MOLECULAR AND STABLE ISOTOPIC ANALYSES OF THE FATTY ACYL COMPONENTS OF THE POTTERY OF ÇATALHÖYÜK, TURKEY: UNDERSTANDING THE RELATIONSHIPS BETWEEN ANIMAL DOMESTICATION, CERAMIC TECHNOLOGY, ENVIRONMENTAL VARIATION AND THEIR ROLES IN THE SECONDARY PRODUCTS REVOLUTION

A DISSERTATION
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Abstract

An extensive study of the organic residue associated with the Neolithic pottery of Çatalhöyük has further confirmed the timing of dairy production on-site after following the methods of a previous study (Evershed et al. 2008). By utilizing gas chromatography (GC) on 313 potsherds, and high temperature-GC/mass spectrometry (HT-GC/MS), GC-combustion-IRMS (GC-C-IRMS) and GC-thermal conversion-IRMS (GC-TC-IRMS) on subsets of that pottery collection from the Neolithic site of Çatalhöyük in central Turkey, the first well-dated stratigraphic record of both compound-specific $\delta^{13}C$ and δD values of $C_{16:0}$ and $C_{18:0}$ fatty acids has now been established.The combination of this new information with the faunal and stable isotope records of the same site has provided a more detailed account of changes in animal management strategy over time. This study provides an in-depth look at some of the oldest dairy residues found to date as well as environmental and social factors that may have contributed or resulted from the transition to secondary product use during the Neolithic.

In addition, a newly developed palaeoenvironmental proxy may provide a direct link between changes in local precipitation levels and changes in subsistence practices by assessing stable hydrogen isotope (δD) values of fatty acids extracted from pottery residues. The origins of the fatty acids were determined based on their $\delta^{13}C$ values as arising largely from ruminant adipose and dairy fats. A δD record was constructed, based on a subset of ruminant adipose fats only, which showed most negative isotopic values from ~6900 to 6600 cal BC indicative of wet conditions, followed by a drying trend which reached a maximum at or just after 6280 cal BC, coincident with the 8.2 ka (~6200 cal BC) cold, dry climate event. The drying trend is consistent with that observed in the $\delta^{18}O$ record from the nearby lake Eski Acıgöl carbonates. Thus, δD analysis of archaeological residues may be useful in assessing broader environmental and climatic changes directly from cultural residues.

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I dedicate this work to my father, Herman Pitter, who passed on during my first year in graduate school. I hope that through me you feel you have accomplished and will continue to accomplish great things.

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Chapter 1 Introduction

1.1 The Neolithic Revolution

The Neolithic Revolution was a time period marked by many changes in people's attempts to manipulate and adapt to their environments, and how they understood themselves in relation to the natural world. Most notably, the Neolithic period included the beginnings of settled life, when people gained control over their food supplies through plant and animal domestication. Within south-central Turkey this cultural transition is estimated to have occurred between approximately 8000–5000 BC (Ozdöğan and Başgelen 1999). Even though this period is referred to as a revolution it is clear that it was a relatively slow, complex process.

It was also a period in time that involved the development of ceramic pottery. It can be inferred that this, along with the other social and economic changes occurring at this time, would have had great impacts on the human psyche (Childe 1951).

But why were these changes occurring?

Understanding the developments associated with the Neolithic Revolution and the reasons behind them have long been prominent goals of archaeological studies. In the early 1950's, V.G. Childe first coined the term "Neolithic Revolution," which corresponded to Braidwood's idea of "incipient cultivation and domestication" (Bar-Yosef 1998). These ideas originally related several aspects of settlement development and plant and animal cultivation to each other as contemporaneous results of either environmental, as suggested by Childe, or cultural phenomena, as suggested by Braidwood (Bar-Yosef 1998).

At Abu Hureyra, a Neolithic site located in modern-day Syria along the banks of the Euphrates, one community's transition to cultivation and domestication of plants and animals can be witnessed within the archaeological record. The Neolithic community at Abu Hureyra most likely began domesticating plants and animals after wild resources in their surrounding area became depleted due to increased aridity (Moore et al. 2000). It is possible that such environmental factors may have encouraged many subsistence changes throughout the history of humankind.

Another possibility is that population expansion among nomadic hunter-gatherer groups may have placed increased stress on resource availability. An increasingly stable climate in the early Holocene would have been conducive to the growth of abundant wild crops, allowing population increase throughout the Near East. In turn, the growing populations may have reached a critical point at which cultivation of plants and the domestication of animals became necessary to support ever-expanding human populations.

Although there is a plethora of information regarding the status of climatic, demographic, health and resource factors during the development of agriculture, there is still not a widely accepted explanation for what could have caused such a widespread change in separate subsistence economies around the world. The main enquiries focus on what sort of subconscious and conscious factors were responsible for the transition to full agricultural economies. It seems that one of the major questions behind what caused humans to become agriculturalists is what level of awareness did they have about the costs and benefits associated with a transition to mixed subsistence and, finally, to permanent, agricultural economies?

It would appear that the accumulation of nutritional resources would have been crucial to the development of agricultural societies. Thus, it seems likely that people who were making the transition from mobile to permanent settlements would have decided to achieve the most "bang for their buck" when it came to the resources available to them. For this reason this thesis will test the hypothesis that *the use of dairy products would have taken place much earlier than previously supposed* as suggested by Vigne and Helmer (2007). This would mean that the secondary products revolution suggested by Sherratt (1981) would have taken place much earlier, or perhaps been part of the Neolithic revolution. Studies of changes in faunal culling practices during the PPNB of the Levant have demonstrated that sheep and goat herds would have been used for both meat and milk (Vigne 2007; Vigne et al. 2011). Also, although only a limited number of domestic cattle specimens were available for analysis, it was suggested that cow milk was exploited during the Neolithic of the Near East as early as the 8th millennium cal BC). Although there is no genetic evidence of lactase persistence in adults during occupation of Çatalhöyük, a recent study by Evershed et al. (2008) supports the idea that dairying was a part of the early Neolithic package (Burger et al. 2007). Due to the probable lack of genetic lactose persistence in the 8th millennium cal BC one possible explanation for the presence of milk fats in pottery is the use of fermented milk products and cheese, which would have been easier to digest than raw milk fats (Brüssow 2013). It is possible that cattle as well as sheep and goats were milked at Çatalhöyük. However, current evidence suggests that dairy was not a substantial part of early (PPNB) Neolithic subsistence and a dairy boom may have occurred much later. But to understand this we must first look at previous assumptions about the evidence for the first uses of dairy products in the archaeological record.

1.2 The Secondary Products Revolution

In addition to the Neolithic Revolution, Andrew Sherratt predicted that there was a later separate subsistence revolution that resulted in the exploitation of animals for milk, wool and other secondary products. This was appropriately termed the Secondary Products Revolution (Sherratt 1981).

The clearest evidence for the first instances of dairy use appears in iconic depictions of cattle being milked, such as the scene shown below, which was found on the façade of a shrine at Tell Ubaid in modern-day Iraq. This particular depiction dates back to the fourth millennium B.C. (Fig. 1.1; Postgate 1992).

Figure 1.1. Stone frieze on the façade of the EDIII shrine at Tell Ubaid (Postgate 1992).

However, with technical improvements in the ability to determine demographic profiles of archaeological faunal remains evidence has emerged suggesting the use of mixed meat and milk subsistence regimes as early as the 8th millennium BC (Middle PPNB) with goats primarily being the sources of milk (Vigne and Helmer 2007). As discussed below, these interpretations concur with the results of organic residue analysis, which confirm the presence of mixed meat and milk diets in early Neolithic populations.

Most notably, a recent study performed by Evershed et al. (2008) suggests that dairying may have taken place in the Near East much earlier than previously assumed. In this study the oldest dairy fats detected came from Tell Sabi Abyad in Syria (6.5–6.0 kyr B.C.) and Çatalhöyük (7.0–6.0 kyr B.C.). Stronger evidence appeared at 7th millennium sites around the Sea of Marmar, showing greater than 30% milk fats out of the samples chosen. In order to understand this development further, a major aim of this thesis was to examine more closely the organic residues present in the ceramic pottery of Çatalhöyük, in order to place the addition of dairy products to the diet of the people of Çatalhöyük within the context of their wider subsistence strategies.

1.3 The Development of Pottery in the Near East

According to Childe (1955), pottery was viewed as part of the Neolithic package, a series of defining elements that also included exponential population growth, the domestication of plants and animals and an agricultural economy. Pottery development at Çatalhöyük has been determined to have taken place ca. 7400 cal. BC (Mellaart 1975; Cessford et al. 2005). This record predates pottery development in the southern Levant (Zeder 2009). Due to the similar timing of the development of pottery at Çatalhöyük and other sites within the Near East (Moore 1995; Aurenche et al. 2001) the findings of this thesis will be an important step in developing the general picture for the development of secondary product use and intensification of animal exploitation during the Neolithic in the Near East and Central Anatolia. A more detailed description of the changes of pottery styles and material make-up of pots from Çatalhöyük can be found in Chapter 3 of this thesis.

1.4 Çatalhöyük

Çatalhöyük is one of the earliest proto-urban, agricultural settlements known in human prehistory. The site is located in south-central Anatolia and was situated on the bank of the Çarşamba River during the Neolithic period (Fig. 1.2). James Mellaart discovered the site in 1961. Prior to the discovery of Çatalhöyük it was assumed that there were no inhabitants of Anatolia during the Neolithic period (Balter 2005). The current excavation project began in 1993 under the direction of Professor Ian Hodder of Stanford University. The site provides a rich material record of life during the Neolithic period from approximately 7400 to 6000 cal BC (Cessford et al. 2005).

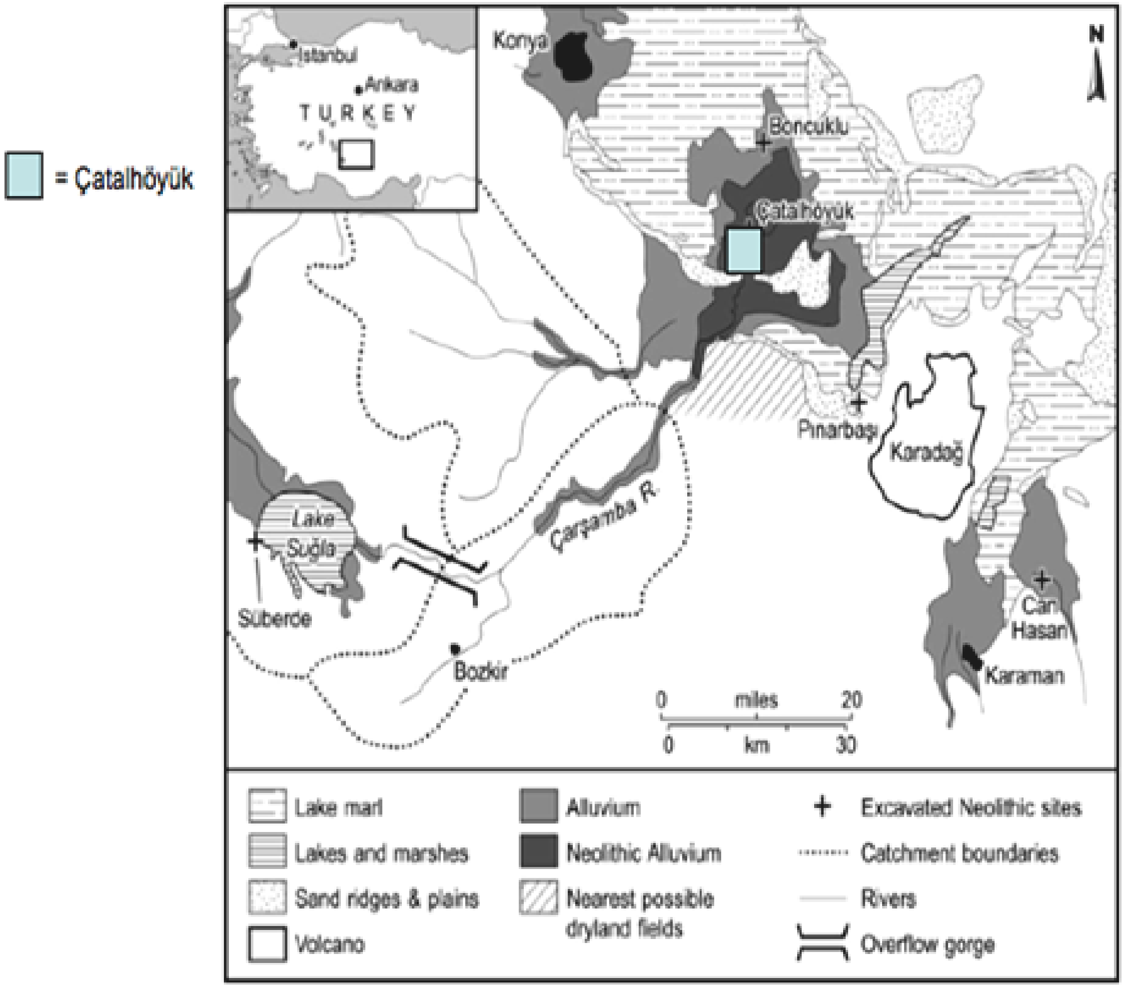

Figure 1.2. Location of Çatalhöyük (adapted from Roberts and Rosen 2009).

