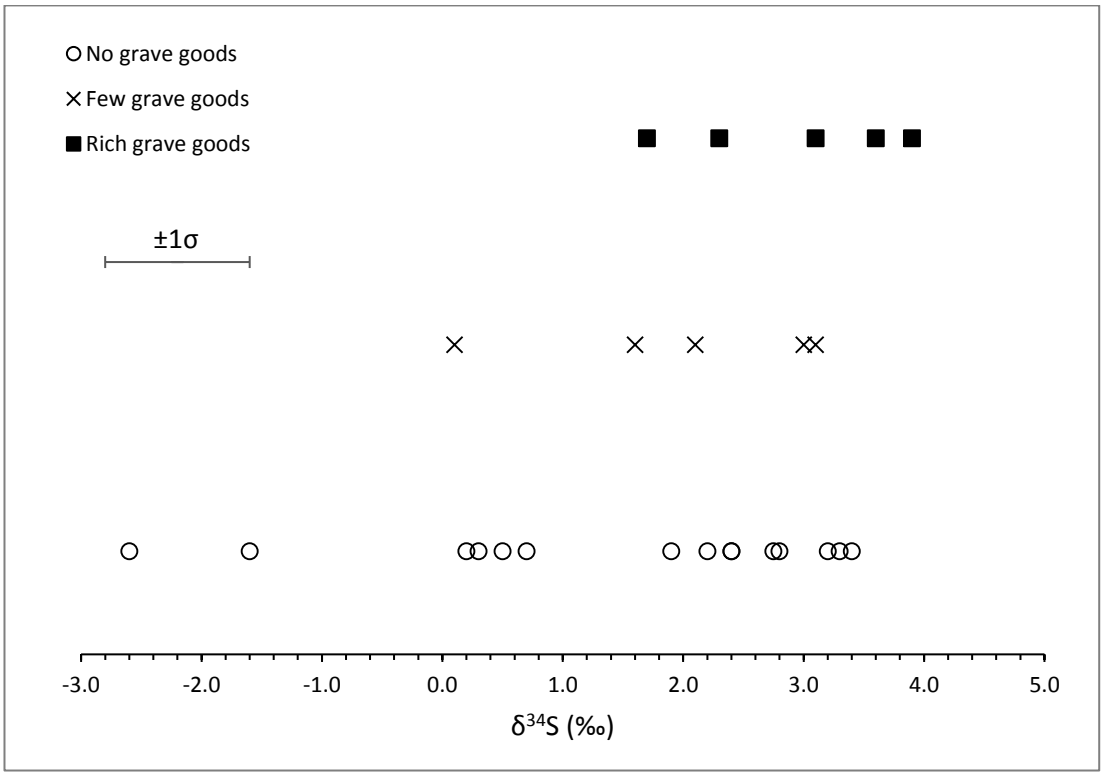


Figure 53. Human bone collagen $\delta^{34}S$ values from Sărata Monteoru by grave goods

It is unfortunate that neither of the two females with the most negative $\delta^{34}S$ values were among those individuals that were sampled from multiple skeletal locations. This would have revealed whether there were differences between the long-term (as represented by a cortical bone) and short-term (as represented by a trabecular bone) isotopic signals, which could signify a change in diet and/or location. For the individual with the most extreme $\delta^{34}S$ value (-2.6‰), the sample was taken from a femur. Considering that this individual was fully adult (approximately 25–35 years

old), the femur isotope value likely reflected collagen synthesized during late adolescence. The sample from the other individual with a negative $\delta^{34}S$ value (-1.6‰) was obtained from a rib bone. If this individual had originated from a region where local bedrock was more depleted in sulphur, it may be that her rib $\delta^{34}S$ value was starting to reach equilibrium with the (local) Sărata Monteoru sulphur signal obtained through diet (and characterised by slightly more positive $\delta^{34}S$ values). However, without additional isotope data, this should be considered as a working hypothesis.

Furthermore, considering the lack of knowledge of geological sulphur isotope ratios from the central Balkans, and the scarcity of similar studies conducted in the region, it would be premature to try to pinpoint the origin of the two possible outliers. It is worth mentioning, however, that none of the studies referred to earlier (with data from Germany, Ukraine, Greece, and the Iron Gates) displayed human $\delta^{34}S$ values lower than -2‰. Additional $\delta^{34}S$ analyses from other areas in and around the Carpathians are necessary to determine the true nature and extent of the movements of the Monteoru people.

6.9. Regional perspective

As this is the first isotopic palaeodietary study of material from the Romanian Carpathians, there are unfortunately few comparative data from the immediate area. For Romania, human stable isotope data have only been published for the Iron Gates region near the Romania–Serbia border, although these relate mainly to the Mesolithic and Early Neolithic (e.g. Bonsall *et al.* 1997, 2004; Cook *et al.* 2001; Borić *et al.* 2004). Compared to the 'fishing communities' of the Iron Gates (cf. Gurova & Bonsall 2014) with a high intake of aquatic protein reflected in relatively high $\delta^{13}C$ and $\delta^{15}N$ values, diet at Sărata Monteoru indicates a very different mode of subsistence based on farming and herding.

The results from this study will be integrated with those from the Bronze Age in the wider geographical region. These include published isotope data from sites in Bulgaria, Ukraine, Croatia and Greece, summarized in Chapter 3.1. The average $\delta^{13}C$

and $\delta^{15}N$ values for these sites are plotted in Figure 54, along with the equivalent data from Sărata Monteoru and Cârlomăneşti.

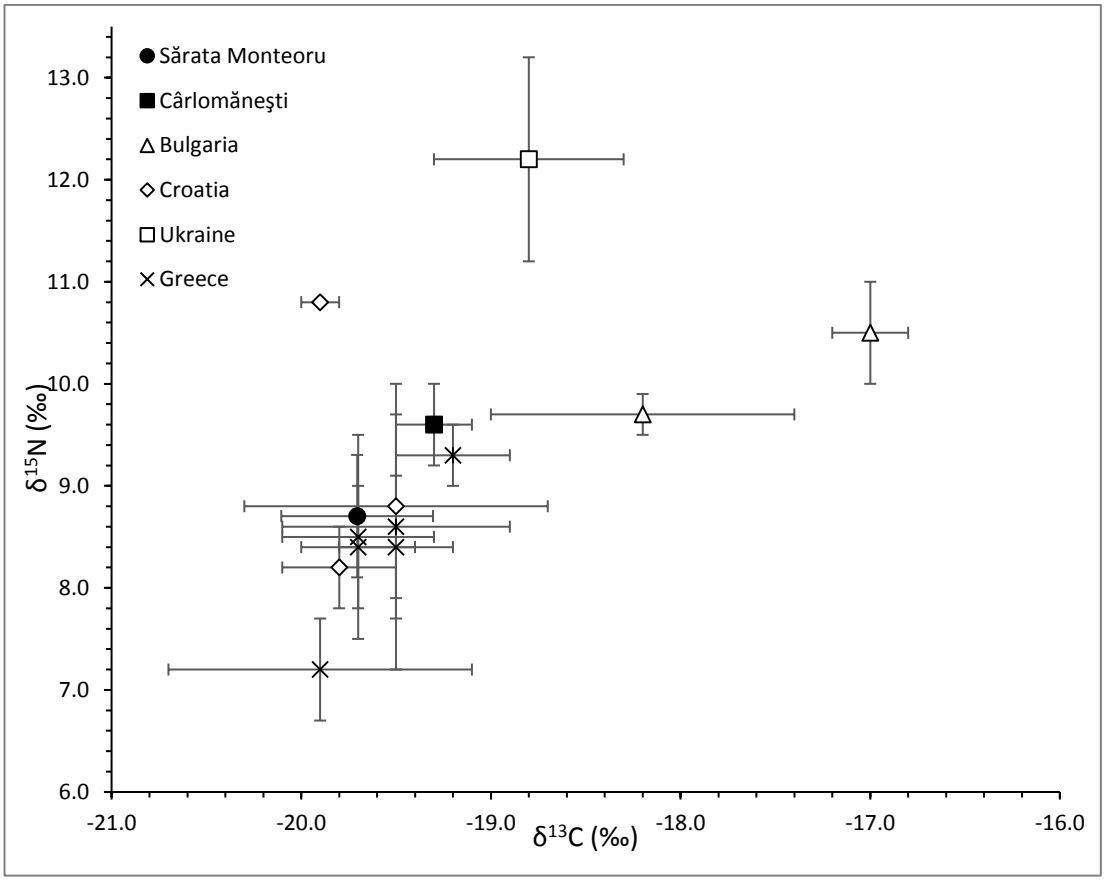


Figure 54. Mean human $\delta^{13}C$ and $\delta^{15}N$ values from Bronze Age sites in Southeast and East Europe (see Chapter 3 and Appendix 1 for references), and Sărata Monteoru and Cârlomăneşti, 1SD marked with error bars

Early Bronze Age sites from Bulgaria (near the Black Sea coast) are geographically closest to Monteoru, reflecting a diet mostly based on C_3 resources, but with influences from C_4 plants (e.g. millet or wild grasses) as well (Gerling 2014). Ukrainian data (from the North Pontic steppes, Early Bronze Age) indicate an emphasis on animal protein (and possibly freshwater fish), although the authors pointed out that aridity may have affected the $\delta^{15}N$ values obtained (Gerling 2014). Both Bulgarian and Ukrainian Early Bronze Age data are quite different from Monteoru sites (although, interestingly, more-so for later-period Sărata Monteoru). This is not surprising considering that the former originate from the grass-steppe region, where the prevailing subsistence economy during the Bronze Age was mobile pastoralism. In addition, considering the more enriched $\delta^{13}C$ values from Bulgaria, this region can be

argued to have been one of the possible origins for the several animals from Cârlomăneşti that displayed high $\delta^{13}C$ values.

Isotope values are also available from sites in coastal and inland Croatia, spanning the duration of the Bronze Age (Lightfoot *et al.* 2012, 2015). Data from coastal sites plot very close to Cârlomăneşti and, especially, Sărata Monteoru. The only isotopic evidence from inland Croatia is distinguished by a relatively high average $\delta^{15}N$ (+10.8‰), which may reflect some aquatic resource consumption due to the close proximity of the site to the Danube (although this value – calculated based on data from two individuals – may not be representative of the whole population). Generally, the Croatian Bronze Age isotope data reflect a predominantly terrestrial, C_3 plant-based subsistence economy, where both the range of crops grown, and the faunal isotope values, are similar to those seen in the Monteoru culture. Some individuals (only humans, none of the fauna) with $\delta^{13}C$ values as high as -17.7‰ were considered to have consumed small amounts of C_4 plants, which led the authors to suggest that millet entered the diet of these communities (although probably was not cultivated and/or consumed in large quantities).

The Greek isotopic data originate from several different studies (Triantaphyllou *et al.* 2008; Petroutsa *et al.* 2009; Petroutsa & Manolis 2010; Vika 2011) and display a close similarity in average $\delta^{13}C$ and $\delta^{15}N$ values to both Monteoru culture sites, especially Sărata Monteoru. The Greek results indicate a mixed farming economy, where domesticated animals and various C_3 grains and legumes constituted the bulk of the diet. Like the Croatian data, $\delta^{13}C$ values of up to -17.8‰ are reported for some humans from Late Bronze Age contexts. The published isotope data again suggest that the local communities had access to millet (as indicated by its presence in archaeobotanical assemblages of the period), but it was only of minor importance to diet.

As in the two Monteoru communities, there seems to have been some inter-site variation in the amount of animal protein consumed, as reflected in the average $\delta^{15}N$ values of Greek sites (ranging between +7.2‰ and +9.3‰). However, $\delta^{15}N$ values from Greek sites display no apparent temporal trend which could be used to argue for

a decline in the importance of animal foods versus plant foods during the Bronze Age. Manuring as a cause of the higher $\delta^{15}N$ values is generally not considered as an important factor in these Greek studies; this seems to be supported by the relatively low $\delta^{15}N$ values (4–6‰) of domesticated animals from these sites.

The lack of a marine isotopic signal from Bronze Age sites located near the Aegean and Adriatic coasts is somewhat surprising. While it can be argued that coastal populations may be under-represented in the archaeological record owing to much of the Bronze Age coastline around the Balkan Peninsula being now submerged (see also Benjamin *et al.* 2011), it is noteworthy that the consumption of aquatic resources seems to have been insignificant also in the Monteoru culture, which was located in an area characterised by numerous small rivers. It seems likely that marine or freshwater fish were consumed by the Bronze Age people of the Balkans, but at levels below isotopic detectability (e.g. to supplement the main dietary intake obtained from domesticated crops and livestock).

In general, the evidence from Sărata Monteoru and Cârlomăneşti fits well among data from nearby regions, although the number of palaeodietary studies on Bronze Age material from temperate regions in the central Balkans is too limited to draw conclusions on possible spatial variations in dietary preferences during this time. However, the Bronze Age in and around the Balkans, with low to moderate human $\delta^{15}N$ values, may have been very broadly characterised by a strong reliance on C_3-based plant foods (e.g. cereals and legumes), low consumption of marine and aquatic resources, and minor contributions of either wild or domesticated (i.e. millet) C_4 plants into human and livestock diets.

The relevance of legumes was evident in estimates generated by FRUITS for the two Monteoru sites, and the importance of these plants in coeval Mediterranean diets has often been suggested as an explanation for relatively low $\delta^{15}N$ values reported for humans. The importance of legumes may explain the observed similarities between average human isotope values obtained from Monteoru and Mediterranean sites. In addition, the Monteoru human isotope values are also very similar to those reported

from a Middle Bronze Age site in northern Italy, for which a significant reliance on plant foods was estimated by the authors (Tafuri *et al.* 2009).

However, it would be incautious to claim that similar human isotope values equal similar diets. Climatic differences between the Mediterranean and the Sub-Carpathians may have influenced baseline isotope values. According to the Köppen–Geiger climate classification (Kottek *et al.* 2006), both regions can be characterised as warm and temperate, but the southern Mediterranean is differentiated by its dry summers, whereas in the northern Balkans the precipitation is more evenly distributed throughout the year. There are also cultural differences that need to be considered. For example, the Mycenaean civilization, dominant in mainland Greece at around the time when Sărata Monteoru cemetery no. 4 was in use, was a very different society compared to the small Monteoru settlements. Applying FRUITS (with similar model parameters as used in this dissertation) to the Mediterranean data may offer a better indication of whether the similarity between the isotope values from the two regions does indeed reflect analogous diets or merely different proportions of food with different isotopic baseline values.

A good example of the differences in isotopic baseline values would be variations in plant $\delta^{15}N$ values due to manuring. As was seen earlier when applying FRUITS to the Monteoru data, manured values led to greater estimated contributions from legumes at the expense of animal protein. However, manuring has not been proposed as an important factor in Greek studies. Most of the claims concerning the practice of manuring in prehistoric Europe have been made based on evidence from Neolithic Germany (e.g. Bogaard *et al.* 2013; Fraser *et al.* 2013; Bogaard 2015; Vaiglova *et al.* 2014). Neolithic humans from Central Europe (e.g. Dürrwächter *et al.* 2006; Nehlich *et al.* 2009; Oelze *et al.* 2011) do seem to have higher average $\delta^{15}N$ values than Neolithic humans from Greece (Papathanasiou 2003).

It should be noted that isotopic data from Neolithic and Bronze Age sites in Greece are very similar, suggesting a degree of continuity in regional subsistence practices. Unfortunately, a similar comparison cannot be made for German sites owing to the

scarcity of published studies on Bronze Age samples from this region. In addition, crop growing conditions were likely quite favourable in the Mediterranean, and there may not have been a need to deliberately increase soil fertility through high-intensity manuring. Although environmentally more similar to Central Europe than the Mediterranean, Monteoru culture sites are known to have been located on chernozem soils, which tend to maintain their fertility naturally, and do not require intensive manuring. However, the presence of fertile soils does not necessarily exclude the possibility that low-intensity manuring occurred incidentally, i.e. by animals grazing near the farmlands or on fallow fields.

There remains the issue of the apparent contradiction between the spread of millet in prehistoric European archaeobotanical assemblages, and its near-invisibility in human isotope values. Its advantages over more 'traditional' crops are obvious – it has a short growing season and tolerates a wide variety of soils and climates; it has even been suggested that millet may have been grown as an emergency crop (Vika 2011; Lightfoot *et al.* 2012; Stika & Heiss 2013). However, even if millet was cultivated by prehistoric farmers in Southeast Europe, it may not have been consumed in large enough quantities (or often enough) to influence $\delta^{13}C$ values on a population level, given that all other dietary staples were likely C_3 plant-based.

It should be noted that almost all other Bronze Age sites covered earlier had at least a few individuals who display $\delta^{13}C$ values below -18‰ (commonly taken as a cut-off point between C_3 and C_4 plant-based diets) – except for the two Monteoru communities. The explanation cannot solely lie in sample selection, since the data set for the current study was significantly larger than for some other sites that produced evidence of human C_4 plant consumption. Rather, one must consider the environmental setting. Millet is highly suitable for warm, arid conditions, and may have been more common in the Mediterranean region, but especially in the Pontic steppes. The steppe region is also more likely to have wild C_4 grasses which means local humans could have obtained the enriched $\delta^{13}C$ values through the consumption of herbivorous animals. Furthermore, given their fertile soils and a temperate climate,

the relatively small Monteoru communities may have produced enough food from the traditional crop package without the need to cultivate millet.

Finally, while remains of broomcorn millet become more frequent among archaeobotanical material in the northern part of the Balkans, including Romania, from the Late Neolithic onwards (Cârciumaru 1996; Monah 2007; Reed 2013), and millet supposedly attains greater prominence in this region during the Bronze Age (Gyulai 1993; Zohary & Hopf 2000; Stika & Heiss 2013), very few archaeobotanical remains have been directly dated. For example, Motuzaite-Matuzeviciute *et al.* (2013) found none of the millet grains attributed to Neolithic sites in this region to be older than ca. 1600 cal BC, with the oldest directly dated sample from Romania (archaeologically associated with a 6th millennium BC Neolithic culture) ascribed to the Late Bronze Age (1434–1268 cal BC). It is thus possible that the importance of millet in Southeast European agriculture in prehistory has been overestimated, and there is indeed no contradiction.

7. Conclusions

Human and faunal osteological material from the sites of Sărata Monteoru and Cârlomăneşti, representing distinct phases of the Middle Bronze Age Monteoru culture, was analysed for $\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$ to provide quantitative information about diet, subsistence practices, and mobility. In addition, multiple skeletal locations were sampled for 27 individuals from Sărata Monteoru to investigate possible changes in diet late in life, and to obtain a better understanding of intraskeletal variation in stable isotope values.

Some isotopic variation between skeletal elements was observed, but generally remained within the 95% confidence range of the measurement error associated with the IRMS procedure. The greatest variations were observed between cortical (e.g. femur shaft) and trabecular (e.g. ribs) bone locations. The maximum difference was 1.4‰ for $\Delta^{13}C$ and 2.1‰ for $\Delta^{15}N$, although it remains unclear whether these intraskeletal variations reflect dietary change during life, or were caused by other factors. Moreover, there was no correlation with either age-at-death or sex.

On an individual level, the majority of the Sărata Monteoru population likely experienced little change in the isotopic composition of their post-childhood diet. Nevertheless, a pattern was documented where intraskeletal $\delta^{13}C$ values showed statistically significantly greater isotopic variation than $\delta^{15}N$ values from the same individual. A further trend in intraskeletal C-isotope values was seen in samples from the femur having lower $\delta^{13}C$ than samples from the rib. No similar pattern was seen in $\delta^{15}N$ values. Several possible interpretations were considered, but without further investigations no convincing explanation can be provided for these results.

Because of the discrepancy in femur–rib C-isotope values, the average $\delta^{13}C$ values for the Sărata Monteoru population, calculated based on rib samples only and femur samples only, were shown to differ statistically (by 0.7‰). While the difference itself was not large, and did not significantly influence conclusions based on either the rib-only or femur-only mean values, the data demonstrate that the choice of sampled

element can potentially affect the outcome of the study. Since the cause(s) of the observed pattern in intraskeletal $\delta^{13}C$ values currently remain unresolved, the present author would recommend always sampling the same type of bone, where possible, to ensure that none of the interindividual or interpopulation variation is influenced by intraskeletal differences.

