Neolithic agricultural management in the Eastern Mediterranean:

new insight from a multi-isotope approach

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degree of Doctor of Philosophy

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Abstract

The work presented in this dissertation explores the nature of agro-pastoral strategies developed by Neolithic farmers as a way to understand how early food production was inter-twined with environmental and socio-economic opportunities and constraints. Towards this end, a multi-isotope approach is used to address questions of scale and intensity of crop cultivation and animal management at the archaeological sites of Kouphovouno, southern Greece, Makriyalos, northern Greece, and Çatalhöyük, south-central Turkey. Measurements of stable carbon, nitrogen, oxygen and strontium isotope values of carbonized plant remains, human and animal bone collagen and animal tooth enamel are used to examine the similarities and differences in the types of treatments that individual species of plants and animals received during the agricultural cycle at the distinct locations. The results show that farmers at the three sites developed variable methods for exploiting the arable and pastoral landscape and catering to their economic and culinary needs. The discussion considers the implications of these findings to our understanding of the complexity and adaptability of early farming systems.

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Dedicated to Ivo Rubík,
an all-rounded enthusiast for whom losing a battle with cancer at a young age was not a reason to stop smiling.

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C	Carbon
$\delta^{13}C$	Ratio of the stable isotopes of carbon ($^{13}C/^{12}C$)
N	Nitrogen
$\delta^{15}N$	Ratio of the stable isotopes of nitrogen ($^{15}N/^{14}N$)
O	Oxygen
$\delta^{18}O$	Ratio of the stable isotopes of oxygen ($^{18}O/^{16}O$)
Sr	Strontium
Rb	Rubidium
ZooMS	Zooarchaeological Mass Spectrometry
FTIR	Fourier Transform Infrared Spectroscopy
IAEA	International Atomic Energy Agency
VPDB	Vienna BeeDee Belemnite
VSMOW	Vienna Standard Mean Ocean Water
AIR	Ambient Inhalable Reservoir
GNIP	Global Network of Isotopes in Precipitation database
‰	per mill, parts per thousand
C_3	Plants that fix 3–carbon compounds
C_4	Plants that fix 4–carbon compounds
CO_2	Carbon dioxide
EN	Early Neolithic
MN	Middle Neolithic
LN	Late Neolithic
ELN	Early Late Neolithic
LLN	Late Late Neolithic
IGME	Greek Institute of Geology and Mineral Exploration

Chapter 1

Introduction

1.1 Project aims and approaches

The adoption of farming during the Neolithic brought about changes that had far-reaching consequences on the functioning of human societies. Much research has been devoted to exploring the question *why*: why was farming adopted as the primary mode of subsistence independently in several regions around the world? Attempts to answer this question have lead to stimulating discussion surrounding the nature of early farming societies but have stopped short of shedding light on how the actual agro-pastoral systems in different locations worked. It is the pursuit of this question – the question of *how* – that forms the backbone of the present study.

The aim of this project is to explore how distinct farming methods employed by farmers in three locations across central Anatolia and the Aegean were inter-twined with the farmers' responses to environmental opportunities and socio-cultural constructs. Towards this goal, a multi-isotope framework is built for reconstructing aspects of both crop cultivation and animal herding at the Neolithic sites of Kouphovouno (southern Greece), Makriyalos (northern Greece) and Çatalhöyük (central Anatolia) (see Fig. 1.1). Stable carbon and nitrogen isotope measurements of archaeological plant remains are used to assess the types of soils in which the ancient crops were cultivated, stable carbon and nitrogen isotope measurements of humans and animals are employed to identify major contributors to these individuals' diets, stable carbon and oxygen isotope values of tooth enamel is used to study the seasonal dietary and mobility patterns of domestic herbivores and strontium isotope values are used to assess long-distance mobility patterns of animals during the first year of their lives. It is hypothesized that nuances in the agro-pastoral systems developed by these Neolithic populations will reflect a combination of both their adaptation to their natural environment as well as the roles that crops and livestock fulfilled in their subsistence economies.

The dissertation is structured so that each case study receives full consideration on its own before similarities and distinctions are discussed on a wider scale. The objectives of each case study are thus to assess the nature of plant and animal management at the three sites particularly in terms of the scale and intensity of crop cultivation and the seasonal feeding habbits of domestic herbivores. The insight gained from the analysis of stable isotope measurements of charred plants, human and animal bone collagen, and sequential tooth enamel carbonate will be considered in light of previous work on the composition of the archaeobotanical and archaeozoological assemblages, reconstruction of the surrounding landscapes, spatial analysis of the distribution of biological finds across the excavation areas and results of scientific undertakings such as ceramic residue analysis (as applied at the different sites). The overall aims of the dissertation are to assess how similarities and differences in management strategies between the three sites inform our understanding of the consistency of decision-making process involved in food production and the flexibility in agro-pastoral techniques developed by early farmers in central Anatolia and the Aegean.

Some of the stable isotopic work that will form part of the wider discussion has already been carried out by other researchers (Bogaard et al.

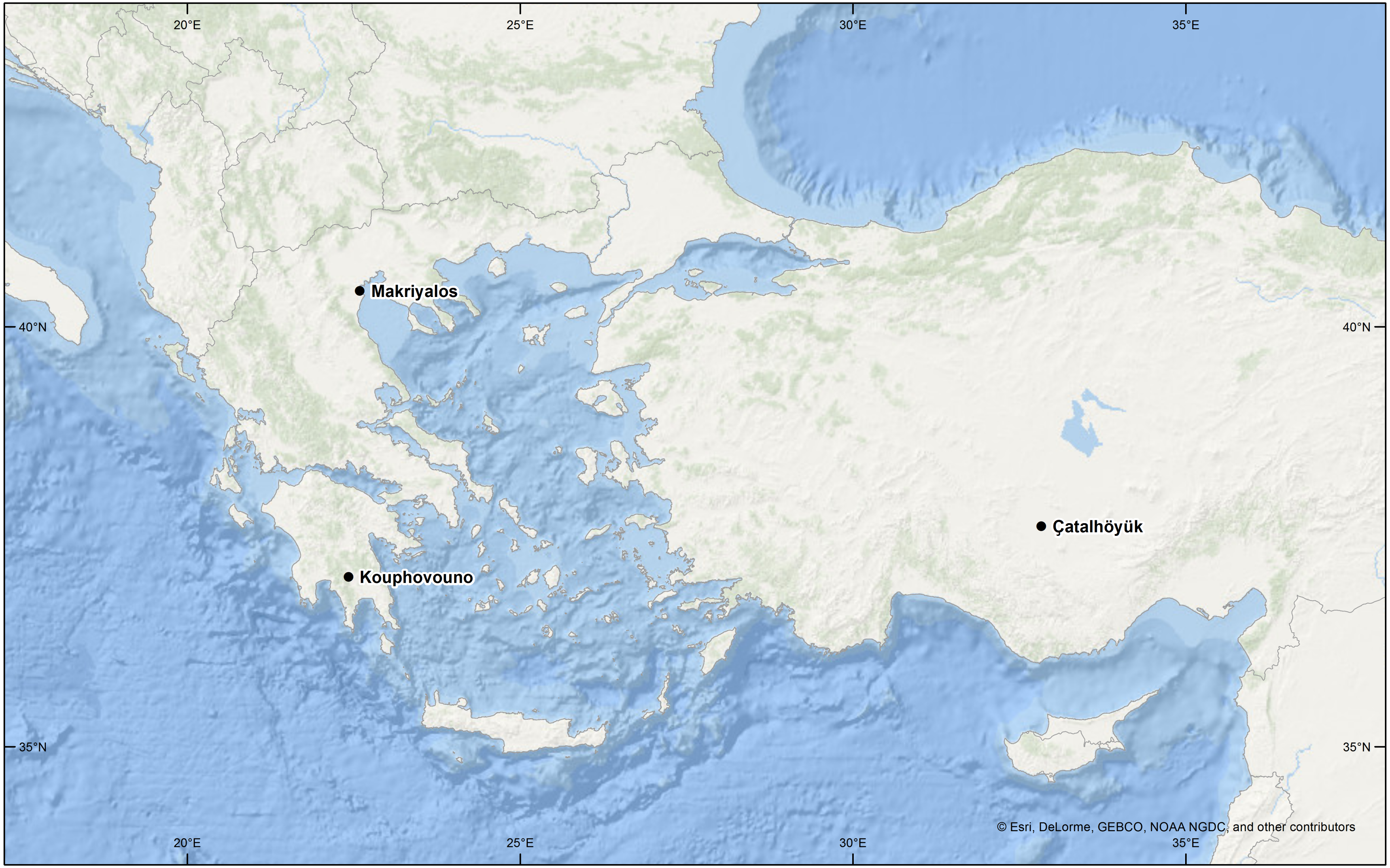


Figure 1.1: Map of Neolithic sites studied in this project: Kouphovouno, southern Greece, Makriyalos, northern Greece, Çatalhöyük, south-central Anatolia (map made by John Pouncett using ArcGIS 10.2)

2014*b*; Henton et al., 2010; Henton, 2012; Pearson et al., 2007; Pearson, 2013; Richards et al., 2003; Styring et al., 2015; Triantaphyllou, 2001, 2008). The analyses carried out herein will complement this earlier work and will be used to build a multi-isotope interpretative framework for addressing the overarching research questions.

1.2 Research aims in archaeological context

1.2.1 Çatalhöyük

Çatalhöyük is an archaeological tell site located in the Konya plain in central Anatolia. Neolithic occupation on the site's East mound took place 7100–6000 cal BC, before habitation shifted to an adjacent mound, the West mound, during the Chalcolithic period (Bayliss et al., 2015). Two very different models have been proposed for what the environment around the site looked like during the Neolithic. The first model inferred that the landscape formed a seasonal swamp which isolated the village for part of the year and forced the farmers to practice cultivation several kilometers away from the settlement (Roberts and Rosen, 2009; Rosen and Roberts, 2005). The second model outlined that the proximal landscape was shaped by a gentler alluvial system that flooded some areas but left others dry, thereby making it possible to cultivate soils closer to the settlement (Charles et al., 2014; Doherty, 2013).

In this study, δ^{13}C and δ^{15}N measurements of charred grains and seeds (n = 135) will provide an opportunity to assess the scale and intensity of crop management practiced by the Neolithic farmers, which will shed light on which environmental model is more plausible. The plant measurements also enable a re-interpretation of the Neolithic human diets, studied previously by Richards et al. (2003), Pearson et al. (2013) and Pearson et al. (2015) using δ^{13}C and δ^{15}N values of human (n = 127) and animal collagen (n = 358). The final discussion will synthesize the new insight gained about land-use around Çatalhöyük with the results of previous measurements of tooth enamel δ^{13}C and δ^{18}O values (Henton, 2012; Henton et al., 2010) and ^{87}Sr/^{86}Sr isotope values (Bogaard et al. 2014*b*) evidencing the animals' early-life grazing patterns. This case study offers an opportunity to observe the mechanism for integrating crop cultivation and animal management at a mega-site situated in an active alluvial landscape.

1.2.2 Kouphovouno

Kouphovouno is an archaeological tell site located in the Sparta basin on the Peloponnesian peninsula in southern Greece. It was occupied between the Middle–Late Neolithic, around 5800–5000 cal BC (Mee et al., 2014). Previous stable isotope work included δ^{13}C and δ^{15}N measurements of a range of charred domestic cereal and pulse grains/seeds (n = 28) and bone collagen of domestic and wild animals (n = 68) (Vaiglova et al. 2014*a*), which were used to assess the scale and intensity of cultivation of free-threshing wheat and barley as well as the possible contribution of these crops to the long-term diets of domestic animals. Since the publication of this work, the full analysis of the archaeobotanical assemblage has been completed (Diffey, 2014), which brought to light a number of additional samples amenable for stable isotope analysis (including a species not measured before: einkorn, *Triticum monococcum*). These samples (n = 19) have been measured in this project in order to expand our understanding of the range of cultivation strategies employed by farmers at this Neolithic site.

To complement the model of the plant management system developed at this site, the question of animal management was pursued through the analysis of sequential tooth enamel carbonate δ^{13}C and δ^{18}O values of sheep and goats (4 teeth per species) from both phases of occupation at the site. The results are used to assess the animals' seasonal grazing patterns and test the hypothesis that some of them were taken to higher altitudes in the proximal Taygetos Mountaints on a transhumant pastoral basis during the summer. Furthermore, the δ^{18}O measurements are used to determine the birth seasonality of the animals – using the method of Balasse et al. 2012*b* – in order to investigate the role of these animals in the subsistence economy of the Neolithic farmers. The insight gained into plant and animal management provides an opportunity to assess the integrity of the agro-pastoral system developed at a relatively small settlement located in a fertile valley.

1.2.3 Makriyalos

Makriyalos is a flat extended settlement located in the coastal region of Pieria in Greek Macedonia. It was occupied during the Early–Late Late Neolithic in two spatially separate phases. During the first phase, Makriyalos I (5500–5000/4900 cal BC), the settlement extended over an area of c.28ha and was enclosed by a pair of concentric ditches. This phase saw the organization of large-scale feasting activity, represented by thousands of animal bones uncovered in pits constructed within the settlement enclosure. During the second phase, Makriyalos II (5000/4900–4500 cal BC), habitation was organized more densely over an area of c.11ha (Pappa et al., 2013).

Previous stable isotopic studies included δ^{13}C and δ^{15}N measurements of human and animal (mostly wild) bone collagen (n = 27) (Triantaphyllou, 2001, 2008). Analysis carried out in the current project will complement the initial analyses by adding samples of other domestic animals (n = 62) and a small number of plants (n = 10) to the dataset. These combined results will provide an opportunity to 1) revise the interpretation of human diets during Makriyalos I, 2) explore the possibility that animals discarded in the feasting deposit had different diets to animals discarded in other types of contexts and 3) assess potential changes in the isotopic composition of domestic animals between the Makriyalos I and II phases. In addition, sequential sampling of tooth enamel carbonate $\delta^{13}C$ and $\delta^{18}O$ values of sheep (4 individuals) and cattle (8 individuals) from both the feasting and habitation contexts will enable a more nuanced assessment of the seasonal grazing patterns of these two animals. Finally, Sr isotope measurement of cattle tooth enamel (8 individuals) will be used to test the hypothesis that some of the animals slaughtered at the large feasts were imported to Makriyalos from the wider geographical landscape.

Due to the limited number of plant samples available for study (resulting from issues of preservation), it will not be possible to draw interpretations about the plant cultivation strategies employed by the farmers at Makriyalos. However, the multi-isotope approach applied on the animal remains will provide a unique opportunity to assess herding management in terms of both land use and large-scale communal consumption.

1.3 Wider contribution to Neolithic archaeology

Discussion following the presentation of the three case studies will synthesize the insight gained by studying aspects of agro-pastoral mechanisms developed by farmers in three different locations across central Anatolia and the Aegean. Even though three case studies are not enough to draw definitive trends in Neolithic farming across the wider geographical region, identifying aspects of diversity between the management systems will be instrumental for assessing the flexibility of the early farming regimes as well as the roles of the agricultural products in the distinct Neolithic societies.

The following questions will guide the discussion of the inferences made in the three case studies:

1. Diversity in arable management: how did crop growing strategies differ at Kouphovouno and Çatalhöyük? Did the farmers cultivate the same crops under the same regimes? What does this tell us about the

environmental opportunities and constraints the farmers faced in these two locations?

2. Diversity in sheep herding: how did sheep management at Kouphovouno, Makriyalos and Çatalhöyük differ? Did these animals graze in local pastures throughout the first year of their lives, were they taken to more distant locations in search of fresh vegetation, or were they foddered on cultivated crops or collected fodder to a significant extent?
3. Human diets: how does the inclusion of plant samples in the stable isotopic datasets at Makriyalos and Çatalhöyük contribute to our understanding of the role that plant foods played in people's long-term diets?
4. Social consumption: what parallels can be drawn between the large-scale consumption of meat during feasts organized at Makriyalos and the public consumption and display of animal products and private storage of plant products at Çatalhöyük (cf Bogaard et al., 2009)?

These themes form the basis for understanding the scope of diversity in agro-pastoral systems developed in separate locations across central Anatolia and the continental Aegean.

1.4 Thesis structure

Chapter 2 presents an overview of the fundamental principles of arable farming. It lays the groundwork for interpreting past agricultural methods by detailing the key steps involved in the agricultural cycle and highlighting where differences in pratices can arise due to variabilities in environmental constraints and farmers' choices and availability of resources.

Chapter 3 provides a review of the main themes and questions in the field of Neolithic archaeology of Anatolia and the Aegean by defining key terms, describing the geogrphy of the study regions and discussing the main debates relevant to the research questions pursued herein.

Chapter 4 details the methodology used in this project by explaining the current state of knowledge of the scientific principles behind stable isotope analysis and discussing the interpretative potential of the materials used in this dissertation (charred plants, bone collagen and tooth enamel carbonate).

The following three chapters describe the work carried out at each of the study sites by first, summarizing the relevant archaeological and environmental background, second, detailing the materials and techniques used in the analysis and third, presenting and interpreting the data in their own right before synthesizing the results within a multi-isotope framework designed to investigate the variability in farming methods across the study locations.

Chapter 5 deals with Çatalhöyük, where the main aim of this new analysis is to use plant stable isotopic values to further our knowledge of crop cultivation strategies employed by farmers at this site and use this knowledge to assess different models of the Neolithic environment that have been put forward by geoarchaeologists.

Chapter 6 presents the case study of Kouphovouno, where the model of intensive small-scale crop cultivation is examined from a new angle and where tooth enamel carbonate values are used to assess ovicaprid management between the two phases of occupation.

Chapter 7 presents Makriyalos, where previous attempts to interpret human diets are re-examined with the inclusion of domestic herbivores in the dataset. The nature of animal diets, on both the seasonal and long-term basis, is explored through contextual analysis of bone collagen data and sequential tooth enamel carbonate values of sheep and cattle. The possiblity of non-locality of cattle consumed during large-scale feasting activity is addressed using strontium isotope measurements of tooth enamel.

Chapter 8 synthesizes the new insight gained into Neolithic farming methods across the case studies and asks questions that seek to compare and contrast the agro-pastoral management systems developed by farmers in the three distinct locations. The theme of diversity is explored through a discussion of variability in arable management practices, herding strategies and consumption of agricultural products.

Chapter 2

Principles of farming

Our ability to imagine how farmers in the past managed their crops and tended to their animals is limited by our understanding of how the agricultural cycle works. Farming is a process that requires strategic planning, acute sense of predicting the weather, knowledge of crops and their growing requirements, and balancing investment into increasing crop yields and decreasing crop failure (Halstead, 2014). It is because the system is so complex that different kinds of agricultural strategies have been developed in distinct ecological niches around the world. Some strategies are more appropriate in certain environmental settings than others, some produce higher yields than others, some involve relocation to new areas on a periodic basis, some leave more traces in the archaeological record than others and all involve decision-making that is entangled with socio-cultural considerations, such as identity, status and technological constraints (Halstead, 2014).

The aim of this section is to provide an introduction to the agricultural process by defining key terms and discussing factors that bring about diversity in practice. First, an outline of the stages of the agricultural cycle will be presented, highlighting where farmers may make decisions that will influence the progress and outcome of the cycle. Second, the discussion will consider how factors such as weather, topography and wealth of farmers impact the timing of the various stages and the choice of management techniques. The section will conclude by outlining the framework used in this project for inferring the scale and intensity of agricultural practice using archaeological materials and warning against absolute quantification of management practices. The discussion will draw heavily on insight gathered by Paul Halstead over years of ethnographic observations and conversations with farmers practicing pre-mechanized forms of agriculture around the Mediterranean (Halstead, 2014). The main modes of agriculture – including shifting and floodplain cultivation, intensive and extensive management and mixed farming – and how they are inter-twined with cultural elements such as social inequality, reciprocity and creation of 'normal' surplus will be discussed in relation to the adoption of farming in the Near East and Southeastern Europe in Chapter 3.3.1.

2.1 The agricultural cycle

The agricultural cycle involves activities that need to be carried out on an annual basis (such as tillage, sowing, harvesting, weeding), inter-annual basis (such as crop-rotation and manuring) and generational cycles (when consumption needs and availability of land, labor and livestock change) (Halstead, 2014, p. 8). Some practices (such as preventative grazing and fallowing) are not necessary, but help reduce the risk of crop failure and improve the soil conditions that will benefit future cultivation (Halstead, 2006). At every stage of the cycle, farmers make decisions that are driven by a combination of cultural elements (identity, status, values), practical elements (rational cost-benefit considerations) and environmental and technological constraints (Halstead, 2014, p. 332). The ways that farmers respond to different choices and available solutions is what causes variability at every step of the process.

Tillage involves the process of turning soil over either by hand with the use of an ard or with the help of draft animals and ploughs in order to help the soil regenerate (Halstead, 2014, p. 34). The process also helps remove any weeds that may have started growing in the soil since the field was last harvested. Some gardens may be too small to maneuver a plough team so they have to be tilled by hand (Halstead, 2014, p. 19). In the Mediterranean, the timing of tillage depends on when the autumn rains are expected to take place: it is beneficial for the crop if the soil is tilled after the rains have started, but waiting too long may mean that the crop will not have time to germinate before the winter frost (Halstead, 2014, p. 23).

Once the soil is ready, seeds can be sown, either in rows (to avoid wasting seedcorn) or by broadcasting (Halstead, 2014, p. 21). The choice may depend on both tradition, skill of efficient broadcasting and the availability of seedcron (Halstead, 2014, p. 29). Crops can be sown either in the autumn/late winter and in the spring. Modern pre-mechanized farmers prefer to sow in the autumn because the crops are more reliable and keep spring sowing as an option in case autumn crops fail due to unfavorable weather conditions or scarcity of labor (Halstead, 2014, p. 25). Uneven land-ownership and access to plough animals can affect the timing of both tillage and sowing (Halstead, 2014, p. 16).

Once mature, crops are harvested by reaping and the timing of this process also depends on weather conditions, availability of labor and the type of crop (or mixtures of crops) that have been sown (Halstead, 2014, p. 67). If crops that ripen at varying times are sown together as a mixed crop ('maslin'), farmers have to find a compromise between reaping too early (when one of the crops is still unripe) and reaping too late (when one crop is too ripe and could shatter) (Halstead, 2014, p. 76). Farmers prefer to harvest either early in the morning or late in the afternoon, when the cereal ears/pulse pods are less dry and less likely to be lost due to shedding (Halstead, 2014, p. 68).

In order to separate grains from straw and remove contaminating weeds and dust, farmers winnow the crop by using large forks to agitate the collected sheaths (if entire sheaths were collected) (Halstead, 2014, p. 151). They then thresh the ears to release the grains from the spikelets. This process tends to take place in the middle of the day to ensure that the crops are dry. Threshing can be done by either beating the cereal ears with wooden implements or using work animals to trample over them on a threshing floor (Halstead, 2014, p. 168). Shod animals (like horses) thresh more quickly than unshod animals (like cattle) (Halstead, 2014, p. 334). The thoroughness of winnowing depends on whether the farmers plan to use the crop to feed themselves or to feed animals. In the case of a fodder crop, the winnowing does not have to be as complete (Halstead, 2014, p. 164).

One of the most reliable ways of improving the fertility of soil and increasing crop yields is by applying manure on soils, but the relationship between amount of manure and the positive benefits it creates is not a simple one (Halstead, 2014, p. 212). Farmers have to make decisions about how much manure to apply depending on the type of soil and the amount of moisture it contains, the type of manure available and how much of it has been applied on a field in the past. Manuring can have negative effects on soil, as it encourages excessive growth of crops which may lead to lodging, it can 'burn' crops if the soil is too dry, it can introduce weeds to the soil and encourage crops to outgrow their water supply (Halstead, 2014, p. 213). For these reasons, farmers have to weigh the costs and benefits of manuring and typically chose to manure at intervals, such as every 10 years (Halstead, 2014, p. 222).

Manuring can be done with silt, ash, leaf mold, kitchen waste and animal dung and urine (Halstead, 2014, p. 212). Animal waste can be either applied manually (by collecting it in stall or byres and applying it on fields after drying and treatment with water) or by allowing animals to graze in fields and drop their dung directly on the soil (Halstead, 2014, p. 226). Halstead

(2014) observed that due to the amount of labor required to apply sufficient amounts of dung on soils, farmers tend to apply manure on fields within 500m of their villages (p. 207, 217). Manure leaves a residual effect on soil, so that ^{15}N–enrichment continues even after the application has stopped, but the effects are highest during the second year after application (Fraser et al., 2011; discussed further in Chapter 4.3).

Preventative grazing is a strategy wherein small animals (ideally sheep, which are most systematic in their grazing behavior) are let onto a cultivated field before the ears of the crops have emerged in order to reduce the height of the crops and help prevent them from lodging (falling over during heavy rains) (Halstead, 2006).

Removal of weeds from fields during the growing season does not only remove competition and improve the soils' water retention, it also helps clean the crop from unwanted materials (some weeds are toxic), makes the crop more suitable for storage and easier to reap (Halstead, 2014, p. 233). Weeding is a laborious process carried out by hand and the types of weeds that grow in soils depend on conditions such as moisture availability, N content, and amount of sunlight available (Halstead, 2014, p. 236).

Irrigation can be done either on a large-scale (when networks of small channels are constructed to feed an area of c.100ha) or a small-scale (when a single stream is diverted into an individual garden of an area smaller than 1ha) (Halstead, 2014, p. 230). Watering enables heavier manuring but increases the need for weeding and preventative grazing and the choice of watering management depends on the scale of agriculture, the amount of people partaking in the system, the resources of the farmers and the availability of water sources (Halstead, 2014, p. 239).

Fallowing is a practice that is designed in order to allow soil to 'rest' (Halstead, 2014, p. 200). Fallow fields can either be cultivated (so that animals can graze on them if pasture is scarce) or uncultivated. Even fallow land has to be ploughed several times in order to help the regeneration process and ensure that the soil does not lose moisture (Forbes, 1976*a*). The availability of fallow fields may increase the numbers of livestock and thus the availability of manure (Halstead, 2014, p. 229).

Farmers can make the best use of their fields by rotating their crops between fields on a regular basis (Halstead, 2014, p. 201). This does not only help the soil regenerate but helps reduce weeds, pests and diseases and increase crop yields. Different kinds of combinations of crops may be rotated: for example, cereals can be rotated with pulses (which fix atmospheric N_2 into the soil), barley can be rotated with wheat and crops can be rotated with fallow (Halstead, 2014, p. 204).

There are many ways in which animals can be integrated into and benefit from arable farming. They can graze in fields cultivated for pasture/green fodder (Halstead, 2014, p. 27), they can eat collected straw (Halstead, 2014, p. 20), weevil-infested or spoiled crop (Halstead, 2014, p. 134), weeds or leafy hay (such as oak) while being stalled (Halstead, 2014, p. 209) or they can be left to graze on fallow fields or failed crops (Halstead, 2014, p. 199). Work animals can feed on straw when they are idle, but need a more nutritious diet when they are employed as draft animals (Halstead, 2014, p. 52). For fattening, animals need to eat 'soft' diets such as cereal grains (Halstead, 2014, p. 141). "Early-bite grazing" can be created by sowing barley on better fields (Halstead, 2014, p. 338). Animals can eat both cereals and pulses, and Halstead (2014) argues that pulse straw is often valued more than cereal straw by farmers around the Mediterranean (p. 78). Sometimes, the decision to use a crop for fodder is taken early in the cycle (when farmers decide to sow the crop early on inadequately tilled soils) or later during the threshing phase (when farmers spontaneously decide to divert some crop for animal feed) (Halstead, 2014, p. 133).

2.2 Diversity in pre-mechanized farming

The choice of management techniques and the timing of the various stages of the agricultural cycle are determined by a combination of environmental constraints, resource availabilities as well as the farmers' motivations.

Timing of weather conditions is critical throughout the entire cycle. Latitude and altitude influence the onset of winter conditions, which impact the timing of sowing (Halstead, 2014, p. 72). For example, in lowland Greece, where the autumn sowing season is short, some crops have to be sown in the spring (Halstead, 2014, p. 25). In higher altitudes, sowing can happen only in a narrow window in October and harvest tends to be delayed so farmers may store crops in sheaths and thresh them over the winter; even though this is less desirable than threshing them in the summer heat and wind (Halstead, 2014, p. 25). In the lowlands, late winter frosts can burn soils, lack of summer breeze may delay winnowing and warm and wet springs may cause excessive growth to crops, which may then suffer through lodging (Halstead, 2014, p. 193). Timing of floods may also be unpredictable (Halstead, 2014, p. 26). Although these climatic fluctuations even out over the long-term, for a given year, they may pose serious threat to the survival of crops and necessitate accurate planning on the part of the farmers.

Topography influences not only the ease with which certain tasks, such as ploughing, can be carried out, but also the timing of when they should be undertaken (Halstead, 2014, p. 57). Scattered landholdings, such as on the island of Methana, have the advantage of allowing farmers to sow and harvest their fields in sequence, which reduces the stress of harvesting all crops in a narrow window of time and the necessity to employ outside labor for the task (Forbes, 1976*b*, 2000). The farmers on this island created scattered landholdings across an altitudinal gradient from the coast into the hills, partly to spread risk and assure that each household is guaranteed a sufficient food supply every year even if a crop fails in one of the rainfall zones, and partly due to a tradition of equal inheritance and dowry. Forbes (1976*b*) argues that this system is geared towards stability rather than productivity.

A significant distinction in farming methods can also be made between farmers of varying wealth status (Halstead, 2014, p. 17). This impacts, for example, how many and what kinds of animals they own. Some farmers have oxen, some have cows, some have donkeys, many have combinations of these animals and many have none. Oxen are advantageous in that they are stronger and last longer, but they cannot be used as pack animals to carry produce and have no other use for secondary products (Halstead, 2014, p. 15). Furthermore, some environments (such as steep slopes or edges of rocky fields) pose practical constraints for this animal. Farmers who are rich can afford to leave a field fallow and still produce enough normal surplus (Halstead, 2014, p. 351). Their fields can thus regenerate more easily and produce bigger yields when cultivated. Rich farmers can also feed their plough animals with better diets (such as oats, hay and straw), which will ensure higher returns on labor. Farmers who cannot supply enough labor through their own means need to rent labor from the outside in exchange for produce or promise of returned labor and thus need to take this into account when deciding how much land to cultivate, what methods to employ and how much produce they will secure at the end (Halstead, 2014, p. 120).

Manuring is an example of a land management strategy that is strongly influenced by the types of resources available to farmers. In addition to climatic constraints such as aridity that affect how much manure is appropriate to apply on a field, the application is constrained by the amount of dung available (collected from stalls), the amount of livestock available (that can be penned or folded in fields), the amount of labor (both human and animal) available to transport the dung to the fields and relocate penning/folding enclosures, the type of manure available (some dung, like chicken dung, is more concentrated in N to the point where it can ‘burn’ the soil), and the type of tools available for transport (carts, wheelbarrows, sledges). The quality of manure is also influenced by the animals' diets and this has an impact on how the manure is used (whether for cereals, vegetables in gardens, tobacco, etc.) (Halstead, 2014, p. 216).

Lastly, the choices that farmers make are influenced by the desired outcome of agro-pastoral system itself. Cows are biologically able to breed all year round (King, 1978), but when their reproductive cycles are not controlled by farmers, their calving period lasts about 2–3 months between May–June/July (Towers et al., 2014). Extending the birth seasonality by staggering the births of calves throughout the year gives farmers the option to secure availability of milk beyond the natural calving season (Balasse and Tresset, 2002). Not all farmers are interested in exploiting animals for their secondary products, however, and the ability to ascertain the length of the birthing season (with the use of $\delta^{18}O$ isotopes, discussed in Chapter 4.7) provides some insight into the motivations behind the subsistence strategy.

2.3 Approaches for interpreting past farming methods

The greatest factor shaping differences between pre-mechanized farming systems is the scale of production. In this project, the scale of production will be inferred through the analysis of:

1. The nuances of diversified systems. Archaeobotanical and archaeozoological analysis suggests that Neolithic farmers domesticated a range of crop and animal species in an attempt to create a diversified strategy that spread risk and assured stability over the long-term (evidence discussed in Chapter 3.2.3), but were distinct crop species cultivated under diverse cultivation regimes? Did some of the regimes involve intensive application of manure?

2. The longevity of land-use: the re-use of habitation space on nucleated tell sites suggests that Neolithic society was interested in long-term sedentism, but did people also make investments for re-using agricultural fields by practicing methods such as crop rotation and manuring? Did these practices change through time?

3. The integration of crop cultivation and animal husbandry: the preservation of a diverse range of both crop and animal species at Neolithic sites suggests that people practiced a mixed farming economy, but how integrated were the two systems? Do the diets of the animals reflect grazing in the arable landscape or consumption of crop products or by-products?

This section illustrated that diversity exists at every level of the agricultural cycle, and for this reason, caution needs to be exercised when quantifying agricultural management, such as extrapolating the amounts of manure or water applied on fields or calculating the sizes of fields. For example, in order to estimate amounts of manure applied to a field, one would have to know what type of manure was used (from what animal), how wet the soil was naturally, and whether/for how long manure has been applied on the field beforehand. In order to estimate amounts of water supplied, one would have to know the exact moisture levels of the soil in a particular field, the rate of evapo-transpiration and the specific amounts of annual rainfall during a given cultivation season. The sizes of fields also depend on a range of factors, such as how rocky the soils were and whether they were amenable for maneuvering by a plough team (Halstead, 2014, p. 31). Because many of these factors cannot be determined with acceptable certainty, in this project, management of crops will be assessed in relative terms through comparison of the treatments of different crops at individual sites rather than by interpretation of their absolute stable isotopic measurements.

Chapter 3

Archaeological background: Neolithic period in Anatolia and the Aegean

3.1 Introduction

Traditional academic discourse on the Neolithic was concerned with addressing issues such as the nature of agricultural technology, the origin of the domesticated species and the consequences of the period on the grand human narrative. Questions were asked such as: what technology made the new mode of food production possible? How were the new species of plants and animals adapted to European conditions? What were the immediate and long-term consequences of the transition from hunting and gathering to farming? (see Price, 2000) More recent work has emphasized the role of bioarchaeological analysis for studying the subsistence economy (for example Asouti and Fuller, 2012; Bogaard et al. 2013*a*; Conolly et al., 2011; Fairbairn et al., 2002; Filipović, 2014; Halstead, 1999; Isaakidou, 2008; Pearson, 2013; Pilloud and Larsen, 2011; Valamoti, 2004), and with this, the attention has shifted towards understanding the mechanics of the agro-pastoral system itself: what management strategies did early farmers employ to create a successful food-producing economy? Can we trace the dispersal of the farming lifestyle through parallels in farming techniques? It is these latter questions that form the backbone of the approach used in the current study.

The aim of this chapter is to introduce key concepts and ideas that define our understanding of the Neolithic in the study regions and form the basis of the research questions pursued in this project. The chapter is structured in the following way:

1. First, the discussion focuses on the multiplicity of definitions and approaches that have been used to conceptualize the process of the adoption of the Neolithic way of life.

2. Second, descriptions of the geographies of the Anatolian plateau and the Aegean illustrate the environmental heterogeneity present in these regions and the advantages they possessed for adopting Near Eastern plant and animal domesticates.

3. Third, a brief overview of the forms of Neolithic houses and villages highlights the commonalities and differences that came to characterize Neolithic settlements across the regions and the opportunities they offered for integrating habitation spaces with the arable landscape.

4. Fourth, a consideration of the social aspect of Neolithic lifestyles brings attention to tensions between domestic and collective identities and the role of rituals in strengthening social networks and people's relationship to their built environment.

5. Fifth, our current state of knowledge of Neolithic subsistence economies is summarized through a review of the results of archaeobotanical and archaeozoological approaches employed in the study regions and pro-

vides a basis for interpreting agro-pastoral management strategies *directly* using stable isotope analysis

6. Lastly, our understanding of the farming phenomenon is reviewed through a brief summary of the debate on the origin and spread of food production from the Near East into southeastern Europe and a consideration of how this new mode of subsistence manifested itself through actual agricultural management strategies reconstructed using bio-archaeological methods.

The discussion of Neolithic lifeways is necessarily limited to the areas where the sites under consideration are located: Kouphovouno is situated in the Sparta basin on the Peloponnesian peninsula, Makriyalos lies a few kilometers from the Aegean coast in Northern Greece and Çatalhöyük inhabits the flat Konya plain in the central Anatolian plateau (see Fig. 1.1).

3.1.1 Defining the Neolithic

The 'Neolithic' has been defined in many different ways – as a time period, a cultural phase, an evolutionary step, a mode of production, a population, a social structure – depending on the agenda of the underlying discussion. Key elements, such as exploitation of domestic plants and animals, manufacture of ceramic objects, and building of sedentary settlements, have been identified as the defining characteristics of this phenomenon. Collectively, these key elements became referred to as the 'Neolithic package' (Halstead, 1996, 2011; Hodder, 1990; Price, 2000; Rowley-Conwy, 2004; Tringham, 2000).

It is now generally accepted that plant and animal species domesticated by early Neolithic farmers originated in the Near East (cf Zohary et al., 2012); the Near East being defined as modern-day Turkey, Iran, Iraq and the eastern Mediterranean (Tringham, 2000). This argument is based on the absence of wild progenitors of the main domestic species (such as sheep, goat and emmer) outside of this region (Bailey, 2000; Halstead, 2011; Valamoti and Kotsakis, 2007), as well as results of ancient DNA analysis which showed that sheep (Lawson Handley et al., 2007), cattle (Edwards et al., 2007) and pig (Larson et al., 2007) originated in the Near East.

There are problems, however, with the view that agricultural domesticates spread across Anatolia and into the Aegean in the manner of a linear influx. Detailed studies of the origins of domestication in the Near East have suggested that multiple domestication events may have taken place across the Fertile Crescent in the Near East (the idea referred to as polycentrism), and thus provided several points of origin and more than one possible trajectory for the travelling domesticates (Asouti and Fuller, 2012; Willcox, 2005). In addition, some species (like grass pea) may have been domesticated locally in Greece (Zohary et al., 2012), thus complicating the picture of what form early plant management took place (Valamoti and Kotsakis, 2007). Sections 3.3.1 and 3.3.2 explore the origins and strategies of early farming in the Aegean in greater detail.

Furthermore, the process of adopting the Neolithic way of life – referred to as ‘Neolithization’ – was by no account uniform across the Near East and southeastern Europe. Archaeological evidence suggests that some elements of the Neolithic package (such as sedentism) were already present in pre-Neolithic contexts outside the Near East (for example at the Mesolithic site of Lepenski Vir in Serbia). Furthermore, regional diversities characterized Neolithic cultures across southeastern Europe (Halstead, 2011; Tringham, 2000).

In light of these complexities, several scholars have attempted to clarify how the concept of the Neolithic package should be used. Sherratt (2004) argued against a unilineal adoption of the package and suggested that the process should be viewed as fractal: that smaller scales of change were intertwined with social and economic trajectories on the continental scale. This would “stop us arguing past each other by using the same terms at different levels” (Sherratt, 2004, pg. 55). Tringham (2000) suggested that the transition into farming in Southeastern Europe should be viewed as a ‘mosaic’, one “which is chaotic and contains unexpected and complex variability” (pg. 21). Halstead (2011) argued more recently that “the cohesion of the package should be understood in terms not of common origins, but of similar responses to inherent and widely encountered tensions in the early farming mode of production” (pg. 144). Moreover, Özdogan (2011), suggested that there were not one, but several packages, diffusing from Southwestern Asia into Southeastern Europe at the same time. The theme of local variabilities in Neolithic lifeways will play an important role in the following discussion of how social dynamics and settlement organization were inter-twined with the modes of food production in early farming sites across a mosaic of distinct environments across the study regions.

3.1.2 Geography of the Anatolian Plateau

The Anatolian plateau hosts an exceptionally diverse range of environmental niches. Özdoğan (1999) argues that Anatolia cannot be conceptuatlized as a single entity, like the Syro-Levantine region, because it is composed of distinct ecological zones, each of which is at least as large as the Levant. Based on topography, Anatolia can be split into two physical regions: the coastal and littoral areas, and a central massif bordered by the Pontic mountains to the north and the Taurus mountains to the south. The mountains extend nearly the entire length of the Anatolian plateau and create a barrier that keeps most rain away from the plain. Based on climatic trends recorded during the Holocene, Anatolia can be divided into three regions: 1) north and northwestern Anatolia, where summer rainfall is plentiful and green vegetation is abundant, 2) western and southern Anatolia, where droughts occur over the summer, but significant rainfall during the winter supports a

Mediterranean woodland cover, and 3) central and eastern Anatolia, which hosts a less wet continental climate and steppic vegetation (Roberts, 2014).

Central Anatolia, which is the focus of the current project, covers an area of more than $150,000\text{km}^2$ and hosts a semi-arid climate with cold winters and dry summers and a mean annual rainfall of 350-400mm (Özbaşaran, 2011). The area is composed of four basins: Cappadocia, a volcanic area to the east; Tuz Gölü, a salt lake in the center; Beyşehir plain in the Lake District to the west; and Konya plain dominated by alluvial soils to the south where Çatalhöyük is located. Archaeological sites in central Anatolia are concentrated in clusters in the Cappadocia region, along the northern flanks of the Taurus Mountains, and along the river. A more thorough investigation of the Konya plain environment is presented in Chapter 5.2.2.

Two regions outside of central Anatolia deserve mention for the role they played during the Neolithic transition. Southeastern Anatolia, where the Tigris river basin is located, formed part of the Northern Levant, which is where plant and animal domesticates from the Old World originated. The coastal region of Marmara is located on the eastern edge of the Anatolian plateau served as a bridge between Anatolia and Southeastern Europe since at least the 7th millennium BC (Esin, 1999; Özdogan, 2011). See Fig. 3.1 for a map of the main Anatolian Neolithic sites.

3.1.3 Geography of the Aegean

Like the Anatolian plateau, the Aegean landscape is a mosaic of ecological microhabitats. Rainfall patterns vary from less than 400mm to 1500mm and the centrally located Pindus Mountains divide the continental landmass into a wetter (the northwest) and a more arid (the southeast) zone (Greig and Turner, 1974; Perlès, 2001). The landscape is about two-thirds mountainous, with mountaintops reaching elevations up to 2,918m. The Aegean Sea to the east shares over 13,000km of coastline with the continent and plays host to

Figure 3.1: Map of the Anatolian Plateau and southeastern Europe showing the location of the main Neolithic settlements. 1: Franchthi, 2: Sesklo, 3: Argitsa-Magoula, 4: Krainitsi, 5: Lepinski Vir, 6: Vlassac, 7: Gradesnitsa, Koprivets, 9: Karanovo, 10: Aşağı Pınar, 11: Hoca Çeşme, 12: Uğurlu-Zeytinlik, 13: Yarımburgaz, 14: Yenikapı, 15: Fikirtepe, 16: Pendik, 17: Ilıpınar, 18: Menteşe, 19: Barçin, 20: Demirci Höyük, 21: Keçiçayırı, 22: Aktopraklık, 23: Troy, 24: Ege Gübre, 25: Ulucak, 26: Yeşilova, 27: Çukuriçi Höyük, 28: Çine-Tepecik, 29: Peynir-çiçeği, 30: Öküzini, 31: Bademağacı, 32: Höyücek, 33: Kuruçay, 34: Hacılar, 35: Süberde, 36: Erbaba, 37: Çatalhöyük, 38: Can Hasan, 39: Aşıklı Höyük, 40: Gelveri, 41: Kaletepe, 42: Tepecik-Çiftlik, 43: Köşk Höyük, 44: Yumuktepe. From Özdogan (2011).

thousands of islands, only a portion of which have been inhabited. The region hosts a Mediterranean climate with hot and dry summers and cool and moist winters. Mineral resources are plentiful, but not distributed evenly across the landscape (Demoule and Perlès, 1993; Perlès, 2001). Some regions are more rocky and isolated (such as the Peloponnesian peninsula) and others are very fertile and host perennial floodplains (such as Thessaly) (Price, 2000).

Varying climatic conditions in northern and southern Greece offer distinct opportunities and constraints on farming (observed ethnographically, Halstead, 2014). Southern Greece hosts a more typical Mediterranean climate with prolonged summer droughts, which shortens ripening season and puts stress on the timeframe in which crops have to be harvested. In the northern lowlands, summer rainfall tends to be variable, which makes pasture on new stubble unpredictable, while in the southern Mediterranean, rainfall is consistently sparse in the summer and variable in the winter and spring. Halstead (2014) argues that it is harder to rear animals in southern Greece which may explain why smaller folds of animals are used here to manure larger pieces of land than in northern Greece. Fields and gardens in the south face fewer problems with weeds than in the north and farmers in this region have been noted to prioritize manure by first applying it on gardens, then on olive trees/vines and any left-overs on cereal fields. Climatic differences, especially rainfall, together with cultural preferences, explain why the archaeological records of northern and southern Greece exhibit such striking differences (see for example Andreou et al., 1996; Bailey, 2000; Demoule and Perlès, 1993; Valamoti, 2004).

With the onset of the Neolithic, people began to move from caves and open coastal and inland sites (Perlès, 2001; Runnels, 2001) into alluvial and colluvial landscapes of the drier eastern and southern regions of Greece (Demoule and Perlès, 1993). See Fig. 3.2 for a map of the main Neolithic settlements in Greece. Some argue that the choice of the new settlement areas was intrinsically linked to the fact that the Near Eastern domesticates (such as sheep) were better suited to drier conditions, which likely aided in their swift adoption (Barker, 1985; Demoule and Perlès, 1993) (see more in Section 3.3.1). In addition to moving into previously uninhabited territories, people radically changed the ways in which they interacted with their environment. They no longer timed their exploitation of environmental resources in seasonal cycles, but actively shaped the environment for year-long occupation by building durable settlements and clearing the landscape for cultivation. They thus created "social landscapes" which bound them to particular places of personal or group importance (Bailey, 2000, p. 46).

An exceptional habitation sequence – spanning from the Paleolithic until the Late Neolithic (Douka et al., 2011; Farrand, 2000) – was excavated at the site of Franchthi, a vast cave complex overlooking the now-submerged coastal plain across the bay of Koiladha in southwestern Argolid. This site has provided unparalleled opportunities for examining the Mesolithic–Neolithic shift and will be referred to throughout this discussion.

3.1.4 Chronology of the Neolithic in the study regions

In broad terms, the Anatolian Neolithic lasted from the 11th until the 6th millennium BC and is divided into pre-pottery and pottery phases (Asouti, 2006, drawing on dates from Aurenche et al., 2001; Baird, 2012*b*):

Pre-Pottery Neolithic A: mid-11th to late 10th millennium BC
Early Pre-Pottery Neolithic B: late 10th to mid-9th millennium BC
Middle Pre-Pottery Neolithic B: mid-9th to mid-8th millennium BC
Late/Final Pre-Pottery Neolithic B: mid-8th to late 8th millennium BC
Pottery Neolithic: 7th millennium BC

The Greek Neolithic lasted from the mid-7th until the 4th millennium

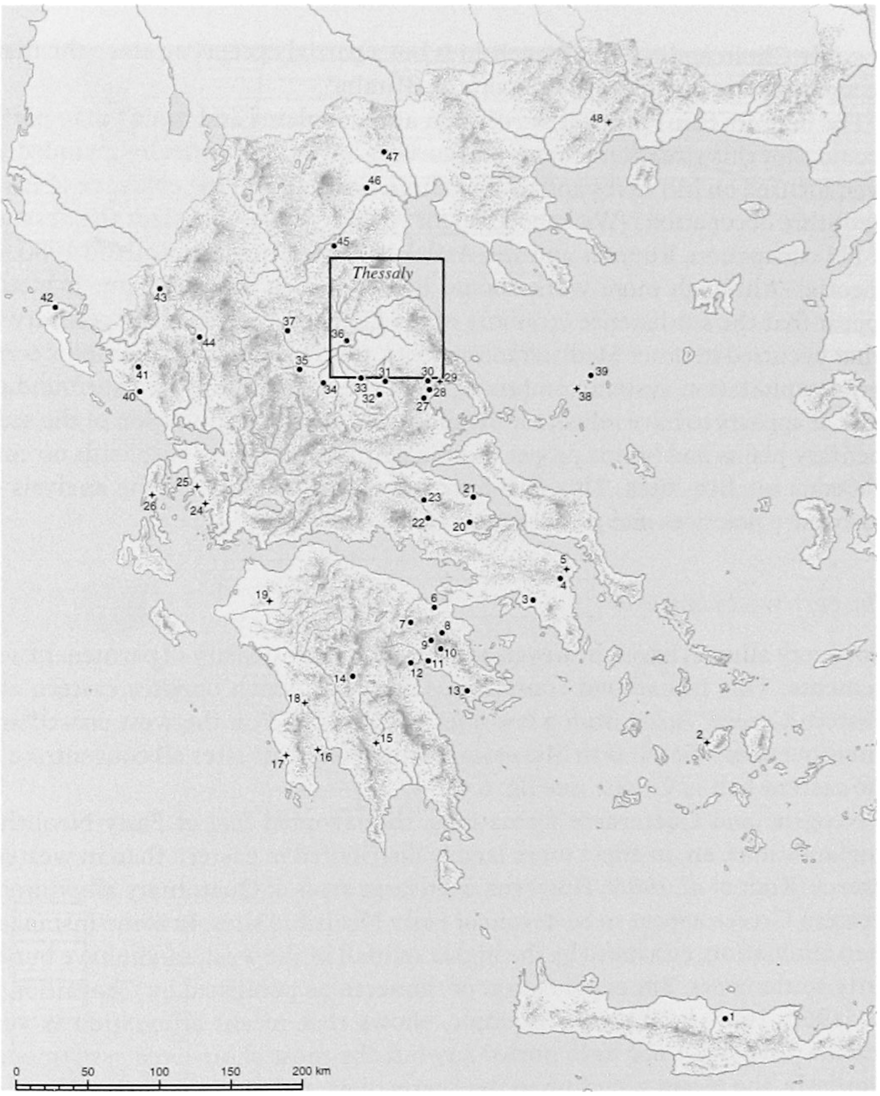


Figure 3.2: Map of Greece, showing the location of the main Neolithic settlements. Dots represent Early Neolithic sites, stars represent later Neolithic sites. 1: Knossos, 2: Saliagos, 3: Athens, 4: Nea Makri, 5: Marathon, 6: Corinth, 7: Nemea, 8: Berbati, 9: Prosymna, 10: Dendra, 11: Koutsoura, 12: Lerna, 13: Franchthi, 14: Asea, 15: Kouphovouno, 16: Kokora Troupa, 17: Cave of Nestor, 18: Malthi Dorion, 19: Portes, 20: Sarakinos, 21: Halai, 22: Chaeronea, 23: Elateia, 24: Ayios Nikolaos, 25: Arconadaria, 26: Choirospilia, 27: Daudza, 28: Pyrassos, 29: Dimini, 30: Sesklo, 31: Tsangli, 32: Achilleion, 33: Myrini, 34: Prodromos, 35: Magoulitsa, 36: Plateia Magoula Zarkou, 37: Theopetra, 38: Ayios Petros, 39: Cyclop's Cave, 40: Ephyra, 41: Paramythia, 42: Sidari, 43: Asfaka, 44: Kastritsa, 45: Servia, 46: Nea Nikomedia, 47: Giannitsa B, 48: Dikili Tash. From Perlès (2001).

BC and is divided into four main sub-phases (Andreou et al., 1996; Bailey, 2000; Demoule and Perlès, 1993; Perlès, 2001; Tringham, 2000):

Early Neolithic (EN): mid-7th to early 6th millennium BC
Middle Neolithic (MN): mid-6th to late 6th millennium BC
Late Neolithic (LN): late 6th to mid-5th millennium BC
Final Neolithic (FN): mid-5th to 4th millennium BC

3.2 Neolithic way of life

3.2.1 Neolithic settlements

Neolithic communities across Anatolia and the Aegean built two types of settlements which left distinct traces in the archaeological record: *tells* (also mounds, 'magoules' and 'toumbes') and flat extended sites. Tells represent the epitome of habitation continuity and investment in socially modified landscapes (Kotsakis, 1999), and examples can be found at the sites of Agrissa, Dimini, Ayia Sophia Magoula, Achilleion, Nea Nikomedia, Otzaki Magoula, Knossos, Kastraki, Mandalo, Halai, Kouphovouno, Çatalhöyük, Ilınıpar, Hacılar, Can Hasan I, and Aşikli Höyük. They can be recognized archaeologically as mounds with long sequences of vertically accumulated habitation deposits that can reach heights of several meters. It has been estimated that tell settlements in Greece were inhabited by several tens to a few hundred people at any point in time (Perlès, 2001). Kotsakis (1999) argues that tells lacked communal organization, but that privatization of space enabled households to develop as independent production units.

Flat extended settlements were built across Northern Greece and the Balkans during the Late Neolithic and represent the opposite of concentrated use of space. This settlement type is exemplified at the sites of Makriyalos, Vasilika, Thermi, and Apsalos. Here, people did not rebuild houses directly on top of earlier house plans, but rather shifted habitation and arable land horizontally within a defined landscape area (Kotsakis, 1999).

A common practice has been to equate tell settlements with dense, nucleated habitation and flat extended sites with more scattered occupation. However, Kotsakis (1999) warns against this simplification because the excavation of flat extended sites has been limited to proportionally small areas and thus quantitative methods for analyzing the settlement densities (such as the built-to-unbuilt ratio and the minimum interbuilding distance, cf Chapman, 1989) can be unreliable. An exception to limited excavation of flat extended settlements is the site of Makriyalos, which will be discussed in Chapter 7. In light of this debate, Kotsakis asserts that the most dependable characteristic for differentiating flat extended settlements from tell sites is their higher potential for expansion. Regardless of settlement density, tells in Greece tend to be smaller (they rarely exceed 2ha) and flat extended sites tend to be larger (approaching 50ha) (Bailey, 2000; Kotsakis, 1999). In central Anatolia, tell sites are much larger in size. Çatalhöyük, for example, stretches over 13ha (Hodder and Farid, 2014).

A number of common features characterize tells and flat extended sites. Boundary walls (at the tells at Sesklo, Dimini and Nea Nikomedia) and ditches (at the sites of Makriyalos, Ayia Sophia Magoula and Achilleion; Kotsakis, 1999) attest to efforts made to protect habitation areas and arable land from outsider presence, both human and wild animal. On the basis of faunal evidence, Halstead (2005) and Isaakidou (2008) argue that both tells and flat extended sites were occupied throughout the year by at least some of their residents. This view importantly takes into account that year-round occupation still allowed settlements to contract and expand on a seasonal basis (Bailey, 2000).

Furthermore, both tells and flat extended sites were conceived around division of space: settlements were sub-divided into domestic sectors, areas of midden/refuse and land used for garden horticulture. A unique example is the site of Sesklo, which contains both a tell and a flat extended portion and exemplifies deliberate and function-driven separation of space. This division of space had both practical and symbolic meaning. On the one hand, it enabled the physical separation of cooked food from rotting garbage, and on the other hand, it strengthened people's control over the built environment: "At all of these sites the evidence that people physically separated areas one from the other suggests that they perceived different parts of community space in particular, perhaps exclusive ways" (Bailey, 2000, pg. 45).

Diversity existed on the level of the Neolithic structures themselves. Buildings within settlements took on one of two forms: rectangular above-surface buildings and sub-terranean pit-huts. The rectangular structures were generally built with timber frames on top of stone foundations, with walls made of wattle and daub and sun-dried mixtures of clay, plants and mud. Pit-huts were constructed in shallow hollows in the ground that were covered with walls and roofs made of branches and small tree-trunks, which were then covered with clay and mud (Bailey, 2000). Some buildings had two stories, such as in the villages of Otzaki and Tsangli, other buildings had partitions, like those at Achilleion and Nea Nikomedia (Bailey, 2000). To illustrate building diversity within a localized region, Bailey (2000) gives the examples of contemporary Late Neolithic sites in Northern Greece, located within 60km of each other, that exhibit distinct building strategies and materials: in Makriyalos, people lived in round pit-huts, in Megalo Nisi, they inhabited rectangular houses built of very solid materials and Mandalo, they created living space in houses built of timbers and compacted mud.

3.2.2 Neolithic people

The Neolithic way of life allowed people to define their identities within two spheres of belonging: the household and the community. On the one hand, people invested significant amounts of labor and resources in building communal structures (such as boundary walls and ditches), partaking in communal events (such as large communal feasts at Makriyalos, see Chapter 7.1.5, and the Pre-Pottery Neolithic Göbekli Tepe, Dietrich et al., 2012), and expressing identities at the institutional level (visible through ceramic styles, figurines and stamp seals; Bailey, 2000). On the other hand, they concentrated vast amount of energy into refining domestic architecture and elaborating symbolic expression within the household. Halstead (2011) argues that this duality, essentially a tension between domestic and collective identities, had far reaching consequences and paved the way for the scale of agricultural food production (discussed further in Section 3.3.2 below).

While some argue that Neolithic villages were primarily organized around communal existence (Nanoglou, 2008; Tomkins, 2004), Halstead (2011) asserts that focus on household independence better explains the employment of more intensive management strategies seen in the bio-archaeological record. In his view, two mechanisms enabled households to function independently without fear of its inhabitants succumbing to food shortages due to annual fluctuations in favorable weather conditions. The first was commensality, or the sharing of food, which, apart from serving as a buffer against crop failure, prompted cultural solidarity and reaffirmed distant social contacts. The second was the exchange of staple food for labor or for obligation of future repayment (in bulk or in labor). It is this independence of households and the ability to operate at both the domestic production-unit level as well as the societal level that defined the management system developed by early farmers in Anatolia and the Aegean.

Large-scale feasts, apart from strengthening social relationships within and between villages, provided a platform for ritual expression. Bailey (2000), in fact, argues that the main function of early ceramic pots was not for cooking, but for displaying the contents of the vessels during ceremonies. Hayden (2003) asserts that the first plant and animal domesticates were used by more powerful members of the society to organize feasts, which were aimed at increasing production of both luxury foods as well as staples. Treatment of the dead formed another important part of people's ritual behavior as people honored their ancestors in diverse ways. Deceased individuals were interred in large ditches (as in Makriyalos), in shallow pits located in open spaces or underneath domestic structures (in Prodromos), and in cremation pots placed next to domestic hearths (in Dimini), buried in open spaces (in Avgi) or deposited in shallow pits (in Platia Magoula Zarkou; Triantaphyllou, 2008; Stratouli et al., 2010). At Çatalhöyük and Köşk Höyük, plastered skulls and headless skeletons were found placed on top of or buried underneath plastered platforms inside houses (Larsen et al., 2015; Özbek, 2009). People were buried individually and in groups and disposed of in primary and secondary ways within settlements and in separate cemeteries (Stratouli et al., 2010; Triantaphyllou et al., 2008).

Secondary manipulation of inhumations, in the form of re-deposition of earlier buried bones (especially long bones), played a large role in treatment of the dead during the Neolithic. Triantaphyllou (2001, 2008) argues that this treatment served the role of re-integrating dead individuals/ancestors into the community, in a way that strengthened people's relationship to their built environments. Along the same lines, Stratouli et al. (2010) argues that the "domestic character" of burials was "expressed through the incorporation of some of the deceased into the built environment of the living community" (pg. 96). Grave goods tended to be few and simple (Stratouli et al., 2010). It was not until the late 6th millennium that inhumations were differentiated by sex and age (Bailey, 2000). Stratouli et al. (2010) raise the point that some Neolithic mortuary practices may have gone unnoticed by archaeologists since the number of detected burials is considerably smaller than the number of people that were estimated to have lived in the settlements.

3.2.3 Neolithic subsistence economy

This section will briefly summarize key archaeobotanical and archaeozoological findings that inform our understanding of the role of different plant and animal species in the subsistence economy of early farmers in Anatolia and the Aegean. Because the focus in this project is on the mechanisms of agricultural management during the ceramic Neolithic, assemblages from aceramic sites are not considered.

Archaeobotanical assemblages from Neolithic sites are largely composed of a diversified set domestic cereals and pulses. Cereal types are dominated by glume wheats: in southern Greece, the primary focus seemed to have been on the cultivation and consumption of einkorn (*Triticum monococcum*), while in northern Greece, both einkorn and emmer (*Triticum dicoccum*) were represented equally (Valamoti, 2004, 2007). Free-threshing wheat (*Triticum aestivum/Triticum durum*) appears in Early Neolithic Knossos on Crete, but is not represented in significant numbers on the continent. It is almost absent in northern Greece (Valamoti and Jones, 2003). Halstead (1989*b*) argues that because free-threshing wheat cannot be stored in spikelets (unlike glume wheats), it is more vulnerable to pests and moisture during storage. Hulled barley (*Hordeum vulgare*) is present across the region in Neolithic contexts, but naked barley seems to be restricted to northern Greece (Valamoti and Jones, 2003). Archaeobotanical assemblages from the Anatolian Neolithic are dominated by barley (two-row and six-row), wheat (einkorn, emmer, bread wheat, spelt) and rye (Cappers, 2014).

The main pulse species consist of lentils (*Lens culinaris*) and peas (*Pisum sativum*), with bitter vetch (*Vicia ervilia*) and grass pea (*Lathyrus sativus*) represented in smaller numbers. Wild plants seem to have been deliberately and consistently left out during the Neolithic, but examples of fig, pistachio, almond, grape, and hackberry suggest that these food items may have been exploited on a seasonal basis to supplement an agricultural diet (Bogaard and Halstead, 2014*a*). In Çatalhöyük, the presence of two types of crucifers (*Capsella* and *Descurainia*) attest to the use of herbs as a culinary preference (Bogaard et al. 2013*a*).

Faunal assemblages are dominated by sheep (*Ovis aries*), especially in the earlier Neolithic (Cantuel et al., 2008; Halstead, 1996). Halstead (2006) argues that dominance of sheep tends to be consistent with small-herd husbandry practices where the animals are confined to cleared plots of land (field margins, fallow fields and stubble) rather than on the stock-breeding of large herds that have more wide-ranging grazing requirements. Mortality profiles of the sheep indicate that these animals were raised mostly for their meat (Halstead, 1987, 1996).

Based on the fact that animal husbandry was oriented towards stock-breeding of sheep on a small-scale and the fact that the mortality profiles preclude the use of animals for specialized milking, Halstead (1989*b*) and Bogaard and Halstead (2014*a*) argue that Neolithic diets were largely composed of crop products, with animal products playing a subsidiary role. However, even though their contribution to Neolithic sites may have been proportionally small, animals played a large role in the subsistence economy – as well as the symbolic realm – of Neolithic farmers: they were used as indirect storage (as a buffer against periodic large-scale failure of crops), as a means of accumulation and display of wealth, as a vehicle for re-affirming social ties between households and in the form of clay figurines appearing alongside anthropomorphic objects displayed in the domestic sphere (Halstead, 2000).

Other domestic species include cattle (*Bos taurus*), goat (*Capra hircus*), pig (*Sus scrofa domesticus*) and dog (*Canis lupus*), which were exploited in smaller numbers and were introduced into the assemblages at a later stage in some areas (such as central Anatolia, Russell et al., 2013). Even though the faunal mortality profiles are largely meat-oriented, it is important to remember is that a meat-oriented strategy does not preclude some use of domestic animals for secondary products (Bogaard and Halstead, 2014*a*) and evidence for the use of secondary products at Stavropouli, Knossos and Cafer Höyük will be discussed below.

Wild animals, most commonly represented by red deer (*Cervus elaphus*), aurochs (*Bos primigenius*) and boar (*Sus scrofa scrofa*), also played a supplementary role in early faming diets; their remains form less than 5% of faunal assemblages in Greece (Cantuel et al., 2008). Since meat cannot be stored as easily as crops, Halstead (1999) argues that decreased consumption of hunted game – in addition to infrequent consumption of domestic meat products – meant that households had to participate in fewer food sharing activities, which further holstered their independence in everyday tasks.

The introductory sections of Chapters 5, 6, and 7 will discuss the results of bio-archaeological studies carried out at the sites under consideration in this project: Çatalhöyük, Kouphovouno and Makriyalos.

3.3 Understanding Neolithic farming

The prevailing subsistence economy during the Pottery Neolithic was agro-pastoral, with the use of wild resources (hunted game, fruits, nuts, herbs) to supplement a cereal-based diet (Bogaard et al., 2013*a*; Fairbairn et al., 2002; Halstead and Jones, 1980; Hansen, 1991; Perlès, 2001; Valamoti, 2004; Valamoti and Kotsakis, 2007). But how did food production become the main mode of subsistence and what strategies did early farmers employ to manage crop cultivation and animal husbandry?

The following two sections will 1) provide a brief overview of scholarship on the development of agriculture in Anatolia and the Aegean, drawing mainly on the debate between demic diffusion and indigenous adoption, 2) discuss how models of early farming methods (including slash and burn agriculture, floodplain cultivation, secondary products revolution and small-scale intensive mixed farming) were and are used to explain farming strategies in Neolithic contexts, and 3) demonstrate how thorough bio-archaeological analyses refine our understanding of what farming methods are more and less suitable for the practice of agriculture across an environmentally diverse region. The material presented in this discussion will provide a foundation for assessing the scope of diversity in farming methods in Neolithic contexts across central Anatolia and the Aegean, particularly how it contributes to our understanding of the Neolithic way of life.

3.3.1 Origins and development of farming in the study regions

Pioneering investigations into the origins of farming were spearheaded by V. Gordon Childe, who argued that colonizers from the Near East brought plant and animal domesticates into Southeastern Europe and thereby sparked a 'Neolithic revolution', which led to the adoption of farming as the main mode of subsistence. Furthermore, Childe postulated that Northwestern Anatolia was the origin of the European Neolithic, which formed in a single wave of expansion (Childe, 1957, 1958, 1969). The idea of migrating farmers – referred to as a model of demic diffusion or colonization – was later adopted and refined by many authors, such as Ammerman and Cavalli-Sforza (1984), Bellwood (2005), Perlès (2001), Renfrew (2002), van Andel and Runnels (1995). Ammerman and Cavalli-Sforza (1973), drawing on Clark (1965), described the spread of farming into Europe in terms of 'waves of advance', visualized maps such as the one shown in Fig. 3.3.

The colonization model outlines that similarities in material culture attest to contact between the regions, and contact enabled demic diffusion. The

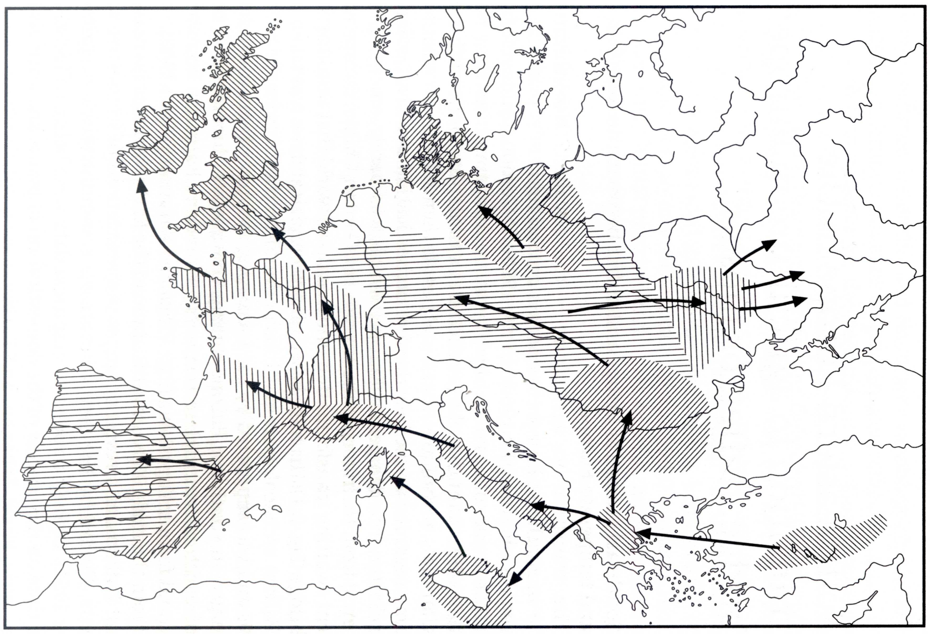


Figure 3.3: Map of Europe and the Near East indicating possible trajectories of the spread of the Neolithic package, from Tringham (2000), after Renfrew (1987).

general sparseness of Mesolithic presence in Southeastern Europe was taken to suggest that the land was empty and lay waiting to be colonized (Runnels, 1995). Furthermore, radiocarbon dates indicated that sites in Southeastern Europe were significantly older than sites in Northwestern Europe, which was taken as support that farming spread across Europe following a southeast-to-northwest trajectory (Tringham, 2000). In addition, the initial limited analysis of plant and animal remains suggested that the shift to reliance on domestic products was much more rapid in Southeastern Europe compared to the Near East (Hodder, 1990; Hole, 1984; Moore, 1985), which was taken as evidence that plants and animals were not domesticated locally in the former region.

Evidence provided in support of demic diffusion is drawn from the analysis of material culture, from the construction of chronologies and more recently from the analysis of ancient mitochondrial DNA (mentioned above).

Özdogan (2011) postulated that the Neolithic spread across Anatolia and into Southeastern Europe in three waves. An initial phase of sporadic westward land movement from central Anatolia and maritime movements from the Levant and Southeastern Anatolia that reached Crete but by-passed the rest of the Anatolian plateau. This phase lasted until around 6500–6400 cal BC and involved the spread of naviform lithic cores. The next wave (c.6450–6100 cal BC) resulted in the establishment of settlements in the Lake District, the Marmara region, Thrace, Greece and possibly Bulgaria, where dark monochrome pottery and rare painted vases have been found. Finally, the last wave of expansion saw an almost instantaneous appearance of settlements across central Anatolia, Western and Northwestern Anatolia and the Balkans towards the end of the 7^{th} millennium BC. The shared material culture included red-slipped and burnished pottery with S-curved profiles, tubular lugs, plastic decorations, anthropomorphic and zoomorphic vessels and a higher proportion of painted pottery. Clare and Weninger (2014) argue that this expansion across Anatolia was triggered by Rapid Climate Changes between 6600–6000 cal BC.

From an Aegean perspective, Perlès (2005, 2014) has argued that the Greek Neolithic (from Thessaly to the Peloponnese) has more in common with the Near East, particularly with respect to ceramic figurines, than with Anatolia. Central Macedonia, however, shares more material culture with Anatolia (such as bone spoons, hooks, tubular lugs, circular scrapers, denticulated sickle-blades, antler tools). On this basis, Perlès argues that two separate waves of advance were responsible for bringing the Neolithic culture into the Aegean world.

At Franchthi cave, a 600 year-long hiatus followed Mesolithic occupation (Farrand, 2003), after which appeared a fully domesticated set of plants and animals (Hansen, 1991, 1992), accompanied by a different ceramic assemblage than seen elsewhere in the Aegean (Demoule and Perlès, 1993). This has been taken to suggest that a different group of people, with a new mode of subsistence economy, colonized the cave during the Neolithic phase. However, the material and bio-archaeological assemblages at Franchthi cave have been re-interpreted in ways that show both indigenous and forager participation in the Neolithization process (Price, 2000) (see more below).

The model of demic diffusion was eventually challenged by archaeologists who assigned larger importance to the role of local agents during the adoption of farming in Southeastern Europe. Tringham (2000) asserted that the Neolithic transition cannot be interpreted in terms of displacement of local populations by incoming colonists, because it was shaped in distinct locations by unique interactions between local foragers and farmers. Anthony (1997) explained the process as a 'chain migration', where people adopted new customs and cultural elements while retaining other elements that tied them to their homeland. They thus created hybrid cultures like the 'Balkano–Anatolian cultural complex'.

More recent archaeological work brought to light evidence that the 'package' did not always arrive intact (Price, 2000). For example, even though chickpea was part of the package, it was almost absent in the archaeobotanical assemblages from Northern Greece (Valamoti and Kotsakis, 2007). On the other hand, grass pea, as mentioned earlier, which was not part of the package, found its way into cultivated soils throughout the course of the Neolithic (Halstead and Jones, 1980; Valamoti, 2004). Regional differences across both Anatolia and the Aegean thus strongly suggest that various factors were involved in determining what form the Neolithic package would take in distinct locations and provide support for Özdoğan's idea of several contemporary Neolithic packages (Özdogan, 2011).

Evidence supporting the development of farming by indigenous populations has been drawn from continuing excavation efforts and from re-interpretation of earlier material. Aceramic layers (dating to around 6,800

BC) have been found at the bases of Neolithic tells in continental Greece as well as on Crete – in sites such as at Agrissa, Gediki, Sesklo and Knossos – and suggest that the Neolithic transition was less abrupt than earlier thought (Bloedow, 1991; Demoule and Perlès, 1993; Tringham, 2000). Excavations at Pınarbaşı and Boncuklu have shown that local processes of sedentism and domestication were at play in central Anatolia, even though the species were imported from the eastern 'core region' (Baird, 2012*a*; Baird et al., 2012). Further analysis of the material cultures of the Near East and Neolithic Aegean (see references in Price, 2000) also suggest that the assemblages of these two regions are more distinct than argued by the colonization supporters.

Despite the 600 year-long hiatus at Franchthi cave, evidence suggests that a more gradual transition into the Neolithic took place at this site, with strong "forager participation in the Neolithization process" (Tringham, 2000, pg. 34). People inhabiting the cave during the Mesolithic collected wild barley, lentils and oats as well as edible fruits and nuts (Valamoti and Kotsakis, 2007) and over time, other plant and animal domesticates were gradually added to their diet (Halstead, 1996). Perlès (1987, 2001) argues that the lithic assemblage from the Neolithic levels showed distinct Mesolithic features, such as microliths. In addition, even though important aspects of the subsistence economy at Franchthi cave have changed (the dominance of wild resources was replaced by the dominance of domestic products), some elements persisted from the Paleolithic through to the end of the Neolithic (such as the exploitation of the same species of molluscs; Shackleton, 1988).

Nowadays, authors contributing to the discussion on the form of early agriculture tend not to take sides in the colonization vs. indigenous adaptation debate (for eg. Asouti, 2006; Halstead, 2011; Valamoti and Kotsakis, 2007). This is because 1) they recognize that the picture is much more complex and cannot be characterized with isolated colonization or adaptation processes, and 2) this binary division is not helpful for advancing our understanding of what early farming looked like. Both Perlès and Özdoğan, who trace similarities in material culture across Southeastern Asia to draw models of demic diffusion accept that a host of other variables were at play. Özdoğan writes that: “There was endemic movement, migration, and colonization by both land and sea; there were ‘frontiers’ merging with local communities, expansion by exchange of knowledge and/or commodities, and to a degree, local development.” (p. S427). The preferred type of discussion on this topic involves an inter-disciplinary examination of the botanical, faunal and ecological evidence, with the aim of explaining the agricultural process within the backdrop of the archaeological context at each given location.

For more thorough discussions of theories relating to the adoption and spread of agro-pastoralism across Southeastern Europe, see Asouti (2006); Harris (1996); Hodder (1990); Moore (1989); Price (2000); Tringham (2000).

3.3.2 Neolithic farming strategies

Amidst attempts to explain the *origins* of farming – where the ideas behind food production came from and how they were locally implemented – prehistorians also made an effort to describe how early farming *strategies* worked. They thus adopted ethnographic models such as ‘slash and burn’ (or swidden) agriculture (Boserup, 1965; Clark, 1952) and floodplain cultivation (Sherratt, 1980) and incorporated them into their grand narratives, which were aimed at making sense in social-evolutionary terms. Isaakidou (2011) argues that a major downside to these models is that they relied on ambiguous and indirect evidence – such as site density, longevity, location, anthropogenic impact on the alluvial record, and artefactual or iconographic evidence for technological know-how – and insufficient or contextually inappropriate analogical foundations. Furthermore, and despite recognizing the importance of archaeobotany, archaeozoology and palaeoecology, these prehistorians did not have access to properly quantified data. Their models were based on the presence and absence of species (such as Hansen, 1991), which, on their own terms, are not very informative (Isaakidou, 2011). The following discussion will demonstrate how more thorough bio-archaeological analysis has brought these legacy theories into question and has instead provided grounds to argue that early farming was small-scale and intensive.

Boserup (1965) argued that farming developed along an evolutionary intensification scheme, wherein early farming was 'primitive' and not very intensive and later farming was more 'developed' and fed more people. The definitions she provided for intensification and extensification, however, vary distinctly from definitions used by bio-archaeologists and ecologists. In Boserup's view, later farming (for example Bronze Age farming compared to Neolithic farming) was more 'intensive', because it involved the mobilization of a larger labor force that cultivated larger fields and produced higher overall yields of grain. In ecological terms though, this scenario describes an extensive strategy, where the limiting factor is availability of land. Intensity is defined by the amount of labor invested and yield produced *per square meter* of cultivated land, with labor posing the limiting factor on production (Bogaard, 2012; Halstead, 2014). Thus, regimes where smaller plots of land are managed with the intent of maximizing yield (per unit area), such as small-scale garden horticulture, are more intensive.

The slash and burn model frames early farming as highly mobile: Neolithic farmers routinely cleared plots of land by burning down trees (which created favorable short term growing conditions) and moved to new locations once the soil nutrients were depleted every few years (Boserup, 1965; Clark, 1952). However, such a mobile strategy could not have been compatible with the permanent lifestyle of the Neolithic people, visible archaeologically through continual reuse of space in nucleated settlements, particularly tells. In addition, analyses of faunal assemblages from sites across Anatolia and the Aegean indicate that animals were exploited as part of a small-scale herding program that was integrated with horticultural management focused on re-using the same soils (Halstead, 1981, 1987, 1989*a*, 1996, 2000, 2011). Furthermore, analysis of the weed ecology from Neolithic botanical assemblages in Central Europe has also provided evidence against short-term cultivation scheme and instead supports the view that efforts were made to improve soil quality (by tillering, manual weeding, regular application of manure and cereal-pulse rotation; Bogaard et al., 2000) as part of a horticultural strategy (Bogaard, 2004, 2005; Bogaard et al., 2000). In Greece, the archaeobotanical assemblages are generally not accompanied by such a rich weed flora, which prevents similar analysis to be carried out in this region (Valamoti, 2004; an exception is the site of Assiros Toumba in northern Greece, Jones, 1987).

Sherratt's (1980, 1981) influential model outlined that early cultivation was limited to alluvial floodplains and that later developments during the 4th–3rd millennium BC brought about exploitation of livestock for their secondary products. According to this model, first farmers sowed their crops in the spring in 'self-cultivating' soils on alluvial fans (such Thessaly and the Konya plain), immediately following the recession of winter floods. Archaeological evidence provided in support of this model came in the form of settlement distribution (early farming sites were located in areas interpreted to sit on top of very high water tables) along with the occurrence of the sedge *Scirpus* in archaeobotanical assemblages. *Scirpus* is a wetland-adapted crop and its presence in archaeological contexts was taken to suggest that crops (and their associated weeds) grew in areas of high water tables. More recent analysis of archaeobotanical assemblages, however, has suggested that Neolithic crops were sown in the autumn, rather than in the spring (Fairbairn, 2005; Fairbairn et al., 2005; Filipović, 2014; Hillman and Davies, 1992) and that *Scirpus* was brought into the settlements in the form of animal dung (Charles, 2011). It thus cannot necessarily be taken as evidence of the growing conditions in the arable landscape.

In the second part of his model, Sherratt (1981) postulated that farming 'intensified' in the Bronze Age (4$^{\text{th}}$–3$^{\text{rd}}$ millennium BC): farmers cultivated larger pieces of land and started exploiting animals for their non-meat products such as wool, milk and traction. Evidence for this hypothesis was mostly iconographic (Isaakidou, 2011) and more recent studies have shown that animals were used for their secondary products much earlier than in the 4$^{\text{th}}$ millennium. Organic residue analysis of pottery sherds from several sites in Central and Northwestern Anatolia, including Çatalhöyük, as well as from Stavropouli in northern Greece (albeit in $< 20\%$ of analyzed sherds in the case of Stavropouli), provides evidence for the use of milk by the 7$^{\text{th}}$ millennium BC (Debono Spiteri et al., 2016; Evershed, 2008). Furthermore, in Neolithic Knossos, a large sample of cattle bones with pathologies suggest that this animal was used for traction in the 7$^{\text{th}}$ millennium BC (Isaakidou, 2006, 2008, 2011) (also see Halstead, 1998, and Rowley-Conwy, 1997, for evidence in other regions). This animal would have been employed in tasks such as tilling the soil and transporting manure to more distant fields, and Isaakidou (2011) argues that "there is no practical reason why draught cattle should not have been widely integrated in a gardening regime" (pg. 107). The mortality profiles of animals from the site of Cafer Höyük also suggest that the animals may have been used for their secondary products (Vigne and Helmer, 2007). An integrated gardening scheme would have allowed crop cultivation and animal husbandry to function in a symbiotic relationship at a high level of intensity.

As the critiques of the earlier models have shown, bio-archaeological investigations have provided several strands of evidence indicating that Neolithic farming was intensive. The compositions of archaeobotanical and archaeozoological assemblages suggest that agro-pastoral strategies were diversified (rather than specialized), showing balanced representation of cereals and pulses and the stock-breeding of several species of animals (Halstead, 2000; see above in Section 3.2.3). Such a strategy represents a contrast to later modes of specialized cultivation (such as in palatial contexts in the Bronze Age, where only one type of cereal was grown for the production of a surplus that supported the functioning of an elite class, Halstead, 2000). In addition, palynological data suggest that unambiguous evidence of large-scale clearence (needed for extensive cultivation) only appeared in the 2$^{\text{nd}}$ millennium BC (Bottema, 1982; Jahns, 1993). Thus, the data suggest that anthropogenic impact during the Neolithic was small-scale and that farmers employed an integrated method of agro-pastoral food production (Halstead, 2000).

An intensive and integrated strategy offers mechanisms to minimize the risk of complete crop failure and thus enables independent households to function as separate production units. These mechanisms include diversification, overproduction and indirect storage (Halstaed, 1994; Halstead, 1989*b*). A diversified, rather than specialized, strategy focuses on cultivation of a range of different types of crops (with varying growing requirements) using different agricultural regimes (for example, growing some crops together in the same field as 'maslin' and others separately as 'monocrops') and stock-breeding of more than one type of domestic animal (with varying grazing potentials). This allows farmers to maximize their use of the surrounding landscape (that offers varying soil types and grazing pastures) and minimize the chances that on any given year, all crops and animals would fail to survive.

Overproduction and indirect storage also serve as buffers against crop failure by enabling farmers to use excess produce (whether in the form of left-overs, waste or storable food surplus) to forge and cement social obligations, which create assurances of reciprocity in the time of need. Produce in the form of bulk grain or fattened livestock (indirect storage) thus serves as a 'normal surplus' (Halstead, 1989*b*), which can be used in exchange for labor at any point during the agricultural cycle, for food items (during times of need) and for participation in communal events, such as feasts (that further serve to cement social relations). The fact that agricultural management can be so closely inter-twined and dependent on social dynamics and settlement organization shows the importance of understanding the precise nature of agricultural systems for understanding larger socio-economic issues that enabled past societies to function.

Chapter 2 illustrated that decisions surrounding the year-to-year management of crops and animals in agro-pastoral societies are inter-twined with social and economic elements that determine the way resources are distributed and culinary preferences are catered to within these societies. In this chapter, a review of the archaeological background across the study regions shed light on socio-economic aspects of Neolithic communities that will help interpret the nature of crop cultivation and animal management techniques employed by past farmers in these locations. Insight into the way people organized themselves within Neolithic settlements, the types of plants and animals they domesticated and how they came together during communal feasting activities provides a foundation for understanding the social constructs that shaped the development of diverse agro-pastoral systems. The questions pursued in this project will help further our understanding of not only the way that Neolithic societies functioned but also contribute to the debate on how the spread of farming may have been influenced by local cultural agents within the environmetal locations under investigation.

Chapter 4

Methodology: Principles of isotope analysis

The aim of this chapter is to outline the scientific principles of isotope analysis and explain how they can be used to interpret bone collagen δ^{13}C and δ^{15}N values, charred plant δ^{13}C and δ^{15}N values, tooth enamel carbonate δ^{13}C and δ^{18}O values, and tooth enamel ^{87}Sr/^{86}Sr values. First, the interpretative potential of the materials used in this project is discussed in relation to the composition and preservation of bone collagen, charred plants and tooth enamel apatite. Next, isotopic variability in the food chain is discussed through an exploration of the factors that influence the δ^{13}C and δ^{15}N values of plants, and subsequent diet-to-tissue enrichment in animal consumers. Variability in δ^{18}O values of enamel tissues is traced through the global distribution of δ^{18}O values of meteoric water and fractionation processes in surface water and plant leaves. The analysis of sequential measurements of tooth enamel carbonate δ^{18}O and δ^{13}C values and the normalization of the maximum δ^{18}O values within teeth are discussed in terms of how they help shed light on the timing of birth, seasonal feeding and mobility patterns of animals during their early lives. Lastly, interpretation of Sr isotopic signatures in robust archaeological materials is explained in terms of principles of

Sr isotope variability in underlying geologies and practices for establishing reference maps of biologically available strontium. The chapter serves as a reference for the guiding principles used to address questions of crop growing conditions, nature of human and animal diets and issues of long-term and short-term movement of animals investigated in this project.

Organic and inorganic materials recovered from archaeological sites, such as bone collagen, tooth enamel and charred plant melanoidins, contain distinct ratios of heavier and lighter isotopes of carbon (^{13}C/^{12}C), nitrogen (^{15}N/^{14}N), oxygen (^{18}O/^{16}O) and strontium (^{87}Sr/^{86}Sr). The ratios of these isotopes are altered due to fractionation caused by chemical and biolocial transformations during processes such as the carbon cycle, the nitrogen cycle, the hydrological cycle, digestion and photosynthesis (in the case of the stable isotopes: ^{13}C/^{12}C, ^{15}N/^{14}N, ^{18}O/^{16}O) or due to radioactive decay (in the case of ^{87}Sr/^{86}Sr) (Sharp, 2007). Some of these processes are better understood than others, but they all cause the materials to fractionate in predictable ways, and measurements of the resulting isotopic ratios serve as useful indicators of the conditions in which the materials developed. As a result, measurements of isotopic ratios can be used to study aspects of soil growing conditions of cultivated crops and human/animal diets and geographical origins (Sharp, 2007).

