Analysis of 13C and 15N isotopes from Eurasian Quaternary fossils: Insights in diet, climate and ecology

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CHAPTER 1

INTRODUCTION

The environmental context in which the cultural and physical evolution of humans took place is a crucial aspect of archaeological research. Copious numbers of papers are devoted to the palaeoenvironmental reconstruction of the hominin niche during the Quaternary; a period that is characterized by major climatic changes as can be deduced from the different proxies preserved in the geological record.

A powerful tool to investigate the palaeoecological conditions in which hominins operated is the analysis of the stable carbon and nitrogen isotope signals in fossil bones and teeth. Fossil tissue reflects the chemical composition of the food that an organism ingested during its life. The stable carbon and nitrogen isotope compositions in the bone collagen of for instance herbivores are related to the isotopic composition of the plants they are eating, and in turn, the stable carbon and nitrogen values in these plants (and soils) are controlled by climatic and (local) environmental parameters. With the growing interest in environmental and dietary issues, combined with major technological innovations, the application of stable isotope studies increased dramatically since the publication of one of the first stable isotope papers written by Vogel and van der Merwe (1977) about the use of stable carbon isotope signals to distinguish between consumption of so-called C3 and C4 plants.

Stable isotope analysis is, nowadays, more commonly used in modern archaeological research. These studies are not limited to human fossils. Stable isotope data of co-occurring animals are also a valuable source of information for the reconstruction of the palaeoenvironment in which humans operated and a big advantage is that animal fossils are much more numerous than hominin remains. The application of stable isotope analysis offers an additional or another perspective on results achieved by other archaeological methods. Given the current sophistication of isotope measurement technology, low costs and fast sample throughput, large data sets are available nowadays.

1.1 Research foci

During the past years, the author was involved in several research projects, amongst others the investigation of fossils from Late Pleistocene Eurasia, from the North Sea region and from the archaeological site Schöningen (Germany). This thesis presents a compilation of several stable isotope case studies executed in the frame of these projects. These studies are mainly based on data from samples collected and chemically prepared by the author and on $\delta^{15}N$ and $\delta^{13}C$ data that were available at the Centre for Isotope Research, University of Groningen. The discussed dataset is extensive and allows to detect and compare inter- and intraspecific, diachronic and spatial patterns of feeding behaviour and habitat use. The dataset is valuable not only for its size, but also for the species it represents, the age of the samples and their geographical origin. The geographical distribution of the investigated samples is presented in Fig. 1.1.

Figure 1.1 The geographical distribution of all investigated samples. Regions are marked with a number that corresponds to the chapter in which the samples are discussed.

The focuses of the case studies are larger herbivores from: 1) the Late Pleistocene and Early Holocene fossil record from a number of regions within the Eurasian mammoth steppe biome, and 2) the Lower Palaeolithic and late Middle Pleistocene archaeological sites at Schöningen (Germany). The mammoth steppe biome and Schöningen are introduced in the sections 1.1.1 and 1.1.2, respectively.

1.1.1 The mammoth steppe ecosystem

The stable isotope data (except those from Schöningen) are from ^{14}C dated samples and are, therefore, mostly Holocene or Late Pleistocene in age with a maximum of ca. 50,000 years (which equals 45,000 yr BP (uncalibrated radiocarbon years BP) or ~ 50,000 cal yr BP, see Reimer *et al.*, 2013; van der Plicht and Palstra, 2016). A timespan that includes the Upper Palaeolithic, during which the Neanderthal got extinct and modern humans expanded their distribution range to north of the Arctic Circle. Numerous cave paintings, from for instance France, date from this period. Many of them depict typical ice age mammals, such as woolly mammoth, woolly rhinoceros, giant deer, and aurochs.

The woolly mammoth (*M. primigenius*), with its large size, long tusks and thick fur, became worldwide an icon for the ice age. Its remains have been recovered abundantly throughout its distributional range that, during the Late Pleistocene, covered geographically a huge territory stretching from Western Europe via Eurasia and Beringia to Alaska and northern North America (Guthrie, 1990). The species inhabited a dry and highly productive environment with cold winters and warm summers (Guthrie, 1982, 1990, 2001); an unrivalled biotope that is characterized by its non-analogue combination of plant and animal species. This former 'tundra-steppe' or 'steppe-tundra' consisted of mosaic-like landscapes dominated by grass and herbs communities, with patches of shrub-tundra and forest (Sher *et al.*, 2005). This biotope is often referred to as 'mammoth steppe' (Guthrie, 1990), after its most famous dweller: the woolly mammoth.