Published archaeobotanical and archaeozoological reports suggested that the Monteoru people engaged in cattle and caprine husbandry, and cultivated wheat, barley, rye, bitter vetch and pea. This is supported by the range of human bone collagen $\delta^{13}C$ and $\delta^{15}N$ values from Sărata Monteoru and Cârlomăneşti, which indicate a diet that was exclusively or predominantly terrestrial in origin with no detectable input of C_4 or marine resources. However, the mean isotope values for the two sites were statistically significantly different, with the later-period Sărata Monteoru population having, on average, lower $\delta^{13}C$ and $\delta^{15}N$ compared to Cârlomăneşti. These differences are unlikely to have been caused by variations in the baseline isotopic values, and this is supported by the overlapping range of faunal isotope values from the two sites.

The slightly lower average $\delta^{13}C$ and $\delta^{15}N$ values for Sărata Monteoru compared to Cârlomăneşti are consistent with a greater reliance on plant foods and may indicate an increased role for dairy products; the rise in the importance of cattle husbandry during the Carpathian Bronze Age may have increased the amount of milk available for dairy products. It is thus possible that a change in subsistence practices between the Early and Late Monteoru periods as represented by the two sites included in this study may have involved a shift from a more meat-based economy to a more dairy- and plant-based economy.

The greater importance of plant-based foods in later-period Sărata Monteoru was also reflected in estimates produced by the Bayesian mixing model FRUITS. Three food groups (animals, cereals, legumes) were considered in the model. At both sites, plant foods (i.e. cereals and legumes) accounted for most of total calorie intake and also a significant portion of total protein intake, but a greater reliance on animal protein (ca.

10%) was calculated for Cârlomăneşti, whereas at Sărata Monteoru legumes were a more important source of dietary protein.

The possibility that manuring had influenced plant $\delta^{15}N$ values was also considered in the model. Using values for manured plants led the model to predict greater contributions from legumes at the expense of animal products. However, it remains unclear to what extent (if any) manuring affected plant $\delta^{15}N$ values. Estimated protein intake from dietary macronutrients was around 21% for both sites on all scenarios; this value is lower than that reported for hunter-gatherer populations, but higher than in modern Western diets. The results of the mixing model reflect a diet similar to that of a typical peasant farming society in pre-modern Southeast Europe, with a heavy focus on cereals, legumes and fruits, and only modest contributions from dairy products and meat.

Faunal isotope values revealed a much greater intrasite variation for samples from Cârlomăneşti, reflected in the presence of several outliers, which may have been due to the larger number of samples from this site compared to Sărata Monteoru, or due to the Cârlomăneşti samples representing a longer period. There were no statistical differences in mean $\delta^{13}C$ values between species; for $\delta^{15}N$, dogs had predictably higher values than herbivores (and similar to those of humans), reflecting their more carnivorous diet. In addition, slight variation in $\delta^{15}N$ values of domesticated herbivores may have resulted from the inclusion of young (i.e. suckling) animals, although the possible influence of consumption of manured plants cannot be excluded.

Based on their $\delta^{13}C$ values, most livestock likely grazed in a similar environment. A few animals (including two caprines and one pig) displayed evidence of feeding on C_4 resources (or, less likely, marine resources), suggesting they were herded away from the settlements. This hints at the kind of opportunistic herd movement between seasonal pastures practised in the Romanian Carpathians even today. Alternatively, the outliers may represent non-local fauna that reached Monteoru settlements through other activities, such as trade or gift exchange. This argument is supported by

archaeological evidence (i.e. foreign goods) of extensive trade contacts of the Monteoru people.

Regarding human isotope ratio differences between groups, there were no discrepancies in mean $\delta^{13}C$ and $\delta^{15}N$ values between males and females, or between individuals buried with varying amounts of grave goods. The only differences appeared among age groups: at Sărata Monteoru, infants and adults had on average higher $\delta^{15}N$ values compared to juvenile and adolescent individuals (the Cârlomăneşti data set contained too few individuals to warrant statistical comparisons). Low $\delta^{15}N$ values of juvenile and adolescent bone collagen are a common trend seen in isotopic dietary studies, usually associated with either low-protein and/or low-trophic level foods consumed during childhood, or with physiological changes related to growth.

Diet during the first decade of life was reconstructed using a combination of data from juvenile bone collagen and incrementally sectioned dentine from permanent first molars of adults. While this approach has been used by previous authors to demonstrate differing dietary and weaning practices between those who died during childhood and those who survived into adulthood, no such pattern emerged from the current data set. Furthermore, there is no evidence that the weaning signal from bone collagen lags significantly behind dentine in reflecting the adoption of non-breastmilk foods, confirming the expectation that bone turnover rate during infancy is very high.

Infant breastfeeding, as reflected in elevated $\delta^{15}N$ values, was practised on average up to the age of 2 years, although the duration showed considerable variation between subjects, possibly due to individual preferences and circumstances. Weaning was likely initiated well before the visible decline in isotope values occurred, especially if low-protein, low-trophic level foods (e.g. gruel) were used. The latter is also supported by the presence of pathological conditions on the skeleton and teeth associated with nutritional and physiological stress which coincide with the approximate age of weaning. While metabolic stress can influence the body's nitrogen balance, a strong correlation between $\delta^{13}C$ and $\delta^{15}N$ values suggests that breastfeeding – and not

physiological factors – was the main cause of the observed high isotope values of infants.

The present study has also provided the first $\delta^{34}S$ data for the Romanian Bronze Age. The relatively narrow range of $\delta^{34}S$ values from Sărata Monteoru humans suggests that the diet of the majority of the population was relatively homogeneous in its isotopic composition and local in origin. However, the presence of two individuals (both adult females) with noticeably different S-isotope values may reflect movement of people between areas with different baseline $\delta^{34}S$ values, perhaps as a result of exogamous practices or economic activities. Furthermore, Sărata Monteoru humans had $\delta^{34}S$ values comparable to terrestrial animals from the Iron Gates region, supporting the interpretation that the observed S-isotope data reflect a terrestrial diet. This is also in agreement with the range of human $\delta^{13}C$ and $\delta^{15}N$ values from this site.

The $\delta^{13}C$ and $\delta^{15}N$ data from the Sub-Carpathians are comparable to those from contemporaneous sites in coastal and inland Greece and Croatia, although they display some differences from the steppe region to the east of the Monteoru culture area. The Bronze Age across the Balkans may have been very broadly characterised by a strong reliance on C_3-based plant foods (e.g. cereals and legumes), low consumption of marine and aquatic resources, and minor contributions of either wild or domesticated (i.e. millet) C_4 plants to human and livestock diets.

Although millet was probably known to Bronze Age farmers in Southeast Europe, and was consumed in varying amounts (either directly or indirectly), there is no evidence for it among the Monteoru human isotope data. On the one hand, millet may not have been consumed in large enough quantities (or often enough) to influence $\delta^{13}C$ values on a population level, given that all other dietary staples were likely C_3 plant-based. Alternatively, considering their fertile soils and a temperate climate, the relatively small Monteoru communities may have produced enough food from the traditional crop package without the need to cultivate millet.

To summarize, as the first major stable isotope study conducted on osteological material from the Romanian Sub-Carpathians, this thesis has provided new insights into the lives of these communities, expanded our knowledge of Bronze Age subsistence strategies in Southeast Europe, and has established a foundation for further isotopic investigations in the region. It has also contributed to existing knowledge on how carbon and nitrogen are incorporated into bone collagen of various skeletal elements, in addition to demonstrating that the choice of sampled element can potentially affect the outcomes of the study.

Still, the intraskeletal sampling strategy devised for this thesis has some weaknesses, as revealed by the isotope results. For example, since infants undergo an isotopically well-documented dietary change during weaning, it was assumed that this would be reflected in the isotope values of skeletal elements with differing turnover rates, i.e. trabecular bone samples mirroring the change at a faster rate than cortical bone samples. However, this was not observed in the present data set, and can be taken to indicate that during infancy the differences between turnover rates of cortical and trabecular bone are not substantial enough to result in significant intraskeletal isotopic variation. An alternative approach that would include the sampling of specific areas of active bone growth *vs* slower growth may produce better intraskeletal evidence of the isotopic change caused by breastfeeding.

In addition, the unforeseen outcome that $\delta^{13}C$ values (but not $\delta^{15}N$) in cortical bone samples are consistently lower than in trabecular bone highlights the need for a systematic sampling of femur and rib bones from archaeological contexts to determine whether the trend seen here only applies to Sărata Monteoru, or occurs more widely. In retrospect, both cortical (e.g. femur) and trabecular (e.g. rib) bone samples could have been analysed from *all* individuals included in the present study, instead of focusing on a smaller group of well-preserved burials that had multiple skeletal locations available for sampling (e.g. femur, rib, vertebra, skull, etc.).

The relatively recent utilization of human dentine increment analysis was shown to be a very effective method for studying childhood diet. As the present study demonstrated

that there were no significant differences between the weaning curves produced by bone and dentine isotope ratios, this approach would be invaluable when no juvenile burials are available for analysis. Additional dentine analyses from human dental material from Sărata Monteoru could demonstrate whether the notable variation in the shape of the weaning curve seen among the four individuals sampled here is characteristic of the wider population.

Although not undertaken in the present study, incremental sampling of dentine from deciduous teeth of individuals who died during childhood (including those with visible skeletal pathologies related to nutritional stress) would provide greater insight into whether weaning practices were influenced by the health of the child. Furthermore, since most of the dentine increments provided sufficient collagen for isotope measurements, thinner sections could be sampled in future studies of Sărata Monteoru dental material. This would also reduce the age range represented by each increment, thereby increasing the overall time resolution.

Despite the wealth of new information obtained from this study concerning the dietary practices of the Bronze Age Monteoru culture, more research is necessary to resolve the issues that have emerged from this dissertation. The next step is to expand the investigation to encompass isotopic and radiocarbon data from other Monteoru culture sites, including more baseline food source data (e.g. from plant remains). Among other research objectives, this would help determine whether the observed shift from a more meat-based economy at early-period Cârlomăneşti to a more dairy- and plant-based economy at later-period Sărata Monteoru is a true temporal trend, or merely reflects intersite dietary preferences.

Additional sulphur isotope analyses from areas in and around the Sub-Carpathians can be used to address the unresolved questions concerning the movement of Monteoru people and fauna, as seen in the presence of the two possible outliers in the human $\delta^{34}S$ data, and in the few animals with $\delta^{13}C$ values outside the 'local' range. Although no faunal $\delta^{34}S$ analyses were conducted as part of this study, it is planned to undertake this work in the near future, using collagen already prepared for this thesis. The new

$\delta^{34}S$ analyses will include samples from animals with deviant $\delta^{13}C$ measurements, and the results will be integrated into publications about the isotopic evidence from the Monteoru culture.

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APPENDIX 1

The complete list of sites and studies included in the current analysis is presented in the table below. The selection was limited to published and well-accessed material (usually from peer-reviewed journals), and the present author acknowledges that some isotopic investigations conducted in the study region may have been regrettably left out, either due to accessibility (e.g. unpublished PhD dissertations and obscure journals) or unawareness (e.g. if isotopic data on a site or region has been published as part of a wider investigation, in compilation books or monographs).

Most entries represent single sites; however, when two or more sites from one study were both geographically and temporally close, the data were pooled in the following conditions: a) the study included several sites but each site only represented a few individuals; b) the average values for the sites were very similar and had low standard deviation. When sites were clearly distinct, they were entered as separate data points, even if that only included one individual. In a few occasions, no raw data or even the average values were given, in which case the average was estimated from published graphs. Whenever possible, repetition of sites was avoided, except when two studies by separate authors produced different results or interpretations for the same material.

All sites were divided into one of five temporal categories. The present author recognises that the time ranges set for the different periods do not take into account regional chronologies and local differences, and that not all sites fitted neatly into one of the five sections (e.g. when a site was dated to a transitional period, or spanned a very wide temporal range). However, in order to keep the analysis as systematic as possible, a best-fit policy was adopted to deal with such a diverse dataset. One of the limitations of this approach is that temporal continuity cannot be directly followed, e.g. a site assigned to the Neolithic and another to the Mesolithic may have been closer in time than two other sites both assigned to the Neolithic. In the end, it must be remembered that this dataset only represents an incredibly small number of sites (and individuals) recorded in Holocene Central and Southeast Europe, and as such, it only offers a glimpse of the dietary habits of the populations in this region.

Appendix 1

$\delta^{13}C$	SD	$\delta^{15}N$	SD	No.	Location	Site	Environmental setting	Date	Period	Publication
Mesolithic-Early Neolithic										
-18.8	0.5	9.7	0.9	n=6	Croatia	2 sites	Coastal (<25km)	ca. 9000–6000 BC	M	Lightfoot *et al.* 2011
-22.5	0.4	12.6	0.5	n=5	Russia (near Moscow)	Zamost	Inland (aquatic)	ca. 8000–4000 BC	M	Iacumin *et al*. 2004
-18.9	0.3	14.8	0.6	n=29	Serbia/Romania	Vlasac	Inland (aquatic)	10 000–6600 cal BC	M	Bonsall *et al.* 1997
-19.6	0.2	15.4	0.4	n=8	Serbia/Romania	Schela Cladovei	Inland (aquatic)	7600–7000 cal BC	M	Bonsall *et al.* 1997
-19.1	0.6	13.6	2.0	n=33	Serbia/Romania	Lepenski Vir	Inland (aquatic)	6600–5600 cal BC	M-EN	Bonsall *et al.* 1997
-19.7	0.2	14.4	0.5	n=4	Serbia/Romania	Padina	Inland (aquatic)	ca. 8700–7800 BC	M	Nehlich *et al.* 2010
-19.2	0.5	15.7	0.7	n=3	Serbia/Romania	Hajdučka Vodenica	Inland (aquatic)	7000–6000 BC	LM	Nehlich *et al.* 2010
-22.4	0.9	10.8	1.8	n=18	Ukraine	7 sites	Inland (aquatic)	6000–4700 cal BC	LM-N	Lillie & Richards 2000
-20.9	0.5	13.4	0.6	n=14	Ukraine	Vasilyevka II	Inland (aquatic)	7300–6000 cal BC	M	Lillie & Jacobs 2006
-20.7	0.4	15.9	1.3	n=2	Ukraine	Oleonostrovski	Inland (aquatic)	ca. 6500 BC	M	Richards *et al.* 2001
Neolithic-Eneolithic										
-20.5	0.2	9.6	0.6	n=13	Austria	Rutzing	Inland (terrestrial)	ca. 5300–4500 BC	N	Bickle *et al.* 2013
-19.8	0.3	9.5	0.5	n=31	Austria	Kleinhadersdorf	Inland (terrestrial)	ca. 5300–4500 BC	N	Bickle *et al.* 2013
-19.6	0.1	9.5	0.4	n=24	Austria	Asparn	Inland (terrestrial)	ca. 5300–4500 BC	N	Bickle *et al.* 2013
-19.3	0.4	10.0	0.6	n=55	Bulgaria	Varna I	Coastal (>5km)	ca. 4500 BC	E	Honch *et al.* 2006
-19.1	0.3	9.3	0.9	n=78	Bulgaria	Durankulak	Coastal (>1km)	ca. 5000–4500 BC	N-E	Honch *et al.* 2006
-20.4	0.1	8.9	0.5	n=9	Bulgaria	Smyadovo	Inland (terrestrial)	4000–3000 BC	E	Gerling 2014[1]
-19.6	0.7	9.4	1.0	n=16	Croatia	8 sites	Coastal (>25km)	ca. 6000–3500 BC	N-E	Lightfoot *et al.* 2011
-20.3	0.5	10.3	1.0	n=20	Croatia	4 sites	Inland (terrestrial/aquatic)	ca. 6000–3500 BC	N-E	Lightfoot *et al.* 2011
-19.8	0.4	9.4	0.4	n=24	Czech Republic	Vedrovice	Inland (terrestrial)	ca. 5300–4500 BC	N	Whittle *et al.* 2013b
-19.4	0.2	9.0	0.4	n=5	Czech Republic	Tešetice-Kyjovice	Inland (terrestrial)	ca. 5300–4500 BC	N	Whittle *et al.* 2013b
-19.7	0.2	10.1	0.3	n=4	Czech Republic	Brno-Stary Liskovec	Inland (terrestrial)	ca. 5300–4500 BC	N	Whittle *et al.* 2013b
-19.8	0.3	8.7	0.7	n=60	Germany	3 sites	Inland (terrestrial)	ca. 5000 BC	N	Oelze *et al.* 2011

M – Mesolithic; LM – Late Mesolithic; N – Neolithic; EN – Early Neolithic; E – Eneolithic

Appendix 1. Continued

$\delta^{13}C$	SD	$\delta^{15}N$	SD	No.	Location	Site	Setting	Date	Period	Publication
Neolithic-Eneolithic										
-19.9	0.2	12.6	0.2	n=10	Germany	Ostorf	Inland (aquatic)	3400–2900 cal BC	N	Fernandes *et al.* 2015
-20.1	0.3	9.8	1.0	n=21	Germany	Herxheim	Inland (terrestrial)	5000 cal BC	N	Dürrwächter *et al.* 2006
-19.8	0.3	9.7	0.6	n=40	Germany	Trebur	Inland (terrestrial)	4900–4600 cal BC	N	Dürrwächter *et al.* 2006
-20.7	0.4	9.0	0.7	n=45	Germany	Vaihingen	Inland (terrestrial)	5500–5000 cal BC	N	Fraser *et al.* 2013
-20.3	0.5	10.4	0.5	n=12	Germany	Nieder-Mörlen	Inland (terrestrial)	ca. 5500–5000 BC	N	Nehlich *et al.* 2009
-20.4	0.3	9.8	0.4	n=48	Germany	Aiterhofen	Inland (terrestrial)	ca. 5300–4500 BC	N	Hofmann *et al.* 2013
-20.1	0.3	8.5	0.3	n=5	Germany	Otzing	Inland (terrestrial)	ca. 5300–4500 BC	N	Hofmann *et al.* 2013
-20.1	0.2	8.9	0.5	n=100	Germany	Schwetzingen	Inland (terrestrial)	ca. 5300–4500 BC	N	Bentley *et al.* 2013
-19.9	0.4	7.2	1.0	n=26	Greece	Alepotrypa cave	Coastal (>1km)	5000–3200 BC	N	Papathanasiou 2003
-19.9	0.2	8.0	0.7	n=20	Greece	Tharrounia	Inland (terrestrial)	5000–3200 BC	N	Papathanasiou 2003
-19.8	0.8	7.4	1.0	n=13	Greece	Theopetra	Inland (terrestrial)	5000–3200 BC	N	Papathanasiou 2003
-19.8	0.0	8.1	0.2	n=2	Greece	Kouveleiki	Inland (terrestrial)	5000–3200 BC	N	Papathanasiou 2003
-19.0	1.0	9.2	1.8	n=14	Greece	Franchthi	Coastal (>1km)	5000–3200 BC	N	Papathanasiou 2003
-19.1	1.1	9.2	0.9	n=5	Greece	Kephala	Coastal (>1km)	5000–3200 BC	N	Papathanasiou 2003
-20.0	n/a	10.5	n/a	n=97	Hungary	9 sites on the Great Hungarian Plain	Inland (terrestrial)	ca. 4500 BC	LN-E	Hoekman-Sites & Giblin 2012[2]
-19.8	0.3	10.3	0.6	n=44	Hungary	Balatonszarszo	Inland (aquatic)	ca. 5300–4500 BC	N	Whittle *et al.* 2013a
-20	0.2	10.4	0.4	n=7	Hungary	Füzesabony-Gubakut	Inland (terrestrial)	ca. 5300–4500 BC	N	Whittle *et al.* 2013a
-19.7	0.0	10.6	0.6	n=4	Hungary	Mezokövesd-Mocsolyas	Inland (terrestrial)	ca. 5300–4500 BC	N	Whittle *et al.* 2013a
-20.0	0.3	10.3	0.6	n=33	Hungary	Polgar-Ferenci-hat	Inland (terrestrial)	ca. 5300–4500 BC	N	Whittle *et al.* 2013a
-21.9	1.2	12.7	0.6	n=3	Poland	Zabie	Inland (aquatic)	3000–2500 BC	N	Pospieszny 2015
-20.3	n/a	9.9	n/a	n=1	Poland	Kowal	Inland (terrestrial)	2800–2500 cal BC	N	Kozlowski *et al.* 2014
-17.5	0.7	13.7	1.0	n=13	Russia (Caucasus)	4 Maikop culture sites, dry region	Inland (terrestrial)	4000–3000 BC	E-EB	Hollund *et al.* 2010