Stable isotopic measurements are expressed as δ^{13}C, δ^{15}N and δ^{18}O values relative to international standards (Vienna Pee Dee Belemnite, VPDB, for carbon; Ambient Inhalable Reservoir, AIR, for nitrogen; and Vienna Standard Mean Ocean Water, VSMOW for oxygen), in units of ‰ (parts per thousand). The values are calculated using the following equation (Sharp, 2007):

$$\delta^{13}\mathrm{C} = \frac{^{13}\mathrm{C}/^{12}\mathrm{C}_{\mathrm{sample}} -^{13}\mathrm{C}/^{12}\mathrm{C}_{\mathrm{standard}}}{^{13}\mathrm{C}/^{12}\mathrm{C}_{\mathrm{standard}}} \tag{4.1}$$

^{87}Sr is the product of radioactive decay of ^{87}Rb, which has a half life of 4.7 x 10^{10} years. Because the half-life is so long, the ratios of ^{87}Sr/^{86}Sr in robust archaeological materials, such as tooth enamel, do not change on archaeological timescales. However, older geological formations have distinct ratios of ^{87}Sr/^{86}Sr compared to younger formations and plants growing on top of variable geologies pass distinct ^{87}Sr/^{86}Sr signatures into members of the food chain (Lee-Thorp, 2008).

4.1 Interpretative potential of materials used

4.1.1 Charred plant remains

Plants form the basis of the food chain and are thus critical for reconstructing ancient foodwebs. However, plants have not been used routinely in stable isotope studies due to a number of reasons. First, they are often preserved in limited quantities on archaeological sites, predominantly in charred form (Charles et al., 2015; Dennell, 1976). Second, their stable isotopic signal may have been altered through both exposure to heat during charring and long-term burial (DeNiro and Hastorf, 1985; Dürrwächter et al., 2006; Hedges and Reynard, 2007).

The issue of isotopic alteration resulting from exposure to heat has been studied experimentally. Styring et al. (2013) investigated the biochemical composition of modern and archaeological charred grain and found that heating of grains causes Maillard reactions between proteins and starch, which lead to the formation of high molecular weight melanoidins. Initial charring experiments suggested that charring imposes an offset of 1‰ on the δ^{15}N value of charred crops and no offset on their δ^{13}C values (Fraser et al., 2013). More extensive studies have suggested that the offset is 0.3‰ for δ^{15}N and 0.1‰ for δ^{13}C (Nitsch et al., 2015). These studies assumed an 'optimal charring window' of 220–240°C (following the results of experimental work on einkorn and emmer, Charles et al., 2015) and the offsets were calculated using measurements of crops charred under these temperatures. In this study, $\delta^{15}N$ and $\delta^{13}C$ measurements of plant values will be corrected for the charring effect using the offsets of 0.3‰ and 0.1‰, respectively (cf Nitsch et al., 2015). Older plant isotope data (from Vaiglova et al. 2014*a*) will be corrected to match these newly determined offsets.

The issue of post-depositional contamination was addressed in a study that aimed to identify and remove three different sources of contamination: carbonates, nitrates and humic acids (Vaiglova et al. 2014*b*). The results showed that the presence of carbonates and nitrates can be identified using Fourier Transform Infrared Spectroscopy (FTIR) and removed with gentle acid treatment and washing in distilled water. Humic acids originate both from organic material in soil (exogenous) and from plant material itself (endogenous), and the two cannot be removed separately. However, contamination from exogenous humic acids would have to be substantial to cause a small change to the $\delta^{13}C$ ratio of charred plant material. Vaiglova et al. (2014*b*) thus concluded that it is unnecessary to treat plant material with an alkaline solution to remove humic acids, unless the samples were excavated from soil with a high organic content.

4.1.2 Bone collagen

Human and animal bone remodels itself throughout the life of an individual and fresh tissue forms out of atoms and molecules derived directly from the individual's diet. DeNiro and Epstein (1981) used the phrase "you are what you eat" to describe this phenomenon. The composition of the inorganic component of bone, bone apatite, reflects the composition of all the dietary macronutrients: proteins, lipids and carbohydrates (Ambrose and Norr, 1993; Lee-Thorp et al., 1989*a*; Tieszen and Fagre, 1993). However, bone apatite is highly susceptible to post-depositional alteration due to its low crystallinity (Driessens et al., 1978; LeGeros, 1991), high organic content (20–30%, Lee-Thorp, 2008) and the fact that it shows high levels of re-crystallization even in the absence of environmental catalysts (Trueman et al., 2004). It is in essence a reactive material (Driessens et al., 1978; LeGeros, 1991) and for this reason, it is not used as frequently in archaeology to reconstruct ancient diets.

Because calcium (Ca) from the soil can easily substitute for Sr in bone hydroxyapatite during recrystallization, and because there are no reliable methods for assessing the extent of these substitutions (Hoppe et al., 2003), bone should also not be used in the measurement of Sr isotope values for mobility studies (Budd et al., 2000; Tuross et al., 1989).

The organic component of bone, composed mostly of the protein collagen, is more robust and can preserve unaltered for over 100,000 years (Collins et al., 2002; Hare, 1980; Jones et al., 2001). A simple measure exists for assessing its preservation quality, using the ratio of C:N in extracted collagen samples. Ratios between 2.9 and 3.6 are deemed sufficiently preserved (DeNiro, 1985). However, carbon in bone collagen is preferentially routed from the protein component of diets and measured $\delta^{13}C$ values thus preferentially reflect the isotopic composition of dietary protein, particularly in individuals with high-protein diets (Ambrose and Norr, 1993; Hedges et al., 2007; Jim et al., 2006; Krueger and Sullivan, 1984; Tieszen and Fagre, 1993). N is not present in lipids and carbohydrates, and so $\delta^{15}N$ values of bone collagen can also only be used to infer the significant sources of dietary protein.

4.1.3 Herbivore teeth

Tooth enamel is one of the most robust materials found in nature. It is not porous, has higher crystallinity and density than bone apatite (LeGeros, 1991) and is composed of higher-order prismatic structures (Boyde, 1967). Enamel contains very small amounts of organics (c.1%, Lee-Thorp, 2008) and shows minimal post-mortem recrystallization and crystal growth even after very long periods of time (Ayliffe et al., 1994; Lee-Thorp and van der Merwe, 1987). It can remain unaltered for thousands and even millions of years (Erickson et al., 1981; Lee-Thorp and van der Merwe, 1987; Lee-Thorp et al., 1989*b*; Quade et al., 1992; Thackeray et al., 1990).

Enamel mineralizes in two stages along the axis of tooth growth (from the tooth crown to the cervix forming the enamel root junction). The first stage involves the deposition of the enamel matrix and the second stage involves its secondary mineralization and maturation (Suga, 1982). Oxygen from water (from both diet and drinking water) is incorporated into carbonate and phosphate moieties of tooth enamel in equilibrium with the δ^{18}O of body water (Land et al., 1980; Luz et al., 1984). Once mineralized during the developmental years of an individual, tooth enamel does not remodel itself (Gage et al., 1989), and its isotopic composition thus reflects the dietary and water inputs consumed during the mineralization period. The second molar (M2) of herbivores mineralizes during the first year of the individuals' life and records an entire annual feeding cycle (Balasse et al., 2001; Brown et al., 1960; Hillson, 2005; Towers et al., 2014; Weinreb and Sharav, 1964). Measurement of δ^{18}O from the carbonate portion of enamel has the advantage of simultaneously providing δ^{13}C values of carbon incorporated into the enamel during tooth mineralization. This is helpful for understanding dietary inputs on a finer scale than collagen, which provides long-term later life dietary averages (Balasse et al., 2002; Bocherens et al., 2001).

As the mineralization of enamel and dentine are complex processes that do not progress linearly, a sub-sample taken on any part of a tooth does not represent material formed during a discrete period of time. It provides an attenuated average formed over an unknown period of time (Balasse, 2003; Balasse and Tresset, 2002; Stevens et al., 2011). However, sequential samples obtained in a consistent manner along the axis of herbivore teeh allow for the reconstruction of seasonal patterns of C and O intake (for example studies by Balasse et al., 2013, Kirsanow et al., 2008, Henton, 2012).

4.2 Variability in plant $\delta^{13}C$ values

Plants have distinct $\delta^{13}C$ values depending on how they fix carbon from the atmosphere during photosynthesis (Cerling et al., 1997; Chisholm et al., 1982; Dawson et al., 2002; Smith and Epstein, 1971; Tieszen, 1991). C_3 plants, like barley and wheat, form 3–carbon compounds (phosphoglyceric acid) and have $\delta^{13}C$ values between –21 and –34‰ (mean –26.7 ± 2.3‰, Cerling et al., 1997). C_4 plants, such as millet and maize, form 4–carbon compounds (carboxylic acid) and have $\delta^{13}C$ values between –9 and –17‰ (mean –12.5 ± 1.1‰, Cerling et al., 1997; see also Vogel and van der Merwe, 1977, and DeNiro and Hastorf, 1985). CAM plants (employing the Crassulacean acid metabolism), such as pineapple, are adapted to fix carbon during very arid conditions. Some species have $\delta^{13}C$ values more similar to those of C_3 plants and some have values more similar to C_4 plants (DeNiro and Hastorf, 1985; Osmond et al., 1975; Silvera et al., 2010). These plants do not form a major contribution to human and animal dietary protein intake and are thus not generally involved in dietary reconstructions.

The photosynthetic pathway of plants determines the plants' rate of ^{13}C discrimination, but variability exists within individual species across time and space. In any geographical location, factors such as humidity, temperature, light and air pressure vary on a seasonal basis and as a result, plants show seasonal fluctuations in $\delta^{13}C$ values (Ehleringer et al., 1991; Farquhar et al., 1989, 1982; Hartman and Danin, 2010; O'Leary, 1981). Stable isotope studies which have the resolution to investigate seasonal dietary patterns (like sequential analysis of tooth enamel) thus show that animals that are confined to one location throughout the whole year record a sinusoisal pattern in $\delta^{13}C$ values (for example sheep raised on the island of Rousay in Scotland, Balasse et al. 2012*b*).

δ^{13}C values of plants growing in different locations can vary to an additional degree due to differences in relative humidity (found to be negatively correlated with δ^{13}C values; Hartman and Danin, 2010). In different chronological time periods, δ^{13}C values of plants can vary due to fluctuations in atmospheric CO_2. This is only relevant when comparing modern plants to plants grown before the industrial revolution (Leuenberger et al., 1992).

Moisture and water availability can alter the δ^{13}C values of plants in the Mediterranean region to a greater extent than any of the other factors (Hartman and Danin, 2010; Wallace et al., 2013). This is due to the fact that plants growing in soils with ample water available keep their stomata (the pores on the surface of their leaves) open and the lighter $^{12}CO_2$ is immediately replenished during photosynthesis. As a result, these plants assimilate a higher proportion of the lighter ^{12}C and have lower δ^{13}C values than plants grown under drier conditions. In conditions of limited water availability, plants close their stomata periodically in order to conserve water. As a result, CO_2 is not replenished and the plants end up assimilating a higher proportion of the heavier ^{13}C and have less negative δ^{13}C values (Farquhar et al., 1989, 1982; Jackson et al., 1993).

Plants growing in the lower canopies of dense forests exhibit more negative values compared to plants growing in the upper canopies and compared to plants of the same species growing in open environments. This is attributed to a combination of two factors: 1) the CO_2 available to plants in the lower canopies is depleted in ^{13}C due to recycling of leaf litter (which releases lighter $^{12}CO_2$), and 2) lack of light in the lower canopies leads to a change in photosynthetic activity and stomatal conductance of plants, increasing the rate of discrimination (Bonafini et al., 2013; Cerling et al., 2004; Drucker et al., 2008; van der Merwe and Medina, 1991). The forests in the Mediterranean are not very dense, so the canopy effect is unlikely to have a strong effect here compared to other places. Nevertheless, visible differences would be expected between species that graze on C_3 vegetation in forests compared to those grazing on C_3 vegetation in more open environments.

Notable differences in $\delta^{13}C$ values also exist between different taxa and between plant parts of the same taxa. For example, if barley and wheat are grown under the same growing conditions, the $\delta^{13}C$ of barley will be between $0.5 - 3‰$ lower than that of the wheat (Araus et al., 1997, 1999). Even different varieties of a given species, such as two-row and six-row barley, can have distinct $\delta^{13}C$ values (Anyia et al., 2007; Jiang et al., 2006; Voltas et al., 1999). Species-specific differences exist because of genetic, structural and functional plant adaptations (Hartman and Danin, 2010), while differences between individual plant tissues vary depending on their carbohydrate and protein content (Badeck et al., 2005; Cernusak et al., 2009; Hobbie and Werner, 2004).

Because the $\delta^{13}C$ of plants is partly determined by the $\delta^{13}C$ value of atmospheric CO_2, in order to be able to isolate the effects of ^{13}C discrimiation within plants, plant ecologists convert $\delta^{13}C$ values into $\Delta^{13}C$ values using the following equation (Farquhar et al., 1980):

$$\Delta^{13}C = \frac{\delta^{13}C_{CO_2} - \delta^{13}C_{plant}}{1 + \delta^{13}_{plant}} \tag{4.2}$$

The conversion changes the directionality of the effect: when water availability increases, $\delta^{13}C$ values become more negative, but $\Delta^{13}C$ values increase.

Wallace et al. (2013) established a framework for interpreting $\Delta^{13}C$ values of archaeological crops by calculating thresholds that separate crops grown under three degrees of water availability. Using measurements of modern bread wheat grown in experimental fields and greenhouses in the UK and in Syria, they argued that 'poorly watered' wheat grains have $\Delta^{13}C$ values below 16‰, 'well-watered watered' wheat grains have $\Delta^{13}C$ values above 17‰, and 'moderately watered' wheat grains have values between 16-

17‰. Furthermore, the authors estimated that there is a difference of 1-2‰ between values of wheat and barley grown under the same conditions (with further distinctions between two-row and six-row barley) and used this offset to calculate barley-specific watering bands.

This framework will not be used in this project to assess water status of ancient crops for the following reasons:

1. The definition of the 'moderately watered' band is unclear. Wallace et al. (2013) define 'poorly watered' crops as "crops for which water availability imposes major limitations on growth", 'well-watered' crops as those "for which water availability is not a major limitation on growth" and 'moderately watered' crops as those "with intermediary Δ^{13}C values" (p. 403). If watering status is defined in terms of a binary condition (water is either limited or not), there should be no intermediary zone.

2. The data used to estimate the watering bands for barley are insufficient. Barley-specific bands should be calculated using measurements of this species grown under different watering inputs rather than by adding an estimated offset to the bands representing wheat. This offset may not be consistent through time and place and moreover, its estimation was not based on measurements of the two crops grown under the same conditions. Wallace et al. (2013) measured the values of wheat and barley collected from modern organic farms in Borja, Spain, but these crops were not grown under controlled conditions and the comparative values gathered from literature (Wallace et al., 2013, Table 5) reported measurements of wheat and barley grown in different countries where the moisture inputs in each of the three categories varied. As such, the available data can be used to infer that there is a physiological difference between the two species (with barley having higher Δ^{13}C values), but they cannot be used to put a numeric value on the offset.

3. Interpreting water status of archaeological plants via comparison to the absolute Δ^{13}C values of crops grown in different environments is problematic. Even though in the Mediterranean region, water status is the primary driver of plant ^{13}C discrimination, other factors – such as temperature and evapo-transpiration – may cause more subtle differences in Δ^{13}C values of plants grown in different locations (as discussed above). For this reason, using Δ^{13}C values in absolute terms may be misleading.

In this dissertation, interpretations of plant Δ^{13}C values will be made through consideration of the intra-group Δ^{13}C variabilities of crops grown at individual sites and through assessment of the relative differences in Δ^{13}C values between different varieties of wheats.

4.3 Variability in plant δ^{15}N values

Variability in δ^{15}N values of consumers on different levels of the food chain begins with variability in the plant-soil systems (Szpak, 2014). Plant δ^{15}N values are primarily determined by the source from which they obtain N, the form in which they ingest it (nitrate, NO_3^-; ammonium, NH_4^+; nitrogen gas, N_2), the manner in which they obtain it (direct uptake or symbiotic fixation by mycorrhiza fungi) and location where N is assimilated (in the roots or in the shoots) (Sharp, 2007; Szpak, 2014).

N_2–fixers, such as members of the *Leguminosae* family, acquire N through symbiotic relationship with mycorrhiza, fungi that live on the plants' root nodules and provide plants with N by fixing atmospheric N_2. This process does not involve fractionation, so the value of N_2–fixers tends to be close to 0‰, which is the value of AIR (Craine et al., 2009; Delwiche et al., 1979; Szpak, 2014). All other non–N_2–fixing plants, like cereals, assimilate nitrogen from the soil and are thus influenced by a host of soil enrichment factors.

A range of both natural and anthropogenic factors cause enrichment in soil ^{15}N. Natural factors include nutrient status (Szpak, 2014), salinity (Ambrose, 1991; Heaton, 1987), denitrification (Högberg, 1997; Tiedje et al., 1982), and topography (Hartman and Danin, 2010). A number of studies reported negative correlation between plant δ^{15}N and mean annual precipitation (Ambrose, 1991; Ambrose and DeNiro, 1989; Amundson et al., 2003; Austin and Vitousek, 1998; Craine et al., 2009; Handley et al., 1999; Hartman and Danin, 2010; Heaton, 1986, 1987; Heaton et al., 1986; Sealy et al., 1987; Szpak et al., 2013). However, it must be noted that large variability exists among plants growing in the same rainfall zone (isohyet), so the effects of aridity can only be interpreted on large scales (between locations with 100mm and 1000mm of annual rainfall, for example).

Other studies showed positive correlation between plant δ^{15}N values and temperature, but the relationship weakens at lower temperatures (Amundson et al., 2003; Martinelli et al., 1999; Pardo et al., 2006). Together, higher temperatures and lower precipitation create conditions which are more prone to N loss; while colder and wetter conditions lead to conservation and recycling of N (Szpak, 2014). However, biochemical reactions in soil may override climate trends. For example, in conditions of extreme wetness (such as in swamps/wetlands), denitrification causes large fractionation and elevates the overall δ^{15}N values of the ecosystem (Högberg, 1997; Szpak, 2014; Tiedje et al., 1982).

Anthropogenic factors include methods to improve soil fertility such as tillage, burning and application of animal manure or decomposing midden material. Tillage promotes mineralization of soil organic matter and brings soil from deeper in a soil profile (and more enriched in ^{15}N, Hobbie and Högberg, 2012) closer to the surface (Szpak, 2014).

Application of manure/compost causes enrichment in ^{15}N because during the process of decomposition, the material releases N in the form of gaseous ammonia (NH_3) to the atmosphere. Burning of soils also causes ammonia volatilization. This gaseous NH_3 is isotopically lighter, leaving the substrate more enriched in ^{15}N. Plants that grow in ^{15}N–enriched soils reflect this soil enrichment (Bateman et al., 2005; Bogaard et al., 2007; Choi et al., 2002, 2003, 2006; Fraser et al., 2011; Guttmann, 2005; Nakano and Uehara, 2007; Simpson et al., 1999; Szpak et al., 2012*a*, 2012*b*; Watzka et al., 2006; Yun et al., 2006; Zhou et al., 2013). Because manuring leaves a residual effect on the $\delta^{15}N$ value of soils, this enrichment will last for several years and agricultural use can thus be detected even after the practice has ceased (Koerner et al., 1999). The actual degree of enrichment depends on the type of fertilizer used, the amount applied and the duration of application.

Similarly as with $\delta^{13}C$ values, different plant parts may have different $\delta^{15}N$ values. This is because some plant parts serve as N sinks (like grains, which form during reproductive growth when vegetative growth has slowed down) and some serve as N sources (leaves and stems, which may reallocate some of their N to other tissues such as fruits) (Evans, 2001; Hobbie and Högberg, 2012; Szpak, 2014). Fraser et al. (2011) suggest that grains of cereals are typically enriched in ^{15}N over rachis (cereal chaff), and Szpak (2014) argues that in species such as maize, bean, rice, squash and pepper, the grains are depleted in ^{15}N compared to plant parts like leaves and stems. These varying offsets between grain and non-grain components may partly be species-specific and partly component-specific. It may be that while rachis of cereals is depleted, other non-grain plant parts are enriched in ^{15}N compared to grain. This brings into question the approach of estimating the values of crop by-products by subtracting the offset between grain and rachis from measured grain $\delta^{15}N$ values (for example in Vaiglova et al. 2014*a*) to assess their potential contribution in animal diets. As rachis forms a small component of the total non-grain mass of cereals, the overall $\delta^{15}N$ value of the fodder feed may actually be enriched in ^{15}N if other larger components are enriched, as Szpak (2014) argues. Further studies are necessary to explore the δ^{15}N value offsets between various plant components before these estimations can be more reliable.

4.4 Factors influencing bone collagen δ^{13}C and δ^{15}N values

4.4.1 Trophic enrichment and δ^{15}N values

Interpretation of bone collagen δ^{13}C and δ^{15}N values depends on a number of established principles. Tissues of organisms become systematically enriched in ^{15}N with every level of the food chain. As a result, carnivores have higher δ^{15}N values than herbivores they consume and herbivores have higher δ^{15}N values compared to the plants they eat (DeNiro and Epstein, 1981; Hedges and Reynard, 2007; Minagawa and Wada, 1984). This trophic enrichment has been studied by comparing the offset between $\delta^{15}N_{\text{diet}}$ to $\delta^{15}N_{\text{tissue}}$ and is estimated to be between $3-6$‰ (Ambrose, 2000; Bocherens and Drucker, 2003; Hedges and Reynard, 2007; O'Connell et al., 2012; Schoeninger and DeNiro, 1984).

The marine food chain is much longer than the terrestrial food chain, so there is more scope for enrichment in ^{15}N for high-level marine carnivores (Richards and Hedges, 1999; Schoeninger and DeNiro, 1984). Thus, animals like seals and sea lions have been found to have very elevated δ^{15}N values, around 17.0‰ and 18.0‰, respectively (DeNiro, 1985; Schoeninger and DeNiro, 1984).

Problems with equifinality complicate the interpretation of δ^{15}N values. For example, consumption of both high quantities of meat and plants that have been heavily manured can elevate the δ^{15}N value of consumer tissues to the same extent, so high δ^{15}N values of humans cannot be easily equated with high meat consumption. In order to disentangle between different food sources that may be similarly enriched in ^{15}N, the remains of as many potential food sources (including plants) must be measured from contemporary archaeological deposits and interpretations made by comparison (Bogaard et al. 2013*b*; Fraser et al., 2011).

In the past, researchers used the mean collagen δ^{15}N of herbivores measured from a site minus trophic level enrichment of c.4.0‰ to estimate the value of the "environmental baseline" (as reviewed by Hedges and Reynard, 2007). This was done in order to determine whether collagen values from different sites could be compared in absolute terms. While this estimation of the baseline serves as a rough indicator of whether major ecosystemic differences exist between different locations, these values cannot be assumed to be indicative of the δ^{15}N values of cultivated plants, which are affected by a host of other factors, such as anthropogenic manipulation. In addition, the actual trophic enrichment in various locations may have varied due to factors such as the size of the animals, metabolic fitness and quality of diet (Robbins et al., 2005; Sponheimer et al., 2003*a*; Sponheimer et al., 2003*b*), adding uncertainty to the estimated baseline value. For this reason, in order to estimate the contribution of cultivated plants in human and animal diets and understand what kinds of soils the crops were grown in, the remains of the actual grains/seeds must be measured.

Climatic factors may also influence consumer isotope values to a greater or lesser extent than diet. To disentangle between two possible explanations of why herbivores in arid environments in the eastern Mediterranean have elevated δ^{15}N values – 1) it is a physiological response to heat and water stress or 2) the animals consume plants that have naturally higher δ^{15}N values – Hartman (2011) investigated the relationship between gazelle and ibex keratin δ^{15}N values and environmental factors such as mean daily temperature, mean annual rainfall, relative daily humidity, and aridity index. In the absence of correlation between these factors and δ^{15}N values, the author concluded that diet is the main driver of the elevated herbivore δ^{15}N values.

4.4.2 Diet to tissue enrichment and δ^{13}C values

Diet to tissue δ^{13}C value offset is 3 – 6‰ for collagen (Krueger and Sullivan, 1984; Lee-Thorp et al., 1989*a*; van der Merwe and Vogel, 1978) and 9 – 15‰ for bioapatite; the actual offset depending on the animals' digestive physiology (Cerling and Harris, 1999; Krueger and Sullivan, 1984; Lee-Thorp et al., 1989*a*; Passey et al., 2005). Thus, predominantly–C_3 consumers have collagen values of around –21‰ and bioapatite carbonate values around –12‰, and predominantly–C_4 consumers have collagen values of around –8‰ and carbonate values of around 1‰ (Cerling et al., 1997; Ehleringer et al., 2002). Cerling et al. (1997) argues that below –8‰, tooth enamel values of large herbivores may be assumed to be predominantly C_3. This value is used in this project as the lower endpoint of the bracket indicating inputs of C_4 vegetation in herbivore's diets. More subtle differences in dietary signatures are governed by nuanced variabilities in δ^{13}C and δ^{15}N values in plants discussed above.

4.5 Distribution of δ^{18}O in water and mammalian tooth enamel

4.5.1 Global distribution of meteoric δ^{18}O values

δ^{18}O values of meteoric water are determined by fractionation during the hydrological cycle. As water evaporates from the oceans, the lighter ^{16}O is preferentially lost to the atmosphere in the form of water vapor, leaving ocean water more enriched in ^{18}O. Clouds, which are isotopically lighter compared to ocean water then move from coastlines inland, losing the heavier ^{18}O in the form of rain along the way. As a result, precipitation in areas closer to the coast has higher δ^{18}O values compared to precipitation in more upland areas. δ^{18}O in meteoric water also decreases with increasing latitude. At mid-high latitudes, there is a strong correlation between temperature and δ^{18}O of precipitation (Bowen and Wilkinson, 2002; Dansgaard, 1964; Hoefs, 2009; Rozanski et al., 1992, 1993; Sharp, 2007).

The variation in meteoric δ^{18}O values has been mapped globally (see for example Bowen and Wilkinson, 2002), and local rainfall data collected at meteoric stations around the world are compiled on the Global Network of Isotopes in Precipitation database (GNIP, http://www-naweb.iaea.org). Fluctuations in δ^{18}O through time measured in proxies such as ice cores, tree rings, shells, and lake sediments, but also from archaeological materials such as tooth enamel have been used to calculate past precipitation and temperature levels (Fricke et al., 1995; Hartman et al., 2016; Lécolle, 1985; Stevens et al., 2011; van Dam and Reichart, 2009; Zanazzi et al., 2007) and robust methods for assessing the errors attached to the calculations were explored by Pryor et al. (2014).

4.5.2 δ^{18}O values in surface water and plant leaves

Surface water and groundwater generally follow the same pattern as meteoric water, but the actual δ^{18}O values at local scales are further influenced by evaporation and condensation, mixing and transportation (Bowen, 2010; Gat, 1996; Kendall and Coplen, 2001). In semi-arid environments, evapo-transpiration causes the δ^{18}O of water in soil to become enriched in ^{18}O compared to the δ^{18}O of precipitation (Allison and Hughes, 1983).

Plant leaves have higher δ^{18}O values compared to water in soil because they lose the lighter ^{16}O during evapo-transpiration. The actual degree of ^{18}O-enrichment is dependent on factors such as relative humidity, temperature, pressure, transpiration rate and δ^{18}O value of water vapor in the atmosphere (Dongmann et al., 1974; Farquhar et al., 2006). During the summer months in the Mediterranean region, the combination of higher temperatures and lower humidity favor evaporation and as a result, plants have the highest $\delta^{18}O$ values in the summer and lowest in the winter (Gat, 1980; Rozanski et al., 1993). An expected annual cycle of plants growing in these latitudes are sinusoidal curves where the amplitude denotes the difference between summer and winter $\delta^{18}O$ values.

4.6 Seasonal fluctuations in mammalian tooth enamel $\delta^{18}O$ and $\delta^{13}C$ values

Oxygen in tooth enamel of herbivores like cattle, sheep and goats is precipitated in equilibrium with body water, the $\delta^{18}O$ value of which reflects a balance between O inputs (food, water, atmospheric O_2) and outputs (sweat, urine, water vapor) (Bryant et al., 1996; Kohn, 1996; Land et al., 1980; Luz and Kolodny, 1985; Luz et al., 1984). Changes in tooth enamel $\delta^{18}O$ values are mainly driven by fluctuation in $\delta^{18}O$ values of plant water and surface water, which are in turn determined by the $\delta^{18}O$ values of meteoric water, over the course of the tooth mineralization phase (Longinelli, 1984; Luz et al., 1984). Sequential sampling along the growth axis can thus be used to assess seasonal variations in enamel $\delta^{18}O$ values (Fricke and O'Neil, 1996).

These intra-tooth sequential patterns can then be used to reconstruct the animals' feeding patterns, and whether or not they involved seasonal movement during an episode of their development (Balasse et al., 2002, 2013; Bocherens et al., 2001; Henton, 2012; Henton et al., 2010; Kirsanow et al., 2008). However, it must be kept in mind that species-specific differences control body water $\delta^{18}O$ and some species correlate better with meteoric water than others (Iacumin and Longinelli, 2002). Balasse et al. (2013) noted that the amplitudes of $\delta^{18}O$ variation tend to be higher in sheep than in cattle so caution must be exercised when interpreting absolute values of tooth carbonate δ^{18}O values (Balasse, 2003).

Animals which spend the whole year feeding on plants growing in a micro-environment in the Mediterranean exhibit sinusoidal annual enamel sequences, with $\delta^{18}O_{max}$ values corresponding to the summer and $\delta^{18}O_{min}$ values corresponding to the winter. The matching δ^{13}C values can thus be used to approximate what kind of vegetation the animals obtained during the hotter and colder seasons. The smoothness of the curves reflect how variable the diets of the animals are. The tooth enamel sequences of animals grazing in restricted pastures should in principle be smoother than curves of animals that visit a number of pastures over the course of a season. A possible explanation for lack of correlation between δ^{13}C and δ^{18}O values may be the provision of fodder, a practice that has been observed and noted isotopically using δ^{13}C and δ^{15}N values of tooth dentine in modern sheep from Mongolia (Makarewicz and Tuross, 2006).

Movement between different altitudes can also influence the δ^{18}O values of animals tissues. The intra-tooth sequences of animals that migrate trans-altitudinally tend to be dampened (have smaller amplitudes) compared to animals that do not move over such distances. Longinelli and Selmo (2003) argue that a 100m increase in altitude equates to 0.3‰ decrease in δ^{18}O values. However, Makarewicz and Pederzani (in press) observed that domestic and wild caprines inhabiting the same location in the Gobi desert exhibit varying amplitudes of δ^{18}O values and attributed this to variable water intake (graze and ground-water). Thus, it must be borne in mind that δ^{18}O values are not strictly driven by meteoric water and that using the intra-tooth amplitude to assess vertical mobility may be misleading.

In this project, tooth enamel carbonate $\delta^{18}O_{VSMOW}$ values were converted into $\delta^{18}O_{VPDB}$ values using the following equation (Friedman and

O'Neil, 1977):

$$\delta^{18}O_{VPDB} = \frac{\delta^{18}O_{VSMOW} - 30.91}{1.03091} \tag{4.3}$$

4.7 Estimating birthing seasonality using normalized $\delta^{18}O$ values

Farmers extend the birth seasonality of cows in order to secure supplies of milk for the entire year (assuming that lactation lasts 6 – 7 months, cf wild cattle studied by Peske and Tresset in Balasse et al. 2012*b*). Restricted timing of births was observed in free-ranging semi-wild cattle breeds in Scotland and Northern France. The animals, whose birthing was not controlled, were all born between May and July (Balasse et al. 2012*a*; Reinhardt et al., 1986).

Balasse et al. (2012*b*, 2013) established a method for assessing the seasonality of birth of domestic herbivores by normalizing the distance at which the $\delta^{18}O_{max}$ values occur in each tooth relative to the length of the crown. It is necessary to normalize the values because the same teeth (for example M2s) may grow at slightly different rates in different individuals. The calculated values, x_0/X, represent the distance from the enamel root junction at which the $\delta^{18}O_{max}$ occurs (x_0) with respect to the period (X) and indicate at what % of the recorded annual cycle the highest $\delta^{18}O$ values occur. The values are derived from a model of best fit (least squares) using the following equation:

$$\delta^{18}O_{model} = a\cos(2\pi\frac{x - x_0}{x + bx}) + M \tag{4.4}$$

Balasse et al. (2012*a*) investigated the birth seasonality of Neolithic cattle from Bercy, France, using this method and concluded that calving at this site took place over six months, and that this was likely the result of a management strategy aimed to extend the availability of milk (Balasse et al. 2012*a*). This method is used in the present study to determine the birth seasonality of sheep and cattle at Makriyalos and sheep and goats at Kouphovouno (using an Excell spreadsheet shared with Marie Balasse).

4.8 Sr isotopes in geological formations

4.8.1 Incorporation of Sr from bedrock into the biosphere

Strontium is a trace element that originates in bedrock and makes its way into the food chain through rock/soil weathering, plant intake and dietary ingestion. The isotope ratio of Sr does not fractionate during this process, so the ^{87}Sr/^{86}Sr in animal tissues reflects the ^{87}Sr/^{86}Sr ratio of the food sources, which in turn reflects the isotopic composition of bioavailable strontium (Evans et al., 2009; Lee-Thorp, 2008; Price et al., 2002). Plants have a higher concentration of Sr than meat, and so plant foods have a higher impact on the Sr isotope composition of consumer tissues than do animal products (Burton et al., 1999; Elias, 1980).

Bioavailable strontium derives from both geological weathering and exogenous atmospheric input. Hartman and Richards (2014) observed that exogenous atmospheric input plays a central role in the Sr isotope value of plants collected across a long gradient in the Levantine coast. In this location, the contribution of atmospheric Sr has been found to be more important than bedrock weathering as the age of the rock increases (although the opposite has been reported to be the case in New Mexico) (Hartman and Richards, 2014).

^{87}Sr is produced by the ratioactive decay of ^{87}Rb in rocks and the specific Sr isotope composition is dependent on the age of the rock and its initial ^{87}Rb content. Older rocks have higher ^{87}Sr/^{86}Sr values than younger rocks (Faure and Powell, 1972). In the Golan Heights, Pliocene basalt was found to have ratios of 0.70687 ± 0.00080 and Late Pleistocene basalt was found to have ratios of 0.70465 ± 0.00017 (Hartman and Richards, 2014). The modern value of the ocean is 0.7092 and as Sr from the ocean is carried by meteoric water and deposited on coastal regions, these areas show a noticeable 'sea spray effect' (Elderfield, 1986). For example, seashore sand collected from the Mediterranean coast in the Levant was measured to have ratios between 0.7090 – 0.7092 (Hartman and Richards, 2014).

Measurements of $^{87}Sr/^{86}Sr$ from robust archaeological materials like tooth enamel can be used to identify possible outsiders, people/animals who were born outside of the local environment where they ended up buried (Richards et al., 2008; Snoeck et al. 2016). In this context, the definition of 'local' depends on how variable the surrounding geology is. If the area within a 20km radius of an archaeological site is underlain by geology of the same age, then no distinction can be made between residence at sites within this radius. If, on the other hand, the geology 5km away from a site is strikingly different to the geology on which the site sits, then the local sphere is reduced and possible outsiders may be identified from shorter distances.

4.8.2 Establishing reference maps of bioavailable strontium isotope values

Establishing the variability in local Sr isotope values is critical for interpreting Sr isotope values from archaeological materials. This can be done by measuring the isotope value of bioavailable Sr obtained from samples of modern biological materials (such as ground vegetation, tree leaves, snail shells, water and soil leachates) from different geological zones in the surrounding landscape (Evans et al., 2010, 2009; Laffoon et al., 2012; Porder et al., 2003; Sillen et al., 1998). Each location will have a range of Sr isotope values rather than a single value due to variabilities in the composition of different rock materials, plant parts and input from water sources (Bentley and Knipper, 2005).

Best practice sampling of the biosphere needs to avoid places which may have been affected by anthropogenic inputs, such as chemical fertilizers and pesticides, and avoid urban settlements. In addition, in order to most appropriately characterize the variability in local Sr isotope values, an attempt should be made to obtain plants whose roots reach varying soil depths.

Some researchers (Bentley and Knipper, 2005; Bentley et al., 2004; Price et al., 2002) attempted to establish local Sr isotope values using archaeological samples of low-mobility species, such as pigs and rodents. However, even short-ranging livestock may have been brought to a site through trade/exchange and may thus not represent local births and the values of small rodents, may be 'too local', unrepresentative of a realistic catchment of human subsistence (Snoeck et al. 2016, Madgwick et al. 2012). Due to variability in the density of distribution of archaeological settlements, measurement of archaeological samples may also lack the coverage that can be achieved by sampling modern materials.

Chapter 5

Çatalhöyük

This chapter presents the case study at Çatalhöyük. First, the main archaeological findings are synthesized to provide a picture of the Neolithic village and its chronology. Next, the two main models used to describe the surrounding environment are summarized and assessed in terms of their contribution to our understanding of the crop cultivation strategies employed by the Neolithic farmers. The findings of archaeobotanical analysis undertaken by several teams of researchers are then summarized and used to frame the questions pursued in this project. A description of the materials used and the results obtained in this study follow. The final discussion focuses mainly on the issue of diversity in crop management and access to fields by the production households connected through social networks across the densely populated settlement. The discussion also provides an opportunity to further the interpretation of diets of humans buried across the site, previously studied by Richards et al. (2003) and Pearson et al. (2015, 2013).

5.1 Introduction and archaeological background

The East mound at Çatalhöyük covers an area of 13.5ha and was occupied in the Neolithic period between 7100–6000 cal BC (Bayliss et al., 2015; Hodder and Farid, 2014; Marciniak et al., 2015). During the Neolithic, the East mound played host to a densely populated village consisting of clusters of tightly packed mudbrick buildings, some of which may have been two-story in height, interspersed with open areas and 'alleyways' used for outdoor activities and the disposal of refuse (Bogaard et al., 2014*c*; Hodder, 2006, 2013*a*).

The mound was not homogenously occupied at all times during its 1100–year Neolithic occupation; different parts of the mound were built up at different times as the population grew and shrank. Distinctions in dental traits and tooth size of humans from the North and South areas (see below for description of the areas) suggest that these two areas of the mound were inhabited by separate communities (Larsen et al., 2015). It is estimated that between 3,500 and 8,000 people inhabited the site at any one time (Hodder and Farid, 2014). The settlement reached its maximum size about halfway through the Neolithic sequence; this is the time that the 'neighborhood' exposed in the excavations of the North area was in use. The layout of the village reflects fluctuations in population density and emphasizes the tradition of reuse of space: "There are almost no true right angles and the feeling is of an organic, cellular agglomeration of buildings over time rather than a unified planned layout" (Matthews and Hodder, 1994).

The first phase of excavations took place during the 1960s, under the direction of James Mellaart (Mellaart, 1962, 1963, 1964, 1966, 1967) and a renewed phase, which started in 1993 is still ongoing under the direction of Ian Hodder (Hodder, 2013*a*, 1996, 2000, 2005*a*,*b*,*c*, 2007, 2013*c*,*d*, 2014). Excavation has concentrated on several areas stretching across the mound's 'eminences' and peripheries (see Fig. 5.1). For this study, samples have been obtained from the South area and Team Poznan Connection area (TPC) (these two will be referred to collectively as South Area) as well as the North, 4040 and BACH areas (these two will be referred to as North Area). In addition, the KOPAL trench, located off the northern edge of the mound will be discussed in relation to the geomorpohological work conducted at the site in order to reconstruct the Neolithic landscape and place the establishment of the settlement into its environmental and chronological context.

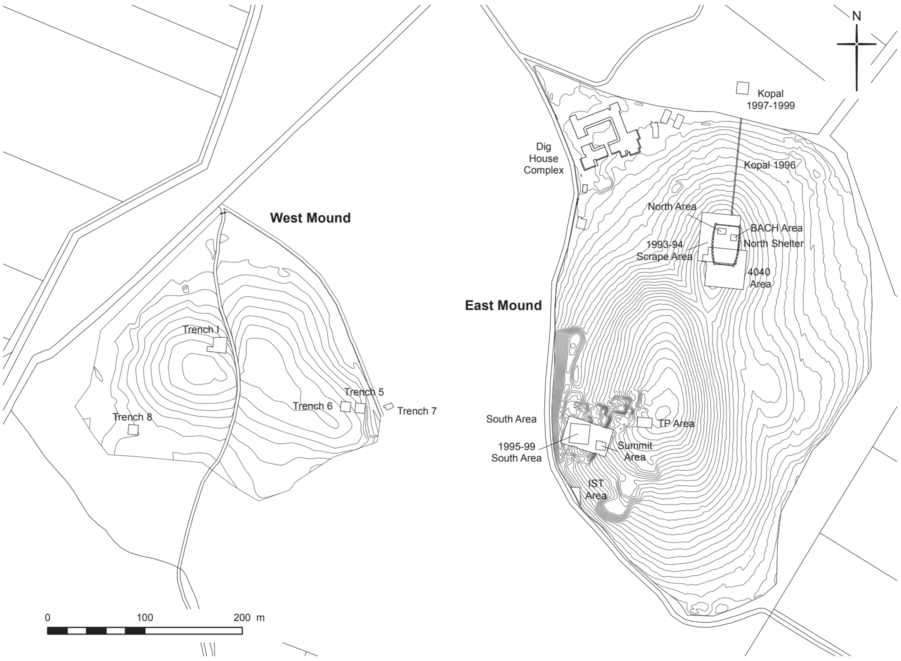


Figure 5.1: Map of the East and West mounds at Çatalhöyük showing the areas that have been excavated between 1993 and 2013

In the absence of public buildings or areas designated for social gatherings, the central element of the Neolithic village was the household (Hodder, 2006). Although not completely standardized in size and layout (see below), houses went through similar cycles of building, use, and rebuilding. Some houses may have been intentionally burnt down, perhaps as part of an abandonment ritual, before they were leveled and new houses were built on top. These houses are referred to by the excavation team as 'burnt buildings', but debate is still ongoing as to the intentionality of their destruction (Hodder, 2013*c*).

The interiors of houses were generally characterized by a main room and one or more side rooms. The side rooms were accessed through crawl holes and contained a range of different storage features – such as bins and baskets – as well as installations and debitage that attest to their use for food preparation and tool making. The main rooms of buildings show emphasis on display of elaborate wall paintings and symbolic horn installations, which were affixed to platforms situated along the walls. The central rooms were used for both ritual and domestic activities, with the former taking place in the 'cleaner' parts of the room – usually situated in the north – and food preparation carried out in the 'dirtier' parts of the room where ovens and hearths were located (Hodder, 2006).

Holes in the roofs above the ovens were used both as chimneys and as entryways for climbing in on ladders. The walls of the rooms were periodically re-plastered with white lime plaster sourced from the vicinity of the mound, in an effort to cover up the soot from the smoke produced during cooking. The people buried their dead underneath the platforms in the main rooms and used a range of different materials, including bone, antler, clay and stone to produce tools and decorative items such as needles, chisels, hammers, choppers, spear points, plaster tools, spatulas, harpoons, beads, rings, pendants and figurines. In addition, the exceptional preservation of organic material at the site has provided us with evidence of wooden objects and utensils, plates, platters, boxes and spoons, that were used for food preparation and consumption (Hodder, 2006).

Although patterns can be identified, houses at Çatalhöyük display a notable amount of variability through time and space. There was variation in the sizes of houses and rooms as well as in house layouts. Some houses had a few storage bins, others had several (building 5 in the North area had seven) (Bogaard et al., 2009; Demirergi et al., 2014; Hodder, 1998). The locations of ovens within houses varied, as did the placement and number of burials found underneath the floors. Some people were buried with a wooden basket on their head or alabaster bracelets on their wrists, yet others were buried headless, arm/leg-less or with animals such as lambs. One person was buried holding a plastered skull (Hodder, 2013*b*). In addition, investigation of the composition of mudbricks indicates that large variability existed in the types of materials used, suggesting that different households made their own mudbrick (Love, 2012).

It has initially been suggested that variability on the level of households and neighborhoods attests to "tendencies towards social differentiation" (Hodder, 2010, pg. 1). Elements that have been taken to signify special status of buildings include a substantially large amount of sub-floor burials, the lack of ancillary rooms, small size of the main room, longevity of the house, careful abandonment of the house and rebuilding of subsequent houses on top of the same floor plans. Emphasis was placed on the maintenance of memories and cultural values, and these houses came to be called 'history houses'. One such 'history house' is the sequence of buildings 65–56–44–10. More recent interpretation, however, has overturned the hypothesis that Çatalhöyük was socially stratified and the current view is that history houses were no more special than other houses, apart from the fact that they contained significantly larger number of burials. In this study, the idea of social stratification will be put to test by examining whether houses had differential access to arable land of variable quality, in particular the plots of land that were most proximal to the nucleated settlement.

5.1.1 Excavation and chronology

In the current phase of excavations, work in the South area focuses on piecing together sections that cover the length of the Neolithic stratigraphic sequence on the East mound. The focus in the North area (which includes area 4040) is to investigate the settlement organization, and the possibility of the use of alleyways/streets in a neighborhood (cluster of buildings) about mid-way through the Neolithic sequence.

Over the course of the two excavation campaigns, material from Çatalhöyük has been recorded and interpreted using two chronological phasing systems. Initially, James Mellaart created a system based on 14 levels, going from level 0 at the top of the sequence to level XII at the bottom of the sequence and including levels VIA and VIB (Farid, 2008). This system operates under a number of assumptions, which eventually started causing problems: it assumes that buildings lying side-by-side were contemporary, that the vertical sequence of houses was continuous and that different parts of the mound were occupied at the same time. In order to address these problems and better represent the "nuances of the temporal sequence and material culture", a new system was devised in the recent excavations (Farid, 2008, pg. 20).

The new system is based on a single 'strand' of continuous buildings/ columns in each area and uses letters, which start in the middle of the alphabetical sequence in order to allow for additions on either end. The main strand is in the South area, and is used as a backbone for the radiocarbon dating programme (Bayliss et al., 2015; Farid, 2008).

It is difficult to relate stratigraphically some parts of the North and 4040 areas because no direct link has been excavated. For this reason, some of the phase assignments have question marks in them (for eg. North.?G). These labels mean that there are good reasons to believe that a building/space belongs to this level, but that there is not a direct stratigraphic link. The question marks remind us that it should not be assumed that buildings lying in one horizon were necessarily contemporary and that the clusters forming the neighborhoods may have been the result of temporal rather than spatial patterning (Farid, 2008).

5.2 The environment

5.2.1 Geographical setting

Çatalhöyük (37° 40’ 4.60” N, 32° 49’ 38.86” E) is located in the Konya plain which stretches across the south–central Anatolian plateau in modern-day Turkey (Fig. 5.2). Today, the plain hosts three types of vegetation – steppe, forest and wetland (Hastorf, 1998) – in a climate that is semi-arid, with annual precipitation below 300mm (Leng et al., 1999; Taha et al., 1981). The summit of the East mound sits at an elevation of 1000m above sea level. The Konya plain is bordered to the south by the Taurus mountain range, where peaks reach an elevation of 3,000masl, and where the river Çarşamba originates. In Neolithic times, the river flowed on the western periphery of the East mound, but it was canalized in the 20th century and now passes a few kilometers south of the site (Doherty et al., 2008). The river goes through a three-stage cycle over the course of the year: in the late spring, it reaches its peak flow after the snow from the Taurus mountains has melted, in the summer, the flow is at its lowest as the region undergoes a summer drought, and the flow picks up again in the autumn, winter and early spring. Rosen and Roberts (2005) argue that the river followed the same pattern in the early Holocene.

5.2.2 The Konya plain through the Pleistocene–Holocene

During the Pleistocene, the Konya plain was submerged under a lake, Lake Konya, which formed during the Last Glacial Maximum (Boyer et al., 2006; Erol, 1978; Leng et al., 1999). At this time, the climate was hospitable to a wide range of wild animals and mobile hunter-gatherers (Rosen and Roberts, 2005). When the lake dried up in the terminal Pleistocene (c.17,000 BP), it left behind a ‘gently undulating’ surface covered by marl, a white calcareous clay (Boyer et al., 2006, pg. 676). With the onset of Younger Dryas global

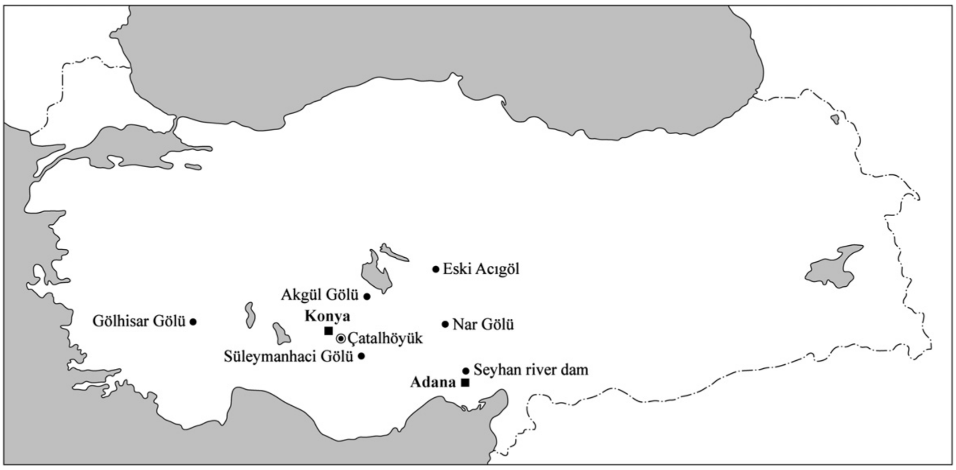


Figure 5.2: Map of Anatolia showing the location of Çatalhöyük in the South–central Konya Basin (Bar-Yosef Mayer et al., 2012)

cooling event, the Konya basin became dessicated and inhospitable to human, animal and plant populations. This lasted until the early Holocene, when the climate became warmer and alluviation from the Taurus mountains started to create the Çarşamba alluvial fan. Çatalhöyük is located roughly in the center of this fan (Boyer et al., 2006; Rosen and Roberts, 2005).

The Holocene alluviation went through two main phases, which left their trace in the geomorphological record (Boyer et al., 2006) (see Fig. 5.3 for a map of the geomorphology of the Konya Basin). The initial phase saw the deposition of a dark grey-brown alluvial clay called the Lower Alluvium. Initially interpreted as evenly spread across the Çarşamba plain (Rosen and Roberts, 2005), a more recent coring study suggests that this alluvial layer may not have been as continuous as earlier thought (Charles et al., 2014; Doherty, 2013). This horizon has a lower organic content, but a higher silt content and magnetic susceptability than the overlying Upper Alluvium. The latter is composed of much drier and more red (more oxidized) alluvial clay and is dated to the Neolithic–Chalcolithic transition (Boyer et al., 2006). The results of optically stimulated luminescence dating (OSL) of material from the KOPAL trench at Çatalhöyük suggest that the onset of the alluvial activity in the plain (8000–7500 cal BC.) pre-dated the first occupation of the site (c.7100 cal BC), although the OSL dates must be treated with caution as they have very large uncertainties (Roberts et al., 1999; Rosen and Roberts, 2005).

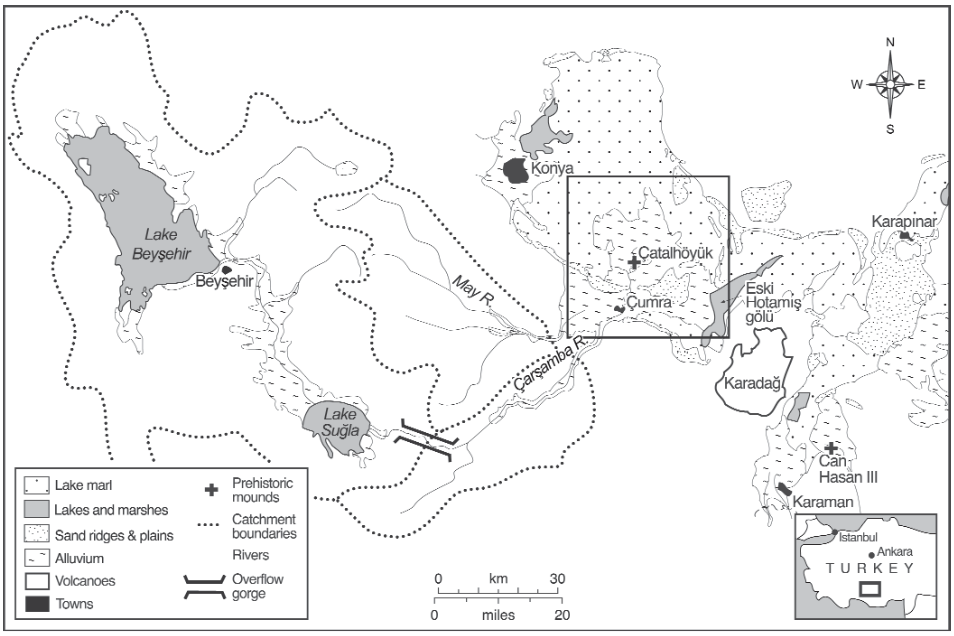


Figure 5.3: Geomorphological map of the western Konya Basin, Turkey (Boyer et al., 2006)

5.2.3 The Neolithic landscape

Reconstruction of the Neolithic landscape around the Çatalhöyük East mound has its own history. Todd (1976) described the landscape as a mixture of backswamp and alluvial areas and argued that most of the land in the vicinity of the village was suitable for grazing and arable farming. He estimated that if all the suitable local soils were cultivated, the food produced would feed 7,500 people. All subsequent theories embraced the central element of this reconstruction – that the landscape was heterogeneous – and over the past five decades, the environment has been described as a type of ‘mosaic’: “Their [Çatalhöyük’s inhabitants] local world was an island of rich marsh and riverine life, dotted with riparian copses, dry fields and forage areas” (Atalay and Hastorf, 2005, pg. 109). “When the first Neolithic people arrived in the area, they found an increasingly complex mosaic of depositional environments and vegetation associations” (Rosen and Roberts, 2005, pg. 45). “The marl surface of the retreating Pleistocene Lake Konya would have been eroded to produce a mosaic landscape of small rises and depressions” (Doherty, 2013, pg. 55).

Two theories came to dominate the debate on what the surrounding environment looked like during the recent phase of excavations at Çatalhöyük. The first was brought forward by the geomorphological team that excavated the KOPAL area and carried out a coring program in the Çarşamba fan, combined with a field survey of contemporary prehistoric sites (Roberts et al., 1999, 1996; Roberts and Rosen, 2009; Rosen and Roberts, 2005). The mosaic they described was one of seasonal wetlands at the time of very active alluviation that leveled the whole of the Çarşamba fan. This reconstruction was revised more recently in light of evidence from a soil coring program that aimed at understanding the sources of clays used at the site for the production of mudbrick, pottery and other clay objects like clay balls used for cooking (Charles et al., 2014; Doherty, 2013; Doherty et al., 2007, 2008). This new mosaic is one of interspersed wet and dry areas. Even though the central elements of this model are not new – Atalay and Hastorf (2005) embraced the idea that the landscape was dotted with ‘islands’ of drier land and Fairbairn et al. (2005) described marl hummocks cropping up above the wetland which may have provided land situated high enough to avoid the spring floods – the two models have been employed in contrasting interpretations of land use around the Neolithic site.

According to Roberts et al. (Roberts et al., 1999; Roberts and Rosen, 2009; Rosen and Roberts, 2005), the Neolithic village was surrounded by a patchwork of seasonal wetlands. Waters from the Çarşamba flooded the basin in the late spring, and for two months, the alluvial fan sat under water. Çatalhöyük thus became an island cropping up above a vast marsh 'back-swamp' that stretched for more than a dozen kilometers in every direction. During the flood season, people moved across the marsh on reed boats/rafts (none of which have been preserved). Levees "could not form a significant part of the Neolithic landscape" (Roberts and Rosen, 2009, pg. 396) and the closest soils which would have enabled dryland farming were located on Neogene terraces c.13km to the south. The evidence used to support the presence of a marsh environment was derived from the archaeobotanical and archaeozoological record, which has provided the remains of marsh plants, ducks and other water birds (Russell and McGowan, 2005; Siddell and Scudder, 2005). In addition, wet conditions from the early stages of the mound's occupation have been interpreted from the presence of molluscs, algae and mineralized uncharred plant material in the KOPAL trench (Asouti et al., 1999).

When it came time to interpret where the domestic crops – that had been found in vast quantities at the site – were cultivated, Roberts et al. drew on two findings from the macrobotanical and phytolith record: that the crops were sown in the autumn, and that they were cultivated in dry soils (Fairbairn et al., 2005; Rosen, 2005). The authors argued that if the crops were cultivated close to the site, they would not survive the spring floods, because this event coincided with the period when the cereal seed heads need to dessicate in order to be harvested. They thus asserted that cultivation, as well as animal grazing and sourcing of clay for the production of mudbrick, was carried out at a distance from the site; the closest location being the Neogene terraces to the south. This would have necessitated the Çatalhöyük population to fission into task groups during the flood season, with a number of people moving to more temporary arrangements in order to tend to their fields and graze their sheep and goats on drier soils. The population then fused back together during the winter, when they lived off of the cultivated grain stored in the houses and partook in ritual activities symbolizing the taming of the wilderness (Rosen and Roberts, 2005).

In this model, the subsistence economy integrated both a broad-spectrum use of wild resources (fruits, nuts, tubers, waterfowl, wild auroch) during the harvest season and the consumption of domestic products during the rest of the year. This model explained the choice of location of the Neolithic settlement in terms of proximity to wild marshland resources as well as a possible symbolic underpinning (perhaps the place held some mythical significance). Proximity to arable farmland did not figure into the choice of location and plant cultivation was thus relegated to a 'minimalistic' (or at least a non-dominant) role in the subsistence economy (Atalay and Hastorf, 2005; Rosen and Roberts, 2005).

Further investigations of the archaeological material from Çatalhöyük brought some aspects of Roberts et al.'s model into question. Strontium isotope analysis was carried out on 7 sheep teeth (M2) obtained from midden contexts from phases North.I, South.S, South.G, South.R and the values of 6 of the samples fell inside the range of modern plants measured from the alluvial plain (0.7076–0.7081), while the value of 1 sample fell into the range of modern plants from the limestone terraces (0.7069–0.7076) (Bogaard et al. 2014*b*). This suggests that the animals more likely grazed in the plain rather than in the more distant uplands. Archaeobotanical material ($n = 5$) measured as part of the same study also indicated that barley was cultivated in the Konya plain rather than on the Neogene substrate, however, it remains to be determined how susceptible archaeological grain is to post-depositional processes and whether their Sr isotope ratio can be reliably measured. In addition, the heavy use of the drier (red) clays for the production of mudbrick (especially after phase South.M), which could not have been sourced from the dark Lower Alluvium and are unlikely to have been carried from very long distances, suggests that the alluvial deposition and flooding was not as continuous as earlier thought – it could have been limited in spatial extent as well as seasonal (Doherty, 2013).

The revised model posits that the build-up of the Çarşamba alluvial fan occurred much more slowly and thus the 'undulating' marl surface of the palaeolake was not leveled by alluvium in the early Holocene. Instead, the landscape was dotted by both depressions that got infilled by alluvium as well as more elevated marl hummocks that remained exposed during the Neolithic. This landscape presented the Neolithic inhabitants with a mosaic of wetter and drier sediment types: more permeable sandier facies that would have drained more quickly during the spring flood and less permeable silt facies. Together, these two soil types would have created a "depressional wetland surrounded by grass steppe on thinner marl soils" (Doherty, 2013, pg. 66). The people thus chose to build their village at a lower elevation (despite the availability of higher ground), which suggests that the spring flooding was not so threatening. This model proposes that access to clay resources played a key role in the choice of location of the Neolithic settlement.

In light of this reconstruction, cultivation was possible closer to the site than 13km away, on the raised marl hummocks and sandier facies (Charles et al., 2014; Doherty, 2013). There may have been a standing body of water located nearby, which would have provided opportunities for exploitation of a range of wild resources, but arable farming could now fulfill a more dominant role in the subsistence economy of the Çatalhöyük people. Recent archaeobotanical work (see Section 5.3) indeed provides further support for a more intensive cultivation system.

5.3 Plant resource use

Results of the various archaeobotanical analyses will be crucial for interpreting the crop stable isotope measurements carried out in this study. The aim of this section is to provide a summary of the composition of the archaeobotanical assemblage (including changes in the use of certain plant species over time), outline some of the preservation issues related to the interpretation of the recovered plant remains (including distinctions made between plants deriving from human processing and those brought to the site via animal dung), discuss aspects of plant use (including crop processing and plant storage) and review what the results of archaeobotanical analysis tell us about cultivation strategies and crop growing conditions in Neolithic Çatalhöyük.

The recovered plant material shows that the inhabitants of Çatalhöyük used a core set of plant species throughout the Neolithic sequence (Bogaard et al., 2013*a*; Fairbairn et al., 2005). These staple foods complemented each other nutrionally: cereals (einkorn, emmer, new type glume wheat, two- and six-row naked barley, bread wheat) were carbohydrate-rich, pulses (peas, lentils, bitter vetch) were protein-rich, and wild mustard and nuts (almonds, acorns, pistachio) were oil-rich. Hackberry fruit also formed part of the core set of plant resources. These plant foods (and others appearing more sporadically across time and space, such as chickpea, fig and grass pea) were used in combination at the household level, where they were stored and prepared for consumption (Bogaard et al., 2013*a*). Changes through time occurred with the shift from emmer to new type glume wheat and pea to lentil in the mid-Neolithic sequence (Bogaard et al., 2017), the replacement of six-row barley by two-row barley during the later Neolithic sequence, and the eventual replacement of naked barley by hulled barley in the late Neolithic/early Chalcolithic phase (Bogaard et al. 2013*a*).

The most common type of cereal in the assemblage are glume wheat cereals – one-grained and two-grained einkorn, emmer, new type glume wheat – of which emmer dominated the earlier assemblage and new type glume wheat dominated the mid-Neolithic sequence (Bogaard et al., 2013*a*). New type glume wheat is a cereal whose taxonomic classification still remains uncertain: it is a tetraploid like emmer, but it is unclear whether it belongs to a separate genome (Jones et al., 2000). Its identification at Çatalhöyük was aided by the discovery of a pure deposit of whole spikelets in the storage room of building 77. Since then, more spikelets have been recovered in the TPC area (Fuller et al., 2014). Regardless of its taxonomy, the fact that this cereal was stored separately suggests that the farmers treated it as a distinct crop (Bogaard et al., 2013*a*) and one of the aims of the present study is to investigate whether this translated to the application of different management strategies.

Even though the core set of plant foods utilized by farmers at Çatalhöyük bears resemblance to the Neolithic 'package' that spread across Europe from the Near East (Bogaard, 2004, 2005; Colledge, 2005; Colledge et al., 2004; Halstead, 1989*a*), some aspects of the Çatalhöyük assemblage distinguish it from other contemporary sites in the region. For example, in the later Neolithic sequence, six-row naked barley is replaced by two-row naked barley, but the latter has not been previously discussed in the archaeobotanical literature of Southwestern Asia (Bogaard et al., 2013*a*). Similarly, the use of mustard seeds (*Descurainia*) as a condiment also appears to be a Çatalhöyük specialty, as it does not form part of the archaeobotanical ensemble elsewhere (Bogaard et al., 2013*a*).

Evidence for crop processing – in the form of glume wheat glume bases, barley rachis and remains of legume pods – is useful for interpreting both the treatment of plants and the use of space on and off site (Jones and Halstead, 1995). Earlier stages of cereal crop processing (such as winnowing, see Chapter 2.1) are represented in the deposit excavated in the KOPAL area in the form of mineralized cereal awns (the bristles growing from spikelets of grasses). Later stages, namely dehusking of glume wheat spikelets, are visible at the household level with the presence of glume bases as well as wheat husk phytoliths inside buildings (Bogaard, 2012; Bogaard et al., 2013*a*; Filipović, 2014). In fact, glume bases dominate most archaeobotanical samples from the site, irrespective of the depositional context. Their presence in tight storage rooms of buildings underscores the emphasis on privacy placed on the preparation of cereals for cooking. An additional benefit may have been their usefulness in starting fires in ovens and hearths (Bogaard et al., 2013*a*). Other types of plant processing activities are visible in the record, for example the presence of almond nut shells and kernels indicates that these nuts were de-shelled on the 'dirty floor' of B.97 (Bogaard, 2012).

Storage rooms, which form a key element of houses excavated at Çatalhöyük, did not only contain crops ready for processing. Some buildings stored concentrations of cleaned grains, such as naked barley found on the floor of building 80 (Bogaard et al., 2010). Excavated bins/seed concentrations tend to be dominated by one crop species and variations in stored food are found across buildings. For example, building 52 contained large amounts of stored pea, while building 1 was more focused on the storage of lentils (Bogaard et al., 2013*a*; Filipović, 2014). Remains of cooked foods have also been found inside houses: a unit excavated near the ladder emplacement in the south–eastern corner of building 77 contained a deposit of charred peas fused with small (anchovy-sized) fish bones (Bogaard et al., 2013*a*).

Even though plant material was found in a range of depositional contexts across the site: from primary contexts (fire installations inside buildings, room fill of burnt buildings, external fire spots), to secondary and tertiary contexts (house burials and middens), most of the units included in the archaobotanical analysis derived from primary contexts. This was done in order to "maximize inferences related to space use" (Bogaard et al., 2013*a*, pg. 93), as primary contexts provide evidence for individual events as well as localized activities (represented by unmixed activity residue preserved *in situ*). One such distinct 'event' was recorded in the fire spot in the South area, where peas were found in association to the large-seeded wild taxon *Galium* (bedstraw). These seeds are understood to "mimic the size of peas", and so the deposit was interpreted as evidence of hand cleaning of cultivated peas in this external area (Bogaard and Charles, 2007, pg. 201).

A suite of archaeobotanical remains entered the site in the form of animal dung and got charred and preserved in primary contexts through the use of dung cakes as fuel (mostly in outdoor spaces) (Bogaard et al., 2013*a*; Filipović, 2014). A modern experimental study on the effects of digestion on the preservation of grains/seeds was carried out in the village next to Çatalhöyük, Küçükköy, and involved the burning of dung from sheep whose diet was closely monitored. The results showed that cereal grain and by-products are less likely to survive the digestion process than seeds of wild flora due to greater robustness of their seed coat (Wallace and Charles, 2013). Contexts that are dominated by dung-derived plant material can thus be used to assess the nature of the wild vegetation consumed by these grazing animals and wild seeds preserved in house storage features are useful for assessing the arable weed flora associated with the cultivated crops. Bogaard et al. (2013*a*) and Filipović (2014) discuss how contexts representing arable weeds and pastoral weeds can be differentiated.

Analysis of the arable weed flora has provided us with initial insight into the crop cultivation strategies developed by farmers at Çatalhöyük. In her analysis of the early–mid Neolithic sequence, Filipović (2014) concluded that the whole suite of crops was sown in the autumn, in small-scale permanent fields under intensive treatments in dry soils. The author used the more recent environmental reconstruction (Charles et al., 2014; Doherty, 2013) to suggest that these fields were located on marl hummocks/levees cropping up from the wetland landscape in the vicinity of the village. Similarly for the later phases, Bogaard et al. (2013*a*) have argued that intensive cultivation placed in the vicinity of the site (rather than more than 13km away in the dryer uplands of the Konya region), cannot be excluded based on the analyzed material. Furthermore, analysis of the sizes of wheat husk silica skeletons conducted during phytolith analysis suggests that the crops were grown in a range of wet and dry conditions (Ryan, 2013). The results of stable isotope analysis in this study will be particularly useful for gaining deeper insight into whether/how the different crops were managed through time as well as by different near-contemporary production units (i.e. households in one neighborhood).

5.4 Materials

5.4.1 Species

Two sets of plant stable isotope data are presented in this study. The first set consists of 102 samples pre-treated and measured by the author (PV) and the second set consists of 33 unpublished samples pre-treated and measured by Rebecca Fraser (RF) and Michael Wallace in an earlier project (Amy Bogaard's NERC Crop Isotope Project). Some of the carbon isotope measurements (n = 25) from the latter set have been published in Wallace et al. (2015). See Table 5.1 for a breakdown of the species analyzed.

Each sample contained between 5 and 37 counts of crop seeds/grains (or fragments thereof) or between 120 and 328 counts of *Scirpus* seeds. *Descurainia* was sampled in 1mL quantity. Most of the samples (n = 104) came from units excavated by Ian Hodder's team (between 1993 and 2013), but a small number (n = 31) came from the archive created by Hans Helbaek in the 1960s and shared by Andrew Fairbairn.

Crop category	Common name	Latin name	n =	Comment
Cereal	Einkorn grain	*Triticum monococcum* L.	7	5 samples of the 1-grain variety, 1 sample of the 2-grain variety and 1 sample not identified to variety
	Emmer grain	*Triticum dicoccum* Shrank.	6	
	Bread wheat grain	*Triticum aestivum* Desf.	17	
	Naked barley grain	*Hordeum vulgare* var. *nudum* L.	39	most likely of the two-row variety, given that this is the most dominant variety for this phase at the site
	New type glume wheat grain	no Latin name	15	
	Wheat grain indeterminate	*Triticum* sp.	5	obtained from the Helbaek archive, one sample only yielded a δ^{13}C value
Pulse	Lentil seed	*Lens culinaris* Medik.	4	
	Pea seed	*Pisum sativum* L.	21	
Nut	Almond kernel	*Amygdalus* L.	3	
	Almond shell	*Amygdalus* L.	4	
	Acorn	*Quercus* L.	3	
Wild	Club-rush	*Scirpus maritimus* L.	5	one sample only yielded a δ^{15}N value
	Wild mustard	*Descurainia sophia* (L.) Webb	4	one sample only yielded a δ^{13}C value
		Rumex L.	1	
	Reed	*Phragmites* australis (Cav.) Trin.	1	culm/stem

Table 5.1: Descriptions of archaeobotanical samples from Çatalhöyük analyzed in this study

Samples measured by the author (ID codes starting with CTH and PRT) were pre-treated using a gentle acid-treatment with HCl – a protocol that was established using material from this assemblage (Vaiglova et al. 2014*b*); the samples starting with PRT were the same ones as used in the experiment. This experimental work has shown that although the %N values of plant samples from Çatalhöyük are much higher than those of samples from other archaeological sites, nitrate contamination is not the cause of this high nitrogen content. This is based on the fact that no nitrates were detected on the infra-red spectra of the untreated and pre-treated samples as well as the fact that all samples were rinsed in water (which should have removed all water-soluble nitrates). Samples measured by Rebecca Fraser were pre-treated using a gentle acid-base-acid treatment with 0.5M HCl and 0.1M NaOH (Fraser et al., 2013).

Analysis of the samples pre-treated by the author was carried out on a SerCon 20/22 continuous flow mass spectrometer coupled to a Callisto elemental analyzer at the Research Laboratory for Archaeology and the History of Art, University of Oxford. δ^{13}C and δ^{15}N values were measured separately and normalized to Vienna Pee Dee Belemnite (VPDB) and Ambient Inhalable Reservoir (AIR), respectively. Measurement uncertainty was assessed based on the within-run variability of an internal alanine standard and two certified reference materials placed in each run, calculated using a two-point calibration method (cf Kragten, 1994). The reference materials used were IAEA–CH6 and IAEA–CH7 for δ^{13}C and IAEA–N2 and USGS–40 for δ^{15}N. Calculations were performed using a script written by Erika Nitsch (of the AGRICURB project) in the statistical programming language R (3.2.2). The average measurement uncertainty (1σ) for δ^{13}C was $0.22 \pm 0.18‰$ (with a range between 0.05 and 0.52‰). The average measurement uncertainty (1σ) for δ^{15}N was $0.52 \pm 0.18‰$ (with a range between 0.19 and 0.77‰).

Analysis of the samples pre-treated by Rebecca Fraser was carried out at the NERC Isotope Geoscience Laboratory on two different instruments. δ^{15}N values were measured on a ThermoFinnigan Delta + XL mass spectrometer coupled to a ThermoQuest Flash 112 elemetal analyzer. δ^{13}C values were measured on a VG TripleTrap and Optima dual-inlet mass spectrometer. Measurement error for δ^{15}N was assessed using replicate measurements of an in-house sample of homogenized barley ($1\sigma = 0.4‰$). Measurement error for δ^{13}C was assessed using replicate measurements of an in-house sample of homogenized wheat ($1\sigma = 0.1‰$) (Fraser et al., 2013).

All plant measurements were subsequently corrected for a charring enrichment of 0.31‰ for δ^{15}N and 0.11‰ for δ^{13}C following experimental findings by Nitsch et al. (2015). Uncorrected values are presented in Appendix E. δ^{13}C values were converted to Δ^{13}C values using the equation shown in Chapter 4.2. The $\delta^{13}C_{CO_2}$ value for the Neolithic period was estimated to be -6.5‰ using the AIRCO2_LOESS data calibrator (Cleveland, 1979; Ferrio et al., 2005; Indermühle et al., 1999; Leuenberger et al., 1992).

A large number of human and animal samples from this site was measured and published in previous studies (Pearson, 2013; Pearson et al., 2015, 2007; Richards and Pearson, 2005; Richards et al., 2003) and will be collated with this plant dataset for interpretation of ancient human and animal diets.

5.4.2 Contexts

The aim of the sampling strategy was to obtain both horizontal and vertical coverage of Neolithic contexts from Çatalhöyük in order to address questions of synchronic variability as well as diachronic change (see Section 5.1.1). All primary contexts which contained at least 10 counts of a given species in the fraction analyzed were sampled (in addition to some contexts that contained between 5 and 10 counts), but due to the nature of the preserved material and the excavation strategy, the sampled species are not equally distributed through space and time. For example, most of the new type glume wheat samples come from burnt building 77 and most of the bread wheat and naked barley come from burnt building 52.

All of the sampled material comes from primary burnt contexts from excavated buildings and external spaces (see Table 5.2 for details of the contexts represented in the dataset). These contexts represent deposits in features in storage rooms (bins, basins, baskets, ovens) (n = 57), burnt fill from main room platforms, ovens, and ladder emplacements as well as storage room fill (n = 66) and primary burnt material from external middens and fire spots/ash lens (n = 11). One of the barley samples from Building 77 was obtained from a deposit of fused barley and fish remains, unit 16498. The new type glume wheat samples from this same building were taken from a pure stored deposit of spikelets; the preservation of this cereal in spikelet form is in fact what enabled the secure identification of this species at the site (Bogaard et al. 2013*a*). Refer to Appendix D for the contextual information of all individual samples.

The storage areas in the side rooms of buildings did not only contain remains of crops or crop by-products. For example, the bins from Buildings 52 and 77 contained variable amounts of animal remains (including animal bone and antler clusters, cattle-sized rib fragments, polished sheep long bones likely used for tool making) and stone tools (including an obsidian 'toolkit'). The collapse that fell onto bin F.2004 in B.52 contained the complete skull of a wild boar. This has implications on the use and the symbolism of the material stored in these rooms.

For more thorough descriptions of the contexts/units sampled and for a discussion of their botanical compositions, refer to Bogaard et al. (2013*a*) and Filipović (2014).

Area	Mellaart Level	Hodder Level	Building	Space	No. of samples per context	No. of samples by species	Cereal species	Pulse species	Wild species
NORTH (North, 4040 and BACH areas)									
4040		4040.I	-	**Sp.279**	2	1	new type glume wheat		
						1	emmer		
		4040.H	**B.45**	Sp.238	1	1	free-threshing wheat		
		4040.G	**B.52**	Sp.93	57	12	free-threshing wheat		
						27	naked barley		
						1	new type glume wheat		
						10		pea	
						6			almond
						1			descurainia
		4040.?G	**B.77**	Sp.336, 337	15	2	einkorn, 1gr		
						1	naked barley		
						10	new type glume wheat		
						2		pea	
			-	**Sp.60**	1	1			scirpus
BACH		BACH.?G	**B.3**		2	1			rumex
						1			reed
North		North.?G	**B.1**	Sp.71, 186, 187	5	1	naked barley		
						1			descurainia
						2		lentil	
						1			acorn
SOUTH (South area and TPC)									
TPC	II-III	Unstratified Neolithic	**B.122**	Sp.493	2	1	new type glume wheat		
						1	naked barley		
South	II	South.?S	**A.II.1**		6	3	naked barley		
						1	emmer		
						1	new type glume wheat		
						1		pea	
	IV	South.?Q	**E.IV.4**		1	1		pea	
	V	South.P	**B.75**	Sp.328	2	1	naked barley		
						1		pea	
			-	**Sp.132**	6	1	free-threshing wheat		
						2	naked barley		
						1	einkorn, 2gr		
						2		pea	
				Sp.427	1	1			scirpus
			A.V.4		1	1			acorn
			E.V.8		1	1		pea	
		South.O	**B.79**	Sp.134	1	1	free-threshing wheat		
			B.80	Sp.135	1	1		pea	
	VI.A-B	South.?O-South.?N	**A.VI.3**		1	1	wheat indet		
			E.VI.1		4	1	new type glume wheat		
						2	wheat indet		
						1			acorn kernel
			E.VI.2		2	1	free-threshing wheat		
						1	wheat indet		
			E.VI.17		3	1	einkorn, 1gr		
						1	einkorn no var.		
						1			descurainia
			E.VI.2/E.VI.17		1	1	emmer		
			E.VI.18		1	1	einkorn, 1gr		
			E.VI.19		1	1	einkorn, 1gr		
			E.VI.24		2	1	naked barley		
						1	emmer		
			E.VI.25		1	1		pea	
			E.VI.44		1	1			descurainia
			E.VI.50		1	1	naked barley		
			E.VI		1	1		pea	
	VII	South.?L	**E.VII.24**		1	1	naked barley		
			E.VII.25		1	1	free-threshing wheat		
			E.VII.34		1	1	wheat indet		
			-	**Sp.115**	1	1	emmer		
	IX	South.K	**B.17**	170	2	1	emmer		
						1		lentil	
		South.?K	**B.2**	116	1	1		lentil	
	Pre XII	South.G	**-**	**Sp.181**	4	3			scirpus
						1			almond

Table 5.2: Contextual information of archaeobotanical samples from Çatalhöyük analyzed in this study

5.4.3 Burnt buildings

A large number of the samples (n = 72) came from burnt buildings from the North area: Building 52 and Building 77 (See Figs. 5.4 and 5.5). These buildings are among the more elaborate buildings excavated at the site (Hodder, 2008) and were burnt down in a single event; debate among the excavators continues as to whether this process was accidental or a result of planned abandonment practice (Bogdan, 2005; Harrison et al., 2013; Twiss et al., 2008). Regardless of the purpose, the house-wide burning has caused large amounts of material to be preserved extremely well. This has provided us with a very rich archaeobotanical assemblage, the remains of charred human brain preserved in the skull of a buried individual (Hager et al., 2011) and the remains of linen cloth used to wrap an individual before burial under a house platform (Fuller et al., 2014).

The storage room from Building 52 (space 93) was particularly rich in preserved plant material. This small room (2m x 2.5m) contained four bins, one basket and a seed concentration spilled on the floor. During excavation, the material in the bins was removed in stages, and as result, it was possible to obtain several samples of the same storage feature. For example, six different units from bin F.2002 were sampled, which represent material stored in the upper, middle and lower sections of the bin as well as a grain spill located between the bin and the abutting wall. It is uncertain how long it took for the bin to fill up (i.e. what timeframe of the use of the building it represents), but comparing the stable isotope values of crops stored in different sections of the bin will enable us to investigate whether the grains/seeds may have come from the same harvest/plot of land or whether they more likely represent yields from notably different cultivation regimes.

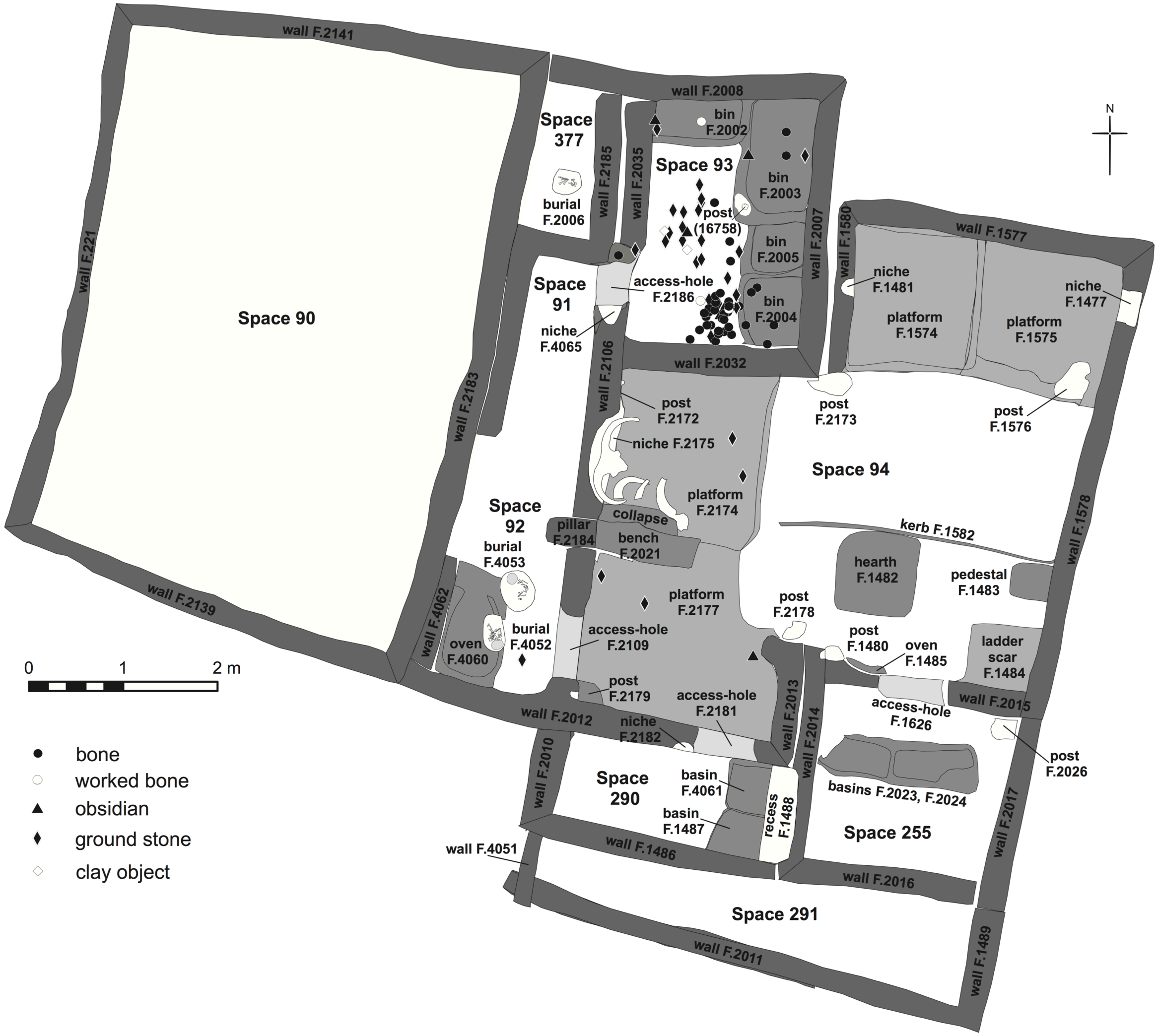


Figure 5.4: Plan of Building 52 in the North area at Çatalhöyük, level North.G (produced by Camilla Mazzucato, Çatalhöyük Research Project)

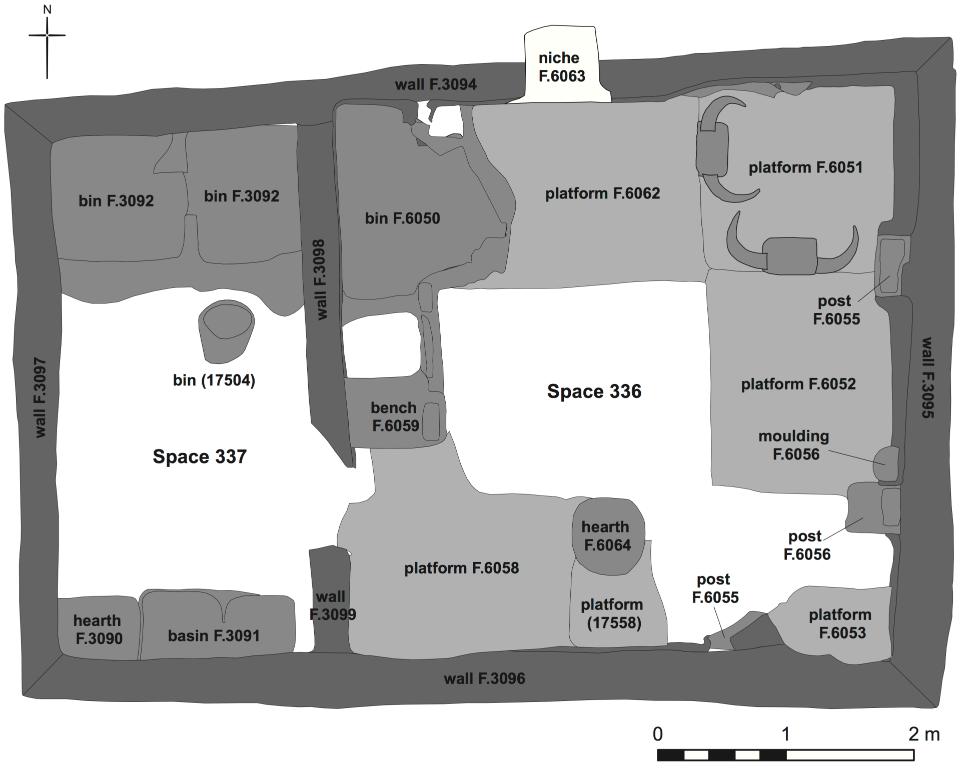


Figure 5.5: Plan of Building 77 in the North area at Çatalhöyük, level North.?G (produced by Camilla Mazzucato, Çatalhöyük Research Project)

5.5 Results

5.5.1 Overall description of the plant stable isotope data

Fig. 5.6 shows all the plant δ^{13}C and δ^{15}N values measured in this study. For summary statistics of the entire dataset, see Table 5.3, and for all raw and corrected data, refer to Appendix E. The samples exhibit a wide range of stable isotope values, on both the carbon and nitrogen scales: $\delta^{15}\mathrm{N}_{\mathrm{max}} = 17.0$‰, $\delta^{15}\mathrm{N}_{\mathrm{min}} = 1.3$‰, δ^{15}N range = 15.7‰; $\delta^{13}\mathrm{C}_{\mathrm{max}} = -20.5$‰, $\delta^{13}\mathrm{C}_{\mathrm{min}} = -25.3$‰, δ^{13}C range = 4.8‰. When discussing plants alone, Δ^{13}C conversions will be used (refer to Chapter 4.2 for details): $\Delta^{13}\mathrm{C}_{\mathrm{max}} = 19.2$‰, $\Delta^{13}\mathrm{C}_{\mathrm{min}} = 14.2$‰, Δ^{13}C range = 4.9‰.