There has been a specific relationship between hominins and woolly mammoths throughout the Palaeolithic. For instance, woolly mammoths have been depicted in paintings and sculptures, have formed an important food source, and their bones have been used as construction materials in dwellings and in modified form as tools (Soffer *et al.*, 1997; Svoboda *et al.*, 2005; Braun and Palombo, 2012; Agam and Barkai, 2018; Guil-Guerrero *et al.*, 2018).

At the end of the Pleistocene, climatic ameliorations from cold and arid to warmer and wetter circumstances caused sea level rise and replacement of the original 'mammoth steppe' vegetation by less productive mesic tundra in the north and (larch) forest further south (Lozhkin, 1993; Hoffecker and Elias, 2007; Andreev *et al.*, 2011). The environmental alterations were critical for the geographical distribution of many plant and animal species. Several typical mammoth steppe faunal elements, including the woolly mammoth, became extinct (Guthrie, 2001; Stuart *et al.*, 2002; Lister and Stuart, 2008; Stuart, 2015; Puzachenko *et al.*, 2017).

The mammoth steppe ecosystem has been subject to extensive multidisciplinary investigations, using 'classical' palaeontological methods and applying 'modern' techniques to study changes in different proxies. The adaptation of flora and fauna to the changes in climate during the Late Pleistocene-Early Holocene is an important research topic.

Insights into the geographical distribution of mammoths during the last 50,000 years have been obtained by analysing huge datasets of radiocarbon (^{14}C) dated remains from more than a thousand localities which yielded woolly mammoth remains (Stuart, 2005; Puzachenko *et al.*, 2017; Lister and Stuart, 2019). Moreover, extensive stable carbon and nitrogen isotope studies on various mammoth steppe dwellers from numerous localities across Eurasia and Alaska have been performed (Iacumin *et al.*, 2000; Bocherens, 2003; Drucker *et al.*, 2003b, 2014; Richards and Hedges, 2003; Stevens and Hedges, 2004; Fox-Dobbs *et al.*, 2008; Szpak *et al.*, 2010).

1.1.2 The Lower Palaeolithic sites of Schöningen

Successful stable isotope research is not restricted to samples within the ^{14}C age range. As long as collagen is well preserved, older samples can also yield reliable stable isotope data that can be used to reconstruct for instance the diet of specific species and their palaeoenvironmental conditions further back in time. Even Lower Palaeolithic samples can be good enough as indicated by the investigations of the fossils from Schöningen (Germany), assessed to be about 300,000 years old (van Kolfschoten *et al.*, 2012; Lang *et al.*, 2012).

The Schöningen Lower Palaeolithic sites are located east of the German village Schöningen, in an area with remnants of huge quarries; the result of opencast brown coal exploitation. In order to reach the Tertiary lignite, the overlying Quaternary sediments had to be removed. This resulted in the discovery of a number of sites yielding important archaeological finds. Most famous are the Palaeolithic wooden throwing sticks and perfectly shaped wooden spears discovered in 1995 (Thieme, 1997). The spears were found at the so-called Schö 13 II-4 site, referred to as the 'spear horizon', amongst thousands of remains of butchered horses (Voormolen, 2008; van Kolfschoten *et al.*, 2015a).

The fossil remains are extremely well preserved, allowing a detailed study of the bone surface displaying numerous cut marks, (long) scraping marks and small and large impact notches indicative for hominin activities such as dismembering, intensive marrow extraction and the use of bones as tools (van Kolfschoten *et al.*, 2015b). The excellent preservation is also reflected in the state of the fossil bone collagen. The collagen of many bones is in pristine condition which allows to investigate the stable isotope signal of the Lower Palaeolithic bones.