N – Neolithic; LN – Late Neolithic; E – Eneolithic; EB – Early Bronze Age

Appendix 1. Continued

$\delta^{13}C$	SD	$\delta^{15}N$	SD	No.	Location	Site	Setting	Date	Period	Publication
Neolithic-Eneolithic										
-19.3	0.4	11.2	1.1	n=38	Russia (Caucasus)	11 Maikop culture sites, forested region	Inland (terrestrial)	4000–3000 BC	E-EB	Hollund *et al.* 2010
-22.7	0.0	11.8	0.4	n=2	Russia (near Moscow)	Spas-Klepiki	Inland (terrestrial)	ca. 3000 BC	N	Iacumin *et al.* 2004
-19.5	n/a	10.5	n/a	n=1	Serbia/Romania	Lepenski Vir	Inland (aquatic)	4200–3900 cal BC	E	Bonsall *et al.* 2004
-20.7	0.2	11.5	0.8	n=5	Serbia/Romania	Vinča-Belo Brdo	Inland (aquatic)	5500–5400 BC	EN	Nehlich *et al.* 2010
-20.2	0.3	10.2	0.4	n=41	Slovakia	Nitra	Inland (terrestrial)	ca. 5300–4500 BC	N	Whittle *et al.* 2013b
-21.0	0.7	7.5	1.4	n=12	Slovenia	Ajdovska Cave	Inland (terrestrial)	4400–4000 cal BC	N	Ogrinc & Budja 2005[3]
-20.5	0.2	8.7	0.6	n=10	Slovenia	Ajdovska Cave	Inland (terrestrial)	4400–4000 cal BC	N	Bonsall *et al.* 2007[3]
-23.4	0.5	12.8	1.2	n=7	Ukraine	Dereivka	Inland (aquatic)	5300–4750 cal BC	N	Lillie *et al.* 2011
-22.4	0.3	14.2	0.3	n=8	Ukraine	Yasinovatka	Inland (aquatic)	5550–4460 cal BC	N	Lillie *et al.* 2011
-23.1	0.3	13.2	0.7	n=7	Ukraine	Nikolskoye	Inland (aquatic)	5400–4800 cal BC	N	Lillie *et al.* 2011
-21.9	0.8	12.1	0.6	n=5	Ukraine	Molukhov Bugor	Inland (aquatic)	3951–3640 cal BC	E	Lillie *et al.* 2011
-23.4	0.3	11.6	0.3	n=2	Ukraine	Dereivka	Inland (aquatic)	ca. 6000–5000 BC	N	Richards *et al.* 2001
Bronze Age										
-17.0	0.2	10.5	0.5	n=5	Bulgaria	Boyanovo	Inland (terrestrial)	3000–2000 BC	EB	Gerling 2014[1]
-18.2	0.8	9.7	0.2	n=3	Bulgaria	Benkovski	Inland (terrestrial)	3000–2000 BC	EB	Gerling 2014[1]
-19.8	0.4	8.2	0.3	n=3	Croatia	Gumanca Vela Luka	Coastal (>5km)	1500–600 BC	B-I	Lightfoot *et al.* 2012
-19.5	0.8	8.8	0.9	n=45	Croatia	9 sites	Coastal (>10km)	2000–1000 BC	B	Lightfoot *et al.* 2015
-19.9	0.1	10.8	0.0	n=2	Croatia	Ilok Dvor Knezova Iločkih	Inland (aquatic)	2200–1600 BC	EB	Lightfoot *et al.* 2015
-19.9	0.8	7.2	0.5	n=70	Greece	Aghia Triada	Inland (terrestrial)	1600–1100 BC	LB	Petroutsa & Manolis 2010
-19.2	0.3	9.3	0.3	n=34	Greece	Almyri	Coastal (>5km)	1600–1100 BC	LB	Petroutsa & Manolis 2010
-19.7	0.3	8.4	0.6	n=20	Greece	Zeli	Inland (terrestrial)	1600–1100 BC	LB	Petroutsa & Manolis 2010
-19.7	0.4	8.5	1.0	n=14	Greece	Kalapodi	Inland (terrestrial)	1600–1100 BC	LB	Petroutsa & Manolis 2010
-20.1	0.2	8.3	0.7	n=24	Greece	Voudeni	Coastal (>10km)	1600–1100 BC	LB	Petroutsa *et al.* 2009

N – Neolithic; EN – Early Neolithic; E – Eneolithic; B – Bronze Age; EB – Early Bronze Age; LB – Late Bronze Age; I – Iron Age

Appendix 1. Continued

$\delta^{13}C$	SD	$\delta^{15}N$	SD	No.	Location	Site	Setting	Date	Period	Publication
Bronze Age										
-17.6	n/a	8.6	n/a	n/a	Greece	Rhymnio	n/a	1600–1100 BC	LB	Triantaphyllou 2001
-18.6	n/a	7.4	n/a	n/a	Greece	Spathes	Inland (terrestrial)	1600–1100 BC	LB	Triantaphyllou 2001
-19.2	n/a	8.7	n/a	n/a	Greece	Korinos	Coastal (>5km)	1600–1100 BC	LB	Triantaphyllou 2001
-19.5	0.3	8.4	0.7	n=39	Greece	Lerna	Coastal (>5km)	2100–1700 BC	MB	Triantaphyllou *et al.* 2008
-19.5	0.6	8.6	1.4	n=12	Greece	Thebes	Coastal (>20km)	ca. 3000–1000 BC	B	Vika 2011
-20.5	n/a	11.5	n/a	n=50	Poland	10 Unetice culture sites	Inland (terrestrial)	2100–1600 BC	EB	Pokutta & Howcroft 2013[2]
-17.4	1.2	14.6	2.2	n=8	Russia (steppe)	Abganerovo	Inland (terrestrial)	ca. 3000–1100 BC	LN-B	Iacumin *et al.* 2004
-16.3	3.8	14.0	0.7	n=3	Russia (steppe)	Ipatovo	Inland (terrestrial)	ca. 3000–1 BC	LN-B	Iacumin *et al.* 2004
-18.2	0.7	14.1	1.5	n=5	Russia (steppe)	Steppe Majkop culture sites	Inland (terrestrial)	3800–3000 cal BC	B	Shishlina *et al.* 2009
-17.5	1.1	14.7	2.0	n=11	Russia (steppe)	Yamnaya culture sites	Inland (terrestrial)	3000–2450 cal BC	B	Shishlina *et al.* 2009
-18.1	0.3	14.2	1.9	n=2	Russia (steppe)	Steppe North Caucasus culture sites	Inland (terrestrial)	2500–2300 BC	B	Shishlina *et al.* 2009
-17.3	0.9	15.2	2.0	n=17	Russia (steppe)	Eastern Manych Catacomb culture sites	Inland (terrestrial)	2500–2000 cal BC	B	Shishlina *et al.* 2009
-17.6	0.6	14.7	1.3	n=3	Russia (steppe)	Lola culture sites	Inland (terrestrial)	ca. 2000 cal BC	B	Shishlina *et al.* 2009
-17.7	1.2	15.2	1.8	n=34	Russia (steppe)	Catacomb culture sites	Inland (terrestrial)	ca. 2900–2000 cal BC	B	Shishlina *et al.* 2007
-18.8	0.5	12.2	1.0	n=26	Ukraine	4 sites	Inland (terrestrial)	4000–2000 BC	E-B	Gerling 2014[1]
Iron Age										
-18.6	1.3	8.9	0.7	n=16	Austria	9 Hallstatt culture sites	Inland (terrestrial)	ca. 700–500 BC	EI	Le Huray & Schutkowski 2005
-18.5	0.5	10.1	1.1	n=54	Bulgaria	Apollonia	Coastal (>5km)	400–100 BC	C	Keenleyside *et al.* 2006

LN – Late Neoltihic; E – Eneolithic; B – Bronze Age; EB – Early Bronze Age; MB – Middle Bronze Age; LB – Late Bronze Age; EI – Early Iron Age; C – Classical Greek

Appendix 1. Continued

$\delta^{13}C$	SD	$\delta^{15}N$	SD	No.	Location	Site	Setting	Date	Period	Publication
Iron Age										
-18.8	0.7	9.7	0.7	n=38	Croatia	Nadin-Gradine	Coastal (>20km)	1100–200 BC	LB-I	Lightfoot *et al.* 2012
-19.0	1.1	8.5	0.5	n=13	Croatia	Dragisic	Coastal (>10km)	600–1 BC	I	Lightfoot *et al.* 2012
-19.3	0.4	9.4	0.7	n=6	Croatia	Zadar-Relje	Coastal (>10km)	700–600 BC	I	Lightfoot *et al.* 2012
-17.7	1.4	9.3	0.9	n=9	Croatia	Vinkovci-Nama	Inland (terrestrial)	ca. 1000 BC	EI	Lightfoot *et al.* 2015
-18.9	0.5	9.8	0.6	n=87	Czech Republic	3 La Tène culture sites	Inland (terrestrial)	ca. 450–100 BC	LI	Le Huray & Schutkowski 2005
-19.7	0.4	9.6	0.8	n=50	Germany	Magdalenenberg	Inland (terrestrial)	600 BC	I	Oelze *et al.* 2012b
-19.7	0.4	8.3	0.9	n=13	Greece	Agios Dimitrios	Coastal (>5km)	800–700 BC	I	Papathanasiou *et al.* 2013
-19.2	0.5	10.0	1.0	n=74	Greece	Thebes	Coastal (>25km)	500–30 BC	C-H	Vika 2011
-15.5	0.7	12.1	1.3	n=4	Russia (near the Black Sea)	Novorossiisk	Coastal (>5km)	ca. 500 BC–500 AD	I	Iacumin *et al.* 2004
-17.7	1.5	12.9	1.2	n=3	Russia (steppe)	Abganerovo	Inland (terrestrial)	ca. 350 BC–250 AD	I	Iacumin *et al.* 2004
Roman and Medieval										
-18.8	0.4	10.1	0.8	n=76	Croatia	3 sites	Coastal (>10km)	200–600 AD	R-LA	Lightfoot *et al.* 2012
-17.9	0.6	9.6	0.6	n=260	Croatia	4 sites	Coastal (>25km)	600–1000 AD	EMed	Lightfoot *et al.* 2012
-17.8	0.6	10.0	1.0	n=24	Czech Republic	Kostelisko	Inland (terrestrial)	ca. 800–900 AD	Med	Halffman & Veleminsky 2015
-18.7	0.3	8.7	0.6	n=15	Greece	Servia	Inland (terrestrial)	1000–1400 AD	Byz	Bourbou *et al.* 2011
-19.2	0.3	9.5	0.7	n=12	Greece (Crete)	Petras	Coastal (>1km)	1100–1200 AD	Byz	Bourbou *et al.* 2011
-19	0.3	8.7	0.5	n=11	Greece	Nemea	Inland (terrestrial)	1100–1200 AD	Byz	Bourbou *et al.* 2011
-18.9	0.6	8.2	1.4	n=27	Greece (Crete)	Eleutherna	Coastal (>10km)	500–600 AD	Byz	Bourbou *et al.* 2011
-19.2	0.3	8.7	0.6	n=21	Greece	Messene	Inland (terrestrial)	500–600 AD	Byz	Bourbou *et al.* 2011
-18.2	0.3	9.5	0.3	n=27	Greece	Sourtara	Inland (terrestrial)	500–600 AD	Byz	Bourbou *et al.* 2011
-18.8	0.4	9.2	1.1	n=26	Greece (Crete)	Kastella	Coastal (>1km)	1000 AD	Byz	Bourbou & Richards 2007
-18.8	0.7	9.4	1.7	n=10	Greece (Crete)	Stylos	Coastal (>5km)	1000–1200 AD	Byz	Bourbou *et al.* 2011
-17.9	0.7	9.7	0.5	n=30	Poland	Rogowo	Inland (terrestrial)	100–200 AD	R	Reitsema & Kozlowski 2013

LB – Late Bronze Age; I – Iron Age; EI – Early Iron Age; LI – Late Iron Age; C – Classical Greek; H – Hellenistic Greek; R – Roman; LA – Late Antique; Byz – Byzantine; Med – Medieval; EMed – Early Medieval

Appendix 1. Continued

$\delta^{13}C$	SD	$\delta^{15}N$	SD	No.	Location	Site	Setting	Date	Period	Publication
Roman and Medieval										
-17.0	0.8	11.6	1.2	n=3	Russia (steppe)	Abganerovo	Inland (terrestrial)	ca. 1200–1300 AD	Med	Iacumin *et al.* 2004
-18.5	n/a	9.6	n/a	n=4	Serbia/Romania	Lepenski Vir	Inland (aquatic)	ca. 300–1500 cal AD	R/Med	Bonsall *et al.* 2004[2]
Eurasian Bronze Age										
-18.9	0.2	10.7	0.5	n=8	Georgia	Chobareti	Inland (terrestrial)	3000 BC	EB	Messager *et al.* 2015
-20.9	0.2	11.6	0.2	n=3	Great Britain (England)	Yarnton	Inland (terrestrial)	4000–750 BC	N-B	Lightfoot *et al.* 2009
-20.3	0.4	11.4	1.2	n=6	Great Britain (England)	Eton Rowing Lake	Inland (terrestrial)	ca. 2500–750 BC	B	Stevens *et al.* 2012
-19.8	n/a	10.0	n/a	n=1	Great Britain (Scotland)	Galson	Coastal (>1km)	ca. 1500 BC	B	Richards *et al.* 2011
-15.2	0.8	9.4	0.8	n=19	Italy	Olmo di Nogara	Inland (terrestrial)	ca. 1600–1100 BC	MB/LB	Tafuri *et al.* 2009
-17.7	0.1	8.3	0.2	n=2	Italy	Sedegliano	Inland (terrestrial)	ca. 2000–1600 BC	EB	Tafuri *et al*. 2009
-19.6	0.2	8.2	0.5	n=14	Italy	Toppo Daguzzo	Inland (terrestrial)	ca. 1600–1100 BC	MB	Tafuri *et al.* 2009
-19.5	0.1	8.5	0.5	n=4	Italy	Lavello	Inland (terrestrial)	ca. 1600–1100 BC	MB	Tafuri *et al.* 2009
-18.8	0.3	8.8	0.7	n=15	Jordan	Ya'amūn	Inland (terrestrial)	3600–1400 cal BC	MB-LB	Sandias & Müldner 2015
-19	0.5	11.8	1.0	n=21	Kazakhstan	Bestamak	Inland (terrestrial)	2032–1640 cal BC	MB	Miller *et al.* 2014
-18.9	0.5	11.1	2.2	n=34	Kazakhstan	Lisakovsk	Inland (terrestrial)	1800–1600 cal BC	LB	Miller *et al.* 2014
-17.8	0.2	10.7	0.6	n=2	Lithuania	2 sites	Inland (terrestrial)	ca. 1100–800 BC	LB	Antanaitis & Ogrinc 2000
-19.6	0.0	9.4	0.3	n=3	Portugal	Bolores	Coastal (>10km)	ca. 2800–1800 cal BC	LN-EB	Lillios *et al.* 2010[1]
-18.7	0.4	11.6	0.6	n=83	Russia (Southern Siberia)	Okunevo	Inland (terrestrial)	2400–1800 BC	EB	Svyatko *et al.* 2013
-19.2	0.5	11.2	0.6	n=22	Russia (Southern Siberia)	Andronovo	Inland (terrestrial)	1800–1400 BC	B	Svyatko *et al.* 2013
-16.4	1.3	11.4	0.5	n=33	Russia (Southern Siberia)	Karasuk	Inland (terrestrial)	1400–800 BC	LB	Svyatko *et al.* 2013

LN – Late Neolithic; N – Neolithic; B – Bronze Age; EB – Early Bronze Age; MB – Middle Bronze Age; LB – Late Bronze Age; R – Roman; Med – Medieval

Appendix 1. Continued

$\delta^{13}C$	SD	$\delta^{15}N$	SD	No.	Location	Site	Setting	Date	Period	Publication
Eurasian Bronze Age										
-19.9	0.2	9.4	0.3	n=13	Spain	Cova de Santo Cave	Inland (terrestrial)	1890–1600 cal BC	MB	Lopez-Costas *et al.* 2015
-20	0.4	9.9	0.5	n=10	Sweden (Öland)	Resmo	Coastal (>5km)	1800–1100 BC	EB	Eriksson *et al.* 2008
-20.1	0.4	9.4	0.9	n=14	Sweden (Öland)	Torsborg	Coastal (>5km)	2300–1100 BC	LN-EB	Eriksson *et al.* 2008
-20	0.3	9.8	0.6	n=6	Sweden (Öland)	Algustrum	Coastal (>5km)	1800–500 BC	B	Eriksson *et al.* 2008

LN – Late Neolithic; B – Bronze Age; EB – Early Bronze Age; MB – Middle Bronze Age

[1] – Average values and SD estimated from published graphs

[2] – Average values estimated from published graphs

[3] – Same site, partly the same material

APPENDIX 2

Descriptions of human burials from **Sărata Monteoru cemetery no. 4** sampled for stable isotope analysis:

1. Burial no. 12

Description: Juvenile (9–11 years), sex indeterminate. Buried in a crouched position. Orientated N–S, head to the south. Depth 0.85m. Skeleton had slipped on the slope of the hill and was badly preserved.

Pathological conditions and skeletal changes: None detected

Grave goods: Two ceramic vessels located near the chin and a fragment of an undecorated bronze ring.

2. Burial no. 13

Description: Young adult, female. Buried in a crouched position, hands located near the mouth. Orientated E–W, head to the west. Depth 0.98m.

Pathological conditions and skeletal changes: Caries on upper left first molar. Tibial and fibular diaphyses showed mild bilateral periostitic reactions (inflammation of the periosteum).

Grave goods: None

3. Burial no. 24

Description: Juvenile (1.5–2 years), sex indeterminate. Buried in a crouched position, hands near the mouth. Orientated E–W, head to the west. Depth 1m. The box containing the remains of burial no. 24 held fragments from two different mandibles, similar in size. Due to the similar size and the relatively incomplete nature of the remains, it is difficult to ascertain with confidence which mandibular fragments belong to the rest of the skeleton.

Pathological conditions and skeletal changes: The medial surface of the right mandibular ramus displays discoloration and abnormal porosity often associated with nutritional deficiencies (Fig. 1, Appendix 3). There is also a periostitic reaction on the lateral surface of the same bone fragment (Fig. 2). The other mandibular or cranial fragments do not show any pathological changes. Besides a mild bilateral periostitic reaction on tibial diaphyses (Fig. 3) there are no other signs of metabolic stress on the bones. It is therefore likely that the pathological mandibular fragment does not belong with the rest of the remains.

Grave goods: None

4. Burial no. 35a

Description: Adolescent (17–19 years), female. Double burial of a woman (identified as 35a) and a child (35b) 1.5–2 years old. The adolescent (35a) was buried in a crouched position, arms close to the body and bent at the elbow, hands near the face with palms under the head. Orientated E–W, head to the west. Depth 1.75m.

Pathological conditions and skeletal changes: None detected

Grave goods: The burial had a rich funerary inventory; in fact, Bârzu (1989:44) referred to it as one of the richest graves in the whole cemetery. Four ceramic vessels were placed in the grave: two near the chest, a third near the skull, a fourth near the feet. This is also the highest number of ceramic vessels in one grave from Sărata-Monteoru Cemetery no. 4. The grave also contained thirteen beads (2 of bronze, 9 of bluish glass paste and 2 of amber), two loop rings (one of gold, the other of bronze) and a bronze spiral.

5. Burial no. 35b

Description: Juvenile (1.5–2 years), sex indeterminate. Double burial of an adolescent female (identified as 35a) and a child (35b). The child was buried in a crouched position, arms folded at the elbow, lying face to face with the woman. Orientated E–W, head to the west. Depth 1.75m. Skeleton was poorly preserved.

Pathological conditions and skeletal changes: None detected

Grave goods: See burial no. 35a

6. Burial no. 40

Description: Adolescent (17–18 years), female. Buried in a crouched position, arms folded at the elbow, palms near the mouth. Orientated W–E, head to the west. Depth 1.75m.

Pathological conditions and skeletal changes: Slight amount of calculus was present on the majority of teeth. Enamel hypoplasia was evident on upper and lower canines and premolars. It was expressed by at least two stress lines on the lower half of the crown, which would have formed between 2–4 (for canines) and 5–7 (for premolars) years of age. Squatting facet on the neck of the talus suggests habitual squatting. Microporosity and slight discoloration was observable on the left medial surface of the mandibular ramus (Fig. 4). Similar microporosity was present on the right side, although the area was more difficult to observe due to breakage and green staining. Microporosity on the medial surface of the mandibular ramus can be associated with nutritional stress. However, except for a mild periostitic reaction on the right femoral and right fibular shafts, no other pathologies were detected that could be indicative of nutritional stress.