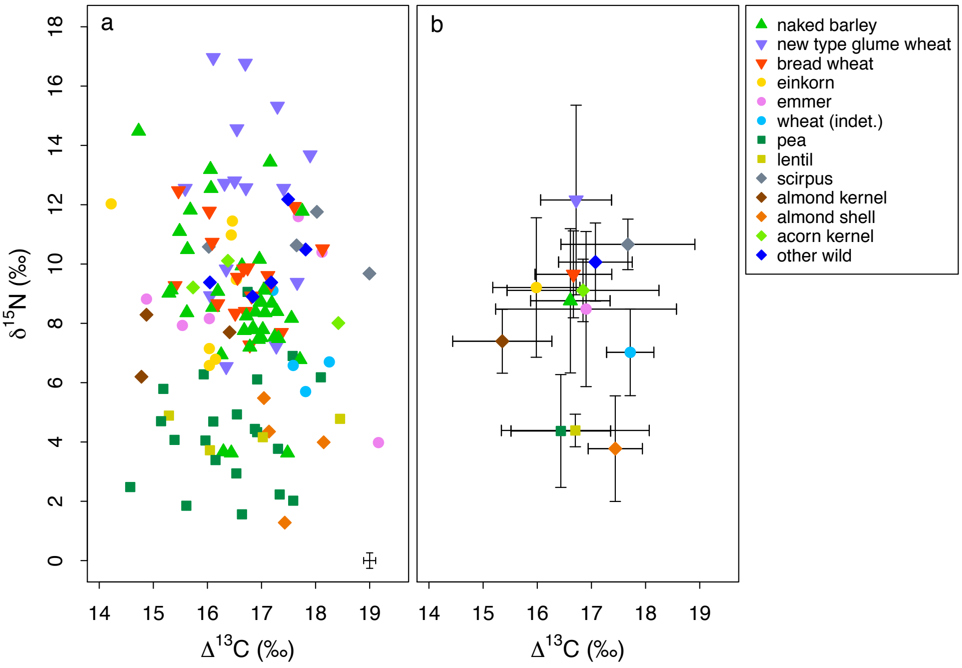


Figure 5.6: Bi-variate scatter plot of all plant δ^{15}N and Δ^{13}C measurements from Çatalhöyük. a) individual measurements; b) mean and standard deviations of each species where $n > 2$. Measurement error is shown in the bottom-right of panel **a**.

The wide range of stable isotope values will be a key focus in the discus-

Species	n=	$\delta^{15}N_{max}$	$\delta^{15}N_{min}$	$\delta^{15}N_{mean}$	$\delta^{15}N_{SD}$	$\delta^{15}N_{range}$	$\delta^{13}C_{max}$	$\delta^{13}C_{min}$	$\delta^{13}C_{mean}$	$\delta^{13}C_{SD}$	$\delta^{13}C_{range}$	$\Delta^{13}C_{max}$	$\Delta^{13}C_{min}$	$\Delta^{13}C_{mean}$	$\Delta^{13}C_{SD}$	$\Delta^{13}C_{range}$
lentil	4	4.9	3.7	4.4	0.5	1.2	-21.6	-24.6	-22.9	1.3	3.0	18.6	15.4	16.8	1.4	3.2
pea	21	9.1	1.6	4.4	1.9	7.5	-20.9	-24.3	-22.7	0.9	3.4	18.2	14.7	16.5	0.9	3.5
emmer	6	11.6	4.0	8.5	2.6	7.6	-21.2	-25.3	-23.1	1.6	4.1	19.3	15.0	17.0	1.7	4.3
einkorn, 1gr	5	11.0	6.6	8.2	1.9	4.4	-22.3	-22.8	-22.5	0.2	0.5	16.6	16.1	16.4	0.2	0.5
einkorn, 2gr	1	11.5	11.5	11.5	-	0.0	-22.7	-22.7	-22.7	-	0.0	16.6	16.6	16.6	-	0.0
einkorn, no var	1	12.0	12.0	12.0	-	0.0	-20.5	-20.5	-20.5	-	0.0	14.3	14.3	14.3	-	0.0
all einkorn	7	12.0	6.6	9.2	2.4	5.5	-20.5	-22.8	-22.2	0.8	2.2	16.6	14.3	16.1	0.8	2.3
naked barley	39	14.5	3.6	8.8	2.4	10.9	-21.0	-23.9	-22.8	0.7	2.9	17.9	14.8	16.7	0.7	3.0
new type glume wheat	15	17.0	6.5	12.2	3.2	10.4	-21.9	-24.1	-22.9	0.6	2.2	18.0	15.7	16.8	0.7	2.3
bread wheat	17	12.5	7.3	9.7	1.5	5.2	-21.7	-24.3	-22.9	0.7	2.6	18.2	15.5	16.8	0.7	2.7
wheat indet.	5	9.1	5.7	7.0	1.5	3.4	-23.0	-24.4	-23.7	0.6	1.5	18.4	16.9	17.6	0.6	1.5
almond kernel	3	8.3	6.2	7.4	1.1	2.1	-21.1	-22.7	-21.6	0.9	1.6	16.5	14.9	15.5	0.9	1.6
almond shell	4	5.5	1.3	3.8	1.8	4.2	-23.3	-24.3	-23.6	0.5	1.1	18.3	17.2	17.6	0.5	1.1
acorn kernel	3	10.1	8.0	9.1	1.1	2.1	-22.0	-24.6	-23.1	1.3	2.6	18.5	15.8	17.0	1.4	2.7
Scirpus	5	11.8	9.7	10.6	0.8	2.1	-22.3	-25.1	-23.9	1.2	2.9	19.1	16.1	17.8	1.2	3.0
descurania	4	12.2	9.4	10.3	1.6	2.8	-22.3	-23.7	-23.0	0.7	1.4	17.6	16.2	16.9	0.7	1.4
rumex	1	10.5	10.5	10.5	-	0.0	-24.0	-24.0	-24.0	-	0.0	17.9	17.9	17.9	-	0.0
phragmites	1	8.9	8.9	8.9	-	0.0	-23.1	-23.1	-23.1	-	0.0	17.0	17.0	17.0	-	0.0

Table 5.3: Summary statistics of the plant stable isotope dataset from Çatalhöyük

sion of this dataset. Even though many of the plant samples have extremely high δ^{15}N values (i.e. higher than carnivore values reported in other studies, Richards and Hedges, 1999; Richards and Trinkaus, 2009), these exceptionally high values cannot be interpreted solely as a result of an eco-systemic enrichment. If that were the case, all samples would be expected to have values elevated by a constant amount. Instead, a model will need to be presented which explains accentuated soil–^{15}N differences: it makes the plants grown in the more ^{15}N–enriched soils look very enriched and the plants grown in the less ^{15}N–enriched soils look very depleted in comparison.

5.5.2 Plant nitrogen isotope results

Fig. 5.7 shows the δ^{15}N measurements grouped by species. The main finding is that the nitrogen variability of the entire dataset is not a result of the large number of species measured; most of the species exhibit significant intra-group variability on their own. The four crops that were sampled most extensively have the following ranges of δ^{15}N values: peas = 7.5‰ (n = 21), naked barley = 10.9‰ (n = 39), bread wheat = 5.2‰ (n = 17), new type glume wheat = 10.4‰ (n = 15). Emmer (n = 6) has a δ^{15}N range of 7.6‰.

The mean δ^{15}N values of the main cereal types are as follows: bread wheat = 9.7 ± 1.5‰, naked barley = 8.8 ± 2.4‰, new type glume wheat = 12.2 ± 3.2‰. Note that most of the new type glume wheat samples come from a single building (B.77 in North area) and the over-representation of contexts containing this crop (accounted for by preservation bias) may be responsible for pulling the mean δ^{15}N values of this crop up.

Multi-variate analysis was carried to compare the mean δ^{15}N values of the three main cereals (bread wheat, naked barley and new type glume wheat). The analysis could not include all the cereal types, because the group sizes of the other species are too small. Shapiro–Wilk test revealed that the data are not normally distributed (W = 0.95, p = 0.01), so the non-parametric

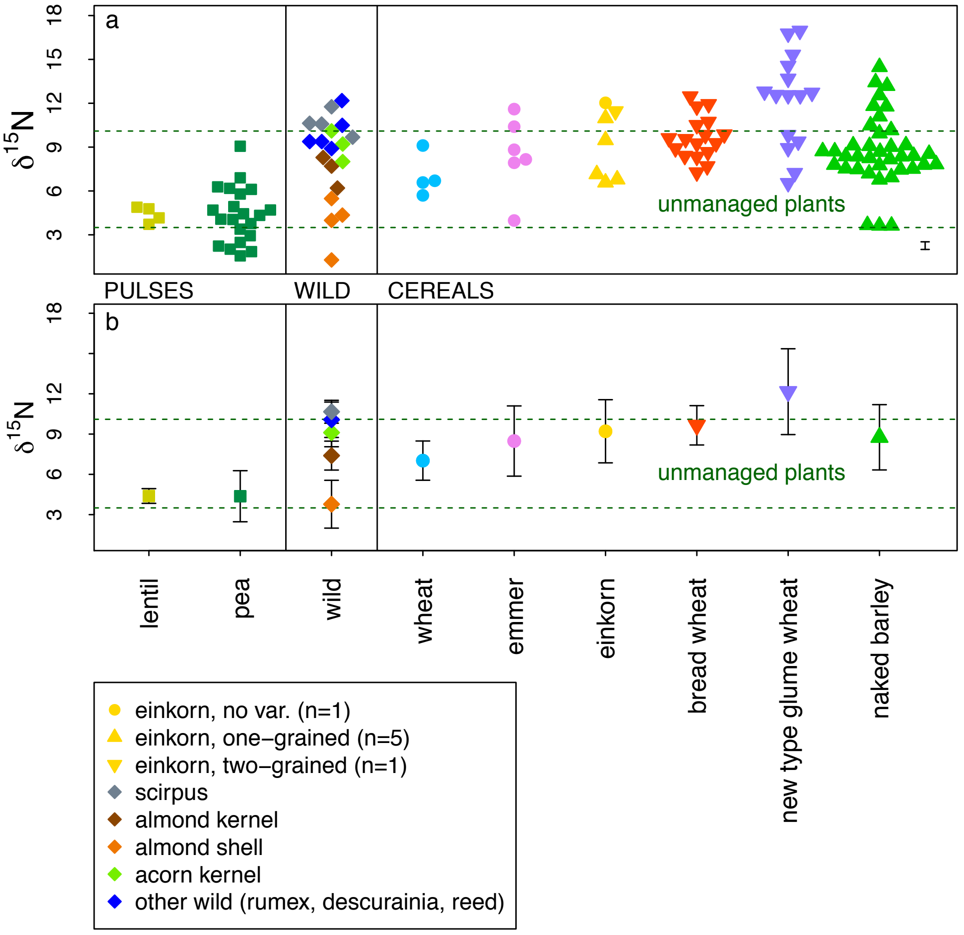


Figure 5.7: Uni-variate scatter plots of plant $\delta^{15}N$ values from Çatalhöyük. a) all measured samples, and b) means and standard deviations of each species. Wheat category contains samples of wheat grains of indeterminate variety. For discussion of the unmanaged plant zone, see Section 5.5.6. Measurement error is shown in the bottom-right of panel **a**.

Kruskall–Wallis test was used. The results show that there are statistically significant differences amongst the groups (H(2) = 13.7, p = 0.001) and a Bonferroni post-hoc test indicates that these differences are between new type glume wheat and bread wheat (p = 0.015) and between new type glume wheat and naked barley ($p < 0.01$), but not between bread wheat and naked barley (p = 0.64).

Three samples of naked barley (CTH04, CTH06, CTH38) have lower δ^{15}N values than the rest of the group: 3.7‰, 3.6‰and 3.6‰, respectively; the rest of the samples have values greater than 6‰. Two of the samples come from a building excavated by James Mellaart, building A.II.1 (these are, however, not the only naked barley samples measured from this building: CTH03 has a value of 9.9‰). The third sample comes from B.52.

Wheat (of indeterminate variety) has the lowest mean δ^{15}N values: (7.0± 1.5‰; n = 5, only 4 yielded a δ^{15}N measurement and all samples come from the Helbaek archive).

Both one-grained (n = 5) and two-grained (n = 1) einkorn was sampled in the present study, in addition to one sample of indeterminate variety. Fig. 5.7 shows that the two highest measurements represent the sample with no variety and the sample of the two-grained variety, with all the one-grained einkorns lying below these. As the sample size of seven is too small to assess any further differences within the einkorns, both varieties will be treated as one group in the discussion that follows.

Pulses are N_2–fixing plants, which obtain most of their N from the atmosphere, and are thus expected to have values close to 0‰ (see Chapter 4.3). In a traditional farming setting on the Greek island of Evvia, broad beans and fava beans grown in soils manured with high inputs of sheep/goat dung were all recorded to have δ^{15}N values lower than 5‰ (Fraser et al., 2011). In addition, Treasure et al. (2015) recorded values of up to 7.7‰ for broad beans grown under manured conditions. In the present dataset, pulses have statistically lower δ^{15}N values compared to the cereals (independent two-group t–test, $t = 11.2, p < 0.01$), and more than half of the peas measured at Çatalhöyük (15 out of 21) have δ^{15}N values higher than 5‰. Considering such high enrichment of the Çatalhöyük pulses over AIR, it is likely that both environmental and anthropogenic factors were at play determining the soil ^{15}N–enrichment in this landscape.

Five samples of *Scirpus* were measured in this study, and their mean δ^{15}N value is 10.6 ± 0.8‰. In addition to growing in crop fields, this species can grow in wetland soils and its values thus *may* be able to provide an indication of ^{15}N–enrichment in waterlogged soils. In this study, however, the values of *Scirpus* lie in the same range as the 'other wild' species, all of which were likely arable weeds – *Rumex* ($n = 1$), *Descurainia* ($n = 4$), *Phragmites* ($n = 1$) (these have combined δ^{15}N values of 10.1 ± 1.3‰).

It has been suggested previously that grain-components of cereal plants have higher δ^{15}N values than the non-grain components such as stalk (Fraser et al., 2011), although (Szpak, 2014) argues the opposite. Data in this study show that kernels of almonds ($n = 3$) have higher values than almond shells ($n = 4$) (kernels: 7.4 ± 1.1‰; shells: 3.8 ± 1.8‰). Two pairs of matching shell and kernels from the same nut were measured (CTH94/CTH95 and CTH96/CTH97) and the offsets between the two plant components are 3.9 and 4.9‰, respectively for each pair. Acorn kernels ($n = 3$) also have some of the highest δ^{15}N values of all the wild species measured: 9.1 ±1.1‰.

As mentioned earlier, this paper argues that measurements of charred plant material from Çatalhöyük are not affected by the presence of exogenous nitrates (suggested as a possible explanation for the anomalously high %N values of the samples, Brock et al., 2012) because all potential nitrates would have been removed through pre-treatment. Even though the high % N values still remain to be explained, it should be noted that the corresponding high δ^{15}N values are not unique. Modern samples of cereals from an oasis in

Morocco (Styring et al. 2016*a*), for example, show values even higher than those reported here (see Fig. 5.8).

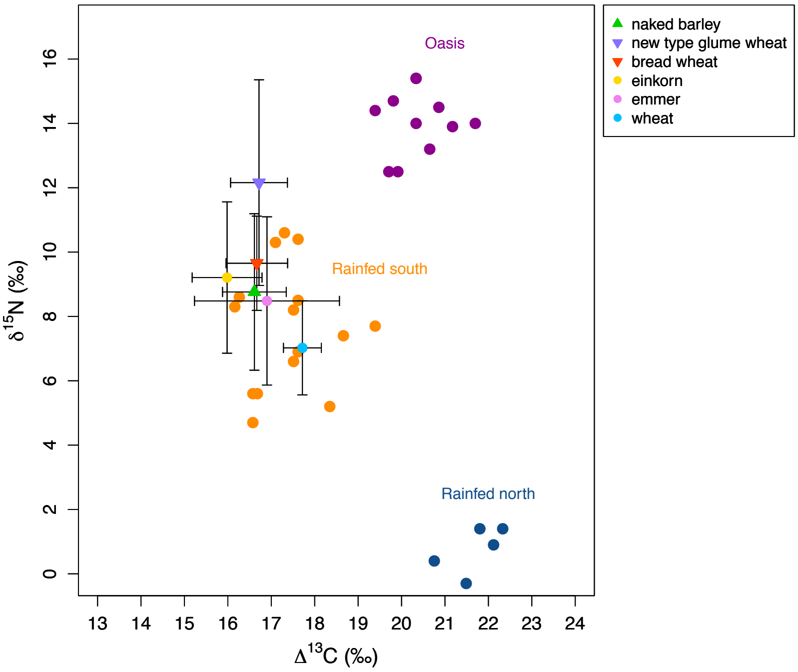


Figure 5.8: Bi-variate scatter plot showing the mean δ^{15}N and Δ^{13}C values of cereal species from Çatalhöyük measured in this study compared to samples of modern crops collected in traditionally farmed fields in Morocco. Modern data obtained from Styring et al. (2016*a*). For descriptions of the sampled regions, see Section 5.5.2.

Comparison of the data from Çatalhöyük to the data obtained at traditional modern farms across three environmental zones in Morocco – 1) a rainfed region in the south (annual mean rainfall 272mm) where crops received manure biennially, 2) a rainfed region in the north (annual mean rainfall 703mm) where crops received no manure, and 3) an 'oasis' in the south (annual mean rainfall 194mm) where crops were irrigated and received manure twice a year – show that the Neolithic material resembles most closely the crops grown in the low-annual-rainfall zone that received some manure (see Fig. 5.8). However, not all the material in this study falls into this category. Many other samples, especially those of new type glume wheat, overlap with the 'oasis' samples from Morocco on the δ^{15}N scale. These observations strongly suggest that the conditions in which the Neolithic crops grew were extremely variable, and that the range in δ^{15}N measured cannot be explained by natural variability encompassed by crops grown in fields that received the same treatment in a single semi-arid rainfall zone.

5.5.3 Plant carbon isotope results

The Δ^{13}C results show that notable variability exists on the carbon scale as well (see Fig. 5.9). The most well sampled species have the following ranges of Δ^{13}C values: naked barley = 3.0‰ (n = 39); bread wheat = 2.7‰ (n = 17); new type glume wheat = 2.3‰ (n = 15); pea = 3.5‰ (n = 21). Interestingly, some of the less-well sampled species have equally wide ranges of Δ^{13}C values: lentils = 3.2‰ (n = 4) and emmer = 4.3‰ (n = 6).

Fig. 5.9 shows that the mean Δ^{13}C values of the three main cereals are statistically indistinguishable: bread wheat, 16.8 ± 0.7‰; naked barley, 16.8 ± 0.7‰; new type glume wheat, 16.7 ± 0.7‰. The data are normally distributed (Shapiro–Wilk test, W = 0.98, p = 0.486), and homogenous (Levene's test, $F(2, 67) = 0.30$, p = 0.743) so an ANOVA test was used to compare the differences between the means of the three groups. The outcome was not statistically significant ($F(2, 67) = 0.128$, p = 0.881).

The indeterminate wheat, which was found to have the lowest mean δ^{15}N value of all the cereal types measured, has the highest mean Δ^{13}C value: 17.6 ± 0.6‰. The species with the lowest mean Δ^{13}C value is einkorn: 16.0 ± 0.8‰.

The one sample of einkorn which was not assigned to variety (CTH02) has a much lower Δ^{13}C value (14.2‰) compared to the other six samples, which all group within 0.5‰ of each other (16.0 – 16.5‰).

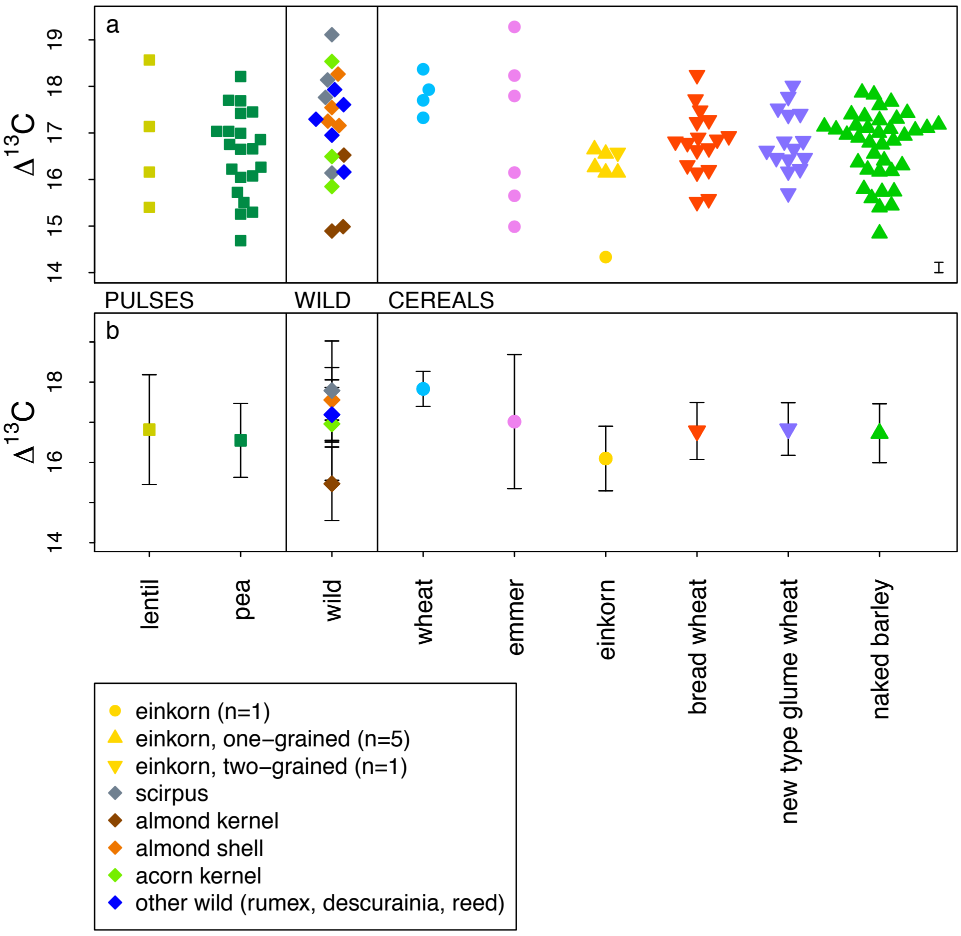


Figure 5.9: Uni-variate scatter plots of plant $\Delta^{13}C$ values from Çatalhöyük. a) all measured samples, and b) means and standard deviations of each species. Measurement error is shown in the bottom-right of panel **a**. Wheat category contains samples of wheat grains of indeterminate variety.

Of the five *Scirpus* samples measured, only four yielded a carbon isotope measurement, and their mean Δ^{13}C value is 17.8 ± 1.2‰. All the wild species combined (*Rumex, Descurainia, Scirpus, Phragmites*, almond, acorn) cover a wide range of Δ^{13}C values: 14.8 – 19.0‰. Almond shells have consistently higher Δ^{13}C values (17.6 ± 0.5‰) compared to almond kernels (17.0 ± 1.4‰). The offsets between the matching pairs of kernel and shell from two individual almond nuts are 2.3‰ for CTH94/CTH95 and 2.7‰ for CTH96/CTH97.

Carbon discrimination in plants is species-specific, so different species of crops grown under the same conditions of moisture availability would not be expected to exhibit comparable Δ^{13}C values (see Chapter 4.2). As the offset in Δ^{13}C values between wheat and barley has not been established reliably, comparisons cannot be made between the water status of these two crops. However, looking at the Δ^{13}C variabilities between the crops included in this study, the data suggest that barley, new type glume wheat and bread wheat were grown under equally variable watering conditions. Emmer, with a wider range of Δ^{13}C values, seems to have been grown under more variable moisture availability and wheat sampled from Mellaart buildings in the 1970's that has not been assigned to variety seems to have been cultivated under higher moisture availability than all the other wheats.

Even though lentils were sampled in much smaller numbers than peas, both of these two pulses indicate a similar range of watering conditions (comparable to the emmer rather than all the other cereals).

Interpretation of the water status of the measured crops is constrained by the discussion of the environmental factors that drive the variability in the stable isotope ratios, particularly nitrogen. Water status has been shown to be the most dominant factor influencing carbon isotope discrimination in plants in semi-arid areas (Farquhar et al., 1989, 1982; Hartman and Danin, 2010; Wallace et al., 2013), with statistical analysis ruling out the impact of manure on Δ^{13}C values (Fraser et al., 2011). However, the relationship between ^{15}N–enrichment and water status has not been investigated fully and it may be that in a landscape that is ecosystemically enriched and where crops have inexplicably high %N values, carbon isotope discrimination may behave differently.

5.5.4 Chronology

The South area was dug for vertical coverage, in order to expose and piece together the length of the Neolithic sequence on the East mound, while the North area was dug for horizontal coverage, in order to study the relationships between houses and spaces in a single cluster of habitation near the center of the mound. Thus, in the South area, differences in stable isotope values between samples from different phases can be the result of a combination of management choices and/or chronological environmental shifts, while in the North area, the differences would be constrained to management choices (both manipulation of soil conditions and placement of crops in variable soils).

Fig. 5.10 shows the plant data divided by the two excavation areas. The variability in δ^{15}N values is lower in the South area (South area range: 11.9‰; North area range: 15.7‰), which suggests that chronological shifts are not the major cause of variation in the δ^{15}N values of the measured samples. The higher δ^{15}N values in the North area are a result of the ^{15}N–enriched new type glume wheat from B.77 and the lower δ^{15}N values in the South area are a result of the more ^{15}N–depleted peas that come mostly from Mellaart buildings.

The two best represented species in both areas are peas and naked barley. Their overall intra-species variabilities (as stated in Section 5.5.2 and 5.5.3) are generally maintained when they are split into the two excavation areas: naked barley δ^{15}N value range = 10.9‰ (North) and 9.8‰ (South); pea

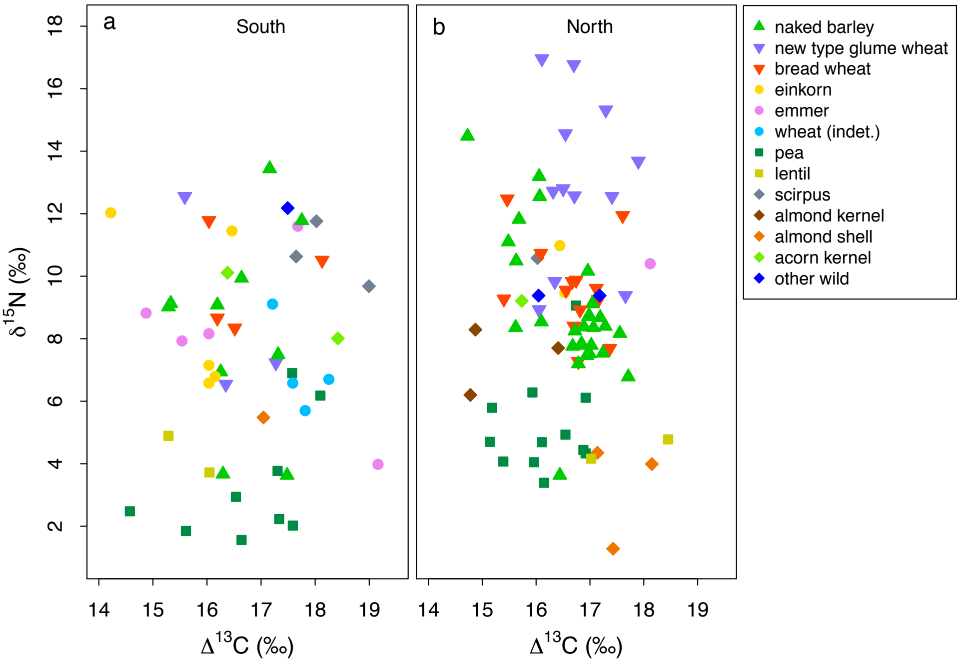


Figure 5.10: Bi-variate scatter plots of plant δ^{15}N and Δ^{13}C values from the South (a) and North (b) excavation areas at Çatalhöyük

δ^{15}N value range = 5.7‰ (North) and 5.3‰ (South). There is no statistically significant difference between the mean δ^{15}N value of the barley in the two excavation areas (independent two-group t–test, $t = 0.44, p = 0.67$). The difference of 0.4‰ between the means of pea δ^{15}N values in the two areas is significant at 95% confidence (independent two-group t–test, $t = 2.34, p = 0.034$). The combined cereal values from each of the two areas were not compared because the mean of the North area is skewed by the presence of the new type glume wheat group from a single building.

Figs. 5.11–5.12 show the δ^{15}N values and Figs. 5.13–5.14 show Δ^{13}C values according to their chronological phases: North Hodder levels G, H and I and South Hodder levels G, K–L, N–O, P, Mellaart Levels VII, VI, V, IV, III–II and II (a combination of the two phasing systems is used in order to preserve the excavators' original assignments without making conversions and Hodder/Mellaart levels that roughly correspond to each other have been

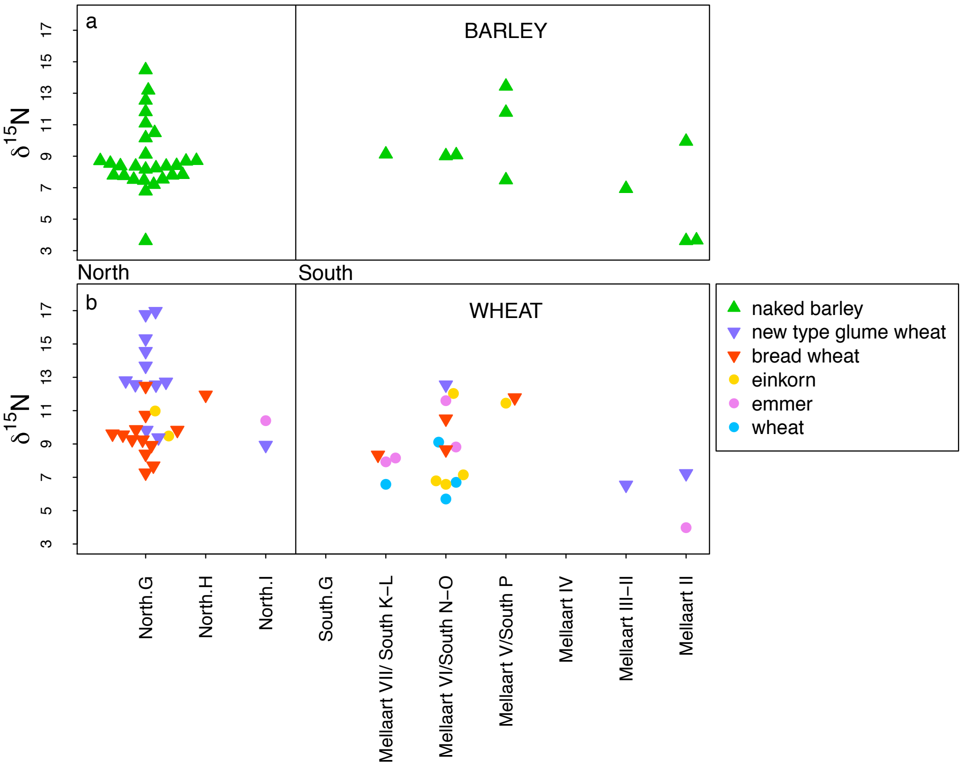


Figure 5.11: Uni-variate scatter plots of plant δ^{15}N values of naked barley (a) and wheats (b) from Çatalhöyük divided into chronological phases in each excavation area

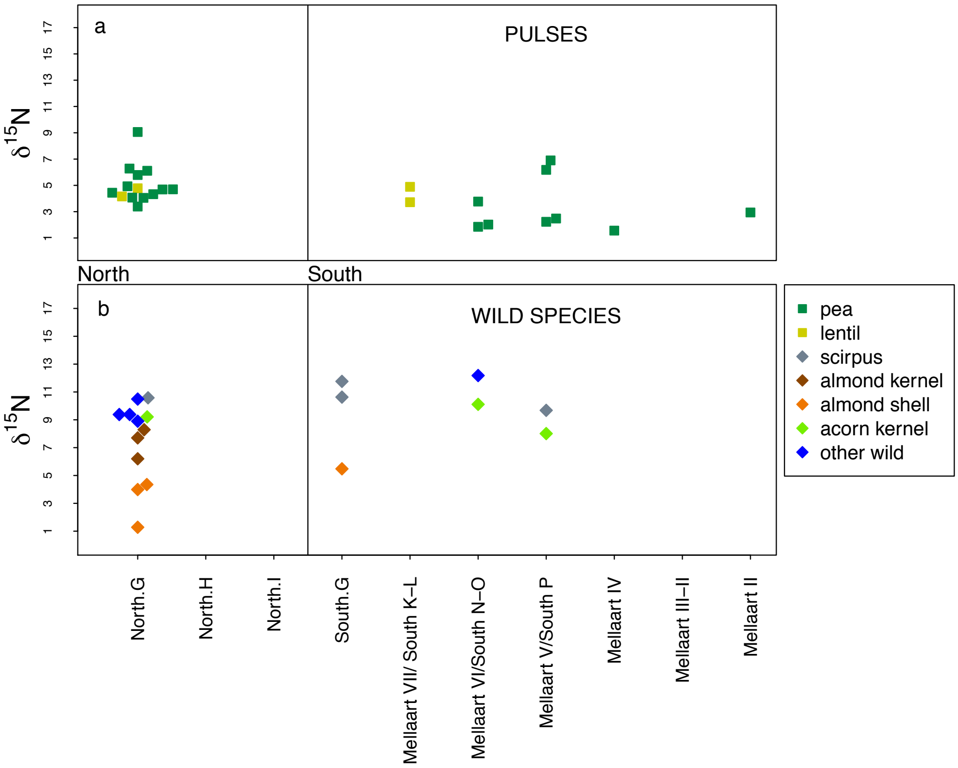


Figure 5.12: Uni-variate scatter plots of plant δ^{15}N values of pulses (a) and wild plants (b) from Çatalhöyük divided into chronological phases in each excavation area

placed in the same groups). The levels are arranged from the oldest within each area (on the left) to the youngest (on the right). The data do not show any patterns through time for both carbon and nitrogen, although the group sizes are too small to properly test this possibility.

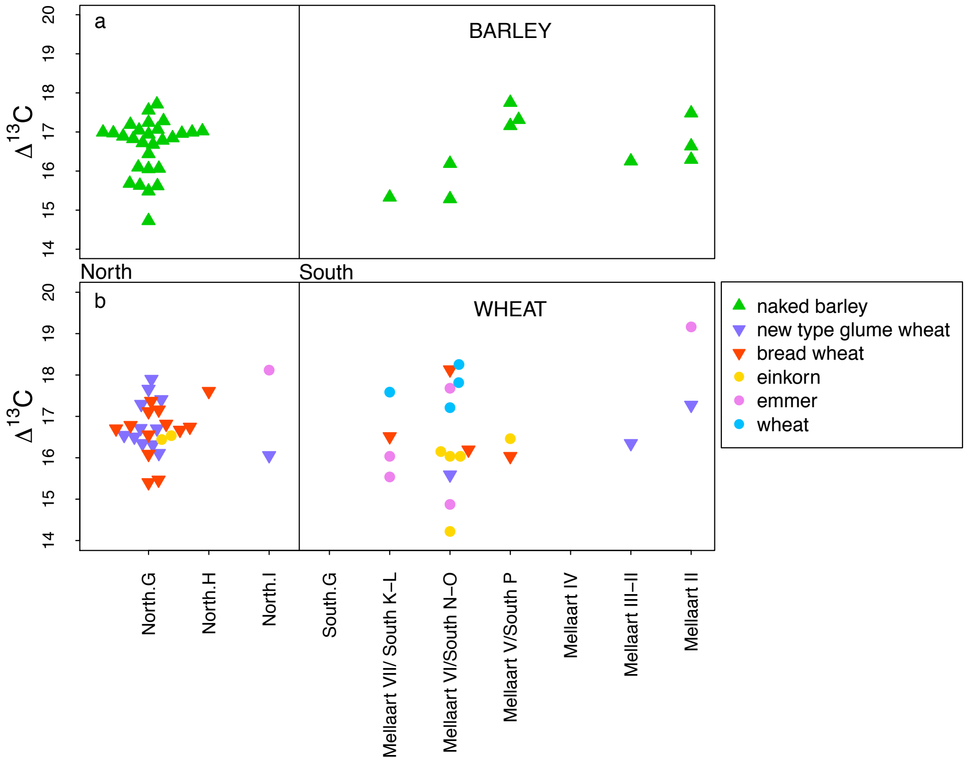


Figure 5.13: Uni-variate scatter plots of plant Δ^{13}C values of naked barley (a) and wheats (b) from Çatalhöyük divided into chronological phases in each excavation area

In addition to the stable nitrogen isotope variability captured by the data, there are similarities between samples of different species from a single phase. In South.P, a sample of bread wheat (CTH24), naked barley (CTH26), and einkorn (CTH30) plot almost on top of each other with values of 11.8‰, 11.8‰ and 11.5‰, respectively. In Mellaart II, a sample of emmer (CTH10) plots next to two samples of naked barley (CTH04 and CTH06) with values of 4.0‰ 3.7‰ and 3.6‰, respectively. In the later

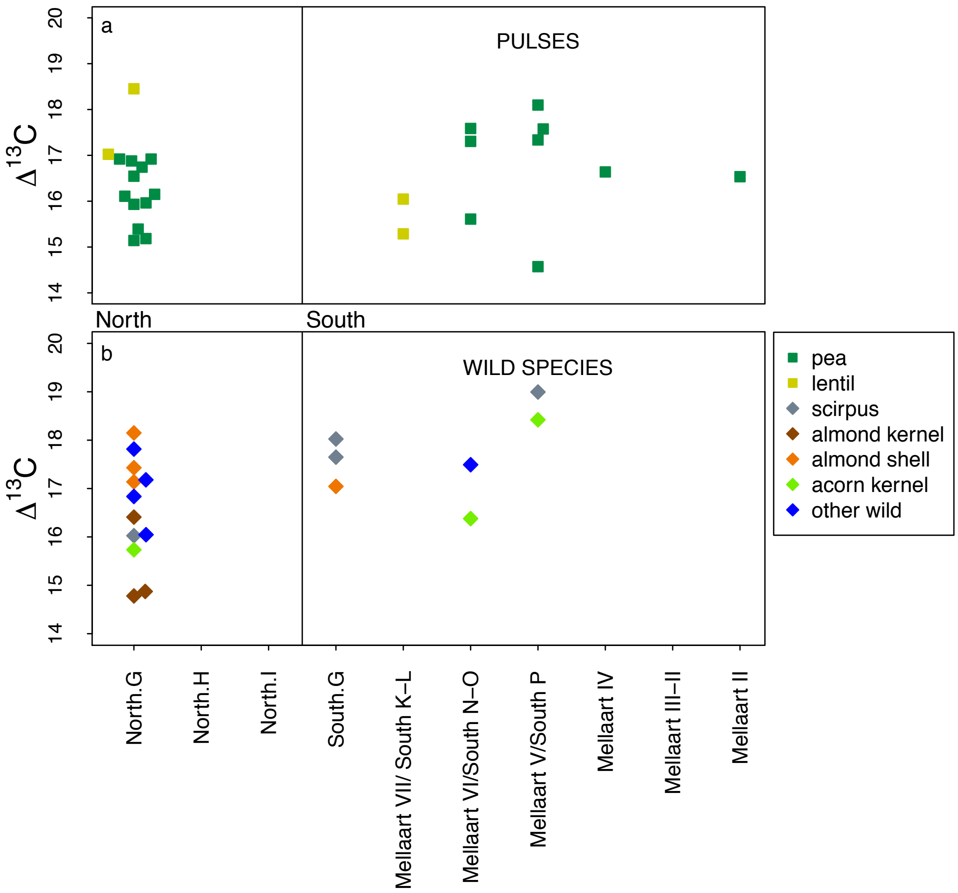


Figure 5.14: Uni-variate scatter plots of plant $\Delta^{13}C$ values of pulses (a) and wild plants (b) from Çatalhöyük divided into chronological phases in each excavation area

Neolithic levels from TPC area (Mellaart levels III–II) a sample of barley (PRT4bB) sits close to a sample of new type glume wheat (CTH90) (7.0‰ and 6.5‰, respectively). Significant overlaps can also be seen with bread wheat/naked barley in B.52 and naked barley/new type glume wheat in B.77 (see more in Section 5.5.5). These observations suggest that at particular points in time, different crop species were grown in similar growing conditions (similar in terms of ^{15}N–enrichment), but only some of the time and not always in the same combinations.

5.5.5 Well-sampled buildings

Fig. 5.15 shows the results of the two well-sampled burnt buildings from North.G, buildings 52 and 77. The contents of the two houses differ in terms of species composition – the assemblage from B.77 is dominated by new-type glume wheat and B.52 mostly contains naked barley and bread wheat, but a comparison of the δ^{15}N values from these two groups may shed some light on whether people storing their crops in these two buildings may have had access to land with variable ^{15}N content. There are statistically significant differences in the δ^{15}N values of the cereals from the two houses (independent two-group t–test, $t = -6.28$, $p < 0.01$), which indicates that farmers who stored their crops in B.77 had access to more ^{15}N–enriched soils than farmers storing their crops in B.52.

5.5.5.1 Building 52

Fig. 5.16 shows the δ^{13}C and δ^{15}N measurements of the main crops (naked barley, bread wheat and pea) from the different archaeological contexts in B.52. All samples from this building were obtained from features in the side storage room (Sp.93): storage bins F.2002, F.2003, F.2004 and F.2005, a ‘basket’ F.2040 and primary burnt room fill (see Fig. 5.4 for a plan of the contexts in B.52). Two estimates of natural variability within a single field

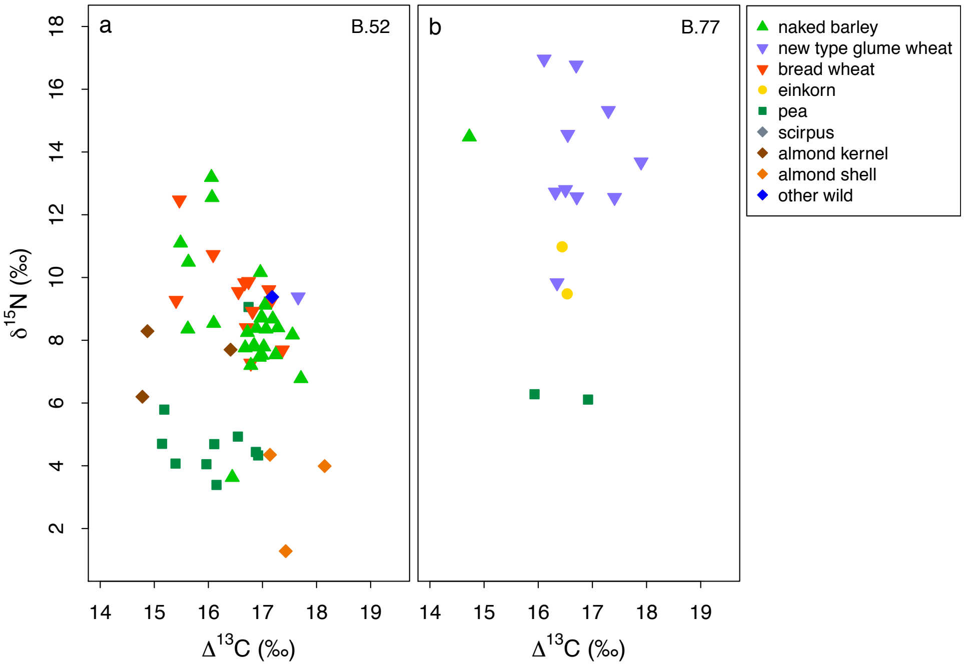


Figure 5.15: Bi-variate scatter plot of plant δ^{15}N and Δ^{13}C values from building 52 (a) and building 77 (b) in the North area at Çatalhöyük

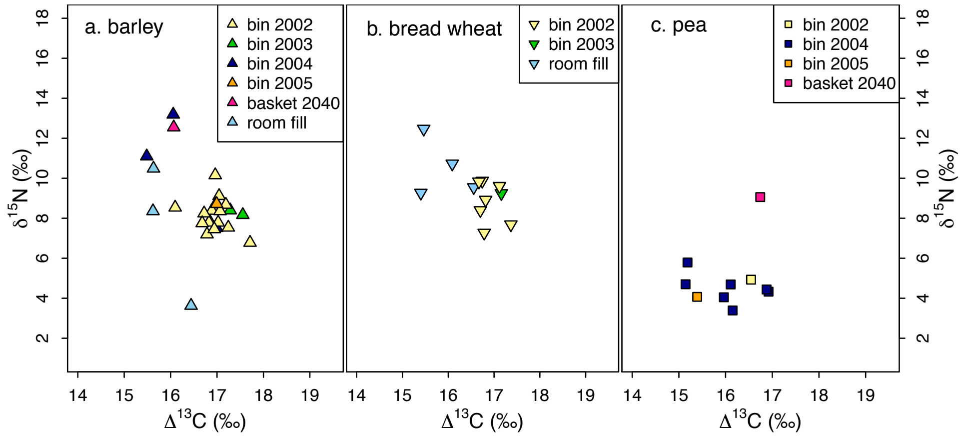


Figure 5.16: Bi-variate scatter plots of δ^{15}N and Δ^{13}C values of naked barley (a), bread wheat (b) and pea (c) from Building 52 at Çatalhöyük

(one from an archaeological context and one from a modern experiment) are used as proxies to assess whether the different crops stored in this building may have been grown in a single field/area of land.

Styring et al. (2016*b*) analyzed a large number of naked wheat, barley and einkorn grains from the Neolithic lakeshore settlement of Hornstaad-Hörnle. Most of the settlement burnt down in a fire in the year 3910 BC (determined through dendrochoronological dating), preserving an extremely rich archaeobotanical assemblage which included entire storage deposits of unthreshed cereal ears. Using a statistical method that identifies clusters of similar isotope values, the authors determined that house 9 at Honstaad stored high–δ^{15}N wheat values that were significantly different from the wheat grain stored in other houses. Similarly, house 11d contained significantly different low–δ^{15}N wheat values. Styring et al. (2016*b*) suggested that the inhabitants of these houses stored crops grown in separate fields during a single season of harvest. The standard deviations of these stored grain collections (0.5‰ and 0.7‰, respectively) were smaller than the variability measured in modern crops grown in several replicate fields at farming locations around Europe: 1.8‰ (Fraser et al., 2013).

In their charring experiment of several taxa of modern cereals and pulses, Nitsch et al. (2015) used statistical methods to estimate average variability in a single growing context (by examining the residual standard error of a multiple regression model) and estimated a 95% confidence interval of c.1‰ for the δ^{15}N values.

Fig. 5.16a shows patterns in the distribution of naked barley from B.52. Samples with the highest δ^{15}N and at the same time the lowest Δ^{13}C values come from features that were sampled in few numbers: one sample from basket 2040 and two out of three measured samples from bin 2004. Both of these features were located in the southern part of the storage room. The two samples from bin 2003 have some of the highest Δ^{13}C values, similar in value to some samples from bin 2002. These two features were located in the northern part of the storage room. Samples from the room fill have the most variable δ^{15}N and Δ^{13}C values, likely due to mixing, as the grains preserved on the floor may have originated from different sources. The room fill provided one of the lowest δ^{15}N values from the entire site. The one value from bin 2005 fits within the bin 2002 cluster. Bin 2002 was sub-sampled several times in order to investigate the possibility that different portions of the bin stored grain obtained from different sources. However, the nitrogen isotope results from this feature are less variable than the overall results for this building: standard deviation of barley δ^{15}N values from B.52 = 1.9‰, standard deviation of barley δ^{15}N values from bin 2002 = 0.8‰, which is within the estimated variation of a single field defined above). The results from this building thus suggest that while barley grain stored in the storage room of B.52 at the time of its destruction by fire may have been obtained from more than one field managed using variable treatments, the grain stored in bin 2002 may have derived from a single plot of land.

Fig. 5.16b shows the results of bread wheat from B.52. Even though this species was sampled in fewer numbers than naked barley, spatial patterns can be seen. Most notably, all samples from the room fill have lower Δ^{13}C values compared to the samples from the other two contexts (bin 2002 and 2003); the difference in mean Δ^{13}C values is 1.0‰ and a t–test between the two-groups yielded differences significant at 95% confidence ($t = 3.6$, $p = 0.026$). In addition, the room fill also provided the two highest δ^{15}N values, although the sample sizes of the groups are too small and differences are not significant overall.

As shown in Fig. 5.16c, most of the peas measured from B.52 come from bin 2004, with three other contexts represented by a single sample each. Similarly to naked barley, where the basket provided one of the highest δ^{15}N values from this building, the pea sample from the same basket yielded a notably higher δ^{15}N value compared to the rest of the samples. The samples from the other contexts (bin 2002 and bin 2005) fit within the cluster of samples from bin 2004, which themselves show a wide spread in Δ^{13}C values and thus a range of watering signatures.

Overall, it looks like crops were not distributed randomly across the storage space of B.52. The grains stored in bin 2002 represent more constrained growing conditions than the rest of the crops stored in this side room. The basket located in the southern portion of the floor space contained both cereal grains and pulse seeds that were grown in some of the most ^{15}N–enriched soils. Discussion later in this chapter will consider the possible reasons why the grains stored in the basket were kept separate from the other food items in this room and what the range of growing conditions represented in this building suggests about the agricultural land use around the Neolithic site.

5.5.6 Plant and collagen data

This section will consider the δ^{13}C and δ^{15}N values of the plants measured in this study in relation to the values of humans and animals sampled and analyzed previously by Mike Richards and Jessica Pearson (Pearson, 2013; Pearson et al., 2015, 2007; Richards and Pearson, 2005; Richards et al., 2003). See Fig. 5.17 for a combined plot of all the plants, animals and humans. The first observation to make is that the plants have more variable δ^{15}N values than the animals/humans (plant δ^{15}N range: 15.7‰; animal/human δ^{15}N range: 13.3‰). The animal range includes the one sample of wolf with a higher value (16.8‰) than the rest of the animals (δ^{15}N < 15‰).

The fact that the animal/human δ^{15}N values are more constrained should not be surprising, because consumers average the δ^{15}N values of the foods they eat. However, the large dataset represents a wide spatial and chronological coverage and many of the samples are nowhere close to contemporary. For this reason and so to better visualize the data, the samples were divided

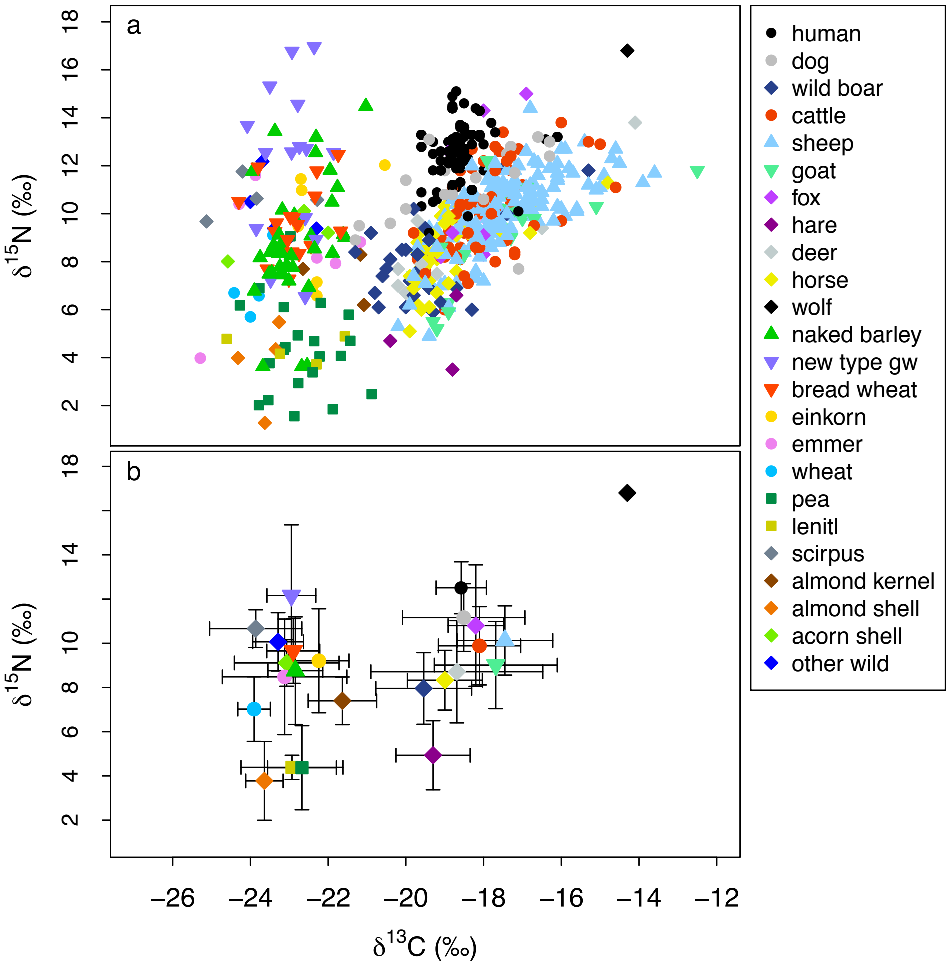


Figure 5.17: Bi-variate scatter plots of all plant (measured in this study) and animal collagen (Jessica Pearson pers.comm.) δ^{15}N and δ^{13}C values from Çatalhöyük. a) individual measurements; b) means and standard deviations of species where n > 2.

into the North and South areas (see Fig. 5.18).

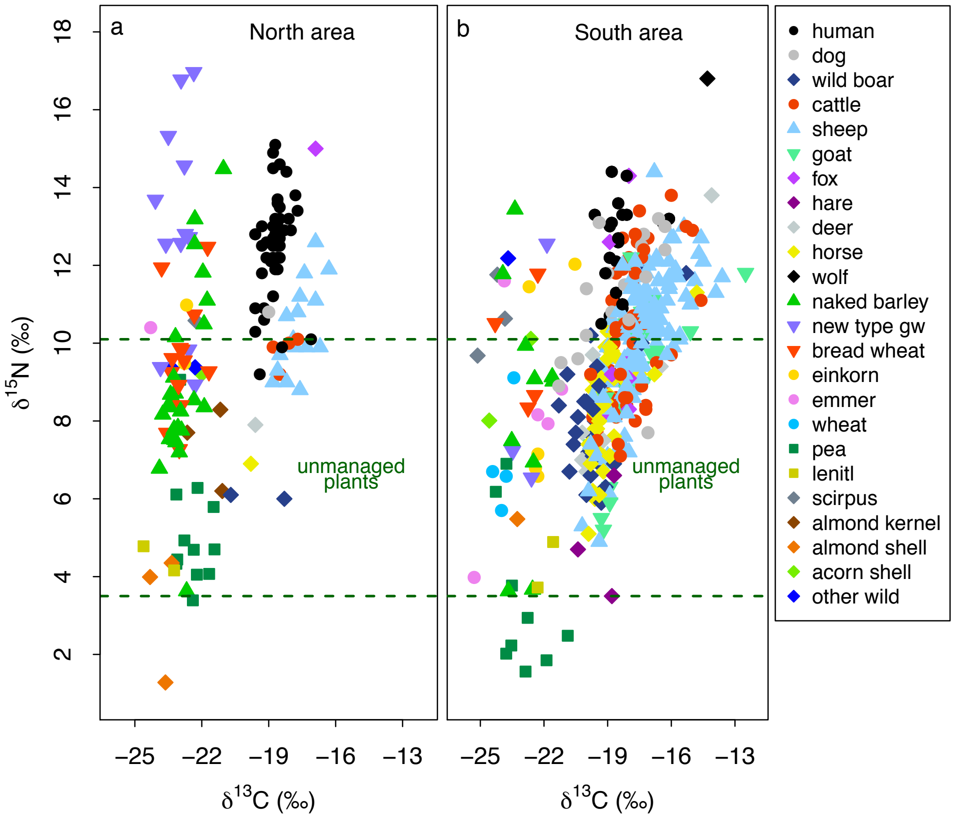


Figure 5.18: Bi-variate scatter plots of all plant (measured in this study) and bone collagen (Jessica Pearson pers.comm.) δ^{15}N and δ^{13}C values from the North (a) and South (b) areas at Çatalhöyük. The 'unmanaged plant' zone indicates the region of estimated values of vegetation (both grain and non-grain components) consumed by unmanaged herbivores (cattle, hare, deer). For more details, see Section 5.5.6.

Human δ^{15}N values from the two excavation areas are very similar: North, mean $\delta^{15}\text{N} = 12.5 \pm 1.2$‰ (n = 49), South, mean $\delta^{15}\text{N} = 12.5 \pm 1.1$‰ (n = 75) (all collagen data from Pearson pers. comm.). Their δ^{13}C values are also not statistically different: –18.7 ± 0.5‰ (North) and –18.5 ± 0.7‰ (South) (independent two-group t–test, t = 0.13, p = 0.90). Subtracting a 4.0‰ trophic level offset from the δ^{15}N values gives an average of 8.5‰ for the protein component of the human diets. This value is lower than the mean δ^{15}N values of any of the herbivore domesticates (North: sheep = 10.4‰, cattle = 9.8‰; South: sheep = 10.1‰, goat = 9.0‰, cattle = 9.9‰), suggesting that another more ^{15}N–depleted food source must have been consumed in significant proportions by the humans. Wild boars are one such food source, with collagen δ^{15}N values of 6.1‰ (North) and 8.1‰ (South). However, it is the cereals (excluding the anomalously high new type glume wheat from B.77) that have the most similar values to the human dietary average: 9.2‰ (North) and 8.5‰ (South). Unfortunately, no human data could be obtained from B.52 and B.77 due to preservation issues (Jessica Pearson pers. comm.), so it is impossible to assess the potential input of the ^{15}N–enriched new type glume wheat grains into the diets buried in B.77. Values of deer from both areas approximate those of the cereals (7.9‰, North; 8.8‰, South), however, zooarchaeological analysis of the assemblage excludes consumption of this animal in significant amounts. Pulses have the lowest averages of all (5.1‰, North; 3.5‰, South) and may have been responsible for decreasing the human δ^{15}N averages.

Bogaard et al. (2013*a*) argue, based on the botanical composition of sheep/goat dung pellets – keeping in mind that cereal grain is less likely to survive digestion than wild seeds (Wallace and Charles, 2013) – that it is more likely that these animals were grazed than fed with fodder. This is based on the fact that most of the taxa represented in the dung come from plants that are too small for it to be practical to collect and store them. The data presented in this study further support this view, as estimated values of the non-grain component of most of the measured crops are higher than the dietary signals of these animals: mean δ^{15}N of sheep/goat: 10.0‰; estimated δ^{15}N value of sheep/goat diet: 6.0‰; emmer chaff: 6.1‰, einkorn chaff: 6.8‰, naked barley chaff: 6.4‰, new type glume wheat chaff: 9.8‰, bread wheat chaff: 7.3‰, wheat (indet) chaff: 4.6‰(the values were estimated by subtracting 2.4‰ from the values of the measured grain, cf Fraser et al., 2011). Thus, the results support the ecological expectation that the small herbivores were not foddered on grain products all year round.

The average δ^{15}N value of the unmanaged herbivores (cattle, deer, hares) is 9.6 ± 2.1‰, which is c.3‰ below the average of the humans (δ^{15}N mean for both areas = 12.5 ± 1.2‰). Sheep and goats may have subsisted on vegetation that was grown on or at the edges of the arable lands, and thus may have been affected by anthropogenic inputs. Subtracting 4.0‰ from the unmanaged herbivore δ^{15}N mean (to account for trophic enrichment) gives an average value of the herbivore diet of 5.6 ± 2.1‰. This diet may have been a mixture of grain and non-grain components of plants available for pasture, but the bulk of it was most likely composed of non-grain parts. Adding 2.4 ‰ to this value (cf Fraser et al., 2011) provides an estimate of possible values of the grains of the plants consumed by these animals: 8.0 ± 2.1‰. The range that encompasses the uncertainties of both the grain and non-grain components of the herbivore forage is thus $3.5 - 10.1$‰. This provides a rough estimate of the possible δ^{15}N values of the 'unmanaged plants' (both C_3 andC_4 around Çatalhöyük, and can be used as an environmental baseline to assess the extent of anthropogenic ^{15}N enrichment of the cultivated soils, Fig. 5.18).

Many of the measured crops lie above the unmanaged plant region. This indicates that these crops grew in different soils than the plants that the herbivores consumed. In the following discussion, comparison between the unmanaged plants and the cultivated crops will be used to interpret the growing conditions of the sampled crops. The discussion will also consider the possibility that some crops grown in some fields were consumed as a staple, while others may have been consumed on rarer occasions by the humans.

5.6 Discussion

5.6.1 Cultivating a mosaic landscape

The two main reconstructions of the Neolithic environment around Çatalhöyük both describe the landscape as heterogeneous. In the first model, the environment is a seasonal wetland created by high-energy river and alluvial activity (Roberts et al., 1999, 1996; Roberts and Rosen, 2009; Rosen and Roberts, 2005). The second is a mosaic of wetter and drier patches, with alluviation occurring at a slower rate (Charles et al., 2014; Doherty, 2013). The second model accounts for the possibility that crops were cultivated within the vicinity of the mound and it is this reconstruction that is supported by the results of the current study.

The average $\delta^{15}N$ value of wild herbivores (cattle, hares, deer) at Çatalhöyük is higher here than at any other Neolithic/Mesolithic site in Europe; see Table 5.4 for comparative data. In addition, amino acid $\delta^{15}N$ values of herbivores from Çatalhöyük, Makriyalos and Vaihingen suggest that the plants consumed by the herbivores at Çatalhöyük were significantly enriched in ^{15}N compared to the plants consumed by herbivores at the other two sites (Styring, 2012). These observations suggest that an environmental factor caused a landscape-wide ^{15}N–enrichment of the soils.

Aridity is one factor that can cause such systematic enrichment and has been found to be correlated with higher $\delta^{15}N$ plant values in the Eastern Mediterranean (Hartman and Danin, 2010). It is impossible to quantify the exact degree of this enrichment, as many other variables (such as %N content and types of micro-bacteria inhabiting the soil) distinguish the soils in the Konya plain from the soils in modern aridity studies. However, significant ^{15}N–enrichment caused by aridity only occurs in very low rainfall zones – in Hartman and Danin's (2010) study, the highest $\delta^{15}N$ values were recorded at the site of Ezuz which receives 75mm of rainfall p.a., and in Craine et al.'s

Site	Country	Wild mean $\delta^{15}N$ (in ‰)	Species	Reference
Çatalhöyük	Turkey	9.8 ± 1.9	cattle (n=70), deer (n=8)	Pearson (2013)
Makriyalos	Greece	4.0 ± 1.3	wild boar (n=5), red deer (n=12), roe deer (n=2)	Triantaphyllou (2008), this study
Champ-Durand à Nieul-sur-l'Autise	France	4.6 ± 0.5	red deer (n=10)	Schulting and Hamilton (2012, Table 45)
Karsdorf	Germany	6.2 ± 0.1	aurochs? (n=3)	Oelze et al. (2011, Table 2)
Rochedane	France	4.8 ± 0.6	red deer (n=2)	Bocherens et al. (2007, Table 3)
Noyen-sur-Seine	France	5.7 ± 0.4	red deer (n=1), aurochs (n=1)	Bocherens et al. (2007, Table 3)
Vaihingen	Germany	6.6 ± 0.7	aurochs (n=2), red deer (n=9)	Fraser (2013, Table 4)
Slatina	Bulgaria	4.5 ± 0.3	"large wild herbivores" (n=5)	Bogaard et al. (2013*b*, Table 2)
Ecsegfalva	Hungary	7.0 ± 1.0	"large wild herbivores" (n=8)	Bogaard et al. (2013*b*, Table 2)
Hornstaad-Hörnle	Germany	4.8 ± 0.5	"large wild herbivores" (n=10)	Bogaard et al. (2013*b*, Table 2)
Hambledon Hill	England	5.5 ± 1.6	"large wild herbivores" (n=5)	Bogaard et al. (2013*b*, Table 2)
Kouphovouno	Greece	4.2	wild goat (n=1)	Vaiglova et al. (2014*a*, Table 2)

Table 5.4: $\delta^{15}N$ values of wild herbivores from Neolithic and Mesolithic sites in Europe

(2009) global survey, variability in δ^{15}N of leaves was so high within each isohyet that patterns in ^{15}N enrichment were only visible on a large scale between 100–1000mm. Since Çatalhöyük receives an average of 350mm of rainfall a year (Leng et al., 1999; Taha et al., 1981), aridity is unlikley to be the main cause of natural enrichment. The specific causal mechanisms are, however, yet to be determined.

The eco-systemic enrichment only tells part of the story, however. The rest of the story resides in the variability in plant δ^{15}N values, and it is in explaining this variability where lessons can be learned about the farmers' cultivation practices.

The wide range of δ^{15}N values suggests that the soils in which the crops grew did not all undergo the same processes of nitrogen transfer, and the causal mechanisms of these variable processes may have been both natural and anthropogenic. The bulk of the cultivated cereals charred and preserved in the North and South areas of the Neolithic mound lie in the 'unmanaged plant' region, indicating that these crops grew in soils similar to those on which the herbivores grazed. This suggests that a large portion of the arable landscape was cultivable without the need to add organic fertilizers. In addition, because the 'unmanaged plant' zone itself displays notable δ^{15}N variability – exceeding the 0.5 – 1.0‰ proxy value for natural variability in a single field (cf Nitsch and Styring, Section 5.5.2) – natural causes were at play in creating a mosaic of soils enriched in ^{15}N to variable degrees.

One possible natural cause of δ^{15}N variability is topography. In their survey of modern plants across a large rainfall-gradient in Israel, Hartman and Danin (2010) noticed that in arid zones, plants growing in localized dry exposed ridges have lower δ^{15}N values than plants growing in seasonally wet dry-washes (*wadis*). These differences of up to 4.0‰ led the authors to conclude that topography significantly influences the δ^{15}N of plants in arid environments independently of rainfall patterns as it supports localized denitrification. In their survey of traditionally farmed fields in semi-arid Morocco, Styring et al. (2016*a*) used the same reasoning to explain high δ^{15}N of barley cultivated in an oasis zone which experienced seasonal wetting and drying (14.0 ± 1.0‰). While the landscape around Çatalhöyük did not have the same type of dry-washes that can be found in the Levant, for example, topography may have been responsible for the uneven spread of ^{15}N–enriched nitrates across the landscape.

The mechanisms discussed so far only explain the values of samples in the 'unmanaged plant' zone. Those that are located above it were likely cultivated either in naturally exceptionally ^{15}N–enriched soils or in soils that were enriched anthropogenically. Section 5.6.2 will discuss the dynamics of intensive management in greater detail.

Just like the nitrogen isotope data, the carbon isotope data suggest that the plants were grown in a wide range of growing conditions. In the absence of any relationships between the δ^{15}N and the Δ^{13}C values, it cannot be argued that crops grown in less ^{15}N–enriched soils had a less optimal watering status.

A subset of the plant Δ^{13}C measurements presented here has previously been interpreted to indicate that barley was grown in drier soils than the other cereals (barley, n = 5; bread wheat, n = 3; einkorn/emmer, n = 9; samples were obtained from B.1, B.52, B.77 and Mellaart buildings) (Wallace et al., 2015). This was inferred from values of barley, which fell into the 'poorly watered band' defined by Wallace et al. (2013) (see Chapter 4.2). It is argued in this study that our understanding of the species-specific differences in Δ^{13}C values of wheat and barley are not understood to a sufficient degree as to permit comparison of their moisture availability. The fact the Δ^{13}C values of the barley are almost indistinguishable from the Δ^{13}C values of the two main wheat varieties would suggest that their moisture availability differed (since they are meant to have different values under the same conditions). However, to make this inferrence at Çatalhöyük would be risky, because 1) the offset (and its variability and consistency) has not been quantified and 2) the environment around the site has been shown to be isotopically unpredictable so it is not beyond the realm of possibilities that the extreme ^{15}N–enrichment had an effect on the water status of the plants as well. Thus, it is not argued herein that the data show that barley was grown in drier conditions at Çatalhöyük.

5.6.2 Degrees of intensive management

The desirable outcomes of intensive farming are that it improves/maintains soil fertility and tractability (ease of working the soil) as well as regulates crop growth. However, this happens at the expense of higher labor inputs. Jones et al. (1999) argue that intensive cultivation can feasibly be carried out only within a 1000m radius of a settlement and Halstead (2014) made observations at dozens of farms around the Mediterranean, where most manure was transported to distances of 500m from the animal stalls.

Analysis of the weed ecology in the archaeobotanical assemblage at Çatalhöyük indicates that the crops were grown under an intensive regime (Bogaard et al., 2013*a*; Filipović, 2014). In addition, the extreme enrichment of the N_2–fixing pulses above 0‰ (some of the samples are above 10.0‰), suggests that these crops were grown in very ^{15}N–enriched soils. Even in a landscape which was ecosystemically enriched and offered localized sources of natural ^{15}N–enrichment, it is very unlikely that the pulses could have attained such high values without the manual enrichment of the soils using organic manure.

Based on these observations, it is probable that farming at Çatalhöyük involved at least some degree of intensive management. One possible scenario is that the land close to the site (within 1km of the settlement) was turned into small-gardens, where some of the crops were grown in manured soils.

Part of the soil nitrogen enrichment may have been caused by organic waste (from middens) coming off of the site or penned animals dropping their dung on the soils. Pulses may have been periodically rotated with the non–N_2–fixing cereals in order to maximize the use of the proximal soils. Of the more distant plots of land, some of the soils suitable for cultivation may have been managed under a lower intensity and others used for pasture.

Archaeobotanical analysis suggests that crops at Çatalhöyük were generally treated on an individual basis (storage features tend to be dominated by a single crop species and houses look like they specialized in a few crop species), not in mixtures (Bogaard in press). In light of this observation and the fact that no species received unique treatment (see more below), the isotope variability on both the carbon and the nitrogen scale can be explained with the use of a diversified strategy, one where the various patches of the mosaic landscape were used to grow the whole range of crops individually. This strategy helped with minimizing risk of crop failure and allowed the farmers to make the most use of the surrounding landscape for cultivation.

Analysis of the frequency of new type glume wheat in deposits from the South area suggests that new type glume wheat began to replace emmer at around South.Q phase (which is roughly contemporary with North.H and post-dates building 77 from North.G) (Bogaard et al., 2017). What is interesting is that the data presented here show that this crop was grown at a high intensity/in the most ^{15}N–enriched soils just at the point when it was starting to achieve its dominance. Further assessment of long-term chronological trends at Çatalhöyük will be carried out in collaboration with Elizabeth Stroud, who measured plant δ^{13}C and δ^{15}N values from the Chalcolithic levels at the site.

5.6.3 Accessing the land for farming

Seeing that the farmers made use of a range of different types of soils and practiced some degree of intensive management, the question then arises: who got access to the more proximal parts of the land where intensive agriculture could be carried out and who got access to the distant plots of land? Were there patterns in land use on the household or neighborhood level?

The data suggest that the crops stored in building 52 were not all grown under the same regime or in the same plot of land, but their distribution across the various storage features in the side room suggests that they were not stored in heterogeneous mixtures. The thoroughly sampled bin 2002 contained crops that were grown in similar growing conditions, possibly even the same ‘field’; although ‘fields’ may have had more fluid boundaries than they have today. Moreover, the basket in the southern part of the room contained barley and pea with some of the highest $\delta^{15}N$ values, and may thus have served a specific purpose to do with storage/transport of crops from a more valued (more proximal or more intensively managed) plot of land.

Similarly, the crops stored in B.77 were also likely sourced from different parts of the arable landscape. One of the plots of land was used to grow the new type glume wheat, and it is perhaps not a coincidence that crops from this field were stored in B.77. Hodder (2008) argues that B.77 belonged to one of the more elaborate buildings found at the site – it may have been a history house – and Wright (2014) asserts, based on the presence of a rare large quern, that this house may have been used for special food processing activities. It may be that this building was used to store crops that were grown in most favorable soils and were used only for special communal functions. This may help explain why they did not contribute substantially to the protein intake of the humans (see below).

As it is not the case – from the two thoroughly studied buildings presented here – that storage rooms received crops cultivated under the same regime, a mechanism must have existed that dictated where crops were sown, and which storage room they ended up in. It may be that the people who stored their food in a given house had access to several different plots of land or that storage rooms were used by several groups of people partaking in the agricultural activities communally (cf Bogaard's (in press) supra-household co-operation) and sharing the end product. Both scenarios would make sense from an ecological perspective for helping to minimize risk of crop failure and would explain why houses could specialize in the processing of certain cereal or pulse species. To understand the way in which land may have been divided between different production units requires taking a closer look at the social geography of the village (Hodder, 2008).

Excavations at Çatalhöyük have shown that settlement of the Neolithic mound was divided into sectors, much like neighborhoods, similar to ones found at the site of Aşıklı Höyük (Hodder, 2008). Hodder (2008) interprets these divisions as signs of larger scale social groupings and argues that the sectors were oriented and defined by radial lines, created partly by midden space and partly by the alignment of walls (see Fig. 5.19 for an example). Furthermore, he argues that the society functioned by creating a series of networks that provided them with a means of social storage (cf Halstead and Barrett, 2004) and a mechanism for managing risk in the absence of social hierarchies or any centralized systems.

Hodder (2008) finds evidence for the maintenance of these social networks in similarities between houses, which displayed the same types of rare leopard reliefs, horned benches, splayed figures, hand-prints and stone statuettes. "The implication [of having a network of relationships] is that a person or house could get food (or obsidian or wood or clay) from people on their terrace, in their sector, in their burial group, in the group of people that have bears or leopards on the walls, in their bull-feasting group, in their neigh-

Figure 5.19: Plan of Level South.?N at Çatalhöyük showing radial divisions in the neighborhood (Hodder, 2008)

borhood and so on" (Hodder, 2008, pg. 153). This created a binary system in which houses were both self-sufficient and at the same time dependent on one another in times of need.

Analysis of DNA (Pilloud and Larsen, 2011), dental variations (Hillson et al., 2008) and other osteological indicators (Larsen et al., 2015) of humans recovered from sub-floor burials in Çatalhöyük indicates that the people buried in individual houses did not necessarily belong to a single biological family, i.e. those that were buried in one house were no more genetically related to others buried in the same house than to those buried in different houses. This has been taken to suggest that settlement on the mound was organized around 'practical kin groups', which made up this complex social network of relationships.

In such a system, the farmers may have managed crop production intensively in small-scale units, while sharing labor and the product within their larger network groups. Larsen et al. (2015) argue that the creation of the practical kin group system may have been motivated by the need to collaborate in economic related activities like planting crops and herding animals. It may be that access to the arable landscape was dictated by the radial divisions that delineated the settlement sectors: houses in a given sector could access soils that were aligned with their area (an idea earlier suggested by Charles et al., 2014) and because the surrounding landscape was variable, each sector ended up cultivating a range of different types of soils. In addition, crops may have been shared between people living in the different sectors (as per the various kin groups or cohorts), and that is why grain in a single storage room records variable signatures of growing conditions. Unfortunately, the data obtained in this study do not provide a good enough coverage to examine differences in crop isotope values between crops stored in the different radial sectors of the site, so the possible division of the landscape based on the radial lines can only be suggested based on the observed variability in stable isotope values.

5.6.4 Reinterpreting human diets

In the previous stable isotopic studies, dietary habits of people buried in Çatalhöyük have been interpreted in light of the feeding practices of the associated fauna (Pearson, 2013; Pearson et al., 2015, 2007; Richards et al., 2003). Richards et al. (2003) provided support for the revision of Mellaart's original assertation in which cattle played a dominant role in the diets of the inhabitants of this Neolithic village: the stable isotope values showed that the bulk of human dietary protein could not have been obtained from cattle products. Pearson et al. (2007) demonstrated that δ^{13}C and δ^{15}N values of domestic sheep and goats were notably variable by comparing them to caprine values from the site of Aşıklı Höyük, where the diets of these predomestic animals were very similar. The variability in the caprine diets was explained with the consumption of different degrees of mixed C_3/C_4 diets through the exploitation of a range of vegetation zones. As the variability was found to increase in the later levels of the site's occupation (and note that this temporal trend was multi-directional, Pearson, 2013), the authors suggested that herding management switched from small-scale to large-scale. Pearson et al. (2015) argued that it was not just sheep and goats that exploited a range of C_3/C_4 environments, as cattle – domesticated at a later date at this site – was also found to have equally variable δ^{13}C and δ^{15}N values.

From the initial stages of stable isotope work at Çatalhöyük, human diets were also found to be variable. Richards et al. (2003) offered several possible reasons for this: 1) people buried at Çatalhöyük spent considerable amounts of time away from the settlement and obtained varied diets based on the local environments of their seasonal habitation, 2) the variability in human dietary signatures was caused by considerable variability in the faunal isotope values, and 3) people living at Çatalhöyük had differential access to food. With the re-interpretation of long-distance cultivation strategies, the population living at Çatalhöyük is now viewed as more sedentary than in the initial stages of the site's excavation, so the first explanation is less plausible. Even though the variability in faunal isotope values is considerable, as a general trend, the human values show negligible contribution of C_4 plants in their diet. This holds in spite of the increased contribution of C_4 plants in the animal diets later in the Neolithic sequence (Pearson et al., 2015), although the input of C_4 vegetation may have been counterbalanced by the consumption of increasing amounts of C_3 cereals. Thus, it is most likely that differences in people's diets were caused by differential access to foods.

Pearson (2013) speculates whether the herbivores' increased consumption of C_4 plants in the later occupation levels points to a shift in the environmental conditions around the site: C_4 plants grow in drier soils and it may be that through time, climatically-induced reduction in the availability of C_3 grasslands led the people to involve the more marginal zones as grazing habitats. However, the lack of any temporal trends in the plant isotope data presented here contradict the suggestion that a chronological shift impacted the wider isotope ecology. Larsen et al., (2015) argue that there was a shift towards higher human $\delta^{15}N$ values later in the sequence and suggest that one possible explanation is that "the Çatalhöyük population began a practice of manuring" (pg. 38). The discussion in this study shows that farming strategies employed at Çatalhöyük were sophisticated from the outset and the farmers were well versed with the application of manure for increasing soil fertility from the early levels.

Analysis of the human data on a finer level showed that people buried in individual houses had isotopically variable diets. This was taken to suggest that people buried together did not necessarily share the bulk of their meals together over the long-term (Pearson, 2013; Pearson et al., 2015). In addition, no significant correlation was found between the stable isotope values of human individuals buried underneath house floors and those of animals deposited in contemporary middens associated with those houses. The results did not show the expected trophic shift between human consumers and animal food products and the humans recorded a much weaker C_4 signal in their $\delta^{13}C$ values than the animals. For these reasons, Pearson et al. (2015) argue that human diets were not determined on a domestic house unit basis, but rather by another larger-scale form of social organization. This may have been achieved by feasting and food sharing across the intra-community networks, while at the same time allowing the people to utilize the household on a practical kinship basis. This is consistent with the plant isotope data, which indicate that harvested crops were likely shared among several different households.

Pearson et al. (2015) argue that individuals with values above the site mean (12.7‰) would have consumed more meat, on average, than the others. Two individuals, with values of around 14‰, are singled out as having particularly high $\delta^{15}N$ values and the authors present three possible explanations for this: 1) they consumed large amounts of meat, 2) they consumed proportionally more animal products with elevated $\delta^{15}N$ values, 3) they subsisted on "as yet unmeasured food with much higher nitrogen values" (Pearson et al., 2015, pg. 77). The results of the present study show plant foods fit the description of the third category, and need to be considered as potentially significant, not just secondary, contributors to human diets.

The stable isotope values of the humans suggest that the people did not obtain the bulk of their dietary protein from cereals that were grown in the most ^{15}N–enriched soils (i.e. the soils in which the new type glume wheat from B.77 was cultivated). As the humans are not situated a whole trophic level above the measured animals, they did not obtain most of their dietary protein from meat either. This suggests that either pulses played a significant role in the diets of these farmers, or the bulk of dietary protein was derived from cereals grown in 'average' soils, while crops that grew in more productive soils were consumed on rarer occations.

5.7 Conclusions

The analysis of charred plant remains from Çatalhöyük yields insight into diversity of growing conditions under which crops were cultivated by the Neolithic farmers. The results provide an opportunity to evaluate the two landscape reconstruction models that have been put forward since the start of the renewed excavations at the site in the 1990s. That data suggest that the landscape provided a wide scope of variability, but also that crop cultivation involved a certain degree of intensive management, thus conferring with the more recent model that the more proximal landscape (less than 13km) was usable for cultivation.

All the domestic crops exhibit varying degrees of ^{15}N–enrichment over the estimated 'unmanaged' plants, and this suggests that they were sown in the whole range of soils available. No crops received distinct treatment. Some cereals may have been grown in the same fields together with some pulses, but this crop rotation regime was not dictated by crop types.

New type glume wheat from building 77 has statistically higher δ^{15}N values compared to the other crops stored in the same building as well as most of the other crops measured from other contexts. However, the over-representation of samples of new type glume wheat from B.77 in the dataset (caused by favorable preservation) may accentuate its relationship to more ^{15}N–enriched fields. It does not seem to be the case that at least at a certain point in time (halfway through the Neolithic sequence, when the neighborhood from North level G was in use), houses had access to one type of field. Soil-management may thus have been determined and maintained by the existence of networks – also visible in the ceramic record and in the wall paintings – that may have been the reason behind social cohesion on such a large scale.

Chapter 6

Kouphovouno

This chapter presents the case study at Kouphovouno. The introduction provides an overview of the archaeological and environmental setting of the site, along with a summary of the results of analysis of the archaeobotnaical assemblage. The materials and results sections describe the analysis carried out in two stages in this study: the first stage involved the measurement of δ^{13}C and δ^{15}N values of charred plant samples and the second stage involved the analysis of sequential δ^{13}C and δ^{18}O values of tooth enamel carbonate of sheep and goats. The discussion demonstrates how crop cultivation and animal husbandry were integrated into an agro-pastoral strategy that was driven by species separation.

6.1 Introduction and archaeological background

Kouphovouno (37° 3' 46.70" N, 22° 25' 14.20" E) is a Middle–Late Neolithic tell site that was occupied continuously between 5800–5000 cal BC. The site is located c.2.5km southwest of modern-day Sparta in Central Lakonia on the Pelopponesian peninsula (Fig. 6.1). The village may have been one of a series of large Neolithic sites that were sparsely distributed across southern Greece (Cavanagh et al. 2004, 2007, in press; Mee et al., 2014).

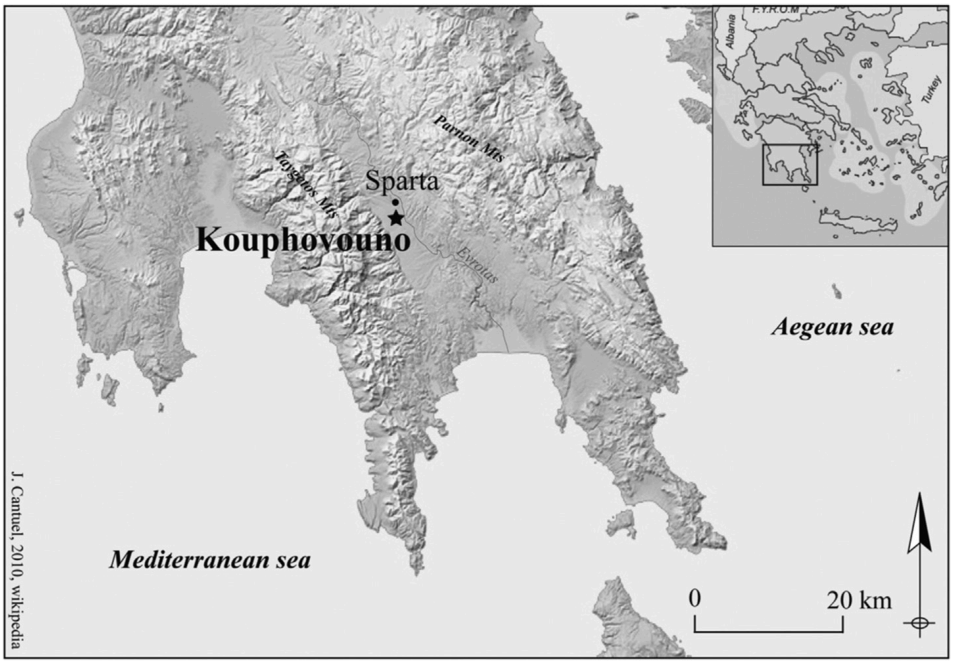


Figure 6.1: Map of the Pelopponesian peninsula, southern Greece, showing the location of Kophovouno in the Sparta Basin (prepared by Jean Cantuel, from Rivals et al., 2011)

6.1.1 Geographical setting

The mound rises to an elevation of 5m above the surrounding Sparta basin and spreads over 4–5ha. The soils in its immediate environment are composed of gravels, sands, clayey sands, clays, marls and sandstone, ranging in age from Pliocene to Holocene (Pope and Millington, 2000). The mound is bordered in the north by a seasonal stream, Parori, which originates in the alluvial fans to the west and feeds into the Evrotas river 3.5km to the east. To the south, the mound is met by a perennial pond (Fouache et al., 2007). To the west, the plain is bordered by a series of alluvial fans, characterized by clayey/carbonate cement, which formed out of Plio–Pleistocene lacustrine deposits. The alluvial fans occupy the piedmont zone of the Taygetos Mountains, a limestone massif that formed during the late Mesozoic/Cenozoic Alpine orogeny and reaches an evelation of 2,404masl. Stretching over the southeastern part of the Sparta Basin is a series of hills that rise out of Neogene/Pleistocene bedrock and reach elevations under 500m (Cavanagh et al., 2004; Pope and Millington, 2000) (see Fig. 6.2). Geomorphological reconstruction suggests that water was abundant close to the surface in much the same way as it is today as the landscape was prone to flooding and anthropogenic changes imposed by the Neolithic population would not have significantly altered groundwater recharge (Fouache et al., 2007).