1.2 Research objectives

This research contributes to our understanding of the palaeoecological conditions during the Pleistocene/Early Holocene in Eurasia by analysing the stable isotope compositions of fossils from specific mammalian species which inhabited Eurasia. More specifically, the case studies in this thesis contribute - directly or indirectly - to answering the following research questions (RQs):

1. *What are the geographical as well as temporal differences in the stable isotope signals of the woolly mammoth fossils?*
2. *Does the stable isotope signal of the fossil bone tissue of the last surviving woolly mammoths in North-Eastern Siberia show similar changes as detected in Eastern Europe?*
3. *Was climate change the fatal blow for the woolly mammoth?*
4. *Which regional palaeoenvironmental conditions might have prevented an earlier human migration to the east?*
5. *What are the factors behind the observed discrepancy in $\delta^{15}N$ values between herbivores?*

6. *What was the diet of the* Elasmotherium sibiricum*, and how might this have contributed to its extinction?*
7. *What is the preservation state of the collagen from the Schöningen fossils like?*
8. *What was the proportion of forest versus open landscape during the deposition of different levels in Schöningen?*
9. *What was the diet of the Schöningen horses like, leading to such a distinct molar wear pattern?*

The research topics are elaborated in the following two sections.

1.2.1 Research questions concerning the mammoth steppe ecosystem

Although our knowledge of the mammoth steppe ecosystem has increased over the last decades, there are still several questions unanswered. Key questions concern the uniformity of the mammoth steppe biome through time and space (**RQ 1**). Studies on various proxies revealed interregional differences, which are in particular clear if one compares Eurasia and Alaska (Guthrie, 2001; Bocherens, 2003; Rivals *et al.*, 2010; Szpak *et al.*, 2010). Stable isotope studies indicate a distinctive pattern of elevated stable nitrogen values and depleted stable carbon values in mammal samples from Siberia compared to the values in samples from Europe, as well as from Alaska (Bocherens, 2003; Szpak *et al.*, 2010).

Diachronic differences in stable carbon and nitrogen isotope values have been observed in mammoth steppe faunal species other than woolly mammoths that occurred in North-western Europe and, although less pronounced, in Alaska. The changing isotope compositions have been linked to changes in environmental circumstances, especially those that were driven by major climatic changes that took place around the Last Glacial Maximum (LGM) and the Pleistocene/Holocene transition dating to roughly 25,000 and 11,000 years ago, respectively (Drucker *et al.*, 2003b, 2008; Richards and Hedges, 2003; Stevens and Hedges, 2004; Fox-Dobbs *et al.*, 2008).

Indeed, several regions of the woolly mammoth steppe biome have been extensively studied. However, in specific regions there are often chronological hiatuses in the stable isotope record and/or low sampling density within parts of the mammoth steppe biotope, which hampers a comparison of the data and the observation of possible changes through time (Fox-Dobbs *et al.*, 2008). For instance, published stable nitrogen and carbon data of woolly mammoth samples with a post-LGM age and in particular with an LGM age are scarce. However, it is interesting to know if the diet of the mammoth and hence, the stable isotope signal in the fossil bone tissue changed when the species approached its extinction (**RQ 2, 3**). North-eastern Siberia (number 3 in Fig. 1.1) was more or less continuously inhabited by the woolly mammoth from its first presence (~ 400,000 years ago) until its very extinction (~ 4,000 years ago). The most recent woolly mammoth remains with an age of 3685 ± 60 ^{14}C yr BP (Vartanyan *et al.*, 2008) are from Wrangel Island.

There is an ongoing debate about what caused the megafauna extinctions (including the woolly mammoth) towards the end of the Pleistocene (for example, Lorenzen *et al.*, 2011; Stuart, 2015). Among the predominant hypotheses for the extinction of the woolly mammoth, are a) the overkill hypotheses stating that mainly human hunters are responsible for the extinction whereas other scholars assume that b) climate change played a major role; a third option is that the combination of overkill and climate change led to the megafauna extinction (for example, Martin, 1984; Koch and Barnosky, 2006; Haynes, 2007; Nikolskiy *et al.*, 2011; Braje and Erlandson, 2013; Cooper *et al.*, 2015). A dramatic shift in the stable carbon and nitrogen isotope values, observed in woolly mammoth fossils from the central East European Plains, coincide with the local extinction of the species. The shift in isotope values is associated with changing diet and environmental change and points to niche competition with other large herbivores. The changing circumstances possibly made in particular the woolly mammoths susceptible to overhunting (Drucker *et al.*, 2014, 2018).