Grave goods: Two bronze spiral rings, three fragments of bronze wire and a bronze tube. Green staining on the right medial and lateral surface of the mandibular ramus indicates the earlier presence of a copper or bronze item in the vicinity of either the neck or the right ear.

7. Burial no. 41

Description: Juvenile (7–9 years), sex indeterminate. Buried in a crouched position, arms bent at the elbow, hands near the face. Orientated W–E, head to the west. Depth 1.98m. The edge of the grave pit closest to the slope was lined with a row of eight small stones.

Pathological conditions and skeletal changes: None detected

Grave goods: None

8. Burial no. 46

Description: Adolescent (16–18 years), sex indeterminate. Buried in a crouched position, arms bent at the elbow and hands near the mouth. Orientated E–W, head to the west. Depth unspecified.

Pathological conditions and skeletal changes: Moderate amount of calculus present on majority of teeth. Enthesopathy involving the left proximal humerus (Fig. 5) at the insertion of the *pectoralis major* and *teres major* muscles, suggesting intensive physical activity of the left upper arm.

Grave goods: No information available

9. Burial no. 48

Description: Fully/Mature adult, sex indeterminate. Buried in a crouched position, arms bent at the elbow and hands near the face. Orientated E–W, head to the west. Depth unspecified. Skeleton was incompletely preserved.

Pathological conditions and skeletal changes: None detected

Grave goods: Ring with superimposed ends made of bronze wire.

10. Burial no. 50

Description: Juvenile (1–3 years), sex indeterminate. Information concerning the body position and depth is lacking due to the poor preservation of the remains.

Pathological conditions and skeletal changes: A mild periostiteal reaction is evident on the left humeral and tibial diaphyses (right side missing).

Grave goods: Small decorated ceramic vessel.

11. Burial no. 53

Description: Young adult, female. Buried in a crouched position, arms bent at the elbow and hands near the face. Orientated E–W, head to ENE. Depth 1.58m. Skeleton was incompletely preserved.

Pathological conditions and skeletal changes: Mild bilateral periostitic reaction (vertical striations) on femoral and tibial shafts.

Grave goods: None

12. Burial no. 54a

Description: Fully/Mature adult, female. Part of a double burial of a woman (identified as 54a) and a child (54b) 1–2 years old, although only the adult was sampled. The woman (54a) was buried in a crouched position, arms bent at the elbow, hands near the face. The child (54b) was crouched in front of the woman, head in the opposite direction. Orientated E–W, head to the east. Depth 1.62m. Both remains were incompletely preserved. A pair of femurs and a mandible belonging to a child of about 9–15 months old was also identified among the remains by the present author, but not mentioned by Bârzu (1989).

Pathological conditions and skeletal changes: Degenerative changes on the margins of tarsal bones (bony ridges on tali and calcanei) of the adult.

Grave goods: None

13. Burial no. 61

Description: Adolescent (17–19 years), female. Buried in a crouched position, arms bent at the elbow, hands near the face. A large stone was deposited over the feet. Orientated E–W, head to the east. Depth 1.58m.

Pathological conditions and skeletal changes: Mild bilateral periostitic reaction (vertical striations) on femoral and tibial shafts.

Grave goods: None

14. Burial no. 62

Description: Fully adult, male. Buried in a crouched position, arms bent at the elbow, hands near the face. Orientated W–E, head to ENE. Depth 1.55m. Skeleton was incompletely preserved. The box containing the remains of burial no. 62 also held skull fragments and teeth belonging to a child of ca. 6 years old, not mentioned by Bârzu (1989).

Pathological conditions and skeletal changes: None detected

Grave goods: None

15. Burial no. 63

Description: Adolescent (19–21 years), female. Buried in a crouched position, arms bent at the elbow, hands near the mouth. Orientated E–W, head to the east. Depth 1.77m.

Pathological conditions and skeletal changes: Enamel hypoplasia was evident on upper and lower canines. It was expressed by faint stress lines on the lower half of the crown, which would have formed between 2–4 years of age.

Grave goods: Two bronze rings.

16. Burial no. 64

Description: Fully/Mature adult, female. Buried in a crouched position, arms bent at the elbow and hands near the face. Orientated E–W, head to the west. Depth 1.30m. Skeleton was incompletely preserved.

Pathological conditions and skeletal changes: None detected

Grave goods: None

17. Burial no. 65

Description: Fully/Mature adult, sex indeterminate. Buried in a crouched position, arms bent at the elbow and hands near the face. Orientated E–W, head to the west. Depth 1.31m. Skeleton was incompletely preserved.

Pathological conditions and skeletal changes: Degenerative changes on the spine (marginal osteophytic lipping on lumbar vertebra).

Grave goods: None

18. Burial no. 66

Description: Fully adult, sex indeterminate. Buried in a crouched position, arms bent at the elbow and hands near the face. Orientated E–W, head to the west. Depth 1.47m. Skeleton was incompletely preserved.

Pathological conditions and skeletal changes: None detected

Grave goods: None

19. Burial no. 68

Description: Young adult, male. Buried in a crouched position, left arm extended along the torso, right arm bent at the elbow at a right angle. Orientated E–W, head to the west. Depth unspecified. The box containing the remains of burial no. 68 also held long-bones belonging to a child of 8–10 years old, not mentioned by Bârzu (1989).

Pathological conditions and skeletal changes: Slight amount of calculus on molars. Enthesopathies involving both proximal humeri at the insertion of the *pectoralis major* and *teres major* muscles (Figure 6), suggesting intensive physical activity of the upper arms.

Grave goods: Bronze spiral ring.

20. Burial no. 69

Description: Adolescent (15–17 years), sex indeterminate. Buried in a crouched position, arms bent at the elbow, hands near the face. Orientated E–W, head to the west. Depth unspecified. Skeleton was incompletely preserved.

Pathological conditions and skeletal changes: None detected

Grave goods: Bronze spiral.

21. Burial no. 70

Description: Juvenile (8–10 years), sex indeterminate. Buried in a crouched position. Orientated E–W, head to the west. Depth unspecified. Skeleton was poorly preserved.

Pathological conditions and skeletal changes: None detected

Grave goods: None

22. Burial no. 71

Description: Fully adult, male. Buried in a crouched position, arms bent at the elbow, hands near the mouth. Orientated E–W, head to the west. Depth 1.70m. Skeleton was badly preserved.

Pathological conditions and skeletal changes: None detected

Grave goods: A large, two-handled ceramic vessel decorated with geometric shapes, and a mace head made from deer antler. Bârzu (1989:50) assigned symbolic value and social significance to the antler mace and identified this individual as one of the potential political and/or military leaders of the community.

23. Burial no. 72

Description: Juvenile (7–9 years), sex indeterminate. Buried in a crouched position. Orientated E–W, head to the west. Depth unspecified.

Pathological conditions and skeletal changes: None detected

Grave goods: Six glass paste beads, two of them broken.

24. Burial no. 74

Description: Fully/Mature adult, female. Buried in a crouched position, arms bent at the elbow and hands near the face. Orientated E–W, head to the west. Depth 1.58m. The box containing the remains of burial no. 74 also held bones belonging to a child of ca. 6 years old, not mentioned by Bârzu (1989).

Pathological conditions and skeletal changes: Marked muscle attachments on humeri, radii and ulnae indicate mechanical stress in the form of intense physical activity.

Grave goods: None

25. Burial no. 75a

Description: Fully adult, female. Possibly part of a double burial of an adult (75a) and a child (75b) 1–2 years old. Neither Maximilian (1962:25) nor Bârzu (1989:66) mention a second burial when describing the adult in grave 75. The woman (75a) was buried in a crouched position, arms bent at the elbow, left hand under the head, right hand near the left shoulder. A large stone was deposited in front of the head. Orientated E–W, head to the west. Depth 1.60m.

Pathological conditions and skeletal changes: Marked muscle attachments on humeri, radii and ulnae indicate mechanical stress. Lower right second premolar and second molar are missing due to antemortem tooth loss.

Grave goods: None

26. Burial no. 75b

Description: Juvenile (1–2 years), sex indeterminate. Possibly part of a double burial of an adult female (75a) and a child (75b). Neither Maximilian (1962:25) nor Bârzu (1989:66) mention a second burial when describing the adult in grave 75. The remains of the child were likely left unnoticed by the original investigators. Depth and body position of the child are undetermined.

Pathological conditions and skeletal changes: None detected

Grave goods: None

27. Burial no. 77

Description: Mature adult, male. Buried in a crouched position, arms folded at the elbow, hands near the face. Orientated E–W, head to the west. Depth 1.25m.

Pathological conditions and skeletal changes: Occlusal wear on maxillary teeth (mandible was missing) is much more advanced on the right side compared to the left (Fig. 7). Slight amounts of calculus present on majority of teeth. Degenerative changes on the spine (marginal osteophytic lipping on 5th lumbar vertebra) and on the margins of the joints (bony ridges on talus and femoral heads) are associated with possible osteoarthritis. Marked muscle attachments on arm bones indicate mechanical stress. In addition, he had a healed fracture on the left 3rd proximal phalanx.

Grave goods: Wild boar tooth on the wrist of the right hand. The tooth has four perforations and is 10cm in length. Bârzu (1989:50) assigned symbolic value and social significance to the boar tooth ornament and identified this individual as one of the potential political and/or military leaders of the community.

28. Burial no. 78

Description: Mature adult, male. Buried in a crouched position, arms bent at the elbow, legs crossed. Orientated E–W, head to the west. Depth unspecified.

Pathological conditions and skeletal changes: Moderate amount of calculus present on majority of teeth. Degenerative changes are evident on lumbar vertebrae (marginal osteophytic lipping). Robust and mechanically altered femora, tibiae and fibulae indicate high physical activity during life.

Grave goods: Three ceramic vessels.

29. Burial no. 79

Description: Mature adult, male. Buried in a crouched position, arms bent at the elbow, hands behind the head. Orientated NNE–SSW, head to NNE. Depth 2.25m.

Pathological conditions and skeletal changes: Degenerative changes on the spine (marginal osteophytic lipping on lumbar vertebra) and on tarsal bones (eburnation and the presence of bony ridges). Femora, tibiae and fibulae are robust with marked muscle attachments, indicating high physical activity during life.

Grave goods: None

30. Burial no. 80

Description: Juvenile (2–4 years), sex indeterminate. Buried in a crouched position. Orientated E–W, head to the east. Depth 1.05m.

Pathological conditions and skeletal changes: Abnormal porosity covers the medial surface of the mandibular rami being especially prominent on the right side (Fig. 8). Microporosity is also visible on the lateral surface of the right mandibular ramus, left mandibular corpus and around the mental eminence (Fig. 9); on the anterior surface of the left maxilla; above and inside the right orbit; on the frontal bone near the glabellar region; bilaterally on the temporal bone above the mastoid process (Fig. 10); and on the ectocranial surface of the basilar part of the occipital (Fig. 11). A mild periostiteal reaction with occasional abnormal porosity is present on almost all observable long-bone diaphyses with the left tibia being affected by more marked bony changes (Fig. 12). Figure 13 illustrates the state of preservation of burial 80 and the locations of skeletal elements which have been affected by periostitis or abnormal porosity. The nature and pattern of these pathological changes, taken together, are strongly indicative of chronic vitamin C deficiency (scurvy), as based on criteria first established by Ortner & Ericksen (1997).

Grave goods: Small decorated ceramic vessel.

31. Burial no. 81

Description: Young adult, sex indeterminate. Buried in a crouched position, arms bent at the elbow and hands near the face. Orientated E–W, head to the west. Depth 1.30m. Skeleton had slipped on the slope of the hill and was incompletely preserved.

Pathological conditions and skeletal changes: Skeletal lesions inside both orbits can be described as cribra orbitalia (Fig. 14). Mild bilateral periostiteal reaction on femoral and tibial shafts.

Grave goods: Decorated bronze spiral ring.

32. Burial no. 82

Description: Adolescent (15–17 years), sex indeterminate. Buried in a crouched position, arms bent at the elbow and hands behind the head. Orientated NNE–SSW, head to the SSE. Depth 1.08m. Skeleton is incompletely preserved.

Pathological conditions and skeletal changes: None detected

Grave goods: Ring made of bronze wire.

33. Burial no. 85

Description: Fully adult, female. Buried in a crouched position, face up, arms folded at the elbow, right hand near the mouth, left one under the head. Orientated E–W, head to the west. Depth 0.68–1m. Skeleton had slipped on the slope of the hill.

Pathological conditions and skeletal changes: Slight amounts of calculus are present on upper incisors, canines and premolars. Enamel hypoplasia was evident on upper and lower incisors. It was expressed by faint stress lines at the middle of the crown,

which would have formed between 2–3 years of age. Marked muscle attachments on humeri, femora and tibiae, and general robusticity of long-bones indicate high physical activity during life. There is mild bilateral periostiteal reaction on the proximal third of the femoral shafts (vertical striations and new bone formation).

Grave goods: None

34. Burial no. 86

Description: Adolescent (18–20 years), male. Buried in a crouched position, arms bent at the elbow, hands near the mouth. Orientated E–W, head to the west. Depth 1.85m.

Pathological conditions and skeletal changes: Supplementary tooth (mesiodens) in the hard palate between the first incisors.

Grave goods: None

35. Burial no. 88

Description: Juvenile (7–9 years), sex indeterminate. Buried in a crouched position, arms bent at the elbow and hands near the face. Orientated E–W, head to the west. Depth 1m.

Pathological conditions and skeletal changes: Abnormal porosity was present on the medial surface of the mandibular rami, being especially prominent on the right side (Fig. 15). Microporosity was also observed on the inferior surface of the hard palate, on the anterior surface of the maxilla and bilaterally on the temporal bone above the mastoid process. Mild bilateral periostitic reaction (vertical striations and microporosity) was observable on tibial diaphyses.

Grave goods: Two decorated ceramic vessels, a thick bronze ring decorated with small marked grooves, two complete and two fragmentary beads of glass paste, and perforated shells. Green staining on the medial surface of the mandibular corpus below the right submandibular fossa indicates the earlier presence of a copper or bronze item in the vicinity of the neck or the right ear.

36. Burial no. 90b

Description: Juvenile (1–2 years), sex indeterminate. Part of a double burial of another juvenile (identified as 90a) ca. 7–8 years old and a very poorly preserved infant (90b), although only the infant was sampled. Body position undetermined. Orientated NNE–SSW, head to NNE. Depth 0.40m.

Pathological conditions and skeletal changes: None detected

Grave goods: None

37. Burial no. 101

Description: Young adult, female. Buried in a crouched position. Orientated E–W, head to the west. Depth 0.90m. Skeleton had slipped on the slope of the hill.

Pathological conditions and skeletal changes: Mild bilateral periostiteal reaction (vertical striations) on tibial and femoral diaphyses. Marked muscle attachments on humeri.

Grave goods: Thin bronze tube, possibly a fragment of a bracelet, as suggested by the presence of green staining on the lateral surface of the right ulnar and radial diaphyses.

38. Burial no. 102

Description: Adolescent (15–17 years), sex indeterminate. Buried in a crouched position, arms bent at the elbow, hands under the head. Orientated E–W, head to the ESE. Depth 1.40m. Skeleton had slipped on the slope of the hill.

Pathological conditions and skeletal changes: None detected

Grave goods: None

39. Burial no. 105

Description: Young adult, female. Buried in a crouched position, arms bent at the elbow, hands near the face. Orientated E–W, head to the ENE. Depth 1.47m. Skeleton was incompletely preserved.

Pathological conditions and skeletal changes: Mild bilateral periostiteal reaction on tibial and femoral diaphyses.

Grave goods: Large, decorated ceramic vessel and a ring made of bronze wire.

40. Burial no. 106

Description: Fully adult, female. Buried in a crouched position, arms were probably bent at the elbow. Orientated E–W, head to the ESE. Depth 1.82m.

Pathological conditions and skeletal changes: Healed fracture on the left ilium (Fig. 16 and 17) with associated deformation on the left pubis, probably the result of a fall. Marked muscle attachments and general robusticity of all major long-bones seem to indicate high physical activity during life.

Grave goods: No documented funerary inventory, although this grave contained three articulated bones (tibia, talus and tarsal) from the heel area of a sheep or goat (Fig. 18).

41. Burial no. 107

Description: Young adult, female. Buried in a crouched position, arms bent at the elbow, hands near the face. A limestone slab was deposited near the skull. Orientated E–W, head to the west. Depth 2.10m.

Pathological conditions and skeletal changes: None detected

Grave goods: Fragmentary bronze ring (decorated), two bronze spiral rings, and two bronze lock rings.

42. Burial no. 108

Description: Fully/Mature adult, male. Buried in a crouched position, arms bent at the elbow, hands near the face. Orientated E–W, head to the ENE. Depth unspecified.

Pathological conditions and skeletal changes: Severe caries on lower left first molar which may have resulted in the more advanced occlusal wear on the right side.

Grave goods: None

43. Burial no. 112

Description: Adolescent (18–20 years), male. Buried in a crouched position, arms bent at the elbow, hands near the mouth. Orientated E–W, head to the ESE. Depth unspecified.

Pathological conditions and skeletal changes: None detected

Grave goods: None

44. Burial no. 115a

Description: Mature adult, female. Part of a double burial of an adult woman (identified as 115a) and a child (115b) ca. 9 years old, although only the adult was sampled. The pair was buried in a crouched position, one in front of the other, with the woman holding the child in a close embrace, her arms around the child's head. Orientated E–W, head to the west. Depth 1.90m.

Pathological conditions and skeletal changes: Marked muscle attachments and general robusticity of all major long-bones seem to indicate high physical activity during life. The left humerus is especially altered compared to the right one (Fig. 19). Degenerative changes on the spine (slight marginal osteophytic lipping on lumbar vertebrae) and on the edges of joints (bony ridges on femoral and tibial epiphyses) are associated with possible osteoarthritis. Mild bilateral periostiteal reaction is evident on femoral diaphyses. Periostitis (vertical striations and new bone formation) has also affected the tibiae and fibulae, although it is more severe on the right side. Additionally, the right tibia and fibula are slightly deformed in shape (Fig. 20),

possibly due to a healed fracture. Due to the bilateral nature of the periostiteal reaction, it is unlikely that it is related to the healed fracture.

Grave goods: None

45. Burial no. 116

Description: Juvenile (3–5 years), sex indeterminate. Buried in a crouched position, arms were probably bent at the elbows. Orientated E–W, head to the east. Depth 1.40m.

Pathological conditions and skeletal changes: Mild periostitic reaction is visible bilaterally on tibial diaphyses.

Grave goods: No recorded funerary inventory although a bone point was identified among the skeletal material during osteological analysis.

46. Burial no. 117

Description: Juvenile (2–3 years), sex indeterminate. Buried in a crouched position, arms were probably bent at the elbow, hands near the face. Orientated E–W, head to the east. Depth 1.35m.

Pathological conditions and skeletal changes: Mild periostiteal reaction (vertical striations and microporosity) is observable bilaterally on tibial diaphyses.

Grave goods: None

47. Burial no. 119

Description: Juvenile (5–6 years), sex indeterminate. Buried in a crouched position, arms bent at the elbow, hands near the chin. Orientated E–W, head to the west. Depth 2.28 m.

Pathological conditions and skeletal changes: Abnormal porosity was present on the medial surface of the mandibular rami, being especially prominent on the right side (Fig. 21). Microporosity was also observable on the frontal bone above the glabellar region, bilaterally on the temporal bone above the mastoid process, and on the ectocranial surface of the basilar part of the occipital. Mild periostiteal reaction (vertical striations and microporosity) was visible bilaterally on tibial diaphyses.

Grave goods: Two-handled ceramic vessel situated near the face. Green staining on the 1st and 2nd right rib indicates the earlier presence of a copper or bronze artefact.

48. Burial no. 120

Description: Juvenile (9–10 years), sex indeterminate. Buried in a crouched position, arms bent at the elbow, hands near the face with the right hand under the head. Orientated E–W, head to the west. Depth 1.37m.

Pathological conditions and skeletal changes: Microporosity is present on the frontal bone above the glabellar region and bilaterally on the temporal bone above the mastoid process. Unfortunately, both the mandible and the maxilla were missing so it is impossible to reconstruct a complete pattern of cranial pathological changes.