The population of the site is estimated to have been anywhere between 3,000 and 8,000 people during occupation, making it one of the largest (~13.5 ha), densely populated settlements in the Near East during the Neolithic (Cessford 2005; Hodder 2007). As depicted in Figure 1.3, the buildings of Çatalhöyük were clustered together with the walls of one dwelling supporting the walls of another. Each dwelling typically contained a hearth and a raised platform, under which the dead of the household were buried.

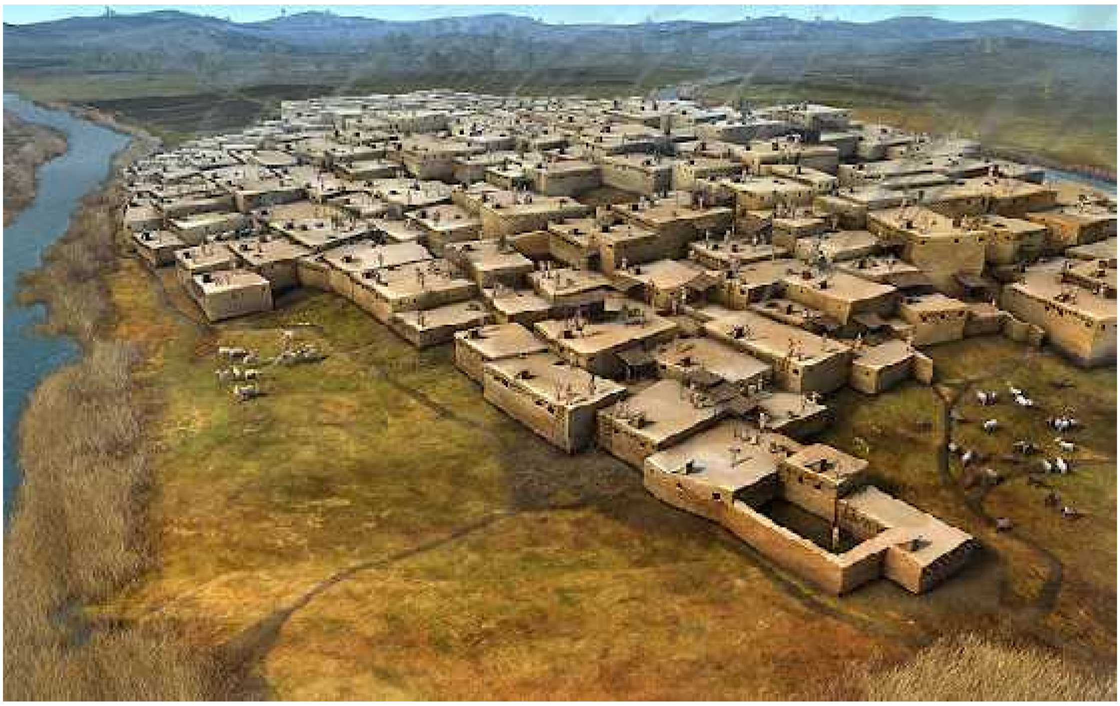

Figure 1.3 Depiction of household structures at Çatalhöyük during the time of occupation (Anonymous 2013).

1.5 Lipid Residue Analysis

Organic residue analysis provides unique information that was not previously available using traditional methods of archaeological investigation, such as the study of faunal remains. The value of such analyses was first suggested by Thornton et al. (1970) through a study of "bog butters" associated with archaeological materials using gas chromatography, although it is now recognized that a combination of molecular and stable isotope techniques is required to identify degraded fats (and oils) in the archaeological record (Evershed 2008). When used in combination with traditional methods, a more complete picture of palaeodiet can be produced. This is particularly useful for products that would have been difficult to detect in the archaeological record, such as fish and dairy foodstuffs. Although ruminant animals cannot be identified to species level using compound-specific isotope techniques, the combination of organic residue analysis with faunal studies can reveal a great deal of information about food processing and procurement at a particular site. In fact, during this study the use of faunal evidence was critical in discovering which animals were most likely to have been the source of dairy products at Çatalhöyük.

Although there are other types of molecular remains that can be analysed to reconstruct palaeodiet, fatty acids have been found to be particularly useful due to their resistance to degradation arising from their hydrophobic nature compared to proteins, carbohydrates and nucleotides (Evershed 2008). Fatty acids are also protected within organic or clay matrices, such as the fabric of unglazed ceramic pots (Evershed 1993; Forbes et al. 2005). However, pre- and post-burial degradation processes do lead to the breakdown of more complex lipid components, such as triacylglycerols (TAGs) to diacylglycerols (DAGs), monoacylglycerols (MAGs) and, ultimately, free fatty acids. Thus, free fatty acids, primarily $C_{16:0}$ and $C_{18:0}$, resulting from the processing of animal fats (Fig. 1.4) are the most abundant compounds found in organic residue in archaeological ceramics. Therefore, the primary compounds studied in this thesis were the $C_{16:0}$ and $C_{18:0}$ surviving in “cooking” pot sherds (Fig. 1.4; Evershed 2008).

In order to improve the understanding of the secondary products revolution within the Near East the primary focus of this study was to link changes in the compositions of organic residues preserved in archaeological ceramics to changes in environmental, cultural and technological factors. The main aim of the thesis was to use fatty acids as proxies to determine the timing of the emergence of dairy production and the possible significance of environmental change to the general intensification of animal processing at Çatalhöyük. A further consideration was whether the emergence of cooking pots in the ceramic record at Çatalhöyük was related to intensification of animal processing and/or the emergent use of secondary products. Due to the similar timing of the development of pottery at Çatalhöyük and other sites in the Near East (Moore 1995), this could reflect general developments of secondary product use and intensification of animal product use during the Neolithic in the Near East. Also explored in this thesis was whether changes in animal management strategies appear to have occurred at the household or site level and whether subsistence changes were linked to changes in site human demographics or overall organization. The techniques described in this dissertation make it possible to link these cultural and subsistence practices in a more defined manner than was previously achievable.

As described by Heron and Evershed (1993), organic residue analysis can provide a plethora of information in archaeological contexts including “the identification of food preparation and consumption patterns in human groups, 2) the types of activities occurring at sites or at particular activity loci within sites, 3) an assessment of the period of introduction of specific foodstuffs, and 4) the identification of shifts in subsistence practices and resource exploitation.” These points emphasise how an organic residue approach is used to answer the questions posed in this particular research project. Thus, the methods chosen for use in this work include: gas chromatography (GC), gas chromatography-mass spectrometry (GC/MS), gas chromatography-combustion-isotope ratio mass spectrometry (GC-C-IRMS) and GC-thermal conversion-IRMS (GC-TC-IRMS). The use of these methods will help to distinguish the origin of residues (i.e., adipose versus dairy fat) and explore variations in precipitation based on compound-specific carbon and hydrogen stable isotope ratios of fatty acids preserved within ceramic artifacts from Çatalhöyük. Furthermore, this information is compared to studies of the isotope stratigraphy of the nearby Konya Basin during the Holocene occupations in order to determine the usefulness of stable isotope signals preserved in fatty acids as palaeoclime proxies (Baird 2002; Boyer et al. 2006; Roberts and Rosen 2009; Jones et al. 2007).

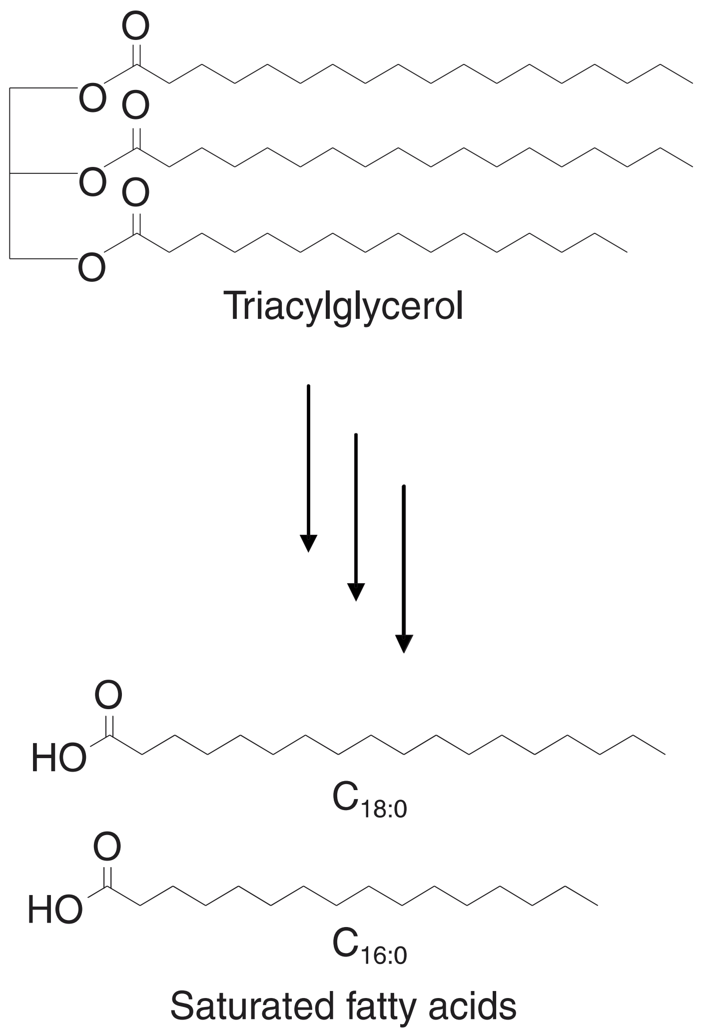

Figure 1.4. Diagram of the formation of the saturated fatty acids studied from the hydrolysis of triacylglycerols (TAGs) during processing and/or burial (Evershed 2008). These compounds were the most typical compounds found in the pottery of Çatalhöyük.

In Figure 1.5 typical distributions of saturated fatty acids ($C_{14:0}$, $C_{16:0}$ and $C_{18:0}$), ketones (K), diacylglycerols (DAG), triacylglycerols (TAG) and an internal standard (*n*-tetratriacontane; IS) are shown. These partial gas chromatograms demonstrate the types of compounds that are typically extracted from archaeological pottery. These particular distributions, with high abundances of $C_{18:0}$, are indicative of the presence of animal fats (Evershed et al. 1997). The TAG and DAG components are only seen when fats have been well preserved. Long-chain ketones are indicative of high levels of heating (Evershed et al. 1995; Raven et al. 1997).