It is very unlikely that niche competition with other large herbivores or human presence played a role in the extinction of the woolly mammoths at Wrangel Island (Gerasimov *et al.*, 2006; Nikolskiy *et al.*, 2011; Zimov *et al.*, 2012). If climate change is the major trigger that led to the extinction of the woolly mammoth, it is most probably reflected as changes in the stable carbon and nitrogen values in the fossil bones (**RQ 3**).

North-eastern Siberia is of major interest from an archaeological point of view, because humans crossed the area on their way from Eurasia to North America. Humans inhabited North-eastern Siberia (western Beringia) well before the onset of the LGM (for example, Pitulko *et al.*, 2004). Recent data support previous indications that show that humans were present even north of the polar circle as early as ca. 45,000 years ago (Pitulko, 2016). The timing of the human migration to the Americas, via Beringia, is a topic of an ongoing debate. There seems to be a general consensus, based on archaeological data, that the dispersal into North America did not take place until ca. 14,000 years ago (Guthrie, 2006; Wooller *et al.*, 2018). However, Vachula *et al.* (2019) suggest, based on for example recent genetic data and on the discovery of faecal biomarkers in the sediment archive of Lake E5 (Alaska), that humans might have been present in eastern Beringia (the American Arctic) already by ca. 32,000 years ago. The Late Pleistocene palaeoenvironmental conditions in Beringia play a crucial role in the debate on the timing and the pathway of human migration into North America and include among others the restricted geographical distribution of species such as the woolly rhinoceros, which flourished throughout Eurasia, but never crossed the Beringian land bridge between Eurasia and America (Guthrie, 2001; **RQ 4**).

The concentration of the stable carbon and nitrogen stable isotopes in, for instance bone collagen, is influenced by natural fractionation processes and depends heavily on the diet of the individual. The nitrogen values depend heavily on the trophic level of a species (DeNiro and Epstein, 1981; Schoeninger and DeNiro, 1984). However, stable nitrogen isotope data from Late Pleistocene mammals often show dramatic differences between those values of the extinct Pleistocene woolly mammoth and those of coeval living large herbivores (Bocherens, 2003; **RQ 5**).

Another impressive mammoth steppe dweller, the giant rhinoceros or Siberian unicorn (*Elasmotherium sibiricum*), raised questions that demand stable isotope research. It was generally assumed that this Pleistocene megafauna species survived in the steppic zone of eastern Europe and Asia until ca. 200,000 years ago (see number 5 in Fig. 1.1). However, new ^{14}C data of specimens from a number of localities convincingly indicate an extinction during the Late Pleistocene (Kosintsev *et al.*, 2019). The unique morphology of the dentition of the animal suggests a highly specialised diet (**RQ 6**).

1.2.2 Research questions concerning the Palaeolithic sites at Schöningen

The application of stable isotope research on older material is challenging. The Middle Pleistocene bones, botanical remains, and even insect remains collected at the sites in Schöningen are extraordinary well-preserved (see number 6 in Fig. 1.1). In case the collagen is preserved as well (**RQ 7**), stable isotope studies can contribute to the debate on environmental and morphological issues at the Schöningen sites. Since the discovery in 1992 of Palaeolithic bones and wooden- and stone artefacts, the focus of the ongoing multidisciplinary research has been on (bio)stratigraphical dating of the sites and the individual find horizons, on reconstructing the palaeoenvironment in which the hominins operated, and on subsistence strategies of the hominins. The Lower Palaeolithic finds are from a period of changing climate: from an interglacial optimum at the base of a sequence of successive depositional levels to the next cold stage at the top of the sequence. Botanical proxies are indicative for the occurrence of warm deciduous forest during the warm phase and for boreal forest and steppe vegetation during the colder periods. However, such a climate and environmental change within the different successive deposits is less obvious in the mammalian faunal record (**RQ 8**).