6.1.2 Excavation and chronology

The archaeological site was first mapped and excavated by Otto Wilhelm von Vocano in 1941 and the results of his work were published by Renard (1989). A more recent undertaking was carried out by a Franco–British team co-directed by William Cavanagh, Christopher Mee and Josette Renard. An initial two seasons of survey revealed that the size of the settlement did not vary significantly between the two occupation phases, as Middle and Late Neolithic sherds were found scattered to roughly the same extent around

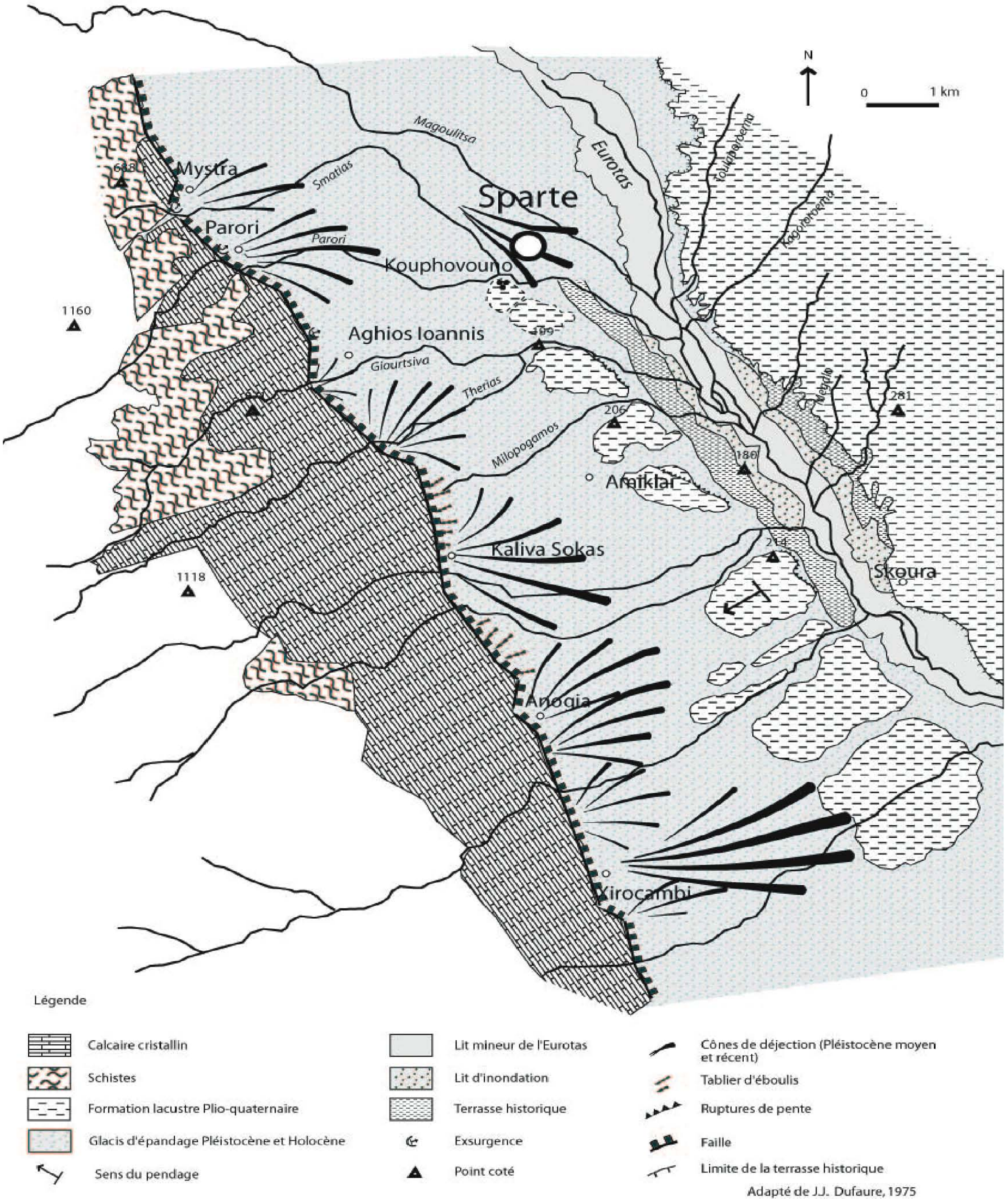


Figure 6.2: Geomorphological map of the Sparta Basin, southern Greece (Fouache et al., 2007)

the Neolithic mound. Ground-penetrating imaging suggested that burnt structures lay beneath the surface (Cavanagh et al., 2004). Over the course of five seasons of excavation carried out between 2001–2006, seven excavation areas were opened on the central part of the hill (Cavanagh et al., 2007). In addition, two deep soundings, in Areas C and G, were excavated with a view to recovering a full chronological sequence that could be used to date the Neolithic occupation of the site (Mee et al., 2014).

The excavated areas suggest that the settlement was nucleated and may have been divided into neighborhoods, with rubbish disposal areas located in close proximity to the habitation spaces. A possible garden was identified in Area G. A chronological shift was encountered in the architecture, with more ephemeral features, including post-holes and parts of walls, characterizing the Late Neolithic levels. In addition to bioarchaeological material (plant and animal remains, discussed below), recovered material finds include bone tools, polished axes, and anthropomorphic and zoomorphic figurines made of clay and stone. No human remains dating to the Neolithic levels were found (Cavanagh et al., 2007). Cavanagh and Renard (2014) argue that the diverse collection of figurines, together with obsidian and flint blades suggests that the Neolithic inhabitants participated in a network of exchange that extended beyond the Adriatic zone – the Balkans to the north and Italy to the west – into the eastern Aegean.

A thorough dating programme was carried out which combined stratigraphy, pottery typology, seriation and Bayesian modeling of radiocarbon dates of charred seeds (Mee et al., 2014). The results suggest that Kouphovouno was settled after the start of the Middle Neolithic in Greece, during the third of five Middle Neolithic (MN) phases identified at Franchthi cave, c.5800 cal BC. Middle Neolithic occupation continued until c.5400 cal BC, when black ware ceramics appeared, signaling the start of the Late Neolithic phase; this lasted until c.5000 cal BC. The data from Kouphovouno suggest that the

Middle to Late Neolithic transition in Southern Greece was not abrupt, unlike earlier thought (Mee et al., 2014).

One of the defining features of the transition from the Middle to Late Neolithic at Kouphovouno is change from uniformity to diversity reflected in the ceramic record (Mee et al., 2014). In the Middle Neolithic, people made Urfirnis-type pottery that was remarkably homogenous. Mee et al. (2014) argue that the function of ceramic vessels during this period was to promote social integration, as emphasis was placed on presentation of food and drink for consumption during social gatherings. In the Late Neolithic, the ceramics became more diverse. Both the range of decorative styles and the range of functions expanded. In addition to continuing the Urfirnis ceramic tradition, people now produced black ware, grey ware and matt painted pottery. Coarse vessels also became more abundant and served a range of cooking functions. Despite the change towards an emphasis on individuality, however, Mee et al. (2014) argue that the "symbolic dimension to the pottery cannot be ruled out" (Mee et al., 2014, pg. 29). The authors also argue that because of the continuation of the use of Urfirnis ware, the ceramic record cannot be used to support the theory that the Middle Neolithic population was displaced by a wave of newcomers during the Late Neolithic.

6.1.3 Plant resource use

Recovery and initial analysis of the archaeobotanical assemblage was undertaken by Amy Bogaard during excavation and full analysis of the assemblage was completed by Diffey (2014). The results show that the assemblage is dominated by domestic crop types, mainly cereals. Hulled barley is the most ubiquitous taxon and although glume wheats (einkorn and emmer) and free-threshing wheats occur in roughly the same number of samples, free-threshing wheat occurs in higher quantities. Cereal chaff occurs in very low quantities across both occupation phases. Apart from Neolithic Knossos, where free-threshing wheat was recovered in layers dating to the 7th millennium BC (Sarpaki, 1995), the high incidence of free-threshing wheat at Kouphovouno presents an anomaly amongst Neolithic sites from south-eastern Europe and a striking contrast to the situation in Northern Greece, where farmers are argued to have rejected this crop by choice (Valamoti and Jones, 2003).

At Kouphovouno, free-threshing wheat is not only found in rich storage contexts, but previous stable isotope analysis suggests that it was cultivated at a higher intensity than hulled barley, and that it was likely grown exclusively for human consumption (Vaiglova et al. 2014*a*).

Diffey (2014) suggests that there was a shift from focus on free-threshing wheat in the Middle Neolithic to focus on einkorn in the Late Neolithic. However, she warns that this may be because the presence of grain-rich storage samples (containing free-threshing wheat) from the MN may be skewing the results. Stable isotope values of einkorn have not been previously measured, but the opportunity to do so in the present study will provide a chance to evaluate whether this species was cultivated under the same intensity as the free-threshing wheat or the hulled barley. Alternatively, it may have been managed under another strategy, which would suggest that crop management here was even more diverse than earlier thought.

Pulses are mainly represented by lentils and peas, with grass pea and bitter vetch occurring more sporadically. Diffey (2014) suggest that the latter two species may have been grown as fodder crops for animal consumption. Previous stable isotope work suggests that peas were grown at a high intensity, possibly in rotation with free-threshing wheat, under additional hand-watering treatment (Vaiglova et al. 2014*a*). As only one additional sample of pulse (grass pea) was available for analysis, our understanding of pulse cultivation will be only minimally enhanced.

Remains of fig have been found not only in the form of charred seeds but in the form of charred flesh as well. This suggests that this fruit was dried and stored for year-round consumption. Pistachio, flax and grape occur in low quantities, but the grape may represent some of the oldest remains of this species in Greece, predating those found in the 5th millennium Dikili Tash (Valamoti et al., 2007).

6.1.4 Animal resource use

The archaeozoological assemblage is also dominated by domestic species, namely sheep, goats, pigs and cattle. Wild fauna is not common, but include instances of red deer, roe deer, wild boar, aurochs, wild boar, hare, wolf, fox, cat and weasel (Cantuel et al., 2008; Gardeisen, 2007). The faunal specialists (Cantuel and Gardeisen) argue for the presence of wild goat, either *Capra ibex* or *Capra aegagrus*, but the presence of this species has been put into question by Paul Halstead (pers. comm.).

The feeding behavior and management strategies of the animals have been evaluated by analysis of the kill-off patterns (Cantuel et al., 2008), the dental micro– and meso–wear patterns of adult faunal teeth (Rivals et al., 2011) and a combination of the plant and animal stable isotope measurements (Vaiglova et al. 2014*a*). The dental wear analysis suggests that the diets of domestic and wild animals discarded at Kouphvouno differed: the wild taxa were browsers, while the domestic taxa were grazers.

No differences were observed in the dental wear patterns between the ovicaprids, but it must be pointed out that the teeth were identified using morphological criteria and not using ZooMS analysis. Stable isotope results (which were differentiated using ZooMS analysis), however, suggest that there was a chronological shift in the composition of the ovicaprids' diet. The shift was towards more variability in $\delta^{15}N$ during the Late Neolithic (see more in the discussion). Based on the tooth-wear analysis, pigs were likely kept close to the village in a free-ranging arrangement and the results of the stable isotope analysis suggest that they may have consumed the by-products of cereal and pulse crops or the grains of hulled barley, but not the grains of free-threshing wheat (Vaiglova et al. 2014*a*).

The composition of the faunal assemblage remains constant throughout the occupation of the site, but the mortality profiles indicate that there was a chronological shift in the animal exploitation strategy. In the Middle Neolithic, the animals were likely exploited for their secondary products, as the age profiles are generally older, while in the Late Neolithic, they may have been kept for provision of meat. The mortality profiles of the cattle could not be determined due to the low numbers of preserved individuals.

Stable isotope analysis of tooth enamel carbonate $\delta^{13}C$ and $\delta^{18}O$ values carried out in this study will provide an opportunity to assess the nature of ovicaprid diets on a finer scale. The aim is to shed light on the seasonal patterns of the animals' feeding behavior during their first year of life, as well as possible changes in their management strategies and the timing of their births over the course of the two Neolithic occupation phases. The question of whether some of the animals participated in an annual transhumant migration cycle between the lowlands and the highlands will be addressed by examining the sequential patterns in their $\delta^{18}O$ values. This will provide an opportunity to review the nature of small-scale mixed mode of agricultural production developed by the Neolithic community.

6.2 Materials

The analysis carried out in this study builds on previous stable isotope work in which charred plants and animal bone collagen were measured in a first attempt to understand the scale and intensity of farming at this Neolithic tell site (Vaiglova et al. 2014*a*). Following the completion of the archaeobotanical analysis (Diffey, 2014), additional plant samples – which include species that were not measured before – became available for analysis, and their δ^{13}C and δ^{15}N values were measured in Stage 1 of the present study. In Stage 2, samples of enamel carbonate from the teeth of sheep and goats were measured in order to investigate the animals' feeding behaviors on a seasonal scale and address the possibility of their transhumant movement.

6.2.1 Stage 1: Additional charred plant samples

In Stage 1 of this study, a total of 19 samples of charred grains/seeds were measured for their δ^{13}C and δ^{15}N values. See Table 6.1 for a breakdown of the species analyzed.

Crop category	Common name	Latin name	n =	Comment
Cereal	Einkorn grain	*Triticum monococcum* L.	6	all samples of 1-grained variety
	Free-threshing wheat grain	*Triticum aestivum* Desf. /*Triticum durum* Desf.	4	
	Hulled barley grain	*Hordeum vulgare* L.	8	
Pulse	Grass pea seed	*Lathyrus sativus* L.	1	

Table 6.1: Descriptions of archaeobotanical samples from Kouphovouno analyzed in this study

Each sample was taken from a discrete contextual unit and included between 3 and 13 whole grains/seeds, or fragments thereof. 9 samples came from the Middle Neolithic and 10 from the Late Neolithic levels.

Samples were chemically pre-treated using a gentle acid-only treatment with 0.5M HCl at 80°C for 30min (Vaiglova et al. 2014*b*). All measurements were corrected for a charring-induced enrichment of 0.31‰ in δ^{15}N and 0.11‰ in δ^{13}C (Nitsch et al., 2015). The results obtained in this study were combined with the previously measured plant values ($n = 28$, Vaiglova et al. 2014*a*), whose δ^{13}C and δ^{15}N values were corrected according the more recent charring offset (the offset used at the time of the publication was 1.0‰ in δ^{15}N, cf Fraser et al., 2013). One sample of hulled barley and one sample of free-threshing wheat (both from the Middle Neolithic) yielded only a reliable δ^{15}N measurement and one sample of free-threshing wheat (also from the MN) yielded only a reliable δ^{13}C measurement. δ^{13}C values were converted to Δ^{13}C values using the equation shown in Chapter 4.2.

Analysis was carried out on a SerCon 20/22 continuous flow mass spectrometer coupled to a Callisto elemental analyzer at the Research Laboratory for Archaeology and the History of Art, University of Oxford. δ^{13}C and δ^{15}N values were measured separately and normalized to Vienna Pee Dee Belemnite (VPDB) and Ambient Inhalable Reservoir (AIR), respectively. Measurement uncertainty was assessed based on the within-run variability of an internal alanine standard and two certified reference materials placed in each run, calculated using a two-point calibration method (cf Kragten, 1994). The reference materials used were IAEA–CH6 and IAEA–CH7 for δ^{13}C and IAEA–N2 and USGS–40 for δ^{15}N. Calculations were performed using a script written by Erika Nitsch (of the AGRICURB project) in the statistical programming language R (3.2.2). The average measurement uncertainty (1σ) for δ^{13}C was $0.52 \pm 0.15‰$ (with a range between 0.08 and 0.92‰). The average measurement uncertainty (1σ) for δ^{15}N was $0.34 \pm 0.03‰$ (with a range between 0.30 and 0.41‰). The unexpectedly higher uncertainty for δ^{13}C measurements compared to δ^{15}N measurements was caused by random drift in the C run.

6.2.2 Stage 2: Tooth enamel carbonate samples

In the second stage of analysis, sequential samples of tooth enamel were taken from the second molars (M2) of sheep and goats recovered from Kouphovouno. M2s mineralize within 12 months of the animals' birth (Balasse et al., 2001; Brown et al., 1960; Hillson, 2005; Towers et al., 2014; Weinreb and Sharav, 1964), so results from this analysis will shed light on the seasonal patterns in their grazing behavior during the first year of their lives. Two sheep and two goats date to the Middle Neolithic and two sheep and two goats date to the Late Neolithic. The samples were obtained from Areas

C, D, and G.

All four sheep and two of the goat teeth were extracted from fragments of mandibles, and their identification as M2s cannot be contested. Two of the goat teeth were found removed from their mandibles, and their identification was carried out by Maria Theodosi from the Ephorea of Antiquities of Laconia, and Paul Halstead and Valasia Isaakidou from the University of Sheffield. ZooMS analysis was performed on the tooth dentine by Mike Buckley at the University of Manchester to confirm the species identification (Buckley et al. 2009, 2010; the comparative spectra are shown in Appendix A). The results show that the faunal specialists did not make any wrong species identifications and that ZooMS analysis proved useful for clarifying inconclusive determinations ('sheep/goat' and '?goat').

In those cases where the mandibles were available, ages of the ovicaprids were assessed by Paul Halstead and Valasia Isaakidou using tooth wear stages established by Payne (1972). However, due to the state of preservation of the teeth, most of these identifications are uncertain. The sheep fall into categories ?D (1–2 years), ?E (2–3 years), ?F–G (3–6 years) and G (4–6 years) and the goats fall into categories E (2–3 years) and G (4–6 years) (see Table 6.2).

Prior to sampling, the external surface of the teeth was cleaned using a laboratory aluminium oxide sandblaster and a Dremel tool with a tungsten drill bit. FTIR analysis of a randomly chosen tooth showed that the enamel was not contaminated with calcite and had not undergone significant recrystallization (see Appendix B). Sub-samples (weighing between 5–10mg) of powdered enamel were taken at 1mm intervals from the tooth crown to the enamel root junction (erj) on the buccal side of each tooth, following the protocol used by Balasse (2002) (see Fig. 6.3). The number of sub-samples taken per tooth ranged from 15–16 in sheep (total $n = 61$) and 11 to 22 in goats (total $n = 65$). The crown heights ranged from 22–30mm in sheep and

ID	species identification (ZooMS)	species identification (morphology)	context	context type	phase	number of sub-samples	wear stage	estimaged age	crown height (in mm)	sample obtained from
KFO209	sheep	sheep	C 1708/32	room fill	Middle Neolithic	15	?F-G	(3-6 years)	28	mandible
KFO210	sheep	sheep	C 1040/10	room fill	Late Neolithic	15	G	4-6 years	22	mandible
KFO212	sheep	sheep	G2 1136	accumulation of debris	Late Neolithic	15	?D	(1-2 years)	30	mandible
KFO217	sheep	sheep	C 1752	room floor	Middle Neolithic	16	E?	(2-3 years)	30	mandible
KFO204	goat	sheep/goat	C 1731/4	midden fill	Middle Neolithic	11	G	4-6 years	24	mandible
KFO207	goat	goat	C 1713	midden fill	Middle Neolithic	20	-		30	loose tooth
KFO214	goat	?goat	D 0308/18	accumulation of debris	Late Neolithic	16	E	2-3 years	28	mandible
KFO216	goat	?goat	G 1648	accumulation of debris	Late Neolithic	18	-		28	loose tooth

Table 6.2: Descriptions of sheep and goat teeth sampled in phase 2 of this study. Wear stages have been assessed following Payne (1972).

24–30mm in goats.

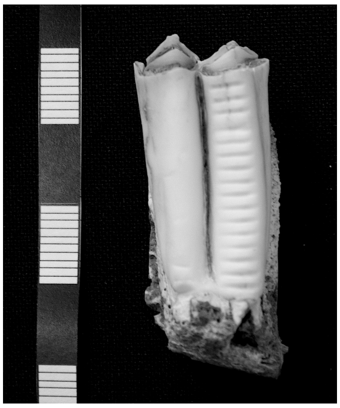


Figure 6.3: Photograph showing the sequence of enamel sub-samples obtained by drilling from the buccal side of an ovicaprid second molar from Kouphovouno (sample KFO214)

All samples were pre-treated using 1M Ca–buffered acetic acid for 30min at room temperature in order to remove possible carbonate contamination (Snoeck and Pellegrini, 2015). Analysis was carried out by Andrew Gledhill at the School of Archaeological Sciences, University of Bradford, on an automated Thermo Gas Bench II device coupled to a Thermo Delta V Advantage mass spectrometer. Raw values were normalized to VPDB for $\delta^{13}C$ and VSMOW for $\delta^{18}O$ and $\delta^{18}O_{VSMOW}$ values were converted to $\delta^{18}O_{VPDB}$ using the equation in Chapter 4.6. Measurement uncertainty was assessed using replicate measurements of two internal standards (BES, bioapatite enamel standard, and Merck $CaCO_3$, and three international standards (IAEA-CO-1, IAEA-CO-8 and NBS-19). The average measurement error for all standards (1σ) was 0.15 ± 0.15‰ for $\delta^{13}C$ (from 0.01 to 0.55‰) and 0.29 ± 0.24‰ for $\delta^{18}O$ (from 0.03 to 1.11‰).

6.3 Results

6.3.1 Stage 1: Additional plant δ^{13}C and δ^{15}N measurements

6.3.1.1 Overall description of data

Fig. 6.4 shows the results of all plant δ^{13}C and δ^{15}N measurements from Kouphovouno. Raw and corrected measurements obtained in this study are shown in Appendix F. The results are interpreted in conjuction with previously measured data from this site (Vaiglova et al. 2014*a*). Table 6.3 shows the summary statistics of the combined datasets and Fig. 6.5 shows a scatter plot of all the plant and animal data from this Neolithic assemblage.

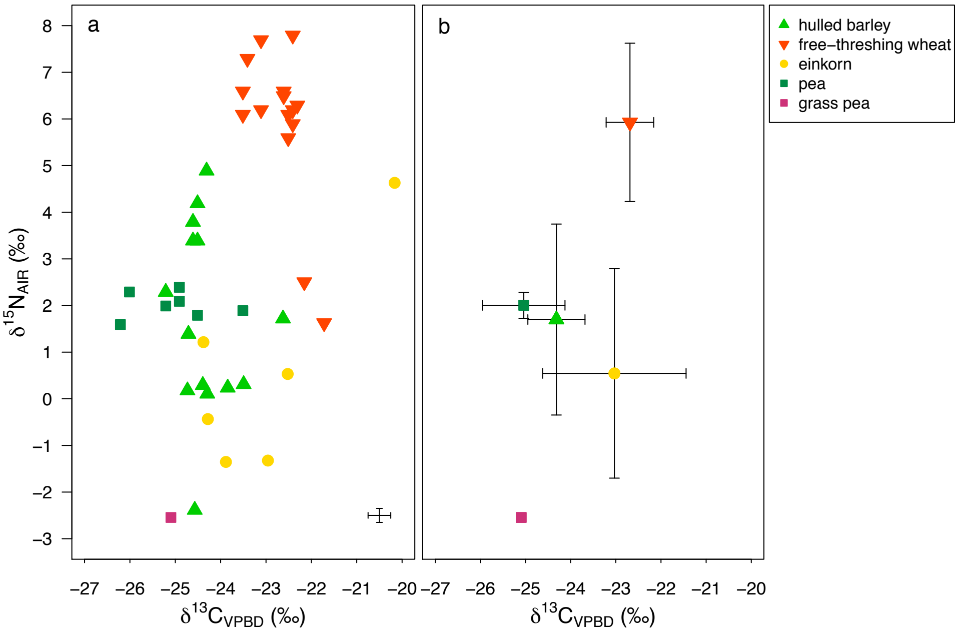


Figure 6.4: Bi-variate scatter plot of all plant δ^{15}N and Δ^{13}C values from Kouphovouno. a) individual measurements; b) mean and standard deviations of each species where n > 2. The combined dataset includes samples measured in the present study (n = 19) and samples measured previously by the author (n = 28, Vaiglova et al. 2014*a*). Measurement error is shown in the bottom-right of panel **a**.

This phase of analysis revealed an even larger variability in plant stable

species	n=	$\delta^{15}N_{max}$	$\delta^{15}N_{min}$	$\delta^{15}N_{mean}$	$\delta^{15}N_{SD}$	$\delta^{15}N_{range}$	$\delta^{13}C_{max}$	$\delta^{13}C_{min}$	$\delta^{13}C_{mean}$	$\delta^{13}C_{SD}$	$\delta^{13}C_{range}$	$\Delta^{13}C_{max}$	$\Delta^{13}C_{min}$	$\Delta^{13}C_{mean}$	$\Delta^{13}C_{SD}$	$\Delta^{13}C_{range}$
free-threshing wheat	17	7.8	1.6	5.8	1.7	6.2	-21.7	-23.5	-22.7	0.5	1.8	17.4	15.6	16.6	0.5	1.9
hulled barley	15	4.9	-2.4	1.7	2.0	7.3	-22.6	-25.2	-24.3	0.6	2.6	19.2	16.5	18.3	0.7	2.7
einkorn	6	4.6	-1.4	0.5	2.2	6.0	-20.2	-24.4	-23.0	1.6	4.2	18.3	13.9	16.9	1.6	4.4
pea	7	2.4	1.6	2.0	0.3	0.8	-23.5	-26.2	-25.0	0.9	2.7	20.2	17.4	19.0	1.0	2.8
grass pea	1	-2.5	-2.5	-	-	-	-25.1	-25.1	-	-	-	19.1	19.1	-	-	-
lentil	1	-	-	-	-	-	-25.3	-25.3	-	-	-	19.3	19.3	-	-	-

Table 6.3: Summary statistics of all plant δ^{13}C and δ^{15}N values from Kouphovouno. The dataset includes samples measured in the present study (n = 19) and samples measured previously by the author (n = 28, Vaiglova et al. 2014*a*).

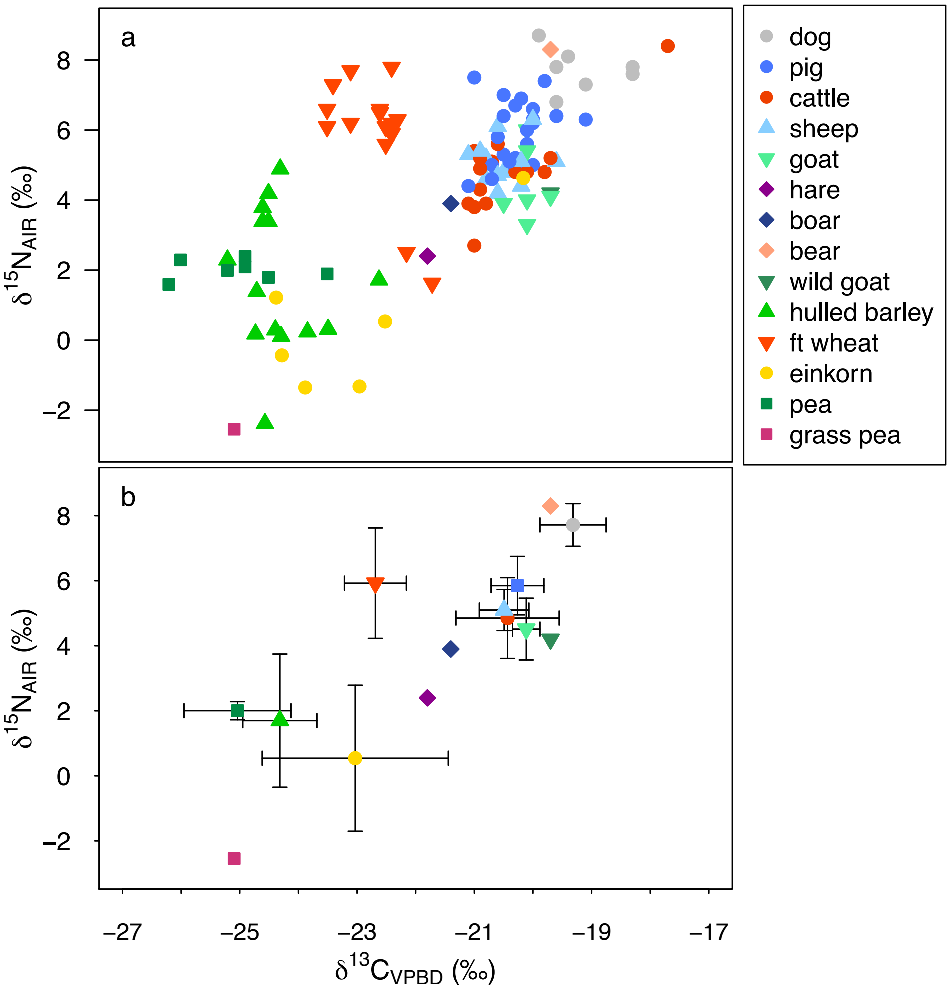


Figure 6.5: Bi-variate scatter plots of all plant and animal collagen δ^{15}N and δ^{13}C values from Kouphovouno. a) individual measurements; b) means and standard deviations of species where n > 2. The dataset includes samples measured in the present study (n = 19) and samples measured previously by the author (n = 28, Vaiglova et al. 2014*a*).

isotope values than seen previously at this site. The δ^{15}N values of free-threshing wheat (n = 17) range from 1.6 to 7.8‰, while barley (n = 15) ranges between –2.4 and 4.9‰. Einkorn (n = 6), which was not measured previously, exhibits a range of –1.4 to 4.6‰. With values going below 0‰, the new dataset provides some of the lowest δ^{15}N values measured from archaeological plants at any site to date. It remains to be explained why cereal δ^{15}N values would be negative.

One of the einkorn samples, the only sample of this species dating to the Middle Neolithic (KFO35 from Area C), is a possible outlier, as it differs significantly from any of the other plant measurements and lies in the middle of the sheep/goat cluster (see Fig. 6.5). Excluding this sample from the einkorn group, the variability is reduced to –1.4 to 1.2‰ in δ^{15}N and –24.4 to –22.5‰ in δ^{13}C. Even with the outlier removed, the variability in einkorn δ^{13}C values is still greater for this species compared to the other two cereal crops (SD = 0.5‰ for free-threshing wheat, 0.6‰ for hulled barley, 0.8‰ for einkorn).

Differences between the mean δ^{15}N values of the species where $n > 1$ were tested statistically using multi-variate analysis of variance. The einkorn sample identified as an outlier (KFO35) was not included in the analysis. The data are normally distributed (Shapiro–Wilk test, W = 0.95, p = 0.060), but not homogenous (Levene's test, $F(3, 39) = 3.02, p = 0.041$), so the non-parametric Kruskall–Wallis test was used. The results show that there are significant differences between the mean δ^{15}N values of the four groups (H(3) = 27.21, $p < 0.01$) and a post-hoc Bonferroni test reveals that the differences are between the free-threshing wheat and each of the other three species (hulled barley, einkorn, pea, $p < 0.01$ in all cases), but not between any pair of the other species (hulled barley and einkorn, p = 0.14; einkorn and pea, p = 0.13; hulled barley and pea, p = 1.0). The mean δ^{15}N values of the four species are: 5.8 ± 1.7‰ for free-threshing wheat, 1.7 ± 2.0‰ for

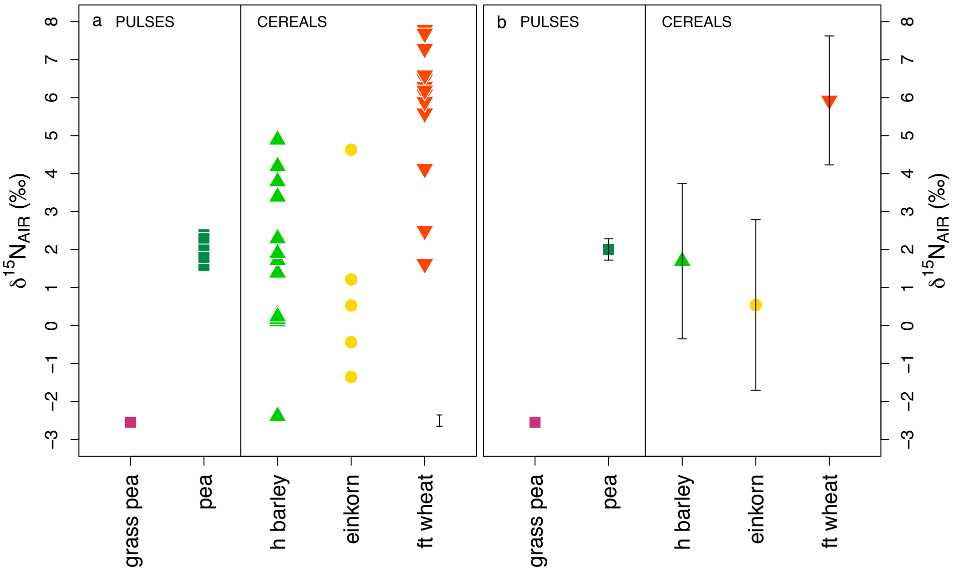


Figure 6.6: Uni-variate scatter plots of plant δ^{15}N values from Kouphovouno. a) all measured samples, and b) means and standard deviations of each species. The dataset includes samples measured in the present study (n = 19) and samples measured previously by the author (n = 28, Vaiglova et al. 2014*a*). Measurement error is shown in the bottom-right of panel **a**.

hulled barley, 0.5 ± 2.2‰ for einkorn, and 2.0 ± 0.3‰ (see Fig. 6.6).

In the case study of Çatalhöyük (Chapter 5), the plant δ^{15}N measurements are be evaluated with reference to the 'unmanaged plant zone' – an estimated region where the grain and non-grain components of plants consumed my wild herbivores would lie. In this study, only two wild herbivores were available for analysis (hare and wild goat) and the identification of the goat as wild has been put into question. As the estimation of the 'unmanaged plant zone' at Kouphovouno would be inaccurate, interpretations in this case study will be made by solely by considering the relative differences between the measured species.

The ranges in Δ^{13}C values of the cereal grain also increased with the additional measurements: 15.6 to 17.4‰ in free-threshing wheat, 16.5 to 19.2‰ in hulled barley, and 13.9 to 18.3‰ in einkorn; the range of peas remained at 17.4 to 20.2 (see Fig. 6.7). The data for the four species are normally distributed (Shapiro–Wilk test, W = 0.95, p = 0.088) and homogenous (Levene's test, $\mathrm{F}(3, 37) = 1.05, \mathrm{p} = 0.38$) so an ANOVA test was used to assess statistically significant differences between the mean Δ^{13}C values of the four groups. The results indicate that there are significant differences ($\mathrm{F}(3, 37) = 24.3, \mathrm{p} < 0.01$) and a post-hoc Bonferroni test reveals that the differences are between free-threshing wheat and hulled barley and between free-threshing wheat and pea ($\mathrm{p} < 0.01$ in both cases), but not between any of the other groups of species.

Only one additional sample of a pulse crop was available for analysis. This sample of grass pea provided a significantly lower δ^{15}N value (–2.5‰) compared to the seven samples of peas measured previously. Its Δ^{13}C value (19.1‰) lay in the middle of the pea cluster.

In the previous study, the watering bands described by Wallace et al. (2013) were plotted with the data from Kouphovouno and used to draw inferences about the crops' watering status (Vaiglova et al. 2014*a*). This frame-

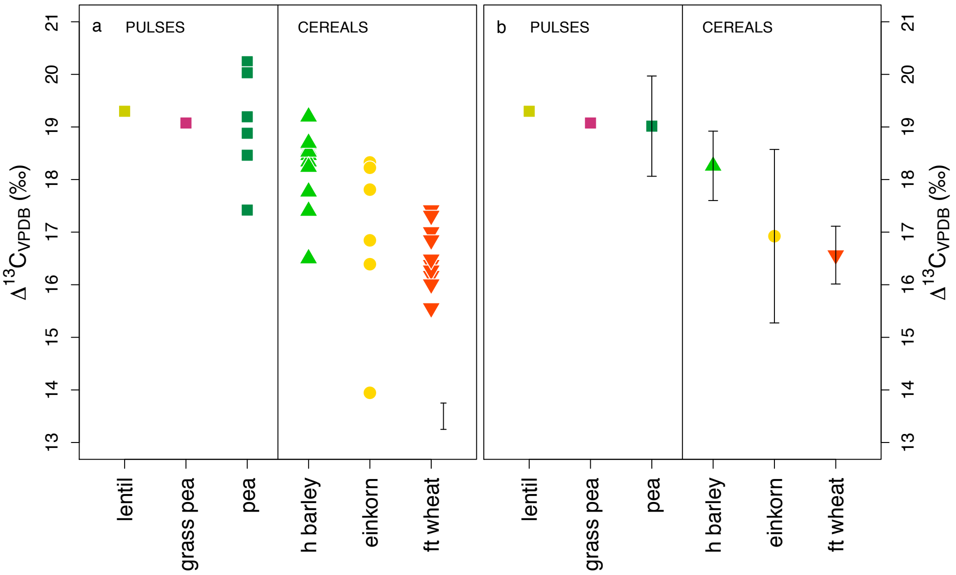


Figure 6.7: Uni-variate scatter plots of plant Δ^{13}C values from Kouphovouno. a) all measured samples, and b) means and standard deviations of each species. The dataset includes samples measured in the present study (n = 19) and samples measured previously by the author (n = 28, Vaiglova et al. 2014*a*). Measurement error is shown in the bottom-right of panel **a**.

work is no longer used in the current study (see Chapter 4.2). The data show that both the means and standard deviations of the free-threshing wheat and einkorn groups differ, which provides further support for the interpretation that these two crops were grown in different soils (as apparent from the δ^{15}N values). The absolute Δ^{13}C values of the barley are higher compared to the other two cereals, and this may be the result of species-specific physiological differences rather than a difference in moisture availability (Araus et al., 1997). Both the lentil and the grass pea fall into the range of pea Δ^{13}C values, suggesting that their water status was similar (but caution should be exercised when interpreting such small sample sizes).

6.3.1.2 Chronology

Fig. 6.8 shows all plant and animal δ^{13}C and δ^{15}N values divided according to their chronological phases. Only three samples of free-threshing wheat were available from the Late Neolithic (from Areas B and G), and all three samples cluster tightly together in the high range of δ^{15}N values. Free-threshing wheat from the Middle Neolithic is more numerous (n = 14) and covers the whole range of δ^{15}N values measured for this species. Most of the samples have δ^{15}N values above 5‰, but three lie below with values of 1.6‰ (KFO54, Area C), 2.5‰ (KFO39, Area B) and 4.1‰ (KFO50, Area C, did not yield a reliable δ^{13}C measurement). A second free-threshing wheat sample that only provided one measurement (KFO52) exhibits a δ^{13}C value in the middle of the MN cluster (–23.0‰).

Hulled barley is represented by a similar number of samples in the two periods (MN, n = 8; LN, n = 7). It exhibits a narrower range of δ^{13}C values in the Middle Neolithic (MN: –24.4 ± 0.3‰; LN: –24.2 ± 0.9‰). Its δ^{15}N values are overall higher but similarly variable during the Middle Neolithic compared to the Late Neolithic (MN: 2.3 ± 2.0‰; LN: 1.0 ± 1.8‰). A student's t–test between the two groups shows that there are no statistically

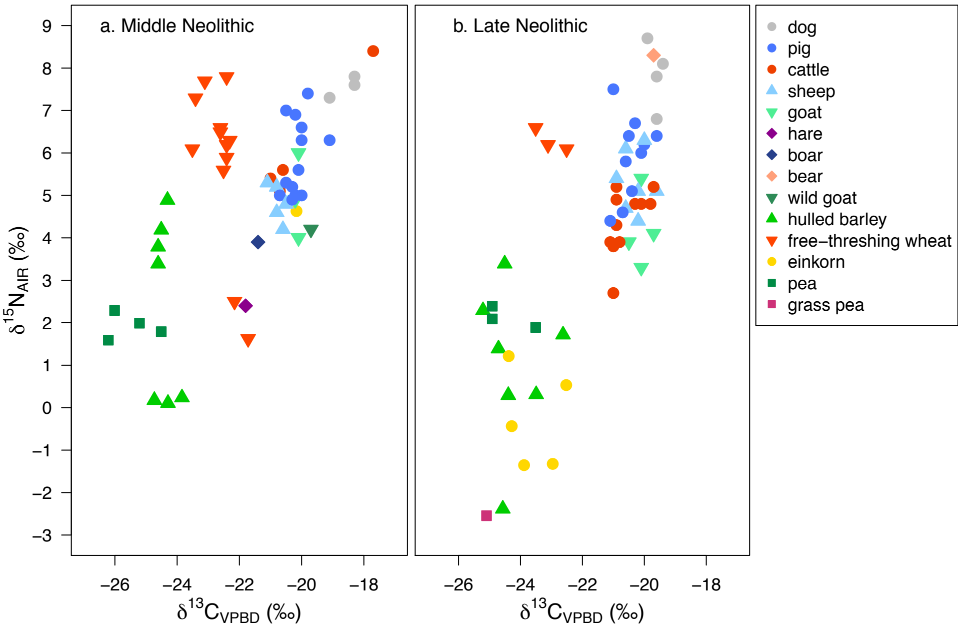


Figure 6.8: Bi-variate scatter plots of all plant and bone collagen δ^{15}N and δ^{13}C values from Middle Neolithic (a) and Late Neolithic (b) levels at Kouphovouno

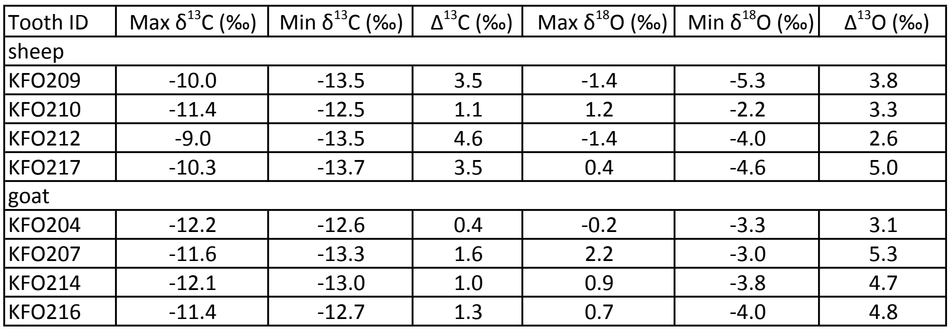
significant differences between the means of the MN barley and the LN barley (t = –1.35, p = 0.2). One additional sample from the MN that did not provide a δ^{13}C measurement (KFO34) yielded a δ^{15}N value of 1.9‰. As mentioned above, only one sample of einkorn was available from the Middle Neolithic, and it may be an outlier.

6.3.2 Stage 2: Tooth enamel carbonate measurements

6.3.2.1 Seasonal mobility and diets

Fig. 6.9 shows the δ^{13}C and δ^{18}O measurements of sequentially sampled tooth enamel from sheep and goat teeth from the two phases of occupation of Kouphovouno. Table 6.4 presents the summary statistics and Appendix G lists all the individual measurements. δ^{13}C values vary from –13.7 to –9.0‰ in sheep and –13.3 to –11.4‰ in goats, with mean intra-tooth variation of

3.2‰ (from 1.1 to 4.6 ‰) in sheep and 1.1‰ (from 0.4 to 1.6‰) in goats. δ^{18}O values vary from –5.3 to 1.2‰ in sheep and –4.0 to 2.2‰ in goats, with mean intra-tooth variation of 3.7‰ (from 2.6 to 5.0‰) in sheep and 4.5‰ (from 3.1 to 5.3‰) in goats.



Tooth ID	Max δ^{13}C (‰)	Min δ^{13}C (‰)	Δ^{13}C (‰)	Max δ^{18}O (‰)	Min δ^{18}O (‰)	Δ^{13}O (‰)
sheep						
KFO209	-10.0	-13.5	3.5	-1.4	-5.3	3.8
KFO210	-11.4	-12.5	1.1	1.2	-2.2	3.3
KFO212	-9.0	-13.5	4.6	-1.4	-4.0	2.6
KFO217	-10.3	-13.7	3.5	0.4	-4.6	5.0
goat						
KFO204	-12.2	-12.6	0.4	-0.2	-3.3	3.1
KFO207	-11.6	-13.3	1.6	2.2	-3.0	5.3
KFO214	-12.1	-13.0	1.0	0.9	-3.8	4.7
KFO216	-11.4	-12.7	1.3	0.7	-4.0	4.8

Table 6.4: Summary statistics of the tooth enamel carbonate $\delta^{13}C_{VPDB}$ and $\delta^{18}O_{VPDB}$ measurements of sheep and goat samples Kouphovouno. Δ values indicate the range of values between the maxima and the minima.

None of the animal individuals exhibit notable consumption of C_4 vegetation during the first year of their life. One sheep (KFO212 from the LN) records the highest δ^{13}C values of all the individuals, but these values are still below the –8‰ cutoff for C_4 input in mixed diets, (cf Cerling et al., 1997). This sheep also has the flattest δ^{18}O signal of all the eight animals studied (amplitude of 2.6‰), which may be the result of movement across altitudes. Its δ^{18}O values are not higher or lower in absolute terms compared to those of the other animals. This Late Neolithic sheep may have spent part of the year grazing at a different elevation, where it had access to more ^{13}C–enriched vegetation.

Fig. 6.10 shows the intra-tooth δ^{13}C sequences of the ovicaprids grouped according to species. The patterns suggest that the feeding habits of the two animals differed. While most of the sheep (three out of four) exhibit predictable annual fluctuations in their δ^{13}C values (with higher values in the summer and lower values in the winter), the sequences of the goats (and one sheep, KFO210 from the LN) are nearly flat. This may be because these five

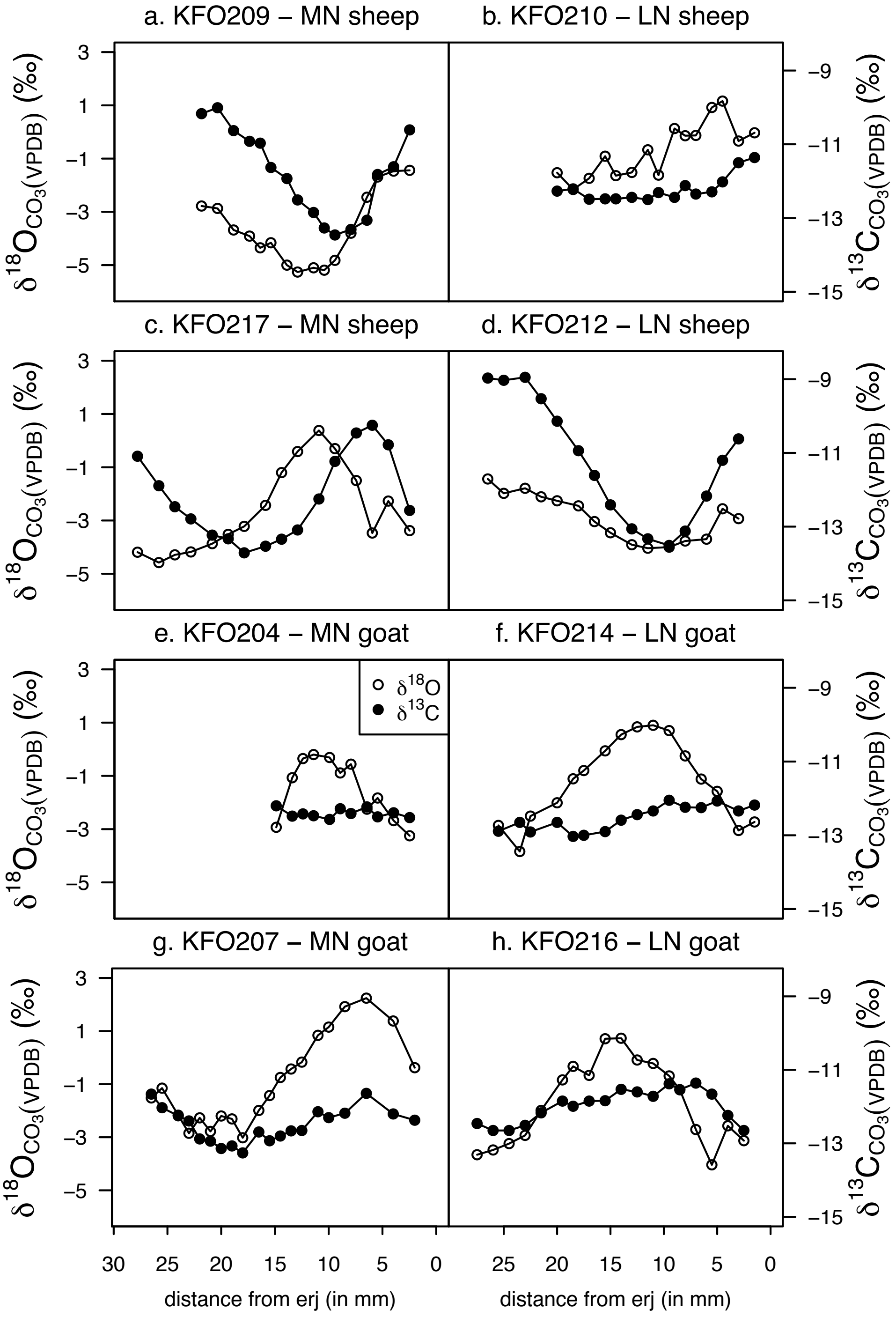


Figure 6.9: Bi-variate line plots of sequential tooth enamel carbonate $\delta^{18}O$ and $\delta^{13}C$ values of sheep (a-d) and goats (e-h) from Middle (MN) and Late Neolithic (LN) levels at Kouphovouno. Positions of sub-samples are recorded as distances (in mm) from the enamel root junction (erj)

individuals consumed plants grown in one season over the entire year, possibly because they were being foddered. This explanation is based on the fact that some (but not all) modern fodder-fed sheep from Mongolia have similarly flat δ^{13}C signals (Makarewicz, 2014). The ovicaprids in Kouphovouno may have been foddered either on collected woody vegetation, cultivated barley and/or einkorn grain and/or chaff because the δ^{15}N values of grains of these two species are located a trophic level below the δ^{15}N values of the ovicaprid bone collagen values (assuming a trophic offset of 4.0‰; see Fig. 6.5).

The δ^{18}O curves of the goats look more consistent (sinusoidal with similar amplitudes) compared to the curves of the sheep (see Fig. 6.11). This may be because in addition to subsisting on fodder for at least part of the year, the goats may have obtained the bulk of their body water by drinking rather than through plant consumption. Their consistent δ^{18}O values may thus reflect the composition of local precipitation. Fig. 6.12 shows the estimated mean monthly δ^{18}O values of precipitation for Kouphovouno and three other locations situated at higher altitudes in the Taygetos Mountains for comparison[1] (oxygen data obtained from the Online Isotope Precipitation Calculator, `http://wateriso.utah.edu/waterisotopes/pages/data_access/oipc.html`). The data from Kouphovouno have an annual amplitude of variation of 3.1‰, which is slightly lower compared to the intra-tooth variation recorded in the goat teeth.

It is not the case that the individuals that have dampened δ^{13}C sequences exhibit the weakest correlation between δ^{13}C and δ^{18}O values. KFO212, mentioned above, is the only animal to exhibit strong correlation between its δ^{13}C and δ^{18}O values ($r^2 = 0.95, p < 0.01$). Two goats (KFO207) and (KFO216) show weak correlation ($r^2 = 0.38$ and 0.35, respectively; $p < 0.01$

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[1] Location 1: 37° 2’ 59.9” N, 22° 23’ 12.1” E, elevation: 591masl; Location 2: 37° 2’ 42.14” N, 22° 20’ 25.3” E, elevation: 1,335masl; Location 3: 36° 57’ 47.0” N, 22° 21’ 16.0” E, elevation: 2,092masl

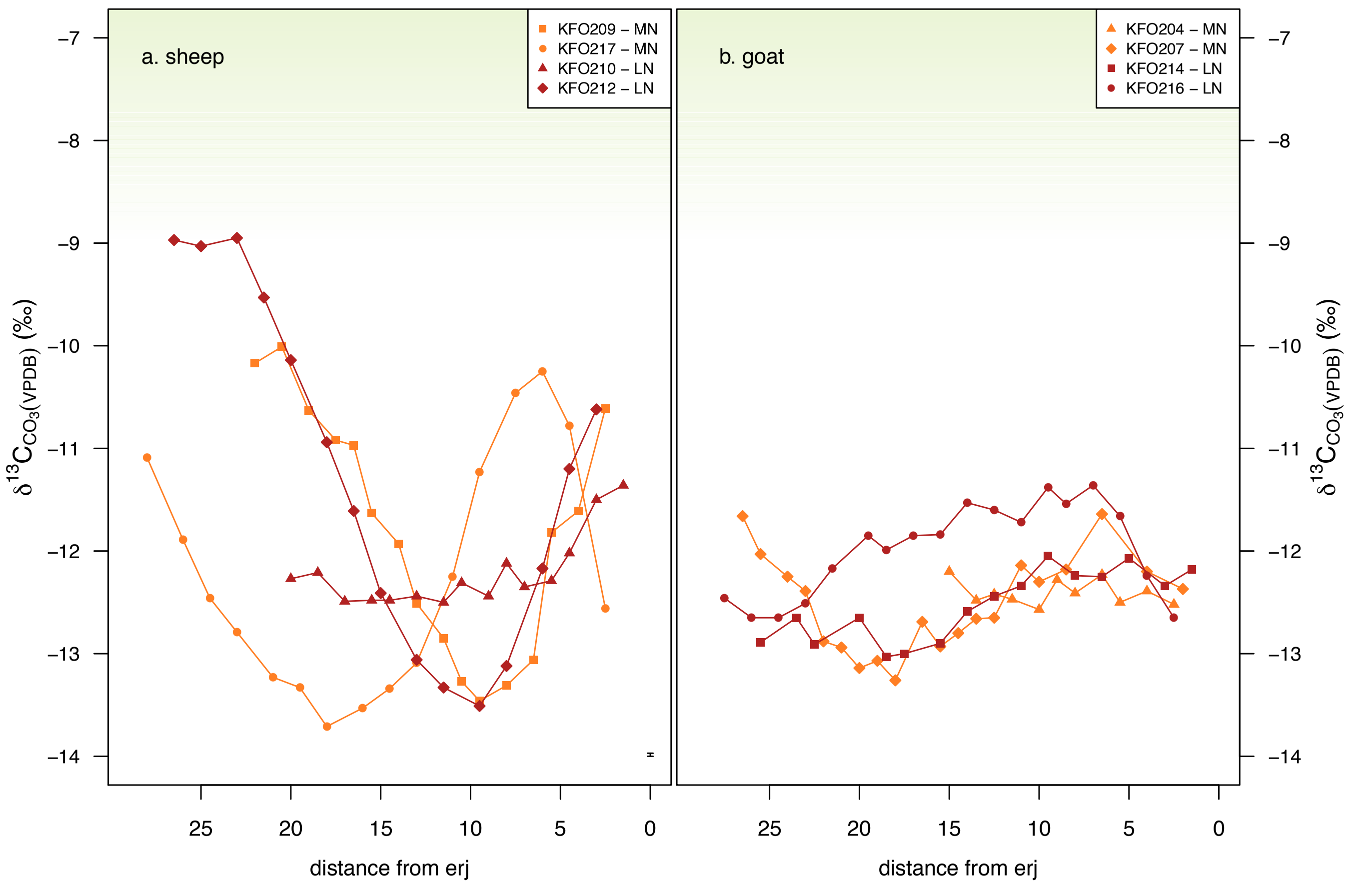


Figure 6.10: Bi-variate scatter plots of sequential tooth enamel carbonate δ^{13}C values of sheep (a) and goats (b) from Middle (MN) and Late Neolithic (LN) levels at Kouphovouno. Green shading on the y–axis indicates theoretical values of consumers with increasing levels of C_4 input (the lower endpoint is –8‰, cf Cerling et al., 1997). Measurement error is shown in the bottom-right of panel **a**.

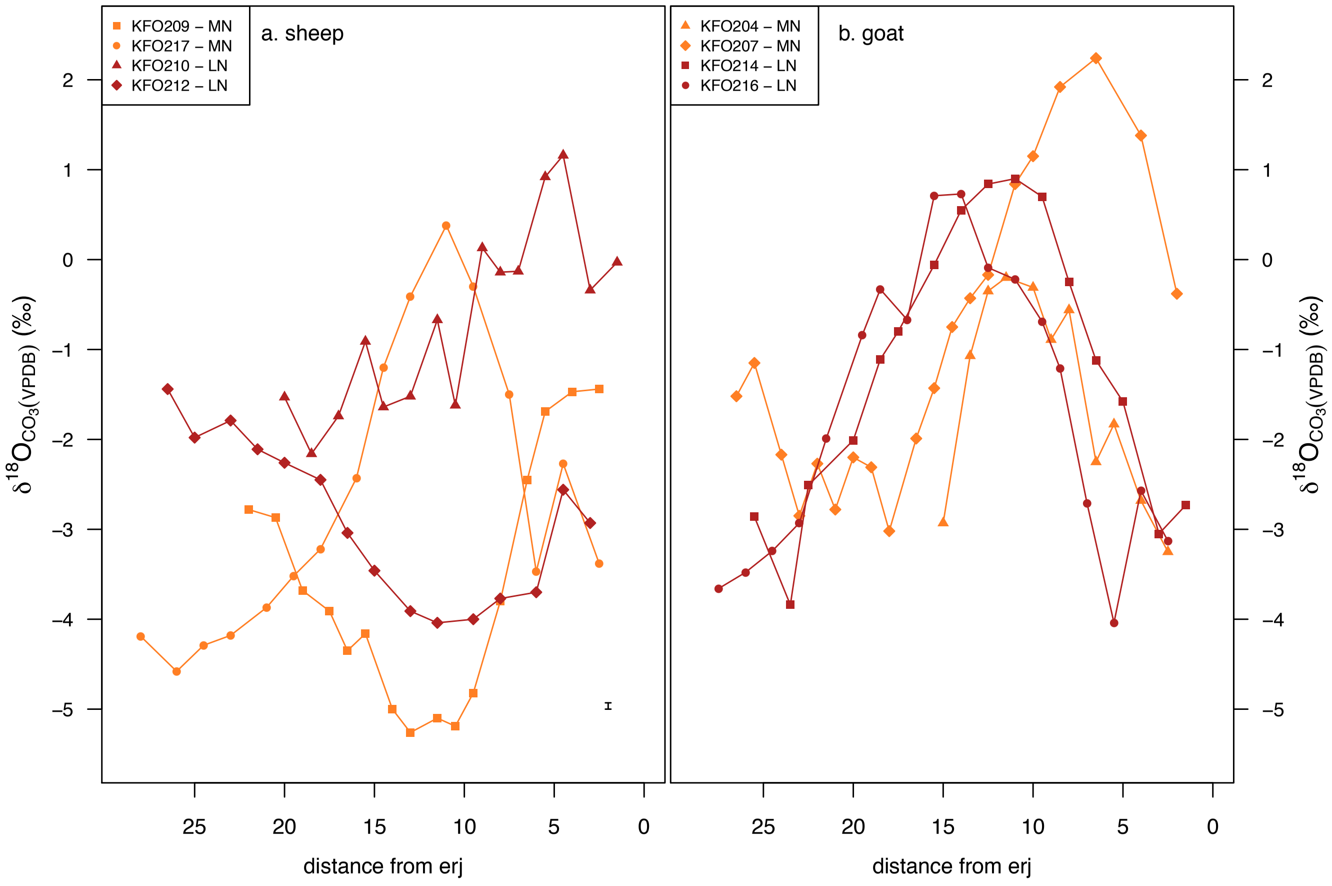


Figure 6.11: Bi-variate scatter plots of sequential tooth enamel carbonate δ^{18}O measurements of sheep (a) and goats (b) from Middle (MN) and Late Neolithic (LN) levels at Kouphovouno. Measurement error is shown in the bottom-right of panel **a**.

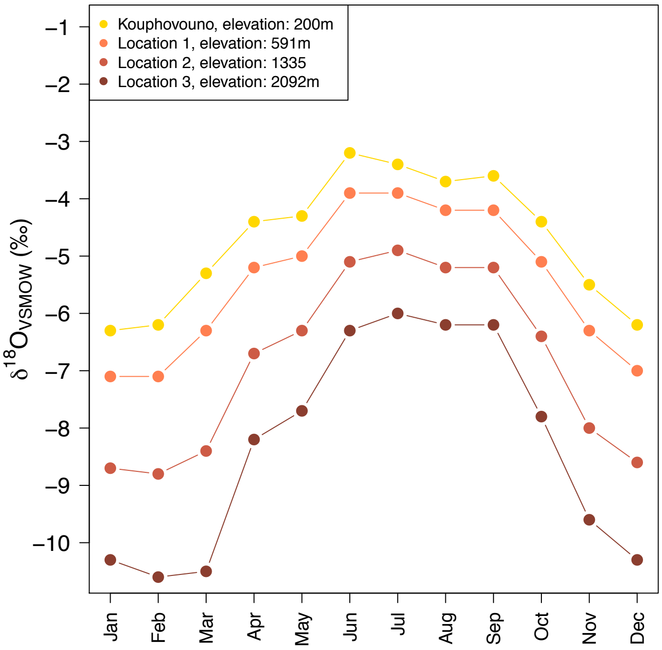


Figure 6.12: Mean monthly δ^{18}O values of local precipitation estimated for Kouphovouno and three other locations situated at higher altitudes in the Peloponnesian peninsula (see text for GSP coordinates). Data obtained from the Online Isotope Precipitation Calculator (`http://wateriso.utah.edu/waterisotopes/pages/data_access/oipc.html`).

in both cases) and all the other animals show almost no correlation at all (KFO209, $r^2 = 0.20, p = 0.08$; KFO210, $r^2 = 0.12, p = 0.2$; KFO204, $r^2 = –0.11, p = 0.31$; KFO214, $r^2 = 0.04, p = 0.48$; KFO217, $r^2 = 0.00, p = 0.84$) (see Fig. 6.13).

6.3.2.2 Seasonality of birth

The distances at which the maximum $\delta^{18}O$ values occur within each tooth were normalized to the period representing the annual cycle using a line of best-fit (least squares), following the method established by Balasse et al. (2012*a*) (see Chapter 4.7). One individual (KFO210) could not be modelled because the measured $\delta^{18}O$ values did not show a clear sinusoidal pattern. The parameters calculated by the model are shown in Table 6.5. The lines of best fit are shown in Appendix C. Fig. 6.14 shows the normalized delay, x_0/X, of each group of MN and LN sheep and goats. The y–axis is divided into 12 segments, each corresponding to one month of the year. x_0/X values that lie in adjacent segments can be attributed to births occuring within one month of each other, while x_0/X values that lie farther away from each other on the y–axis are likely born several months apart; the estimated gap corresponding to the number of segments that separates them.

The x_0/X values of MN sheep (0.04 and 0.40) suggest that these two animals were born within four months of each other. The one sheep from the LN was born in a different season to those from the Middle Neolithic (x_0/X value of 0.87). The x_0/X values of MN goats (0.27 and 0.69) suggests that these goats were born within five months of each other, while those of LN goats (0.52 and 0.61) suggests that they were born within a month of each other. Only in the case of the LN goats can it be suggested that the animals' birth seasonality was not manipulated.

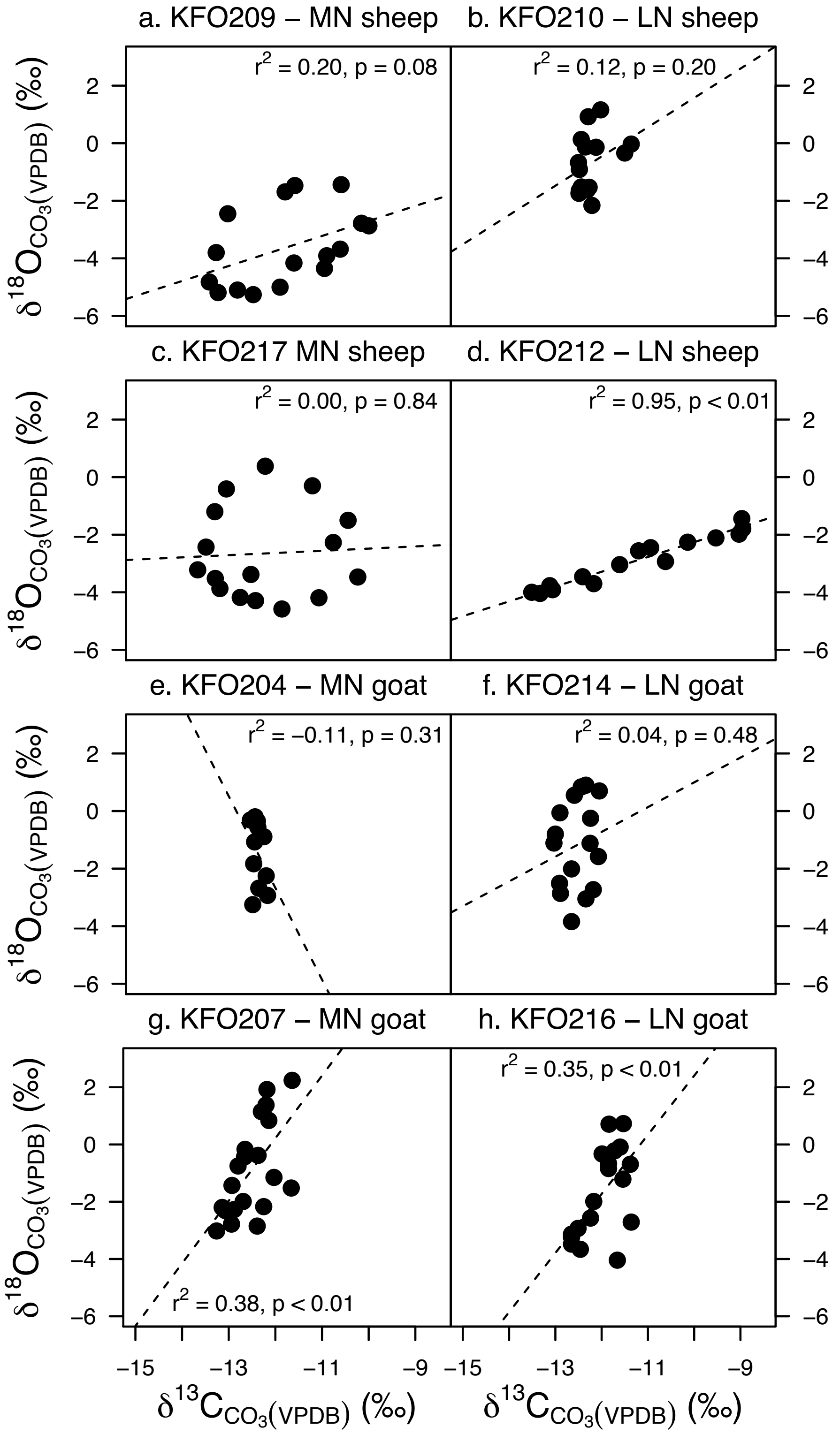


Figure 6.13: Bi-variate scatter plots of tooth enamel carbonate δ^{13}C and δ^{18}O values of sheep (a-d) and goats (e-h) from Middle (MN) and Late Neolithic (LN) levels at Kouphovouno. The dots are joined based on their position on the tooth axis.

ID	species	phase	X (mm)	A (‰)	x0 (mm)	M (‰)	x0/X	r (Pearson)
KFO209	sheep	MN	24.9	2.0	1.0	-3.2	0.0	0.95
KFO212	sheep	LN	28.5	1.2	24.8	-2.8	0.9	0.97
KFO217	sheep	MN	26.8	2.1	10.8	-2.5	0.4	0.97
KFO204	goat	MN	14.9	1.5	10.3	-1.7	0.7	0.93
KFO207	goat	MN	26.7	2.3	7.2	-0.5	0.3	0.97
KFO214	goat	LN	23.3	1.9	12.2	-1.0	0.5	0.99
KFO216	goat	LN	23.8	2.0	14.5	-1.4	0.6	0.98

Table 6.5: Results of the calculation of a line of best fit (using the method of least squares) for variation in period (X), amplitude (A), position of the $\delta^{18}O_{max}$ value (x_0), and mean $\delta^{18}O$ (M) of tooth enamel carbonate sequences from Kouphovouno. Pearson's r expressess the correlation between the measured and the modelled values. x_0/X represents the delay of $\delta^{18}O_{max}$ values with respect to the period, used in this study to assess the timing of the animals' births. The model (established by Balasse et al. (2012*b*) uses the equation $\delta^{18}O_m = a\cos(2\pi(x - x_0)/(x + bx)) + m$.

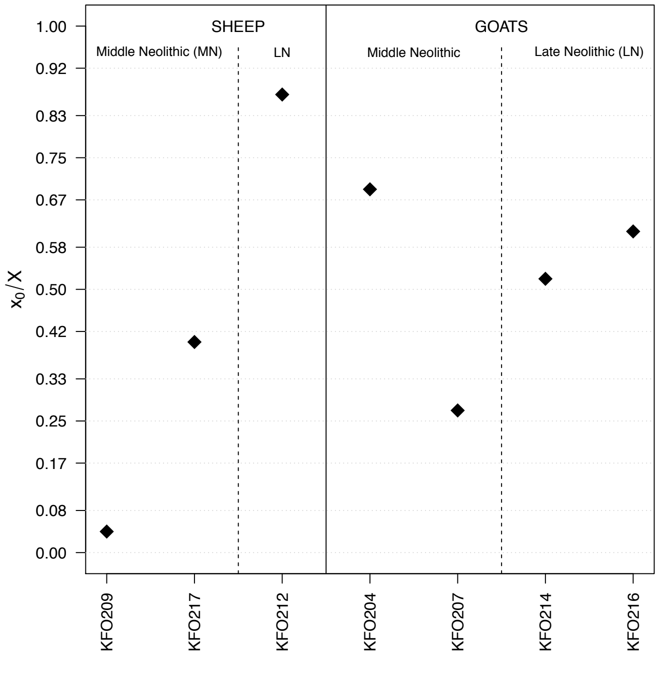


Figure 6.14: Uni-variate scatter plot of x_0/X values (distance at which $\delta^{18}O_{max}$ values occur in a tooth, x_0, with respect to the period recording the annual cycle, X) of sheep and goat teeth samples from Kouphovouno analyzed in this study. The y–axis is divided into 12 units, each corresponding to one month of the year.

6.4 Discussion

Previous stable isotope work carried out on the plant and animal assemblages from Kouphovouno demonstrated that this site provides a unique opportunity to observe variability in agricultural management strategies in a Neolithic context. The results raised more questions about the dynamics of a small-scale intensive system, and these questions formed the basis of the renewed stable isotope work carried out in this project. The following discussion will expand our understanding of the range of agricultural regimes employed by the farmers at Kouphovouno through an interpretation of a larger dataset of free-threshing wheat and hulled barley grains, together with data for a crop that was not measured previously (einkorn). The possible contribution of the crops to the diets of the domestic animals will be considered at the end of the first part of the discussion.

The second part of the discussion will integrate the measurements of bone collagen δ^{13}C and δ^{15}N values of sheep and goats with the results of their sequential tooth enamel carbonate δ^{13}C and δ^{18}O values with the view to gaining a more nuanced understanding of their diets on a seasonal basis and address the possibility that these animals partook in transhumant mobility. The results will also be used to assess whether the farmers controlled the timing of the birth of the ovicaprids. In conjunction with the analysis of the mortality profiles of these animals, this new insight will inform our understanding of the animals' roles in the subsistence economy and how these roles may have changed between the Middle and the Late Neolithic.

6.4.1 Crop management in Neolithic Kouphovouno

Even with only two cereal species available for analysis, the previous stable isotope study showed that Neolithic farmers not only distinguished between different species of cereals, but that they systematically cultivated them under varying cultivation regimes. Free-threshing wheat was consistently grown in more ^{15}N–enriched soils, likely under an intensive system of management, exclusively for human consumption. Peas were also likely grown under high intensity, both in terms of water availability and soil enrichment (Vaiglova et al. 2014*a*).

Einkorn is a glume wheat that played an important role in the Neolithic packages of northern and southern Greece (Sarpaki, 1995; Valamoti and Kotsakis, 2007). In Kouphovouno, it was found in contexts generally dating to the Late Neolithic (Diffey, 2014). The results in this study show that δ^{15}N values of einkorn are systematically lower compared to the values of free-threshing wheat and mostly lower compared to those of hulled barley. This suggests that on the whole, einkorn was cultivated in more marginal plots of land, without the investment of significant amounts of resources and labor. Perhaps it was intended as a fodder crop. Alternatively, it may have been cultivated to provide reserves – for both animals and humans – in case of shortages of the other crops.

The expanded dataset also brings more variability to both the free-threshing wheat and the hulled barley. Three samples of free-threshing wheat exhibit lower δ^{15}N values compared to the rest of the group, suggesting that this crop was not always grown in the most productive soils. In the case of hulled barley, the new samples extend the range of both δ^{15}N and δ^{13}C values, but none of the samples reach δ^{15}N values as high as the bulk of the free-threshing wheat.

Even though wheat is more demanding in terms of its soil growing requirements than barley (barley can withstand drier conditions, poorer soils and a degree of salinity, Zohary et al. 2012), it is not the case that farmers consistently placed wheat in more ^{15}N–enriched soils. At the Neolithic site of Halai in central Greece, for example, barley has higher δ^{15}N values compared to free-threshing wheat (Vaiglova et al. in prep). This suggests that the farmers at Kouphovouno were not simply catering to the crops' growing requirements by consistently sowing it in more fertile soils. Together with the fact that free-threshing what does not appear in Neolithic assemblages on the Greek mainland (Valamoti and Jones, 2003) and the fact that at Kouphovouno, it mostly occurrs in grain-rich deposits (Diffey, 2014), it would seem that the farmers at Kouphovouno had distinct reasons to cultivate it in the first place and may have placed higher value on this crop than they did on barley.

Occasionally, the farmers sowed free-threshing wheat in the same soils as the barley – either as a risk-buffering strategy or due to the lack of availability of the most desirable soils. Barley was the most ubiquitous crop in the assemblage (Diffey, 2014) and it seems that the farmers were concerned about producing large amounts of the crop, (likely by growing it under more extensive treatments) but did not make effort to increase its yield per unit area.

The sample sizes of the plant stable isotope data are still quite small to investigate potential chronological shifts in crop management. Free-threshing wheat is only represented by three samples in the Late Neolithic and einkorn is only represented by one sample in the Middle Neolithic; and the latter sample may be an outlier. Even though barley presents more samples for comparison and even though the mean δ^{15}N values of barley from the two phases are different, there is no statistical significance to this difference. It is noteworthy that the crop δ^{15}N values below 0‰ are a Late Neolithic phenomenon, and it may mean that farmers had to seek new fields that were more distant and/or less naturally enriched in ^{15}N to cultivate their crops. The δ^{13}C values of the hulled barley are more variable in the Late Neolithic and this may simply be a reflection of the fluctuation in mean annual rainfall during this phase of occupation.

The offsets between the mean bone collagen δ^{15}N values of the domestic animals (cattle: 4.9 ± 1.2‰, sheep: 5.1 ± 0.6‰, goat: 4.5 ± 1.0‰, pig: $5.9 \pm$

0.9‰) and the values of barley grain (1.7±2.0‰), einkorn grain (0.7±2.1‰) and peas (2.0 ± 0.3‰) are within the range of trophic enrichment. This suggests that the animals may have consumed any of these plant products on a regular basis. The bulk of free-threshing wheat grain, however, exhibits values similar to those of the animals' bone collagen (5.8 ± 1.7‰) and the lack of trophic offset indicates that this crop was still likely to be consumed only by humans.

6.4.2 Seasonal management of sheep and goats

The age profiles of the ovicaprids at Kouphovouno are generally older in the Middle Neolithic and younger in the Late Neolithic. Cantuel et al. (2008) argue that this may mean that the exploitation strategy changed from secondary products to primary procurement of meat. Alternatively, the authors argue that the farmers may have practiced a mixed strategy throughout the occupation of the site.

Previous stable isotope data indicated subtle differences in δ^{13}C and δ^{15}N values of the Middle and Late Neolithic sheep and goats. Vaiglova et al. (2014*a*) argue that during the Middle Neolithic, the δ^{13}C values of goats and sheep differed while their δ^{15}N values were the same, and in the Late Neolithic, the δ^{13}C values of these animals were indistinguishable, while their δ^{15}N values differed. Although the Middle Neolithic trend is statistically significant (keeping in mind the small sample sizes), in this study, it is no longer considered worthy of discussion, since the mean δ^{13}C values of the two animals only differed by 0.3‰. The Late Neolithic pattern of varying δ^{15}N values, however, is still worth mentioning since the mean values differ by 1.1‰.

What the bone collagen data thus show is that during the Middle Neolithic, the two ovicaprid species consumed isotopically similar diets, while in the Late Neolithic, they subsisted on vegetation variably enriched in ^{15}N.

This may have been the result of their grazing on different soils or consuming different plant types/plant parts. Vaiglova et al. (2014*a*) suggested that in the Late Neolithic, the animals may have been kept in smaller herds closer to the arable landscape and their differences in δ^{15}N values possibly reflect their variable browsing/grazing adaptations. In this study, it is reiterated that this is only one possibility, and that other explanations (like grazing in distinct parts of the landscape) are equally likely.

While the precise mechanism responsible for the differences in Late Neolithic δ^{15}N values cannot be determined, it is noteworthy that an isotopic shift occurred and the investigation of seasonal dietary patterns of the ovicaprids at Kouphovouno provides an opportunity to investigate this further.

The tooth enamel carbonate data show that there were clear differences in first-year diets of the sheep and the goats during the Middle and the Late Neolithic. The sheep from the Middle Neolithic exhibit sinusoidal δ^{13}C and δ^{18}O curves of similar amplitudes. Such intra-annual fluctuations are likely a result of seasonal climatic changes in moisture and temperature and so these animals likely subsisted on fresh vegetation growing in the Sparta Basin throughout the entire annual cycle. The varying mis-match between their δ^{13}C and δ^{18}O maxima may be a result of variable proportions of vegetation from different grazing pastures.

The goats, on the other hand, have both dampened δ^{13}C signals as well as distinctly variable δ^{18}O curves. These animals may have been foddered on vegetation that was collected from one location over a restricted portion of the year, such as crop products or by-products. Being obligate drinkers, the goats may have obtained most of their water through direct consumption rather than from the vegetation, and this may explain the annual fluctuation in their δ^{18}O values. Alternatively, unlike the sheep – which may have subsisted on a combination of C_3 and C_4 plants – the goats may have eaten a diet composed mostly of C_3 browse, so do not show such pronounced seasonal variation in their $\delta^{13}C$ values.

During the Late Neolithic, only part of the picture changes. In this phase, the sheep no longer exhibit consistent sinusoidal curves. One individual (KFO210) has a dampened $\delta^{13}C$ signal (possibly because it was being seasonally foddered), while the other one (KFO212) has the widest range of $\delta^{13}C$ values of all the ovicaprids measured in this study. In addition, its $\delta^{18}O$ signal is slightly dampened and this may be the result of trans-altitudinal movement to an area that provided more ^{13}C–enriched vegetation. This area may not necessarily have been higher up in the mountains, but closer to the coast. The dietary patterns of the goats did not change and these animals likely continued to be foddered during the latter phase of occupation.

Overall, the results show that sheep management at Kouphovouno was more variable. Initially, sheep may have grazed in the local environment all year round, while goats may have been foddered. In the later phase, sheep were engaged in both foddering as well as transhumance, while the goats were still being foddered. Balasse and Ambrose (2005) argue that because it is so costly and labor-intensive, foddering is “unlikely to occur when not necessitated nor facilitated” (pg. 700). So why then – when presumably ample amounts of grazing pasture were available for the animals in the surrounding alluvial plain – were the goats systematically foddered?

It may be that the availability of local grazing pasture was actually more restricted than the environmental model admits and priority was given to the sheep. It may have been even more restricted during the Late Neolithic than it was during the Middle Neolithic, which prompted the farmers to look for new ways of herding their sheep. However, the fact that goats would be more constrained than sheep is unexpected, as goats are more adaptable to rocky topography and can graze in more marginal areas. More likely, the farmers had a reason to fodder the goats and may have fed them with einkorn and hulled barley to fatten them. If the foddering implies that the animals were being fattened, a higher incidence of foddering in the Late Neolithic (both goats and one of the sheep) would be consistent with a change towards a meat-oriented exploitation strategy in the Late Neolithic.

6.4.3 Timing of ovicaprid births

The results of the modelling suggests that the sheep and goat individuals studied from Makriyalos were not all born in a single season of birth, which is what would happen if their reproductive cycles were manipulated by the farmers (Balasse et al. 2012*a*). The two sheep from the Middle Neolithic were born about 4 months apart. The two goats from the Middle Neolithic were born c.6 months apart and the two goats from the Late Neolithic were born c.2 months apart. There are no systematic differences in terms of the archaeological contexts from which the samples derived.

Although it is dangerous to generalize based on such small sample sizes, the possibility that sheep and goat births were extended during the Middle Neolithic cannot be ruled out. In the Late Neolithic, the values of the goats suggest that these two individuals may have been born in the same season and thus, there may have been a shift from milk to meat-oriented management. However, caution needs to be exercised in making conclusions based on such limited sample sizes.

Together, the three lines of evidence – the grazing patterns during their first year, the isotopic composition of long-term diets and the timing of the animals' births – point to different types of changes that occurred over the course of the Neolithic occupation of Kouphovouno. The sequential $\delta^{13}C$ and $\delta^{18}O$ variation implies that there was a change in the grazing behavior of the sheep between the two phases. The sequences of the goats imply that no temporal change in feeding patterns occurred, but their births may have become less controlled in the latter phase. The differences in $\delta^{15}N$ between sheep and goats during the LN suggest that unlike in the MN, the ovicaprids in the latter phase had access to vegetation from different niches of the Sparta basin (and possibly beyond) during the mature ages of their lives.

6.5 Conclusion

The picture of farming at Neolithic Kouphovouno is one of diversity. The farmers grew three main cereal crops – free-threshing wheat, hulled barley and einkorn – and each of these crops received distinct treatment during cultivation. Free-threshing wheat was grown in the most ^{15}N–enriched soils, likely because it was grown exclusively for human consumption and enjoyed a special role in the subsistence economy of the Neolithic society. The high ^{15}N–enrichment may have been achived by directed application of farmyard manure on fields within less than 1km diameter of the village (cf Halstead, 2014). Hulled barley was grown in soils fertilized to a smaller extent, while einkorn grew in soils that were not fertilized at all. Both hulled barley and einkorn may have been cultivated as a fodder crop to feed the animals. All the cereals received equal amounts of water during growth, likely because they were rainfed. Pulses reflect consistently higher amounts of water availability, but this may be because their Δ^{13}C values reflect a wetter portion of the year.

In terms of long-term dietary signatures recorded in their bone collagen values, sheep and goat had isotopically similar diets during the Middle Neolithic, but their δ^{15}N values differed by c.1.1‰ during the Late Neolithic (Vaiglova et al. 2014*a*). Sequential tooth enamel carbonate analysis carried out in this study sheds light on the seasonal feeding habits of these animals and shows that the first-year grazing patterns of these two animals differed throughout the two periods of occupation. While goats were foddered in both phases, sheep were grazed in the local landscape during the Middle Neolithic and foddered and taken to other altitudes during the Late Neolithic. This argues against a completely symbiotic small-scale intensive farming strategy which would keep all animals in the proximity of the site throughout the year. The different $\delta^{15}N$ values of the Late Neolithic ovicaprids may thus have been a result of consumption of plants grown in distinct locations with variably ^{15}N–enriched soils. The timing of births of the sheep and the goats was staggered during the Middle Neolithic, while both goats from the LN were born in the same season. This suggests that the farmers may have made an effort to extend the birthing seasonality of the ovicaprids in order to obtain milk throughout the entire year at least during the former phase. This case study demonstrates that plant and animal management systems used by Neolithic farmers were diverse, flexible, and species-specific and that stable isotope analysis of plant and animal remains can be used to detect some of this variability and chronological change.

Chapter 7

Makriyalos

This chapter presents the case study at Makriyalos. The first section provides a thorough review of the archaeological findings in conjunction with the results of a range of scientific analyses carried out on the plant, animal, human and ceramic assemblage dating to the two phases of occupation of the site during the Late Neolithic. The environmental setting is discussed with particular focus on the geology that characterizes the wider landscape. The materials and results are described in three stages: stage one involves the measurement of plant and animal $\delta^{13}C$ and $\delta^{15}N$ values from both phases of occupation, stage two involves the analysis of sequential tooth enamel carbonate $\delta^{13}C$ and $\delta^{18}O$ values of cattle and sheep from two different types of contexts dating to the first phase of occupation of the site and the third stage involves the measurement of Sr isotope values of cattle that were consumed in large numbers during feasting activities during the first chronological phase. The discussion provides insight into the timing of the birth and the seasonal grazing behavior of domestic herbivores, an assessment of feeding practices and geographical origins of animals that were consumed during large scale feasting events, as well as a re-examination of the diets of humans buried in large enclosure ditches that surrounded the sparsely populated Makriyalos I settlement (studied previously by Triantaphyllou, 2001, 2008).

7.1 Introduction and archaeological background

The Late Neolithic site of Makriyalos stands out among other sites on the Greek mainland, both in terms of its remarkable size and in the richness of archaeological finds that it has provided through excavation. With the Pieria Mountains lying 15km to the west and the Thermaic Gulf 2km to the east, the site sits at the intersection of the Balkans and Thessaly, two regions that witnessed the development of strong localized Neolithic traditions (Fig. 7.1). It exemplifies a flat extended type of settlement, which was characteristic of Macedonia and the Balkans to the north (see Chapter 3.2.1), while at the same time drawing on both the 'Larissa' and 'Dimini' ceramic traditions of Thessaly in the south (Pappa and Besios, 1999*a*,*b*).