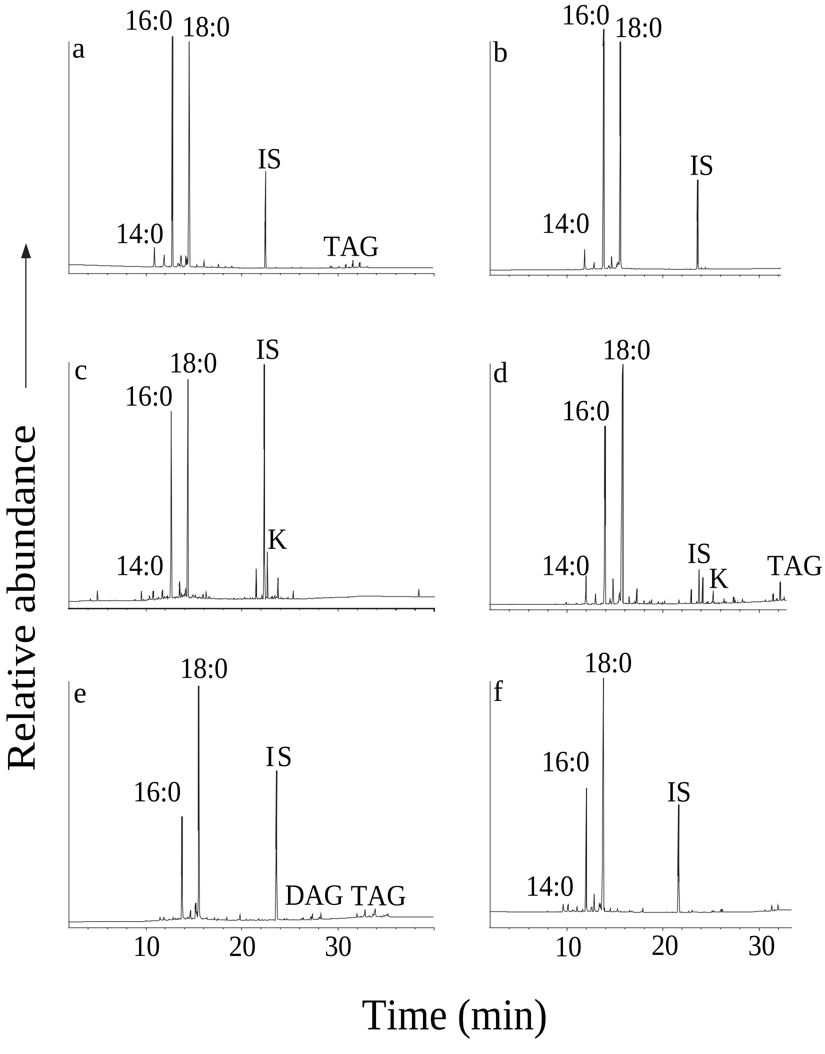

Figure 1.5 Typical partial gas chromatograms of total lipid extracts (TLEs) from archaeological pottery collected from a) Mağura (southeastern Europe); b) Makriyalos(northern Greece); c) Pendik (northwestern Anatolia); d) Çatalhöyük(central Anatolia); e) Çayönü Tepesi (southeastern Anatolia); and f) Tell Sabi Abyad (Levant; from Evershed et al. 2008).

1.6 Compound-Specific Stable Isotope Analysis

Chapters 4 and 5 of this thesis cover the use of compound-specific stable isotope analysis of the fatty acyl components of residues from the pottery at Çatalhöyük. Specifically, $\delta^{13}C$ values of $C_{16:0}$ and $C_{18:0}$, obtained via GC-C-IRMS, were utilized in order to recover information about the types of animal resources exploited (ruminant adipose and dairy fats as well as non-ruminant fats; Evershed et al. 1997). An injected sample, in this case a fatty acid methyl ester (FAME), is vaporized and carried by a carrier gas (helium) to a chromatographic column. The compounds of interest ($C_{16:0}$ and $C_{18:0}$) are then separated based on interaction with the stationary phase of the column. The compounds are then eluted into a combustion reactor maintained at 940°C. The isotopomers $^{12}C^{16}O_2$, $^{13}C^{16}O_2$ and $^{12}C^{18}O^{16}O$ are separated by their masses into Faraday cups detecting *m/z* at 44, 45 and 46 (Meier-Augenstein 1999).

Furthermore, δD values of the same fatty acids were used to reveal palaeoenvironmental information regarding changes in relative levels of precipitation for this particular site. This latter method, which utilizes GC-TC-IRMS (Fig. 1.6), is a potentially novel palaeoenvironmental proxy. This instrument uses a similar setup to GC-C-IRMS but includes a high-temperature thermal conversion reactor in place of the combustion reactor. Instrument details are further described in Chapter 2 of this thesis.

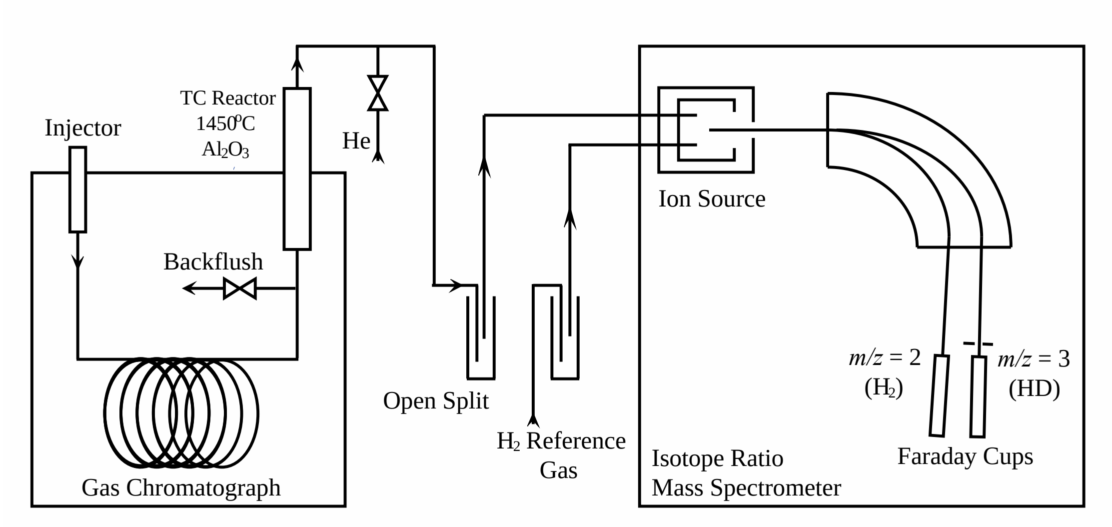

Figure 1.6. Schematic diagram of the GC-TC-IRMS instrument utilized in obtaining δD values of $C_{16:0}$ and $C_{18:0}$ fatty acids (Stear 2008).

1.6.1 Carbon Stable Isotope Analysis

Dudd and Evershed (1998) and Copley et al. (2003) showed there is a difference in the $\delta^{13}C$ values of the $C_{18:0}$ fatty acid of ruminant adipose and dairy fats, which arises from the differing biosynthetic capacities of the adipose and mammary tissues. Critically, the mammary glands cannot biosynthesise the $C_{18:0}$ fatty acid and the demand for this fatty acid cannot be met by supply from the adipose tissue store. As a result ca. 50% of this component of dairy fats is primarily derived from biohydrogenated unsaturated C_{18} fatty acids from the diet, which are ^{13}C-depleted compared to the $C_{18:0}$ biosynthesised in the adipose tissue using acetate produced during rumen digestion, mainly of dietary carbohydrates. Adipose fats thus have higher $\delta^{13}C$ values for their $C_{18:0}$ fatty acid than the milk fat $C_{18:0}$ produced by the same animal; the dairy fat $\delta^{13}C_{18:0}$ value is ca. 2.3‰ lower than ruminant adipose fat $C_{18:0}$ (Fig. 1.7).

These values can be utilized to establish whether the fats comprising the organic residues originate from dairy or adipose fats (Fig. 1.7), as well as a number of other factors, including the consumption of C_4 plants by the animals. In order to account for variation in $\delta^{13}C$ values due to variability in environmental factors (e.g.

aridity, soil moisture, temperature, light exposure) as well as the types of plants grazed on another proxy ($\Delta^{13}C$) has been defined. In Figure 1.7a the $\Delta^{13}C$ values, where $\Delta^{13}C = C_{18:0} - C_{16:0}$, are used to distinguish ruminant adipose, ruminant dairy and porcine adipose fats in modern reference fats (Copley et al. 2003). Figure 1.7b demonstrates the separation of these categories based on the $\delta^{13}C$ values of $C_{18:0}$ and $C_{16:0}$ in modern reference fats (Copley et al. 2003).

In a more recent study by Dunne et al. (2012) global $\delta^{13}C$ values of $C_{16:0}$ and $C_{18:0}$ from modern and archaeological contexts were combined to confirm the separation of ruminant dairy fats, adipose fats and non-ruminant adipose fats based on $\Delta^{13}C$ values. A new collection of fats from areas of Saharan Africa were analysed via GC-C-IRMS. Modern fats collected from animals placed on varying diets of C_3 and C_4 plant consumption also contributed to the expansion of this proxy (Dunne et al. 2012). Thus, the values presented herein are based on modern reference values collected from Kenya, Libya, the United Kingdom, Switzerland, Kazakhstan and several countries throughout Europe and the Near East (Dunne et al. 2012 and references therein).

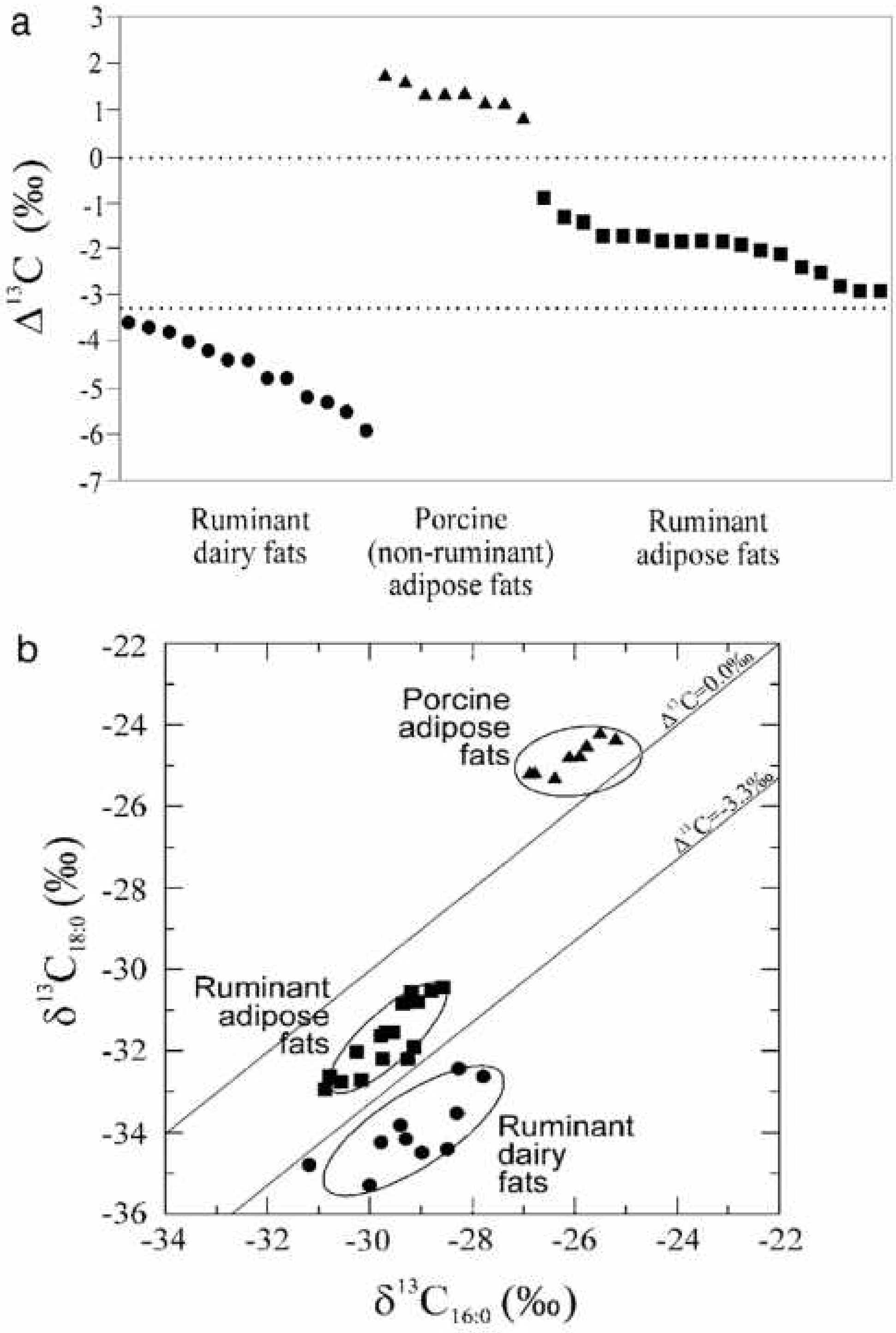

Figure 1.7. a) Graph showing the differences in δ^{13}C values from $C_{18:0}$ and $C_{16:0}$ fatty acids of animal fats from modern specimens raised on C_3 diets. The dashed lines depict the mean and 2SD of data collected (Copley et al. 2003). b) Graph of P=0.684 confidence ellipses separating the different types of fats based on δ^{13}C values from $C_{18:0}$ and $C_{16:0}$ fatty acids (Copley et al. 2003).