In addition, the macro- and microwear patterns of the horse molars from Schöningen diverge from those found in most other periods and sites in Central Europe (Rivals *et al.*, 2015). They show unusual pointed cusps indicating an abnormal diet (**RQ 9**).

1.3 Outline of the thesis

After the Introduction (**Chapter 1**), **Chapter 2** discusses the basic principles of ^{13}C and ^{15}N stable isotope research and its applications, and the applied analytical methods. The following chapters (3 - 6) present stable isotope research that has been published in different journals. The data and conclusions presented in the chapters match those in the original publications. However, the text presented in the chapters 3-6 has been modified in order to enhance coherence and consistency and prevent repetition throughout the thesis, and occasionally extra (background) information is provided. That is, parts of the introduction of the original articles have been incorporated in this thesis in the section on research goals and site description (Chapter 1), and most of the methodological aspects from the articles have been aggregated in Chapter 2.

Chapter 3 discusses an extensive stable isotope record of Late Pleistocene and Holocene woolly mammoths from North-eastern Siberia. Aim of the stable isotope studies of the east Siberian mammoth, presented in **Chapter 3**, is to track possible shifts within the stable carbon and nitrogen record coinciding with global climatic changes as were observed in other parts of the mammoth steppe biotope. Special focus is drawn to the Holocene data of fossils from Wrangel Island, in order to increase our understanding of the conditions under which the last mammoths lived.

Chapter 3 provides us with information about the conditions in the central part of the mammoth steppe biome, whereas **Chapter 4** presents stable isotope data from the western part of the mammoth steppe ecosystem, that is, the North Sea area (see number 4 in Fig. 1.1). During the Weichselian, the sea-level dropped dramatically and a landmass, that can be regarded as the western extension of the North European Plain (Schild, 1976), connected the European Continent and Great Britain. This landmass was intersected by large rivers (Hijma *et al.*, 2012) and covered by a characteristic mammoth steppe vegetation. The large amount of (mainly unstratified) fossils, including Neanderthal and anatomically modern human remains, indicate that the area was roamed by the typical mammoth steppe fauna with species such as the woolly mammoth, the woolly rhinoceros and large carnivores such as cave hyenas and lions. In the past decades, thousands of fossil remains have been collected, often from a stratigraphically disturbed context. In order to place the finds within a chronological context, many fossils have been ^{14}C dated. This resulted in a large set of ^{14}C data as well as stable isotope data, both from animals and humans. These data are discussed in **Chapter 4**.

Fossil remains from the characteristic Pleistocene megafauna in South-eastern Europe and adjacent areas in Asia indicate that the mammoth steppe biome stretched well into these regions. **Chapter 5** presents Late Pleistocene data of an extinct species that lived in the southern part of the mammoth steppe, the giant rhinoceros (*Elasmotherium sibiricum*). New ^{14}C data of fossils from the giant rhinoceros convincingly show that the species became extinct much later than assumed, that is during the Late Pleistocene (Kosintsev *et al.*, 2019). Changes within the environmental conditions might explain the extinction of the species. An additional, interesting topic is the diet of Elasmotherium. The species has extremely high-crowned rootless molars; a feature that is regarded as an adaptation to very abrasive food. The stable isotope data as examined in **Chapter 5** are an important proxy in the debate on the diet of the 'Siberian unicorn'.

Good quality collagen in bones that are way older than 50,000 years is scarce. In 2009, a pilot study, financially supported by the Leiden University Foundation (LUF), was executed to investigate whether the bones from the Middle Pleistocene archaeological sites in Schöningen, despite their age, contain collagen that potentially could be used for isotope research. Because of the very promising results (van der Plicht *et al.*, 2011) more fossils from different taxa and from different stratigraphical horizons were sampled for stable carbon and nitrogen isotope analyses in order to gain additional environmental and dietary information of the various animal species in Schöningen. **Chapter 6** presents and discusses the carbon and nitrogen isotope data from the faunal remains from Schöningen (~ 300,000 years old). Because of the age of the samples, special attention is given to preservation issues of the collagen.

The results and conclusions of the case studies presented in the **Chapter 3-6** are integrated and discussed in **Chapter 7**.

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