Ancient Makriyalos spreads over an area of 50ha. It was occupied in two successive phases that overlapped only partially in space: Makriyalos I (dating to the Early Late Neolithic, ELN, 5500–5000/4900 cal BC) and Makriyalos II (dating to the Late Late Neolithic, LLN, 5000/4900–4500 cal BC) (Pappa and Besios, 1999*a*,*b*; Pappa et al., 2013; Tsokas et al., 1997). The site was encountered through survey in the 1970s, when large parts of it were destroyed. It was not until the 1990s that an intensive 20–month long rescue excavation took place ahead of the expansion of the national road and railway. The excavation, co-directed by Maria Pappa and Manthos Bessios, exposed 6ha of the settlement and was primarily aimed at understanding the nature of flat extended settlements and how they compare to vertically-accumulated tell sites (Pappa and Besios, 1999*a*,*b*).

This section will provide an introduction to the site by: 1) briefly describing the geographical and geological setting of the site, 2) outlining the layout of the Neolithic village and the key architectural features (both domestic and communal) constructed during the two phases of its Late Neolithic occupation, 3) discussing the evidence behind the large-scale feasting hypothesis, and 4) discussing how the analysis of bio-archaeological material has con-

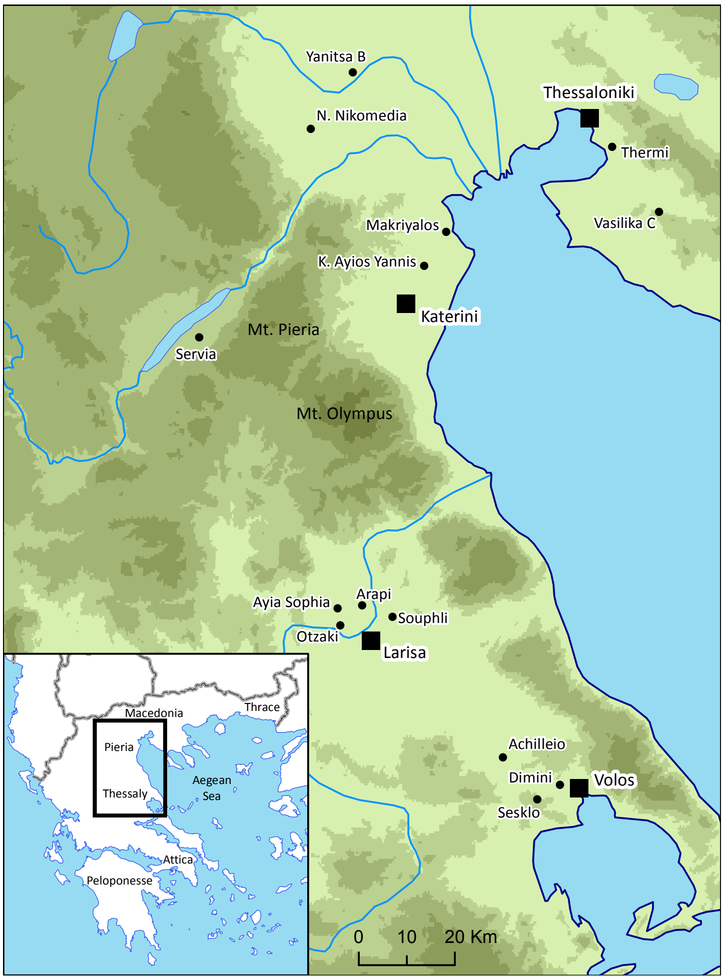


Figure 7.1: Map of Pieria and Thessaly, northern and central Greece, showing the location of Makriyalos (Pappa and Besios, 1999*b*)

tributed to our understanding of human burial practices, plant resourse use, and animal husbandry. Questions that form the basis of this current study will be discussed as they relate to the findings and ideas presented in this section.

7.1.1 Geographical and geological setting of the site

Makriyalos (40° 25' 6.32" N, 22° 35' 30.10" E) is located on the northern coastal fringe of Pieria, a region which lies directly north of Thessaly. The landscape is characterized by three physiographic units: 1) the Pieria mountains, which rise to an altitude of 2,188masl, 2) the Pieria hills, which constitute a stretch of rolling fertile landscape that rises to an altitude of 400masl, and 3) the coastal plains extending up to 40masl along the Thermaic Gulf in the Aegean Sea (See Fig. 7.2). Mean annual precipitation recorded at two meteorological stations close to Makriyalos was 644mm (Katerini) and 828 (Skoteina) for the period between 1950–1981 (Krahtopoulou, 2010).

Geoarchaeological reconstructions suggest that from the late Pleistocene throughout the Holocene, the coastal environment of Northern Pieria has been in a constant state of change (Krahtopoulou, 2010; Krahtopoulou and Veropoulidou in press; Ghilardi et al. 2008*a*, 2008*b*). At the end of the Pleistocene, the region formed part of an extensive coastal plain that stretched from Anatolia to Thessaly. During the early Holocene, rapid marine transgression flooded the coastal plain and the shoreline lay about 3.5km west of its present position. In the Final Neolithic, the northern part of the Thermaic Gulf extended 30–35km more inland compared to its current position, while large-scale alluviation to the south pushed the shoreline back eastwards and created a sand barrier. The Bronze Age saw the formation of the deltaic Thessaloniki–Giannitsa plain in the north (Ghilardi et al. 2008*a*, 2008*b*) and the creation of a lagoon in a large part of the Korinos area to the south of Makriyalos (Krahtopoulou and Veropoulidou in press). The lagoon

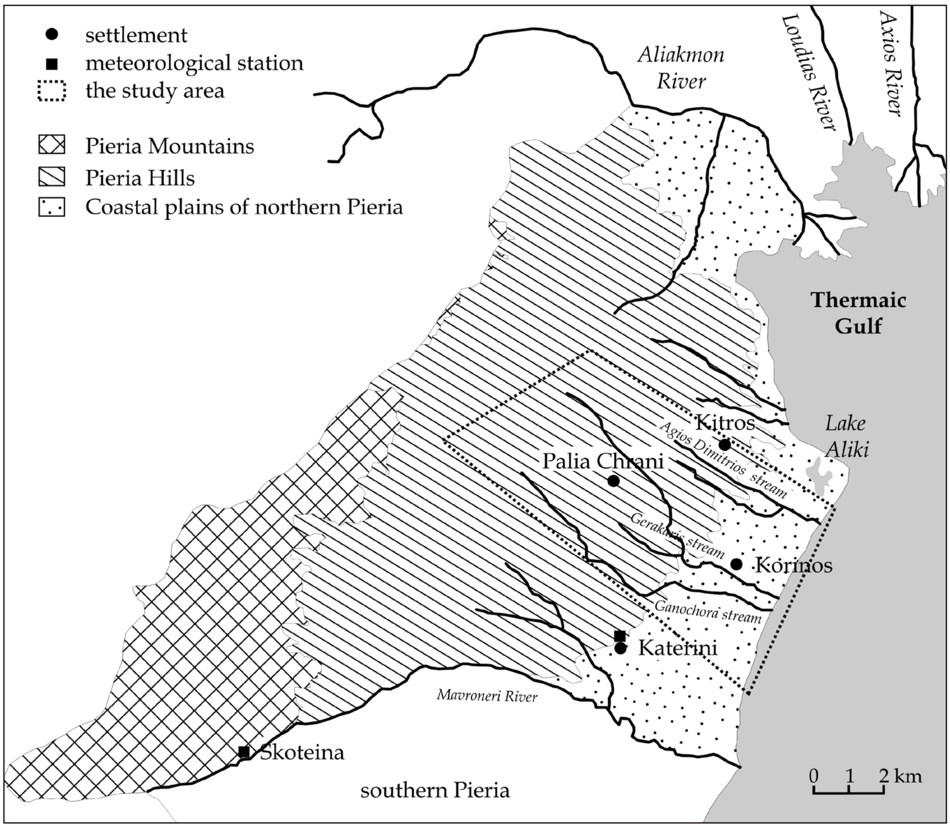


Figure 7.2: Map of northern Pieria, northern Greece, showing the locations of the major zones that characterize the region: Pieria hills, Pieria mountains and coastal plains (Krahtopoulou, 2010)

was eventually displaced by the formation of the modern Korinos coastal plain hosting coastal marshlands. High-resolution modeling suggests that between 10,000 and 6,000 BP, the mean level of the Thermaic Gulf was between 46–3m lower than its present position (Lambeck1996) and during the Late Neolithic, the shoreline proximal to Makriyalos was located a few hundred meters east of its present position (Krahtopoulou, 2010; Krahtopoulou and Veropoulidou in press).

Fig. 7.3 shows a map of the geology of the region. The site sits on the border of the Pierian hills and the coastal landscape, in a zone characterized by Neogene mudstones. Two ravines pass by the site, one to the northeast and one to the southwest (Pappa and Besios, 1999*b*). Coastal brackish marshes are presently located c.7–8km to the north and south of the archaeological site. Along the coast, an alluvial plain consisting of unconsolidated Holocene alluvial deposits stretches for c.45km south of the site. This zone is bordered to the west by Pleistocene silts and lacustrine formations, created through erosion of the Pierian mountains and the Olympic range located to the west. Mesozoic (Lower Cretaceous, Jurassic and Triassic) limestones form the area where Mt Olympus is located, and Neopaleozoic-Jurassic marbles, ophiolites and schists and Paleozoic gneisses and schists lie to the west. The area between this oldest Pre-Alpine zone and the archaeological site (c.30km) is mostly composed of Neogene formations consisting of sandstones, mudstones, clays and marls (the Neogene formations within c.15km of the site are defined in greater detail in Fig. 7.10). Directly to the west of the Neogene zone is an area characterized by Lower Cretaceous flysch and ophiolites interspersed with areas of Cretaceous limestones (IGME, 1985, 1986, 1988, 2002).

Approximate distances from Makriyalos to the main formations (as the crow flies) are 19km to the Cretaceous limestone (altitude of c.300masl), 20km to the Lower Cretaceous flysch and ophiolites (altitudes over 500m),

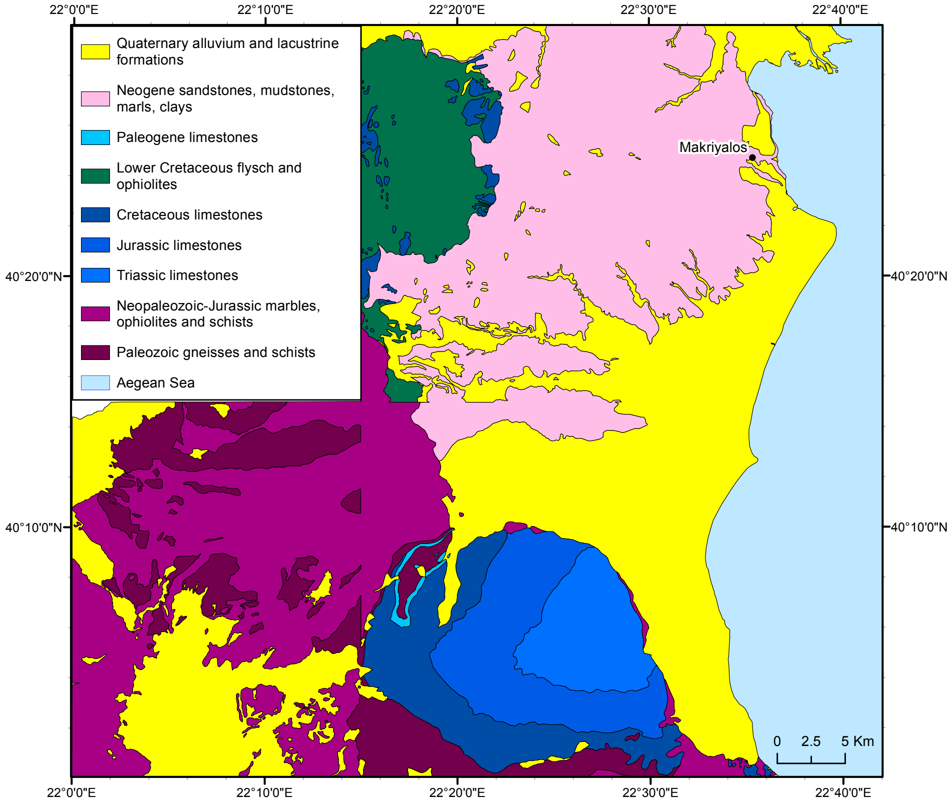


Figure 7.3: Geological map of Pieria, northern Greece. Prepared by Andrea Kay using material published by the Greek Institute of Geology and Mineral Exploration (IGME, 1985, 1986, 1988, 2002). The published information was digitized using ArcGIS 10.2 and georeferenced to the Greek grid.

34km to the Paleozoic gneisses and schists (altitudes of c. 1500m) and 32km to the Mesozoic limestones to the south (altitudes of c.300masl). See Fig. 7.4 for a topographical map of the region indicating access routes from the archaeological site to these zones which involve least amount of vertical scaling. Most of the journey would take place at elevations of around 200m and only the last 4-5km would involve ascent to altitudes over 1000m.

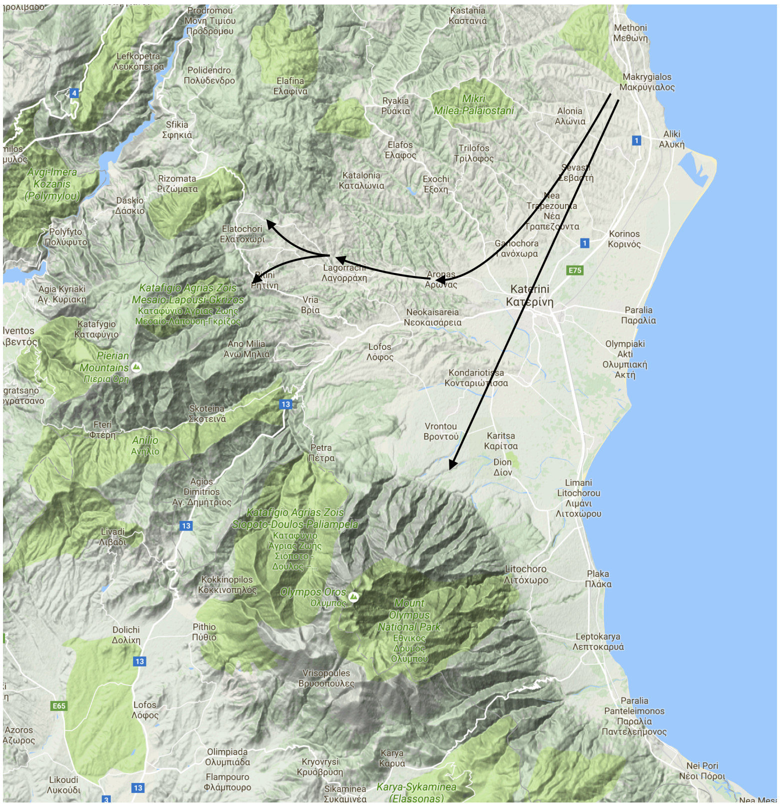


Figure 7.4: Topographical map of Pieria showing routes from the archaeological site to the areas with older geologies in the Pieria mountains which involve the least amount of vertical scaling (Map data © 2016 Google).

7.1.2 Layout of the villages: Makriyalos I and II

Fig. 7.5 shows a plan of the excavated parts of Makriyalos I (MKI) and Makriyalos II (MKII). MKI is larger in extent than MKII, but excavation of these two phases of occupation yielded similar amounts of archaeological material, largely because settlement was more concentrated in the latter phase. MKII settlement went through two sub-phases, which are characterized by the presence of distinctly shaped settlement structures. No Makriyalos I sherds were encountered through excavation of Makriyalos II, suggesting that the first settlement was completely abandoned and covered with soil before the second settlement was established (Pappa and Besios, 1999*a*,*b*).

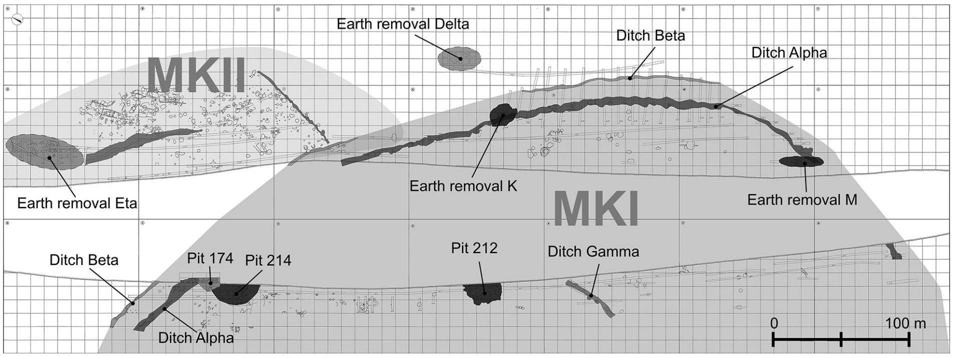


Figure 7.5: Plan of the two settlements at Makriyalos. MKI: Makriyalos phase I (Early Late Neolithic), MKII: Makriyalos phase II (Late Late Neolithic) (Pappa et al., 2013).

Habitation in Makriyalos I was loosely organized into clusters of semi-subterranean pit-dwellings in a space of 28ha enclosed by a pair of concentric ditches (Ditch Alpha and Beta) (see Fig. 7.6). Excavation encountered part of a third ditch (Ditch Gamma) running through the middle of the enclosed space, which may have been used to divide the settlement (see more on the ditches below). The pit-huts served a mostly domestic purpose and Halstead (2011) argues that some of the huts were large enough to accommodate an entire family. Part of the enclosed space may have been used for cultivation of crops (an idea suggested by Andreou and Kotsakis, 1994, and Chapman, 1989) and/or the grazing of livestock (Mainland and Halstead, 2005) and it is an aim of the current work to comment on the plausibility of this practice.

Unlike in Makriyalos I, there was no empty space between buildings in Makriyalos II and the excavated area essentially consists of the underground

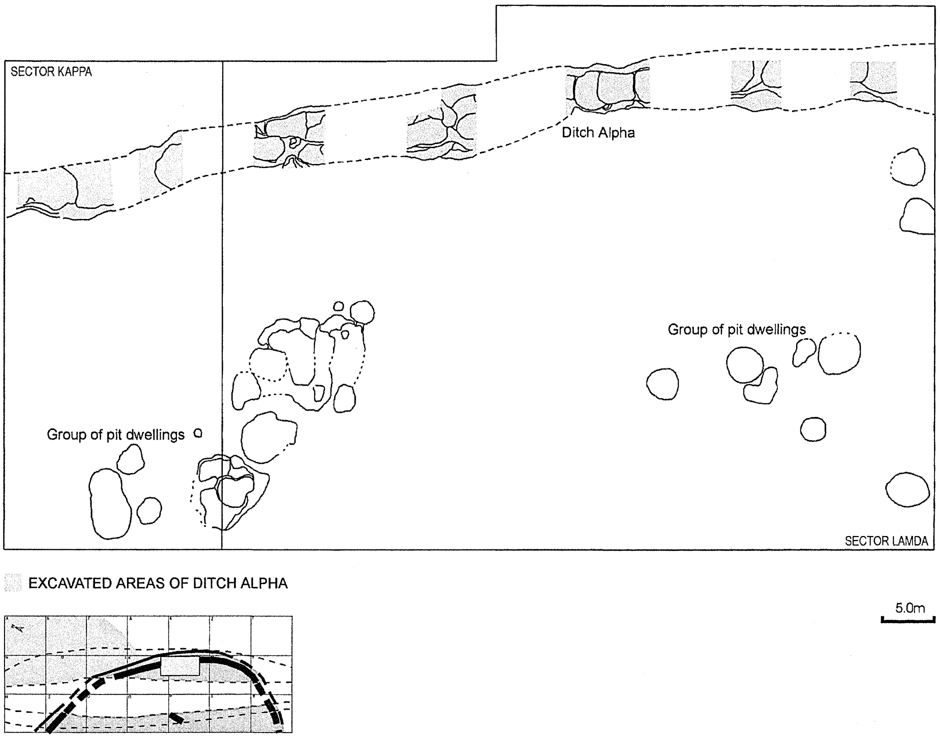


Figure 7.6: Plan of two excavation sectors in Makriyalos I, Kappa and Lamda, showing the location of boundary Ditch Alpha and the density of habitation features within the enclosure area (Pappa and Besios, 1999*b*)

part of the settlement (sub-terranean pits, basements, refusal areas etc.) spreading over an area of c.11ha (see Fig. 7.7). The first sub-phase saw the continuation of the type of pit-huts built in Makriyalos I, while the second phase encountered the erection of similarly-aligned above-surface apsidal buildings. The best preserved of these apsidal buildings, which came to be called the 'megaron', had a deep storage pit inside the apse that contained flax seeds. No stone was used in the construction of the buildings, but the excavators suggest that there may have been stone-paved yards amongst the structures (Pappa and Besios, 1999*a*,*b*).

Figure 7.7: Plan of two excavation sectors in Makriyalos II, Eta and Theta, showing the density of occupation and the two types of habitation structures (round and apsidal) (Pappa and Besios, 1999*b*)

Apart from round pits that formed the structural foundation of the sub-terranean pit-huts, two other pit features were found at both phases at Makriyalos: pits with hearths and ovens inside them and 'borrow pits'. 29 hearths and ovens were excavated in specially formed pits in external spaces across the two settlement areas. The size of these features suggests that cooking took place outdoors in “modest quantities” (Pappa et al., 2013, pg. 80). ‘Borrow pits’ were formed by the removal of soil and underlying bedrock to be used in construction and were eventually turned into habitation spaces or areas for disposal of refuse (Pappa and Besios, 1999*a*,*b*). They reached up to 30m in diameter. One example – pit 212 – yielded, on its own, the majority of faunal, ceramic and small find materials from the entire site. Pit 212 came to be called the ‘feasting deposit’, based on the fact that it preserved evidence for large-scale feasting activity that took place at the site over a relatively short period of time (a few months rather than several years, see more below) (Pappa et al., 2004).

The most impressive feature of the entire site is the system of ring ditches built around the early MKI settlement. This enclosure system is composed of series of pits that formed an inner and outher ditch, Ditch Alpha and Beta, that run c.10m apart and parallel to each other and that were in constant state of renewal during the Early Late Neolithic (Pappa and Besios, 1999*b*). The ditches fulfilled several possible functions: 1) they served as defensive boundary walls (further reinforced by wattle and daub, as well as stone, structures built on the edges of Ditch Alpha), 2) they were used to keep wild animals out and people/livestock inside the settlement, and 3) they functioned for the disposal of refuse, and human remains. Large quantities of animal bones and ceramics and smaller quantities of human bones and small finds were excavated in Ditch Alpha (although the quantities were smaller compared to pit 212) deposited in horizons that were separated by thin mud layers indicating the presence of water (Pappa and Besios, 1999*b*).

Even though initially, the excavators argued that a possible inner partition, a boundary ditch and a chain of pits connected by a channel formed parts of an enclosure ditch in Makiryalos II (Pappa and Besios, 1999*b*), they have argued more recently that Makriyalos II was not surrounded an enclosure and that this phenomenon is thus only characteristic of the first phase of occupation (Pappa et al., 2013).

The context that yielded the largest amount of archaeological finds was pit 212 from sector Pi in MKI: the 'feasting deposit' (Pappa et al., 2004). Pit 212 was a borrow pit, which was created by the removal of about 500m^3 of soft bedrock, likely for use in construction. A 'carpet of finds' was encountered in the lower levels of the southern section the pit, which contained thousands of bones, ceramic sherds and no intervening soil (see Fig. 7.8). Pappa et al. (2004) estimate that the faunal material represents tens of tons of meat consumed during the period represented by the discarded remains. The density of finds and preservation of bone remains suggests that the material that formed this layer was deposited fairly rapidly, over the course of a few months, rather than years. Butchery marks and evidence for the extraction of bone marrow suggests that the whole sequence of carcass processing took place in close proximity to the pit. The plant assemblage shows evidence for the processing of grain crops.

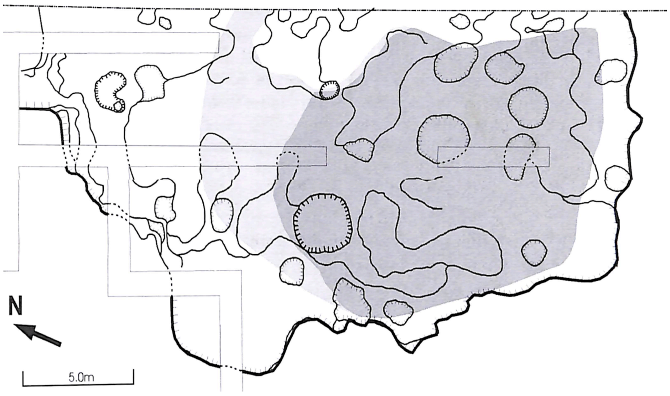


Figure 7.8: Plan of Pit 212, the 'feasting context', located in sector Pi, Makriyalos I. The dark shaded area indicates the rich 'carpet of finds' excavated in the lower levels of this feature (Pappa et al., 2004)

The contents of pit 212 (and a similar pit 214, which was smaller and studied in less detail) have been interpreted to represent consumption – or 'feasting' – organized on an unusual scale; scale that "possibly transcends even the communal level" (Pappa et al., 2004, pg. 84). No human remains have been recovered from this pit, and as this is unusual compared to the contents of other pits at the site, the authors argue that consumption took place within an activity that did not have a mortuary dimension. The ceramic assemblage exhibits significant stylistic variability (including the presence of 'individualized cups' with zoomorphic handles), which suggests that the vessels originated from a wide geographical region of participations. In addition, the overwhelming presence of tableware finds among the ceramic sherds largely implies consumption rather than storage of food. Pappa et al. (2004) argue that the tens of tons of meat represented by the animal remains in pit 212 (some of which came from large carcasses like aurochs and adult sheep, goats and pigs) were consumed by at least several dozen to a few hundred people (likely even thousands) and that the consumption took place in the vicinity of pit 212.

7.1.3 The people of Makriyalos

Human remains were found in a range of depositional contexts in both phases of occupation at Makriyalos (Triantaphyllou, 1999, 2001). They appeared in both primary and secondary burials in MKI, but were restricted to secondary burials in MKII. Nineteen fully articulated skeletons were found in the lower layers of Ditch Alpha and one in pit 212. A large part of the human bone assemblage was found scattered amongst faunal material in habitation and ditch deposits. No biases in body part representation were identified within the group of non-articulated remains. In MKI, females outnumbered males (24 to 9 individuals), but no females were excavated in MKII. Triantaphyllou argues that secondary burial at the site "symbolized incorporation into the community of collective dead or ancestors" (Triantaphyllou, 2008, pg. 145). Some secondary burials were covered with stones, a material that was used in the construction of a boundary feature on the edge of Ditch Alpha, but that was avoided in the construction of dwelling structures (Pappa and Besios, 1999*b*).

Dietary habits of people buried at Makriyalos were studied using a combination of dental macro– and microscopic analyses and stable isotopic measurements. Macroscopic analysis of teeth indicated a high frequency of calculus depositions and a low frequency of dental caries, possibly indicating a diet rich in animal proteins and low in carbohydrates (Triantaphyllou, 2001). This finding stands in contrast to Halstead's argument that Neolithic diets were dominated by plant foods and that animal products played a supplementary role in people's caloric intake (Halstead, 1989*b*). Dental microwear analysis showed a high degree of enamel abrasions, likely resulting from the inclusion of small stone particles in processed food (from grinding stones, for example) (work by Ingrid Mainland and Sevi Triantaphyllou, cited in Pappa et al., 2013).

Stable isotope analysis of humans from MKI indicated a consistent diet dominated by terrestrial food items, with no significant differences between people buried in ditches and people buried in other settlement deposits (Triantaphyllou, 2001). Two individuals with distinctly low $\delta^{15}N$ values were interpreted as reliant on pulses and Pappa et al. (2013) argued – albeit in the absence of plant $\delta^{13}C$ and $\delta^{15}N$ measurements – that human diets were primarily based on consumption of plant proteins.

Compound-specific stable isotope analysis showed no difference in the $\delta^{15}N$ values of phenylalanine of humans ($n = 5$), sheep ($n = 5$), cattle ($n = 5$) and wild deer ($n = 3$) (Styring et al., 2015). The authors argued that as phenylalanine should reflect only the plant portion of consumer diets, the diets of the humans at Makriyalos were isotopically similar to those of the herbivores. They further estimated the $\delta^{15}N$ value of the plant portion of human diets to be 1.5‰, which was higher than the mean value of emmer grains measured at the time (0.4‰). Styring et al. (2015) thus concluded that another plant source with higher δ^{15}N values than the emmer (for example heavily manured pulses) must have made a significant contribution to the diets of the humans. Unfortunately, pulses were only recovered from the MKII phase at Makriyalos – and the analyzed humans date to the MKI phase – so this claim cannot be subjected to further empirical testing.

7.1.4 Plant resource use

The archaeobotanical assemblage was mostly composed of cereal chaff (crop by-product), with only limited presence of cereal grains and pulse seeds Valamoti (1999, 2004, 2005). Valamoti (2004) argues that the chaff remains represent remnants of fuel used in cooking installations like hearths and ovens as well as animal dung (also used as a source of fuel). The densities of archaeobotanical material per volume of soil were generally very low and the units were virtually free of weed/wild seeds, which precluded proper analysis of crop growing conditions and animal grazing habits. In spite of this limitation, Valamoti (2004, 2007) used the presence of a small number of wild/weed seed identified to suggest a possible trend in the management of livestock (discussed in section 7.1.5). No plant biomarkers were identified during residue analysis of pottery sherds, indicating that plant foods were not processed in ceramic vessels at Makriyalos (Whelton et al. in prep.).

The most common type of crop represented in the plant assemblage are the glume wheats: einkorn (*Triticum monococcum*), emmer (*Triticum dicoccum*) and new type glume wheat (no Latin name), with only rare occurrence of free-threshing wheat (*Triticum aestivum/Triticum durum*). Other species include barley (*Hordeum vulgare*) (which was common, but appeared in low proportions), lentils (*Lens culinaris*), bitter vetch (*Vicia ervilia*), pea (*Pisum sativum*), grass pea (*Lathyrus sativus*) and flax/linseed (*Linum usitatissimum*). Only barley and lentils were found in large enough quantities to asses if they were cultivated at the site. Fruits include grape (also common but appearing in low proportions), blackberry, elderberry, Cornelian cherry, and apple/pear/*Sorbus*. Preserved remains of nuts include acorn and terebinth (Valamoti, 2004).

In spite of the paucity of stored grains, Valamoti (2004) argues that the presence of caches of lentils, flax and terebinth as well as the by-products of crop processing indicates that these plant foods were consumed by humans; and for this purpose they were either cultivated or systematically gathered. In most instances, emmer and einkorn were found in mixed deposits, but in a unit from Ditch A, they were found at different stages of processing, indicating that they may have been cultivated separately. Unfortunately, no einkorn or barley grain was available for stable isotopic analysis.

7.1.5 Animal management and feasting activity

The faunal bone assemblage is primarily composed of domestic species (Collins and Halstead, 1999; Pappa et al., 2013). Domesticates form 99% of the assemblage in MKI and 96% of the assemblage in MKII. Pigs are the most numerous (especially in MKII), followed by cattle and sheep, with goats forming the smallest proportion of the assemblages. Dogs are relatively infrequent. Wild fauna, which forms a minor proportion of the identified bones, include aurochs, boar, roe deer, bear, wolf, fox, hare and examples of small types of birds.

The fish bone assemblage is dominated by small-size species (<15cm in length), suggesting that fishing took place in shallow coastal waters/lagoons. Pappa et al. (2013) argue that this is consistent with fishing patterns identified throughout much of Aegean history. However, lipid residue analysis carried out on pottery sherds from the site has not indicated the presence of aquatic biomarkers in the samples, suggesting that aquatic foodstuffs were not processed in ceramic vessels (Whelon et al. in prep.). Invertebrate fauna has also been recovered from the site, and analysis showed that most of the remains are cockles, with smaller proportions of oysters and surf clams (Pappa et al., 2013). However, as stable isotopic analysis (mentioned above) showed that humans did not rely on marine resources for much of their protein intake, these food items likely played only a supplementary role to human diets.

Analysis of animals' ages at death allowed for the reconstruction of mortality profiles, which are useful for assessing the nature and purpose of animal exploitation (cf Payne, 1972). The results suggest that sheep and goat were raised for their meat, with slaughter happening on site throughout the whole year (Halstead, 2005). This is consistent with the results of lipid residue analysis, in which no milk residues were detected in potsherds from Makriyalos (n = 103, c.35% of the sherds analyzed contained $> 5\mu g\ g^{-1}$ of lipid, mean lipid concentration was $90\mu g\ g^{-1}$) (Evershed et al., 2008; the numbers for Makriyalos alone are presented in the supplementary material of Debono Spiteri et al. 2016). Further work on lipid residue from Makriyalos is being carried out by Whelton et al. (in prep.).

Butchery marks – inferred as traces of skinning, dismembering and filleting – are indicative of cooking large carcasses of animals, which were likely shared among a number of social groups (Pappa et al., 2013). There is some indication that a large number of animals was slaughtered between late autumn and winter, possibly suggesting that the large-scale feasting activity (discussed later) took place during this season (Pappa et al., 2004).

Several lines of evidence have been used to assess the nature and scale of animal husbandry practiced by the agro-pastoral farmers at Makriyalos. Dental microwear analysis of sheep, goat and pig teeth was used to study the short-term dietary habits of these animals (Mainland and Halstead, 2005; Pappa et al., 2013). Stable isotope analysis of a small number of pig and boar collagen samples was used to compare the long-term dietary input of domestic pigs to wild-roaming boars (Pappa et al., 2013; Triantaphyllou, 2001). Compound-specific δ^{15}N values of humans, sheep, cattle and red deer were used to address the type of vegetation that contributed to the diets of these species on a finer scale (Styring, 2012; Styring et al., 2015) and further work has been undertaken to address the compound specific δ^{13}C values of the same samples (Helen Whelton et al. in prep.). The results of the analysis of seeds preserved in animal dung were used to suggest a possible seasonal trend in animal management (Valamoti, 2004, 2007). Other ongoing work includes the application of a refined dental microwear technique to address possible differences in diets between distinct groups of species (Lucy Lawrence in prep.).

Dental microwear suggests that pigs were free-ranging (rather than stall-fed) and stable isotope analysis indicates that these animals had distinct diets from the boars (Pappa et al., 2013). Based on this observation, Pappa et al. (2013) argued that pigs were not likely left to roam in forests (as the boars did), but were rather herded within enclosed areas in closer proximity to the site; perhaps on the arable landscape. Dental microwear further showed that sheep and goat had highly abrasive diets, which has been interpreted to show that these animals grazed on 'disturbed ground'; also possibly on the cultivated soils (Mainland and Halstead, 2005). Large-scale management of animals would require more extensive use of the woodlands by the pigs and exploitation of unenclosed pastures by the ovicaprids, and as this is not what the data show, the scale of pig and ovicaprid management was likely to be small (Pappa et al., 2013).

Compound-specific stable isotope analysis indicates a strong correlation between the amino acid δ^{15}N values of cattle and sheep, suggesting that the bulk of the vegetation consumed by these animals was similar (Styring et al., 2015). The amino acid profiles were significantly different to those of herbivores from Çatalhöyük indicating that the animals managed at these sites consumed very different diets (see further discussion in Chapter 8).

Valamoti (2004, 2007) argues, based on the composition of plant remains originating from animal dung used as fuel, that livestock may have spent part of the year away from the site. This is based on the absence of wild/weed plants that produce seed in the summer in the remains of animal dung. Valamoti stresses that this interpretation should be treated with caution, because the amount of preserved wild species was extremely limited and precluded proper investigation (using correspondence analysis) of their contribution to animal diets. However, if this finding points to a real trend, it would suggest that animals were either fodder-fed during the summer months or grazed away from the site during this season. The latter explanation would imply that the scale of management was not as limited as implied by the earlier findings or that farmers only collected animal dung in seasons when the wild plants were not in seed.

Valamoti writes that “During the summer, the animals might have been taken outside the confines of the settlement to woodland and/or pastures at low or high altitudes in search of grazing/browsing” (Valamoti, 2007, pg. 1058). It is the question of altitudinal movement that can be directly assessed using stable oxygen isotope measurements of tooth enamel carbonate, and which will be carried out on samples of sheep and cattle teeth in this study. This will help shed light on annual mobility patterns of both large and small-size livestock and feed into the discussion of how the scale of management constrained the animals’ movement.

The presence of a large number of animal remains preserved in feasting deposits at Makriyalos presents a unique opportunity to investigate the possibility of whether animals that were consumed as part of this communal activity received differential treatment from animals that were consumed on a more mundane basis. Were the animals that were slaughtered for the feast managed together with the other animals? Did the two groups have the same diets? Or indeed, given the scale of the feasting activity implied by the archaeological deposit, were all the animals raised locally, or could some have been imported from more distant locations to be slaughtered as part of this special ritual?

Mainland and Halstead (2005) used dental microwear analysis to investigate whether the short-term diets of ovicaprids preserved in the feasting deposits differed from those preserved in habitation deposits (n = 30, 8 goats and 22 sheep). The microwear pits preserved on the surface of the teeth indicate that individuals from the feasting contexts resembled modern sheep fed on 'soft textured foods'. Diets consisting of cereal chaff and figs (cf Valamoti, 2004) would constitute a soft diet. Mainland and Halstead (2005) argue that the inter-contextual variabilities show that animals slaughtered for the feast were fed on different diets, which may have been more 'fattening', than animals that ended up in domestic refuse. It is important to remember that dental microwear records the dietary habits of the last 2–3 weeks of the individuals' lives and that it is thus possible that the 'feasting ovicaprids' switched to a different diet only shortly before they were slaughtered.

Stable isotope work carried out in this study provides a renewed opportunity to assess the differences in dietary habits of sheep and cattle buried in the two types of contexts at Makriyalos I. The results are not directly comparable to the results of dental microwear, since the two techniques reflect diets from distinct periods of the animals' lives – while tooth microwear is indicative of the last several weeks of the animal's lives, tooth enamel carbonate reflects the period of enamel mineralization (the first year of the individual's life in the case of second molars).

7.2 Materials

7.2.1 Stage 1: Animal bone collagen and charred grains

In this study, a new attempt will be made at interpreting Neolithic human diets at Makriyalos, studied previously by Triantaphyllou (2001, 2008) by way of comparison to wild boar, red deer and domestic pig δ^{13}C and δ^{15}N values and by Styring et al. (2015) using compound specific δ^{15}N values of humans and animals. Here, the comparative dataset was expanded with measurement of 72 additional samples. These included 62 samples of animal bone collagen (mostly from domestic species) and 10 samples of charred grains/seeds (See Table 7.1). Sampling took account of side of body and size of the element (*femora* for humans, *humeri* for domestic animals and *radius/tibias* of deer) to ensure that no individual was sampled twice. The results will be interpreted in conjunction with the published bulk bone collagen measurements from the earlier study (Triantaphyllou, 2001, 2008).

	Common name	Latin name	n =	
			MKI	MKII
Domestic animal	Cattle	*Bos taurus*	14	4
	Sheep	*Ovis aries*	13	5
	Goat	*Capra hircus*	19	5
Wild animal	Red deer	*Cervus elaphus*		2
Cereal	Emmer grain	*Triticum dicoccum*	5	
Pulse	Grass pea seed	*Lathyrus sativus*		1
	Lentil seed	*Lens culinaris*		3
Wild plant	Pistachio shell	*Pistacia*		1

Table 7.1: Descriptions of archaeobotanical and archaeozoological (post-cranial) samples from Makriyalos analyzed in this study

Sheep and goat samples were differentiated on the basis of morphological characteristics by Paul Halstead. An additional 12 measurements of δ^{13}C and δ^{15}N values of mandibular cattle collagen were taken in order to guide sampling in Stage 2. These values will be shown in Section 7.3.1.1, but because these samples may represent some of the same individuals as the post-cranial samples, they will not be included in the bulk of the analysis. Unfortunately, due to the fact that most of the archaeobotanical assemblage is composed of chaff remains (see Section 7.1.4), the sample size of grains/seeds available for analysis was too limited to assess crop growing conditions at Neolithic Makriyalos. The discussion will thus center on the interpretation of consumption practices.

The samples come from both phases of occupation of the site: Makriyalos I (n = 51) and Makriyalos II (n = 21). 25 samples come from the 'feasting' deposits (pit 212, sector Pi, n = 13; and pit 214, sector Xi, n = 12) and 47 samples come from 'non-feasting' deposits (ditches from sectors I, K, L, R, Xi, n = 14; habitation contexts from sectors O and R, n = 8; and 'other' contexts from sectors H, L, Th, X, 'Megaron', and the area south of the hearths/ovens in MKII, n = 21). Appendix H details the contextual information of all samples measured in this stage of analysis.

Collagen was extracted by Rebecca Fraser following a modified Longin (1971) procedure described in Richards and Hedges (1999). δ^{13}C and δ^{15}N measurements of the bone collagen samples were carried out in duplicate: the first set (RF) were obtained at the NERC Isotope Geoscience Laboratory (NIGL) in Keyworth, UK, on a VG TripleTrap and Optima dual–inlet mass spectrometer; the second measurements were carried out by the author (PV) at the Research Laboratory for Archaeology and the History of Art (RLAHA), University of Oxford, on a SerCon 20/22 continuous flow mass spectrometer coupled to a Callisto elemental analyzer. All bone collagen measurements had C:N values in the accepted range of 2.9-3.6 (cf DeNiro, 1985).

Plant samples were pre-treated by the author using a gentle acid-only treatment using 0.5M HCl for 30min at 80°C (Vaiglova et al. 2014*b*). δ^{13}C and δ^{15}N values were measured separately on the same instrument as the collagen samples at the RLAHA.

$\delta^{13}C$ and $\delta^{15}N$ values were normalized to Vienna Pee Dee Belemnite (VPDB) and Ambient Inhalable Reservoir (AIR), respectively. Plant measurements were corrected for the charring offset of 0.31‰ ($\delta^{15}N$) and 0.11‰ for ($\delta^{13}C$) following experimental findings by Nitsch et al. (2015).

Measurement uncertainty of samples prepared by the author was assessed based on the within-run variability of an internal alanine standard and two certified reference materials placed in each run, calculated using a two-point calibration method (cf Kragten, 1994). The reference materials used were IAEA–CH6 and IAEA–CH7 for $\delta^{13}C$ and IAEA–N2 and USGS–40 for $\delta^{15}N$. Calculations were performed using a script written by Erika Nitsch (of the AGRICURB project) in the statistical programming language R (3.2.2). The average measurement uncertainty (1σ) for $\delta^{13}C$ was 0.30 ± 0.35‰ (with a range between 0.08 and 0.93‰). The average measurement uncertainty (1σ) for $\delta^{15}N$ was 0.35 ± 0.39‰ (with a range between 0.09 and 1.10‰).

Measurement uncertainty of samples prepared by Rebecca Fraser was assessed using replicate measurements of an in-house sample of homogenized barley ($1\sigma = 0.4$‰) for $\delta^{15}N$ values and homogenized wheat ($1\sigma = 0.1$‰) for $\delta^{13}C$ values (Fraser et al., 2013).

In their study, Styring et al. (2015) presented the averages of the bone collagen and three emmer grain values measured at NIGL, but this is the first time that the full dataset (including duplicate measurements and including the re-identification of two human samples as cattle) is being presented and analyzed with respect to the context from which the samples originated.

7.2.2 Stage 2: Tooth enamel carbonate

In Stage 2, tooth enamel from 8 cattle and 4 sheep second molars (M2) was sampled sequentially for measurement of carbonate $\delta^{13}C$ and $\delta^{18}O$ values. The teeth were extracted from almost-complete mandibles: all had their M2s in place, but some were missing their third molars (M3s). The use of mandibles as a starting point for sampling (as opposed to loose teeth) aided the determination of species (carried out by Paul Halstead) and secure identification of the M2s.

The aim of the sampling strategy was to:

1. Avoid sampling juvenile individuals. For this reason, preference was given to mandibles with erupted third molars (M3).
2. Sample teeth that were in good state of preservation. Preference was given to teeth with un-cracked enamel surfaces that could be cleaned using a laboratory drill. The integrity of the enamel and the potential presence of contamination was assessed using Fourier Transform Infrared Spectroscopy (FTIR) on a subset of the teeth. The test indicated that the enamel samples submitted for stable isotope measurement were free of calcite and had not undergone significant recrystallization (see Appendix B).
3. Obtain an equal number of teeth from both feasting and habitation contexts.
4. Attempt to have an equal representation of animals with predominantly C_3 and predominantly C_4 long-term average signatures of diets (determined using $\delta^{13}C$ of the mandibular collagen). This aim was harder to accomplish because a number of the collagen measurements from mandibles that fulfilled the first two criteria failed due to unacceptable C:N ratios. Nine out of twelve teeth analyzed provided matching bone collagen readings.
5. Obtain additional samples of dentine from each tooth in order to measure its $\delta^{13}C$ and $\delta^{15}N$ values as another line of assessment of the animals' dietary signal.

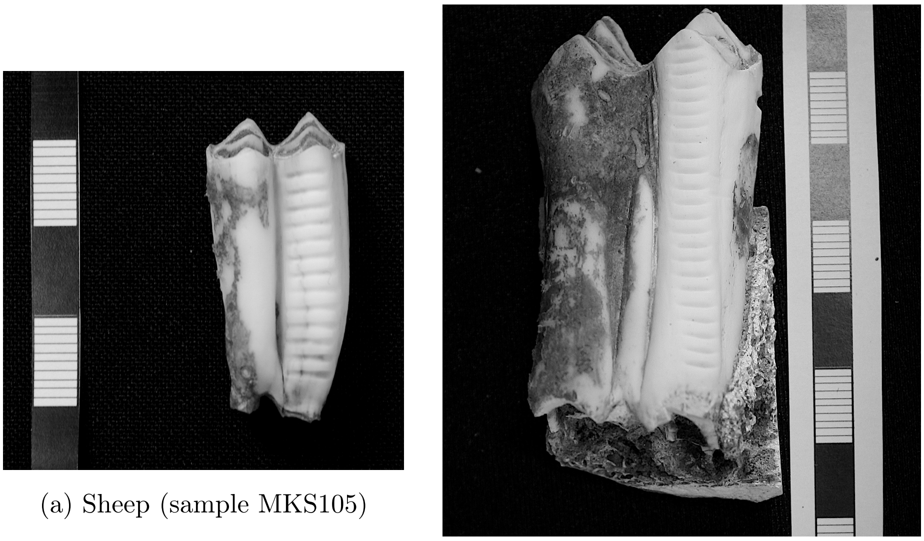
Ages of the individuals were determined by Paul Halstead using assessment of tooth wear (following Payne, 1972, for sheep and following an adaptation of Payne's method for cattle: Halstead, 1985, and Jones and Sadler, 2012). The sheep mandibles sampled in this study fall into tooth wear stages E (age 2–3 years), F (3–4 years) and G (4–6 years). The cattle mandibles fall into tooth wear stages D (16–28 months), E (2–3 years), and EF (2–3.5 years) (see Table 7.2). The M2s of all individuals were 'in wear' at the time of death. The crown heights of the sampled teeth ranged between 42–61mm for cattle and 26–32mm for sheep. The samples were obtained from excavation areas Pi, Rho, Xi and Omikron.

Enamel surfaces were cleaned with a laboratory sandblaster (aluminium oxide) and the external surface was removed by drilling with a tungsten drill bit. Sub-samples of powdered enamel (each weighing c.5–10mg) were taken perpendicularly to the tooth crown on the buccal side of each tooth, approximately every 1mm along the growth axis, starting from the crown and ending at the enamel root junction (erj); following procedures outlined in Balasse (2002). See Fig. 7.9 for examples of teeth after completion of sampling. The number of sub-samples taken from each tooth ranged from 18–32 (cattle) and 10–15 (sheep) with total number of 192 (cattle) and 51 (sheep) samples measured.

All samples were pre-treated using 1M Ca–buffered acetic acid for 30min at room temperature to remove any exogenous carbonates (Snoeck and Pellegrini, 2015). Measurement of $\delta^{13}C$ and $\delta^{18}O$ ratios was carried out by Andrew Gledhill at the School of Archaeological Sciences, University of Bradford, on an automated Thermo Gas Bench II device coupled to a Thermo Delta V Advantage mass spectrometer. Raw values were normalized to VPDB for $\delta^{13}C$ and VSMOW for $\delta^{18}O$ and $\delta^{18}O_{VSMOW}$ values were converted to $\delta^{18}O_{VPDB}$ using the equation in Chapter 4.6. Measurement uncertainty was assessed using replicate measurements of two internal

ID	Microwear number	species	context	deposit type	crown height (in mm)	number of sub-samples	wear stage	estimated age
MKS001	MK69	cattle	R 0654080	habitation	42	18	EF	2-3.5 years
MKS004	MK66	cattle	Xi 0121014	habitation	55	22	E	2-3 years
MKS006	MK63	cattle	R 0642017	habitation	52	26	E	2-3 years
MKS007	MK67	cattle	R 0543090	habitation	61	32	D	16-28 months
MKS014	MK61	cattle	Pi 0572031	feasting	54	22	D	16-28 months
MKS015	MK56	cattle	Pi 0573058	feasting	53	22	D	16-28 months
MKS016	MK54	cattle	Pi 0564018	feasting	58	27	E	2-3 years
MKS017	MK60	cattle	Pi 0572031	feasting	55	23	D	16-28 months
MKS104	MK31	sheep	R 0642008	habitation	26	10	G	4-6 years
MKS105	MK19	sheep	Pi 0572012	feasting	31	13	E	2-3 years
MKS106	MK20	sheep	Pi 0571035	feasting	27	13	F	3-4 years
MKS107	MK36	sheep	O 0672022	habitation	32	15	E	2-3 years

Table 7.2: Descriptions of cattle and sheep teeth sampled in phase 2 of this study. *ID* refers to the names assigned in this study, *Microwear number* refers to the codes used by Lucy Lawrence (in prep.). Wear stages have been assessed following Payne (1972).



(a) Sheep (sample MKS105)

(b) Cattle (sample MKS017)

Figure 7.9: Photographs showing the sequences of enamel sub-samples obtained by drilling from the buccal side of herbivore second molars from Makriyalos

standards (BES, bioapatite enamel standard, and Merck $CaCO_3$, and three international standards (IAEA-CO-1, IAEA-CO-8 and NBS-19). The average measurement error for all standards (1σ) was $0.15 \pm 0.15‰$ for $\delta^{13}C$ (from 0.01 to 0.55‰) and $0.29 \pm 0.24‰$ for $\delta^{18}O$ (from 0.03 to 1.11‰).

Enamel was sampled sequentially and consistently in this study, and the averaged values may thus be used to assess chronological changes in dietary inputs over the time period of the crown formation. Dentine, however, was not sampled sequentially and the sampling location was not consistent. Some of the samples were taken on the side of a tooth and some on the occlussal surface (depending on which part was less cracked and better preserved); it also did not undergo pre-treatment. Thus, it is impossible to compare the time-resolution of the enamel and dentine, and the two will only be used to assess the maximum degree of C_4 input during the first year of the animals' lives. Comparison of these early-life indicators to the mandibular collagen values will then be useful for assessing possible longer-term dietary changes throughout the life of the individuals.

7.2.3 Stage 3: Modern vegetation and tooth enamel for Sr isotope analysis

To establish the range of bioavailable Sr isotope values in the region around Makriyalos and aid with the interpretation of archaeological measurements, samples of tree leaves and ground vegetation were collected at 34 sampling locations across the seven geological formations within c.15km of the archaeological site. Unfortunately, the geological maps that cover the older zones in the Pieria mountains were not available at the time of sampling so reference values for these locations could not be obtained. However, the collected samples provide a sufficient basis for establishing the 'local range' of ^{87}Sr/^{86}Sr values at Makriyalos. GPS points were recorded and used to calculate latitude, longitude and elevation at each sampling location. 20 samples were submitted for Sr isotope measurement (see Fig. 7.10). MAK22 was collected as close as possible to the 'coastal marshes'. It lies on the border between this zone and the Holocene alluvium, but will be grouped together with the other marsh samples due to its proximity to this zone.

The plant samples were collected into dry paper bags and transported into the laboratory, where they were washed three times with de-ionized water to remove physical contamination. About 200mg of each sample was weighed out into microwave containers, added 2mL of 8M HNO_3, and placed on a hotplate overnight to allow for the initial reaction and gas release to take place. Subsequently, 4mL of HNO_3 and 10µL of H_2O_2 were added to each sample and left for an hour. The same step was repeated again, but left only for a few minutes to check that no further reaction takes place. The samples were then microwaved at 150°C for 15–20min and allowed to cool for 1–2 hours. They were then added 10µL of H_2O_2 and placed on a

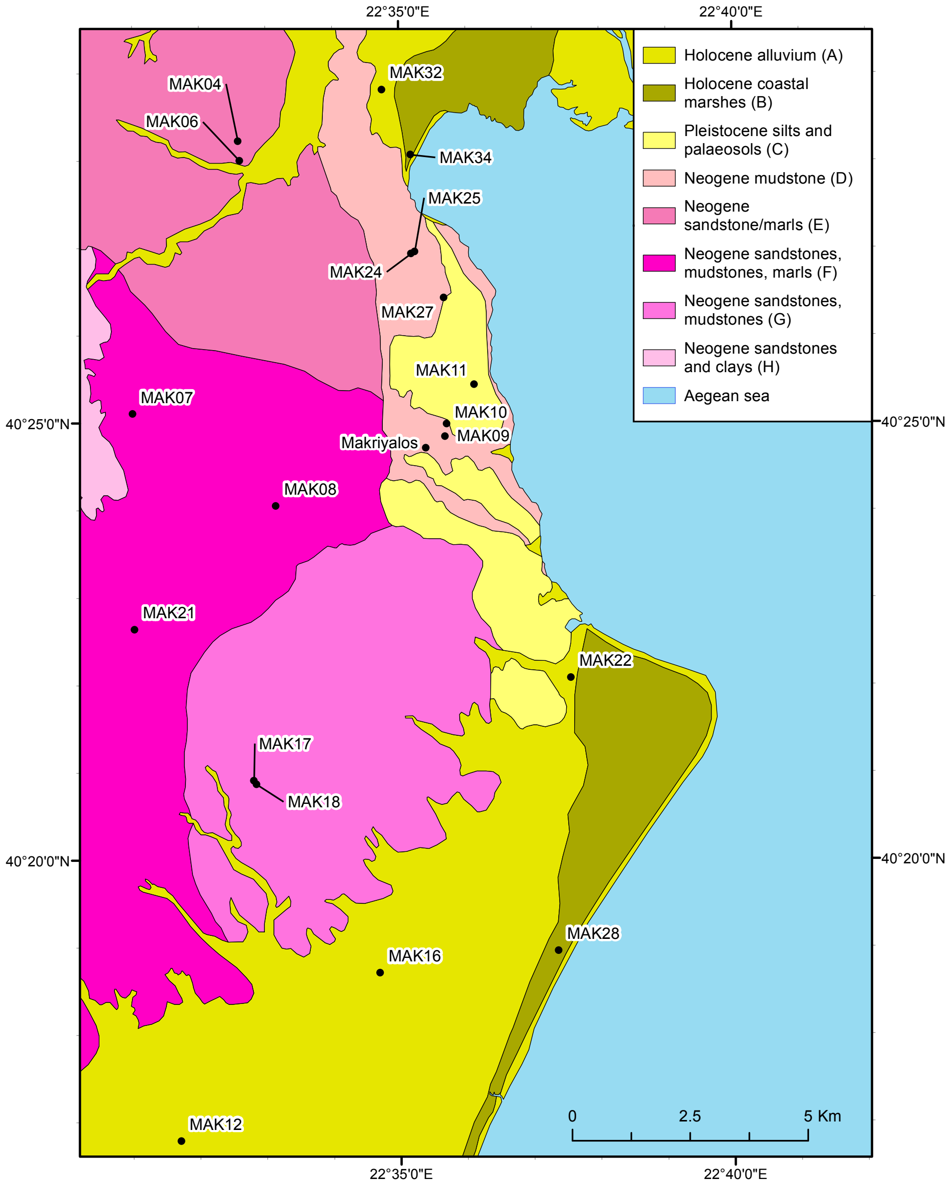


Figure 7.10: Geological map of the immediate landscape around Makriyalos (within 15km of the archaeological site), indicating the sampling locations of modern vegetation obtained for Sr isotope analysis in this study. Map was prepared by Andrea Kay using information from IGME (1986). The published information was digitized using ArcGIS 10.2 and georeferenced to the Greek grid.

hotplate overnight. This microwave assisted plant digestion method is based on a modified Heier et al. (2009) technique (Evans et al., 2010).

The archaeological samples (weighing c.10–20mg) were obtained from the same cattle teeth that were previously analyzed for $\delta^{13}C$ and $\delta^{18}O$ carbonate values using a Dremel tool with a diamond drill bit. Two sub-samples per tooth were submitted for Sr isotope analysis, one from the portion of the enamel that mineralized in the winter and one from the portion that mineralized in the winter (the regions were determined using the $\delta^{18}O$ maximum and minimum values measured in stage 2; total n = 16). See Fig. 7.11 for examples of the incisions made by drilling in this stage of analysis.

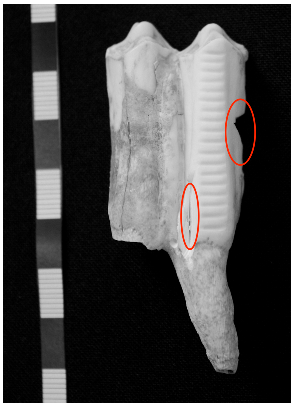


Figure 7.11: Photograph showing a cattle tooth after the completion of both sequential sampling for enamel carbonate stable isotope analysis as well as removal of two samples (one targeting enamel that mineralized in the summer and one targeting enamel that mineralized in the winter) for Sr isotope analysis (sample MKS001)

The sampled enamel was cleaned with acetone and subsequently in a de-ionized water ultrasonic bath before being placed on a hotplate (also in de-ionized water) at 50°C for one hour. An ^{84}Sr–enriched spike was added to the samples, which were then dissolved in 2mL of 8M HNO_3 and converted to chloride. The samples were then transferred to a calibrated cation exchange column (Dowex AG 50W–X12) to enable separation of Sr.

Measurement was performed on a ThermoFinnigan Triton multi-collector, magnetic sector, thermal ionization mass apectrometer at the NERC Isotope Geosciences Laboratory (NIGL) housed at the British Geological Survey (BGS) in Keyworth. Analytical uncertainty was assessed using measurements of the international standard NBS987, which provided a value of 0.710251 ± 0.000005 ($n = 19$, 2σ). Uncertainty of the overall process (including the dissolution) was assessed using the measurement of an apple leaf standard, which provided a value of 0.71393 ± 0.00004 ($n = 18$, 2σ). Long-term internal precision of $^{87}Sr/^{86}Sr$ measurements at this laboratory is better than 0.00001 (2σ) (Jane Evans, pers. comm.).

7.3 Results

7.3.1 Stage 1: Bone collagen and plant $\delta^{13}C$ and $\delta^{15}N$ values

Fig. 7.12 shows the results of $\delta^{13}C$ and $\delta^{15}N$ measurements of animal collagen and charred plant samples obtained in the first phase of this study. Refer to Appendix I for all raw and corrected measurements. The results are compared to previous measurements of Neolithic human and wild animal collagen values published by Sevi Triantaphyllou where humans ($n = 12$) showed mean $\delta^{15}N$ values of 7.6 ± 1.1‰ and mean $\delta^{13}C$ values of -20.2 ± 0.3‰, domestic pigs ($n = 5$) showed mean $\delta^{15}N$ values of 5.3 ± 0.8‰ and mean $\delta^{13}C$ values of -20.5 ± 0.3‰, wild boar ($n = 5$) showed mean $\delta^{15}N$ values of 4.2 ± 0.8‰ and mean $\delta^{13}C$ values of -20.4 ± 0.4‰ and red deer ($n = 5$) showed mean $\delta^{15}N$ values of 3.2 ± 1.3‰ and mean $\delta^{13}C$ values of -21.7 ± 0.4‰ (Triantaphyllou, 2001, 2008). Summary statistics of the data obtained herein are shown in Table 7.3.

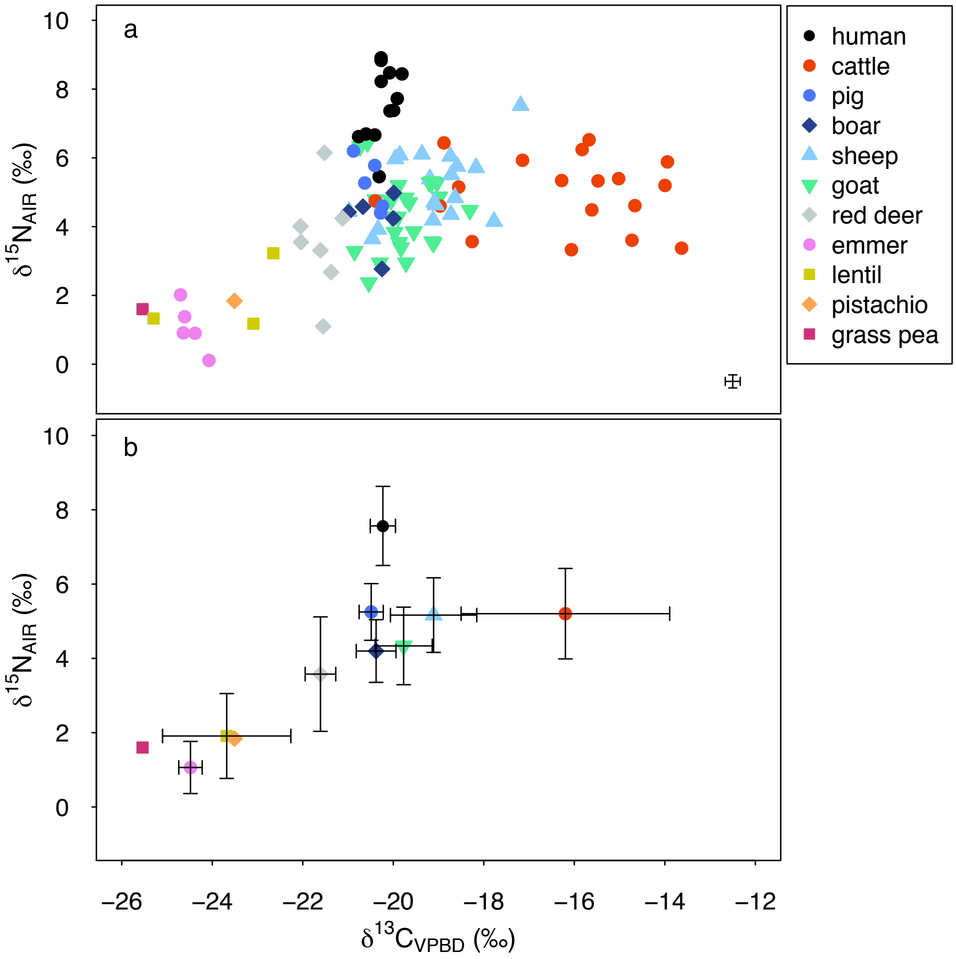


Figure 7.12: Bi-variate scatter plots of all plant and animal δ^{15}N and δ^{13}C measurements from Makriyalos. a) individual measurements; b) mean and standard deviations of each species where n > 2. Human, pig, wild boar and 5 red deer samples reproduced from Triantaphyllou (2001, 2008).

species	n=	$\delta^{15}N_{max}$	$\delta^{15}N_{min}$	$\delta^{15}N_{mean}$	$\delta^{15}N_{SD}$	$\delta^{15}N_{range}$	$\delta^{13}C_{max}$	$\delta^{13}C_{min}$	$\delta^{13}C_{mean}$	$\delta^{13}C_{SD}$	$\delta^{13}C_{range}$
cattle	18	6.5	3.3	5.0	1.0	3.2	-13.6	-20.4	-16.3	2.0	6.8
sheep	18	7.5	3.6	5.2	1.0	3.9	-17.2	-21.0	-19.1	1.0	3.8
goat	24	6.4	2.4	4.3	1.0	4.1	-18.3	-20.9	-19.8	0.6	2.5
red deer	2	6.1	2.7	4.4	2.5	3.5	-21.4	-21.5	-21.4	0.1	0.1
emmer	5	2.0	0.1	1.1	0.7	1.9	-24.1	-24.7	-24.5	0.3	0.6
lentil	3	3.2	1.2	1.9	1.1	2.1	-22.7	-25.3	-23.7	1.4	2.6
grass pea	1	1.6	1.6	1.6	-	0.0	-25.5	-25.5	-25.5	-	0.0
pistachio	1	1.8	1.8	1.8	-	0.0	-23.5	-23.5	-23.5	-	0.0

Table 7.3: Summary statistics of the plant and animal $\delta^{13}C$ and $\delta^{15}N$ values from Makriyalos obtained in stage 1 of this study

7.3.1.1 Overall description of data

Domestic cattle (n = 18) exhibits a notable range of δ^{13}C values (–20.4 to –13.6‰), compared to the other domestic species (sheep: –21.0 to –17.2‰, goats: –20.9 to –18.3‰). The data are not normally distributed (Shapiro–Wilk test, W = 0.86, $p < 0.001$), so the non-parametric Kruskall–Wallis test was used to compare the δ^{13}C means of the three herbivore groups. The results show that there are a statistically significant differences in δ^{13}C values amongst these animals (H(2) = 30.0, $p < 0.01$) and a post-hoc Bonferroni test reveals that cattle differs significantly from the other two species ($p < 0.01$ for both pairs), but sheep and goats do not vary from each other (p = 0.30).

δ^{15}N values range from 3.3 to 6.5‰ in cattle, 3.6 to 7.5‰ in sheep and 2.4 to 6.4‰ for goats. The data are normally distributed (Shapiro–Wilk test, W = 0.99, p = 0.79), and homogenous (Levene's test, $F(2, 57) = 0.002$, p = 0.99), so an ANOVA was carried out to compare differences in the δ^{15}N means of the domestic herbivores. The results show that there is a statistically significant difference in the data at a 95% confidence ($F(2, 57) = 3.86$, p = 0.027) and a post-hoc Bonferroni test reveals that the difference is between the sheep and the goats (p = 0.037).

Of the two extra samples of red deer measured in this study (to add to the 5 samples measured by Sevi Triantaphyllou, all dating to the Makriyalos II phase), one individual (MAK438) exhibits the highest δ^{15}N value of the whole group (6.1‰); comparable to the highest δ^{15}N value of the domestic pigs. The combined mean values of all 7 red deer are 3.6 ± 1.5‰ for δ^{15}N values and -21.6 ± 0.3‰ for δ^{13}C values.

Plants were sampled in limited numbers (see Section 7.1.4) and the two species which are represented with more than one sample have δ^{15}N values that range from 0.1 to 2.0‰ (emmer) and 1.2 to 3.2‰ (lentil) and δ^{13}C values that range from –24.7 to –24.1 (emmer) and –25.3 to –22.7‰ (lentil).

For comparative purposes, the values of mandibular collagen of cattle (measured in order to aid selection of samples for tooth enamel carbonate analysis) are shown together with the data obtained in phase 1 of this study (see Fig. 7.13). Some of these samples may have come from the same individuals that are represented by the post-cranial measurements, but their inclusion in the dataset causes the ranges for both δ^{13}C and δ^{15}N to increase to –20.4 to –10.3‰ and 3.3 to 8.5‰, respectively.

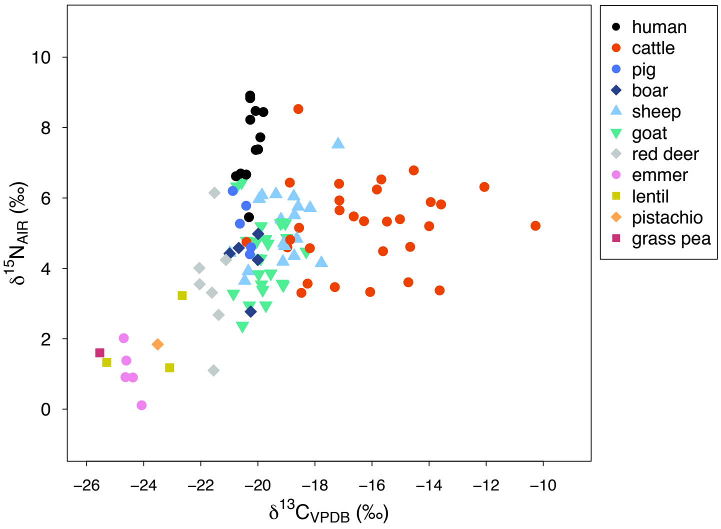


Figure 7.13: Bi-variate scatter plot of all plant and animal δ^{15}N and δ^{13}C values from Makriyalos, including measurements of mandibular collagen of cattle measured in stage 2 of this study, which may represent the same individuals as some of the post-cranial samples. Human, pig, wild boar and 5 red deer samples reproduced from Triantaphyllou (2001, 2008).

7.3.1.2 Chronology

Fig. 7.14 shows the results grouped by phase of occupation. In Makriyalos I, the domestic species are represented by a larger number of samples, and the difference in δ^{13}C values between cattle (n = 14, –15.8 ± 1.6‰) and the ovicaprids (sheep, n = 13, –18.8 ± 0.8‰; goats, n = 19, –19.7 ± 0.6‰) is clear, with cattle exhibiting substantial contribution of C_4 vegetation.

An ANOVA test revealed that there are statistical differences between the δ^{13}C means of the three groups of herbivores from MKI ($F(2, 43) = 58.52$, $p < 0.01$) and a post-hoc Bonferroni test confirmed that these differences are between the cattle and the goats ($p < 0.01$) and cattle and the sheep ($p < 0.01$). The δ^{15}N values of these animals are statistically indifferent ($F(2, 43) = 2.04$, $p = 0.14$; cattle: 5.2 ± 1.1‰; sheep: 5.3 ± 1.0‰; goats: 4.6 ± 0.9‰).

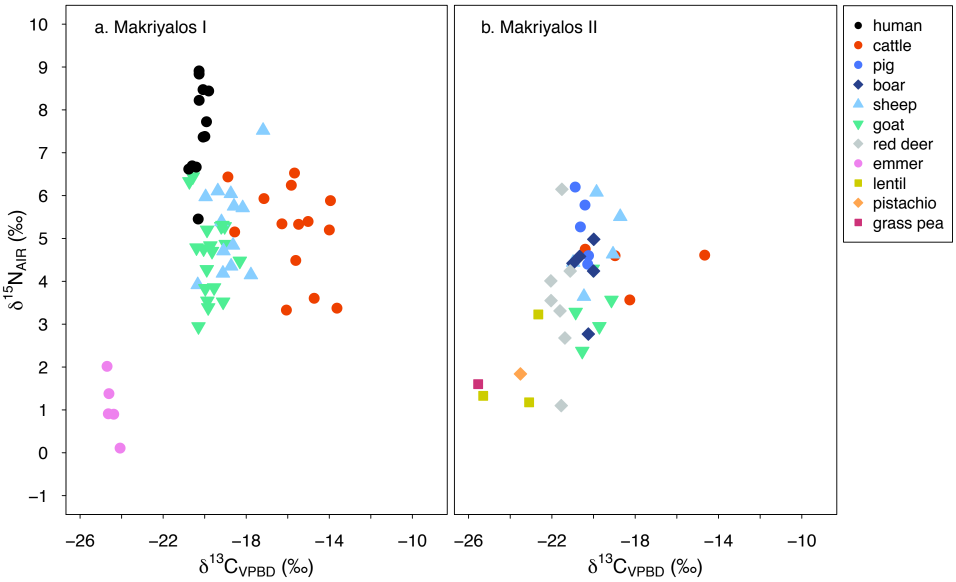


Figure 7.14: Bi-variate scatter plot of all plant and bone collagen δ^{15}N and δ^{13}C values from Makriyalos I (a) and Makriyalos II (b). Human, pig, wild boar and 5 red deer samples reproduced from Triantaphyllou (2001, 2008).

The numbers of samples available from Makriyalos II was more limited, but a clear difference can be seen between the δ^{15}N values of the sheep ($n = 5$; 4.9 ± 0.9) and the goats ($n = 5$; 3.3 ± 0.7). An ANOVA test showed that there is a statistically significant difference at 95% confidence between the means of δ^{15}N values of the three main domestic herbivores ($F(2, 11) = 5.42$, $p = 0.023$) and a post-hoc Bonferroni test revealed that the difference is between the sheep and the goats ($p = 0.024$). This means that the difference between the two ovicaprids mentioned above (for both phases combined) is driven by differences during the second phase of occupation. There are no statistically significant differences between the δ^{13}C means of the three domestic herbivores ($F(2, 11) = 2.39$, $p = 0.14$; cattle: –18.1 ± 2.4‰, sheep: –19.8 ± 0.9‰, goats: –20.1 ± 0.7‰).

7.3.1.3 Feasting vs. non-feasting

Samples from Makriyalos I were divided according the type of context they were obtained from: feasting (Pit 212 and 214) and non-feasting (all other domestic and refuse contexts). δ^{13}C values range from –18.9 to –13.6‰ for feasting cattle, from –17.1 to –14.0 for non-feasting cattle, from –20.3 to –17.2‰ for feasting sheep, from –20.0 to –18.6 for non-feasting sheep, from –20.7 to –18.3‰ for feasting goats, and –20.4 to –19.0‰ for non-feasting goats. δ^{15}N values range from 3.3 to 6.4‰ for feasting cattle, 4.5 to 6.5‰ for non-feasting cattle, 3.9 to 7.5‰ for feasting sheep, 4.2 to 6.1‰ for non-feasting sheep, 2.9 to 6.4‰ for feasting goats, and 3.5 to 5.3‰ for non-feasting goats.

Fig. 7.15 indicates that there are no apparent differences in bone collagen δ^{13}C and δ^{15}N values between animals from the feasting deposit and those from habitation deposits. The δ^{13}C values are not normally distributed (Shapiro–Wilk test, $W = 0.87$, $p < 0.01$), so the non-parametric Kruskall–Wallis test was used to test the mean δ^{13}C values of the six groups. The results suggest that there are statistically significant differences between the groups ($H(5) = 31.16$, $p < 0.01$) and a Bonferroni post-hoc test revealed that the differences exist between all cows and all sheep and goats (for all eight pairs, $p < 0.01$), but not between feasting and non-feasting cattle.

The δ^{15}N values are normally distributed (Shapiro–Wilk test, $W = 0.98$, $p = 0.66$), but not homogenous (Levene's test, $F(5, 40) = 2.57$, $p = 0.041$), so the Kruskall–Wallis test was used to compare the δ^{15}N value means between the six groups of feasting and non-feasting herbivores. The results show

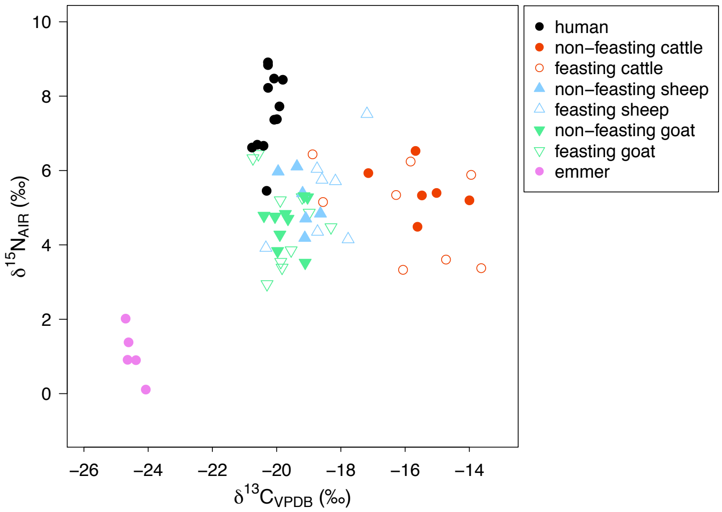


Figure 7.15: Bi-variate scatter plot of all plant and bone collagen δ^{15}N and δ^{13}C values from Makriyalos I, indicating which samples came from feasting contexts (Pit 212 and Pit 214) and which come from non-feasting (all other) contexts

that there are no statistically significant differences between the six groups of feasting and non-feasting herbivores (H(5) = 5.34, p = 0.38).

Interestingly, however, there does appear to be a difference in δ^{13}C values between sheep and goats from Pit 214 (See Fig. 7.16). The difference is 1.7‰ (sheep: –18.3 ± 0.4‰, goats: –20.0 ± 0.4‰) and is likely a result of goats grazing in a more closed environment compared to the sheep. Their δ^{15}N values are indistinguishable.

7.3.2 Stage 2: Tooth enamel carbonate results

7.3.2.1 Overall description of data

The results of sequential analysis of tooth enamel carbonate δ^{13}C and δ^{18}O values are shown in Fig. 7.17 (sheep) and Fig. 7.18 (cattle). Table 7.4 shows the summary statistics and Appendices J and K present all the individual measurements. Shading on the graphs indicates theoretical values of consumers with increasing levels of C_4 input (the lower endpoint is –8‰, cf

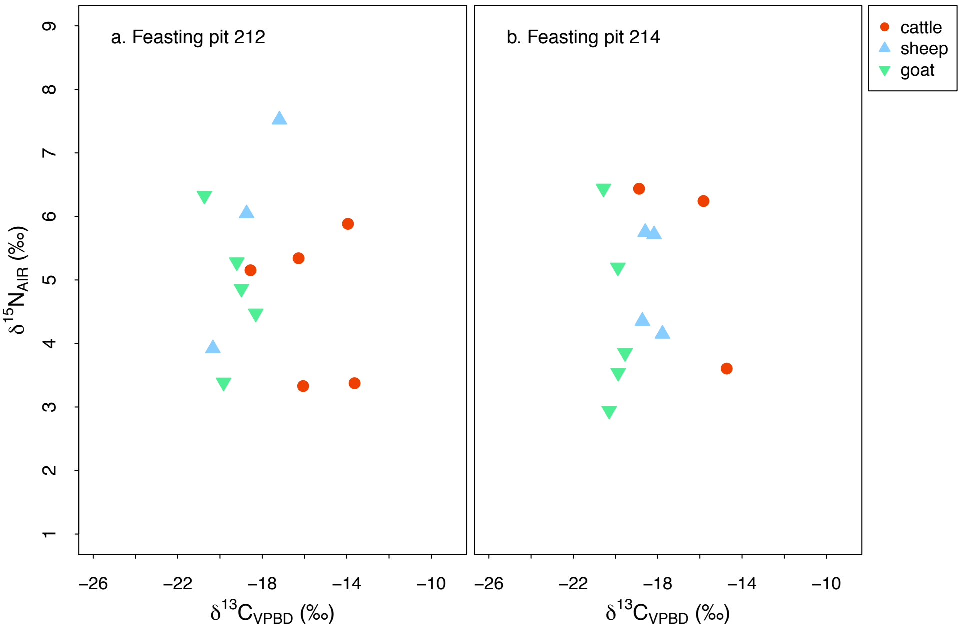


Figure 7.16: Bi-variate scatter plots of δ^{15}N and δ^{13}C values of cattle, sheep and goats from Pit 212 (a) and Pit 214 (b) at Makriyalos I

Cerling et al., 1997). Matching δ^{13}C and δ^{15}N values of mandibular collagen and bulk dentine along with intra-tooth average enamel carbonate δ^{13}C values from each tooth are shown in Table 7.5.

Tooth ID	Max δ^{13}C (‰)	Min δ^{13}C (‰)	Δ^{13}C (‰)	Max δ^{18}O (‰)	Min δ^{18}O (‰)	Δ^{13}O (‰)
cattle						
MKS001	-2.6	-6.4	3.8	-2.8	-5.8	3.0
MKS004	-8.4	-11.2	2.8	-2.7	-7.7	4.9
MKS006	-5.7	-11.2	5.5	-3.2	-7.7	4.6
MKS007	-7.9	-11.6	3.7	-2.7	-7.9	5.2
MKS014	-3.4	-9.8	6.4	-3.8	-6.3	2.5
MKS015	-8.7	-11.0	2.3	-2.9	-6.4	3.5
MKS016	-9.7	-12.6	3.0	-3.1	-6.9	3.8
MKS017	-9.2	-12.9	3.7	-3.5	-7.6	4.1
sheep						
MKS104	-6.8	-11.8	5.0	-1.4	-5.0	3.7
MKS105	-8.7	-13.5	4.9	-1.1	-6.3	5.2
MKS106	-5.7	-13.3	7.6	-1.3	-6.0	4.7
MKS107	-10.4	-14.6	4.2	-2.3	-6.9	4.6

Table 7.4: Summary statistics of the tooth enamel carbonate $\delta^{13}C_{VPDB}$ and $\delta^{18}O_{VPDB}$ values of sheep and cattle from Makriyalos. Δ values indicate the range of values between the maxima and the minima.

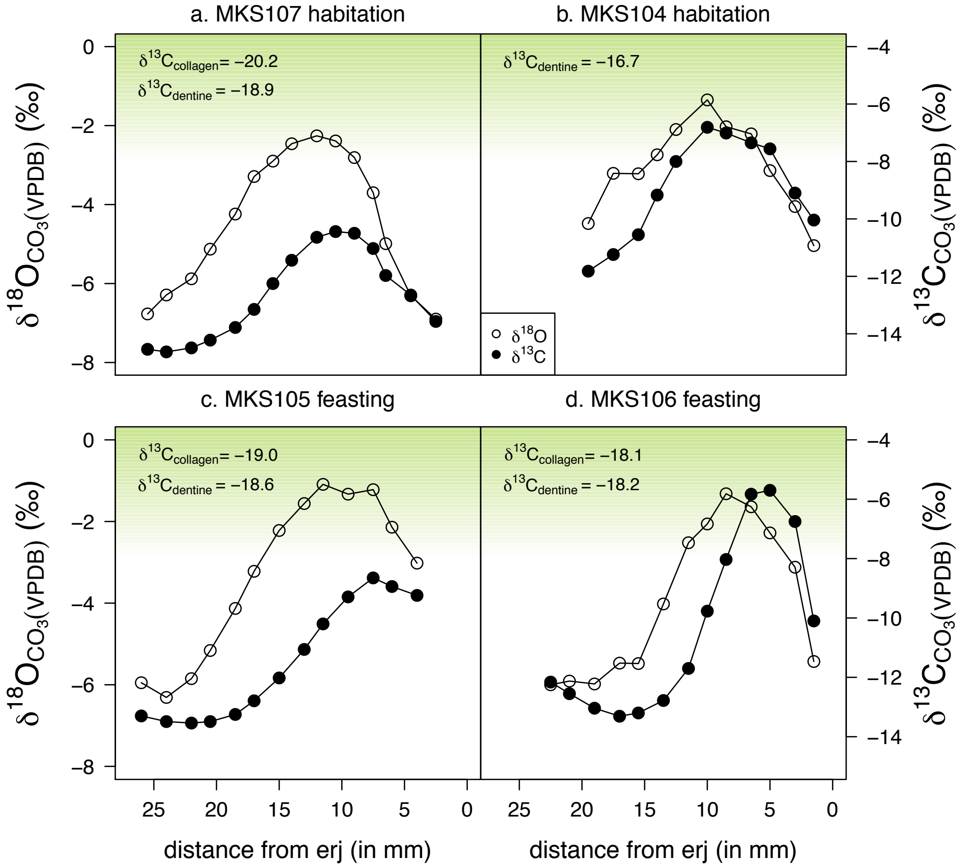


Figure 7.17: Bi-variate line plots of sequential tooth enamel carbonate δ^{18}O and δ^{13}C values of sheep from habitation contexts (**a–b**) and feasting context (Pit 212, **c–d**) at Makriyalos I. Positions of sub-samples are recorded as distances (in mm) from the enamel root junction (erj). δ^{13}C values of matching dentine and mandibular collagen (where C:N ratio was acceptable) are included for reference. Green shading indicates theoretical values of consumers with increasing amounts of C_4 vegetation in their diet (the bottom endpoint is set at –8‰, cf Cerling et al., 1997).