1.6.2 Hydrogen Stable Isotope Analysis

One major part of this thesis aimed to develop a record of water availability and precipitation/evaporation variability through an understanding of the δD record of fatty acid residues associated with changes in subsistence practices, and compare this to the emergence of dairying, at Çatalhöyük.

Hydrogen stable isotope ratio (δD) values for the $C_{16:0}$ and $C_{18:0}$ fatty acids, as determined by GC-TC-IRMS (Fig. 1.6), were assessed as a possible palaeoenvironmental proxy. δD values have the capacity to serve as a proxy for precipitation levels at the time the animal product was being used.

The basis of the fatty acid-based δD proxy explored during this thesis rests on the fact that water molecules containing the lighter hydrogen isotope (^{1}H) are preferentially evaporated in precipitation compared to those containing the heavier isotope deuterium (^{2}H). This relationship results in the increase of δD values of liquid water relative to vapor. Generally, when humidity increases and evaporation is reduced, the δD value of the precipitation becomes less enriched in the heavy stable hydrogen isotope, deuterium (Bradley 1999). Groundwater is absorbed into the soil and is then absorbed into plants with little fractionation (Darling et al. 2003; Schiegl and Vogel 1970). Thus, the isotopic values of precipitation are incorporated from groundwater into organic structures through the food chain, and can be seen in the fatty acids of grazing animals, although somewhat depleted through each stage of incorporation (Schiegl and Vogel 1970). The source of hydrogen in animal tissues is derived from the hydrogen of water and plant matter consumed by the animal (Hobson et al. 1999). By studying δD values of the tissues from modern quail raised with two different sources of drinking-water, Hobson et al. determined that the birds obtained 18-24% of their nonexchangeable hydrogen in internal tissues from drinking water. Drinking water was found to contribute to both the lipid and nonlipid tissues with lipids showing highly depleted values compared to the original water values. As of yet the exact values cannot be retraced between fatty acid values and precipitation. However, relative changes in δD values found in fatty acids reflect enrichment and depletion changes in the precipitation δD values when controlling for other factors (i.e., differences in altitude or water and plants consumed from widely varied locales).

Since the fatty acids studied in archaeological pottery are actually an accumulation of meat from many animals over time, the δD values are averaged and variations due to seasonal differences would not account for changes seen in the overall record spanning several centuries as studied in this thesis project. There is also little evidence of variations in altitude of grazing in the sheep and most likely other grazing animals at Çatalhöyük (Henton 2010). In a past study of plant lipids the C_{23} *n*-alkane of lipids was found to exhibit δD values that were particularly sensitive to climatic change, with negative values marking the timing of the Little Ice Age (Xie et al. 2004). These findings also corresponded to the δD record determined from tree rings from the same time period in Scotland, Germany and the United States, demonstrating that the δD record of specific compounds, such as the C_{23} *n*-alkane of lipids, may provide an excellent proxy for both temperature and precipitation changes (Xie et al. 2004).

Another study of fatty acid components extracted from archaeological pottery suggested that higher δD values of $C_{16:0}$ and $C_{18:0}$ fatty acids from Kazakhstan were consistent with increased aridity confirmed by other palaeoenvironmental proxies (Outram et al. 2009 and references therein). Thus, lower δD values obtained from an extensive fatty acid organic residue record can be understood to correspond to higher levels of precipitation, and vice versa, when compared to the meteoric water line of global water δD and $\delta^{18}O$ values defined by the equation (Faure and Mensing 2005):

$$\delta D = (7.96 \pm 0.02)\ \delta^{18}O + 8.86 \pm 0.17 \qquad \text{(Equation 1.1)}$$

In order to use this relationship to understand changes in past precipitation levels the δD values of the fatty acids can also be compared to $\delta^{18}O$ of nearby lake sediments in order to determine relative changes in precipitation levels over time (see Roberts and Rosen 2009). This concept is explored in Chapter 5 of this thesis.

1.7 Previous Studies

Until recently, past faunal population distributions and changes in cattle, goat and sheep specimen sizes via the study of faunal remains were the only means available for estimating approximate timing of the emergence of dairying at Çatalhöyük (Russell et al. 2005) and elsewhere. These studies are limited in how accurately they can define the beginnings of dairy processing in relation to cattle herding, especially since many factors could potentially contribute to changes in animal population distributions, such as variations in hunting strategies or changes due to environmental rather than management factors (Russell et al. 2005). Thanks to a recent study (Evershed et al. 2008), it is now known that there is potential to determine dates for the beginnings of dairy production at Çatalhöyük by analyzing fatty acid residues from cooking pots via GC-C-IRMS and placing them within the chronology of the site based on stratigraphic context. The stratigraphic levels of Çatalhöyük were previously dated via radiocarbon dating (Cessford et al 2005). The Evershed et al. (2008) study points to a date of ca. 6500 cal yrs BC or around Level VII of the Çatalhöyük stratigraphic sequence (Table 1.1; Cessford et al. 2005). This date significantly differs from the evidence for dairy subsistence practices that had been suggested based upon changes in animal population demographics. Previous estimates based on faunal evidence placed this change in diet around Level IV or approximately 6200 cal BC (Russell et al. 2005; Cessford et al. 2005).

Table 1.1 Stratigraphic classification schemes

Time (cal BC)	Mellaart	South	North (4040)
	0,I,II,III	TP 6 levels	
		T	J
		S	J
		R	I
		Q	H, I
6295 ± 75		P	H
6425 ± 95	VIA	O	G
	VIB	N	G
6580 ± 80	VII	M	G
6615 ± 95	VIII	L	F
6755 ± 95	IX	K	F
6860 ± 90	X	J	
	XI	I	
6955 ± 115	XII	H	
	Pre XII	G	

The various chronologic schemes featured in Table 1.1 will be referred to throughout the dissertation. The original classification scheme (labeled Mellaart) was used in early literature related to Çatalhöyük. During the current excavation project a new classification scheme has been developed that links the North and South areas (Hodder 2012). Calibrated dates (cal BC) have also been included for clarification when comparing the data presented herein with external records (Cessford et al. 2005).

1.8 Aims and Objectives

The abundant archaeological material record available at Çatalhöyük allows detailed analysis of the cultural, environmental and agricultural changes occurring throughout the long site chronology. By combining information from faunal, archaeobotanical, skeletal and ceramic remains with the lipid record, it will be possible to enhance the interpretations of material and social changes at Çatalhöyük. Thus, the main aims of this project were:

1) To produce accurate estimates of the timing of dairy production at this particular site in order to shed light on the probable timing of the secondary products revolution in the Near East.

2) To define the technological, environmental and social elements that were changing contemporaneously with the emergence of dairy production at Çatalhöyük.

3) To determine how these factors influenced the decision to raise domesticated animals for milk production rather than meat production.

4) To determine whether stable isotope analysis (particularly hydrogen stable isotope ratio analysis) of fatty acid residues is a viable palaeoenvironmental proxy.

The specific aims and objectives of Chapter 3 are:

i. To extend previous lipid residue anlayses of the pottery at this site. In order to achieve this, potsherds with visible charring and rim sherds—which have been found to contain the highest concentration of lipids—were chosen for analysis (Charters et al. 1993, 1997; Evershed 2008).

ii. To determine any differences in how pots were used based on chronological and spatial placement as well as vessel structures and material make-up. This includes identifying the presence and concentration of lipids through GC and GC/MS analysis.

iii. To extend previous studies of the organic residue record at Çatalhöyük, including the presence of dairy lipids, and to determine whether or not they were a significant part of the residue record for this particular site by identifying the types of commodities present via molecular and stable carbon isotope determinations.

iv. To identify any possible links between trends in lipid residue composition preserved in the pottery vessels and changes in the ceramic technology of Çatalhöyük over time, including the initial development of pottery and the proliferation of styles and fabrics.

The aims and objectives of Chapter 4 are to:

i. Select FAMEs identified for the analysis described in Chapter 3 of this thesis for further analysis based on the high presence of $C_{18:0}$ (indicative of animal fats) and $C_{16:0}$. The use of these FAMEs will then be used for further stable isotope analysis as described in Chapters 4 and 5 of this thesis.

ii. Perform GC-C-IRMS analyses on selected FAMEs to obtain $\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$ values for selected residues and identify types of residue present to confirm the presence of dairy fats.

iii. Compare types of organic residue found (i.e., ruminant adipose, ruminant dairy, non-ruminant adipose) to faunal evidence based on chronology by using $\Delta^{13}C$ values. This will allow determination of whether the presence of milk fats in pottery coincide with the appearance of domesticated cattle on-site and whether the organic residues reflect any other changes in domestic animal populations (i.e., morphologic and demographic factors) at Çatalhöyük.

iv. Identify any links between stable isotopic data gathered from collagen to organic residue results. This will confirm other broader changes in animal management strategy (e.g. wider herding ranges and household based herding).

The aims and objectives of Chapter 5 are to:

i. Identify the compounds present in the pottery of Çatalhöyük, Turkey in order to extend previous analyses (Copley et al. 2005; Evershed et al. 2008).

ii. Place the lipid residues in a chronologic context linked to changes in Neolithic subsistence practices at this particular site.

iii. Create a well-dated δD record using organic residues for archaeological ceramics.

iv. Compare this δD record to geologic and archaeological evidence of environmental and cultural change to identify possible connections between the different proxies as well as confirm the validity of the proxy developed within this study.

By assessing 313 pottery samples with these objectives in mind, this study provides one of the most extensive residue records of a single archaeological site to date.

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Chapter 2 Methods

2.1 Glassware, solvents and reagents

Laboratory shared glassware was washed three times with Deacon 90 (Deacon Laboratories), rinsed with acetone and kept in an oven heated to 450°C (minimum of 4 h). Modern materials were analysed in a separate lab from archaeological materials to avoid contamination. For each batch of samples (usually ten in number) a blank was prepared to test for possible contamination. All solvents used were of HPLC grade (Rathburn). Analytical grade reagents (≥98% purity) were used during the entire analysis process.

2.2 Archaeological pottery, clay balls and oven samples

Samples were collected from the material storage unit at Çatalhöyük, Turkey during the summers of 2008 and 2009. Samples were chosen in order to maximize coverage of the spatial and chronological spread of pottery throughout the Neolithic portion of the site. This included sherds from Levels South.H to South.T and North.F through North.J. Many Mellaart collected potsherds were also sampled.

Sherds were collected from areas 4040, South mound, North, IST and TP for varied spatial coverage of the site. A detailed account of the site chronology can be found in the Introduction of this thesis (Table 1.1). A preliminary study (Pitter 2009) also revealed an improvement in residue yield when sampling was biased towards rim sherds of pots that bore evidence of heating, such as visible charring.

Also within each level, the potsherds from cooking pots that represent each ware group and pot type (i.e., cream ware vs. dark mineral ware, open-mouth vs. holemouth) have been sampled in as close to equal numbers as the available material would allow. As a result thirty-one organic tempered and 178 mineral tempered pots, including six sandy wares, were analysed from throughout the

Neolithic chronological sequence of the site. Forty-four holemouth pots and thirty vessels classified as bowls were also collected. Most of the holemouth vessels (~70%) are from the upper levels (Level V and above or approximately 6300 cal BC and later according to Cessford et al. 2005). The ceramic bowls from levels V (South.P) and above represent about 55% of the bowl samples collected. Additional cream ware pots were also gathered, for a total of sixty-four, for sampling during the 2009 field season in order to test the hypothesis arising from the preliminary study that these pots were not used for cooking. In all 313 samples were screened for the presence of organic residues. This collection included a few non-pottery samples, such as fragments of ovens and hearths (n = 8; Fig. 3.5) and clay balls (n = 13; Fig. 3.4).