Grave goods: None

49. Burial no. 122

Description: Young adult, female. Buried in a crouched position, arms bent at the elbow, hands near the mouth, left hand almost touching a ceramic vessel near the cheek. Orientated E–W, head to the west. Depth 1.80m.

Pathological conditions and skeletal changes: Considerable amount of calculus on molars, slight amount of calculus also evident on premolars and incisors. Marked muscle attachments on humeri indicate physical activity involving the upper arms.

Grave goods: Two large ceramic vessels (one decorated), a bronze ring, a bronze spiral ring, one bead of light-coloured amber and ten beads of bluish-white glass paste. Green staining on the external surface of both mastoid processes indicates the earlier presence of copper or bronze items in the vicinity of the ears.

50. Burial no. 123

Description: Adolescent (17–19 years), male. Buried in a crouched position, arms bent at the elbow, hands near the face. Two stones were deposited nearby – a large one close to the elbows and knees, a smaller one near the left shoulder. Orientated E–W, head to the west. Depth 1.65m.

Pathological conditions and skeletal changes: Slight amount of calculus on almost all teeth. Enamel hypoplasia is evident on both upper and lower canines and premolars (Fig. 22). It is expressed by multiple stress lines on the lower half of crown which would have formed between 2–4 (for canines) and 5–7 (for premolars) years of age. Mild bilateral periostiteal reaction (vertical striations) is visible on femora. Microporosity was observed bilaterally on the medial surface of the mandibular ramus (Fig. 23 and 24), also above the external auditory meatus (bilaterally), on the maxilla and on the lateral surface of the left zygomatic bone (Fig. 25) (right zygomatic bone was non-observable).

Grave goods: None

51. Burial no. 124

Description: Juvenile (2–4 years), sex indeterminate. Buried in a crouched position, arms bent at the elbow, hands towards the mouth. Orientated E–W, head to the west. Depth 1.61m.

Pathological conditions and skeletal changes: Abnormal porosity can be observed bilaterally on the medial surface of the mandibular rami (Fig. 26, 27). Microporosity is also present on the frontal bone above the glabellar region (Fig. 28); on the lateral surface of the mandibular corpus (Fig. 29) and around the mental eminence (Fig. 30); bilaterally on the temporal bone above the mastoid process; on the endocranial surface of the occipital; inside the maxillary and mandibular sockets (Fig. 31); and on the medial surface of the ilia. A mild periostiteal reaction (vertical striations and microporosity) has affected the tibial and femoral diaphyses. The pattern of pathological changes on this skeleton is similar to the one observed in burial no. 80 and could also be indicative of chronic vitamin C deficiency (scurvy).

Grave goods: None

52. Burial no. 125

Description: Adolescent (17–19 years), female. Buried in a crouched position, arms bent at the elbow and hands near the face. Orientated E–W, head to the ENE. Depth 1.25m.

Pathological conditions and skeletal changes: Enthesopathy involving both proximal humeri, suggesting intensive physical activity of the upper arms. Right distal tibia has been affected either by an infectious reaction (localized osteomyelitis) or severe inflammation (periostitis) (Fig. 32). Right scapula is deformed (Fig. 33), possibly caused by a trauma. It is also significantly enlarged compared to the left one. The size difference could be caused by the trauma, or one of the scapulae could belong to a different individual. Both humeral heads were either missing or broken which complicates the determination of provenance for both scapulae. Mild periostitis is also present on the right femoral diaphysis and the posterior surface of the right ilium (Fig. 34), indicating a possible traumatic event (such as a fall) that could have affected the whole right side.

Grave goods: Small, decorated ceramic vessel, a bronze wire ring and a small discoidal bronze button with two marginal and opposite perforations.

53. Burial no. 126

Description: Mature adult, male. Buried in a crouched position. Orientated E–W, head to the west. Depth 1m.

Pathological conditions and skeletal changes: Mild bilateral periostiteal reaction is visible on femoral, tibial and fibular diaphyses. Marked muscle attachments on humeri

and tibiae indicate high physical activity during life. This is supported by observed degenerative changes on the bones of the feet (tali and metatarsals).

Grave goods: None

54. Burial no. 127

Description: Mature adult, male. Buried in a crouched position, arms bent at the elbow, hands near the face, right hand under the cheek. Orientated E–W, head to the west. Depth 1.95m.

Pathological conditions and skeletal changes: Moderate amount of calculus present on all available teeth (lower canines, premolars and molars). Degenerative changes are visible on the spine (marginal osteophytic lipping on lumbar vertebra). Marked muscle attachments on femora, tibiae and fibulae indicate physical activity during life. Mild bilateral periostiteal reaction can be observed on femora. Microporosity is observable on the frontal bone above the glabellar region.

Grave goods: None

55. Burial no. 128

Description: Juvenile (8–12 years), sex indeterminate. Buried in a crouched position. Orientated E–W, head to the west. Depth unspecified. Skeleton was incompletely preserved.

Pathological conditions and skeletal changes: None detected

Grave goods: None

56. Burial no. 130

Description: Young adult, female. Buried in a crouched position, arms bent the elbow and hands near the face. Orientated NNE–SSW, head to the SSE. Depth 1.22 m.

Pathological conditions and skeletal changes: Enthesopathy involving both proximal humeri, suggesting intensive physical activity of the upper arms. This is supported by marked muscle attachments and general robusticity of humeri and ulnae. Mild periostitic reaction (vertical striations) is present bilaterally on tibial diaphyses. Enamel hypoplasia is evident on lower canines and premolars. It is expressed by faint stress lines on the bottom third of the crown which would have formed between 2–4 (for canines) and 5–7 (for premolars) years of age.

Grave goods: None

57. Burial no. 133

Description: Adolescent (17–19 years), female. Buried in a crouched position, arms bent at the elbow, hands near the face. Orientated E–W, head to the east. Depth 1.22m.

Pathological conditions and skeletal changes: Marked muscle attachments and general robusticity of all major long-bones seem to indicate high physical activity during life.

Grave goods: An amber bead (found between the head and the neck), a bronze ring and pieces of perforated bone.

58. Burial no. 134

Description: Fully/Mature adult, female. Buried in a crouched position, arms bent at the elbow and hands near the face. Orientated E–W, head to the west. Depth 1.33m.

Pathological conditions and skeletal changes: Severe caries on lower right and left first molar. Marked muscle attachments on humeri (Fig. 35) and general robusticity of all major long-bones are indicative of high physical activity during life.

Grave goods: None

59. Burial no. 135

Description: Mature adult, female. Buried in a crouched position, arms bent the elbow, hands near the face. Orientated E–W, head to the west. Depth 1.10m.

Pathological conditions and skeletal changes: Caries on right and left upper canine. Lower right premolars are missing due to antemortem tooth loss. Degenerative changes on the spine (marginal osteophytic lipping on thoracic and lumbar vertebra, two thoracic vertebrae are fused) and on the margins of tarsal bones (bony ridges on tali and calcanei) can be associated with osteoarthritis. Marked muscle attachments on all major long-bones indicate physical activity during life.

Grave goods: None

APPENDIX 3

Photographical illustrations (taken by the present author) of pathological conditions, skeletal changes, and noteworthy finds recorded among human burials from **Sărata Monteoru cemetery no. 4**:

Figure 1. Discoloration and abnormal porosity on the medial surface of the right mandibular ramus, burial 24

Figure 2. Periostitis on the lateral surface of the right mandibular ramus, burial 24

Figure 3. Mild periostitis on the left tibial diaphysis, distal is to the left, burial 24

Figure 4. Discoloration and microporosity on the left medial surface of the mandibular coronoid process, burial 40

Figure 5. Enthesopathy involving the left proximal humerus at the insertion of the pectoralis major *and* teres major *muscles, burial 46*

Figure 6. Enthesopathy involving both proximal humerii at the insertion of the pectoralis major *and* teres major *muscles, burial 68*

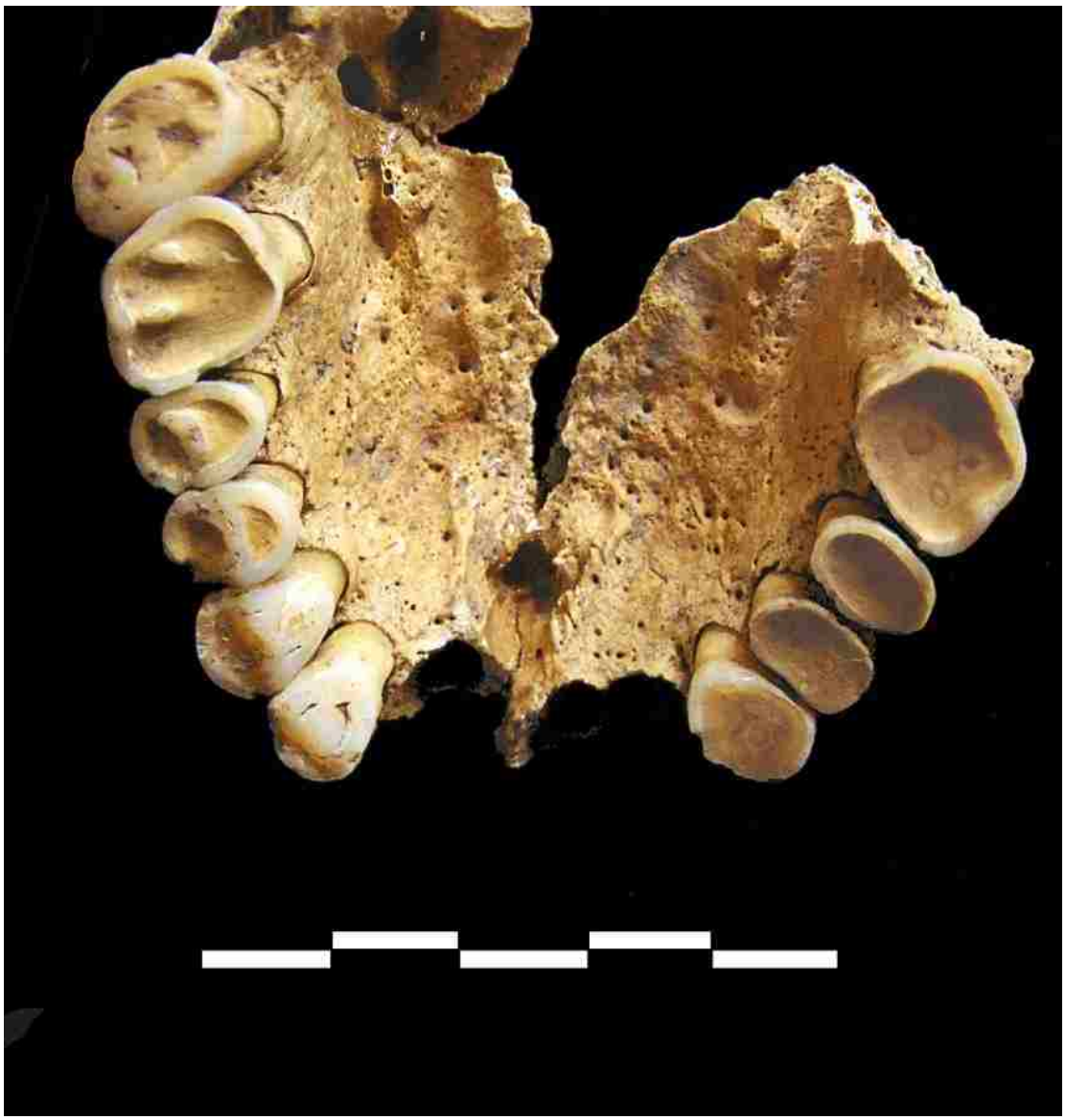

Figure 7. Inferior view of maxilla with much heavier occlusal wear on the right side compared to the left, burial 77

Figure 8. Abnormal porosity on the medial surface of the right mandibular ramus, burial 80

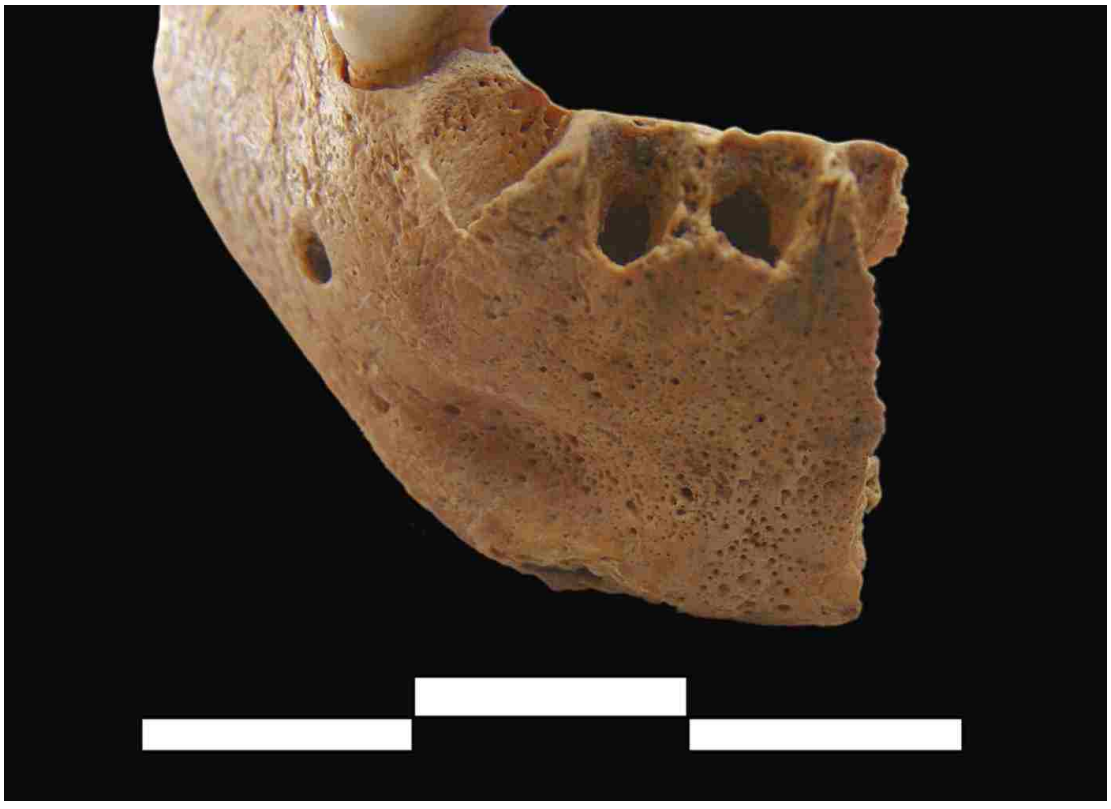

Figure 9. Porosity around the mental eminence on the mandible, burial 80

Figure 10. Porosity and discoloration on the left temporal bone above the mastoid process, burial 80

Figure 11. Porosity on the ectocranial surface of basilar part of the occipital, burial 80

Figure 12. Severe periostitis on the left tibia, burial 80. Top: distal is to the right. Bottom: close-up of the affected area, distal is to the right

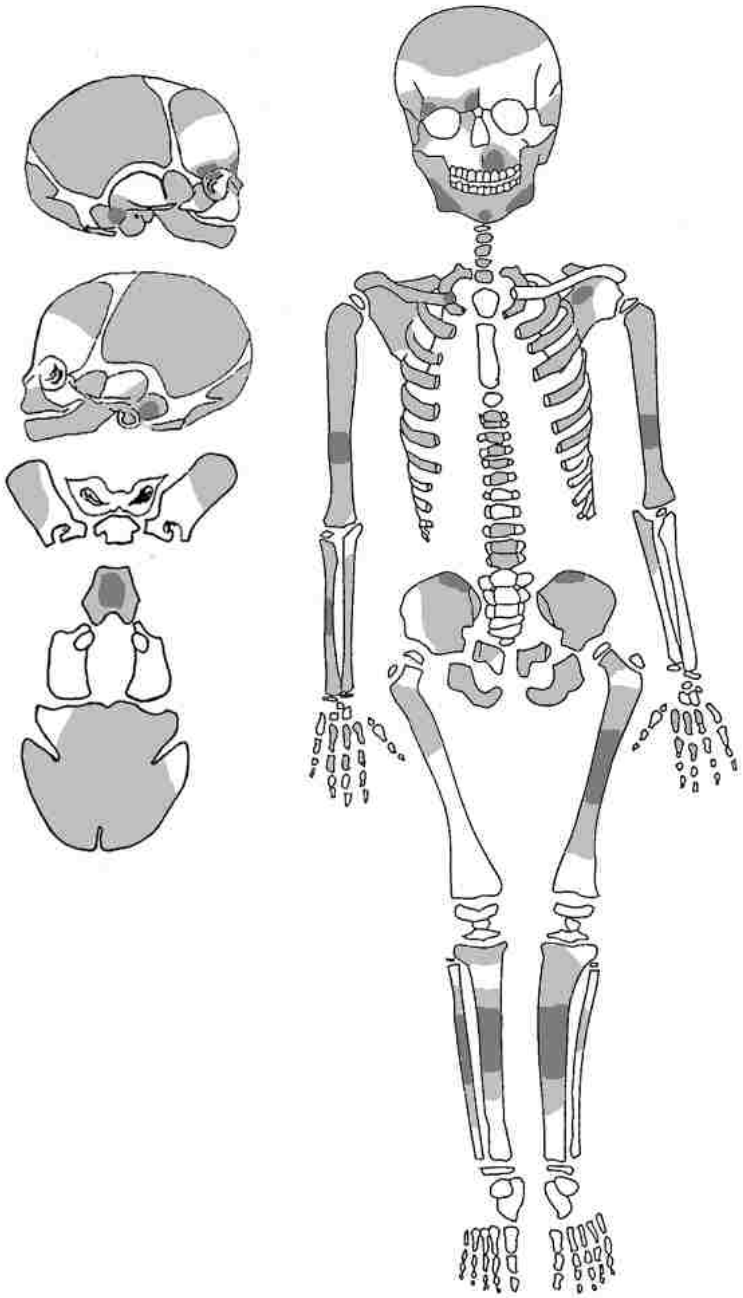

Figure 13. Light-gray represents observable skeletal elements, dark-grey represents areas affected by abnormal porosity or periostitis, burial 80

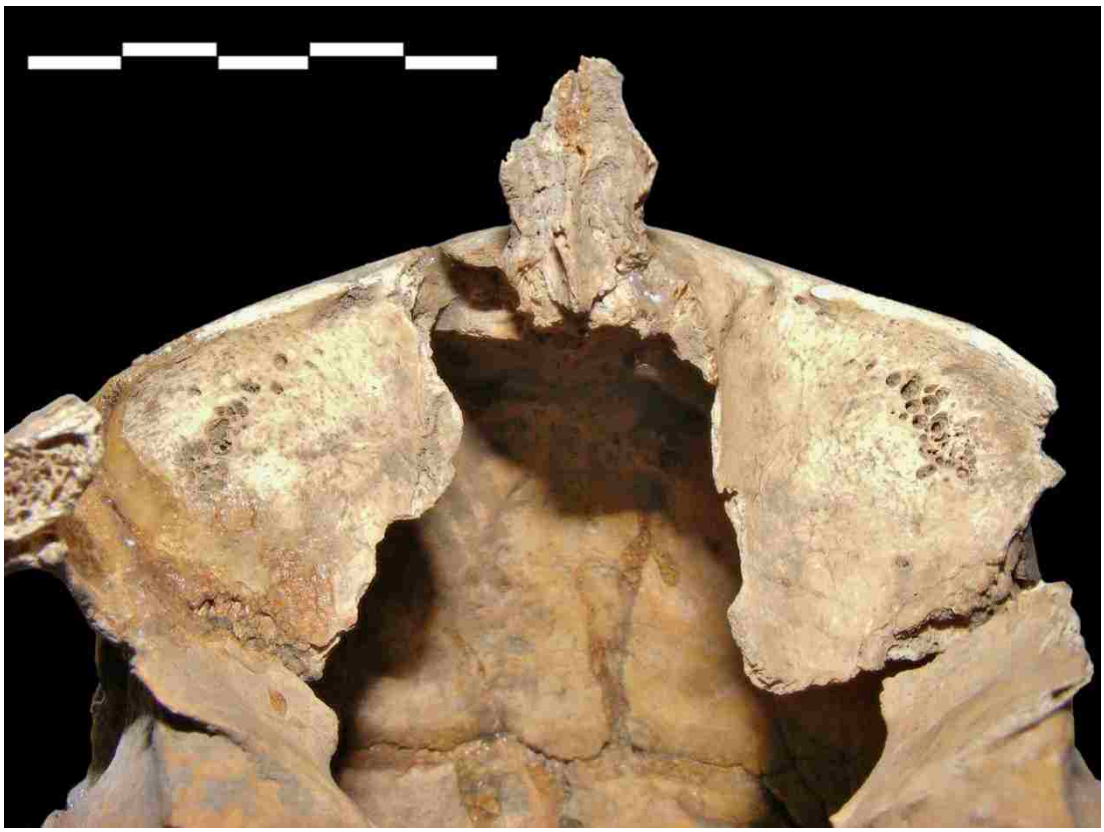

Figure 14. Skeletal lesions inside both orbits, associated with cribra orbitalia, burial 81