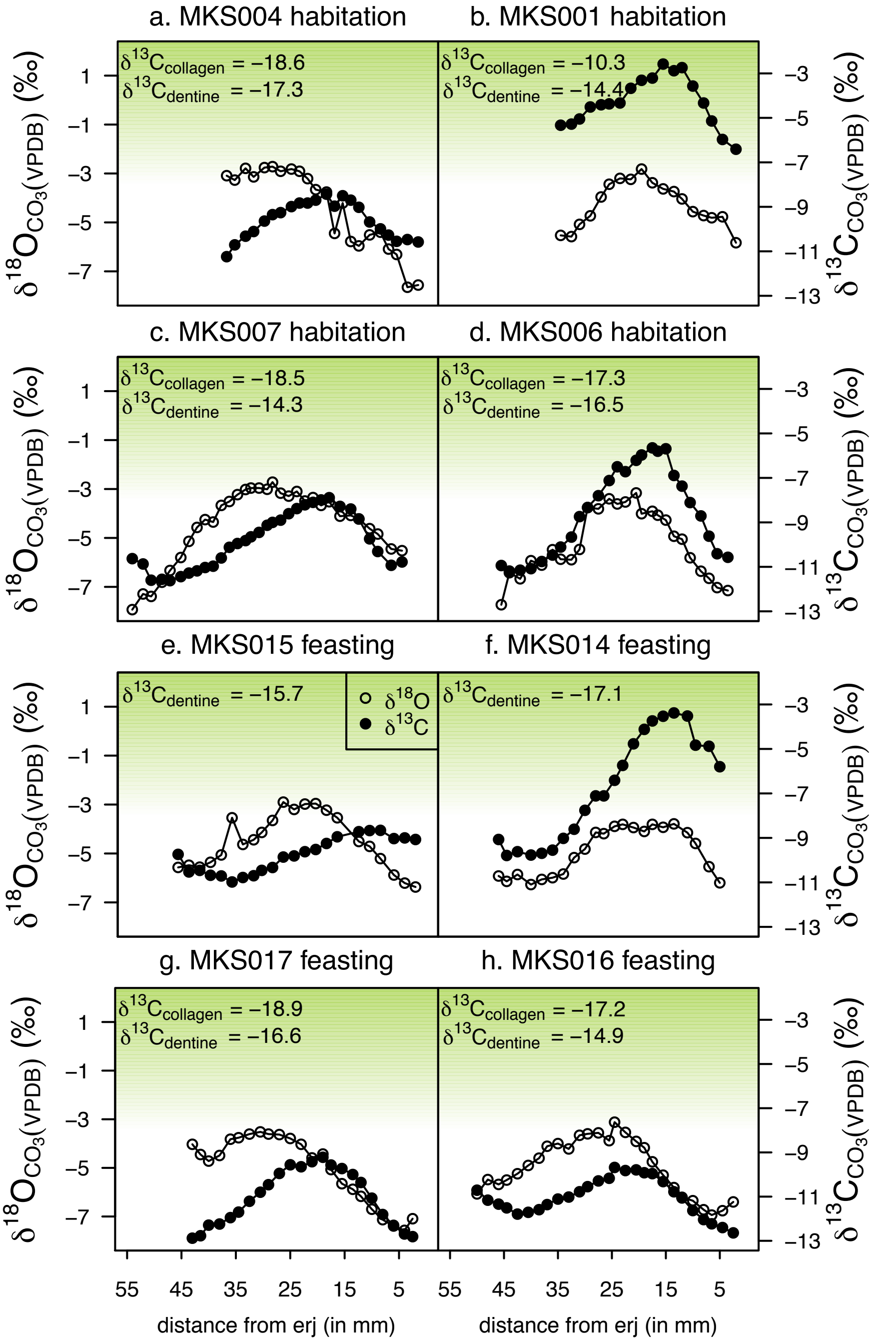


Figure 7.18: Bi-variate line plots of sequential tooth enamel carbonate $\delta^{18}O$ and $\delta^{13}C$ values of cattle from habitation contexts (a-d) and feasting context (Pit 212, e-h) at Makriyalos I. Positions of sub-samples are recorded as distances (in mm) from the enamel root junction (erj). $\delta^{13}C$ values of matching dentine and mandibular collagen (where C:N ratio was acceptable) are included for reference. Green shading indicates theoretical values of consumers with increasing amounts of C_4 vegetation in their diet (the bottom endpoint is set at –8‰, cf Cerling et al., 1997).

tooth	species	material	$\delta^{13}C_{VPDB}$	$\delta^{13}C_{SD}$	%C	$\delta^{15}N_{AIR}$	$\delta^{15}N_{SD}$	%N	CN
MKS001	cattle	collagen	-10.3	0.1	41.0	5.2	0.2	14.4	3.3
		dentine	-14.4	0.5	2.8	6.2	0.9	0.7	4.9
		enamel (average)	-4.3	1.1					
MKS004	cattle	collagen	-18.6	0.1	24.8	8.5	0.2	8.6	3.4
		dentine	-17.3	0.5	2.7	9.9	0.7	0.6	5.2
		enamel (average)	-9.6	0.8					
MKS006	cattle	collagen	-17.3	0.1	40.0	3.5	0.2	14.4	3.2
		dentine	-16.5	0.5	3.5	6.0	0.9	0.9	4.5
		enamel (average)	-8.5	2.0					
MKS007	cattle	collagen	-18.5	0.1	16.9	3.3	0.2	5.5	3.6
		dentine	-14.3	0.5	1.4	-0.9	1.2	0.1	12.1
		enamel (average)	-9.9	1.2					
MKS014	cattle	collagen	unacceptable CN ratio						
		dentine	-17.1	0.5	2.1	4.5	0.9	0.4	6.2
		enamel (average)	-6.7	2.4					
MKS015	cattle	collagen	unacceptable CN ratio						
		dentine	-15.7	0.5	2.4	4.2	1.0	0.5	6.1
		enamel (average)	-9.8	0.8					
MKS016	cattle	collagen	-17.2	2.7	37.4	6.4	0.2	13.6	3.2
		dentine	-14.9	0.5	4.2	9.7	0.7	0.9	5.4
		enamel (average)	-11.0	0.8					
MKS017	cattle	collagen	-18.9	0.1	22.5	4.8	0.2	7.5	3.5
		dentine	-16.6	0.5	2.6	2.3	1.1	0.4	7.8
		enamel (average)	-11.1	1.3					
MKS104	sheep	collagen	unacceptable CN ratio						
		dentine	-16.7	0.5	3.9	8.7	0.8	1.0	4.3
		enamel (average)	-9.0	1.8					
MKS105	sheep	collagen	-19.0	0.2	27.5	4.6	0.3	8.9	3.6
		dentine	-18.6	0.6	3.0	6.2	0.9	0.7	4.8
		enamel (average)	-11.5	2.0					
MKS106	sheep	collagen	-18.1	0.5	30.7	4.5	0.9	10.5	3.4
		dentine	-18.2	0.5	3.4	5.6	0.9	0.8	4.8
		enamel (average)	-10.4	2.9					
MKS107	sheep	collagen	-20.2	0.6	34.0	4.2	1.0	11.7	3.4
		dentine	-18.9	0.6	5.2	7.7	0.8	1.4	4.5
		enamel (average)	-12.6	1.6					

Table 7.5: Summary of $\delta^{13}C$ and $\delta^{15}N$ values of mandibular collagen and tooth dentine, and average $\delta^{13}C$ values of tooth enamel carbonate of cattle and sheep measured in stage 2 of this study. SD of collagen and dentine values refer to the instrument error attached to each measurement, while the SD of enamel indicates intra-tooth variability.

δ^{13}C values vary from –14.6 to –5.7‰ in sheep and from –12.9 to –2.6‰ in cattle, with mean amplitude of intra-tooth variation at 5.4‰ (from 4.2 to 7.6‰) for sheep and at 3.9‰ (from 2.3 to 6.4‰) for cattle. δ^{18}O values vary from –6.9 to –1.1‰ in sheep and –7.9 to –2.7‰ in cattle, with mean intra-tooth variation of 4.6‰ (from 3.7 to 5.2‰) for sheep and 3.9‰ (from 2.5 to 5.2‰) for cattle.

7.3.2.2 Sheep

In the case of sheep, the correlation between δ^{13}C and δ^{18}O values is similar in all four cases (for linear regressions between δ^{13}C and δ^{18}O, $r^2 = 0.55$ for MKS104, 0.68 for MKS105, 0.58 for MKS106, and 0.62 for MKS107, $p < 0.01$ in all cases; see Fig. 7.19). Surprisingly, the strongest linear correlations (in MKS105 and MKS107) are found in teeth that show a weaker input of C_4 plants in their early-life diets. However, the differences in r^2 values are negligible (within 0.1).

Two sheep individuals (MKS104 and MKS106) venture into the C_4 region in terms of their tooth carbonate values (see Fig. 7.17) and also exhibit less negative dentine δ^{13}C values comapred to the other two sheep (MKS104: $\delta^{13}C_{\mathrm{dentine}}$ = –16.7 ± 0.5‰, MKS106: $\delta^{13}C_{\mathrm{dentine}}$ = –18.2 ± 0.5‰, MKS105: $\delta^{13}C_{\mathrm{dentine}}$ = –18.6 ± 0.6‰, MKS107: $\delta^{13}C_{\mathrm{dentine}}$ = –18.9 ± 0.6‰). Statistical analysis was not carried out to test this distinction due to the small number of samples.

The sheep with an early-life C_4 contribution in their diet were slaughtered at older ages (MKS104: 4–6 years, MKS106: 3–4 years) than the other two sheep (both died at 2–3 years of age; see Table 7.2). Three sheep yielded a mandibular collagen value with an acceptable C:N ratio (MKS105, MKS106, MKS107) and seem to have consumed consistent diets throughout their lives: both their intra-tooth average enamel carbonate δ^{13}C values and their mandibular collagen δ^{13}C values are predominantly C_3 (see Fig. 7.17

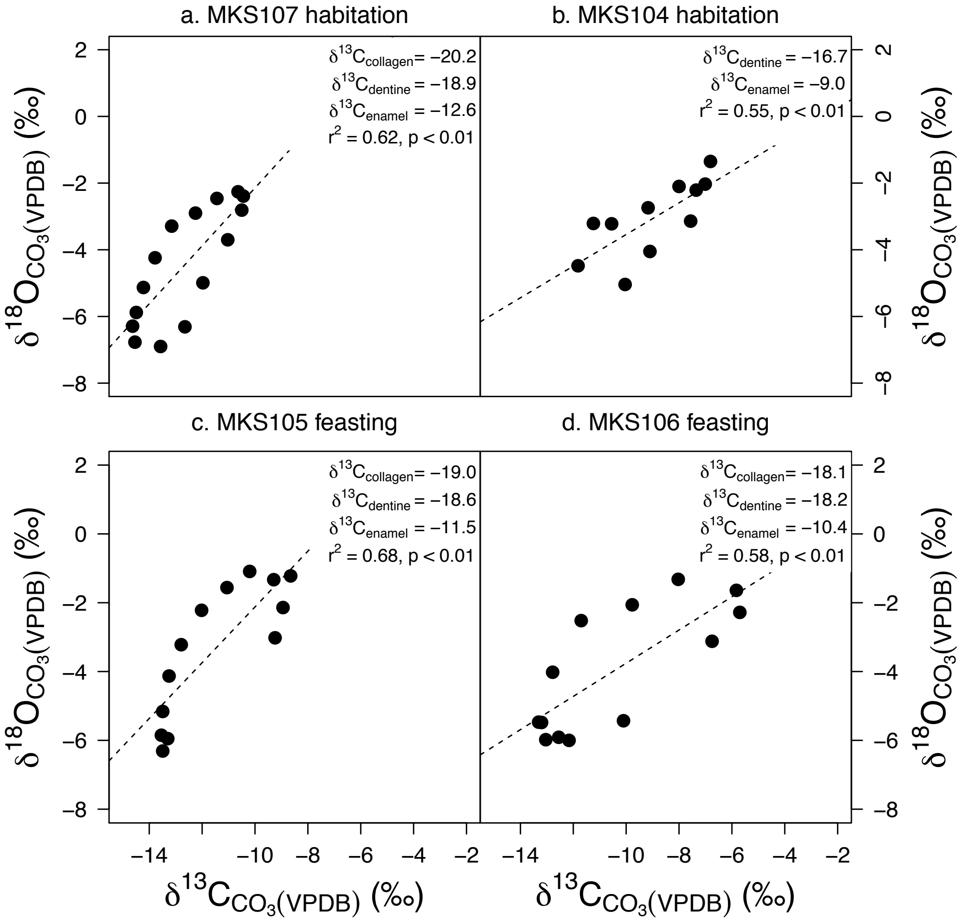


Figure 7.19: Bi-variate line plots of tooth enamel carbonate $\delta^{13}C$ vs. $\delta^{18}O$ values of sheep from habitation contexts (a-b) and feasting context (Pit 212, c-d) at Makriyalos I. The dots are joined based on their position on the tooth axis. Available dentine, mandibular collagen and average enamel carbonate $\delta^{13}C$ values are included for reference.

and Table 7.5; keeping in mind that the diet-tissue enrichment is different for collagen and carbonate, see Chapter 4.4.2). The individual without a reliable collagen value (MKS104) yielded the lowest dentine signal (–16.7‰).

Bearing in mind the sample size of four individuals, the data suggest that there are no differences in the grazing behavior between sheep discarded in Pit 212 and those discarded in habitation contexts. Both groups have one individual with slight contribution of C_4 plants during the first year of its life (MKS104 – habitation, and MKS106 – feasting) and one individual that is a predominantly a C_3 feeder (MKS107 – habitation, and MKS105 – feasting).

7.3.2.3 Cattle

In the case of cattle, five individuals exhibit correlation between their $\delta^{13}C$ and $\delta^{18}O$ values ($r^2 = 0.55$ for MKS001, 0.72 for MKS006, 0.54 for MKS016, 0.60 for MKS014 and 0.48 for MKS007, $p < 0.01$ in all cases, see Fig. 7.20), but three individuals do not ($r^2 = 0.06, p = 0.29$ for MKS004; $r^2 = 0.09, p = 0.16$ for MKS017; $r^2 = 0.01, p = 65$ for MKS015). Unlike with the sheep, it is the individuals with the highest input of C_4 vegetation in their tooth carbonate signatures (MKS001, MKS006, MKS014) that exhibit the strongest correlations. These same individuals also show varying inputs of C_4 plants in their matching mandibular collagen and dentine $\delta^{13}C$ values: MKS001: $\delta^{13}C_{collagen} = –10.3 \pm 0.1‰$, $\delta^{13}C_{dentine} = –14.4 \pm 0.5‰$; MKS006: $\delta^{13}C_{collagen} = –17.3 \pm 0.1‰$, $\delta^{13}C_{dentine} = –16.5 \pm 0.5‰$; MKS014: $\delta^{13}C_{dentine} = –17.1 \pm 0.5‰$; the mandibular collagen of MKS014 had an unacceptable C:N ratio.

For the rest of the individuals (MKS004, MKS007, MKS015, MKS016, MKS017), tooth carbonate $\delta^{13}C$ values indicate consumption of C_3 vegetation during M2 enamel mineralization, and dentine values suggest a noticeable input of C_4 plants at some point during the M2 dentine formation: MKS004: $\delta^{13}C_{dentine} = –17.3 \pm 0.5‰$, MKS007: $\delta^{13}C_{dentine} = –14.3 \pm$

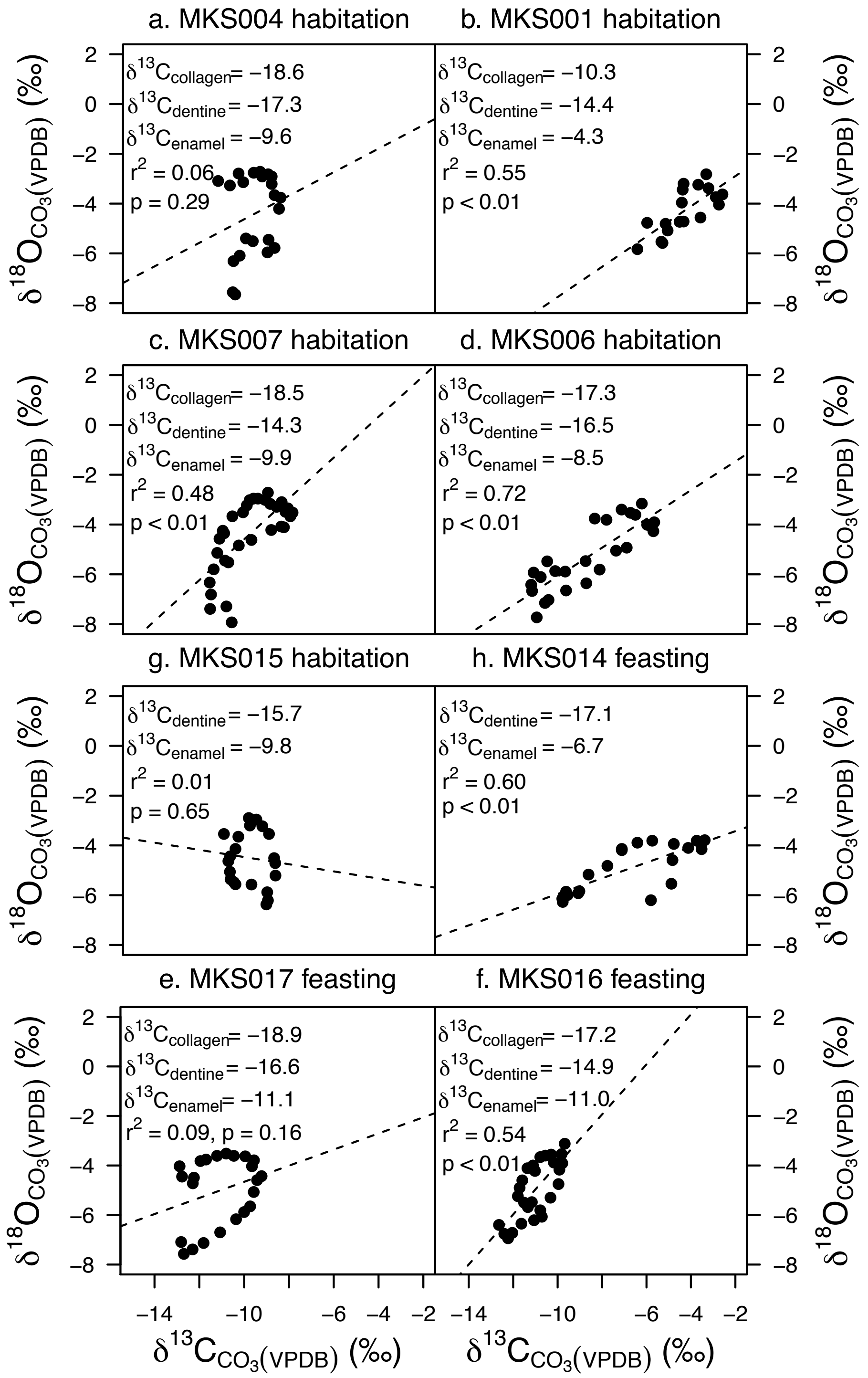


Figure 7.20: Bi-variate line plots of tooth enamel carbonate $\delta^{13}C$ vs. $\delta^{18}O$ values of cattle from habitation contexts (a-d) and feasting context (Pit 212, e-h) at Makriyalos I. The dots are joined based on their position on the tooth axis. Available dentine, mandibular collagen and average enamel carbonate $\delta^{13}C$ values are included for reference.

0.5‰, MKS015: $\delta^{13}C_{\text{dentine}}$ = –15.7 ± 0.5‰, MKS016: $\delta^{13}C_{\text{dentine}}$ = –14.9 ± 0.5‰, MKS017: $\delta^{13}C_{\text{dentine}}$ = –16.6 ± 0.5‰. The matching mandibular collagen values show a slight influence of C_4 plants in the long-term dietary average of four of these five cows (MKS004: $\delta^{13}C_{\text{collagen}}$ = –18.6 ± 0.1‰, MKS007: $\delta^{13}C_{\text{collagen}}$ = –18.5 ± 0.1‰, MKS016: $\delta^{13}C_{\text{collagen}}$ = –17.2 ± 2.7‰, MKS017: $\delta^{13}C_{\text{collagen}}$ = –18.9 ± 0.1‰). The time-periods represented in the enamel and dentine cannot be distinguished with precision beyond stating that they were formed during the first year of the individuals' lives (see Section 4.1.3). However, the fact that the three lines of evidence (enamel, dentine and bone collagen) show varying inputs of C_4 vegetation in the diets of these five individuals suggests that they did not consume uniform diets over the course of their first year and their life (see more below).

Compared to the sheep, the intra-tooth sequences of the cattle are not as 'smooth', which may suggest that cattle grazed in a larger number of different pastures over the course of their first year. This can be due to the fact that vegetation from several locations involves a higher variability in seasonal fluctuations in temperature and moisture, so the resulting curves are more 'noisy'. Despite the larger variability in management strategies of the cattle, there do not seem to be any systematic differences between cattle recovered in the feasting pit and those buried in habitation deposits. There are also no distinctions correlated to the age at which the animals were slaughtered, although the cattle were all slaughtered either between 16–28 months or between 2–3/3.5 years (see Table 7.2).

7.3.2.4 Sheep and cattle combined

Overall, cattle records a stronger dietary intake of C_4 vegetation than sheep (see Fig. 7.21), but lower consistency between long-term and short term dietary signatures. Fig. 7.22 shows that sheep lie closer to the regression line between mean $\delta^{13}C_{carboante}$ and $\delta^{13}C_{collagen}$ values, which indicates that they consumed more uniform diets over the course of their lives.

Correlation between $\delta^{13}C$ and $\delta^{18}O$ does not seem to be dependent on the amount of C_4 input in the animals' diets. As mentioned above, the sheep that have a marginally stronger correlation have weaker input of C_4 vegetation in their tooth carbonate signals, but with the cattle, it is the opposite. Of the five cows that do not show significant C_4–input based on their tooth carbonate values (MKS004, MKS007, MKS015, MKS016, MKS017), two exhibit correlation between $\delta^{18}O$ and $\delta^{13}C$ values (MKS016 and MKS007) and three do not (MKS004, MKS015 and MKS017).

A possible explanation for this observation is that all of these five individuals subsisted on a mixed C_3–C_4 diet, but the former two obtained their C_4 plants during the summer (when C_4 vegetation is in season) while the latter three others did not; perhaps because they were foddered on these plants at other times of the year. In Makarewicz's (2014) study of modern fodder-fed sheep in Mongolia, some individuals exhibited flat patterns in $\delta^{13}C$ intra-tooth variation, while others did not, and the authors interpreted this variability in terms of differences in feeding practices: farmers would decide on an individual basis how to distribute fodder depending on the animals' reproductive abilities and their health. Thus, based on the results from Mongolia, it can be seen that fodder intake does not always cause the $\delta^{13}C$ sequences to be flat (as seen in Chapter 6.3.2.1). They may show the expected Mediterranean annual variation in $\delta^{13}C$ values, but may, however, exhibit lower correlation between their $\delta^{13}C$ and $\delta^{18}O$ values.

It is unlikely that either the cattle or the sheep were herded at higher altitudes at any point during the year that their enamel was mineralizing. Trans-altitudinal mobility tends to dampen $\delta^{18}O$ amplitudes (Longinelli and Selmo, 2003) and both of these species in fact show a wider $\delta^{18}O$ amplitude (4.5‰ for sheep and 3.9‰ for cattle) compared to the intra-annual variation of local

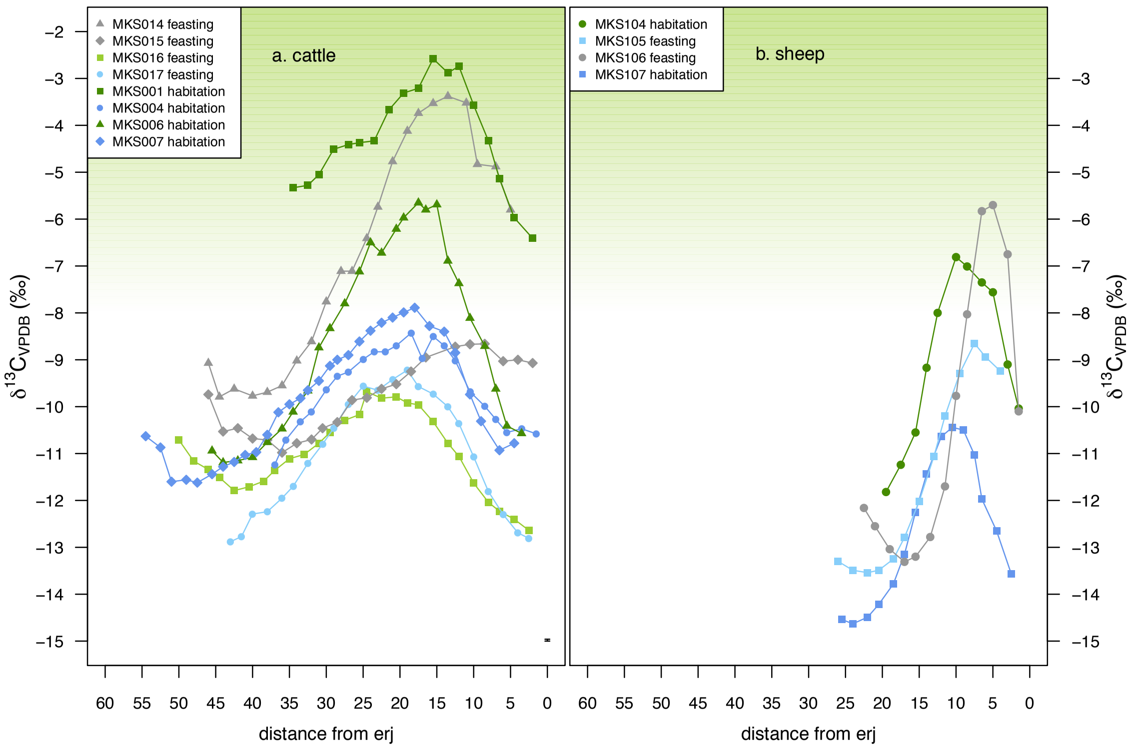


Figure 7.21: Bi-variate scatter plots of sequential tooth enamel carbonate δ^{13}C values of cattle (a) and sheep (b) from Makriyalos I. Green shading indicates theoretical values of consumers with increasing levels of C_4 input (the lower endpoint is –8‰, cf Cerling et al., 1997). Measurement error is shown in the bottom-right of panel **a**. Colors of the points correspond to the results of mandibular collagen δ^{13}C measurements: blue points are from predominantly long-term C_3 feeders, green points are from predominantly long-term C_4 feeders. Grey points are from individuals where C:N ratios of mandibular collagen failed.

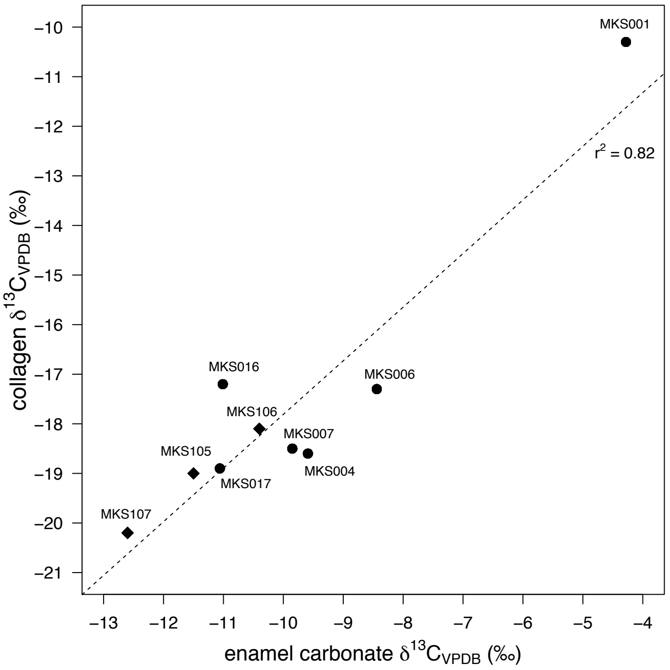


Figure 7.22: Bi-variate scatter plot of mean tooth enamel carbonate δ^{13}C values and bone collagen δ^{13}C values of cattle and sheep analyzed in stage 2 of this study. Circles represent cattle, diamonds represent sheep.

precipitation (3.6‰). Fig. 7.30 shows a plot of estimated average monthly local $\delta^{18}O_{VSMOW}$ values from the coastal region, along with values for the two zones with different expected $^{87}Sr/^{86}Sr$ values (Cretaceous limestone[1] and Palaeozoic flysch[2]; data obtained from the Online Isotope Precipitation Calculator, `http://wateriso.utah.edu/waterisotopes/pages/data_access/oipc.html`; discussed further in Section 7.3.3.2).

Sheep record higher $\delta^{18}O$ values compared to the cattle (see Fig. 7.23). Similar observations have been made at the sites of Măgura-Boldul lui Moş Ivănuş and Vităneşti in Romania, (where the amplitudes of variation were 4.9 – 7.0‰ for sheep and 2.3 – 4.4‰ in cattle; Balasse et al., 2013) in Bercy, France (2.5 – 4.8‰ in sheep and 1.5 – 4.0‰ in cattle; Balasse et al. 2012*a*) and Orkney (3.4 – 3.9‰ for sheep and 1.6 – 2.8‰ in cattle; Balasse et al., 2006). It is tempting to interpret this difference in terms of grazing behavior, however, species-specific patterns and rate of enamel mineralization mean that sheep and cattle raised in the same environment may naturally exhibit varying degrees of ^{18}O-enrichment. Balasse (2003) further warns against the interpretation of absolute $\delta^{18}O$ values due to differences in behavior and physiology. For these reasons, no attempt will be made to explain the differences between sheep and cattle absolute $\delta^{18}O$ values.

7.3.2.5 Birth seasonality

The timing of births of cattle and sheep at Makriyalos I was assessed using normalized values of $\delta^{18}O_{max}$ (following method established by Balasse et al. 2012*a*; see Chapter 4.7). Two individuals (MKS007 and MKS104) were missing the minimum values, so they could not be modelled. The parameters calculated by the model are shown in Table 7.6. The lines of best fit are shown in Appendix C. Fig. 7.24 shows the normalized delay, x_0/X, of the two groups of domestic animals. The y–axis is divided into 12 segments,

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[1] 40° 26' 50.51" N, 22° 21' 58.14" E, 365masl

[2] 40° 24' 56.34" N, 22° 19' 54.72" E, 543masl

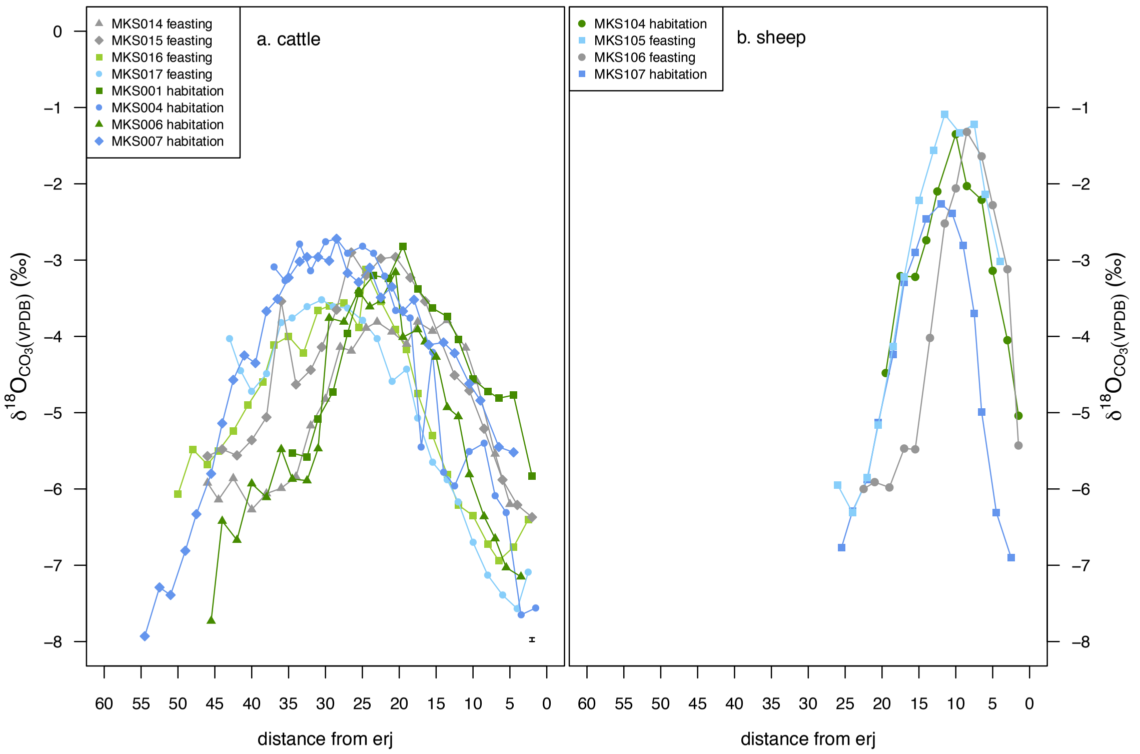


Figure 7.23: Bi-variate scatter plots of sequential tooth enamel carbonate $\delta^{18}O$ values of cattle (a) and sheep (b) from Makriyalos I. Measurement error is shown in the bottom-right of panel **a**. Colors of the points correspond to the results of mandibular collagen $\delta^{13}C$ measurements: blue points are from predominantly long-term C_3 feeders, green points are from predominantly long-term C_4 feeders. Grey points are from individuals where C:N ratios of mandibular collagen failed.

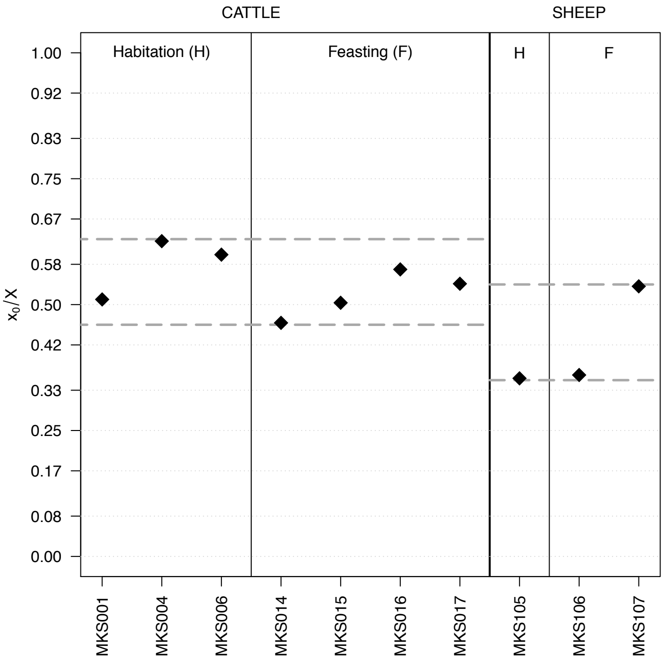
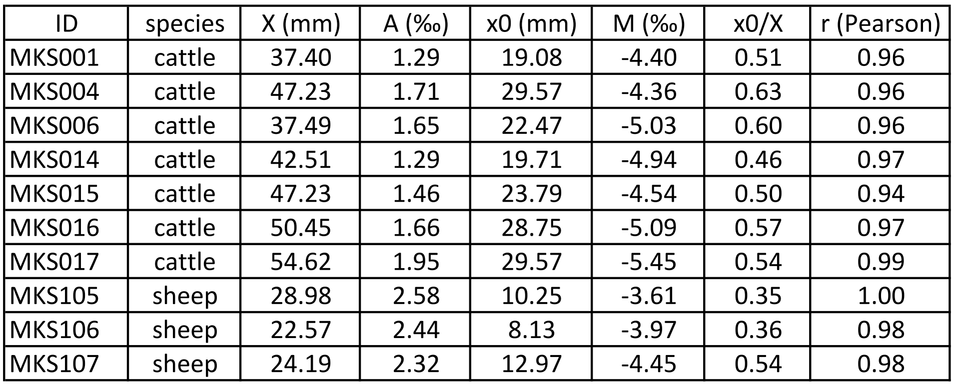


Figure 7.24: Uni-variate scatter plot of x_0/X values (distance at which $\delta^{18}O_{max}$ values occur in a tooth, x_0, with respect to the period recording the annual cycle, X) of cattle and sheep from habitation and feasting contexts at Makriyalos I. The y–axis is divided into 12 units, each corresponding to one month of the year.

each corresponding to one month of the year. The farther apart that the x_0/X values lie from each other on the y–axis, the bigger the gap between the births of those two individuals.



ID	species	X (mm)	A (‰)	x0 (mm)	M (‰)	x0/X	r (Pearson)
MKS001	cattle	37.40	1.29	19.08	-4.40	0.51	0.96
MKS004	cattle	47.23	1.71	29.57	-4.36	0.63	0.96
MKS006	cattle	37.49	1.65	22.47	-5.03	0.60	0.96
MKS014	cattle	42.51	1.29	19.71	-4.94	0.46	0.97
MKS015	cattle	47.23	1.46	23.79	-4.54	0.50	0.94
MKS016	cattle	50.45	1.66	28.75	-5.09	0.57	0.97
MKS017	cattle	54.62	1.95	29.57	-5.45	0.54	0.99
MKS105	sheep	28.98	2.58	10.25	-3.61	0.35	1.00
MKS106	sheep	22.57	2.44	8.13	-3.97	0.36	0.98
MKS107	sheep	24.19	2.32	12.97	-4.45	0.54	0.98

Table 7.6: Results of the calculation of a line of best fit (using the method of least squares) for variation in period (X), amplitude (A), position of the $\delta^{18}O_{max}$ value (x_0), and mean $\delta^{18}O$ (M) of tooth enamel carbonate sequences from Makriyalos. Pearson's r expressess the correlation between the measured and the modelled values. x_0/X represents the delay of $\delta^{18}O_{max}$ values with respect to the period, used in this study to assess the timing of the animals' births. The model (established by Balasse et al. 2012*b*) uses the equation $\delta^{18}O_m = a\cos(2\pi(x - x_0)/(x + bx)) + m$.

The results show that the cattle were born within two months of each other (their x_0/X values lie between 0.46 and 0.63). The sheep individuals were born within 2.5 months of each other (their x_0/X values lie between 0.28 and 0.36). This suggests that all inviduals in the two groups were born within a single season and that the farmers at Makriyalos were not manipulating the births of the animals in order to secure milk supplies throughout the whole year.

7.3.3 Stage 3: Modern and archaeological Sr isotope results

7.3.3.1 Modern samples

Fig. 7.25 and Table 7.7 show the $^{87}Sr/^{86}Sr$ measurements of the modern vegetation in the seven geological zones around Makriyalos.

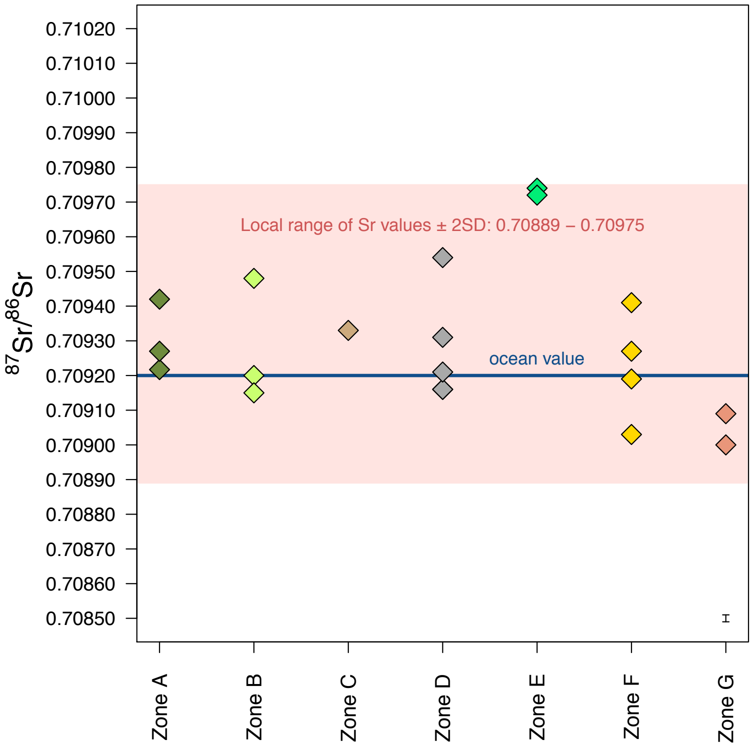


Figure 7.25: Uni-variate scatter plot of $^{87}Sr/^{86}Sr$ measurements of modern vegetation collected in the seven geological zones within 15km around Makriyalos. The measurements are used to establish the local range of $^{87}Sr/^{86}Sr$ values (see Section 7.3.3.1). For location of sampling points within each zone, see Fig. 7.10. Measurement error is shown in the bottom-right corner of the plot.

ID	Common name	Geological zone	Distance from coast (in km)	Elevation (in m)	Latitude	Longitude	Chronology	$^{87}Sr/^{86}Sr$
MAK04a	*Populus* sp., tree leaves	Zone E	3.8	101.8	40.47039	22.54325	Upper Miocene/Lower Pliocene	0.70974
MAK06a	*Tilia* sp., tree leaves	Zone E	3.7	75.0	40.46667	22.54367	Upper Miocene/Lower Pliocene	0.70972
MAK07a	*Quercus* sp., tree leaves	Zone F	7.6	297.1	40.41842	22.51678	Upper Miocene/Lower Pliocene	0.70941
MAK07b	*Teraxacum* sp., ground vegetation	Zone F	7.6	297.1	40.41842	22.51678	Upper Miocene/Lower Pliocene	0.70927
MAK08a	*Ficus carica*, tree leaves	Zone F	5.0	74.6	40.40081	22.55253	Upper Miocene/Lower Pliocene	0.70919
MAK09a	*Quercus* sp., tree leaves	Zone D	1.4	24.2	40.41403	22.59481	Pleistocene	0.70931
MAK10a	*Quercus* sp., tree leaves	Zone D	1.3	36.6	40.41642	22.59525	Pleistocene	0.70954
MAK11a	*Quercus* sp., tree leaves	Zone C	0.3	18.9	40.42392	22.60214	Pleistocene	0.70933
MAK12a	*Juglans regia*, tree leaves	Zone A	6.2	29.9	40.27975	22.52853	Holocene	0.70922
MAK16a	*Populus* sp., tree leaves	Zone A	3.5	17.8	40.31175	22.57822	Holocene	0.70942
MAK17a	*Quercus* sp., tree leaves	Zone G	7.6	106.2	40.34847	22.54683	Upper Miocene/Lower Pliocene	0.70900
MAK18a	*Quercus* sp., tree leaves	Zone G	7.6	109.5	40.34778	22.54750	Upper Miocene/Lower Pliocene	0.70909
MAK21a	*Juglans regia*, tree leaves	Zone F	8.6	132.0	40.37728	22.51719	Upper Miocene/Lower Pliocene	0.70903
MAK22a	*Ulmus* sp., tree leaves	Zone B	1.2	1.3	40.36800	22.62611	Holocene	0.70920
MAK24a	*Quercus* sp., tree leaves	Zone D	0.8	62.7	40.44889	22.58647	Pleistocene	0.70916
MAK25a	*Quercus* sp., tree leaves	Zone D	0.7	66.2	40.44925	22.58739	Upper Miocene/Lower Pliocene	0.70916
MAK27a	*Quercus* sp., tree leaves	Zone D	0.9	38.3	40.44047	22.59458	Upper Miocene/Lower Pliocene	0.70921
MAK28a	*Paliurus sprinta christi, shrub* leaves	Zone B	0.3	1.2	40.31597	22.62278	Holocene	0.70948
MAK32a	*Paliurus sprinta christi, shrub* leaves	Zone A	1.5	1.0	40.48019	22.57925	Holocene	0.70927
MAK34a	*Paliurus sprinta christi, shrub* leaves	Zone B	0.2	0.5	40.46778	22.58639	Holocene	0.70915

Table 7.7: $^{87}Sr/^{86}Sr$ results of modern plant samples collected from the geological zones around Makriaylos.

The results show that apart from higher values in Zone E (Neogene sandstones and marls), all the zones in the local environment – Neogene to Holocene in age – have indistinguishable ^{87}Sr/^{86}Sr values. The higher values in Zone E may reflect an alluvial component originating in a more radiogenic source. The values of all plants range between 0.70900 – 0.70974, with mean value of 0.70929±0.00041 (2σ). As the mean ± 2σ interval (0.70889–0.70970) does not include the measurements from Zone E (which reaches very close to the site; values of 0.70974 and 0.70972), in order to define the 'local range' of ^{87}Sr/^{86}Sr values, the top boundary was extended to include values from Zone E plus measurement error of 0.00001: 0.70889 – 0.70975.

Fig. 7.26 shows that there is no correlation between plant Sr isotope measurements and distance to the coast. More samples from the zones which lie directly next to the coast (Zone B, C and D) have values close to the value of the ocean (0.70920; Elderfield, 1986), but samples from the more distant zones lie both above and below this value. This suggests that the effects of sea spray cannot be directly detected at this range in the Pierian hill landscape.

Biologically available strontium on the Greek mainland has not yet been sufficiently mapped. Nafplioti (2011*b*) attempted to provide a first such map for the Aegean, but the bulk of measurements were done on archaeological enamel (and a few samples of archaeological bone), which cannot be assumed to be local to the depositional environment. A small number of modern shells were also measured at some of the sites (see also Nafplioti 2008, 2011*a*,*b*) but the results were not correlated to the underlying geologies, rather to isopic zones, which are made up of geologies of varying ages.

The most radiogenic values measured by Nafplioti (2011*b*) come from archaeological sheep/goat enamel from Tharrounia (Evvia) (value of 0.71110) and archaeological pig and sheep/goat enamel from Agio Galas on Chios (values of 0.71187, 0.71053, 0.71108). Even though the early life residence

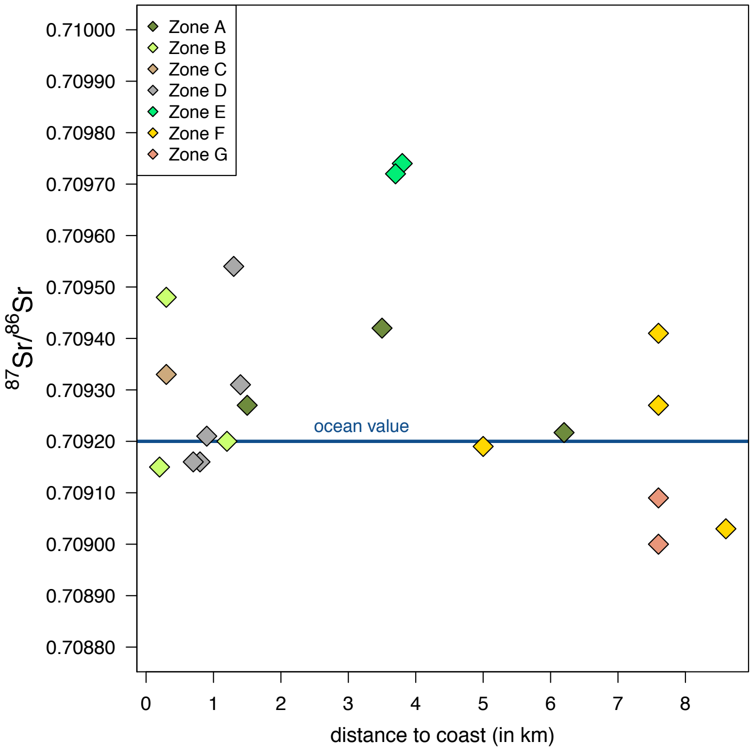


Figure 7.26: Bi-variate scatter plot of ^{87}Sr/^{86}Sr values of modern vegetation versus the distance from the coast of each sampling location. For a description of the geological zones, see Section 7.1.1 and Fig. 7.3.

of these animals is unknown, both geographical regions lie close to Palaeozoic formations (metamorphozed flysch on Chios and schist on Evvia), which formed at the same at as the Upper Palaeozoic–Middle Triassic schists in the Pieria mountains and which should thus have similar $^{87}Sr/^{86}Sr$ values.

7.3.3.2 Archaeological samples

Fig. 7.27 and Table 7.8 show the $^{87}Sr/^{86}Sr$ results of the archaeological cattle enamel. Two individuals (MKS001 from a habitation context and MKS014 from Pit 212) have identical summer and winter values, five individuals (MKS004, MKS006, MKS007, MKS015, MKS016) have summer and winter values within 0.00006 of each other, and one individual (MKS017) has distinctly different summer and winter values (difference of 0.0008). There is no relationship between $^{87}Sr/^{86}Sr$ values and Sr concentrations of the measured samples (See Fig. 7.28; cf Montgomery et al., 2014).

ID	context	estimated age	sample.position (in mm from erj)	$^{87}Sr/^{86}Sr$	Sr concentration (ppm)
MKS001-I	habitation	2-3.5 years	17.5	0.70969	70
MKS001-II	habitation	2-3.5 years	2	0.70969	71
MKS004-I	habitation	2-3 years	30	0.70941	267
MKS004-II	habitation	2-3 years	1.5	0.70936	295
MKS006-I	habitation	2-3 years	15	0.70931	214
MKS006-II	habitation	2-3 years	3.5	0.70937	230
MKS007-I	habitation	16-28 months	28.5	0.7095	192
MKS007-II	habitation	16-28 months	4.5	0.70955	217
MKS014-I	feasting	16-28 months	34	0.70945	188
MKS014-II	feasting	16-28 months	11	0.70945	152
MKS015-I	feasting	16-28 months	20.5	0.71061	160
MKS015-II	feasting	16-28 months	6	0.71055	166
MKS016-I	feasting	2-3 years	22.5	0.7093	164
MKS016-II	feasting	2-3 years	8	0.70936	157
MKS017-I	feasting	16-28 months	32.5	0.70844	78
MKS017-II	feasting	16-28 months	2.5	0.70924	117

Table 7.8: $^{87}Sr/^{86}Sr$ measurements of archaeological cattle tooth enamel from Makriyalos. –I and –II refer to sub-samples targeting the summer and winter portion of the crown (determined using $\delta^{18}O$ maximum and minimum values obtained in phase 2 of this study).

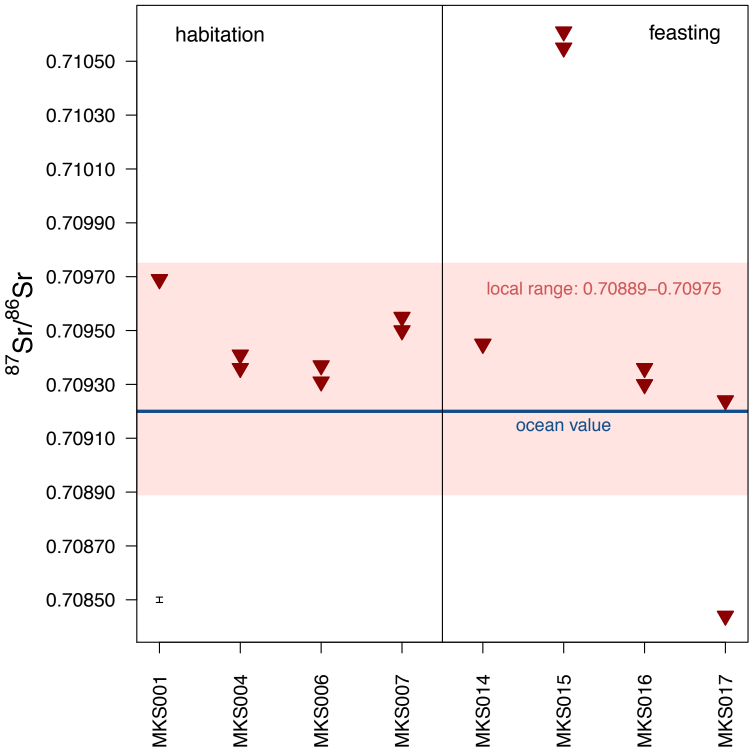


Figure 7.27: Bi-variate scatter plot of ^{87}Sr/^{86}Sr measurements of archaeological tooth enamel samples of cattle from habitation and feasting (Pit 212) contexts at Makriyalos I. Each tooth was sampled twice: once at the location that mineralized during the summer and once at the location that mineralized during the winter (determined using the $\delta^{18}O_{max}$ and $\delta^{18}O_{min}$ values obtained in stage 2 of this study, respectively). Measurement error is shown in the bottom-left corner of the plot.

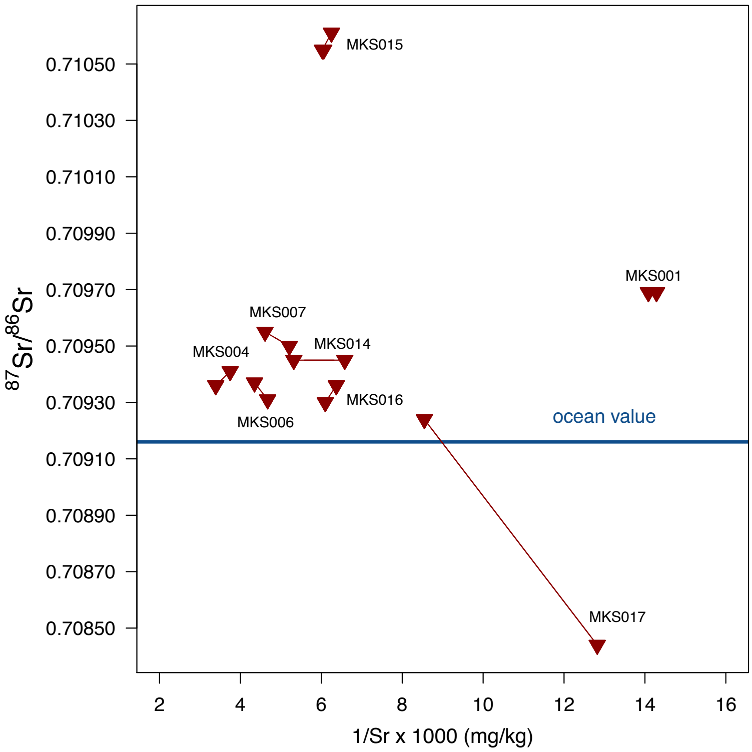


Figure 7.28: Bi-variate scatter plot of ^{87}Sr/^{86}Sr values of archaeological cattle tooth enamel samples from Makriyalos plotted against the inverse of strontium concentration of each sample. Lines connect two sub-samples taken from each tooth.

Most of the cattle values lay within the local ^{87}Sr/^{86}Sr range defined above, but two individuals (MKS015 and MKS017, both from the feasting deposit) show evidence of non-locality. MKS015 spent the first year of its life in a location with more radiogenic Sr geology (summer value = 0.71061, winter value = 0.71055). Similarly radiogenic values (up to 0.7110) were measured in a 40,000 year old Neanderthal tooth from the site of Lakonis in the Pelopponnese (Richards et al., 2008). The authors did not suggest a possible place of origin for this indiviudal, but Palaeozoic phyllites, quartzites and schists are found within a 30km radius of the site (IGME, 1983). The availability of Palaeozoic bedrock both close to Makriyalos and Lakonia suggest that these geologies can serve as possible (but not exclusive by any means) candidates for sources of ^{87}Sr/^{86}Sr values around 0.71061.

MKS017 likely moved after the summer of its first year (summer value = 0.70844, winter value = 0.70924) (see Fig. 7.29). Pure Cretaceous limestone has values of $0.7071 - 0.7078$, estimated using dated marine sediments (McArthur et al., 2001) and it is possible that this individual spent the first year of its life in the Cretaceous limestone zone of the Pieria mountains.

The second molar of MKS015 was in the worst state of preservation of all the teeth sampled. The surface of the mandible was covered in calcified material (resembling cement) and thorough drilling was required to reach the enamel surface, which had some cracks in it. A sample of enamel was taken close to one of the cracks and analyzed using FTIR (see Appendix B) and the results show that the enamel did not contain any calcite peaks (even without pre-treatment). Both the sequential samples for carbonate isotope analysis and the two sub-samples for Sr isotope analysis were taken on the clean portion of the tooth. In any case, contamination cannot be used to explain the high Sr isotope measurements obtained for this individual, because contamination would make the enamel look more local than non-local.

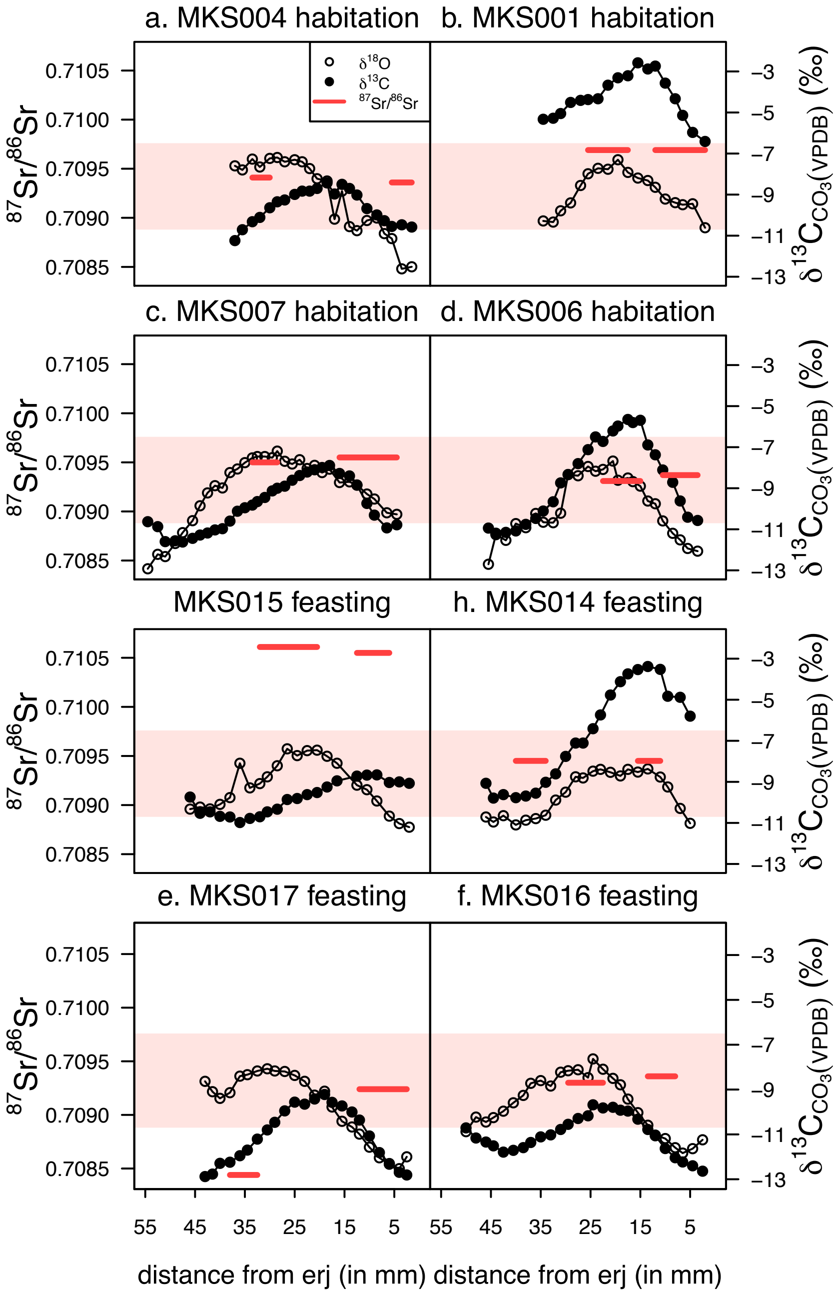


Figure 7.29: Bi-variate scatter plots of δ^{18}O δ^{13}C and ^{87}Sr/^{86}Sr values for all cattle tooth analyzed in this study. The y–axis for δ^{18}O measurements is not shown, as it is the position of the maximum and minimum values within each tooth, rather than the absolute values, that is used to determine the summer and winter portions of each tooth. The pink region indicates the local range of Sr isotope values determined using measurements of modern vegetation from several locations within 15km of the archaeological site (see Section 7.3.3.1 and Table 7.6).

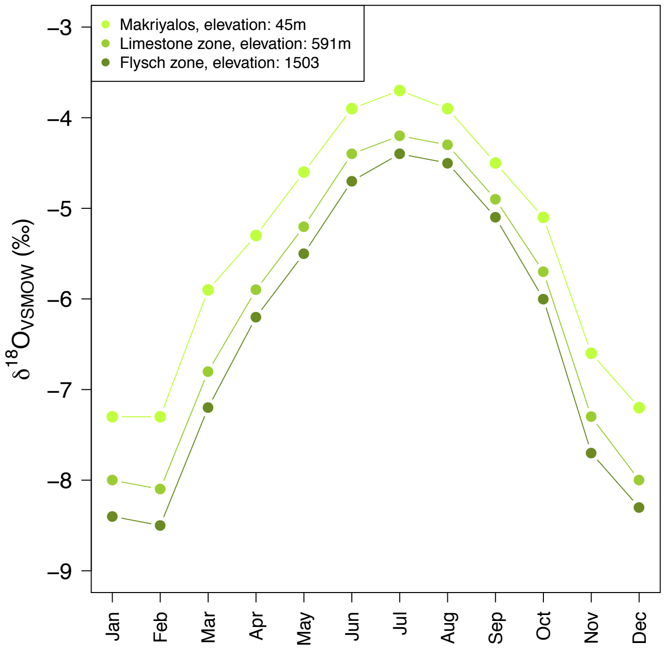


Figure 7.30: Average monthly precipitation $\delta^{18}O_{VSMOW}$ values for the locations of Makriyalos and two zones with different expected $^{87}Sr/^{86}Sr$ values: Cretaceous limestone and Palaeozoic flysch (see text for GPS coordinates of points used). Data obtained from the Online Isotope Precipitation Calculator, `http://wateriso.utah.edu/waterisotopes/pages/data_access/oipc.html`.

7.4 Discussion

The discussion presented in this section seeks to provide an inter-disciplinary synthesis of the findings obtained in this study with the rich body of literature produced during previous studies of the material from Makriyalos. The results of bone collagen analysis of domestic animals from both phases of occupation will be interpreted in light of previous stable isotopic measurements to further our understanding of human dietary habits during Makriyalos I and changes in animal feeding habits between Makriyalos I and Makriyalos II. Particular attention will be paid to the results of faunal and botanical analyses when interpreting the grazing behavior of cattle and sheep on both the short and long-term scales. Furthermore, information about the birthing seasonality of the herbivores will add to our understanding of the economic importance of these animals gleaned through faunal and ceramic residue analyses. Finally, the results of Sr isotope analyses of cattle tooth enamel will provide another angle for deciphering the scale and importance of the regional feasting activities organized at this site.

7.4.1 Human and animal diets at Makriyalos I

Previous stable isotope analysis of the assemblage from Makriyalos I focused exclusively on the remains of humans (Triantaphyllou, 2001). The results showed that the people consumed distinctly terrestrial C_3 diets, as no significant inputs of C_4 plants or marine foods was detected in their bone collagen values. This came as a slight surprise given the abundance of marine fish bones and shells in the faunal assemblage (Pappa et al., 2013). Pappa et al. (2013) argued that these C_3 diets were based on plant protein with "modest animal protein intake". However, this argument was made in the absence of plant and domestic herbivore $\delta^{13}C$ and $\delta^{15}N$ measurements and in spite of striking sparseness of legumes in the archaeobotanical assemblage.

Stable isotopic measurements of domestic herbivore bone collagen and a limited number of charred plant samples carried out in this study enable a closer examination of the diets of humans and animals during the first phase of occupation of Makriyalos. The results show that firstly, cattle had a higher contribution of C_4 plants in their diet than any other animal, both wild and domestic. They were likely herded separately from the other animals, at least over the long-term and particularly during their adult years. In addition to showing higher enrichment in ^{13}C overall, the isotopic signals of the cattle are also more variable, indicating that some individuals obtained higher amounts of C_4 plants than others. This may have been the result of both enforced management (select individuals may have been taken to pastures that were rich in C_4 plants during the summer) and natural variability (some pastures where the cattle were taken to graze may have been naturally more abundant in C_4 vegetation than others). A series of botanical surveys, summarized in Pyankov et al. (2010), show that due to higher temperatures and lower precipitation, the abundance of C_4 plants in southern Europe is higher compared to regions of central and northern Europe, with a total 54–71 species of C_4 plants recorded across Greece (36–47 species of annual and 18–24 perennial C_4 plants). Thus, the species variability of the C_4 biome in the study region was high and offered scope of variability in the δ^{13}C values of available browse and graze. These findings raises questions about the animals' seasonal grazing patterns, which will be discussed further below.

Secondly, the bone collagen results show that cattle products (both meat and milk) did not provide a significant contribution to the human dietary protein intake. The human isotopic signals are not only predominantly terrestrial, but also strikingly non-variable in terms of their δ^{13}C values. Since butchery marks and bone fragmentation data suggest that the cattle were eaten (Pappa et al., 2004) and that their carcasses were processed more intensively than those of sheep, goats and pigs (Halstead, 2007), it would seem that the animals were consumed on episodic occasions, which might not register in long-term bone collagen signatures. These occasions included both large-scale feasts (the remains of which were disposed off in features like Pit 212 and 214) and smaller feasts (which were cleared into everyday disposal areas, such as pits in Ditch Alpha).

Humans have mean collagen δ^{15}N values of 7.6 ± 1.1‰, and assuming a trophic offset of 4.0‰ between diet and tissue, the isotopic composition of their diet is around 3.6‰. As the mean values of the domestic animals are all between 4.3 – 5.2‰, there must have been another dietary source with lower δ^{15}N values, which pulled the values of the humans down. The emmer measured in this study, with values of 1.1 ± 0.7‰, may have been one such source. No other crops (especially pulses) from Makriyalos I were available for measurement, but their contribution to the human diet cannot be ruled out. These findings argue against the results of dental analysis, which showed a high frequency of calculus depositions and a low frequency of dental caries, and which suggested that the bulk of the human diet was composed of meat.

7.4.2 Crop growing conditions in Makriyalos I

The small number of emmer samples that were measured suggests that these crops were grown in ^{15}N–depleted soils. This is striking in light of the results of faunal analysis which suggested that some animals, such as sheep and goat, were kept in close proximity to the arable landscape (Pappa et al., 2013) and would thus have provided a readily available source of manure. It may be that the farmers were 1) not interested in using manure to increase the yield of their cereals, 2) applied manure to other crops, such as pulses, which did not preserve archaeologically or 3) the manure provided by the ovicaprids was insufficient to significantly raise the ^{15}N–enrichment in the soil. Since the sample set is so small, the management of crops will not be further assessed in this study.

7.4.3 Grazing patterns of domestic herbivores during Makriyalos I

Faunal analysis suggests that sheep and goats were slaughtered throughout the whole year and managed on a small-scale and Pappa et al. (2013) make a case that these animals may have grazed on nearby cultivated land or within the settlement enclosure. According to Halstead (2011), the 28ha enclosure may have sustained a few dozen sheep all year round or a few hundred sheep for a few months. Based on these inferences, it was hypothesized in this study that sheep would provide a set of short-ranging 'local' $\delta^{18}O$/ $\delta^{13}C$ tooth enamel carbonate signatures, which will help with interpreting the grazing range of the cattle. The results showed that indeed, sheep were managed on a local scale, as their intra-tooth sequences are consistently sinusoidal and 'smooth'. Their absolute $\delta^{13}C$ values fluctuate predictably due to annual changes in temperature, heat and moisture.

Cattle, on the other hand, were managed using a range of different strategies during the first year of their lives. Some cows (MKS001, MKS006, MKS014) consumed C_4 plants during the summer, while the rest subsisted on predominantly–C_3 diets throughout the entire year. Some cows (MKS004, MKS015, MKS017) were likely foddered during part of the year, as their $\delta^{13}C$ and $\delta^{18}O$ values showed lack of correlation. Compared to the sheep, the cattle show lower uniformity in diets over the course of their lives. The diversity in feeding patterns cannot be explained with seasonal movement away from the site, as Pappa et al. (2013) argue that animals were slaughtered at the site throughout the whole year and that Makriyalos was occupied year-round.

Results of archaeobotanical analysis, which showed a lack of summer weeds in the animal dung (Valamoti, 2004), would suggest that the selective foddering happened during the summer, with plants that were collected at other times of the year. However, it must be pointed out that the weed portion of the archaeobotanical assemblage was extremely limited and any interpretations are tentative. Since the intra-tooth sequences of the three individuals (MKS004, MKS015, MKS017) do not differ from those of the other individuals (the values still fluctuate predictably over the course of the hotter and the colder seasons so the only thing that distinguishes them is the lack of correlation between $\delta^{13}C$ to $\delta^{18}O$ values), the results of the stable isotope analyses cannot be used to determine when the foddering may have taken place.

While the sheep seem to have been restricted to a small number of grazing spaces, the cattle likely visited a range of different pastures over the course of their first year of life. This is based on the fact that their intra-tooth sequences are less smooth, and the fact that their dentine and enamel values do not record equal inputs of C_4 vegetation at distinct points of their first year. However, as the oxygen curves do not suggest mobility between varying altitudes, this seasonal movement was likely restricted to the Pierian hills, stretching over a radius of c.15km from the site. This is consistent with Pappa et al.'s (2013) argument – which is based on the evidence of year-round slaughter of cattle at the site – that the management of cattle was small-scale during the Early Late Neolithic.

The absolute $\delta^{13}C$ values of the domestic herbivores suggest that cattle consumed an overall higher amount of C_4 vegetation than sheep (which is in line with the collagen evidence for long-term diets), but caution needs to be exercised when comparing the absolute enamel carbonate values of different species. It is helpful instead to look at patterns within each group of animals.

While the sheep bone collagen results show that these animals subsisted on a predominantly C_3 diet over the long term, the enamel carbonate results indicate that the same was not the case during their early months. Two individuals (MKS104 and MKS106) consumed significant amounts of C_4 vegetation during the summer of their first year. This suggests that lambs may have had preferential access to C_4 vegetation (either within the settlement enclosure or beyond) compared to older sheep. The fact that some lambs had higher contribution than others may have been a result of being born on different years, when the availability of C_4 vegetation varied. In addition, the winter $\delta^{13}C$ values of three of the sheep (MKS105, MKS106, MKS107) are quite low (reaching to -14‰), which suggests that these individuals may have grazed in closed environments (such as forests) during the cold season.

With the cattle, the trend is reversed. Long-term dietary signatures suggest that on the whole, cattle consumed varying degrees of C_4 vegetation, while the first-year dietary signatures indicate that most of the diets were predominantly C_3 and only some individuals enjoyed seasonal or year-round intake of C_4 vegetation. The fact that the signatures of the calves are less C_4–influenced than the signatures of the older cows may mean that cattle of different ages were taken to distinct parts of the landscape for grazing. Thus, cows may have been given preferential access to C_4 pastures later in their lives. None of the measured cows exhibit such low winter $\delta^{13}C$ values as the sheep, suggesting that these animals are unlikely to have spent significant amounts of time in closed environments during the winter season.

7.4.4 Timing of cattle and sheep births during Makriyalos I

All the cattle and the sheep that were modelled were within a single season. This suggests that the farmers did not extend the animals' birthing season in order to obtain milk for year-round consumption. Together with the facts that 1) the faunal specialists argue that both sheep and cattle husbandry at Makriyalos was not milk-oriented (Pappa et al., 2013), and 2) no milk residues have been detected through analysis of ceramic remains (Evershed et al., 2008), it is argued in this study that cow milk did not play a large role in the subsistency economy at Makriyalos.

7.4.5 Management of feasting and non-feasting cattle during Makriyalos I

The results of both long-term diets recorded in bone collagen and early-life diets recorded in tooth enamel suggest that the management of cattle was not driven by the function that the individual animals were going to fulfill. Both feasting and non-feasting cows show equally wide variability in their long-term δ^{13}C values, and thus varying degrees of input of C_4 vegetation. The seasonal dietary patterns of calves from the feasting deposit and those from habitation deposits are all variable (implying management under a range of different strategies), but the choice of early-life management was not related to the type of context that the animals were going to be buried in. This is not the case with the sheep and the goats, as dental microwear results suggest that individuals from the feasting deposit had variable diets to sheep and goats from habitation deposits (Mainland and Halstead, 2005). However, this argument is further being brought into question by a more recent and more large-scale dental tooth microwear study (conducted by Lucy Lawrence), where preliminary results suggest that there is no systematic dietary distinction between the two groups.

7.4.6 Importing animals for the feast during Makriyalos I

Two cattle individuals (MKS015 and MKS017), both of which were likely foddered during part of their first year of life, show signs of non-local management based on their strontium isotope values. This suggests that they spent a portion of their first year grazing beyond the Pieria hills and the alluvial coast around Makriyalos.

MKS015 spent both the summer and winter of its first year on more radiogenic geology, such as on the Palaeozoic schists in the Pieria Mountains, at an altitude of over 1000m. It may have been foddered on vegetation from lower altitudes during a season when it were not available in that location.

MKS017 spent the summer of its first year in a location with lower Sr isotope values (such as the Lower Cretaceous limestones in the mountains, at an altitude of between 500–1000m) and the winter in the more proximal landscape on the Neogene deposits of the Pierian hills. It may have been foddered during either season, but the reason for foddering is counter-intuitive, since summers in the highlands and winters in the lowlands should provide vegetation available for direct consumption.

The presence of two non-local individuals among the feasting cattle points to the fact that the large-scale feast at Makriyalos I was not solely catered with resources managed within the proximal landscape. Instead, it involved movement of animals from more distant parts of the region, either as part of an exchange trade network or as a result of participants coming to the feast and bringing their animals with them as a contribution. Given the sample size of animals studied, this trend cannot be quantified, but the occurrence of an import strategy cannot be disputed.

The two cows that spent their early months in two different locations outside the Pierian hills landscape were most likely born in the Pieria mountains to the west. Other archaeological evidence – namely the presence of grinding stones made of schist and gneiss (Tsoraki, 2007) – suggest that people at Makriyalos had connections to these areas. These connections may have been purely based on a resource-exchange relationship or they may have been upheld on more personal levels, perhaps because of inter-marriages between the two areas. The connections did not end at the Pieria mountains, however. The presence of exotic raw materials (such as quartz, jasper and obsidian) in the lithic assemblage suggests that people at Makriyalos were part of a network that reached more distant parts of northern and southern Greece (Pappa et al., 2013) and the communal feast may have served to solidify these relationships. Regardless of how wide the network of participants was, it seems clear that the presence of ample amounts of meat for the feast was of high importance and that measures were in place to ensure its supply without the need to make the local animal management strategy large-scale.

7.4.7 Animal diets during Makriyalos II

Previous stable isotope analysis showed that during the Late Late Neolithic at Makriyalos II, pig diets differed significantly from boar diets (boars likely roamed in open woodland while pigs were managed close to the site) and red deer had some of the lowest δ^{15}N values of all animals measured (Triantaphyllou, 2001). Pappa et al. (2013) argue that diets of the red deer most closely resembled diets of the wild boar while pig diets were most similar to diets of humans from Makriyalos I.

Data obtained in the current study bring evidence of the diets of domestic animals into the picture and sheds further light on the nature of the diets of the wild species. The results show that unlike in Makriyalos I, sheep and goats had distinct diets during Makriyalos II. This may reflect a similar distinction as the one between the pigs and the wild boars, with the goats grazing in the wooded landscape while the sheep grazing closer to the cultivated areas, which were now likely located on the periphery of the settlement rather than amongst dispersed houses within a large enclosure.

Wild mammals were also more abundant during the latter phase of occupation (Collins and Halstead, 1999), perhaps because the management of domestic animals was scaled down after the period of large-scale feasting. The addition of two more samples of red deer into the stable isotope dataset also changes the range of δ^{15}N values of this species, as one of the red deer now records a δ^{15}N value as high as one of the pigs. In addition to the lower δ^{13}C values likely caused by the canopy effect, this variability in δ^{15}N values of the red deer may be the result of high natural variability in ^{15}N–enrichment of the soils in the wooded landscape around Makriyalos. The small number of lentils measured in this study is insufficient to assess the nature and scale of plant management during Makriyalos II, but the fact that these pulses are all enriched over 0‰ suggests that they grew in significantly ^{15}N–enriched soils.

7.5 Conclusion

The results obtained in this study contribute to the view that everyday lives of farmers at Late Neolithic Makriyalos were shaped by tensions between the individual and the communal spheres of functioning. During the Makriyalos I phase, the farmers organized exceptionally large-scale feasts, which may have taken place over several months of one year. Even though the scale of animal slaughter for the feast was substantial, the farmers managed to keep the scale of their animal husbandry small-scale. Evidence from Sr isotope analysis of cattle enamel further shows that two individuals (out of eight analyzed) were brought in from beyond the local environment to be slaughtered in the large feast indicating that preparation of the feast involved exchange across a regional network.

All the main domestic animal species – cattle, sheep, goats and pigs – were found in both feasting and non-feasting contexts in Makriyalos I, but cattle made a smaller contribution to the diets of the humans. This was likely because cattle occurred on the menu of humans less frequently than the other animals and their consumption during the feasts did not provide a significant protein contribution to the long-term diets of the individuals that were measured.

The results of sequential tooth enamel carbonate δ^{13}C and δ^{18}O measurements show that the herding strategies of sheep and cattle differed during Makiryalos I. While sheep were herded within the local landscape, where some individuals had more access to C_4 vegetation than others, cattle were managed in diverse ways and taken to a wider range of grazing pastures. No patterns were identified between animals (both sheep and cattle) deposited in the feasting contexts and the habitation context in terms of their feeding patterns. The $\delta^{18}O$ measurements further indicate that the timing of sheep and cattle births were not extended beyond the natural season and corroborate the results of ceramic residue (Evershed et al., 2008) and faunal (Pappa et al., 2013) analysis that milk extraction was not a major component of the subsistence strategy.

Chapter 8

Discussion and Conclusions

Academic discourse on the process of Neolithization in the Near East and southeastern Europe has shed light on aspects of diversity in how the new way of life manifested itself across this region. It has been argued (see Chapter 3) that the contents of the Neolithic ‘package’ exhibited regional variabilities and that the participation of local hunter-gatherers in the transition to food production influenced the way that the new ideas were implemented in the distinct environmental settings. Discussion in this chapter provides further insight into levels of diversity within the Neolithic way of life, with specific focus on how distinctive agricultural strategies were inter-twined with socio-cultural elements and environmental opportunities across parts of central Anatolia and the Aegean. The findings provide support for the idea that the spread of farming was not uniform and that the adoption of plant and animal domesticates in regions which did not develop farming independently was influenced by a host of local factors. The sites of Kouphovouno (Middle–Late Neolithic), Makriyalos (Late Neolithic) and Çatalhöyük (Pottery Neolithic) are used as case studies.

8.1 Diversity in arable management

The work conducted in this project provides evidence for the view that agro-pastoral management at Neolithic sites was small-scale and intensive (cf Halstead, 2000). Farmers at Kouphovouno, Makriyalos and Çatalhöyük all strove to achieve similar goals. They developed systems that allowed household-units to control production and mobilized labor and resources to increase their crop yields. The ways in which they went about doing this, however, differed as their decision-making was uniquely intertwined with social constructs that dictated the demand and value of certain crops, and by opportunities and constraints determined by the surrounding environment.

In Kouphovouno, resources used to fertilize cultivated soils were distributed on the basis of crop species. Cereals were grown in separate plots of land and free-threshing wheat and peas (possibly rotated in the same fields) received more manure than hulled barley and einkorn. In Çatalhöyük, on the other hand, all the different species of crops were grown in the full range of soils available around the site and access to these soils may have been partitioned according to physical arrangement of neighborhoods that radiated outwards in the form of radial 'wedges' (cf Hodder 2008). In Makriyalos, emmer was grown in soils which do not look intensively managed, but the possibility that other crops received intensive treatment should not be excluded purely based on the fact that they did not preserve and become available for analysis (see Fig. 8.1).

Reasons why farmers at these three sites treated their crops in distinct ways were rooted in social and environmental constraints and prescriptions. On the one hand, farmers had to understand and cater to the requirements of their crops and to the availability of soils. On the other hand, they could exercise freedom with culinary preferences and socially-mediated demand.

In the first instance, the farmers had to work with what was available. The landscape around Çatalhöyük was exceptionally diverse, and offered

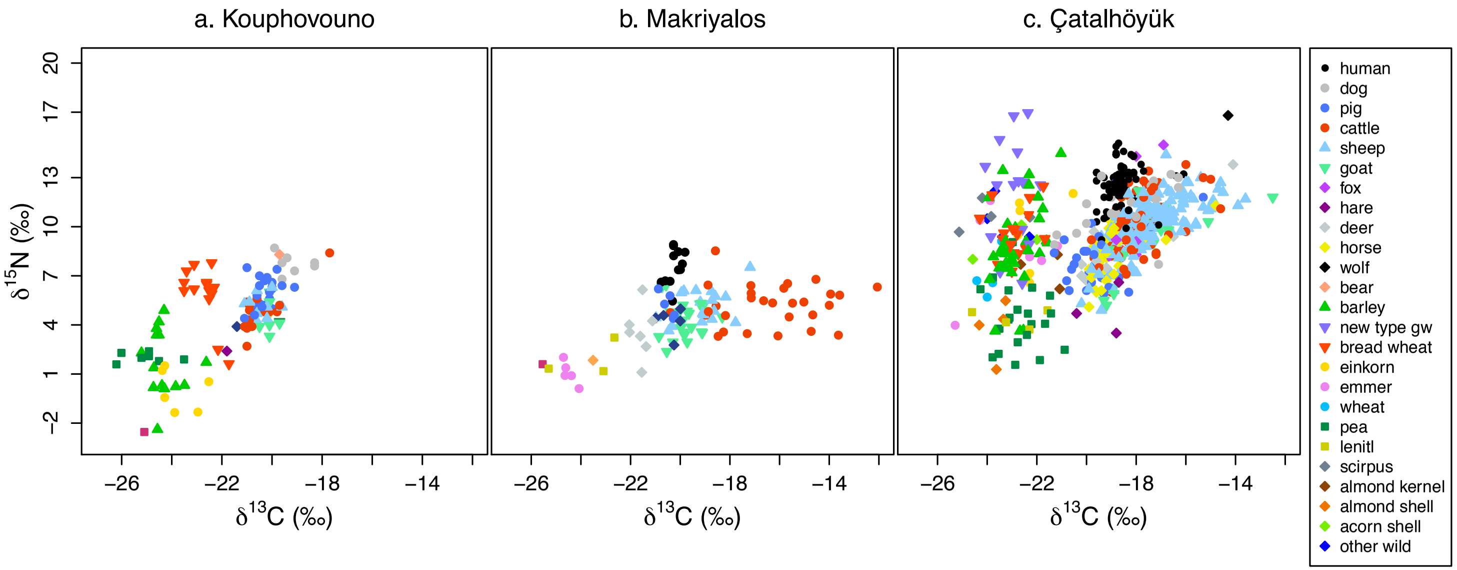


Figure 8.1: Bi-variate scatter plots of all plant and animal δ^{13}C and δ^{15}N values measured at the sites of Kouphovouno (a), Makriyalos (b) and Çatalhöyük (c). Human and wild animal measurements from Makriaylos were obtained from Triantaphyllou (2008). Human and all animal measurements from Çatalhöyük were obtained from Jessica Pearson (pers. comm); analysis published in Pearson (2013); Pearson et al. (2015).

pockets of naturally ^{15}N–enriched soils that were unevenly drained. The farmers thus had a choice to sow some crops in the more ^{15}N–enriched zones and other crops in the more depleted pockets, or to sow their crops in an indiscriminate manner. They chose the latter strategy, which provided them with a buffer against complete failure of any one crop and assured a stable average annual yield of cereals, despite possible fluctuation in productivity of some varieties. The decision for which crops should be grown under more intensive treatment closer to the village may have been done on a yearly basis, depending on the availability of seedcorn or the demands of the community.

Kouphovouno was surrounded by a more consistent spread of soils and only the ones located in close proximity to the village could become more enriched in ^{15}N and therefore more productive. The farmers thus had a choice to grow one type of crop more intensively in the proximal soils or to sow all kinds of crops under both intensive and extensive treatments. They chose to focus on maximizing the returns of one cereal type, while securing a buffer through the other two types.

Environmental constraints determined the types of management strategies that could be employed, but the ways in which the strategies were executed were influenced by the roles that the crops played in the farming communities. Free-threshing wheat was not cultivated widely across the Greek mainland during the Neolithic (Valamoti and Jones, 2003), perhaps because it was a more demanding crop than the glume wheat cereals. The fact that the farmers at Kouphovouno decided to invest in its cultivation may have been accompanied by the assignment of a special status and higher demand, which may have been the reason that consumption of this cereal was restricted to humans. The other two crops may have been grown for both human and animal consumption and may have carried the labels ‘fooder crops’. In Çatalhöyük, on the other hand, none of the cereal grains were likely used to feed the animals. Even the non-grain components of the cereals – apart from emmer – are above the range of the estimated δ^{15}N value of the animals' diet (including those that have the lowest δ^{15}N values of the main domesticates). This suggests that cultivation of fodder was not a primary aim of the cropping strategy at this site.

Preference for some crops over others may also have been determined by balancing considerations such as ease of threshing (free-threshing wheat does not need to be dehusked and is ready to use after threshing) and ease of storage (glume wheats can be stored in spikelets and are thus less prone to infestation) (Halstead, 2014, p. 136).

Taste and narrative may also have played their role in shaping people's preferences of certain crops. Barley has often been called the 'poor man's crop' (Zohary et al., 2012), likely because its cultivation signals smaller investment in resources than cereals such as wheats. In recent years, glume wheats such as einkorn and emmer have been sold at high prices because they have been marketed as 'ancient crops'. People's preferences (or lack thereof) for these crops may thus be influenced by the values/biases that the society imposes on the crops. Neolithic farmers may also have placed labels on their produce – with or without a biological basis – that dictated which crops were more appropriate to consume on a regular basis and which were more suitable for sharing.

8.2 Diversity in animal management

Animal management was also characterized by diversity, as farmers developed systems that integrated a series of decisions governed by their socioeconomic needs and environmental opportunities. Once again, the starting point was their environment. The farmers had to consider the type of vegetation that was available in their immediate surroundings and whether it was sufficient to nourish their animals throughout the whole year. They had to be familiar with the topography of their landscape and understand which animals would thrive better in different kinds of open and closed environmental niches. Sustaining animals in the proximal landscape throughout the winter was a trade-off between provision of manure for soil improvement and quality of food that was available in the valleys in different seasons. As all these factors differed across the regions settled by Neolithic farmers, so too did their management strategies.

The environmental constraints and opportunities provided a foundation on which mixed farming systems suited to the farmers' needs could be built. While all Neolithic communities across the Aegean and Anatolia embraced animal domestication as a mode of food production, their aims in doing so differed. Some communities were interested in procuring both primary and secondary products, others preferred specializing in meat production. Some farmers were interested in slaughtering animals throughout the year, and some favored carrying it out on a seasonal basis to cater for special events (Isaakidou, 2011). Shedding light on the diversity between animal management systems in different regions will thus prove instrumental for understanding the role of animal products in the subsistence economies as well as people's relationship with and impact on their surrounding environment.

The analysis carried out in the case studies considered here shows that the dietary habits of domestic animals differed on both the long-term and short-term scales. Part of this variability was determined by environmental distinctions. In Makriyalos, cattle had a strong C_4 component in their diet, while in Kouphovouno, they did not, possibly because a coastal environment such as the one around Makriyalos is more hospitable to C_4 vegetation (Sage and Monson, 1999). Another part was driven by management choices. In Çatalhöyük, C_4 input in animals' diet increased over time (Pearson, 2013), but as no chronological trends have been detected in the plant isotopic data, the isotopic change in the diets was likely a result of choice of new pasture fields rather than climatic shifts.

Human agency can be seen even more clearly on the seasonal scale. The seasonal grazing behaviors of sheep and goat, for example, differ at all three sites. At Makriyalos I, sheep grazed within the local landscape throughout the year. Some had more access to C_4 vegetation than others, and this may have been a result of grazing in different pastures or of annual fluctuation in vegetation cover. Their mortality profiles suggest that these animals were slaughtered for their meat in all seasons and oxygen isotope analysis further suggests that their births were not staggered throughout the year. Procurement of milk is thus unlikely to have been a major component of the subsistence model.