2.2.1 Solvent extraction of residues

A well-established protocol was utilized in order to extract lipid residues from the archaeological pottery, oven linings and clay balls. For all of these materials 2.0 g were sampled. In the case of potsherds 2.0 g were cleaned using a modelling drill (Como Mini Drill, MFA Como Drills) in order to remove exterior contaminants and surface lipids that may have attached to the sherd via deposition or handling. The cleaned portion of the sample was removed using a hammer and dichloromethane (DCM) rinsed chisel.

Each cleaned potsherd was then ground with a mortar and pestle. An internal standard (*n*-tetratriacontane, 20 µl) was added to each sample of 2.0 g ground sherd. The 2.0 g of ground sherd was ultrasonicated (2 x 15 min) in chloroform: methanol (2:1 *v/v* 2 x 10 ml). Each sherd represents a separate vessel. Total lipid extracts (TLEs) were separated from pottery material via centrifugation and filtration through furnaced (4 h at 450ºC) HPLC grade silica.

2.2.2 Trimethylsilylation derivative preparation

An aliquot (ca. 50 µl) of the TLE was then derivatized with *N*,*O*-bis(trimethylsilyl) trifluoroacetamide (BSTFA; 40 µl; 70ºC, 1 h). The trimethylsilyl (TMS) derivatives were then screened for the presence of lipids via GC and HT-GC/MS.

Depending on the expected concentration of the lipid 50–200 μl of hexane were added to the TMS derivative prior to GC and HT-GC/MS analysis.

2.2.3 TLE Saponification

Methanolic sodium hydroxide (0.5 M; 2 ml) was added to an aliquot of the TLE and heated (70°C, 1 h). After cooling 1ml double distilled water was added and the neutral fraction extracted with hexane (3 x 3 ml). The remaining solution was acidified to pH 3 using HCl 1 M and the free fatty acids extracted with chloroform (3 x 3 ml), which was then removed under nitrogen.

2.2.4 FAME preparation

Aliquots of potsherd lipid extracts or reference animal fats were saponified using sodium hydroxide in methanol and double distilled water (9:1 *v/v*; 0.5M; 2ml; 70°C, 1 h). FAME derivatives of the free fatty acids were prepared by heating with 100 μl BF_3-methanol (14 % *w/v*; Sigma Aldrich Company Ltd.) at 70°C for 1 h Double distilled water was added (1 ml) and the FAME derivatives were extracted with chloroform (3 x 2 ml) and the solvent removed under nitrogen. The addition of hexane (50–250 μl) to FAMEs was made prior to analysis by GC and GC-TC-IRMS. A detailed description of the preparation of FAMEs for $\delta^{13}C$ analysis appears in Mottram et al. (1999) and for δD analysis in Chivall et al. (2012).

2.3 Modern Turkish dairy reference fats

2.3.1 Collection

Modern reference materials were collected with the aid of a local farmer. Milk and cheese were collected from a sheep herd that grazes in the area of Çumra, in the surrounding countryside of Çatalhöyük.

From these materials 12 cheese samples of ca. 2.0 g each and 18 milk samples measuring about 2.0 ml each were saturated in ethanol, in order to halt degradation, and brought back to the laboratory for analysis. Of these a set of 10 milk and 4 cheese samples were chosen for analysis.

2.3.2 Solvent extraction and TMS derivatization

Approximately 1–3 mg of freeze dried milk or cheese were placed in 3.5 ml vials. 1–3 ml of chloroform:methanol (2:1 *v/v*) was added to the samples. An aliquot of approximately 300 µl was then transferred to a furnaced 3.5 ml vial and evaporated under a light stream of nitrogen gas.

Approximately 3 ml of chloroform:methanol (2:1 *v/v*) was then added to each lipid extract, which was then filtered through silica as explained in 2.2.2. The sample was then derivatized using BSTFA as outlined in section 2.2.2.

2.3.3 TLE Saponification

The same process outlined in Section 2.2.3 was utilized for dairy fat TLE saponification.

2.3.4 FAME preparation

FAMEs of the dairy reference materials were prepared in the same way as the FAMEs prepared from archaeological pottery (2.2.4). One aliquot (ca. 50 µl) of the TLE was used for FAME preparation.

2.4 Instrumentation

2.4.1 Gas chromatography

Potsherds (n = 313) were screened for the presence of lipid residues via GC. These analyses were executed on a Hewlett Packard 5890 series II gas chromatograph coupled to a PC with Clarity software. TLEs were injected (1 µl) onto a fused silica capillary column (60 m x 0.32 mm i.d) coated with a high cyanopropyl modified methyl polysiloxane stationary phase (Varian Inc., USA; VF23ms; 0.15µm film thickness). Each TLE was run through the temperature program of 1 min isothermal at 50°C followed by an increase to 100°C at a rate of 15°C min^{-1} then an increase to 240°C at a rate of 4°C min^{-1} followed by a final increase to 260°C at a rate of 15°C min^{-1} with an isothermal period of 15 min at 260°C. A flame ionisation detector (FID) was used to monitor column effluent and hydrogen was the carrier gas with a column head pressure of 10 psi.

2.4.2 High-temperature gas chromatography/mass spectrometry

Twenty-seven potsherds showing significant quantities of residues were further investigated using high temperature gas chromatography/mass spectrometry (HT-GC/MS). HT-GC/MS analysis was performed in order to more precisely determine the compositions of the residues, including identifying hexadecanoic and octadecanoic acids ($C_{16:0}$ and $C_{18:0}$, respectively) as well as seeking to identify other components of the residues.

Trimethylsilylated TLEs were analysed using a Perkin Elmer Turbomass Gold equipped with a fused silica capillary column (J&W; DB1-HT; 15 m x 0.25 mm i.d.; 0.1 µm film thickness). The GC interface was maintained at 350°C. The mass spectrometer was operated in full scan mode (50 – 850 daltons, 1 scan/0.6 sec; 70 eV electron energy and ionisation source temperature of 240°C). Helium was the carrier gas and the GC oven was programmed as follows: 2 min isothermal at 50°C followed by an increase to 350°C at a rate of 10°C min^{-1}, following this, the temperature was held at 350°C for 10 min. Peaks were identified based on their mass spectral characteristics and GC retention times and also by comparison with the NIST mass spectral library in the Xcalibur program.

2.4.3 GC-combustion-isotope ratio MS (GC-C-IRMS)

Compound-specific stable isotope analyses were performed in order to determine both $\delta^{13}C$ and δD values of the fatty acids present in the residue record. GC-combustion-isotope ratio MS (GC-C-IRMS) analysis was performed on fatty acid methyl ester derivatives (FAMEs) of 32 residues determined as being pure animal fats together with 4 reference milk samples for comparison using a Finnigan MAT Delta S in order to determine the $\delta^{13}C$ values of the palmitic and stearic acids present. A detailed description of the preparation of FAMEs appears in Mottram et al. (1999) and section 2.2.4 of this chapter.

Carbon isotope analyses were performed using a Varian 3400 GC coupled to a Finnigan MAT Delta S IRMS via an extensively modified Finnigan MAT type I combustion interface using Cu and Pt wires (0.1 mm o.d) in an alumina reactor (0.5 mm i.d). The reactor temperature was maintained at 860°C and the mass spectrometer source pressure was 6 x 10^{-6} mbar. Faraday cups were used for the detection of ions of *m/z* 44 ($^{12}C^{16}O_2$), 45 ($^{13}C^{16}O_2$ and $^{12}C^{17}O^{16}O$) and 46 ($^{12}C^{18}O^{16}O$). The GC column was a Factor Four VF-23ms column (Varian Chrompack 60 m x 0.32 mm i.d, 0.15 µm film thickness) and the temperature program consisted of an isothermal period of 1 min at 50°C followed by an increase to 240°C at a rate of 10°C min^{-1} followed by an isothermal period of 10 min at 240°C.

2.4.4 GC-thermal conversion-IRMS (GC-TC-IRMS)

Stable hydrogen isotope analysis was performed on 35 of the 116 archaeological fat residues, and the 4 reference milk samples using a ThermoFisher Scientific Delta V Plus GC-TC-IRMS (thermal conversion reactor, 300 × 0.5 mm i.d.; Al_2O_3; 1450ºC). A standard of 15 *n*-alkanes of known isotopic composition (Schimmelman B Standard) was used to verify instrument error between each run. Instrument error was kept between 2 – 7 ‰ error. A retardation lens removed $^4He^{+\cdot}$ ions and a calibration was performed daily using Thermo Finnigan ISODAT NT 2 software to correct for H_3^+ ions; the H_3^+ factor was below 5 ppm V^{-1} and had a rate of change of less than 0.1 ppm V^{-1} day^{-1}. FAMEs were introduced to the GC via an Agilent PTV injector (splitless mode; 50 – 300 ºC; purge time = 1 min) and later an Agilent Split/Splitless injector (splitless mode; 300 ºC; purge time = 2 min). A fused silica capillary column (30 m × 0.25 mm i.d.) with a methylpolysiloxane stationary phase (Zebron ZB-1; 0.25 µm film thickness) was used; column flow was constant at 0.9 mL min^{-1}. The interface was set to backflush mode for the first 500 s of each run. The temperature programme used consisted of an initial isothermal of 2 min at 50 ºC followed by a ramp of 10 ºC min^{-1} to 300 ºC and was kept at this final temperature for 10 minutes. Results were presented in per mil (δD) using ISODAT NT 2 (Chivall 2007).

2.5 Data Processing

2.5.1 Carbon stable isotope analysis

Carbon isotope compositions are expressed as $\delta^{13}C$ values, defined as the difference between the ratio of heavy to light stable carbon isotopes in the sample and a standard, divided by the ratio of the standard and converted to parts per thousand (‰) as given in the equation below (Faure and Mensing 2005):

$$\delta^{13}C = \frac{\frac{^{13}C}{^{12}C_{sample}} - \frac{^{13}C}{^{12}C_{standard}}}{\frac{^{13}C}{^{12}C_{standard}}} \times 1000 \text{ ‰}$$

(Equation 2.1)

The raw data from GC-C-IRMS analysis was then corrected to account for changes in the raw $\delta^{13}C$ values due to carbon added during derivatisation (Rieley, 1994):

$$\delta^{13}C_{FA} = \frac{(\text{no.}\ C_{FAME} \times \delta^{13}C_{FAME}) - \delta^{13}C_{MeOH}}{\text{no.}\ C_{FA}}$$

(Equation 2.2)

2.5.2 Hydrogen stable isotope analysis

Hydrogen stable isotope ratio (δD) values for the $C_{16:0}$ and $C_{18:0}$ fatty acids present in each sample were assessed as a possible palaeoenvironmental proxy. The δD is defined as the difference between the ratio of heavy to light stable hydrogen isotopes ($^2H/^1H$) in the sample and the standard, divided by the ratio of the standard and converted to parts per thousand (‰) as seen in the following equation (Faure and Mensing 2005):

$$\delta D = \frac{\frac{D}{H}_{sample} - \frac{D}{H}_{standard}}{\frac{D}{H}_{standard}} \times 1000\ ‰$$

(Equation 2.3)

2.5.3. ANOVA

In order to compare whether groups of sherds from the lower levels (Levels XII – VIII or South.H-L) to the remaining upper levels from the Neolithic sequence (VII-II or South.M-T) an ANOVA test was applied. All data was found to be normally distributed as is required for the ANOVA test. This statistical method is preferred to the T-test when testing variance between several groups of data, where a T-test would likely result in Type I or Type II errors (Fisher 1925).

2.5.4 Radiocarbon dating

Dates assigned to individual pottery shards used in this study were based on the stratigraphic level each potshard was found within. The stratigraphic levels were dated using radiocarbon dates of charred plant, bone and charcoal remains (Cessford et al. 2005). Raw radiocarbon dates and information on specific materials dated for each level may be found in Appendix C.