Figure 15. Abnormal porosity on the medial surface of the right mandibular ramus, burial 88

Figure 16. Healed fracture on the anterior surface of the left ilium, burial 106

Figure 17. Healed fracture on the posterior surface of the left ilium, burial 106

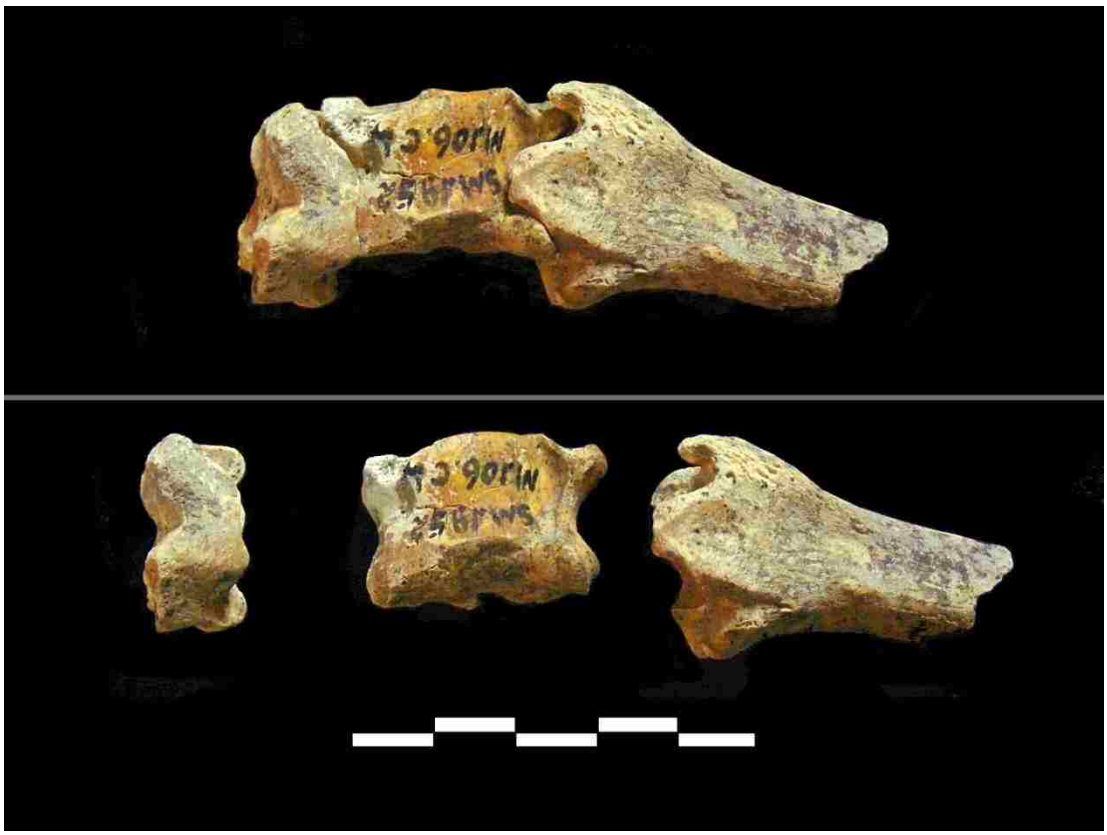

Figure 18. Articulated bones (tibia, talus, tarsal) from the heel area of a sheep or goat, burial 106

Figure 19. Left (top) humerus shows especially developed muscle attachments compared to the right one (bottom), burial 115a

Figure 20. Right tibia and fibula (proximal is to the left) showing signs of deformation, possibly due to a healed fracture, burial 115a

Figure 21. Abnormal porosity on the medial surface of the right mandibular ramus, burial 119

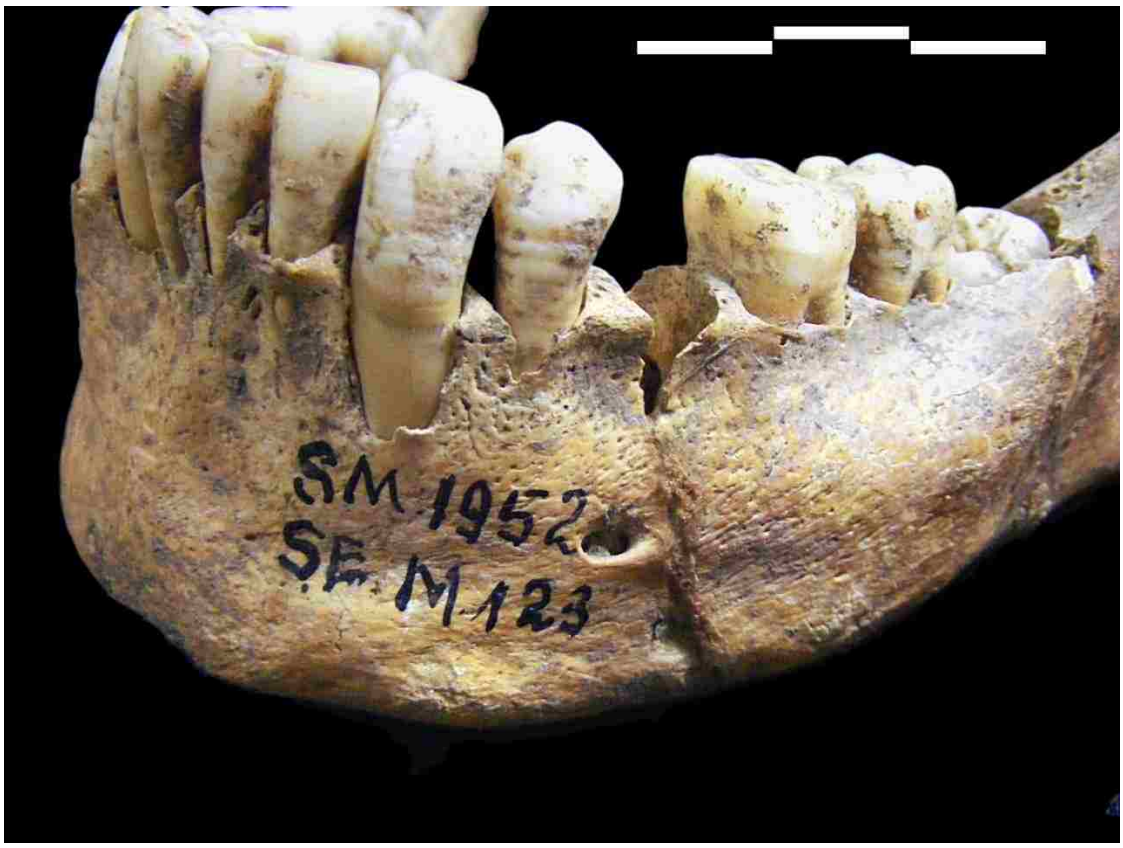

Figure 22. Enamel hypoplasia on mandibular canines and premolars, burial 123

Figure 23. Abnormal porosity on the medial surface of the left mandibular ramus, burial 123

Figure 24. Microporosity on the medial surface of the right mandibular ramus, burial 123

Figure 25. Microporosity and discoloration on the lateral surface of the left zygomatic bone, burial 123

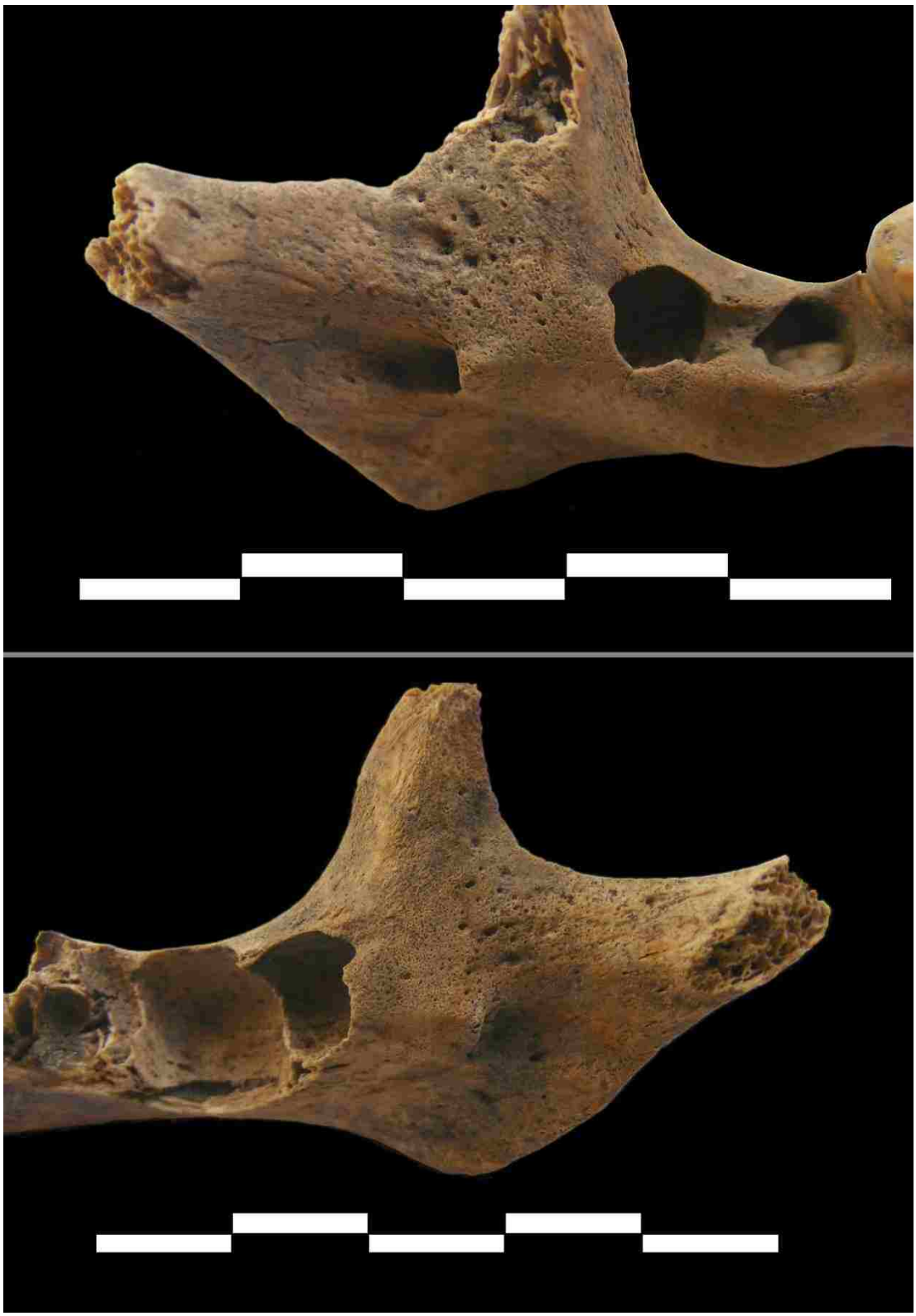

Figure 26. Abnormal porosity on the medial surface of the mandibular ramus, burial 124. Top: left side. Bottom: right side

Figure 27. Close-up of abnormal porosity on the medial surface of the right mandibular ramus, burial 124

Figure 28. Microporosity on the frontal bone above the glabellar region, burial 124

Figure 29. Porosity on the lateral surface of the mandibular corpus, burial 124

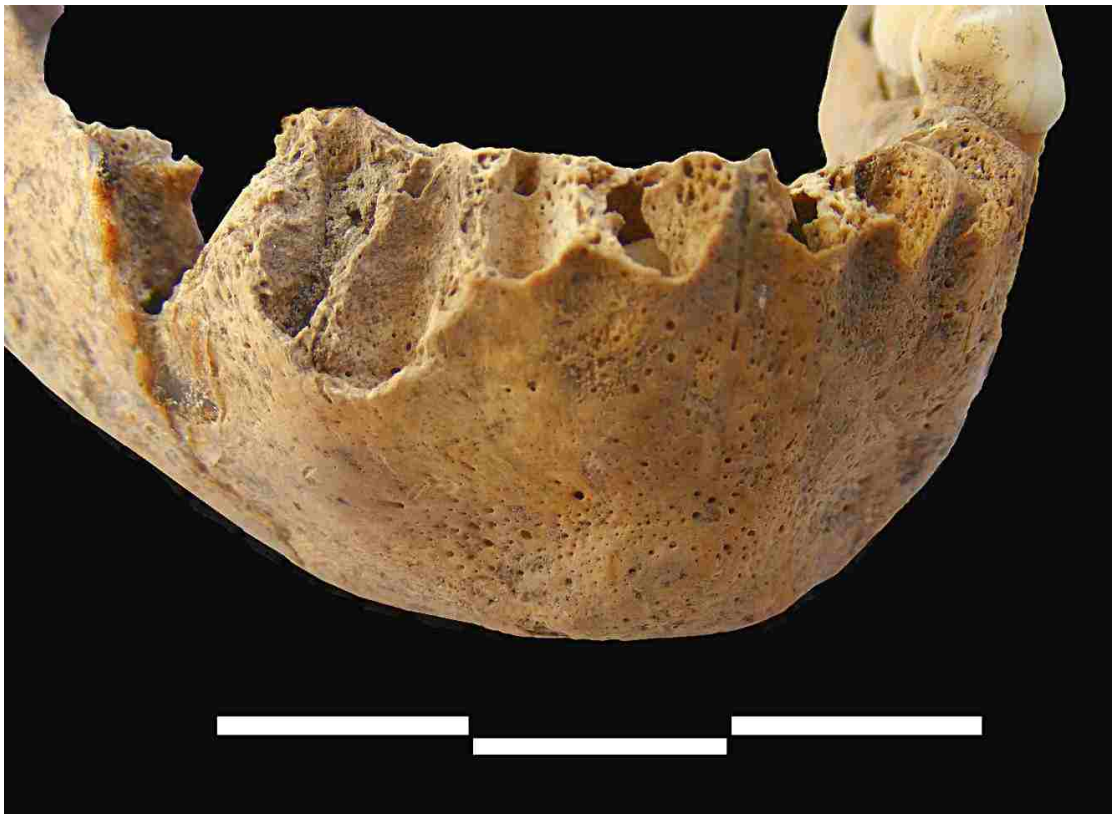

Figure 30. Microporosity around the mental eminence, burial 124

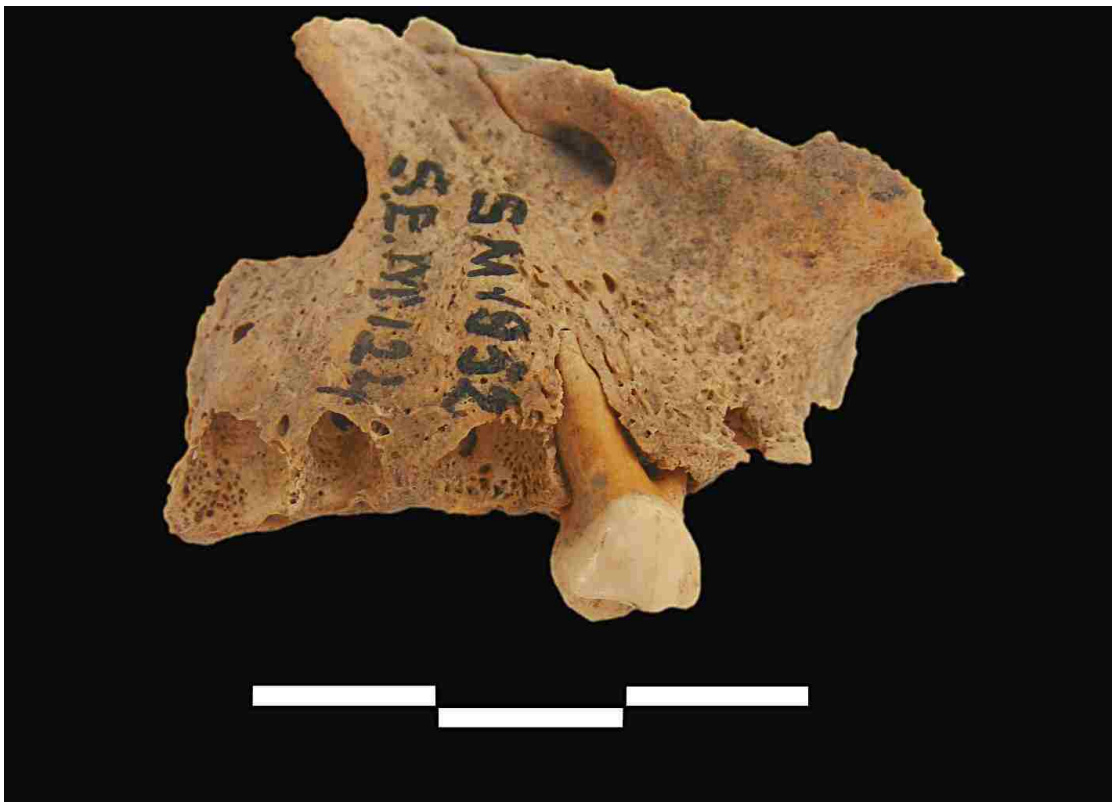

Figure 31. Porosity on the left maxilla and inside the maxillary sockets, burial 124

Figure 32. An infectious reaction (localized osteomyelitis) or severe inflammation (periostitis) on the right distal tibia, burial 125

Figure 33. Right scapula (on the left), posterior view, showing signs of deformation. Compare to the left scapula (on the right), burial 125

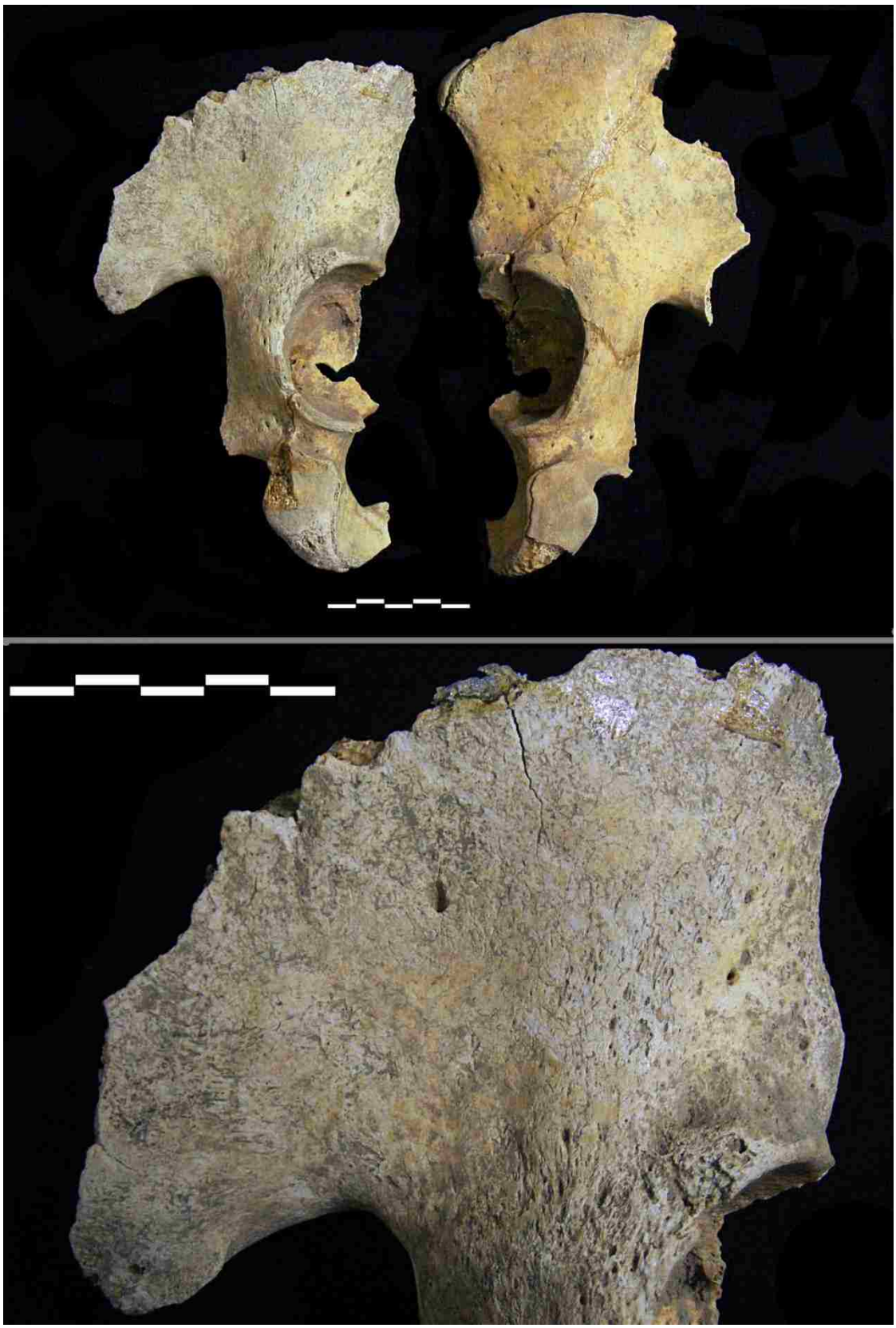

Figure 34. Periostitis on the posterior surface of the right ilium, burial 125. Top: right os coxae (on the left) compared to the left one (on the right). Bottom: close-up of the right ilium

Figure 35. Marked muscle attachments on humeri, burial 134. Top: left humerus of burial 134 (lower) compared to left humerus of burial 106 (upper). Bottom: close-up of the left humeral shaft

APPENDIX 4

Descriptions[1] of human burials from **Cârlomăneşti – La Arman** cemetery sampled for stable isotope analysis:

1. Burial no. 1

Description: Young adult (21–28 years), female. Buried in a crouched position, arms bent at the elbow and hands near the face. Orientated NE–SW, head to the SW. Depth 0.93m. Several river stones were deposited at the bottom of the grave. The grave was situated near a modern road and was partially disturbed, with the skull being visible from the road bank.