In Kouphovouno, however, a local grazing strategy for the sheep only lasted through the Middle Neolithic (for a comparison of sheep at Makriyalos and Kouphvouno, see Fig. 8.2). In the Late Neolithic, evidence suggests that sheep were both foddered and moved trans-altitudinally. The goats, in comparison, appear to have been foddered throughout both Neolithic phases. The changes in sheep management may explain the difference in bone collagen $\delta^{15}N$ values between Late Neolithic sheep and goats (Vaiglova et al. 2014*a*), as sheep taken to different altitudes may have had access to plants with variable $\delta^{15}N$ values. The shift may have been necessitated by changes in the availability of vegetation, sizes of herds or organization of labor. The mortality profiles of the ovicaprids suggest that these animals were raised for both their primary and secondary products, and birth seasonality modelling using stable oxygen isotope analysis further supports this idea for the Middle Neolithic.

Henton et al. (2010) obtained sequential samples of tooth enamel from the second molars of sheep at Çatalhöyük, but used only their $\delta^{18}O$ (carbonate) values to interpret their herding management. Based on the absolute $\delta^{18}O$ values, the authors concluded that four sheep grazed in the local environment and subsisted on fresh vegetation from the edges of arable fields

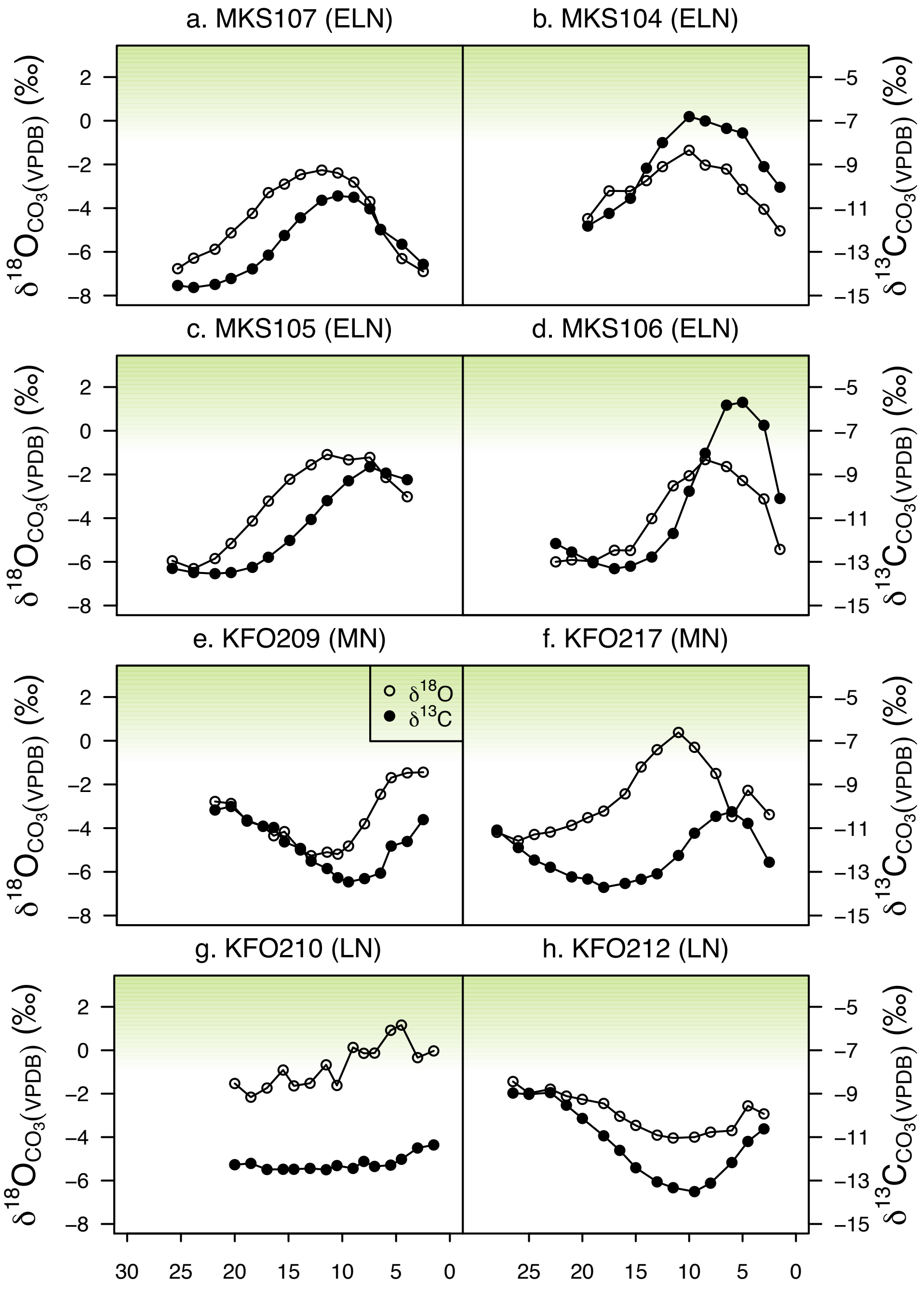


Figure 8.2: Bi-variate line plots of sequential tooth carbonate δ^{13}C and δ^{18}O values of sheep at Makriyalos (a-d) and Kouphovouno (e-h). MN = Middle Neolithic, LN = Late Neolithic, ELN = Early Late Neolithic. The δ^{18}O and δ^{13}C curves in each plot intersect at different points than in Figs. 6.9 and 7.17 because the x– and y– scales have been adjusted to fit all the measurements from both sites.

or on collected fodder. Two individuals, however, with $\delta^{18}O$ curves dampened by c.2‰, may have been herded at altitudes higher by 600m, likely in the Taurus mountains. In a study with a larger number of teeth (n = 58), where $\delta^{18}O$ sequenes from archaeological sheep teeth from Çatalhöyük were compared to modern analogues from the Anatolian plateau, Henton (2012) concluded that 78% of sheep from Çatalhöyük were managed on the Konya plain, 11% were herded in sheltered perennially-watered valleys and 11% may have been taken to higher altitudes where summers were cooler. Consistent with these trends, a small study of Sr isotopic measurements of sheep tooth enamel from Çatalhöyük suggests that most of the sheep (six out of seven individuals) were herded on the plain, with a small number (represented by one sample) grazing on more elevated limestone terraces located over 13km south of the site (Bogaard et al. 2014*b*).

Since the measurements of matching $\delta^{13}C$ values were not presented in Henton's studies, it is impossible to assess the nature of the feeding behavior of these animals in greater detail. $\delta^{13}C$ values would help distinguish fresh vegetation from fodder diets (which, according to the plant isotope measurements, seem unlikely).

Henton (2012) further assessed the shapes of the $\delta^{18}O$ curves (n = 50) in order to interpret the birth seasonality of the sheep from Çatalhöyük and concluded that the majority of sheep were born in late May, with smaller numbers born in late March and in April. However, caution should be exercised when interpreting $\delta^{18}O$ curves in this way as the delay in mineralization of M2s may vary between individuals, and this may affect what the end of a sequential pattern looks like.

Further diversity in seasonal herding practices can be seen amongst the cattle at Makriyalos I. Here, some cows consumed C_4 vegetation during the summer, some consumed it all year round, while others subsisted on C_3 vegetation throughout the whole year. Some cows were foddered during any part of the year. Overall, individual cattle visited a larger number of pasture fields and had less uniform diets over the course of their lives than the sheep. Their birth seasonality was not extended beyond the natural reproductive season, and this is consistent with lack of milk residue indicators on pottery (Evershed et al., 2008) and mortality profiles that were meat-oriented (Pappa et al., 2013).

In Makriyalos, differences between first-year and long-term diets of cattle and sheep support the idea that farmers adjust the management of their animals on a year-to-year basis. Bone collagen signatures show that cattle had variable long-term input of C_4 vegetation, while their first year signatures show that their diets were predominantly C_3, and only some individuals enjoyed seasonal access to C_4 vegetation. Similarly, the sheep show clear long-term C_3 diets, while lambs exhibit notable input of C_4 plants in their first year diets. To explain these temporal disagreements, it has to be borne in mind that farmers make decisions about animals' herding methods based on their health status, reproductive ability, availability of labor, and sizes of herds, all variables that can change from year to year. For this reason, individual animals would not be expected to follow the same routine every year throughout their lives. Bone collagen and enamel tooth carbonate data provide glimpses of different parts of the animals' lives and these provide another level of diversity in animal feeding practices across different regions in the Aegean and central Anatolia.

8.3 Food consumption

Plant foods formed the staple of human diets at Çatalhöyük and Makriyalos. Bone collagen values of humans at these two sites are not situated a trophic level above the values of the animals, so the people buried at these sites must have obtained most of their dietary protein from non-animal products. At the same time, animals and meat played a significant role in the cultures of these Neolithic people. Çatalhöyük preserves an incredible array of animal iconography (Hodder, 2006), which includes wall paintings and skull and horn installations plastered onto house platforms. Makriyalos shows evidence for a series of large communal feasts, which saw the consumption of tens of tons of meat within less than a year (Pappa et al., 2013). So how were these connotations in symbolic expression and ritual activity reflected in the treatment of animals in the agricultural sphere?

At Makriyalos, most of the bones found in the 'feasting deposit' were sheep, but cattle provided the biggest amount of meat (Pappa et al., 2013). While sheep were all managed within the local landscape, making visits to a restricted range of pasture fields, cattle were managed in multiple different ways in a wider catchment area. However, the grazing patterns of the animals were not determined by the function that the animals were going to fulfill, i.e. cattle that were going to be slaughtered at the big feast were not managed separately to the cattle that were going to be consumed on more mundane occasions.

This suggests that even though the feast undoubtedly put pressure on the production sphere, people did not adopt techniques to extensify the scale of their management: they did not create specialized task groups that were responsible for looking after the cattle intended for the feast separately to the other animals. Instead, they made use of their cross-regional network to acquire cattle born outside of the Pierian hill landscape.

Strontium isotope evidence carried out in this project shows that cattle were brought in from at least two distinct locations – likely from the Pieria mountains – where the animals were born and spent part of their first year. The ages at which the imported animals were slaughtered (16–28 months) suggest that at least in some cases, the movement did not directly precede their killing: one of the non-local cows spent several months grazing in the local landscape; long enough for the local Sr isotope signature to get incorporated into its second molar. This indicates that the animals were not all simply brought over on the day of the feast, but that their involvement and preparation was premeditated. At least some of them were integrated into the local herds and adopted the seasonal feeding habits of the other cows. Even though significant altitude difference separates the locations from the Pieria mountains and the coastal environment, bringing cattle to Makriyalos required descending, rather than ascending, these slopes, and this may have facilitated the movement.

Bogaard et al. (2009) argue that meat consumption played a role in maintaining social cohesion at Çatalhöyük, which was necessary for assuring stability in a densely populated village. This argument was based on an examination of the use of space within well-preserved houses, which showed that while plants were kept in storage rooms away from the eyes of people that 'came and went' between the domestic spaces, symbols of animal taming and domestication were displayed in the form of extravagant installations in the main rooms where they could be seen. The authors thus argued that food sharing became a focus of display and was celebrated as a mechanism that kept the society functioning. Makriyalos does not offer evidence for iconographic display of meat consumption, but the scale of animal slaughter represented in the feasting deposit indicates a massive investment in time. This suggests that the people must have had a good reason to organize such large feasts. In a similar way to Çatalhöyük, the driving force behind this may have been the desire to reciprocate with other communities – with whom they were connected via trade networks – in an effort to cement social cohesion.

8.4 Conclusions

The aim of the project presented in this dissertation was to examine the similarities and differences in farming techniques employed by Neolithic farmers at three sites across south-central Anatolia and the Aegean continent through an analysis of stable isotopic signatures of bioarchaelogical material. On the micro– level, the results provided new insight for understanding the mechanisms of crop cultivation and animal herding as well as aspects of the environmental setting around each site. On the macro– level, the interpretations made within each case study contributed to the view that the spread of farming was not uniform and that Neolithic agricultural techniques developed across the wider region were incredibly diverse. People did not always grow the same types of crops under the same regimes, they did not herd their animals in the same ways in different locations and they did not involve the same amounts of plant and animal products in their diets.

The results of charred plant δ^{13}C and δ^{15}N measurements showed that in Kouphovouno, different types of cereals were grown under distinct types of cultivation treatments (Chapter 6.4.1). Samples of einkorn measured in this study added a new dimension to diversity between free-threshing wheat and hulled barley identified earlier (Vaiglova et al. 2014*a*). The expanded dataset showed that while free-threshing wheat was grown in the most ^{15}N–enriched soils, hulled barley and einkorn were grown less intensively, perhaps in more distant plots of land and possibly as fodder crops. In Çatalhöyük, on the other hand, no crop received distinct treatment, as all species of cereals and pulses were cultivated across the naturally variable landscape (Chapter 5.6). Some crops may have been grown more intensively closer to the site, but this kind of treatment was not determined by crop type. None of the crops were likely grown as fodder crops and the by-product of only emmer may have contributed significant amounts of protein to the domestic animal diets. In Makriyalos, the sample size of charred grains is too small to make reliable interpretations about cultivation strategies at this site, but all emmer δ^{15}N measurements are situated in the same range of values as the barley and einkorn at Kouphovouno and may thus have been grown in natural rather than fertilized soils (Chapter 7.4.2).

Long-term diets of domestic animals, elucidated through measurements of bone collagen $\delta^{13}C$ and $\delta^{15}N$ values showed that cattle at Makriyalos consumed a substantially larger amount of C_4 vegetation than any of the other animals measured at the site (Chapter 7.4.1). When compared to previous measurements of contemporary humans carried out by Triantaphyllou (2001, 2008), the cattle $\delta^{13}C$ values suggest that these animals did not provide a significant protein contribution to the human diets during Makiryalos I phase.

While the bone collagen stable isotopic values of sheep and goats were similar during Makriyalos I, they differed during Makriyalos II (Chapter 7.4.7). The $\delta^{13}C$ measurements indicate that in the latter phase, goats grazed in more woody areas than the sheep. They visited habitats similar to those visited by boars, but not quite as affected by the canopy effect as those inhabited by the red deer (measured by Triantaphyllou, 2001, 2008).

The $\delta^{15}N$ values of humans at Çatalhöyük (measured by Pearson, 2013) are not located a trophic level above the average $\delta^{15}N$ values of any of the domestic animals. Initial interpretations posited that humans obtained the bulk of their dietary protein from sources other than the animals analyzed by Pearson, and the plant measurements carried out in this study provide evidence that cereals and pulses cultivated by the farmers could have indeed been used towards this purpose (Chapter 5.6.4). Some crops, notably new type glume wheat from building 77, have higher $\delta^{15}N$ values compared to those of the humans. They may have been consumed on rarer occasions, but caution has to be exercised with this interpretation, as no human samples were available from B.77.

Sequential tooth enamel carbonate $\delta^{13}C$ and $\delta^{18}O$ measurements carried out in this project illustrate another level of diversity in farming techniques employed by Neolithic farmers across the Aegean. In Kouphovouno, sheep and goat were managed separately in both phases of occupation and the management of sheep changed between the Middle and the Late Neolithic phases (Chapter 6.4.2). Based on their dampened $\delta^{13}C$ curves, the goats may have been foddered throughout both phases, but being obligate drinkers, they likely obtained local $\delta^{18}O$ values through direct ingestion of water. Sheep, on the other hand, exhibit $\delta^{13}C$ and $\delta^{18}O$ patterns that suggest that they grazed in the local landscape on fresh vegetation during the Middle Neolithic. In the Late Neolithic, they exhibit signs of both foddering and trans-altitudinal mobility to areas with plants more enriched in ^{13}C.

Farmers at Makiyalos followed the initial strategy of the Kouphovouno farmers to manage their sheep within the proximal landscape (Chapter 7.4.3). Some had more access to C_4 vegetation than others, but all of them exhibit smooth $\delta^{13}C$ and $\delta^{18}O$ curves showing the expected seasonal fluctuation in C and O isotope values. The cattle, however, deviated from this consistent pattern and shows evidence of having been managed in various ways. Some had seasonal or year-round access to fresh C_4 vegetation and may have spent part of the year grazing in coastal areas hospitable to marshland environments. Some cows may have been foddered as they show lack of correlation between their $\delta^{13}C$ and $\delta^{18}O$ values. Most of them subsisted on entirely–C_3 diets, but as their $\delta^{13}C$ and $\delta^{18}O$ curves are more 'noisy' than those of the sheep, they likely visited a wider range of pastures in the first year of their lives.

Mismatch between long-term dietary signatures (preserved in their bone collagen values) and first-year seasonal dietary patterns (indicated by their tooth enamel carbonate sequences) – particularly among the cattle at Makriyalos – supports the idea that farmers adjust their management techniques on an individual basis depending on the animals' reproductive fitness, health and on the sizes of herds.

The sequential tooth enamel $\delta^{18}O$ measurements also provided a chance to assess the exploitation strategy of the domestic animals from another angle to that offered through traditional faunal analysis. The maximum δ^{18}O values within every tooth analyzed in this study were normalized to the sinusoidal period recording an annual cycle; following the method developed by Balasse et al. (2012*a*). The results show that while farmers at Kouphovouno likely extended the birthing season of their sheep and goats (in the MN) in order to secure supplies of milk throughout the year (Chapter 6.4.3), the farmers at Makriyalos did not attempt to do this (Chapter 7.4.4). These interpretations are consistent with the mortality profiles, which suggest that animals at Kouphovouno were likely exploited for both their primary and secondary products, while those at Makriyalos were raised exclusively for their meat.

The case study at Makriaylos provided a unique opportunity to assess the treatment of cattle that were slaughtered during a series of exceptionally large feasts hosted over a period of several weeks or months over the course of one year during the Early Late Neolithic. Bone collagen δ^{13}C and δ^{15}N values suggest that cattle discarded in the large feasting pits (Pit 212 and Pit 214) obtained their sustenance from the same pool variably ^{13}C–enriched vegetation as did the cattle disposed in non-feasting deposits. Furthermore, their tooth enamel sequences indicate that the cattle raised for the feast were not managed in distinct ways during their first year of life compared to the other animals. Lastly, Sr isotope analysis provides evidence for the fact that two of the cattle individuals analyzed were not born in the local Pierian hill landscape but in two locations with distinct underlying geology – the closest candidates being a limestone region and a Palaeozoic flysch region in the Pierian mountains located over 20km to the southwest of the site. These non-local cows were not simply brought to the site on the day of the feast, but were integrated into the local herds and slaughtered once they matured. Despite hosting such large feasts, the farmers at Makriyalos managed to keep their animal management small-scale. An independent line of evidence indicates that an exchange network existed that bringing exotic raw materials to Makriyalos for making stone tools (Pappa et al., 2013) and the presence of non-local cattle suggests that these animals were likely involved in the trade network as well. Maintenance of these networks may have been the precise reason that the feasts were organized.

8.5 Limitations and future research

The scope of modern plant sampling undertaken in this project to measure the values of bioavailable strontium in Northern Pieria is limited due to the distance covered during sampling. Most of the samples were obtained within c.15km of the site and only cover areas with Neogene-Holocene geology. Even though Sr isotope analysis does not have the resolution to identify the actual origins of non-local individuals, a more extensive coverage of modern plant samples would help with understanding Sr isotope variability in the study location and would have wider application for future Sr isotope work carried out in Greece. It is hoped that this can be accomplished in the future.

The awork carried out in this project can only benefit from analysis of larger number of samples, particularly herbivore teeth from Makriyalos and Kouphovouno. At Makriyalos, the use of Sr isotope analysis on not just the cattle individuals, but other animals such as the sheep (which formed a more numerous component of the feasting deposit) would help shed further light on the scope of animal movement involved in the organization of the communal feast.

The next stage of interpretation of the datasets obtained herein will involve collaboration with specialists who are also currently undertaking work on the same assemblages. Helen Whelton (University of Bristol) is carrying out Sr isotope analysis of the human assemblage from Makriyalos. Her work will use the modern plant Sr isotope measurements obtained in this study to assess the possibility that some of humans buried at the site were born outside of the local environment. Comparison of the human and animal Sr isotope measurements will enable a closer examination of the network in which the people at Makriyalos participated. If non-local humans are identified, and their Sr isotope values are the same as values of the non-local cattle, this would point to a more substantial pattern of movement across the landscape than simple trading of animals for the feast.

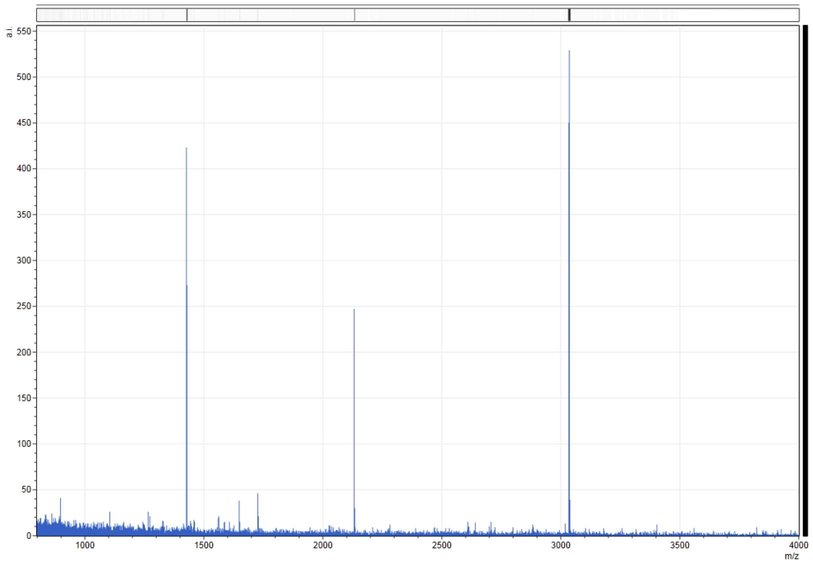
Lucy Lawrence (University of Sheffield) is carrying out a larger investigation (compared to the previous one undertaken by Mainland and Halstead, 2005) of the tooth microwear of animals from Makriyalos. The previous study suggested that sheep and goats buried in the feasting contexts consumed different diets in the last weeks of their lives compared to the ovicaprids from the habitation deposits. This new work is bringing this observation into question and will help shed light on the short-term dietary patterns of the animals. In conjunction with the results obtained in this study, the results of micro-wear analysis will clarify whether the animals slaughtered in the communal feast were managed differently to the animals consumed on more mundane occasions.

The research questions pursued in this project can be explored further through the application of a multi-isotope approach at a larger number of sites. This would provide a stronger basis for investigating possible regional trends and comparing the practices of farmers on the Anatolian plateau to those in the Aegean, and beyond in the Near East and the rest of Europe. Investigation of these regional trends will further the debate on the way that localized Neolithic traditions developed in different areas of the Old World.

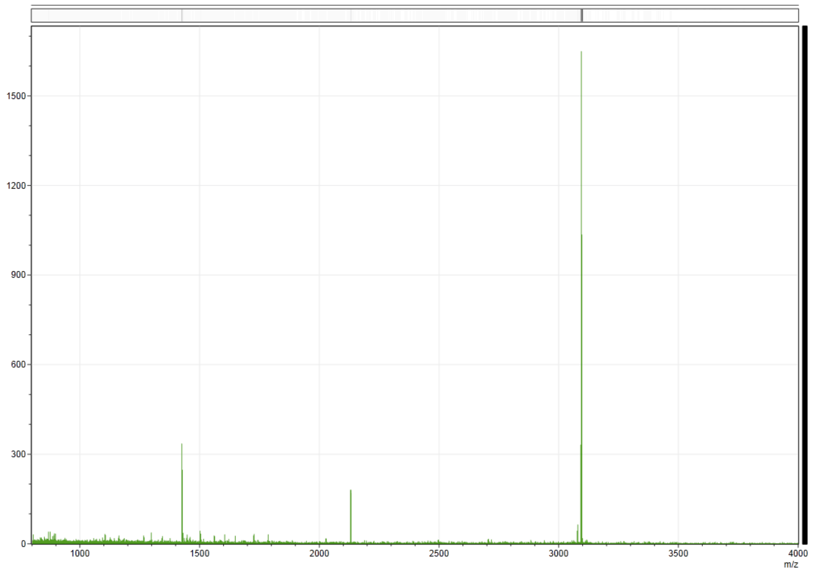
Appendix A

Comparative ZooMS spectra of sheep and goats

Single collagen peptite spectra of sheep and goats obtained using Zooarchaeological Mass Spectrometry (ZooMS). The method was used to speciate ovicaprid teeth from Kouphovouno Buckley et al. (2009, 2010). Analysis carried out by Mike Buckley at the University of Manchester.



Sheep spectra with distinctive mass at 3034.6 m/z



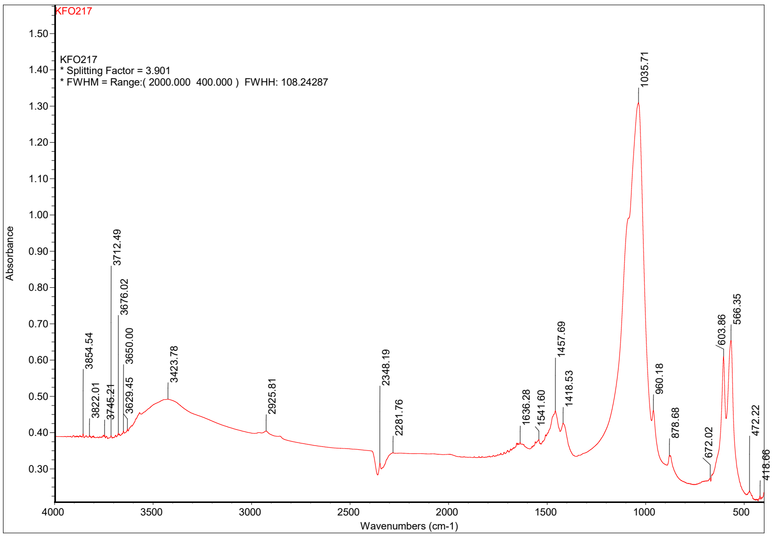
Goat spectra with distinctive mass at 3093.6 m/z

Appendix B

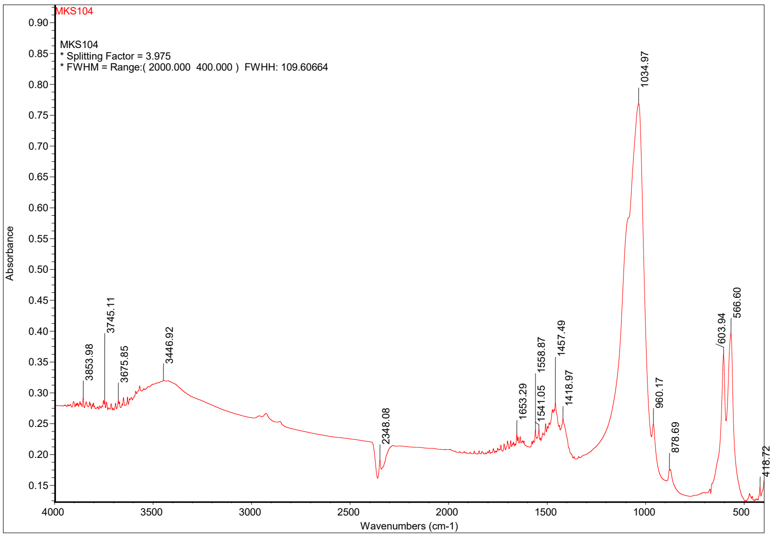
Assessing the integrity of tooth enamel using FTIR

Fourier Transform Infrared Spectroscopy (FTIR) was carried out on three samples of tooth enamel (one cattle and one sheep from Makriyalos and one sheep from Kouphovouno) in order to check that the material was not contaminated with calcite and that it did not undergo recrystallization during burial. The possibility of recrystallization was tested by calculating the splitting factor of each specturm (using a macro for the software OMNIC provided by Steve Wiener from the Kimmel Institute for Archaeological Institute, Weizmann Institute of Science). Modern enamel has a splitting factor around 4.1 (Weiner, 2010, p. 291) and calcite carbonate has a peak at 1436 cm^{-1} (Weiner, 2010, p. 280). The instrument used was a Thermo Scientific Nicolet iS5 transmittance FTIR at the Wiener Laboratory for Archaeological Science, American School of Classical Studies in Athens. The results that follow indicate that the material used in this project has not undergone significant alteration during burial and that it was appropriate for isotopic analysis.

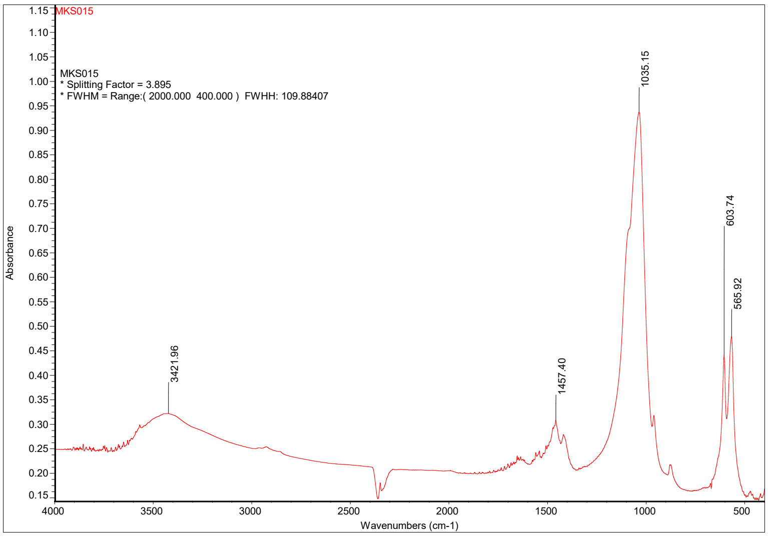
B.1 Kouphovouno, sheep enamel (sample KFO217)



B.2 Makriyalos, sheep enamel (sample MKS104)



B.3 Makriyalos, cattle enamel (sample MKS015)



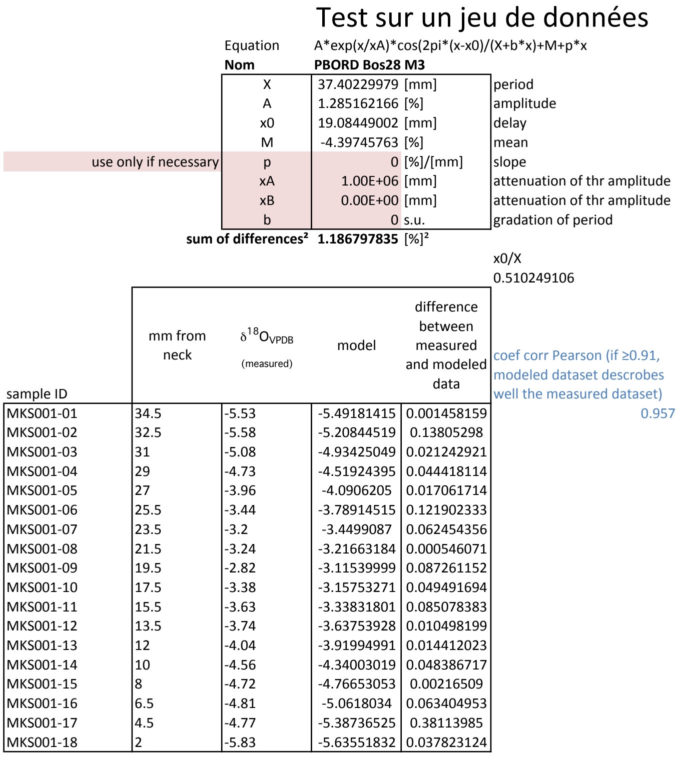
Appendix C

Estimating lines of best fit for carbonate sequences

Details of the model used for normalizing $\delta^{18}O_{\mathrm{max}}$ values from sheep and goat teeth at Kouphovouno and sheep and cattle teeth at Makriyalos. The results are used to estimate birth seasonality of the animals. The model was constructed by Balasse et al. (2012*a*) and shared with the author by Marie Balasse.

C.1 Makriyalos

C.1.1 MKS001 – cattle, habitation context



Test sur un jeu de données

Equation A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x

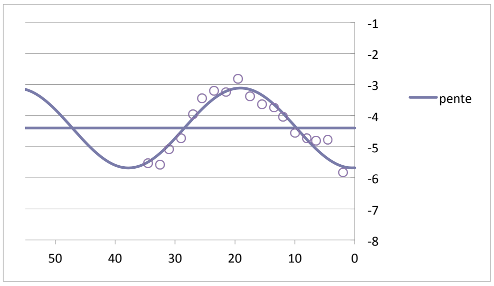
Nom **PBORD Bos28 M3**

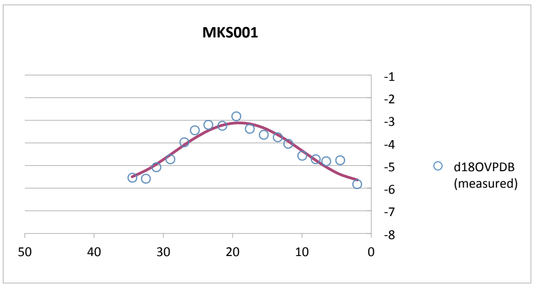
	X	37.40229979	[mm]	period
	A	1.285162166	[%]	amplitude
	x0	19.08449002	[mm]	delay
	M	-4.39745763	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
	sum of differences²	**1.186797835**	[%]²	

x0/X
0.510249106

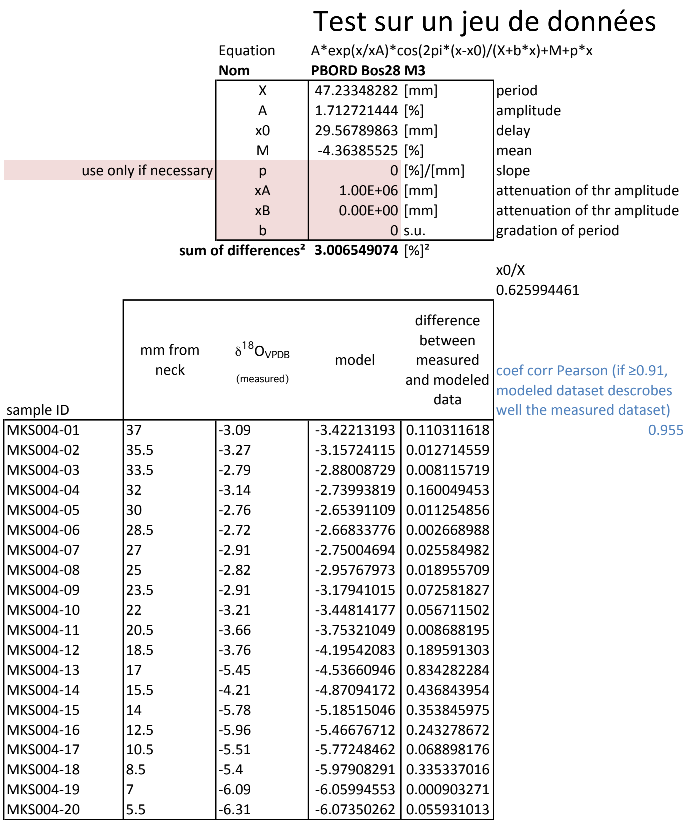
coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.957

sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
MKS001-01	34.5	-5.53	-5.49181415	0.001458159
MKS001-02	32.5	-5.58	-5.20844519	0.13805298
MKS001-03	31	-5.08	-4.93425049	0.021242921
MKS001-04	29	-4.73	-4.51924395	0.044418114
MKS001-05	27	-3.96	-4.0906205	0.017061714
MKS001-06	25.5	-3.44	-3.78914515	0.121902333
MKS001-07	23.5	-3.2	-3.4499087	0.062454356
MKS001-08	21.5	-3.24	-3.21663184	0.000546071
MKS001-09	19.5	-2.82	-3.11539999	0.087261152
MKS001-10	17.5	-3.38	-3.15753271	0.049491694
MKS001-11	15.5	-3.63	-3.33831801	0.085078383
MKS001-12	13.5	-3.74	-3.63753928	0.010498199
MKS001-13	12	-4.04	-3.91994991	0.014412023
MKS001-14	10	-4.56	-4.34003019	0.048386717
MKS001-15	8	-4.72	-4.76653053	0.00216509
MKS001-16	6.5	-4.81	-5.0618034	0.063404953
MKS001-17	4.5	-4.77	-5.38736525	0.38113985
MKS001-18	2	-5.83	-5.63551832	0.037823124





C.1.2 MKS004 – cattle, habitation context



Test sur un jeu de données

Equation A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x

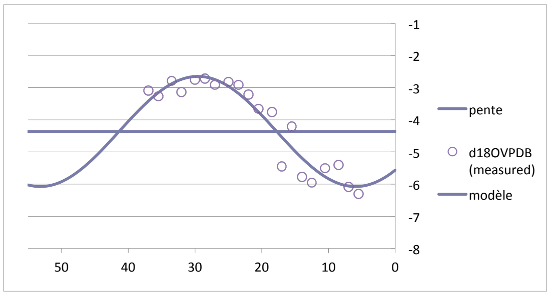
Nom **PBORD Bos28 M3**

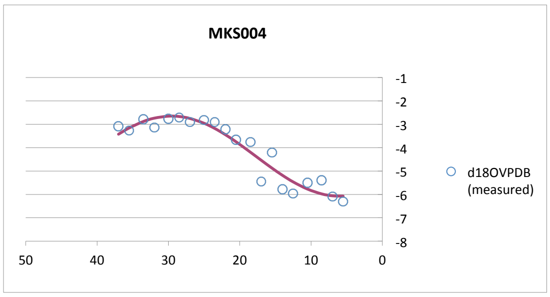
	X	47.23348282	[mm]	period
	A	1.712721444	[%]	amplitude
	x0	29.56789863	[mm]	delay
	M	-4.36385525	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
	sum of differences²	**3.006549074**	[%]²	

x0/X
0.625994461

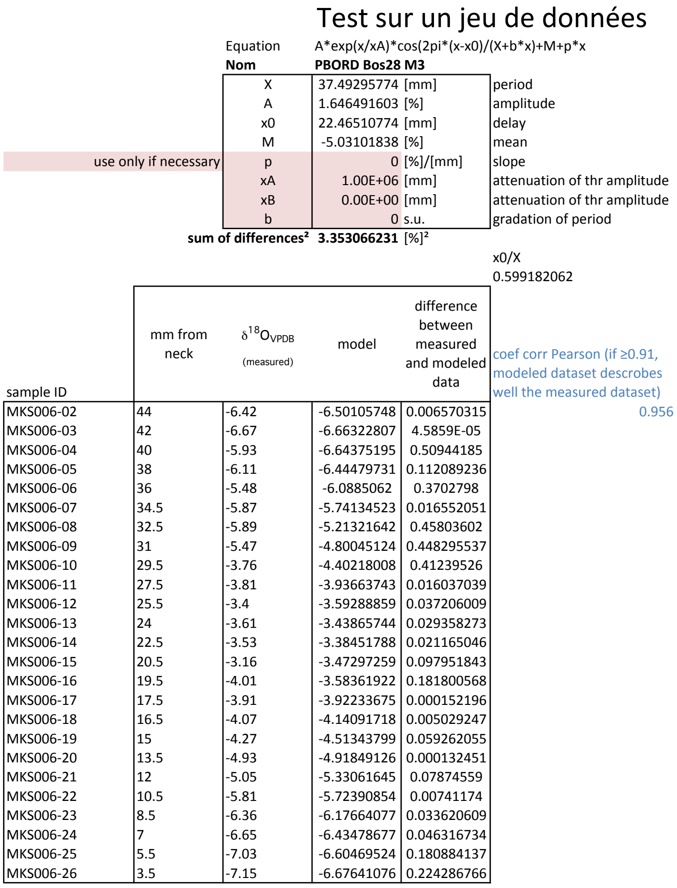
coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.955

sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
MKS004-01	37	-3.09	-3.42213193	0.110311618
MKS004-02	35.5	-3.27	-3.15724115	0.012714559
MKS004-03	33.5	-2.79	-2.88008729	0.008115719
MKS004-04	32	-3.14	-2.73993819	0.160049453
MKS004-05	30	-2.76	-2.65391109	0.011254856
MKS004-06	28.5	-2.72	-2.66833776	0.002668988
MKS004-07	27	-2.91	-2.75004694	0.025584982
MKS004-08	25	-2.82	-2.95767973	0.018955709
MKS004-09	23.5	-2.91	-3.17941015	0.072581827
MKS004-10	22	-3.21	-3.44814177	0.056711502
MKS004-11	20.5	-3.66	-3.75321049	0.008688195
MKS004-12	18.5	-3.76	-4.19542083	0.189591303
MKS004-13	17	-5.45	-4.53660946	0.834282284
MKS004-14	15.5	-4.21	-4.87094172	0.436843954
MKS004-15	14	-5.78	-5.18515046	0.353845975
MKS004-16	12.5	-5.96	-5.46676712	0.243278672
MKS004-17	10.5	-5.51	-5.77248462	0.068898176
MKS004-18	8.5	-5.4	-5.97908291	0.335337016
MKS004-19	7	-6.09	-6.05994553	0.000903271
MKS004-20	5.5	-6.31	-6.07350262	0.055931013





C.1.3 MKS006 – cattle, habitation context



Test sur un jeu de données

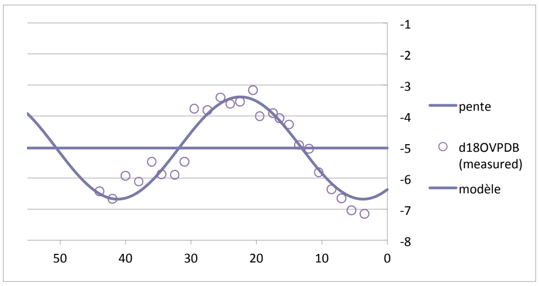
Equation A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x

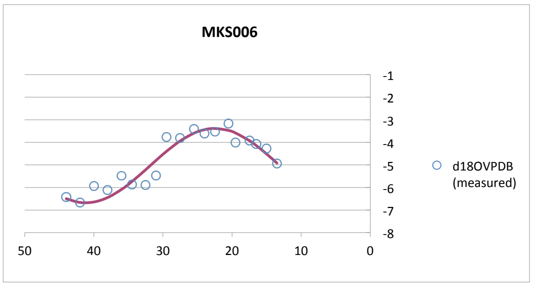
	Nom	**PBORD Bos28 M3**		
	X	37.49295774	[mm]	period
	A	1.646491603	[%]	amplitude
	x0	22.46510774	[mm]	delay
	M	-5.03101838	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
	sum of differences²	**3.353066231**	[%]²	

x0/X
0.599182062

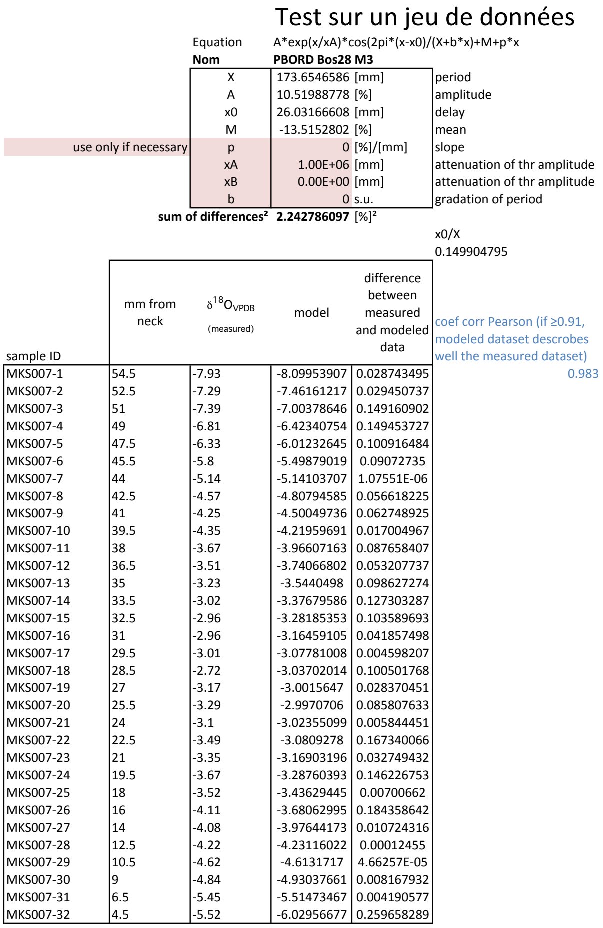
coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.956

sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
MKS006-02	44	-6.42	-6.50105748	0.006570315
MKS006-03	42	-6.67	-6.66322807	4.5859E-05
MKS006-04	40	-5.93	-6.64375195	0.50944185
MKS006-05	38	-6.11	-6.44479731	0.112089236
MKS006-06	36	-5.48	-6.0885062	0.3702798
MKS006-07	34.5	-5.87	-5.74134523	0.016552051
MKS006-08	32.5	-5.89	-5.21321642	0.45803602
MKS006-09	31	-5.47	-4.80045124	0.448295537
MKS006-10	29.5	-3.76	-4.40218008	0.41239526
MKS006-11	27.5	-3.81	-3.93663743	0.016037039
MKS006-12	25.5	-3.4	-3.59288859	0.037206009
MKS006-13	24	-3.61	-3.43865744	0.029358273
MKS006-14	22.5	-3.53	-3.38451788	0.021165046
MKS006-15	20.5	-3.16	-3.47297259	0.097951843
MKS006-16	19.5	-4.01	-3.58361922	0.181800568
MKS006-17	17.5	-3.91	-3.92233675	0.000152196
MKS006-18	16.5	-4.07	-4.14091718	0.005029247
MKS006-19	15	-4.27	-4.51343799	0.059262055
MKS006-20	13.5	-4.93	-4.91849126	0.000132451
MKS006-21	12	-5.05	-5.33061645	0.07874559
MKS006-22	10.5	-5.81	-5.72390854	0.00741174
MKS006-23	8.5	-6.36	-6.17664077	0.033620609
MKS006-24	7	-6.65	-6.43478677	0.046316734
MKS006-25	5.5	-7.03	-6.60469524	0.180884137
MKS006-26	3.5	-7.15	-6.67641076	0.224286766





C.1.4 MKS007 – cattle, habitation context



Test sur un jeu de données

Equation A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x

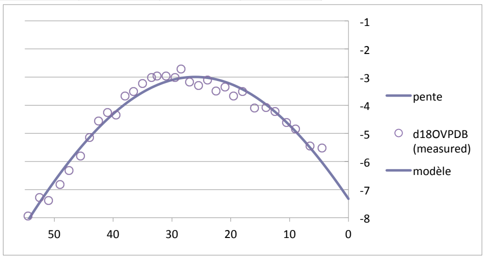
Nom **PBORD Bos28 M3**

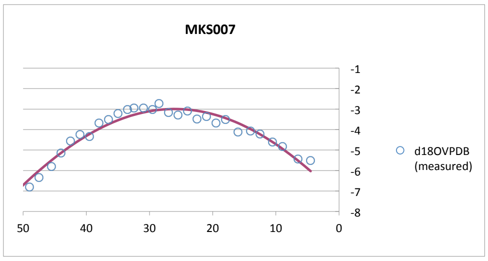
	X	173.6546586	[mm]	period
	A	10.51988778	[%]	amplitude
	x0	26.03166608	[mm]	delay
	M	-13.5152802	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
sum of differences^2		**2.242786097**	[%]^2	

x0/X
0.149904795

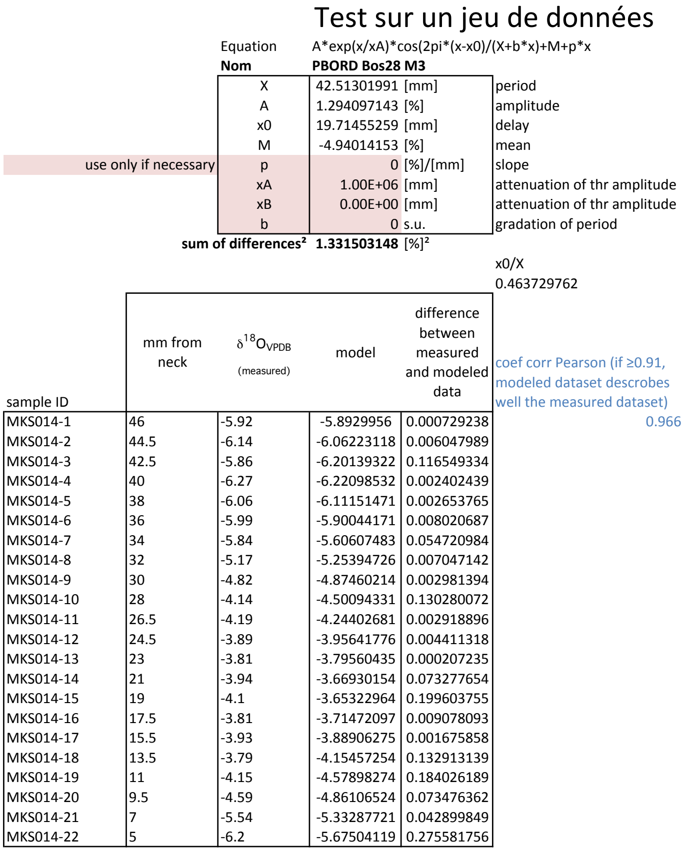
coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.983

sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
MKS007-1	54.5	-7.93	-8.09953907	0.028743495
MKS007-2	52.5	-7.29	-7.46161217	0.029450737
MKS007-3	51	-7.39	-7.00378646	0.149160902
MKS007-4	49	-6.81	-6.42340754	0.149453727
MKS007-5	47.5	-6.33	-6.01232645	0.100916484
MKS007-6	45.5	-5.8	-5.49879019	0.09072735
MKS007-7	44	-5.14	-5.14103707	1.07551E-06
MKS007-8	42.5	-4.57	-4.80794585	0.056618225
MKS007-9	41	-4.25	-4.50049736	0.062748925
MKS007-10	39.5	-4.35	-4.21959691	0.017004967
MKS007-11	38	-3.67	-3.96607163	0.087658407
MKS007-12	36.5	-3.51	-3.74066802	0.053207737
MKS007-13	35	-3.23	-3.5440498	0.098627274
MKS007-14	33.5	-3.02	-3.37679586	0.127303287
MKS007-15	32.5	-2.96	-3.28185353	0.103589693
MKS007-16	31	-2.96	-3.16459105	0.041857498
MKS007-17	29.5	-3.01	-3.07781008	0.004598207
MKS007-18	28.5	-2.72	-3.03702014	0.100501768
MKS007-19	27	-3.17	-3.0015647	0.028370451
MKS007-20	25.5	-3.29	-2.9970706	0.085807633
MKS007-21	24	-3.1	-3.02355099	0.005844451
MKS007-22	22.5	-3.49	-3.0809278	0.167340066
MKS007-23	21	-3.35	-3.16903196	0.032749432
MKS007-24	19.5	-3.67	-3.28760393	0.146226753
MKS007-25	18	-3.52	-3.43629445	0.00700662
MKS007-26	16	-4.11	-3.68062995	0.184358642
MKS007-27	14	-4.08	-3.97644173	0.010724316
MKS007-28	12.5	-4.22	-4.23116022	0.00012455
MKS007-29	10.5	-4.62	-4.6131717	4.66257E-05
MKS007-30	9	-4.84	-4.93037661	0.008167932
MKS007-31	6.5	-5.45	-5.51473467	0.004190577
MKS007-32	4.5	-5.52	-6.02956677	0.259658289





C.1.5 MKS014 – cattle, feasting context



Test sur un jeu de données

Equation A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x

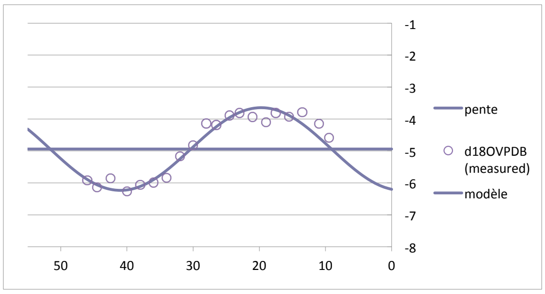
Nom **PBORD Bos28 M3**

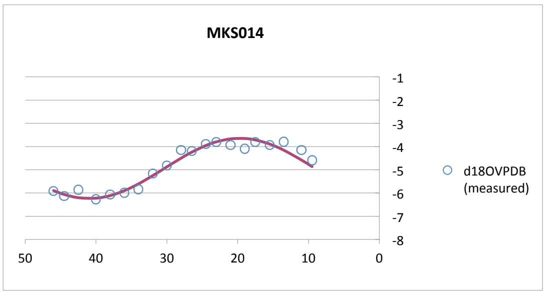
	X	42.51301991	[mm]	period
	A	1.294097143	[%]	amplitude
	x0	19.71455259	[mm]	delay
	M	-4.94014153	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
	sum of differences²	**1.331503148**	[%]²	

x0/X
0.463729762

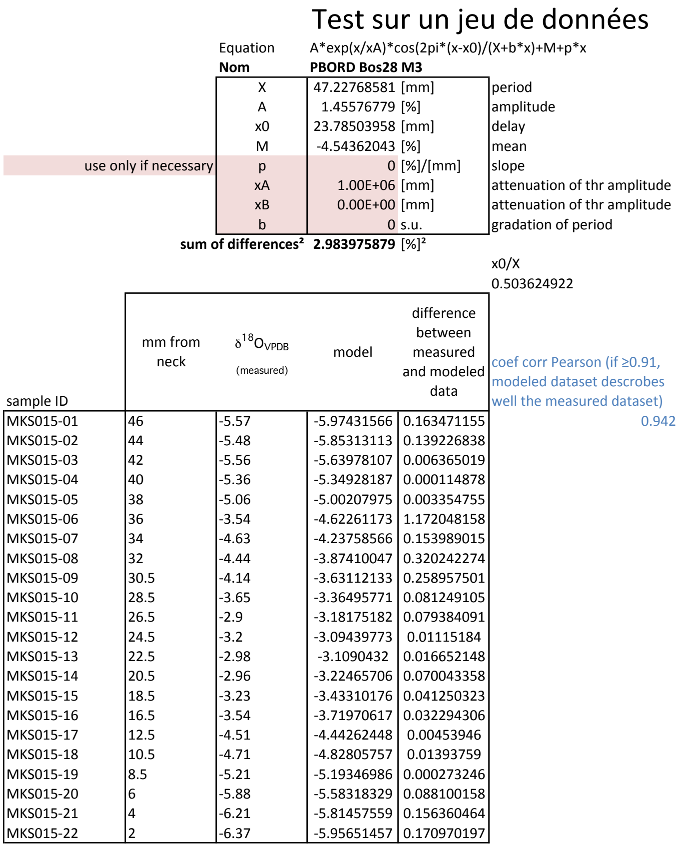
coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.966

sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
MKS014-1	46	-5.92	-5.8929956	0.000729238
MKS014-2	44.5	-6.14	-6.06223118	0.006047989
MKS014-3	42.5	-5.86	-6.20139322	0.116549334
MKS014-4	40	-6.27	-6.22098532	0.002402439
MKS014-5	38	-6.06	-6.11151471	0.002653765
MKS014-6	36	-5.99	-5.90044171	0.008020687
MKS014-7	34	-5.84	-5.60607483	0.054720984
MKS014-8	32	-5.17	-5.25394726	0.007047142
MKS014-9	30	-4.82	-4.87460214	0.002981394
MKS014-10	28	-4.14	-4.50094331	0.130280072
MKS014-11	26.5	-4.19	-4.24402681	0.002918896
MKS014-12	24.5	-3.89	-3.95641776	0.004411318
MKS014-13	23	-3.81	-3.79560435	0.000207235
MKS014-14	21	-3.94	-3.66930154	0.073277654
MKS014-15	19	-4.1	-3.65322964	0.199603755
MKS014-16	17.5	-3.81	-3.71472097	0.009078093
MKS014-17	15.5	-3.93	-3.88906275	0.001675858
MKS014-18	13.5	-3.79	-4.15457254	0.132913139
MKS014-19	11	-4.15	-4.57898274	0.184026189
MKS014-20	9.5	-4.59	-4.86106524	0.073476362
MKS014-21	7	-5.54	-5.33287721	0.042899849
MKS014-22	5	-6.2	-5.67504119	0.275581756





C.1.6 MKS015 – cattle, feasting context



Test sur un jeu de données

Equation A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x

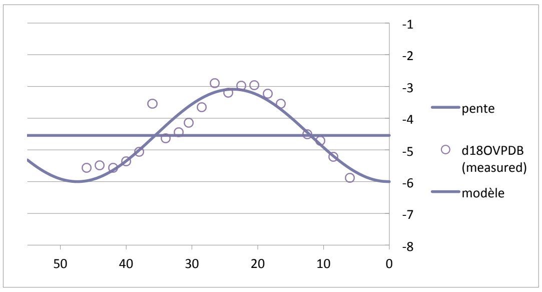
Nom **PBORD Bos28 M3**

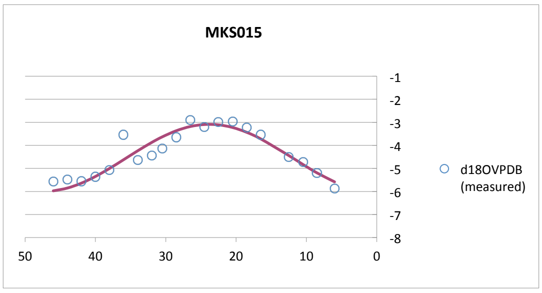
	X	47.22768581	[mm]	period
	A	1.45576779	[%]	amplitude
	x0	23.78503958	[mm]	delay
	M	-4.54362043	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
	sum of differences²	**2.983975879**	[%]²	

x0/X
0.503624922

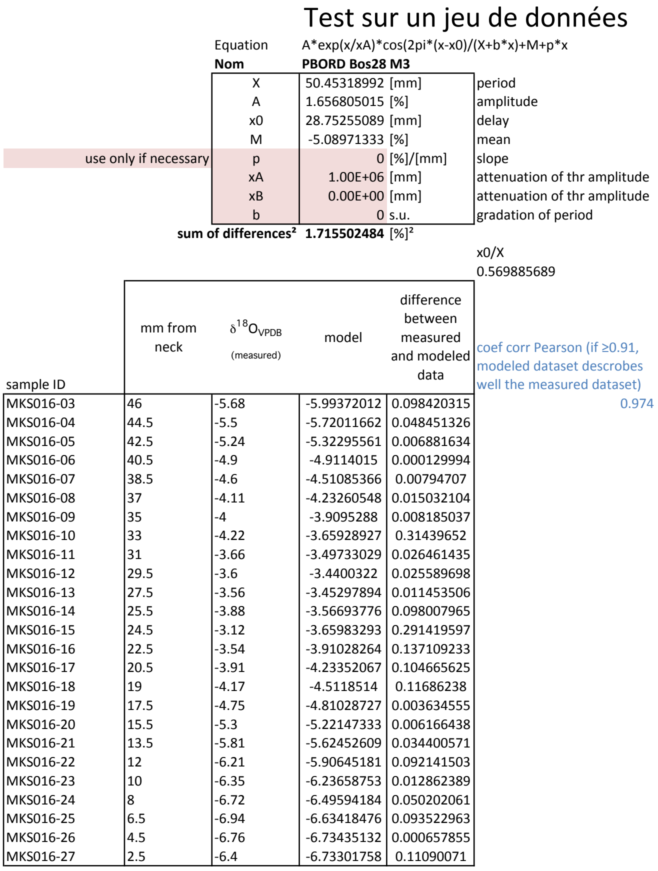
coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.942

sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
MKS015-01	46	-5.57	-5.97431566	0.163471155
MKS015-02	44	-5.48	-5.85313113	0.139226838
MKS015-03	42	-5.56	-5.63978107	0.006365019
MKS015-04	40	-5.36	-5.34928187	0.000114878
MKS015-05	38	-5.06	-5.00207975	0.003354755
MKS015-06	36	-3.54	-4.62261173	1.172048158
MKS015-07	34	-4.63	-4.23758566	0.153989015
MKS015-08	32	-4.44	-3.87410047	0.320242274
MKS015-09	30.5	-4.14	-3.63112133	0.258957501
MKS015-10	28.5	-3.65	-3.36495771	0.081249105
MKS015-11	26.5	-2.9	-3.18175182	0.079384091
MKS015-12	24.5	-3.2	-3.09439773	0.01115184
MKS015-13	22.5	-2.98	-3.1090432	0.016652148
MKS015-14	20.5	-2.96	-3.22465706	0.070043358
MKS015-15	18.5	-3.23	-3.43310176	0.041250323
MKS015-16	16.5	-3.54	-3.71970617	0.032294306
MKS015-17	12.5	-4.51	-4.44262448	0.00453946
MKS015-18	10.5	-4.71	-4.82805757	0.01393759
MKS015-19	8.5	-5.21	-5.19346986	0.000273246
MKS015-20	6	-5.88	-5.58318329	0.088100158
MKS015-21	4	-6.21	-5.81457559	0.156360464
MKS015-22	2	-6.37	-5.95651457	0.170970197





C.1.7 MKS016 – cattle, feasting context



Test sur un jeu de données

Equation A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x

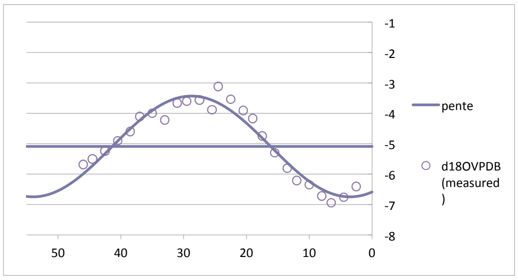
Nom **PBORD Bos28 M3**

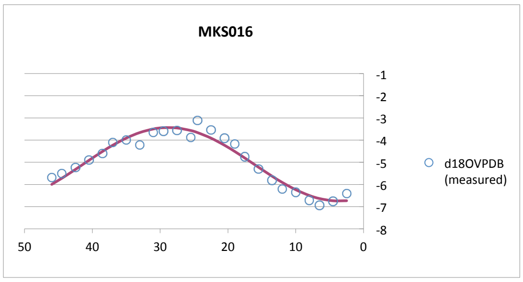
	X	50.45318992	[mm]	period
	A	1.656805015	[%]	amplitude
	x0	28.75255089	[mm]	delay
	M	-5.08971333	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
	sum of differences²	**1.715502484**	[%]²	

x0/X
0.569885689

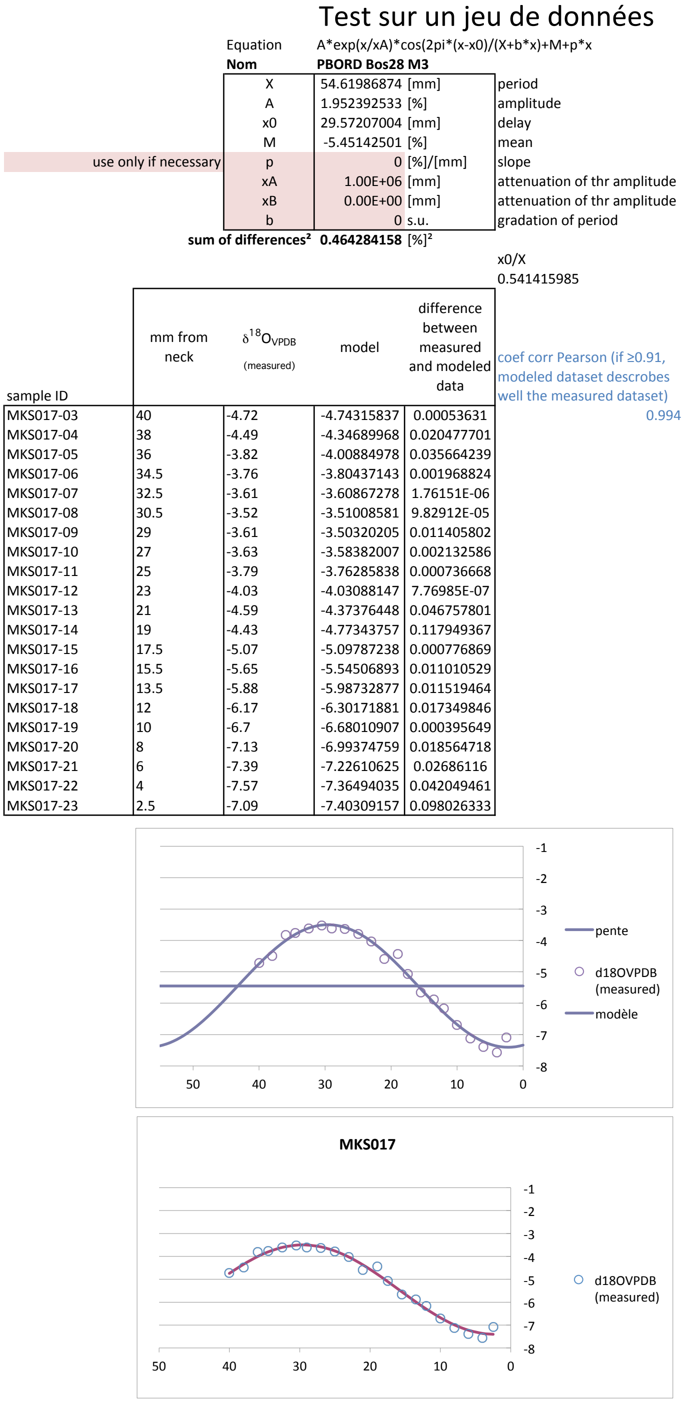
sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
MKS016-03	46	-5.68	-5.99372012	0.098420315
MKS016-04	44.5	-5.5	-5.72011662	0.048451326
MKS016-05	42.5	-5.24	-5.32295561	0.006881634
MKS016-06	40.5	-4.9	-4.9114015	0.000129994
MKS016-07	38.5	-4.6	-4.51085366	0.00794707
MKS016-08	37	-4.11	-4.23260548	0.015032104
MKS016-09	35	-4	-3.9095288	0.008185037
MKS016-10	33	-4.22	-3.65928927	0.31439652
MKS016-11	31	-3.66	-3.49733029	0.026461435
MKS016-12	29.5	-3.6	-3.4400322	0.025589698
MKS016-13	27.5	-3.56	-3.45297894	0.011453506
MKS016-14	25.5	-3.88	-3.56693776	0.098007965
MKS016-15	24.5	-3.12	-3.65983293	0.291419597
MKS016-16	22.5	-3.54	-3.91028264	0.137109233
MKS016-17	20.5	-3.91	-4.23352067	0.104665625
MKS016-18	19	-4.17	-4.5118514	0.11686238
MKS016-19	17.5	-4.75	-4.81028727	0.003634555
MKS016-20	15.5	-5.3	-5.22147333	0.006166438
MKS016-21	13.5	-5.81	-5.62452609	0.034400571
MKS016-22	12	-6.21	-5.90645181	0.092141503
MKS016-23	10	-6.35	-6.23658753	0.012862389
MKS016-24	8	-6.72	-6.49594184	0.050202061
MKS016-25	6.5	-6.94	-6.63418476	0.093522963
MKS016-26	4.5	-6.76	-6.73435132	0.000657855
MKS016-27	2.5	-6.4	-6.73301758	0.11090071

coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.974





C.1.8 MKS017 – cattle, feasting context



Test sur un jeu de données

Equation A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x

Nom **PBORD Bos28 M3**

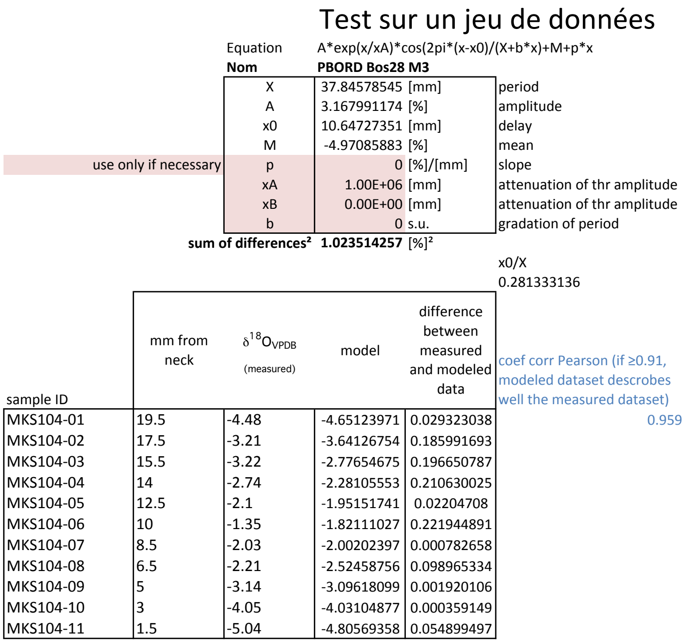
	X	54.61986874	[mm]	period
	A	1.952392533	[%]	amplitude
	x0	29.57207004	[mm]	delay
	M	-5.45142501	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
	sum of differences²	**0.464284158**	[%]²	

x0/X
0.541415985

sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
MKS017-03	40	-4.72	-4.74315837	0.00053631
MKS017-04	38	-4.49	-4.34689968	0.020477701
MKS017-05	36	-3.82	-4.00884978	0.035664239
MKS017-06	34.5	-3.76	-3.80437143	0.001968824
MKS017-07	32.5	-3.61	-3.60867278	1.76151E-06
MKS017-08	30.5	-3.52	-3.51008581	9.82912E-05
MKS017-09	29	-3.61	-3.50320205	0.011405802
MKS017-10	27	-3.63	-3.58382007	0.002132586
MKS017-11	25	-3.79	-3.76285838	0.000736668
MKS017-12	23	-4.03	-4.03088147	7.76985E-07
MKS017-13	21	-4.59	-4.37376448	0.046757801
MKS017-14	19	-4.43	-4.77343757	0.117949367
MKS017-15	17.5	-5.07	-5.09787238	0.000776869
MKS017-16	15.5	-5.65	-5.54506893	0.011010529
MKS017-17	13.5	-5.88	-5.98732877	0.011519464
MKS017-18	12	-6.17	-6.30171881	0.017349846
MKS017-19	10	-6.7	-6.68010907	0.000395649
MKS017-20	8	-7.13	-6.99374759	0.018564718
MKS017-21	6	-7.39	-7.22610625	0.02686116
MKS017-22	4	-7.57	-7.36494035	0.042049461
MKS017-23	2.5	-7.09	-7.40309157	0.098026333

coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.994

C.1.9 MKS104 – sheep, habitation context



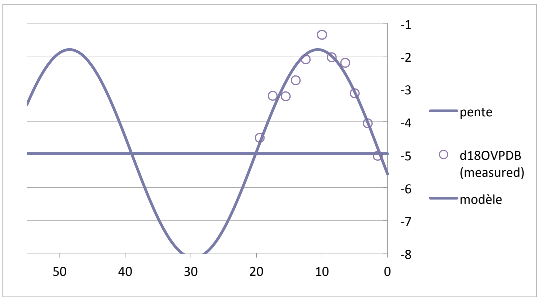
Test sur un jeu de données

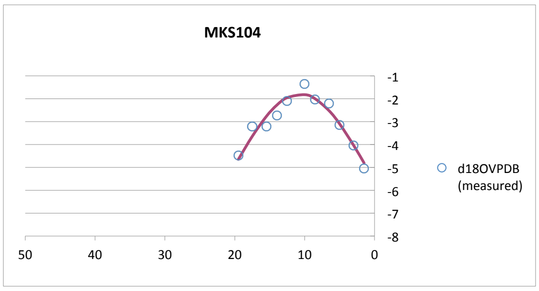
	Equation	A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x))+M+p*x		
	Nom	**PBORD Bos28 M3**		
	X	37.84578545	[mm]	period
	A	3.167991174	[%]	amplitude
	x0	10.64727351	[mm]	delay
	M	-4.97085883	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
	sum of differences²	**1.023514257**	[%]²	

x0/X
0.281333136

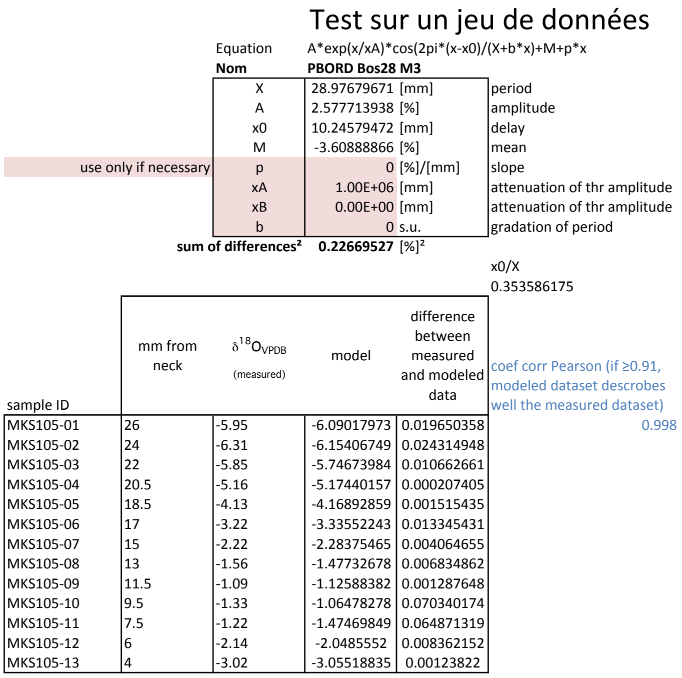
sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
MKS104-01	19.5	-4.48	-4.65123971	0.029323038
MKS104-02	17.5	-3.21	-3.64126754	0.185991693
MKS104-03	15.5	-3.22	-2.77654675	0.196650787
MKS104-04	14	-2.74	-2.28105553	0.210630025
MKS104-05	12.5	-2.1	-1.95151741	0.02204708
MKS104-06	10	-1.35	-1.82111027	0.221944891
MKS104-07	8.5	-2.03	-2.00202397	0.000782658
MKS104-08	6.5	-2.21	-2.52458756	0.098965334
MKS104-09	5	-3.14	-3.09618099	0.001920106
MKS104-10	3	-4.05	-4.03104877	0.000359149
MKS104-11	1.5	-5.04	-4.80569358	0.054899497

coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.959





C.1.10 MKS105 – sheep, habitation context



Test sur un jeu de données

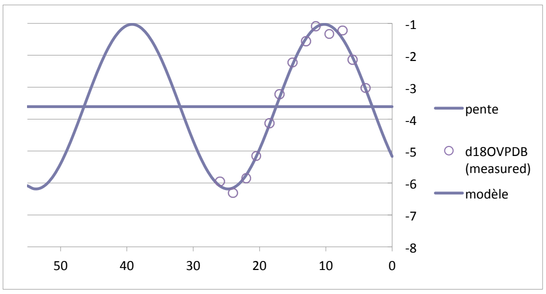
Equation A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x

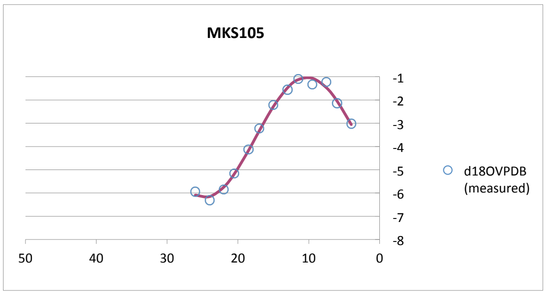
Nom **PBORD Bos28 M3**

	X	28.97679671	[mm]	period
	A	2.577713938	[%]	amplitude
	x0	10.24579472	[mm]	delay
	M	-3.60888866	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
	sum of differences²	**0.22669527**	[%]²	

x0/X
0.353586175

sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data	coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
MKS105-01	26	-5.95	-6.09017973	0.019650358	0.998
MKS105-02	24	-6.31	-6.15406749	0.024314948	
MKS105-03	22	-5.85	-5.74673984	0.010662661	
MKS105-04	20.5	-5.16	-5.17440157	0.000207405	
MKS105-05	18.5	-4.13	-4.16892859	0.001515435	
MKS105-06	17	-3.22	-3.33552243	0.013345431	
MKS105-07	15	-2.22	-2.28375465	0.004064655	
MKS105-08	13	-1.56	-1.47732678	0.006834862	
MKS105-09	11.5	-1.09	-1.12588382	0.001287648	
MKS105-10	9.5	-1.33	-1.06478278	0.070340174	
MKS105-11	7.5	-1.22	-1.47469849	0.064871319	
MKS105-12	6	-2.14	-2.0485552	0.008362152	
MKS105-13	4	-3.02	-3.05518835	0.00123822	





C.1.11 MKS106 – sheep, feasting context

Test sur un jeu de données

Equation A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x

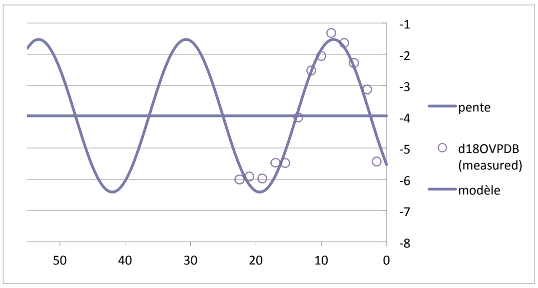
Nom **PBORD Bos28 M3**

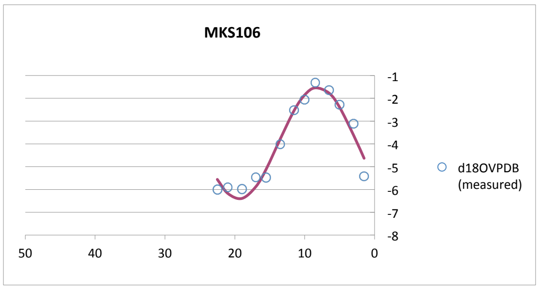
	X	22.56552076	[mm]	period
	A	2.44105023	[%]	amplitude
	x0	8.128391365	[mm]	delay
	M	-3.96813214	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
	sum of differences²	**1.814683111**	[%]²	

x0/X
0.360212886

sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
MKS106-01	22.5	-6	-5.56068106	0.193001133
MKS106-02	21	-5.91	-6.17421906	0.06981171
MKS106-03	19	-5.98	-6.39324959	0.170775222
MKS106-04	17	-5.47	-5.87944093	0.167641871
MKS106-05	15.5	-5.48	-5.09920215	0.145007001
MKS106-06	13.5	-4.02	-3.78494087	0.055252793
MKS106-07	11.5	-2.52	-2.52604282	3.65157E-05
MKS106-08	10	-2.06	-1.85109776	0.043640145
MKS106-09	8.5	-1.32	-1.54011696	0.048451475
MKS106-10	6.5	-1.64	-1.77371714	0.017880275
MKS106-11	5	-2.28	-2.39607703	0.013473877
MKS106-12	3	-3.12	-3.62064187	0.250642286
MKS106-13	1.5	-5.43	-4.63058221	0.639068808

coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.977





C.1.12 MKS107 – sheep, feasting context

Test sur un jeu de données

Equation A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x

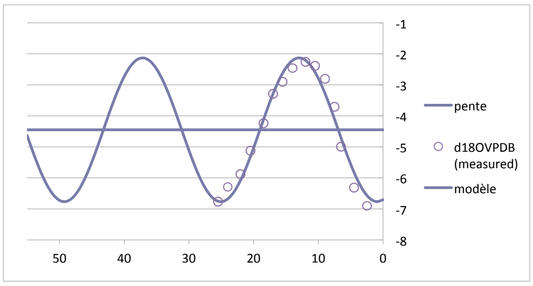
Nom **PBORD Bos28 M3**

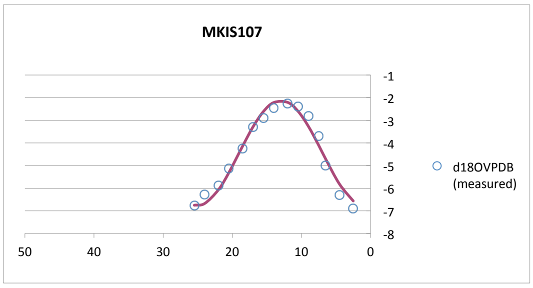
	X	24.19060876	[mm]	period
	A	2.316584391	[%]	amplitude
	x0	12.97307307	[mm]	delay
	M	-4.44950868	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
	sum of differences²	**1.225972042**	[%]²	

x0/X
0.536285515

sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
MKS107-01	25.5	-6.77	-6.75160933	0.000338217
MKS107-02	24	-6.29	-6.67752384	0.150174723
MKS107-03	22	-5.88	-6.06855244	0.035552023
MKS107-04	20.5	-5.13	-5.31786968	0.035295017
MKS107-05	18.5	-4.24	-4.13713605	0.010580993
MKS107-06	17	-3.29	-3.28867497	1.75569E-06
MKS107-07	15.5	-2.9	-2.61420374	0.081679504
MKS107-08	14	-2.46	-2.21481245	0.060116934
MKS107-09	12	-2.26	-2.20649471	0.002862816
MKS107-10	10.5	-2.39	-2.59461943	0.041869111
MKS107-11	9	-2.81	-3.26075623	0.203181182
MKS107-12	7.5	-3.7	-4.10506282	0.164075892
MKS107-13	6.5	-4.99	-4.70496621	0.081244263
MKS107-14	4.5	-6.31	-5.81426307	0.2457551
MKS107-15	2.5	-6.9	-6.56348178	0.113244511

coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.985





C.2 Kouphovouno

C.2.1 KFO204 – MN goat

Test sur un jeu de données

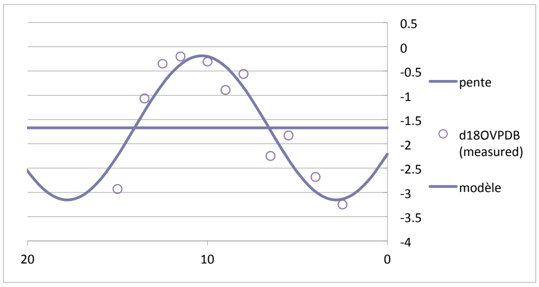
Equation A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x