The program OxCal 4.1 was used in order to standardise all dates reported herein to calibrated years BC (cal BC). The IntCal09 calibration curve was used to estimate dates. Dates are all shown with a 95% probability of accuracy. The dates that were previously reported by others in years BP were entered into the program and converted to cal BC dates.

The radiocarbon dates reported for the stratigraphy at Catlahoyuk are reported in Table 2.1. Values were taken directly from the Cessford et al. (2005) report.

Table 2.1 Overall date ranges for stratigraphic levels at Çatalhöyük based on radiocarbon analyses (Cessford et al. 2005).

Level	Earliest beginning at 95% probability expressed decadally	Latest end at 95% probability expressed decadally	Earliest beginning at 68% probability expressed decadally	Latest end at 68% probability expressed decadally
0	Later than end of Level II	No data	Later than end of Level II	No data
I	Later than end of Level III	No data	Later than end of Level III	No data
II	6410–6200	6380–????	6350–6240	6350–????
III	6430–6250	6410–6200	6400–6300	6350–6240
IV	Later than end of Level VI	Earlier than start of Level II	Later than end of Level VI	Earlier than start of Level II
V	Later than end of Level VII	Earlier than start of Level III	Later than end of Level VII	Earlier than start of Level III
VI A/B	6510–6350	6460–6300	6470–6400	6440–6260
VII	Later than end of Level IX	Earlier than start of Level V	Later than end of Level IX	Earlier than start of Level V
VIII	6830–6500	6660–6420	6740–6570	6590–6460
IX	Later than end of Level XI	Earlier than start of Level VII	Later than end of Level XI	Earlier than start of Level VII
X	7040–6770	6970–6680	6960–6820	6890–6740
XI	7060–6830	7030–6760	7060–6850	6960–6800
XII	7080–6860	7060–6830	7070–6920	7060–6850
Pre XII.A	7080–6810	7080–6860	7080–7010	7070–6920
Pre XII.B	7160–7000	7080–6810	7100–7040	7080–7010

Pre XII.C	7280–7070	7160–7000	7200–7080	7100–7040
Pre XII.D	????–7080	7280–7070	????–7150	7200–7080

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Chapter 3 Pottery and Organic Residue Analysis

3.1 The development of pottery in the Levant and Anatolia

From the stages of its earliest development pottery was very rarely associated with mobile groups (Arnold 1985). Thus, the emergence of pottery has largely been seen as a part of the Neolithic revolution and sedentary life. Evidence for the earliest pottery was recently discovered in the Yuchanyan Cave of the Hunan Province of China, Radiocarbon-dated to a range of 18,300 to 15,430 cal BP (Boaretto et al 2009). Until recently the Jomon pottery was the oldest known, dating to around 12,700 BP (Barnett and Hoopes 1995). In the Levant and southeastern Anatolia stonewares act as precursors to ceramics, dating to about 12,000 cal. BP. However, evidence of ceramic pottery production does not appear in the archaeological record of Southwest Asia until approximately 10,000 cal. BP at the site of Ganj Dareh (Zeder 2009). The appearance of decorated and, eventually, painted pottery does not appear in the Northern Levant or Anatolia until around 8400 BP (ca. 7460 cal BC) with some of the earliest pottery of this region appearing at Çatalhöyük (Zeder 2009; Mellaart 1975). In fact in this study we have definitive evidence for the use of cooking pots by 6860 cal BC through the use of organic residue analysis.

During the 1950’s Kathleen Kenyon discovered that the emergence of pottery occurred nearly 2000 years after the emergence of farming in Jericho (Kenyon 1954). In the Levant, specifically in the foothills of the Zagros, pottery emerges after the domestication of sheep and goats and the use of domesticated grains (Braidwood and Howe 1960). This time period of settlement without the accompaniment of ceramic storage material is termed the Pre-Pottery Neolithic period, which is broken down into the Pre-Pottery Neolithic A (PPNA), PPNB and in some instances PPNC. Although this time period is most appropriately applied to the Levant, the early occupation period of Çatalhöyük is considered to fall within the PPNB, leading to the Pottery Neolithic (Hodder 2007).

Çatalhöyük is especially interesting because it spans the emergence of pottery within the Levant and Anatolia and provides a glimpse of life from this time period into the Chalcolithic, spanning from approximately 7400–6000 cal BC (Cessford et al. 2005). Figurines appear as precursors to pottery on-site, demonstrating manipulation of clay materials from the beginning of site occupation (South.G, ca.7400 cal BC; Meskell et al. 2008).

3.2 Pottery Classification Schemes

An extensive pottery classification scheme, developed by Nurcan Yalman (Yalman 2012) was utilized in this project in order to determine whether pots had been used differently based on the material makeup, design or vessel type (bowl versus holemouth) of the pot.

3.2.1 Ware Type

One set of classification parameters is based on ware type. Ware type is essentially based on types of materials used, the consistency of said materials, and the processes applied to the ceramic surface (i.e., burnishing, mottling, etc.). Examples of specific ware type labels used can be found in Appendix A as adapted from Yalman (2012) along with the full list of ware codes used for the various types of materials used and colors represented based on firing methods and tempers used. The ware type categories are defined as Dark Mineral Standard (DMS), Dark Mineral Mica (DMM), BS (organic tempered, early levels), DMD (Dark mineral dense), CM (Cream mineral), CMD (Cream mineral dense), CO (Cream Organic tempered, early levels), CMO (Cream Mineral Organic), OP (Orange Paste) -D (Dense) or -L (Loose), RP (Red Paste), W (White), SM (Sandy Mineral), SO (Sandy organic). In some instances standard (s) is used in place of (m) for medium wall thickness.

3.2.2 Vessel Type

An additional classification scheme described the structure of the vessels present at Çatalhöyük based on pot profile and decorative or functional additions (i.e., lugs). All vessel categories utilized in this dissertation are represented in Figures 3.1–3.3. The two main types of pottery studied herein were holemouth pots and bowls (Fig. 3.1 and 3.2) (Çatalhöyük Team 2003–2011 Typology Charts). Base sherds are also categorized separately and are shown here simply to demonstrate the variety of sherds available (Fig. 3.3).

Base sherds were also a part of the sample set collected for this particular project. However, it was expected that only a limited amount of residues would be found present in base sherds due to previous studies suggesting that the highest concentrations of absorbed lipids are typically present towards the rims of pots rather than the bases (Charters et al. 1993, 1997; Evershed et al. 2008b). This is due to the immiscible quality of fats and oils when boiled in water, which causes the fats to rise.

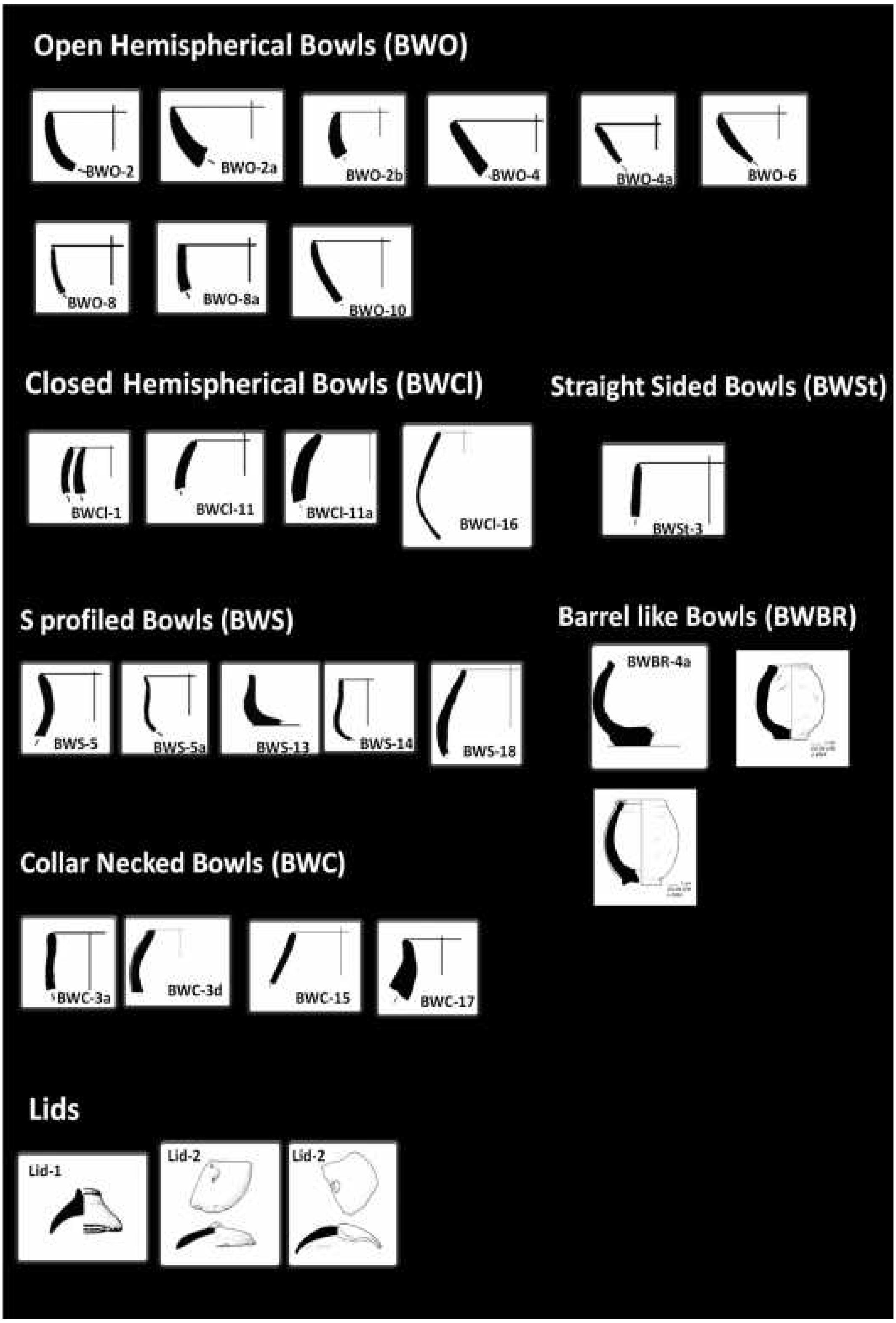

Figure 3.1. Explanation of bowl and lid classifications. (Çatalhöyük Team 2003–2011 Typology Chart).