Grave goods: A decorated two-handled ceramic vessel, *Ösenhalsring* (a type of necklace with twisted ends), a lock ring and a fragment from a bracelet – all three made of either copper or bronze.

2. Burial no. 2

Description: Adolescent (13–15 years), sex indeterminate. Buried in a crouched position, arms bent at the elbow and hands near the face. Orientated N–S, head to the south. Depth 1.41m. The grave pit was dug in two steps, one wider and shallower, the other deeper and narrower. The burial had been partly disturbed by the construction of the nearby road which has resulted in the loss of the skull.

Grave goods: Two-handled ceramic vessel.

3. Burial no. 5

Description: Mature adult (30–40 years), male. Buried in a crouched position, arms bent at the elbow, right hand near the face, left one near the knees. Orientated NE–SW, head to the SW. Depth 0.47m. The skeleton was covered almost entirely with river rocks, on top of which was deposited a large conglomerate boulder. There were also stones at the bottom of the grave.

Grave goods: Sherds from 1–2 ceramic vessels found among the stones covering the skeleton.

4. Burial no. 19

Description: Mature adult (ca. 45 years), female. Buried in a crouched position, arms bent at the elbow, hands near the face. Orientated W–E, head to the west. Depth 0.85m. The skeleton was completely covered with a pile of river rocks (some with traces of burning) and limestone conglomerate boulders. The base of the grave pit was also lined

[1] Excluding palaeopathological information

with stones. The stone filling contained pottery shards and a human bone fragment. In addition, the mandible of burial no. 19 was recovered in a completely unnatural position (with the mental eminence facing the cranium and the condyles projecting outwards away from the skull) which led Motzoi-Chicideanu *et al.* (2012a) to suggest the occurrence of post-mortem handling of the skull.

Grave goods: Two-handled ceramic vessel situated near the skull. Inside it, a small globular vessel. Four additional sherds were recovered from the fill of the burial pit.

5. Burial no. 24

Description: Juvenile (10–12 years), sex indeterminate. Buried in a crouched position, arms bent at the elbow, hands near the face. Orientated WSW–ENE, head to the WSW. Depth 1.23m. One edge of the grave pit was lined with rocks; rocks also partially covered the skeleton.

Grave goods: Two-handled ceramic vessel with a smaller globular vessel inside.

6. Burial no. 51a

Description: Juvenile (9–13 years), sex indeterminate. Buried in a crouched position. Orientated W–E, head to the west. Depth 0.72m. Cranial fragments of a child 0–6 years old (identified as 51b) were found near the legs of burial no. 51a, possibly belonging to a secondary burial. The grave pit was covered and lined with river stones and conglomerate boulders.

Grave goods: Three ceramic vessels (including one in the shape of a bird) near the skull, with another two smaller vessels among the stone filling at the edge of the grave pit. Additionally, 11 astragalus bones from a pig were found in this grave.

7. Burial no. 58

Description: Juvenile (8–9 years), sex indeterminate. Buried in a crouched position. Orientated WSW–ENE, head to the WSW. Depth 1m. The grave was constructed in the style of a catacomb, with a pile of river stones covering a pit of about 60–70cm deep, at the bottom of which was deposited the skeleton.

Grave goods: Two ceramic vessels (one two-handled, one small cup without handles) situated near the feet.

8. Burial no. 80a

Description: Mature adult (30–40 years), female. Part of a double burial of a woman (identified as 80a) and child (80b) 9–12 months old, although only the adult was sampled. The woman was buried in a crouched position. Orientated NW–SE, head to NW. Depth 0.61m. Both sets of remains were poorly preserved.

Grave goods: Three ceramic vessels, a bronze lock ring, a bronze bracelet and a stone spindle whorl.

9. Burial no. 103

Description: Mature adult (30–38 years), female. Buried in a crouched position. A stone was deposited near the skull. Orientated SW–NE, head to SW. Depth 0.56m. The skeleton was poorly preserved.

Grave goods: One ceramic vessel situated near the feet.

10. Burial no. 105a

Description: Juvenile (8–9 years), sex indeterminate. Part of a double burial of two children, the other (105b) 9–14 years old, although only the first was sampled. Both buried in a foetal position, facing the same direction. Orientated NW–SE, head to NW. Depth 0.80m.

Grave goods: Three ceramic vessels.

APPENDIX 5

List of animal bones from Sărata Monteoru (SM) and Cârlomăneşti (CRL) sampled for stable isotope analysis:

Sample code	Site	Burial No./Context	Genus	Skeletal element	Bone weight (g)	Comments
2	SM	12	Ovis/Capra	Scapula	9.8	
3	SM	30	Ovis/Capra	Astragalus	4.6	
4	SM	32	Sus	Phalanx	1.5	Young individual
5	SM	32	Sus	Scapula	4.4	
6	SM	46	Ovis/Capra	Phalanx	3	
7	SM	70	Ovis/Capra	Humerus	30.1	
8	SM	74a	Bos	Metacarpal	2.4	
9	SM	80	Sus	Jaw	1.3	With one tooth
10	SM	80	Bos	Carpal	14.6	
11	SM	99	Ovis/Capra	Phalanx	3.2	
13	SM	106	Ovis/Capra	Tibia	8.8	Three articulated bones (tibia, talus, tarsal) from the heel area
14	SM	107	Bos	Metatarsal	72.7	
15	SM	115a	Bos	Costae	7.1	
16	SM	115a	Canis	Axis	6.9	Small individual (or fox)
19	SM	121	Ovis/Capra	Phalanx	2.4	
20	SM	126	Bos	Carpal	7.1	
21	SM	127	Equus	Metatarsal	15.8	
22	CRL	CRL-09, 4334, W4bN, grid D1-2. -1.84–2.08m	Bos	2nd phalanx	33.4	
24	CRL	CRL-09, 4627, W4bN, grid D1-D2, E1-E2. -1.40–1.57m	Ovis	Metacarpal	11.1	

Appendix 5. Continued

Sample code	Site	Burial No./Context	Genus	Skeletal element	Bone weight (g)	Comments
25	CRL	CRL-09, 4647, W4bN, gridsquare A3. -1.47	Equus	Calcaneus	81.7	
26	CRL	CRL-09, 4647, W4bN, gridsquare A3. -1.47	Ovis/Capra	Calcaneus	5.1	With canid gnaw marks
29	CRL	CRL-09, 4691, W4bN, Gridsquare A3–4, B3–4, -1.45–1.52m	Equus	1st phalanx	49	
30	CRL	CRL-09, 4691, W4bN, Gridsquare A3–4, B3–4, -1.45–1.52m	Bos	Calcaneus	9.9	Young individual
31	CRL	CRL-09, 4691, W4bN, Gridsquare A3–4, B3–4, -1.45–1.52m	Sus	Calcaneus	11.3	
32	CRL	CRL-09, 4691, W4bN, Gridsquare A3–4, B3–4, -1.45–1.52m	Sus	1st phalanx	18.2	With canid gnaw marks. Large individual (or boar)
33	CRL	CRL-09, 4691, W4bN, Gridsquare A3–4, B3–4, -1.45–1.52m	Cervus	1st phalanx	28.8	
34	CRL	CRL-09, 4775, W4bN, Late Monteoru layer, profile cleaning	Sus	Jaw	15.7	With two teeth
35	CRL	CRL-09, 4775, W4bN, Late Monteoru layer, profile cleaning	Canis	Cervical vertebra	9.2	
36	CRL	CRL-09, 4775, W4bN, Late Monteoru layer, profile cleaning	Sus	Metacarpal	1.1	
37	CRL	CRL-09, 4775, W4bN, Late Monteoru layer, profile cleaning	Bos	Tarsal	8.7	
39	CRL	CRL-09, 4775, W4bN, Late Monteoru layer, profile cleaning	Ovis/Capra	Humerus	18.2	
40	CRL	CRL-09, 4796, W4bN, gridsquare A1–2. -1.60–1.78 m	Ovis/Capra	Mandible	6.3	With two teeth
41	CRL	CRL-09, 4809, W4bN. Complex 28, tearing down one of the steps in grid E3–4	Sus	Jaw	11.3	With three teeth

Appendix 5. Continued

Sample code	Site	Burial No./Context	Genus	Skeletal element	Bone weight (g)	Comments
43	CRL	CRL-09, 4809, W4bN. Complex 28, tearing down one of the steps in grid E3-4	Sus	Fibula	1.5	
44	CRL	CRL-09, 4842, W4bN, gridsquare D1–2. -1.72–1.84	Canis	Mandible	15.2	With one tooth
45	CRL	CRL-09, 4858, W4bN, gridsquare C1,C2,C3. -1.78–1.84	Lepus	Tibia	3.4	
46	CRL	CRL-09, 4873, W4bN, B3–B4 Monteoru layer. -1.71–1.78	Bos	Calcaneus	58.5	
47	CRL	CRL-09, 4873, W4bN, B3–B4 Monteoru layer. -1.71–1.78	Bos	Metapodial	13.8	
48	CRL	CRL-09, 4873, W4bN, B3–B4 Monteoru layer. -1.71–1.78	Ovis/Capra	1st phalanx	2.4	
49	CRL	CRL-09, 4873, W4bN, grid B3–B4 Monteoru layer. -1.71–1.78m	Equus	1st phalanx	50.8	
51	CRL	CRL-09, 4882, W4bN, grid D3–4, E3–4. -1.76–1.82m	Bos	1st phalanx	32.2	
52	CRL	CRL-09, 4882, W4bN, grid D3–4, E3–4. -1.76–1.82m	Canis	Mandible	5.6	
53	CRL	CRL-09, 4882, W4bN, grid D3–4, E3–4. -1.76–1.82m	Ovis/Capra	Mandible	3.7	Young individual
55	CRL	CRL-09, 4903, W4bN, grid B1–2. -1.84/1.81–1.93/1.90m	Ovis/Capra	Mandible	4.8	Young individual
56	CRL	CRL-09, 4903, W4bN, grid B1–2. -1.84/1.81–1.93/1.90m	Canis	Astragalus	3.7	
57	CRL	CRL-09, 4928, W4bN, grid D3–E3. -1.81–1.93	Sus	Maxilla	20.5	With three teeth
58	CRL	CRL-09, 4942, W4bN, grid C3. -1.85–1.93	Sus	Jaw	17.5	With two teeth

Appendix 5. Continued

Sample code	Site	Burial No./Context	Genus	Skeletal element	Bone weight (g)	Comments
59	CRL	CRL-09, 4942, W4bN, grid C3. -1.85–1.93	Bos	2nd phalanx	28.9	
60	CRL	CRL-09, 4942, W4bN, grid C3. -1.85–1.93	Bos	2nd phalanx	26	
61	CRL	CRL-09, 4942, W4bN, grid C3. -1.85–1.93	Bos	2nd phalanx	20.3	
62	CRL	CRL-09, 4942, W4bN, grid C3. -1.85–1.93	Canis	Atlas	16.8	Large individual (or wolf)
63	CRL	CRL-09, 4942, W4bN, grid C3. -1.85–1.93	Canis	Atlas	15.9	
64	CRL	CRL-09, 4974, W4bN, grid B3–4	Bos	2nd phalanx	12.9	
65	CRL	CRL-09, 4974, W4bN, grid B3–4	Ovis/Capra	Astragalus	5.1	
66	CRL	CRL-09, 4974, W4bN, grid B3–4	Canis	Metapodial	3.3	
67	CRL	CRL-09, 4989, W4bN, gridsquare A2. -1.98–2.04m	Ovis/Capra	Calcaneus	6.9	With canid gnaw marks

APPENDIX 6

Results of stable isotope analyses from Sărata Monteoru and Cârlomăneşti. Samples marked with an asterisk were analysed at NIGL and the $\delta^{13}C$ and $\delta^{15}N$ values are averaged from duplicate runs. The average 1-sigma standard deviations of the duplicates were ±0.06‰ for $\delta^{13}C$ and ±0.05‰ for $\delta^{15}N$. All other samples measured at SUERC. Samples with collagen quality indicators below the conventionally accepted values are marked in bold.

Burial no.	Age	Sex	Sample no.	Sample	% collagen	$\delta^{13}C$	$\delta^{15}N$	%C	%N	C:N	$\delta^{34}S$	%S	N:S	C:S
Sărata Monteoru human bone collagen														
12	9–11yr	N/A	SM185*	Rib	7.84	-19.7	6.3	41.6	14.7	3.3				
13	Young adult	F	SM2a	Femur	3.77	-19.7	9.8	40.9	14.8	3.2				
			SM2b	Femur	9.43	-19.9	9.9	42.1	15.1	3.3				
			SM14b	Skull	1.83	-19.9	9.5	38.3	13.7	3.3				
			SM14a*	Skull	3.45	**-19.9**	**9.5**	**29.6**	**10.4**	**3.3**				
			SM27	Metacarpal	3.55	-19.6	9.5	42.8	15.5	3.2				
			SM30	Rib	2.72	-19.4	9.4	42.3	15.2	3.2				
			SM40b	Vertebra	2.56	-19.3	8.6	39.5	14.3	3.2				
24	1.5–2yr	N/A	SM77	Femur (cortical)	5.21	-19.8	10.0	41.3	14.9	3.2	0.5	0.21	159	514
			SM90*	Femur (trabecular)	2.84	-19.2	9.8	41.1	14.5	3.3				
35a	17–19yr	F	SM4a	Femur	3.38	-20.2	8.2	40.4	14.7	3.2	3.8	0.26	131	419
			SM4b	Femur	3.11	-19.6	8.3	37.9	13.6	3.2	4.0	0.23	138	449
			SM29*	Rib	5.08	-19.5	8.5	39.1	13.9	3.3				
35b	1.5–2yr	N/A	SM186*	Skull	12.03	-19.2	11.1	41.3	14.8	3.3				
40	17–19yr	F	SM7b	Femur	3.47	-20.6	7.8	37.9	13.4	3.3	3.6	0.27	112	371

Appendix 6. Continued

Burial no.	Age	Sex	Sample no.	Sample	% collagen	$\delta^{13}C$	$\delta^{15}N$	%C	%N	C:N	$\delta^{34}S$	%S	N:S	C:S
Sărata Monteoru human bone collagen														
40	17–19yr	F	SM7a	Femur	3.04	-20.3	7.9	41.2	14.8	3.3	3.5	0.20	167	544
			SM33*	Rib	5.50	-19.5	5.8	39.4	13.8	3.3				
41	7–9yr	N/A	SM187*	Rib	5.28	-20.1	7.7	42.0	14.8	3.3				
46	16–18yr	N/A	SM3a	Femur	2.77	-20.0	9.2	38.7	14.1	3.2				
			SM3b	Femur	2.56	-19.7	9.2	36.2	13.1	3.2				
			SM16b	Skull	1.86	-19.9	9.5	39.9	14.4	3.2				
			SM16a*	Skull	4.34	-19.8	9.5	32.7	11.4	3.4				
			SM21	Metacarpal	3.80	-19.7	9.3	41.9	15.1	3.2				
			SM36	Rib	8.72	-20.4	9.0	46.5	16.8	3.2				
			SM39b	Vertebra	3.69	-19.7	9.2	44.0	15.7	3.3				
48	Fully/Mature	?	SM188*	Metacarpal	7.96	-19.7	8.4	41.4	14.6	3.3				
50	1–3yr	N/A	SM76	Femur	4.04	-19.6	10.7	40.8	14.8	3.2	-0.1	0.25	133	427
			SM98	Rib	4.32	-19.0	10.6	41.8	15.1	3.2	0.3	0.20	174	563
			SM110a*	Vertebra	2.74	-18.8	10.8	36.5	12.8	3.3				
53	Young adult	F	SM189b*	Rib	1.94	-19.3	8.7	40.7	14.6	3.3				
54a	Fully/Mature	F	SM190*	Scapula	7.47	-19.7	8.7	40.3	14.4	3.3				
61	17–19yr	F	SM191*	Metacarpal	11.58	-19.4	7.9	42.1	14.9	3.3				
62	Fully adult	M	SM192*	Metacarpal	6.75	-19.4	9.1	41.7	14.7	3.3				
63	19–21yr	F	SM193*	Metatarsal	4.93	-19.9	7.8	40.4	14.2	3.3				
64	Fully/Mature	F	SM194*	Metatarsal	6.33	-19.6	8.8	42.1	14.8	3.3				
65	Fully/Mature	?	SM195*	Rib	5.38	-19.3	9.1	41.6	14.8	3.3				
66	Fully adult	?	SM196*	Rib	3.02	-19.5	8.3	41.4	14.7	3.3				
68	Young adult	M	SM197a*	Rib	2.86	-19.4	8.9	41.3	14.7	3.3				
69	15–17yr	?	SM198*	Rib	9.75	-19.3	8.8	40.7	14.4	3.3				
70	8–10yr	N/A	SM199*	Rib	9.89	-19.4	8.5	41.6	14.8	3.3				