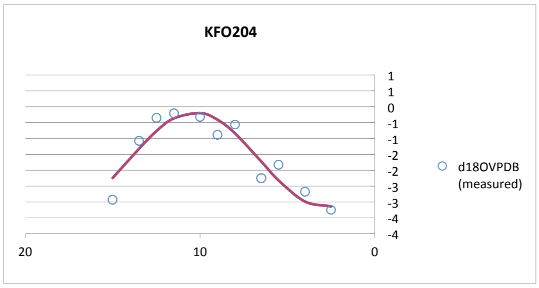
	Nom	**PBORD Bos28 M3**		
	X	14.94109653	[mm]	period
	A	1.485040527	[%]	amplitude
	x0	10.31726577	[mm]	delay
	M	-1.67045542	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
	sum of differences²	**1.684799057**	[%]²	

x0/X
0.690529357

sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
KFO204-1	15	-2.93	-2.24662581	0.467000286
KFO204-2	13.5	-1.07	-1.32848373	0.066813841
KFO204-03	12.5	-0.35	-0.76830469	0.174978813
KFO204-04	11.5	-0.2	-0.36533082	0.02733428
KFO204-05	10	-0.31	-0.19859809	0.012410386
KFO204-06	9	-0.89	-0.40748673	0.232819053
KFO204-07	8	-0.56	-0.83645326	0.076426404
KFO204-08	6.5	-2.25	-1.72164977	0.279153961
KFO204-09	5.5	-1.83	-2.3230922	0.24313992
KFO204-10	4	-2.68	-2.98424551	0.092565332
KFO204-11	2.5	-3.25	-3.1397422	0.012156782

coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.933





C.2.2 KFO207 – MN goat

Test sur un jeu de données

Equation A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x

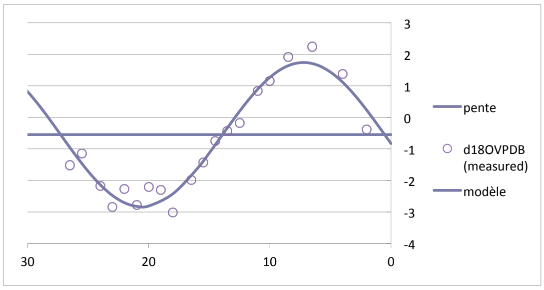
Nom **PBORD Bos28 M3**

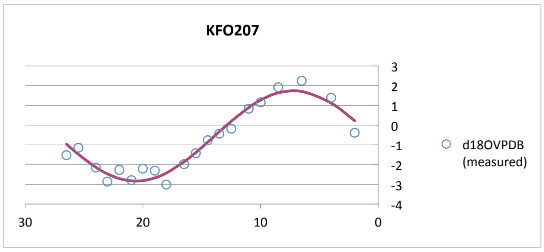
	X	26.74513906	[mm]	period
	A	2.286090179	[%]	amplitude
	x0	7.217040432	[mm]	delay
	M	-0.54713086	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
	sum of differences²	**2.609380397**	[%]²	

x0/X
0.26984494

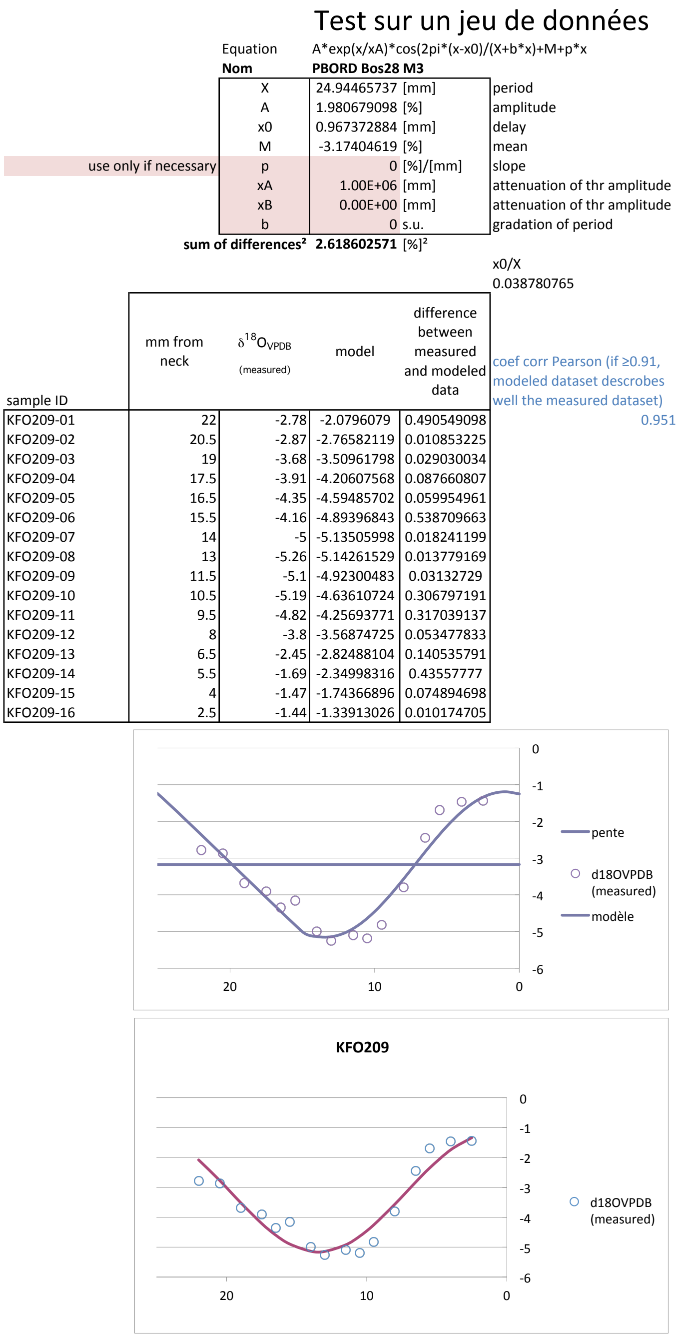
sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
KFO207-01	26.5	-1.52	-0.96154545	0.311871485
KFO207-02	25.5	-1.15	-1.47349918	0.104651721
KFO207-03	24	-2.17	-2.13794002	0.001027842
KFO207-04	23	-2.85	-2.47642684	0.139556905
KFO207-05	22	-2.27	-2.70892171	0.19265227
KFO207-06	21	-2.78	-2.8226521	0.001819201
KFO207-07	20	-2.2	-2.81137013	0.373773439
KFO207-08	19	-2.31	-2.67569588	0.133733475
KFO207-09	18	-3.02	-2.42308323	0.356309635
KFO207-10	16.5	-1.99	-1.85683898	0.017731857
KFO207-11	15.5	-1.43	-1.3846967	0.002052389
KFO207-12	14.5	-0.75	-0.86654134	0.013581885
KFO207-13	13.5	-0.43	-0.33083931	0.009832842
KFO207-14	12.5	-0.17	0.192979064	0.131753801
KFO207-15	11	0.84	0.894043964	0.00292075
KFO207-16	10	1.15	1.26754248	0.013816234
KFO207-17	8.5	1.92	1.635922877	0.080699812
KFO207-19	6.5	2.24	1.706615094	0.284499458
KFO207-21	4	1.38	1.116558295	0.069401532
KFO207-22	2	-0.38	0.22637766	0.367693867

coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.975





C.2.3 KFO209 – MN sheep



Test sur un jeu de données

Equation A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x

Nom **PBORD Bos28 M3**

	X	24.94465737	[mm]	period
	A	1.980679098	[%]	amplitude
	x0	0.967372884	[mm]	delay
	M	-3.17404619	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period

sum of differences² **2.618602571** [%]²

x0/X
0.038780765

sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
KFO209-01	22	-2.78	-2.0796079	0.490549098
KFO209-02	20.5	-2.87	-2.76582119	0.010853225
KFO209-03	19	-3.68	-3.50961798	0.029030034
KFO209-04	17.5	-3.91	-4.20607568	0.087660807
KFO209-05	16.5	-4.35	-4.59485702	0.059954961
KFO209-06	15.5	-4.16	-4.89396843	0.538709663
KFO209-07	14	-5	-5.13505998	0.018241199
KFO209-08	13	-5.26	-5.14261529	0.013779169
KFO209-09	11.5	-5.1	-4.92300483	0.03132729
KFO209-10	10.5	-5.19	-4.63610724	0.306797191
KFO209-11	9.5	-4.82	-4.25693771	0.317039137
KFO209-12	8	-3.8	-3.56874725	0.053477833
KFO209-13	6.5	-2.45	-2.82488104	0.140535791
KFO209-14	5.5	-1.69	-2.34998316	0.43557777
KFO209-15	4	-1.47	-1.74366896	0.074894698
KFO209-16	2.5	-1.44	-1.33913026	0.010174705

coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.951

C.2.4 KFO210 – LN sheep

Test sur un jeu de données

Equation A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x

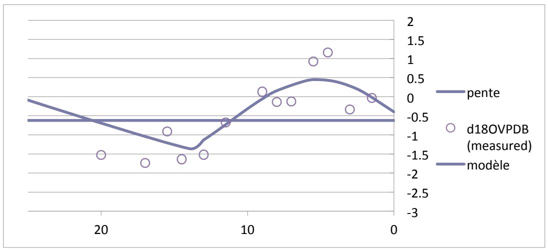
Nom **PBORD Bos28 M3**

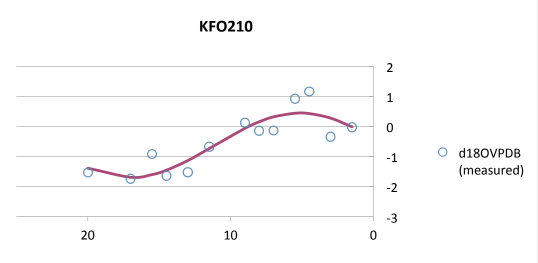
	X	23.82601192	[mm]	period
	A	1.066543002	[%]	amplitude
	x0	5.146745787	[mm]	delay
	M	-0.62185262	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
	sum of differences²	**2.160944005**	[%]²	

x0/X
0.216013733

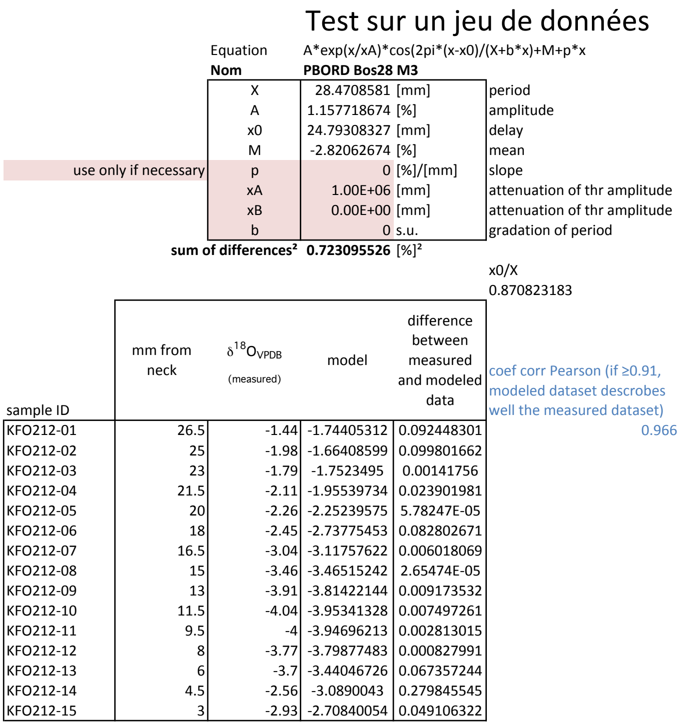
sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
KFO210-01	20	-1.53	-1.38354774	0.021448266
KFO210-03	17	-1.74	-1.68828134	0.002674819
KFO210-04	15.5	-0.91	-1.59945285	0.475345234
KFO210-05	14.5	-1.64	-1.45449882	0.034410687
KFO210-06	13	-1.52	-1.13336923	0.149483351
KFO210-07	11.5	-0.67	-0.73324038	0.003999346
KFO210-09	9	0.13	-0.060157	0.036159686
KFO210-10	8	-0.14	0.156758717	0.088065736
KFO210-11	7	-0.13	0.319839714	0.202355768
KFO210-12	5.5	0.92	0.440071714	0.230331159
KFO210-13	4.5	1.16	0.42922051	0.534038662
KFO210-14	3	-0.34	0.278299539	0.38229432
KFO210-15	1.5	-0.03	-0.01164328	0.000336969

coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.895





C.2.5 KFO212 – LN sheep



Test sur un jeu de données

Equation A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x

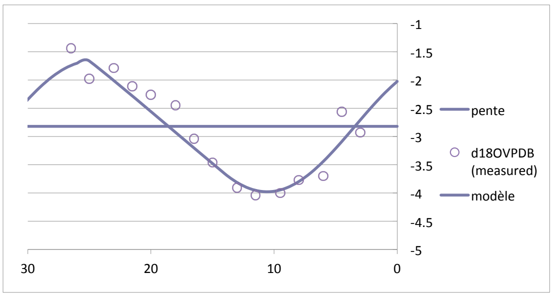
Nom **PBORD Bos28 M3**

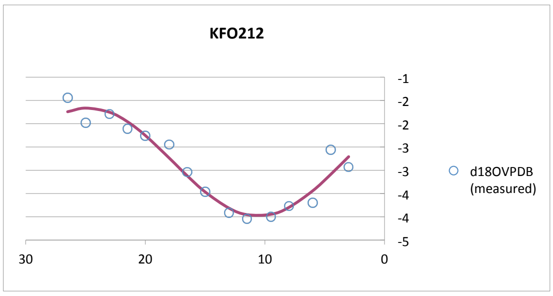
	X	28.4708581	[mm]	period
	A	1.157718674	[%]	amplitude
	x0	24.79308327	[mm]	delay
	M	-2.82062674	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
	sum of differences²	**0.723095526**	[%]²	

x0/X
0.870823183

coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.966

sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
KFO212-01	26.5	-1.44	-1.74405312	0.092448301
KFO212-02	25	-1.98	-1.66408599	0.099801662
KFO212-03	23	-1.79	-1.7523495	0.00141756
KFO212-04	21.5	-2.11	-1.95539734	0.023901981
KFO212-05	20	-2.26	-2.25239575	5.78247E-05
KFO212-06	18	-2.45	-2.73775453	0.082802671
KFO212-07	16.5	-3.04	-3.11757622	0.006018069
KFO212-08	15	-3.46	-3.46515242	2.65474E-05
KFO212-09	13	-3.91	-3.81422144	0.009173532
KFO212-10	11.5	-4.04	-3.95341328	0.007497261
KFO212-11	9.5	-4	-3.94696213	0.002813015
KFO212-12	8	-3.77	-3.79877483	0.000827991
KFO212-13	6	-3.7	-3.44046726	0.067357244
KFO212-14	4.5	-2.56	-3.0890043	0.279845545
KFO212-15	3	-2.93	-2.70840054	0.049106322





C.2.6 KFO214 – LN goat

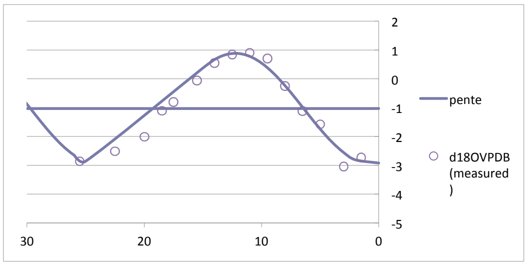
Test sur un jeu de données

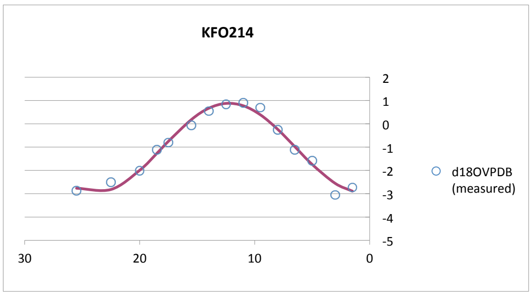
	Equation	A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x		
	Nom	**PBORD Bos28 M3**		
	X	23.29713103	[mm]	period
	A	1.915058603	[%]	amplitude
	x0	12.23004843	[mm]	delay
	M	-1.0323165	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
	sum of differences²	**0.63318512**	[%]²	

x0/X
0.524959422

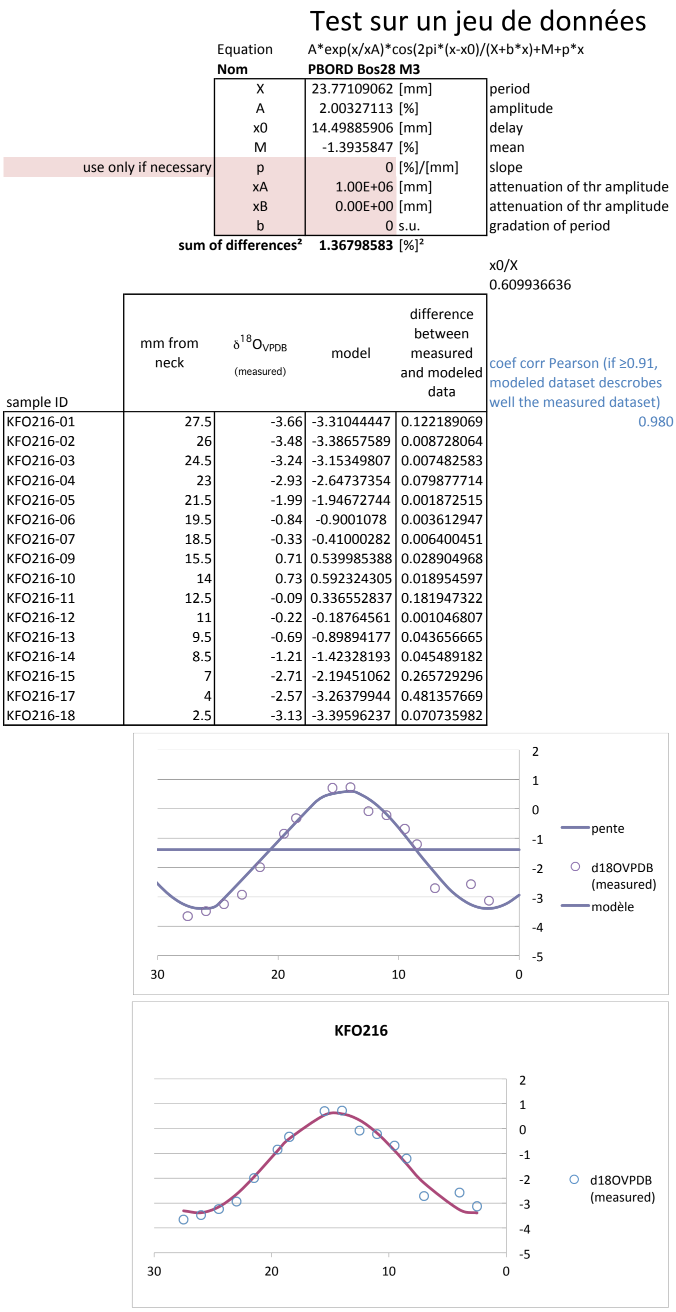
sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
KFO214-01	25.5	-2.86	-2.76722202	0.008607753
KFO214-03	22.5	-2.51	-2.81656235	0.093980477
KFO214-04	20	-2.01	-1.99176143	0.000332646
KFO214-05	18.5	-1.11	-1.26194911	0.023088531
KFO214-06	17.5	-0.8	-0.74707192	0.002801381
KFO214-07	15.5	-0.06	0.185079318	0.060063872
KFO214-08	14	0.55	0.668690268	0.01408738
KFO214-09	12.5	0.84	0.87769272	0.001420741
KFO214-10	11	0.9	0.778346568	0.014799557
KFO214-11	9.5	0.7	0.386690979	0.098162543
KFO214-12	8	-0.25	-0.2340451	0.000254559
KFO214-13	6.5	-1.12	-0.98365061	0.018591156
KFO214-14	5	-1.58	-1.7411104	0.02595656
KFO214-15	3	-3.05	-2.55423484	0.245783091
KFO214-16	1.5	-2.73	-2.88891782	0.025254873

coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.989





C.2.7 KFO216 – LN goat



Test sur un jeu de données

Equation A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x

Nom **PBORD Bos28 M3**

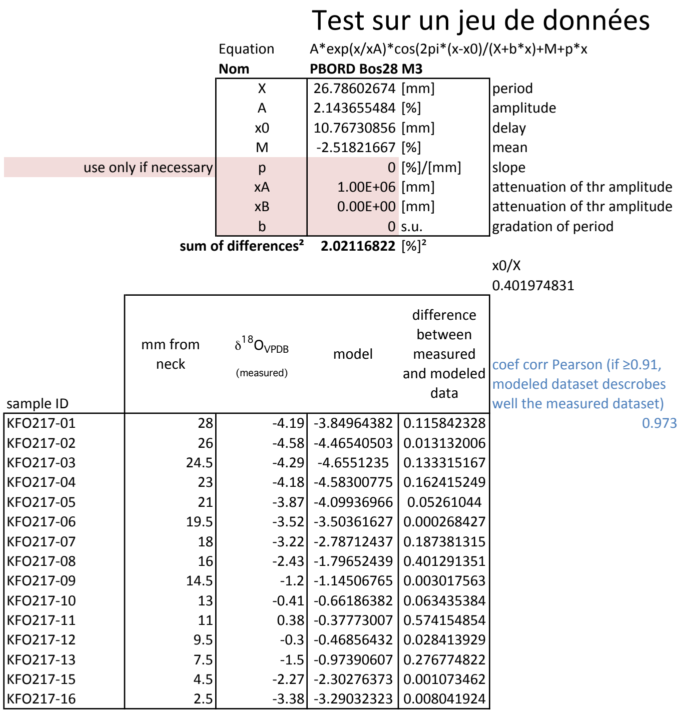
	X	23.77109062	[mm]	period
	A	2.00327113	[%]	amplitude
	x0	14.49885906	[mm]	delay
	M	-1.3935847	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
	sum of differences²	**1.36798583**	[%]²	

x0/X
0.609936636

coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.980

sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
KFO216-01	27.5	-3.66	-3.31044447	0.122189069
KFO216-02	26	-3.48	-3.38657589	0.008728064
KFO216-03	24.5	-3.24	-3.15349807	0.007482583
KFO216-04	23	-2.93	-2.64737354	0.079877714
KFO216-05	21.5	-1.99	-1.94672744	0.001872515
KFO216-06	19.5	-0.84	-0.9001078	0.003612947
KFO216-07	18.5	-0.33	-0.41000282	0.006400451
KFO216-09	15.5	0.71	0.539985388	0.028904968
KFO216-10	14	0.73	0.592324305	0.018954597
KFO216-11	12.5	-0.09	0.336552837	0.181947322
KFO216-12	11	-0.22	-0.18764561	0.001046807
KFO216-13	9.5	-0.69	-0.89894177	0.043656665
KFO216-14	8.5	-1.21	-1.42328193	0.045489182
KFO216-15	7	-2.71	-2.19451062	0.265729296
KFO216-17	4	-2.57	-3.26379944	0.481357669
KFO216-18	2.5	-3.13	-3.39596237	0.070735982

C.2.8 KFO217 – MN sheep



Test sur un jeu de données

Equation A*exp(x/xA)*cos(2pi*(x-x0)/(X+b*x)+M+p*x

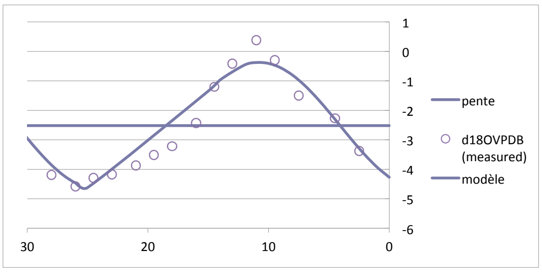
Nom **PBORD Bos28 M3**

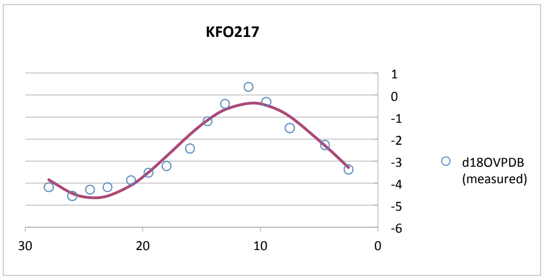
	X	26.78602674	[mm]	period
	A	2.143655484	[%]	amplitude
	x0	10.76730856	[mm]	delay
	M	-2.51821667	[%]	mean
use only if necessary	p	0	[%]/[mm]	slope
	xA	1.00E+06	[mm]	attenuation of thr amplitude
	xB	0.00E+00	[mm]	attenuation of thr amplitude
	b	0	s.u.	gradation of period
	sum of differences²	**2.02116822**	[%]²	

x0/X
0.401974831

sample ID	mm from neck	$\delta^{18}O_{VPDB}$ (measured)	model	difference between measured and modeled data
KFO217-01	28	-4.19	-3.84964382	0.115842328
KFO217-02	26	-4.58	-4.46540503	0.013132006
KFO217-03	24.5	-4.29	-4.6551235	0.133315167
KFO217-04	23	-4.18	-4.58300775	0.162415249
KFO217-05	21	-3.87	-4.09936966	0.05261044
KFO217-06	19.5	-3.52	-3.50361627	0.000268427
KFO217-07	18	-3.22	-2.78712437	0.187381315
KFO217-08	16	-2.43	-1.79652439	0.401291351
KFO217-09	14.5	-1.2	-1.14506765	0.003017563
KFO217-10	13	-0.41	-0.66186382	0.063435384
KFO217-11	11	0.38	-0.37773007	0.574154854
KFO217-12	9.5	-0.3	-0.46856432	0.028413929
KFO217-13	7.5	-1.5	-0.97390607	0.276774822
KFO217-15	4.5	-2.27	-2.30276373	0.001073462
KFO217-16	2.5	-3.38	-3.29032323	0.008041924

coef corr Pearson (if ≥0.91, modeled dataset descrobes well the measured dataset)
0.973





Appendix D

Supplementary table, contextual information of plant samples from Çatalhöyük

ID	Species	Unit no.	Flot no.	Area	Phase	House no.	Space	Context	Feature
CTH01	pea			South	Mellaart IV	E.IV.4		burnt primary house fill	
CTH02	einkorn			South	Mellaart VI	E.VI.17		burnt primary house fill	
CTH03	naked barley			South	Mellaart II	A.II.1		burnt primary house fill	
CTH04	naked barley			South	Mellaart II	A.II.1		primary bin fill (south bin)	
CTH05	new type glume wheat			South	Mellaart II	A.II.1		burnt primary house fill	
CTH06	naked barley			South	Mellaart II	A.II.1		burnt primary house fill	
CTH07	emmer			South	Mellaart VI	E.VI.24		burnt primary house fill	
CTH08	emmer			South	Mellaart VI	E.VI.2/E.VI.17		burnt primary house fill	
CTH09	Triticum sp.			South	Mellaart VI	E.VI.2		burnt primary house fill	
CTH10	emmer			South	Mellaart II	A.II.1		burnt primary house fill	
CTH11	new type glume wheat			South	Mellaart VI	E.VI.1		burnt primary house fill	
CTH12	new type glume wheat	16478	8452	4040	4040.?G	77	337	burnt primary fill of space	
CTH13	new type glume wheat	17511	8567	4040	4040.?G	77	336	wood ash/charcoal layer	platform 6058
CTH14	new type glume wheat	16480	8453	4040	4040.?G	77	337	spread of burnt grain on floor	
CTH15	new type glume wheat	16480	8454	4040	4040.?G	77	337	spread of burnt grain on floor	
CTH16	einkorn 1gr	16472	8370	4040	4040.?G	77	337	bin material consisting mostly of structural collapse	bin 3092
CTH17	new type glume wheat	16478	8437	4040	4040.?G	77	337	burnt primary fill of space	
CTH18	new type glume wheat	16480	8415	4040	4040.?G	77	337	spread of burnt grain on floor	
CTH19	new type glume wheat	16480	8416	4040	4040.?G	77	337	spread of burnt grain on floor	
CTH20	free-threshing wheat	10309	6026	4040	4040.G	52	93	seed concentration	
CTH21	emmer	13164	6839	4040	4040.I		279	external fire spot: lime burning	
CTH22	emmer	1849	677	South	South.?L		115	ash lens	
CTH23	new type glume wheat	16480	8413	4040	4040.?G	77	337	spread of burnt grain on floor	
CTH24	free-threshing wheat	12524	6822	South	South.P		132	midden: lime burning waste	
CTH25	scirpus	16715	8017	4040	4040.?G		60	external fire spot	
CTH26	naked barley	12524	6822	South	South.P		132	midden: lime burning waste	
CTH27	lentil	1314	329	North	North.?G	1	71	bin fill	
CTH28	scirpus	15782	7756	South	South.P		427	external fire	pit/scoop 2626
CTH29	naked barley	12524	6822	South	South.P		132	midden: lime burning waste	
CTH30	einkorn 2gr	12524	6822	South	South.P		132	midden: lime burning waste	
CTH31	new type glume wheat	16478	8428	4040	4040.?G	77	337	burnt primary fill of space	
CTH32	pea	12524	6822	South	South.P		132	midden: lime burning waste	
CTH33	naked barley	10292	5975	4040	4040.G	52	93	burnt primary fill, cluster with burnt animal bone	bin 2003
CTH34	pea	12524	6822	South	South.P		132	midden: lime burning waste	
CTH35	new type glume wheat	13164	6839	4040	4040.I		279	external fire spot: lime burning	
CTH36	free-threshing wheat	10292	5975	4040	4040.G	52	93	burnt primary fill, cluster with burnt animal bone	bin 2003
CTH37	naked barley	10308	6025	4040	4040.G	52	93	seed concentration	
CTH38	naked barley	10285	6020	4040	4040.G	52	93	burnt primary room fill	
CTH39	free-threshing wheat	10308	6025	4040	4040.G	52	93	seed concentration	
CTH40	free-threshing wheat	10285	6020	4040	4040.G	52	93	burnt primary room fill	
CTH41	free-threshing wheat	10081	5859	4040	4040.H	45	238	burnt primary fill	
CTH42	naked barley	11923	6078	4040	4040.G	52	93	burnt primary bin fill	bin 2004
CTH43	naked barley	11906	6044	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH44	pea	11923	6078	4040	4040.G	52	93	burnt primary bin fill	bin 2004
CTH45	pea	11907	6064	4040	4040.G	52	93	burnt primary bin fill	bin 2004
CTH46	naked barley	11970	6224	4040	4040.G	52	93	burnt primary basket fill	basket 2040
CTH47	pea	11970	6224	4040	4040.G	52	93	burnt primary basket fill	basket 2040
CTH48	pea	11923	6081	4040	4040.G	52	93	burnt primary bin fill	bin 2004
CTH49	free-threshing wheat	11906	6044	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH50	pea	11910	6066	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH51	free-threshing wheat	11910	6066	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH52	naked barley	11910	6066	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH53	naked barley	11958	6181	4040	4040.G	52	93	burnt primary bin fill	bin 2005
CTH54	new type glume wheat	10285	5977	4040	4040.G	52	93	burnt primary room fill	
CTH55	pea	11958	6181	4040	4040.G	52	93	burnt primary bin fill	bin 2005
CTH56	naked barley	11906	6058	4040	4040.G	52	93	burnt primary bin fill	bin 2002

ID	Species	Unit no.	Flot no.	Area	Phase	House no.	Space	Context	Feature
CTH57	free-threshing wheat	10285	5977	4040	4040.G	52	93	burnt primary room fill	
CTH58	naked barley	11904	6053	4040	4040.G	52	93	burnt primary bin fill	bin 2004
CTH59	naked barley	16763	8457	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH60	naked barley	10284	6065	4040	4040.G	52	93	burnt primary bin fill	bin 2003
CTH61	einkorn 1gr	16469	8348	4040	4040.?G	77	337	burnt primary fill	
CTH62	free-threshing wheat	16763	8457	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH63	naked barley	10285	5977	4040	4040.G	52	93	burnt primary room fill	
CTH64	free-threshing wheat	11906	6058	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH65	naked barley	10304	6229	4040	4040.G	52	93	burnt primary house fill	
CTH66	naked barley	11903	6031	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH67	naked barley	11900	6027	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH68	emmer	5076	3247	South	South.K	17	170	oven fill	fire installation 555
CTH69	lentil	1845	674	South	South.?K	2	116	midden in abandoned building	wall 72
CTH70	new type glume wheat	16484	8456	4040	4040.?G	77	337	burnt primary fill	platform 6053
CTH71	pea	17513	8612	4040	4040.?G	77	336	burnt primary fill in ladder emplacement	ladder empl. 6054
CTH72	naked barley	17513	8612	4040	4040.?G	77	336	burnt primary fill in ladder emplacement	ladder empl. 6054
CTH73	free-threshing wheat	11903	6033	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH74	naked barley	11903	6033	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH75	naked barley	11911	6051	4040	4040.G	52	93	burnt primary bin fill	bin 2004
CTH76	lentil	5076	3247	South	South.K	17	170	oven fill	fire installation 555
CTH77	pea	11911	6051	4040	4040.G	52	93	burnt primary bin fill	bin 2004
CTH78	naked barley	11903	6052	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH79	free-threshing wheat	11908	6059	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH80	naked barley	11908	6059	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH80	naked barley	11908	6059	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH81	pea	11911	6070	4040	4040.G	52	93	burnt primary bin fill	bin 2004
CTH82	naked barley	11900	6030	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH83	naked barley	11900	6028	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH84	naked barley	11900	6029	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH85	pea	11911	6056	4040	4040.G	52	93	burnt primary bin fill	bin 2004
CTH86	naked barley	11903	6032	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH87	pea	11923	6082	4040	4040.G	52	93	burnt primary bin fill	bin 2004
CTH88	free-threshing wheat	11908	6049	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH89	free-threshing wheat	18596	9176	South	South.O	79	134	seed concentration apparently spilling from bin F.5031	
CTH90	new type glume wheat	30785	10922	TPC	Mellaart III-II	122	493	barley cluster	bin 7182
CTH91	pea	18952	9271	South	South.O	80	135	seed concentration, north of small bin	
CTH92	pea	16536	9256	South	South.P	75	328	seed concentration, "debitage deposition"	
CTH93	naked barley	16536	9256	South	South.P	75	328	seed concentration, "debitage deposition"	
CTH94	almond shell	11908	6049	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH95	almond kernel	11908	6049	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH96	almond shell	11908	6049	4040	4040.G	52	93	burnt primary bin fill	bin 2002
CTH97	almond kernel	11908	6049	4040	4040.G	52	93	burnt primary bin fill	bin 2002
PRT1B	pea	16498	8505	4040	4040.?G	77	336	burnt seed/fish remains	platform 6053
PRT3B	lentil	1344	144	North	North.?G	1	71	bin fill	bin 215
PRT4bB	naked barley	30859	10921	TPC	Mellaart III-II	122	493	barley cluster	bin 7182
CAT180	acorn kernel	3014	1291	North	North.?G	1	71/73		wall 7
CAT181	almond shell	4866	3137	South	South.G	NA	181		
CAT182	reed	6151	3399	BACH	BACH.?G	3	86		burial 154, platform 162
CAT183	rumex	8394	5019	BACH	BACH.?G	3	201		fire installation 785
CAT184	descurania	1442	516	North	North.?G	1	187		
CAT185	naked barley	1227	11	North	North.?G	1	186		
CAT190	naked barley	11900	6030	4040	4040.G	52	93		bin 2002
CAT191	almond shell	11906	6044	4040	4040.G	52	93		bin 2002
CAT192	almond kernel	11906	6044	4040	4040.G	52	93		bin 2002
CAT195	descurania	11956	6225	4040	4040.G	52	93		bin 2005
CAT196	scirpus	4866	3137	South	South.G	NA	181		
CAT197	scirpus	5314	3742	South	South.G	NA	181		

ID	Species	Unit no.	Flot no.	Area	Phase	House no.	Space	Context	Feature
CAT198	scirpus	5277	3324	South	South.G	NA	181		
CAT206	naked barley			South	Mellaart VI	E.VI.24			
CAT207	naked barley			South	Mellaart VI	E.VI.50			
CAT208	naked barley			South	Mellaart VII	E.VII.24			
CAT209	Triticum sp.			South	Mellaart VI	A.VI.3			
CAT210	pea			South	Mellaart II	A.II.1			
CAT211	pea			South	Mellaart VI	E.VI			
CAT212	acorn kernel			South	Mellaart V	A.V.4			
CAT213	acorn kernel			South	Mellaart VI	E.VI.1			
CAT214	Triticum sp.			South	Mellaart VI	E.VI.1			
CAT215	Triticum sp.			South	Mellaart VI	E.VI.1			
CAT216	free-threshing wheat			South	Mellaart VII	E.VII.25			
CAT217	einkorn 1gr			South	Mellaart VI	E.VI.17			
CAT218	einkorn 1gr			South	Mellaart VI	E.VI.18			
CAT219	einkorn 1gr			South	Mellaart VI	E.VI.19			
CAT220	free-threshing wheat			South	Mellaart VI	E.VI.2			
CAT221	descurania			South	Mellaart VI	E.VI.17			
CAT222	pea			South	Mellaart VI	E.VI.25			
CAT223	descurania			South	Mellaart VI	E.VI.44			
CAT224	Triticum sp.			South	Mellaart VII	E.VII.34			
CAT225	pea			South	Mellaart V	E.V.8			

Appendix E

Supplementary table, plant δ^{13}C and δ^{15}N measurements from Çatalhöyük

ID	Species	$\delta^{13}C_{VPDB}$	$\delta^{13}C_{corrected}$	$\delta^{13}C$ SD	%C	$\Delta^{13}C$	$\delta^{15}N_{AIR}$	$\delta^{15}N_{corrected}$	$\delta^{15}N$ SD	%N	CN	Measured by
CTH01	pea	-22.8	-22.9	0.5	57.6	16.8	1.9	1.6	0.3	5.8	11.5	PV
CTH02	einkorn, no variety	-20.4	-20.5	0.5	56.8	14.3	12.3	12.0	0.4	10.8	6.1	PV
CTH03	naked barley	-22.8	-22.9	0.5	62.3	16.8	10.3	10.0	0.3	9.7	7.5	PV
CTH04	naked barley	-22.4	-22.5	0.5	62.9	16.4	4.0	3.7	0.3	3.7	19.7	PV
CTH05	new type glume wheat	-23.4	-23.5	0.5	61.0	17.4	7.5	7.2	0.3	5.9	12.0	PV
CTH06	naked barley	-23.6	-23.7	0.5	68.6	17.6	3.9	3.6	0.3	3.4	23.5	PV
CTH07	emmer	-23.8	-23.9	0.5	61.0	17.8	11.9	11.6	0.4	3.2	22.4	PV
CTH08	emmer	-21.1	-21.2	0.5	57.9	15.0	9.1	8.8	0.3	7.0	9.7	PV
CTH09	wheat indet.	-23.3	-23.4	0.5	58.7	17.3	9.4	9.1	0.3	7.6	9.0	PV
CTH10	emmer	-25.2	-25.3	0.5	64.1	19.3	4.3	4.0	0.3	3.0	25.2	PV
CTH11	new type glume wheat	-21.8	-21.9	0.5	57.2	15.7	12.9	12.6	0.4	11.3	5.9	PV
CTH12	new type glume wheat	-22.5	-22.6	0.1	52.5	16.5	10.1	9.8	0.4	7.2	8.5	PV
CTH13	new type glume wheat	-22.8	-22.9	0.5	56.8	16.8	17.1	16.8	0.4	7.7	8.6	PV
CTH14	new type glume wheat	-22.5	-22.6	0.5	56.5	16.5	13.0	12.7	0.4	12.0	5.5	PV
CTH15	new type glume wheat	-22.3	-22.4	0.5	52.2	16.3	17.3	17.0	0.4	16.2	3.8	PV
CTH16	einkorn, one-grained	-22.7	-22.8	0.5	52.2	16.7	9.8	9.5	0.3	3.9	15.5	PV
CTH17	new type glume wheat	-23.5	-23.6	0.5	54.2	17.5	12.9	12.6	0.4	8.3	7.6	PV
CTH18	new type glume wheat	-23.4	-23.5	0.5	55.5	17.4	15.6	15.3	0.4	10.8	6.0	PV
CTH19	new type glume wheat	-24.0	-24.1	0.5	54.8	18.0	14.0	13.7	0.4	9.3	6.9	PV
CTH20	free-threshing wheat	-21.6	-21.7	0.5	61.9	15.5	9.6	9.3	0.3	5.8	12.5	PV
CTH21	emmer	-24.2	-24.3	0.5	60.6	18.2	10.7	10.4	0.3	5.5	12.8	PV
CTH22	emmer	-22.2	-22.3	0.5	61.3	16.2	8.5	8.2	0.3	4.2	17.2	PV
CTH23	new type glume wheat	-22.7	-22.8	0.5	56.1	16.7	14.9	14.6	0.4	10.7	6.1	PV
CTH24	free-threshing wheat	-22.2	-22.3	0.5	64.7	16.2	12.1	11.8	0.4	5.3	14.1	PV
CTH25	scirpus	-22.2	-22.3	0.5	58.8	16.2	10.9	10.6	0.3	2.0	33.8	PV
CTH26	naked barley	-23.8	-23.9	0.5	64.3	17.8	12.1	11.8	0.4	3.9	19.3	PV
CTH27	lentil	-24.5	-24.6	0.5	59.9	18.6	5.1	4.8	0.3	8.3	8.4	PV
CTH28	scirpus	-25.0	-25.1	0.5	61.4	19.1	10.0	9.7	0.3	1.5	46.8	PV
CTH29	naked barley	-23.3	-23.4	0.1	62.3	17.3	13.8	13.5	0.4	4.2	17.2	PV
CTH30	einkorn, two-grained	-22.6	-22.7	0.1	61.5	16.6	11.8	11.5	0.5	4.4	16.2	PV
CTH31	new type glume wheat	-22.8	-22.9	0.1	59.7	16.8	12.9	12.6	0.4	9.6	7.3	PV
CTH32	pea	-23.7	-23.8	0.1	61.4	17.7	7.2	6.9	0.5	7.8	9.2	PV
CTH33	naked barley	-23.6	-23.7	0.1	61.2	17.6	8.5	8.2	0.5	3.9	18.3	PV
CTH34	pea	-24.2	-24.3	0.1	62.5	18.2	6.5	6.2	0.5	5.1	14.4	PV
CTH35	new type glume wheat	-22.2	-22.3	0.1	60.4	16.2	9.2	8.9	0.5	6.2	11.4	PV
CTH36	free-threshing wheat	-23.3	-23.4	0.1	65.1	17.3	9.6	9.3	0.5	4.5	16.9	PV
CTH37	naked barley	-21.8	-21.9	0.1	61.8	15.7	10.8	10.5	0.5	7.1	10.2	PV
CTH38	naked barley	-22.6	-22.7	0.1	54.0	16.6	3.9	3.6	0.4	31.9	2.0	PV
CTH39	free-threshing wheat	-22.2	-22.3	0.1	59.1	16.2	11.0	10.7	0.5	6.3	10.9	PV
CTH40	free-threshing wheat	-21.6	-21.7	0.1	52.3	15.5	12.8	12.5	0.4	11.1	5.5	PV
CTH41	free-threshing wheat	-23.7	-23.8	0.1	57.8	17.7	12.3	12.0	0.4	5.8	11.6	PV
CTH42	naked barley	-21.7	-21.8	0.1	56.5	15.6	11.4	11.1	0.5	7.3	9.0	PV
CTH43	naked barley	-23.8	-23.9	0.1	61.6	17.8	7.1	6.8	0.5	3.7	19.7	PV
CTH44	pea	-22.1	-22.2	0.1	54.9	16.1	4.4	4.1	0.4	8.2	7.8	PV
CTH45	pea	-23.0	-23.1	0.1	58.2	17.0	4.6	4.3	0.4	8.0	8.5	PV
CTH46	naked barley	-22.2	-22.3	0.1	55.1	16.2	12.9	12.6	0.4	7.3	8.8	PV
CTH47	pea	-22.9	-23.0	0.1	57.2	16.9	9.4	9.1	0.5	11.1	6.0	PV
CTH48	pea	-22.3	-22.4	0.1	64.6	16.3	5.0	4.7	0.6	10.5	7.2	PV
CTH49	free-threshing wheat	-23.5	-23.6	0.1	64.7	17.5	8.0	7.7	0.5	4.8	15.9	PV
CTH50	pea	-22.7	-22.8	0.1	62.5	16.7	5.2	4.9	0.6	8.3	8.8	PV
CTH51	free-threshing wheat	-23.2	-23.3	0.1	60.7	17.2	9.9	9.6	0.5	5.9	12.0	PV
CTH52	naked barley	-22.2	-22.3	0.1	63.2	16.2	8.9	8.6	0.5	4.5	16.4	PV
CTH53	naked barley	-23.1	-23.2	0.1	63.4	17.1	9.0	8.7	0.5	4.3	17.4	PV
CTH54	new type glume wheat	-23.7	-23.8	0.1	62.1	17.7	9.7	9.4	0.5	5.0	14.5	PV
CTH55	pea	-21.6	-21.7	0.1	52.9	15.5	4.4	4.1	0.6	9.1	6.8	PV
CTH56	naked barley	-23.2	-23.3	0.1	60.1	17.2	9.4	9.1	0.5	6.1	11.5	PV
CTH57	free-threshing wheat	-22.7	-22.8	0.1	58.9	16.7	9.9	9.6	0.5	5.8	11.9	PV
CTH58	naked barley	-23.1	-23.2	0.1	60.3	17.1	7.8	7.5	0.4	3.5	20.2	PV
CTH59	naked barley	-23.1	-23.2	0.1	61.5	17.1	10.5	10.2	0.5	5.1	14.1	PV
CTH60	naked barley	-23.4	-23.5	0.1	65.0	17.4	8.7	8.4	0.4	2.5	30.3	PV
CTH61	einkorn, one-grained	-22.6	-22.7	0.1	56.5	16.6	11.3	11.0	0.4	7.0	9.4	PV
CTH62	free-threshing wheat	-22.9	-23.0	0.1	63.4	16.9	10.2	9.9	0.8	4.4	16.8	PV
CTH63	naked barley	-23.1	-23.2	0.1	62.1	17.1	9.0	8.7	0.8	5.5	13.2	PV
CTH64	free-threshing wheat	-22.8	-22.9	0.1	61.3	16.8	10.1	9.8	0.8	5.6	12.7	PV
CTH65	naked barley	-21.8	-21.9	0.1	54.5	15.7	8.7	8.4	0.8	6.5	9.8	PV
CTH66	naked barley	-23.3	-23.4	0.1	61.8	17.3	9.0	8.7	0.8	3.5	20.6	PV
CTH67	naked barley	-23.0	-23.1	0.1	64.0	17.0	8.7	8.4	0.8	3.7	20.1	PV

ID	Species	$\delta^{13}C_{VPDB}$	$\delta^{13}C_{corrected}$	$\delta^{13}C$ SD	%C	$\Delta^{13}C$	$\delta^{15}N_{AIR}$	$\delta^{15}N_{corrected}$	$\delta^{15}N$ SD	%N	CN	Measured by
CTH68	emmer	-21.7	-21.8	0.1	59.2	15.6	8.2	7.9	0.8	4.6	15.1	PV
CTH69	lentil	-22.2	-22.3	0.2	56.7	16.2	4.0	3.7	0.8	6.5	10.2	PV
CTH70	new type glume wheat	-22.6	-22.7	0.2	61.2	16.6	13.1	12.8	0.8	5.8	12.4	PV
CTH71	pea	-22.1	-22.2	0.1	57.5	16.1	6.6	6.3	0.8	8.1	8.3	PV
CTH72	naked barley	-20.9	-21.0	0.2	62.6	14.8	14.8	14.5	0.8	8.8	8.3	PV
CTH73	free-threshing wheat	-22.9	-23.0	0.1	65.5	16.9	7.6	7.3	0.8	3.8	20.1	PV
CTH74	naked barley	-23.3	-23.4	0.1	59.6	17.3	7.9	7.6	0.8	3.8	18.3	PV
CTH75	naked barley	-22.2	-22.3	0.2	61.8	16.2	13.5	13.2	0.8	7.4	9.8	PV
CTH76	lentil	-21.5	-21.6	0.2	64.0	15.4	5.2	4.9	0.8	5.2	14.3	PV
CTH77	pea	-22.3	-22.4	0.2	61.6	16.3	3.7	3.4	0.8	6.2	11.5	PV
CTH78	naked barley	-23.0	-23.1	0.2	71.0	17.0	8.1	7.8	0.8	3.1	26.5	PV
CTH79	free-threshing wheat	-22.8	-22.9	0.2	70.1	16.8	8.7	8.4	0.8	3.4	23.9	PV
CTH80	naked barley	-22.9	-23.0	0.2	64.3	16.9	8.1	7.8	0.8	2.7	28.2	PV
CTH80	naked barley	-23.1	-23.2	0.1	65.5	17.1	8.1	7.8	0.8	2.7	28.7	PV
CTH81	pea	-21.4	-21.5	0.1	54.5	15.3	6.1	5.8	0.8	6.8	9.4	PV
CTH82	naked barley	-22.8	-22.9	0.2	64.1	16.8	8.6	8.3	0.8	3.4	21.9	PV
CTH83	naked barley	-22.8	-22.9	0.2	60.1	16.8	8.1	7.8	0.8	3.2	21.7	PV
CTH84	naked barley	-22.9	-23.0	0.2	63.1	16.9	7.5	7.2	0.8	4.2	17.3	PV
CTH85	pea	-23.0	-23.1	0.2	55.9	17.0	4.8	4.5	0.8	7.1	9.1	PV
CTH86	naked barley	-23.1	-23.2	0.1	64.0	17.1	7.8	7.5	0.8	3.7	20.2	PV
CTH87	pea	-21.3	-21.4	0.2	62.0	15.2	5.0	4.7	0.8	8.1	9.0	PV
CTH88	free-threshing wheat	-22.9	-23.0	0.2	65.5	16.9	9.2	8.9	0.8	4.2	18.1	PV
CTH89	free-threshing wheat	-24.2	-24.3	0.1	64.4	18.2	10.8	10.5	0.8	3.1	24.0	PV
CTH90	new type glume wheat	-22.5	-22.6	0.2	56.2	16.5	6.9	6.6	0.8	9.2	7.1	PV
CTH91	pea	-23.7	-23.8	0.2	63.1	17.7	2.3	2.0	0.8	4.5	16.3	PV
CTH92	pea	-23.4	-23.5	0.2	61.8	17.4	2.5	2.2	0.8	4.2	17.1	PV
CTH93	naked barley	-23.4	-23.5	0.1	62.4	17.4	7.8	7.5	0.8	2.7	27.3	PV
CTH94	almond shell	-23.2	-23.3	0.2	70.0	17.2	4.7	4.4	0.8	1.1	71.6	PV
CTH95	almond kernel	-21.1	-21.2	0.2	61.9	15.0	8.6	8.3	0.4	7.8	9.3	PV
CTH96	almond shell	-23.5	-23.6	0.2	63.2	17.5	1.6	1.3	0.4	1.2	61.4	PV
CTH97	almond kernel	-21.0	-21.1	0.2	61.8	14.9	6.5	6.2	0.3	5.8	12.5	PV
PRT1B	pea	-23.0	-23.1	0.1	55.9	17.0	6.4	6.1	0.3	7.3	8.9	PV
PRT3B	lentil	-23.1	-23.2	0.1	59.3	17.1	4.5	4.2	0.3	7.9	8.8	PV
PRT4bB	naked barley	-22.4	-22.5	0.1	67.7	16.4	7.3	7.0	0.2	7.5	10.5	PV
CAT180	acorn kernel	-21.9	-22.0	0.1	61.3	15.8	9.5	9.2	0.4	2.6	27.6	RF
CAT181	almond shell	-23.2	-23.3	0.1	63.5	17.2	5.8	5.5	0.4	0.6	117.6	RF
CAT182	reed	-23.0	-23.1	0.1	59.8	17.0	9.2	8.9	0.4	0.8	90.6	RF
CAT183	rumex	-23.9	-24.0	0.1	61.1	17.9	10.8	10.5	0.4	3.1	22.9	RF
CAT184	descurania	-22.2	-22.3	0.1	60.7	16.2	9.7	9.4	0.4	6.1	11.7	RF
CAT185	naked barley	-21.8	-21.9	0.1	59.0	15.7	12.1	11.8	0.4	5.9	11.7	RF
CAT190	naked barley	-23.2	-23.3	0.1	58.5	17.2	8.7	8.4	0.4	3.9	17.6	RF
CAT191	almond shell	-24.2	-24.3	0.1	54.9	18.2	4.3	4.0	0.4	1.2	52.5	RF
CAT192	almond kernel	-22.5	-22.6	0.1	60.6	16.5	8.0	7.7	0.4	6.1	11.5	RF
CAT195	descurania	-23.3	-23.4	0.1	62.3	17.3	9.7	9.4	0.4	6.2	11.8	RF
CAT196	scirpus	-24.1	-24.2	0.1	61.2	18.1	12.1	11.8	0.4	1.7	43.3	RF
CAT197	scirpus	-23.7	-23.8	0.1	65.2	17.7	10.9	10.6	0.4	1.8	43.5	RF
CAT198	scirpus						10.4	10.1	0.4	1.3		RF
CAT206	naked barley	-21.5	-21.6	0.1	55.9	15.4	9.3	9.0	0.4	7.4	8.8	RF
CAT207	naked barley	-22.3	-22.4	0.1	60.5	16.3	9.4	9.1	0.4	6.5	10.8	RF
CAT208	naked barley	-21.5	-21.6	0.1	58.0	15.4	9.4	9.1	0.4	7.7	8.8	RF
CAT209	wheat indet.	-24.3	-24.4	0.1	59.6	18.3	7.0	6.7	0.4	4.2	16.5	RF
CAT210	pea	-22.7	-22.8	0.1	57.4	16.7	3.3	3.0	0.4	9.8	6.8	RF
CAT211	pea	-21.8	-21.9	0.1	59.9	15.7	2.2	1.9	0.4	6.3	11.1	RF
CAT212	acorn kernel	-24.5	-24.6	0.1	62.8	18.6	8.3	8.0	0.4	1.9	39.2	RF
CAT213	acorn kernel	-22.5	-22.6	0.1	59.3	16.5	10.4	10.1	0.4	5.4	12.8	RF
CAT214	wheat indet.	-22.9	-23.0	0.1	57.5	16.9						RF
CAT215	wheat indet.	-23.9	-24.0	0.1	58.7	17.9	6.0	5.7	0.4	6.7	10.2	RF
CAT216	free-threshing wheat	-22.6	-22.7	0.1	55.4	16.6	8.7	8.4	0.4	6.9	9.3	RF
CAT217	einkorn, one-grained	-22.2	-22.3	0.1	55.6	16.2	6.9	6.6	0.4	5.9	11.0	RF
CAT218	einkorn, one-grained	-22.2	-22.3	0.1	60.7	16.2	7.5	7.2	0.4	5.3	13.3	RF
CAT219	einkorn, one-grained	-22.3	-22.4	0.1	58.9	16.3	7.1	6.8	0.4	5.2	13.2	RF
CAT220	free-threshing wheat	-22.3	-22.4	0.1	56.4	16.3	9.0	8.7	0.4	7.3	9.0	RF
CAT221	descurania	-23.6	-23.7	0.1	61.5	17.6	12.5	12.2	0.4	5.8	12.4	RF
CAT222	pea	-23.4	-23.5	0.1	55.5	17.4	4.1	3.8	0.4	6.5	10.0	RF
CAT223	descurania	-22.4	-22.5	0.1	58.4	16.4						RF
CAT224	wheat indet.	-23.7	-23.8	0.1	63.3	17.7	6.9	6.6	0.4	3.5	21.1	RF
CAT225	pea	-20.8	-20.9	0.1	58.9	14.7	2.8	2.5	0.4	7.0	9.9	RF

Appendix F

Supplementary table, plant δ^{13}C and δ^{15}N measurements from Kouphovouno

ID	Species	Context	Area	Phase	$\delta^{13}C_{VPDB}$	$\delta^{13}C_{corrected}$	$\delta^{13}C$ SD	%C	$\Delta^{13}C$	$\delta^{15}N_{AIR}$	$\delta^{15}N_{corrected}$	$\delta^{15}N$ SD	%N	CN
KFO30	hulled barley	G2001	G	LN	-22.5	-22.6	0.5	65.6	16.5	2.0	1.7	0.3	2.5	30.1
KFO31	einkorn	G1665	G	LN	-24.3	-24.4	0.9	62.5	18.3	1.5	1.2	0.4	3.6	20.0
KFO32	einkorn	G2001	G	LN	-24.2	-24.3	0.5	63.7	18.2	-0.1	-0.4	0.4	3.7	19.9
KFO33	hulled barley	B0185	B	LN	-23.4	-23.5	0.5	60.8	17.4	0.6	0.3	0.3	2.8	25.4
KFO34	hulled barley	C0918	C	MN						2.2	1.9	0.3	2.7	
KFO35	einkorn	C0825	C	MN	-20.1	-20.2	0.6	62.7	14.0	4.9	4.6	0.3	3.7	19.7
KFO36	einkorn	G2003	G	LN	-22.8	-22.9	0.5	63.9	16.8	-1.0	-1.3	0.4	3.1	24.2
KFO37	hulled barley	G1136	G	LN	-24.3	-24.4	0.5	54.1	18.3	0.6	0.3	0.3	2.4	26.8
KFO38	grass pea	G1136	G	LN	-25.0	-25.1	0.5	56.3	19.1	-2.2	-2.5	0.4	5.6	11.7
KFO39	free-threshing wheat	B0180	B	MN	-22.0	-22.1	0.5	60.7	16.0	2.8	2.5	0.3	3.6	19.7
KFO40	hulled barley	B0149	B	LN	-24.5	-24.6	0.5	65.2	18.6	-2.1	-2.4	0.4	2.2	34.9
KFO41	einkorn	G1136	G	LN	-23.8	-23.9	0.1	63.9	17.8	-1.0	-1.3	0.4	4.5	16.5
KFO42	hulled barley	C0848	C	MN	-24.2	-24.3	0.5	59.1	18.2	0.4	0.1	0.3	2.3	30.4
KFO43	einkorn	G1139	G	LN	-22.4	-22.5	0.5	63.7	16.4	0.8	0.5	0.3	3.3	22.8
KFO50	free-threshing wheat	C0266	C	MN						4.4	4.1	0.3	2.7	
KFO51	hulled barley	C0266	C	MN	-24.6	-24.7	0.5	45.8	18.7	0.5	0.2	0.3	2.2	24.7
KFO52	free-threshing wheat	C0295	C	MN	-22.9	-23.0	0.5	23.8	16.9					
KFO53	hulled barley	C0905	C	MN	-23.7	-23.8	0.5	47.9	17.7	0.5	0.2	0.3	2.4	23.0
KFO54	free-threshing wheat	C0905	C	MN	-21.6	-21.7	0.5	41.6	15.5	1.9	1.6	0.3	2.9	16.8

Appendix G

Supplementary table, sheep/goat δ^{13}C and δ^{18}O measurements from Kouphovouno

KFO204 (MN goat)		KFO207 (MN goat)		KFO209 (MN sheep)		KFO210 (LN sheep)		KFO212 (LN sheep)		KFO214 (LN goat)		KFO216 (LN goat)		KFO217 (MN sheep)	
$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$
-12.2	-2.9	-11.7	-1.5	-10.2	-2.8	-12.3	-1.5	-9.0	-1.4	-12.9	-2.9	-12.5	-3.7	-11.1	-4.2
-12.5	-1.1	-12.0	-1.2	-10.0	-2.9	-12.2	-2.2	-9.0	-2.0	-12.7	-3.8	-12.7	-3.5	-11.9	-4.6
-12.4	-0.4	-12.3	-2.2	-10.6	-3.7	-12.5	-1.7	-9.0	-1.8	-12.9	-2.5	-12.7	-3.2	-12.5	-4.3
-12.5	-0.2	-12.4	-2.9	-10.9	-3.9	-12.5	-0.9	-9.5	-2.1	-12.7	-2.0	-12.5	-2.9	-12.8	-4.2
-12.6	-0.3	-12.9	-2.3	-11.0	-4.4	-12.5	-1.6	-10.1	-2.3	-13.0	-1.1	-12.2	-2.0	-13.2	-3.9
-12.3	-0.9	-12.9	-2.8	-11.6	-4.2	-12.4	-1.5	-10.9	-2.5	-13.0	-0.8	-11.9	-0.8	-13.3	-3.5
-12.4	-0.6	-13.1	-2.2	-11.9	-5.0	-12.5	-0.7	-11.6	-3.0	-12.9	-0.1	-12.0	-0.3	-13.7	-3.2
-12.2	-2.3	-13.1	-2.3	-12.5	-5.3	-12.3	-1.6	-12.4	-3.5	-12.6	0.6	-11.9	-0.7	-13.5	-2.4
-12.5	-1.8	-13.3	-3.0	-12.9	-5.1	-12.4	0.1	-13.1	-3.9	-12.4	0.8	-11.8	0.7	-13.3	-1.2
-12.4	-2.7	-12.7	-2.0	-13.3	-5.2	-12.1	-0.1	-13.3	-4.0	-12.3	0.9	-11.5	0.7	-13.1	-0.4
-12.5	-3.3	-12.9	-1.4	-13.5	-4.8	-12.4	-0.1	-13.5	-4.0	-12.1	0.7	-11.6	-0.1	-12.3	0.4
Δ=0.4	Δ=3.1	-12.8	-0.8	-13.3	-3.8	-12.3	0.9	-13.1	-3.8	-12.2	-0.3	-11.7	-0.2	-11.2	-0.3
		-12.7	-0.4	-13.1	-2.5	-12.0	1.2	-12.2	-3.7	-12.3	-1.1	-11.4	-0.7	-10.5	-1.5
		-12.7	-0.2	-11.8	-1.7	-11.5	-0.3	-11.2	-2.6	-12.1	-1.6	-11.5	-1.2	-10.3	-3.5
		-12.1	0.8	-11.6	-1.5	-11.4	0.0	-10.6	-2.9	-12.3	-3.1	-11.4	-2.7	-10.8	-2.3
		-12.3	1.2	-10.6	-1.4	Δ=1.1	Δ=3.3	Δ=4.6	Δ=2.6	-12.2	-2.7	-11.7	-4.0	-12.6	-3.4
		-12.2	1.9	Δ=3.5	Δ=3.8					Δ=1.0	Δ=4.7	-12.2	-2.6	Δ=3.5	Δ=5.0
		-11.6	2.2									-12.7	-3.1		
		-12.2	1.4									Δ=1.3	Δ=4.8		
		-12.4	-0.4												
		Δ=1.6	Δ=5.3												

Appendix H

Supplementary table, contextual information of plants and animals from Makriyalos

ID	Species	Unit	Area	Phase	Context	Context type	Sample type
MAK127	emmer	L 0133	Ditch A	Makriyalos I (ELN)	Ditch A	non-feasting	grain
MAK128	emmer	L 0124	Ditch A	Makriyalos I (ELN)	Ditch A	non-feasting	grain
MAK129	emmer	L 0124	Ditch A	Makriyalos I (ELN)	Ditch A	non-feasting	grain
MAK130	pistachio	H 0292	H (Megaron)	Makriyalos II (LLN)		non-feasting	shell
MAK201	cattle	Pi 056416	Pi	Makriyalos I (ELN)	Pit 212	feasting	post-cranial
MAK202	cattle	Pi 066116	Pi	Makriyalos I (ELN)	Pit 212	feasting	post-cranial
MAK203	cattle	Pi 066219	Pi	Makriyalos I (ELN)	Pit 212	feasting	post-cranial
MAK204	cattle	Pi 066116	Pi	Makriyalos I (ELN)	Pit 212	feasting	post-cranial
MAK205	cattle	Pi 056453	Pi	Makriyalos I (ELN)	Pit 212	feasting	post-cranial
MAK206	sheep	Pi 056369	Pi	Makriyalos I (ELN)	Pit 212	feasting	post-cranial
MAK207	sheep	Pi 057112	Pi	Makriyalos I (ELN)	Pit 212	feasting	post-cranial
MAK210	sheep	Pi 057143	Pi	Makriyalos I (ELN)	Pit 212	feasting	post-cranial
MAK211	goat	Pi 057324	Pi	Makriyalos I (ELN)	Pit 212	feasting	post-cranial
MAK212	goat	Pi 057317	Pi	Makriyalos I (ELN)	Pit 212	feasting	post-cranial
MAK213	goat	Pi 057350	Pi	Makriyalos I (ELN)	Pit 212	feasting	post-cranial
MAK214	goat	Pi 056420	Pi	Makriyalos I (ELN)	Pit 212	feasting	post-cranial
MAK215	goat	Pi 057127	Pi	Makriyalos I (ELN)	Pit 212	feasting	post-cranial
MAK216	cattle	K 627336	K	Makriyalos I (ELN)	Ditch	non-feasting	post-cranial
MAK217	cattle	K 629107	K	Makriyalos I (ELN)	Ditch	non-feasting	post-cranial
MAK218	cattle	Xi 999199	Xi	Makriyalos I (ELN)	Ditch	non-feasting	post-cranial
MAK220	cattle	K 627252	K	Makriyalos I (ELN)	Ditch	non-feasting	post-cranial
MAK221	goat	K 635201	K	Makriyalos I (ELN)	Ditch	non-feasting	post-cranial
MAK222	goat	R 142430	R	Makriyalos I (ELN)	Ditch	non-feasting	post-cranial
MAK223	goat	L 714102	L	Makriyalos I (ELN)	Ditch	non-feasting	post-cranial
MAK224	goat	L 714295	L	Makriyalos I (ELN)	Ditch	non-feasting	post-cranial
MAK225	goat	I 523304	I	Makriyalos I (ELN)	Ditch	non-feasting	post-cranial
MAK226	sheep	Xi 963127	Xi	Makriyalos I (ELN)	Ditch	non-feasting	post-cranial
MAK229	sheep	L 714136	L	Makriyalos I (ELN)	Ditch	non-feasting	post-cranial
MAK230	sheep	Xi 944405	Xi	Makriyalos I (ELN)	Ditch	non-feasting	post-cranial
MAK232	cattle	Xi 958409	Xi	Makriyalos I (ELN)	Pit 214	feasting	post-cranial
MAK233	cattle	Xi 958423	Xi	Makriyalos I (ELN)	Pit 214	feasting	post-cranial
MAK235	cattle	Xi 958402	Xi	Makriyalos I (ELN)	Pit 214	feasting	post-cranial
MAK236	cattle	O 567220	O	Makriyalos I (ELN)	Habitation	non-feasting	post-cranial
MAK241	goat	Xi 958402	Xi	Makriyalos I (ELN)	Pit 214	feasting	post-cranial
MAK242	goat	Xi 968112	Xi	Makriyalos I (ELN)	Pit 214	feasting	post-cranial
MAK243	goat	Xi 958107	Xi	Makriyalos I (ELN)	Pit 214	feasting	post-cranial
MAK244	goat	Xi 968303	Xi	Makriyalos I (ELN)	Pit 214	feasting	post-cranial
MAK245	goat	Xi 957411	Xi	Makriyalos I (ELN)	Pit 214	feasting	post-cranial
MAK246	sheep	Xi 958204	Xi	Makriyalos I (ELN)	Pit 214	feasting	post-cranial
MAK247	sheep	Xi 958412	Xi	Makriyalos I (ELN)	Pit 214	feasting	post-cranial
MAK249	sheep	Xi 958401	Xi	Makriyalos I (ELN)	Pit 214	feasting	post-cranial
MAK250	sheep	Xi 968206	Xi	Makriyalos I (ELN)	Pit 214	feasting	post-cranial
MAK252	goat	R 153226	R	Makriyalos I (ELN)	Habitation	non-feasting	post-cranial
MAK253	goat	O 567222	O	Makriyalos I (ELN)	Habitation	non-feasting	post-cranial
MAK254	goat	R 142428	R	Makriyalos I (ELN)	Habitation	non-feasting	post-cranial
MAK255	goat	R 143329	R	Makriyalos I (ELN)	Habitation	non-feasting	post-cranial
MAK256	sheep	R 164203	R	Makriyalos I (ELN)	Habitation	non-feasting	post-cranial
MAK257	sheep	O 568115	O	Makriyalos I (ELN)	Habitation	non-feasting	post-cranial
MAK259	sheep	O 567215	O	Makriyalos I (ELN)	Habitation	non-feasting	post-cranial
MAK401	cattle	L 0124027	L	Makriyalos I (ELN)		non-feasting	post-cranial

ID	Species	Unit	Area	Phase	Context	Context type	Sample type
MAK430	cattle	H 302001	H	Makriyalos II (LLN)		non-feasting	post-cranial
MAK431	cattle	H 433038	H	Makriyalos II (LLN)		non-feasting	post-cranial
MAK433	cattle	Th 062065	Th	Makriyalos II (LLN)		non-feasting	post-cranial
MAK434	cattle	X 713014	X	Makriyalos II (LLN)		non-feasting	post-cranial
MAK436	red deer	H 204019	H	Makriyalos II (LLN)		non-feasting	post-cranial
MAK438	red deer	Th 114028	Th	Makriyalos II (LLN)		non-feasting	post-cranial
MAK440	sheep	Th 033023	Th	Makriyalos II (LLN)		non-feasting	post-cranial
MAK441	sheep	H 454019	H	Makriyalos II (LLN)		non-feasting	post-cranial
MAK442	sheep	H 441026	H	Makriyalos II (LLN)		non-feasting	post-cranial
MAK443	sheep	H 541025	H	Makriyalos II (LLN)		non-feasting	post-cranial
MAK444	sheep	H 444018	H	Makriyalos II (LLN)		non-feasting	post-cranial
MAK445	goat	H 174006	H	Makriyalos II (LLN)		non-feasting	post-cranial
MAK446	goat	Th 123026	Th	Makriyalos II (LLN)		non-feasting	post-cranial
MAK447	goat	Th 033042	Th	Makriyalos II (LLN)		non-feasting	post-cranial
MAK448	goat	Th 024099	Th	Makriyalos II (LLN)		non-feasting	post-cranial
MAK449	goat	Th 024099	Th	Makriyalos II (LLN)		non-feasting	post-cranial
MAKP01	emmer	L 0141	L	Makriyalos I (ELN)	Ditch A	non-feasting	grain
MAKP02	emmer	L 0124	L	Makriyalos I (ELN)	Ditch A	non-feasting	grain
MAKP03	grass pea	Th 0094	area south of hearths/ovens	Makriyalos II (LLN)		non-feasting	seed
MAKP04	lentil	Th 0094	area south of hearths/ovens	Makriyalos II (LLN)		non-feasting	seed
MAKP05	lentil	H 0294	H (Megaron)	Makriyalos II (LLN)		non-feasting	seed
MAKP06	lentil	H 0292	H (Megaron)	Makriyalos II (LLN)		non-feasting	seed
MKS001	cattle	R 0654080	Ditch G	Makriyalos I (ELN)		habitation	mandible
MKS002	cattle	R 0424___	Ditch G	Makriyalos I (ELN)		habitation	mandible
MKS004	cattle	X 0121014	Borrow pit	Makriyalos I (ELN)		habitation	mandible
MKS005	cattle	O 0681027	Habitation	Makriyalos I (ELN)		habitation	mandible
MKS006	cattle	R 0642017	Ditch G	Makriyalos I (ELN)		habitation	mandible
MKS007	cattle	R 0543090	Ditch G	Makriyalos I (ELN)		habitation	mandible
MKS008	cattle	R 0654031	Ditch G	Makriyalos I (ELN)		habitation	mandible
MKS009	cattle	R 0654020	Ditch G	Makriyalos I (ELN)		habitation	mandible
MKS012	cattle	Pi 0564041	Pit 212	Makriyalos I (ELN)		feasting	mandible
MKS016	cattle	Pi 0564018	Pit 213	Makriyalos I (ELN)		feasting	mandible
MKS017	cattle	Pi 0572031	Pit 214	Makriyalos I (ELN)		feasting	mandible
MKS018	cattle	Pi 0563039	Pit 215	Makriyalos I (ELN)		feasting	mandible
MKS105	sheep	Pi 0572012	Pit 216	Makriyalos I (ELN)		feasting	mandible
MKS106	sheep	Pi 0571035	Pit 217	Makriyalos I (ELN)		feasting	mandible
MKS107	sheep	O 0672022	Habitation	Makriyalos I (ELN)		habitation	mandible

Appendix I

Supplementary table, plant and animal δ^{13}C and δ^{15}N measurements from Makriyalos

ID	Species	Sample type	$\delta^{13}C_{VPDB}$	$\delta^{13}C_{corrected}$	$\delta^{13}C$ SD	%C	$\Delta^{13}C$	$\delta^{15}N_{AIR}$	$\delta^{15}N_{corrected}$	$\delta^{15}N$ SD	%N	CN	Measured by
MAKP01	emmer	grain	-24.0	-24.1	0.5	60.4	18.0	0.4	0.1	0.3	2.2	32.4	PV
MAKP02	emmer	grain	-24.6	-24.7	0.5	56.2	18.7	2.3	2.0	0.3	2.4	27.2	PV
MAKP03	grass pea	seed	-25.4	-25.5	0.5	61.1	19.5	1.9	1.6	0.3	6.0	12.0	PV
MAKP04	lentil	seed	-23.0	-23.1	0.5	59.3	17.0	1.5	1.2	0.3	6.1	11.3	PV
MAKP05	lentil	seed	-25.2	-25.3	0.5	59.1	19.3	1.6	1.3	0.3	6.0	11.5	PV
MAKP06	lentil	seed	-22.5	-22.6	0.5	53.9	16.5	3.5	3.2	0.3	8.6	7.3	PV
MAK127	emmer	grain	-24.3	-24.4	0.1		18.3	1.2	0.9	0.4	2.8		RF
MAK128	emmer	grain	-24.5	-24.6	0.1		18.6	1.2	0.9	0.4	2.8		RF
MAK129	emmer	grain	-24.5	-24.6	0.1		18.6	1.7	1.4	0.4	2.9		RF
MAK130	pistachio	shell	-23.4	-23.5	0.1		17.4	2.2	1.8	0.4	1.3		RF
MAK201	cattle	post-cranial	-13.9		0.9	41.7		5.9		1.1	15.1	3.2	PV/RF
MAK202	cattle	post-cranial	-16.1		0.9	38.1		3.3		1.1	13.7	3.2	PV/RF
MAK203	cattle	post-cranial	-16.3		0.1	41.4		5.3		0.1	14.8	3.3	PV/RF
MAK204	cattle	post-cranial	-18.6		0.1	41.4		5.2		0.1	14.9	3.2	PV/RF
MAK205	cattle	post-cranial	-13.6		0.9	41.7		3.4		1.1	15.2	3.2	PV/RF
MAK206	sheep	post-cranial	-20.3		0.1	41.4		3.9		0.1	14.8	3.3	PV/RF
MAK207	sheep	post-cranial	-18.7		0.1	45.3		6.0		0.1	16.3	3.2	PV/RF
MAK210	sheep	post-cranial	-17.2		0.1	42.0		7.5		0.2	15.1	3.2	PV/RF
MAK211	goat	post-cranial	-19.8		0.1	40.3		3.4		0.1	14.3	3.3	PV/RF
MAK212	goat	post-cranial	-19.2		0.1	41.9		5.3		0.1	15.0	3.3	PV/RF
MAK213	goat	post-cranial	-18.3		0.1	42.2		4.5		0.1	15.2	3.2	PV/RF
MAK214	goat	post-cranial	-20.7		0.9	39.2		6.3		1.1	14.2	3.2	PV/RF
MAK215	goat	post-cranial	-19.0		0.1	41.8		4.9		0.1	15.1	3.2	PV/RF
MAK216	cattle	post-cranial	-15.0		0.1	42.0		5.4		0.1	15.2	3.2	PV/RF
MAK217	cattle	post-cranial	-14.0		0.9	41.4		5.2		1.1	14.9	3.2	PV/RF
MAK218	cattle	post-cranial	-15.7		0.1	42.1		6.5		0.1	14.9	3.3	PV/RF
MAK220	cattle	post-cranial	-15.5		0.1	41.2		5.3		0.1	15.0	3.2	PV/RF
MAK221	goat	post-cranial	-19.9		0.9	39.4		4.3		1.1	14.1	3.3	PV/RF
MAK222	goat	post-cranial	-19.7		0.9	42.4		4.8		1.1	15.3	3.2	PV/RF
MAK223	goat	post-cranial	-19.6		0.1	41.9		4.7		0.1	15.1	3.2	PV/RF
MAK224	goat	post-cranial	-19.0		0.9	38.9		5.3		1.1	14.0	3.2	PV/RF
MAK225	goat	post-cranial	-20.4		0.1	38.4		4.8		0.1	13.7	3.3	PV/RF
MAK226	sheep	post-cranial	-19.4		0.9	41.5		6.1		1.1	15.1	3.2	PV/RF
MAK229	sheep	post-cranial	-19.2		0.1	41.9		5.4		0.1	15.0	3.3	PV/RF
MAK230	sheep	post-cranial	-19.1		0.9	41.9		4.2		1.1	15.1	3.2	PV/RF
MAK232	cattle	post-cranial	-15.8		0.1	40.4		6.2		0.1	14.4	3.3	PV/RF
MAK233	cattle	post-cranial	-14.7		0.1	45.8		3.6		0.1	16.4	3.3	PV/RF
MAK235	cattle	post-cranial	-18.9		0.1	41.9		6.4		0.1	15.1	3.2	PV/RF
MAK236	cattle	post-cranial	-17.1		0.1	42.6		5.9		0.1	15.3	3.2	PV/RF
MAK241	goat	post-cranial	-20.6		0.1	38.8		6.4		0.1	13.6	3.3	PV/RF
MAK242	goat	post-cranial	-19.5		0.1	41.5		3.9		0.1	14.8	3.3	PV/RF
MAK243	goat	post-cranial	-19.9		0.1	41.0		3.5		0.1	14.8	3.2	PV/RF
MAK244	goat	post-cranial	-19.9		0.1	39.2		5.2		0.1	14.0	3.3	PV/RF
MAK245	goat	post-cranial	-20.3		0.9	41.6		2.9		1.1	15.0	3.2	PV/RF
MAK246	sheep	post-cranial	-18.7		0.9	39.7		4.4		1.1	14.3	3.2	PV/RF
MAK247	sheep	post-cranial	-18.6		0.1	41.7		5.8		0.1	15.0	3.2	PV/RF
MAK249	sheep	post-cranial	-17.8		0.9	39.4		4.1		1.1	14.1	3.3	PV/RF
MAK250	sheep	post-cranial	-18.2		0.9	39.8		5.7		1.1	14.1	3.3	PV/RF
MAK252	goat	post-cranial	-19.1		0.9	39.8		5.3		1.1	14.4	3.2	PV/RF
MAK253	goat	post-cranial	-20.0		0.1	43.8		3.8		0.1	15.7	3.3	PV/RF
MAK254	goat	post-cranial	-20.1		0.1	42.8		4.8		0.1	15.5	3.2	PV/RF
MAK255	goat	post-cranial	-19.1		0.1	39.9		3.5		0.1	14.4	3.2	PV/RF
MAK256	sheep	post-cranial	-18.6		0.1	41.9		4.8		0.1	15.2	3.2	PV/RF
MAK257	sheep	post-cranial	-19.1		0.1	43.6		4.7		0.1	15.5	3.3	PV/RF
MAK259	sheep	post-cranial	-20.0		0.1	42.5		6.0		0.1	15.3	3.2	PV/RF
MAK401	cattle	post-cranial	-15.6		0.1	43.7		4.5		0.1	15.8	3.2	PV/RF
MAK430	cattle	post-cranial	-20.4		0.9	40.4		4.7		1.1	14.4	3.3	PV/RF
MAK431	cattle	post-cranial	-19.0		0.1	46.0		4.6		0.1	16.9	3.2	PV/RF
MAK433	cattle	post-cranial	-18.3		0.1	41.8		3.6		0.1	15.3	3.2	PV/RF
MAK434	cattle	post-cranial	-14.7		0.1	41.1		4.6		0.1	14.9	3.2	PV/RF
MAK436	red deer	post-cranial	-21.4		0.1	39.1		2.7		0.1	14.0	3.3	PV/RF
MAK438	red deer	post-cranial	-21.5		0.1	42.0		6.1		0.1	15.0	3.3	PV/RF
MAK440	sheep	post-cranial	-19.9		0.1	41.8		6.1		0.1	15.1	3.2	PV/RF
MAK441	sheep	post-cranial	-18.7		0.1	42.8		5.5		0.1	15.6	3.2	PV/RF
MAK442	sheep	post-cranial	-21.0		0.1	43.7		4.4		0.1	15.8	3.2	PV/RF
MAK443	sheep	post-cranial	-20.5		0.9	42.5		3.6		1.1	15.4	3.2	PV/RF
MAK444	sheep	post-cranial	-19.1		0.1	43.6		4.6		0.1	15.8	3.2	PV/RF
MAK445	goat	post-cranial	-19.1		0.9	42.0		3.6		1.1	15.1	3.2	PV/RF

ID	Species	Sample type	$\delta^{13}C_{VPDB}$	$\delta^{13}C_{corrected}$	$\delta^{13}C$ SD	%C	$\Delta^{13}C$	$\delta^{15}N_{AIR}$	$\delta^{15}N_{corrected}$	$\delta^{15}N$ SD	%N	CN	Measured by
MAK446	goat	post-cranial	-20.0		0.1	43.5		4.3		0.1	15.6	3.3	PV/RF
MAK447	goat	post-cranial	-20.5		0.1	41.9		2.4		0.1	15.2	3.2	PV/RF
MAK448	goat	post-cranial	-19.7		0.1	41.6		2.9		0.1	15.0	3.2	PV/RF
MAK449	goat	post-cranial	-20.9		0.9	40.4		3.3		1.1	14.4	3.3	PV/RF
MKS001	cattle	mandible	-10.3		0.1	41.0		5.2		0.2	14.4	3.3	PV
MKS002	cattle	mandible	-16.6		0.1	29.1		5.5		0.2	10.4	3.3	PV
MKS004	cattle	mandible	-18.6		0.1	24.8		8.5		0.2	8.6	3.4	PV
MKS005	cattle	mandible	-18.2		0.1	38.3		4.6		0.1	13.4	3.3	PV
MKS006	cattle	mandible	-17.3		0.1	40.0		3.5		0.1	14.4	3.2	PV
MKS007	cattle	mandible	-18.5		0.1	16.9		3.3		0.1	5.5	3.6	PV
MKS008	cattle	mandible	-14.5		0.1	40.6		6.8		0.2	14.8	3.2	PV
MKS009	cattle	mandible	-13.6		0.1	43.6		5.8		0.2	15.4	3.3	PV
MKS012	cattle	mandible	-12.1		0.1	36.9		6.3		0.2	13.0	3.3	PV
MKS016	cattle	mandible	-17.2		0.1	37.4		6.4		0.2	13.6	3.2	PV
MKS017	cattle	mandible	-18.9		0.1	22.5		4.8		0.1	7.5	3.5	PV
MKS018	cattle	mandible	-17.1		0.1	27.5		5.6		0.2	9.7	3.3	PV
MKS105	sheep	mandible	-19.0		0.2	27.5		4.6		0.3	8.9	3.6	PV
MKS106	sheep	mandible	-18.1		0.5	30.7		4.5		0.9	10.5	3.4	PV
MKS107	sheep	mandible	-20.2		0.6	34		4.2		1	11.7	3.4	PV

Appendix J

Supplementary table, cattle $\delta^{13}C$ and $\delta^{18}O$ measurements from Makriyalos

MKS001 (habitation)		MKS004 (habitation)		MKS006 (habitation)		MKS007 (habitation)		MKS014 (feasting)		MKS015 (feasting)		MKS016 (feasting)		MKS017 (feasting)	
$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$
-5.3	-5.5	-11.2	-3.1	-10.9	-7.7	-10.6	-7.9	-9.1	-5.9	-9.7	-5.6	-10.7	-6.1	-12.9	-4.0
-5.3	-5.6	-10.7	-3.3	-11.2	-6.4	-10.9	-7.3	-9.8	-6.1	-10.5	-5.5	-11.2	-5.5	-12.8	-4.5
-5.1	-5.1	-10.3	-2.8	-11.2	-6.7	-11.6	-7.4	-9.6	-5.9	-10.5	-5.6	-11.3	-5.7	-12.3	-4.7
-4.5	-4.7	-10.1	-3.1	-11.1	-5.9	-11.6	-6.8	-9.8	-6.3	-10.7	-5.4	-11.5	-5.5	-12.2	-4.5
-4.4	-4.0	-9.6	-2.8	-10.8	-6.1	-11.6	-6.3	-9.7	-6.1	-10.7	-5.1	-11.8	-5.2	-12.0	-3.8
-4.4	-3.4	-9.4	-2.7	-10.5	-5.5	-11.4	-5.8	-9.6	-6.0	-11.0	-3.5	-11.7	-4.9	-11.7	-3.8
-4.3	-3.2	-9.3	-2.9	-10.1	-5.9	-11.3	-5.1	-9.0	-5.8	-10.8	-4.6	-11.6	-4.6	-11.2	-3.6
-3.7	-3.2	-9.0	-2.8	-9.7	-5.9	-11.2	-4.6	-8.6	-5.2	-10.7	-4.4	-11.4	-4.1	-10.8	-3.5
-3.3	-2.8	-8.8	-2.9	-8.7	-5.5	-11.0	-4.3	-7.8	-4.8	-10.5	-4.1	-11.1	-4.0	-10.5	-3.6
-3.2	-3.4	-8.8	-3.2	-8.3	-3.8	-11.0	-4.4	-7.1	-4.1	-10.3	-3.7	-11.0	-4.2	-10.0	-3.6
-2.6	-3.6	-8.7	-3.7	-7.8	-3.8	-10.6	-3.7	-7.1	-4.2	-9.9	-2.9	-10.8	-3.7	-9.6	-3.8
-2.9	-3.7	-8.4	-3.8	-7.1	-3.4	-10.1	-3.5	-6.4	-3.9	-9.8	-3.2	-10.6	-3.6	-9.7	-4.0
-2.7	-4.0	-9.0	-5.5	-6.5	-3.6	-10.0	-3.2	-5.7	-3.8	-9.6	-3.0	-10.3	-3.6	-9.4	-4.6
-3.6	-4.6	-8.5	-4.2	-6.7	-3.5	-9.8	-3.0	-4.8	-3.9	-9.5	-3.0	-10.2	-3.9	-9.2	-4.4
-4.3	-4.7	-8.7	-5.8	-6.2	-3.2	-9.7	-3.0	-4.1	-4.1	-9.3	-3.2	-9.7	-3.1	-9.6	-5.1
-5.1	-4.8	-9.0	-6.0	-6.0	-4.0	-9.5	-3.0	-3.7	-3.8	-9.0	-3.5	-9.8	-3.5	-9.7	-5.7
-6.0	-4.8	-9.7	-5.5	-5.7	-3.9	-9.1	-3.0	-3.5	-3.9	-8.7	-4.5	-9.8	-3.9	-10.0	-5.9
-6.4	-5.8	-10.0	-5.4	-5.8	-4.1	-9.0	-2.7	-3.4	-3.8	-8.7	-4.7	-9.9	-4.2	-10.4	-6.2
Δ=3.8	Δ=3.0	-10.3	-6.1	-5.7	-4.3	-8.9	-3.2	-3.5	-4.2	-8.7	-5.2	-10.0	-4.8	-11.1	-6.7
		-10.6	-6.3	-6.9	-4.9	-8.6	-3.3	-4.8	-4.6	-9.0	-5.9	-10.3	-5.3	-11.8	-7.1
		-10.5	-7.7	-7.4	-5.1	-8.4	-3.1	-4.9	-5.5	-9.0	-6.2	-10.8	-5.8	-12.3	-7.4
		-10.6	-7.6	-8.1	-5.8	-8.2	-3.5	-5.8	-6.2	-9.1	-6.4	-11.1	-6.2	-12.7	-7.6
		Δ=2.8	Δ=4.9	-8.7	-6.4	-8.1	-3.4	Δ=6.4	Δ=2.5	Δ=2.3	Δ=3.5	-11.6	-6.4	-12.8	-7.1
				-9.6	-6.7	-8.0	-3.7					-12.0	-6.7	Δ=3.7	Δ=4.1
				-10.4	-7.0	-7.9	-3.5					-12.2	-6.9		
				-10.6	-7.2	-8.3	-4.1					-12.4	-6.8		
				Δ=5.5	Δ=4.6	-8.4	-4.1					-12.6	-6.4		
						-8.9	-4.2					Δ=3.0	Δ=3.8		
						-9.7	-4.6								
						-10.3	-4.8								
						-10.9	-5.5								
						-10.8	-5.5								
						Δ=4.7	Δ=5.2								

Appendix K

Supplementary table, sheep δ^{13}C and δ^{18}O measurements from Makriyalos

MKS104 (habitation)		MKS015 (feasting)		MKS106 (feasting)		MKS107 (habitation)	
$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$
-11.8	-4.5	-13.3	-6.0	-12.2	-6.0	-14.5	-6.8
-11.2	-3.2	-13.5	-6.3	-12.6	-5.9	-14.6	-6.3
-10.6	-3.2	-13.5	-5.9	-13.0	-6.0	-14.5	-5.9
-9.2	-2.7	-13.5	-5.2	-13.3	-5.5	-14.2	-5.1
-8.0	-2.1	-13.3	-4.1	-13.2	-5.5	-13.8	-4.2
-6.8	-1.4	-12.8	-3.2	-12.8	-4.0	-13.2	-3.3
-7.0	-2.0	-12.0	-2.2	-11.7	-2.5	-12.3	-2.9
-7.4	-2.2	-11.1	-1.6	-9.8	-2.1	-11.4	-2.5
-7.6	-3.1	-10.2	-1.1	-8.0	-1.3	-10.6	-2.3
-9.1	-4.1	-9.3	-1.3	-5.8	-1.6	-10.4	-2.4
-10.0	-5.0	-8.7	-1.2	-5.7	-2.3	-10.5	-2.8
Δ=5.0	Δ=3.7	-8.9	-2.1	-6.8	-3.1	-11.0	-3.7
		-9.2	-3.0	-10.1	-5.4	-12.0	-5.0
		Δ=4.9	Δ=5.2	Δ=7.6	Δ=4.7	-12.7	-6.3
						-13.6	-6.9
						Δ=4.2	Δ=4.6

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