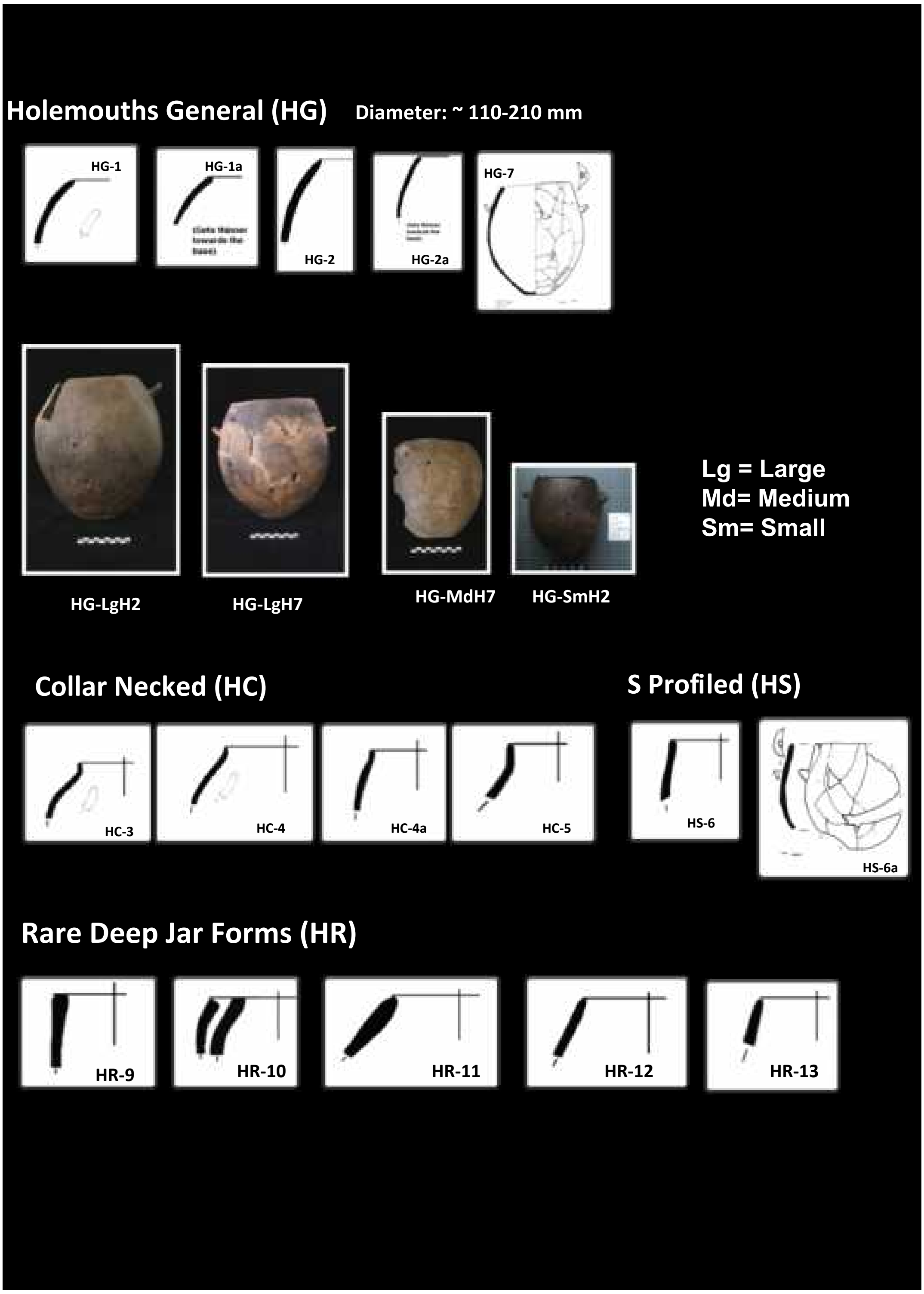

Figure 3.2. Deep jar and holemouth pot classifications. Çatalhöyük Team 2003–2011 Typology Chart).

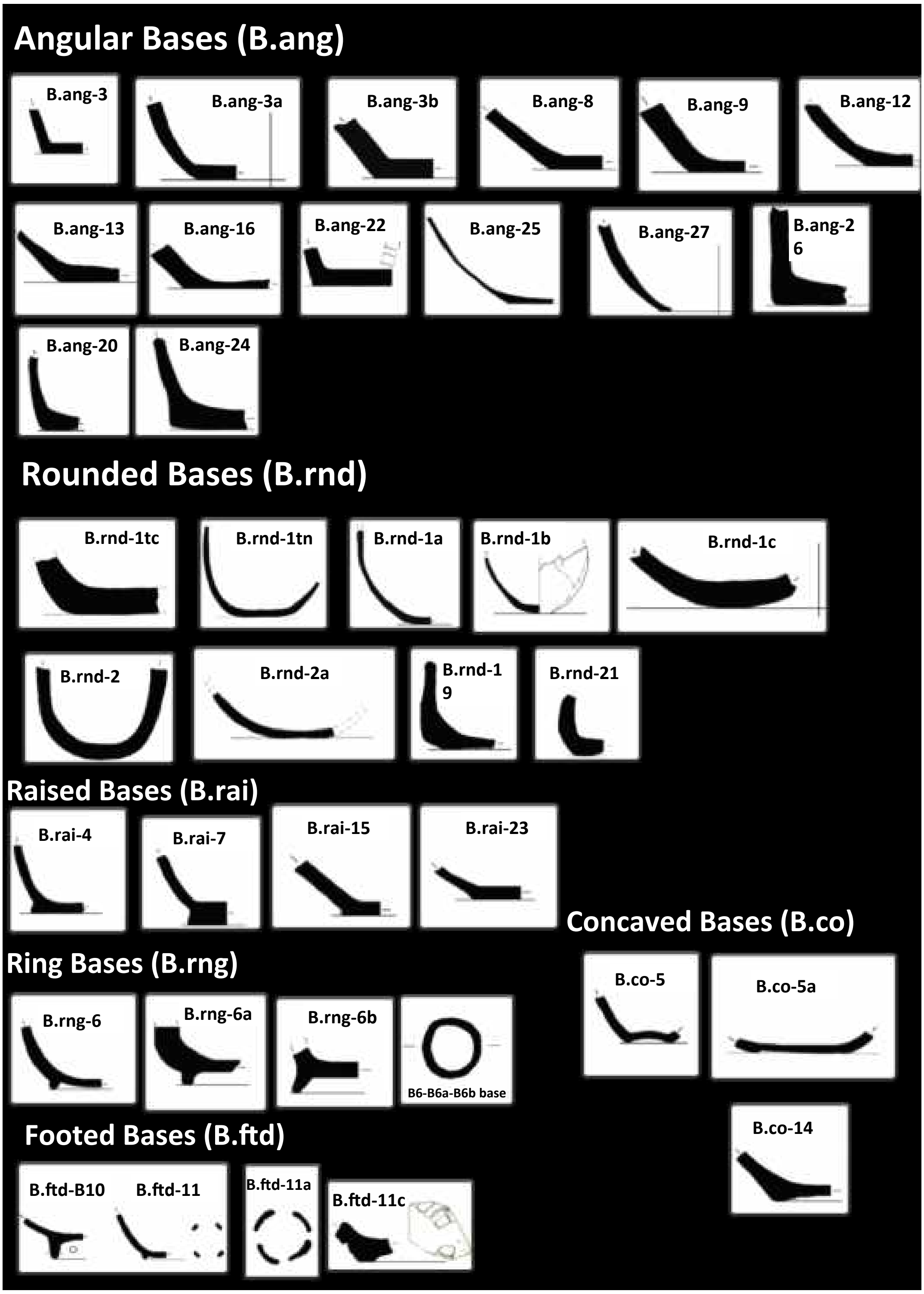

Figure 3.3. Visual representation of pottery base forms. (Çatalhöyük Team 2003–2011 Typology Chart).

3.3 Pottery Usage

3.3.1 Objectives

The residues of Çatalhöyük are among the oldestever analysed and can provide important insights into very early Neolithic life.

The extensive pottery record at Çatalhöyük, which spans from the PPNB (Pre-Pottery Neolithic B) into the Chalcolithic, i.e., ca. 7400 to 6000 cal BC makes it particularly useful for analyzing any links between types of commodities cooked in specific types of vessels (Cessford et al. 2005). Pottery development at Çatalhöyük also occurred nearly contemporaneously with the emergence of pottery throughout Anatolia and the Levant, and thus associated changes in subsistence practices could reflect trends throughout the region.

The emergence of dairying at the site was also of interest. Until recently past population distributions and changes in cattle size via the study of faunal remains were the only means available for estimating approximate timing of the emergence of dairying at this (and any) site (Russell et al. 2005). These studies are limited in how accurately they can define the beginnings of dairy processing, especially since many factors could potentially contribute to changes in animal population distributions, such as variations in hunting strategies or changes due to environmental rather than management factors (Russell et al. 2005). Thanks to a recent study (Evershed et al. 2008) it is now known that there is potential to determine dates for the beginnings of dairy production at Çatalhöyük by analyzing fatty acid residues from cooking pots via GC/MS. This study points to a date of approximately 6690–6460 cal BC or around Level VII/South.M/North.G of the Çatalhöyük stratigraphic sequence as shown in Table 1.1 (Evershed et al. 2008; Cessford et al. 2005). This date significantly differs from the evidence for dairy subsistence practices that had been suggested based upon changes in animal population demographics. Previous estimates placed this change in diet around Level IV or approximately 6200 cal BC (Russell et al. 2005; Cessford et al. 2005).

However, it should be noted that the evidence for cattle domestication has since changed as well (Russell et al. 2012). This will be further explained in Chapter 4.

With respect to pottery use and connections between the residue record and changes in pottery styles the following objectives were defined:

i. To improve previous lipid residue yields from the pottery at this site. In order to achieve this potsherds with visible charring and rim sherds, which have been found to contain the highest concentration of lipids, were preferentially chosen for analysis (Charters et al. 1993, 1997; Evershed 2008b).

ii. To determine any differences in how pots were used based on chronological and spatial placement as well as vessel structure and material make-up. This includes identifying the presence and concentration of lipids through GC and GC/MS analysis.

iii. To extend previous studies of the organic residue record at Çatalhöyük, including the presence of dairy lipids, and to determine whether or not they were a significant part of the residue record for this particular site bye identifying the types of residues present via GC-C-IRMS.

iv. To identify any possible links between trends in lipid residue composition preserved in the pottery vessels with changes in the ceramic technology of Çatalhöyük over time, including the initial development of pottery and the proliferation of styles and fabrics.

3.3.2 Lipid distributions

In this study a total of 313 samples, primarily potsherds, were screened for the presence of organic residues. This collection also included a few non-pottery samples, including a total of 13 clay balls (Fig. 3.4) and 8 fragments of ovens and hearths (Fig. 3.5).

Figure 3.4. Clay balls and geometric clay objects of various sizes (Learning Technologies 2013).

Figure 3.5. Example of a hearth in Building 57, Area 4040, similar to the hearths sampled (Hodder and Farid 2012).

Figure 3.6 shows three examples of chromatograms from TLEs extracted from potsherds. The relative abundances of TAGs, DAGs, MAGs and free fatty acids were determined using GC and GC/MS. Other examples of chromatograms from GC-TC-IRMS analyses may be found in Appendix B.

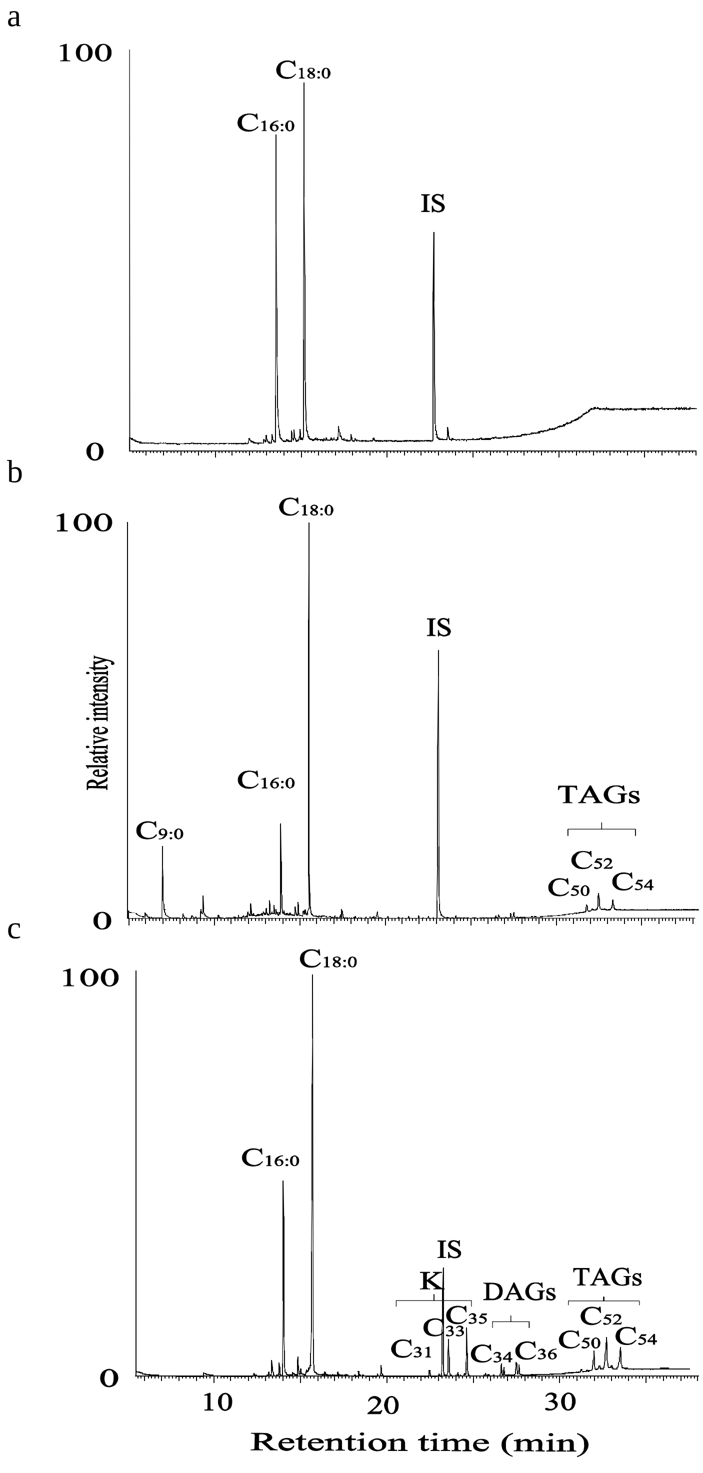

Figure 3.6. a) Typical partial high temperature gas chromatogram of the assemblage at Çatalhöyük with only hexadecanoic and octadecanoic fatty acids preserved. b) Unusual gas chromatogram of a sample featuring nonanoic acid $C_{9:0}$ in addition to the long chain fatty acids typically seen in residues originating from animal fats ($C_{16:0}$ and $C_{18:0}$). c) Example of HT-GC profile of sample T.094.This combined with mass spectra clarify specific types of compounds within the lipid assemblage such as diacylglycerols (DAGS), ketones (K), triacylglycerols (TAGS) as denoted here.