Appendix 6. Continued

Burial no.	Age	Sex	Sample no.	Sample	% collagen	$\delta^{13}C$	$\delta^{15}N$	%C	%N	C:N	$\delta^{34}S$	%S	N:S	C:S
Sărata Monteoru human bone collagen														
71	Fully adult	M	SM200*	Rib	8.38	-19.1	8.9	41.5	14.6	3.3				
72	7–9yr	N/A	SM201*	Rib	8.88	-20.0	6.9	41.5	14.6	3.3				
74	Fully/Mature	F	SM202*	Rib	4.15	-19.0	10.2	41.2	14.4	3.3				
75a	Fully adult	F	SM203*	Rib	4.51	-19.2	9.5	41.7	14.7	3.3				
75b	1.5–2yr	N/A	SM79	Femur	4.47	-19.1	10.8	42.7	15.6	3.2	0.7	0.22	164	523
			SM93*	Rib	4.14	-18.8	11.0	39.2	13.9	3.3				
77	Mature adult	M	SM1a	Femur	1.65	-20.4	7.7	34.1	12.3	3.2				
			SM32b	Rib	1.84	-20.2	8.3	40.7	14.8	3.2	1.6	0.22	157	502
			SM42b*	Vertebra	2.33	-19.3	8.9	39.9	14.0	3.3				
78	Mature adult	M	SM6a	Femur	2.07	-20.3	7.8	33.6	12.0	3.3				
			SM46	Vertebra	6.99	-19.2	8.7	43.2	15.5	3.3	3.0	0.20	179	583
			SM31a*	Rib	1.19	-19.6	8.3	40.0	14.2	3.3				
79	Mature adult	M	SM204*	Rib	1.89	-19.7	8.6	40.4	14.2	3.3				
80	2–4yr	N/A	SM81b	Femur (cortical)	2.92	-20.4	10.6	41.4	14.8	3.3	2.7	0.22	151	492
			SM100	Rib	14.21	-19.0	10.4	42.9	15.3	3.3	3.4	0.19	188	611
			SM89a*	Femur (trabecular)	1.11	-19.4	10.1	39.5	13.7	3.4				
81	Young adult	?	SM205*	Rib	5.30	-19.4	8.2	41.1	14.6	3.3				
82	15–17yr	?	SM206*	Rib	1.79	-19.5	8.5	39.9	14.0	3.3				
85	Fully adult	F	SM5a	Femur	3.00	-20.7	8.0	36.9	13.4	3.2				
			SM35	Rib	5.23	-19.7	8.3	40.5	14.6	3.2	-1.6	0.18	182	590
			SM48*	Vertebra	2.64	-20.0	8.0	40.4	14.2	3.3				
86	18–20yr	M	SM207*	Rib	5.19	-19.7	8.5	42.2	14.8	3.3				
88	7–9yr	N/A	SM72	Femur	2.52	-20.6	7.8	39.7	14.3	3.2	2.3	0.25	129	417
			SM94	Rib	8.61	-20.0	7.9	43.3	15.5	3.3	1.0	0.20	176	576
			SM109*	Vertebra	2.91	-19.7	8.6	40.7	14.3	3.3				

Appendix 6. Continued

Burial no.	Age	Sex	Sample no.	Sample	% collagen	$\delta^{13}C$	$\delta^{15}N$	%C	%N	C:N	$\delta^{34}S$	%S	N:S	C:S
Sărata Monteoru human bone collagen														
90b	1.5–2yr	N/A	SM80	Femur	2.35	-19.8	10.9	41.6	15.2	3.2	1.9	0.21	166	528
			SM66	Skull	3.09	-19.9	10.8	41.3	14.7	3.3	1.9	0.20	168	549
			SM102*	Rib	2.32	-19.3	10.0	38.2	13.5	3.3				
101	Young adult	F	SM208*	Rib	3.22	-19.5	8.6	41.1	14.5	3.3				
102	15–17yr	?	SM209a*	Rib	2.02	-19.8	8.1	39.3	13.8	3.3				
105	Young adult	F	SM210a*	Rib	2.68	-19.7	8.9	42.0	14.8	3.3				
106	Fully adult	F	SM118	Femur	4.69	-20.5	8.4	42.1	15.1	3.3	-2.6	0.22	158	514
			SM120*	Rib	2.67	-19.4	8.6	41.2	14.5	3.3				
107	Young adult	F	SM211*	Rib	5.52	-19.9	8.8	42.2	14.8	3.3				
108	Fully/Mature	M	SM212a*	Rib	4.33	-19.4	10.4	42.2	14.8	3.3				
112	18–20yr	M	SM213*	Rib	3.39	-19.3	8.8	40.8	14.5	3.3				
115a	Mature adult	F	SM119	Femur	1.96	-20.2	9.7	37.9	13.6	3.3				
			SM121	Rib	1.51	-19.9	9.7	42.1	15.1	3.3	2.8	0.19	183	597
116	3–5yr	N/A	SM78b	Femur	3.39	-20.5	8.8	41.6	14.8	3.3	2.2	0.24	140	460
			SM96*	Rib	4.20	-19.5	8.9	39.4	13.9	3.3				
117	2–3yr	N/A	SM75b	Femur (cortical)	3.24	-20.7	7.2	39.4	14.1	3.3	2.8	0.27	120	390
			SM83b	Femur (trabecular)	5.60	-19.8	7.4	42.8	15.2	3.3	2.0	0.24	148	485
			SM97*	Rib	3.54	-20.0	7.7	39.9	13.9	3.3				
119	5–6yr	N/A	SM74b	Femur	3.76	-20.5	7.9	36.9	13.3	3.2				
			SM104a	Vertebra	2.48	-19.9	8.4	42.8	15.4	3.2	2.1	0.23	152	490
			SM99*	Rib	4.22	-19.7	8.3	40.8	14.4	3.3				
120	9–10yr	N/A	SM73	Femur	3.69	-20.3	8.6	39.6	14.2	3.2	3.7	0.24	137	444
			SM95	Rib	4.05	-20.0	8.6	42.6	15.2	3.3	2.7	0.20	171	555
			SM108*	Vertebra	2.94	-19.6	8.8	40.0	14.0	3.3				
122	Young adult	F	SM114	Femur	2.97	-20.6	9.0	40.3	14.5	3.2	3.9	0.21	156	505

Appendix 6. Continued

Burial no.	Age	Sex	Sample no.	Sample	% collagen	$\delta^{13}C$	$\delta^{15}N$	%C	%N	C:N	$\delta^{34}S$	%S	N:S	C:S
Sărata Monteoru human bone collagen														
122	Young adult	F	SM123	Rib	2.20	-20.0	8.8	41.3	14.9	3.2	2.8	0.20	173	561
123	17–19yr	M	SM10a	Femur	1.13	**-20.6**	**7.8**	**28.5**	**9.9**	**3.4**				
			SM34b	Rib	3.22	-19.6	7.5	41.6	15.0	3.2	0.2	0.20	174	564
			SM45b*	Vertebra	1.74	-19.7	7.9	39.0	13.7	3.3				
124	2–4yr	N/A	SM82	Femur (cortical)	2.53	-20.7	8.2	40.7	14.7	3.2	3.2	0.21	159	512
			SM101	Rib	4.50	-20.4	7.9	39.7	14.2	3.3	3.3	0.20	166	542
			SM92b*	Femur (trabecular)	1.79	-19.9	8.2	40.3	14.1	3.3				
125	17–19yr	F	SM115	Femur	2.69	-20.4	8.2	41.0	14.7	3.3	3.3	0.20	164	534
			SM125	Rib	6.34	-19.8	8.3	40.5	14.5	3.3	2.8	0.18	180	586
126	Mature adult	M	SM113	Femur	5.23	-20.4	8.8	39.3	14.1	3.3	2.4	0.22	148	482
			SM124*	Rib	2.68	-19.5	9.3	41.3	14.7	3.3				
127	Mature adult	M	SM9b	Femur	2.44	-20.3	7.9	39.8	14.3	3.2	2.9	0.25	131	424
			SM38b	Rib	1.77	-19.7	8.2	41.2	14.9	3.2	2.6	0.22	156	502
			SM44c*	Vertebra	4.11	-19.2	8.8	41.2	14.5	3.3				
128	8–12yr	N/A	SM214*	Rib	6.17	-19.8	8.5	40.8	14.3	3.3				
130	Young adult	F	SM116	Femur	4.20	-20.4	7.8	40.6	14.6	3.2	0.3	0.22	154	501
133	17–19yr	F	SM117	Femur	2.91	-20.6	7.7	36.4	13.2	3.2				
			SM126	Rib	4.19	-19.5	8.0	42.4	15.2	3.3	2.3	0.19	187	608
134	Fully/Mature	F	SM8b	Femur	2.80	-20.6	7.5	38.6	13.8	3.2	3.2	0.26	121	393
			SM37	Rib	2.92	-20.6	7.5	41.2	14.8	3.2	2.8	0.20	174	562
			SM47a*	Vertebra	1.64	-19.7	8.7	39.0	13.6	3.3				
135	Mature adult	F	SM215*	Rib	3.69	-19.3	9.4	40.4	14.2	3.3				

Appendix 6. Continued

Burial no.	Age	Sex	Sample no.	Sample	% collagen	$\delta^{13}C$	$\delta^{15}N$	%C	%N	C:N	$\delta^{34}S$	%S	N:S	C:S
Cârlomăneşti human bone collagen														
1	Young adult	F	SM216*	Rib	8.90	-19.6	9.7	42.9	15.1	3.3				
2	13–15yr	?	SM217*	Rib	11.46	-19.6	9.2	42.5	15.0	3.3				
5	Mature adult	M	SM218*	Rib	7.83	-19.4	9.7	42.4	14.9	3.3				
19	Mature adult	F	SM219*	Rib	5.89	-19.3	10.2	42.0	14.7	3.3				
24	10–12yr	N/A	SM220*	Rib	6.59	-19.5	9.2	42.4	15.0	3.3				
51	9–13yr	N/A	SM221*	Rib	5.22	-19.2	9.7	41.9	14.9	3.3				
58	8–9yr	N/A	SM222*	Rib	8.00	-18.9	9.0	42.5	15.1	3.3				
80a	Mature adult	F	SM223*	Rib	8.60	-19.3	10.1	42.9	15.2	3.3				
103	Mature adult	F	SM224b*	Rib	1.46	-19.4	10.0	38.0	13.3	3.3				
105a	8–9yr	N/A	SM225*	Rib	7.94	-19.3	9.4	41.6	15.0	3.3				

Context no.	Species	Age	Sample no.	Sample	% collagen	$\delta^{13}C$	$\delta^{15}N$	%C	%N	C:N
Sărata Monteoru animal bone collagen										
2-SM	Ovis/Capra	N/A	SM128*	Scapula	10.64	-19.4	6.1	42.2	14.8	3.3
3-SM	Ovis/Capra	N/A	SM129*	Astragalus	4.02	-20.0	5.9	40.0	14.1	3.3
4-SM	Sus	Young	SM130*	Phalanx	4.58	-19.9	7.4	40.5	14.4	3.3
5-SM	Sus	N/A	SM131*	Scapula	6.64	-19.1	9.8	39.6	13.5	3.4
6-SM	Ovis/Capra	N/A	SM132*	Phalanx	10.47	-19.1	6.4	41.8	14.9	3.3
7-SM	Ovis/Capra	N/A	SM133*	Humerus	6.39	-19.6	5.9	41.1	14.4	3.3
8-SM	Bos	N/A	SM134*	Metacarpal	9.05	-20.0	6.6	38.1	13.6	3.3
9-SM	Sus	N/A	SM135*	Mandible	3.06	-19.5	7.6	40.1	14.1	3.3
10-SM	Bos	N/A	SM226b*	Carpal	1.95	-20.0	6.3	39.9	14.1	3.3
11-SM	Ovis/Capra	N/A	SM227*	Phalanx	3.87	-19.0	5.4	41.1	14.6	3.3

Appendix 6. Continued

Context no.	Species	Age	Sample no.	Sample	% collagen	$\delta^{13}C$	$\delta^{15}N$	%C	%N	C:N
Sărata Monteoru animal bone collagen										
13-SM	Ovis/Capra	N/A	SM139*	Tibia	7.27	-18.9	5.7	34.3	12.1	3.3
14-SM	Bos	N/A	SM228*	Metatarsal	3.36	-20.7	7.8	41.4	14.7	3.3
15-SM	Bos	N/A	SM141*	Rib	4.64	-19.5	6.4	41.1	14.5	3.3
16-SM	Canis	N/A	SM142*	Axis	14.60	-19.2	8.4	42.7	15.0	3.3
19-SM	Ovis/Capra	N/A	SM144a*	Phalanx	3.52	-20.2	7.4	40.4	14.1	3.4
20-SM	Bos	N/A	SM145*	Carpal	3.59	-20.5	6.4	40.1	14.0	3.4
21-SM	Equus	N/A	SM146*	Metatarsal	4.27	-19.9	6.4	41.1	14.4	3.3
Cârlomăneşti animal bone collagen										
22-CRL	Bos	N/A	SM147*	Phalanx	6.96	-20.6	6.5	42.0	14.9	3.3
24-CRL	Ovis	N/A	SM148*	Metacarpal	21.71	-20.1	5.8	41.8	14.9	3.3
25-CRL	Equus	N/A	SM149*	Calcaneus	4.67	**-19.6**	**4.8**	**16.0**	**5.5**	**3.4**
26-CRL	Ovis/Capra	N/A	SM150*	Calcaneus	17.33	-19.9	6.0	41.9	14.9	3.3
29-CRL	Equus	N/A	SM151*	Phalanx	6.77	-19.5	2.8	42.4	15.0	3.3
30-CRL	Bos	Young	SM152*	Calcaneus	5.23	-20.3	7.7	36.7	13.0	3.3
31-CRL	Sus	N/A	SM153*	Calcaneus	11.28	-13.5	6.2	42.4	15.3	3.2
32-CRL	Sus	N/A	SM154*	Phalanx	12.55	-18.5	5.2	41.7	15.1	3.2
33-CRL	Cervus	N/A	SM155*	Phalanx	3.16	**-20.8**	**4.3**	**28.8**	**10.2**	**3.3**
34-CRL	Sus	N/A	SM156*	Mandible	8.80	**-19.5**	**7.9**	**26.2**	**9.1**	**3.4**
35-CRL	Canis	N/A	SM157*	Vertebra	6.50	-20.0	9.8	39.9	14.3	3.3
36-CRL	Sus	N/A	SM158*	Metacarpal	13.44	-18.6	6.3	41.4	14.9	3.2
37-CRL	Bos	N/A	SM159*	Tarsal	7.49	-20.2	5.6	41.7	15.0	3.2
39-CRL	Ovis/Capra	N/A	SM160*	Humerus	18.38	-16.4	6.8	34.5	12.4	3.3
40-CRL	Ovis/Capra	N/A	SM161*	Mandible	17.12	-22.1	6.4	42.5	15.5	3.2
41-CRL	Sus	N/A	SM162*	Mandible	13.08	-20.6	6.1	42.5	15.3	3.3
43-CRL	Sus	N/A	SM164*	Fibula	14.38	-20.5	5.8	42.9	15.1	3.3

Appendix 6. Continued

Context no.	Species	Age	Sample no.	Sample	% collagen	$\delta^{13}C$	$\delta^{15}N$	%C	%N	C:N
Cârlomăneşti animal bone collagen										
44-CRL	Canis	N/A	SM163*	Mandible	9.77	-19.2	9.0	42.0	15.0	3.3
45-CRL	Lepus	N/A	SM165*	Tibia	14.06	-19.5	3.0	42.4	15.0	3.3
46-CRL	Bos	N/A	SM230*	Calcaneus	8.04	-19.5	5.3	41.4	14.8	3.3
47-CRL	Bos	N/A	SM231*	Metapodial	4.95	-20.6	8.2	33.4	11.6	3.4
48-CRL	Ovis/Capra	N/A	SM168*	Phalanx	5.95	-20.3	7.6	41.7	14.7	3.3
49-CRL	Equus	N/A	SM169*	Phalanx	4.60	-20.9	3.2	40.5	14.4	3.3
51-CRL	Bos	N/A	SM170*	Phalanx	9.64	-20.4	6.1	41.4	14.7	3.3
52-CRL	Canis	N/A	SM171*	Mandible	11.59	-19.5	9.7	41.7	14.9	3.3
53-CRL	Ovis/Capra	Young	SM172*	Mandible	11.25	-20.6	6.1	41.8	14.8	3.3
55-CRL	Ovis/Capra	Young	SM173*	Mandible	10.60	-17.1	7.9	42.1	14.9	3.3
56-CRL	Canis	N/A	SM232*	Astragalus	13.20	-19.4	7.9	41.6	14.7	3.3
57-CRL	Sus	N/A	SM174*	Maxilla	12.15	-19.1	6.6	41.9	14.9	3.3
58-CRL	Sus	N/A	SM175*	Mandible	6.19	-19.4	6.7	41.6	14.7	3.3
59-CRL	Bos	N/A	SM176*	Phalanx	10.29	-19.4	6.1	39.7	14.1	3.3
60-CRL	Bos	N/A	SM233*	Phalanx	4.60	-20.2	7.0	38.1	13.3	3.3
61-CRL	Bos	N/A	SM178*	Phalanx	9.63	-20.5	6.1	42.1	15.0	3.3
62-CRL	Canis	N/A	SM179*	Atlas	7.56	-19.5	8.9	41.4	14.7	3.3
63-CRL	Canis	N/A	SM180*	Atlas	10.46	-19.0	9.9	42.1	15.0	3.3
64-CRL	Bos	N/A	SM181*	Phalanx	7.28	-19.8	5.5	41.8	14.9	3.3
65-CRL	Ovis/Capra	N/A	SM182*	Astragalus	7.57	-20.5	4.5	41.8	14.8	3.3
66-CRL	Canis	N/A	SM234*	Metapodial	7.93	-19.1	9.8	42.6	15.0	3.3
67-CRL	Ovis/Capra	N/A	SM184*	Calcaneus	14.80	-20.4	4.9	42.2	15.0	3.3

Appendix 6. Continued

Burial no.	Age	Sex	Sample no.	Sample	% collagen	$\delta^{13}C$	$\delta^{15}N$	%C	%N	C:N
Sărata Monteoru human teeth dentine										
63	19–21yr	F	SM235a	M1 dentine	15.17	-19.7	40.6	10.2	14.5	3.3
			SM235b		23.63	-20.0	35.6	8.5	12.8	3.2
			SM235c		13.46	-20.1	38.9	8.5	14.0	3.3
			SM235d		15.81	-20.2	37.8	8.5	13.5	3.3
			SM235e		17.64	-20.1	38.0	8.1	13.6	3.3
			SM235f		38.60	-20.1	30.9	8.4	11.0	3.3
81	Young adult	?	SM236a	M1 dentine	17.16	-19.1	39.0	10.3	14.1	3.2
			SM236b		13.85	-19.5	39.5	8.4	14.3	3.2
			SM236c		14.24	-19.6	38.9	8.2	14.0	3.2
			SM236d		19.22	-19.6	34.8	8.3	12.4	3.3
			SM236e		26.34	-19.8	31.6	8.8	11.4	3.2
86	18–20yr	M	SM237a	M1 dentine	15.49	-19.8	39.1	9.0	14.0	3.2
			SM237b		12.58	-20.2	41.2	7.9	14.8	3.2
			SM237c		15.20	-20.2	38.4	7.6	13.9	3.2
			SM237d		12.80	-20.1	43.7	7.6	15.8	3.2
			SM237e		21.55	-20.2	36.7	7.8	13.1	3.3
			SM237f		28.35	**-20.0**	**24.3**	**7.9**	**8.7**	**3.3**
105	Young adult	F	SM238a	M1 dentine	15.95	-18.8	38.3	12.4	13.8	3.2
			SM238b		13.77	-19.3	38.6	10.9	13.9	3.2
			SM238c		15.77	-19.8	38.4	9.3	13.9	3.2
			SM238d		19.70	-19.9	32.8	8.9	11.7	3.3

APPENDIX 7

Estimates generated by FRUITS (%) with a 1-sigma standard deviation for Sărata Monteoru using a population mean calculated from all samples, only ribs, and only femurs.

	'All sample'		**'Rib-only'**		**'Femur-only'**	
	Manured	**Un-manured**	**Manured**	**Un-manured**	**Manured**	**Un-manured**
Food (%)						
Animals	17 ± 12	27 ± 14	17 ± 12	26 ± 13	17 ± 13	28 ± 14
Cereals	34 ± 23	37 ± 25	34 ± 24	38 ± 25	33 ± 23	36 ± 25
Legumes	49 ± 20	36 ± 19	49 ± 21	36 ± 19	50 ± 21	36 ± 19
Fraction (%)						
Protein	21 ± 4	21 ± 4	21 ± 4	21 ± 4	21 ± 4	21 ± 4
Energy	79 ± 4	79 ± 4	79 ± 4	79 ± 4	79 ± 4	79 ± 4
Proxy (Food) (%)						
^{13}C Animal	19 ± 19	29 ± 14	18 ± 13	29 ± 14	19 ± 13	30 ± 14
^{13}C Cereal	30 ± 22	33 ± 24	30 ± 22	34 ± 24	29 ± 22	32 ± 23
^{13}C Legume	51 ±20	38 ± 19	52 ± 20	37 ± 19	52 ± 20	38 ± 19
^{15}N Animal	23 ± 15	37 ± 15	23 ± 15	37 ± 15	23 ± 15	38 ± 15
^{15}N Cereal	19 ± 18	22 ± 19	20 ± 18	22 ± 19	19 ± 18	21 ± 19
^{15}N Legume	58 ± 19	41 ± 19	57 ± 19	41 ± 18	58 ± 19	41 ± 18