See Table 3.1 for a list of all samples with residue and types of compounds detected. Lipid concentrations are also listed for samples containing significant concentrations of lipid residues. For the purposes of this study significant concentrations were defined as being greater than 2.5 μg g^{-1}).

3.4 Results

3.4.1 Residue and pottery usage

Although much research has been performed on organic residues within archaeological contexts, the actual potsherds utilized are often treated as mediums for protecting residues, rather than as additional sources of information. In this study, one main objective was to understand the relationship between the pottery chosen and the types of food being processed. This included taking a closer look at changes in ceramic technology over time in conjunction with the types of residues found.

The transition from the Pre-Pottery Neolithic (PPNB) to a flourishing ceramic economy can all be seen within the context of Çatalhöyük. Thus, pre-pottery ceramic objects, referred to as clay balls, were also analyzed as part of this study. There were also many other technological changes to consider. For instance there seems to have been a shift from early, vegetable-tempered wares to more mineral tempered wares that also occurs around Level VII (Last 2005; Doherty 2012). The early wares were made with smectite clays and thus required organic temper in order to prevent major shrinking and swelling during the drying process. All clay materials used in pottery production would have been available within 500 m of the site (Doherty 2012). The transition to siltier materials used for pottery and clay balls as this material would have been able to withstand higher temperatures and required less organic temper (Doherty 2012). It is possible that such differences in ceramic technology may have contributed to the ability to produce secondary dairy products or sterilize milk for consumption as the mineral wares would have been more efficient in terms of heat transfer, allowing the boiling of liquids (Last 2005, Doherty 2012). This may have even affected the material's ability to absorb organic residues of any origin during the cooking process.

A list of lipid concentrations per potsherd may be found in Table 3.1. The concentrations are also depicted in Figure 3.7 to show variations through time. One hypothesis was that the youngest pots would contain the highest concentrations of lipids due to differences in lipid preservation as well as pottery usage. It was thought that the oldest pots might not have been used as extensively as younger pots, as they would have been among the first pots made for this population. However, one of the older pots (ca. 6615 cal BC) was found to contain one of the highest concentrations of lipids at 454.50 $\mu g\ g^{-1}$ potsherd (Fig. 3.7). This suggests that the pots from this time period were used as extensively as pots found in later time periods.

This also demonstrates a high degree of preservation as is to be suspected at the lower levels as other materials (e.g. animal bone, cartilage and ancient DNA) are well-preserved in these older levels (Russell and Martin 1998) along with a rise in lipid concentration is apparent around 6615 cal BC or South. L. This is just before the prolific changes thought to have occurred around 6580 cal BC, or South.M, such as the expansion of pottery styles and materials used, as well as the disappearance of the clay balls. It has also now been suggested that the first appearance of any domesticated cattle on-site occurs around this same time period at level South.M/North.G (Russell et al. 2012).

Table 3.1 Total Pottery and oven lining samples with significant concentrations of lipid

Recording Number	Unit	Lipid concentration (μg g^{-1})	Lipids detected	Age (BC)	Level
P.035	8864	25	FA, DAG, TAG	6295 ± 75	4040.I
P.038	8864	30.9	FA, TAG	6295 ± 75	4040.I
P.039	8864	113.9	FA DAG, TAG	6295 ± 75	4040.I
P.042	8869	700.5	FA	6295 ± 75	Unknown
P.043	8869	80.5	FA, TAG	6295 ± 75	4040.I
P.046	8869	52.5	FA, TAG	6295 ± 75	4040.I
P.052	10084	81.1	FA	6295 ± 75	4040.H
P.109	12456	285.8	FA TAG	6295 ± 75	IST.Unass.Gned
P.110	12456	49	FA, MAG, DAG, TAG	6295 ± 75	IST.Unass.Gned
P.111	12456	352.6	FA, DAG, TAG	6295 ± 75	IST.Unass.Gned
P.179	16590	277.7	FA	6295 ± 75	South.R
P.181	16590	35.2	FA, TAG	6295 ± 75	South.R
P.182	17017	15.3	FA	6295 ± 75	South.R
T.003	10205	130.7	FA	6295 ± 75	4040.H
T.014	10418	35	FA	6295 ± 75	South.R
T.019	12444	203	FA, MAG, DAG, TAG	6295 ± 75	IST.Unass.Gned
T.021	12498	362	FA, DAG, TAG	6295 ± 75	IST.Unass.Gned
T.038	8859	54.4	FA	6295 ± 75	4040.I
T.059	11362	41.7	FA, TAG	6295 ± 75	South.R
Mell sample 16	F V 2	111.5	TAG, FA	6295 ± 75	South.P
Mell sample 30	E V C	59.8	FA	6295 ± 75	South.P
Mell sample 57	E V C	43	TAG, FA	6295 ± 75	South.P
Mell sample 61	F V 8	9.7	FA	6295 ± 75	South.P

Mell sample 62	F V 8	171.6	FA	6295 ± 75	South.P
P.060	10260	20.6	FA	6320 ± 10	4040.H
P.061	10260	19	FA	6320 ± 10	4040.H
P.081	11955	182.8	FA, DAG, TAG	6320 ± 10	4040.H
P.149	15717	19.9	FA, TAG	6320 ± 10	South.QSouth.Q
P.163	16507	562.2	FA	6320 ± 10	South.S
P.164	16534	52.6	FA	6320 ± 10	South.S
P.165	16534	125.7	FA, DAG, TAG	6320 ± 10	South.S
P.166	16534	33.4	TAG only	6320 ± 10	South.S
P.167	16534	385.1	FA, DAG, TAG	6320 ± 10	South.S
P.169	16534	25.6	FA	6320 ± 10	South.S
P.170	16534	43.6	FA	6320 ± 10	South.S
P.171	16568	26.1	FA, TAG	6320 ± 10	South.S
P.174	16568	93.7	FA, TAG	6320 ± 10	South.S
P.175	16568	15.2	FA	6320 ± 10	South.S
T.001	8093	92.9	FA	6320 ± 10	South.S
T.006	10349	282	FA, TAG	6320 ± 10	4040.H
T.007	10349	154.6	FA	6320 ± 10	4040.H
T.008	10353	19.8	FA	6320 ± 10	4040.H
T.011	10377	301.5	FA, MAG, DAG, TAG	6320 ± 10	4040.H
T.016	11929	26.2	FA	6320 ± 10	4040.I
T.018	11962	108.6	FA	6320 ± 10	4040.I
T.037	8085	7.2	FA	6320 ± 10	South.S
T.047	10379	46.4	MAG, DAG, TAG	6320 ± 10	4040.I
T.049	10380	44.5	FA	6320 ± 10	4040.I
T.050	10382	75.4	FA	6320 ± 10	4040.H
T.053	10386	12.3	FA	6320 ± 10	4040.I
T.054	10396	78.1	FA	6320 ± 10	4040.I

T.055	10396	88.2	FA	6320 ± 10	4040.I
T.084	13352	102.1	FA	6320 ± 10	South.Q
T.111	N/A	304.7	FA, DAG, TAG	6320 ± 10	Unknown
P.063	10396	37.6	FA, MAG, TAG	6425 ± 95	4040.I
P.065	10396	380.9	FA	6425 ± 95	4040.I
P.066	10396	258.1	FA	6425 ± 95	4040.I
P.068	10396	287.3	FA, MAG, DAG, TAG	6425 ± 95	4040.I
P.147	14922	32.4	FA	6425 ± 95	4040.I
T.004	10297	93	FA	6425 ± 95	4040.G
T.022	12511	55.1	FA	6425 ± 95	South.P
T.029	12652	50.9	FA	6425 ± 95	South.Q
T.030	12652	283.8	FA	6425 ± 95	South.Q
T.068	12508	6.3	FA	6425 ± 95	South.P
T.073	12519	45	FA	6425 ± 95	South.P
T.075	12541	3.8	FA	6425 ± 95	South.Q
T.087	14145	61.1	FA	6425 ± 95	4040.I
T.093	15724	82.5	FA	6425 ± 95	South.Q
T.094	15724	116.3	FA	6425 ± 95	South.Q
T.097	15743	110.4	FA	6425 ± 95	South.Q
Mell sample 19	E VI	27.4	FA	6425 ± 95	South.O-N
Mell sample 52	E VI	21	FA	6425 ± 95	South.O-N
Mell sample 54	E VI	59.4	FA	6425 ± 95	South.O-N
Mell sample 55	E VI	376.7	FA	6425 ± 95	South.O-N
P.033	7913	134.6	FA	6580 ± 80	4040.G
P.034	7913	133.2	FA, MAG, DAG, TAG	6580 ± 80	4040.G
T.106	4261	18.4	FA, K, TAG	6580 ± 80	Unknown
Mell sample 32	E VII	53.9	FA	6580 ± 80	South.M
T.123	N/A	454.5	FA	6615 ± 95	Unknown

Mell sample 34	E VIII 29	236.8	FA	6615 ± 95	South.L
Mell sample 36	E IX 29	110.9	FA	6755 ± 95	South.K
Mell sample 15	E X 29	89.6	FA, MAG, DAG, TAG	6860 ± 90	South.J
N.9A	7880	25	FA, TAG	N/A	Unknown
P.016	5453	47.6	FA	N/A	South.Unknown
P.025	5520	157.1	MAG	N/A	South.Unstratified Neolithic
P.027	5656	87.8	MAG, DAG, TAG, FA	N/A	South.M
P.032	5678	25	FA	N/A	South.Unknown
P.047	10044	119	FA	N/A	Unknown
P.084	12200	67.8	FA	N/A	Unknown
P.085	12200	60.3	FA, DAG, TAG	N/A	Unknown
P.087	12200	212.9	FA, DAG, TAG, FA	N/A	Unknown
P.088	12200	203.7	FA, DAG, TAG	N/A	Unknown
P.089	12200	194.3	FA, DAG, TAG	N/A	Unknown
P.094	12213	217.3	FA	N/A	Unknown
P.102	12272	67.1	FA	N/A	Unknown
P.105	12454	342	FA	N/A	Unknown
P.106	12454	44	FA	N/A	Unknown
P.107	12454	31.4	FA	N/A	Unknown
P.113	12460	119.9	FA	N/A	Unknown
P.114	12460	232.8	FA, MAG	N/A	Unknown
P.122	13365	45.7	FA, DAG, TAG	N/A	South.Q
P.124	13925	52.7	FA	N/A	IST.Unass.Gned
P.125	13925	31.4	FA	N/A	IST.Unass.Gned
P.153	16247	22.9	FA	N/A	South.QSouth.Q
P.154	16247	107.8	FA, MAG, DAG, TAG	N/A	South.QSouth.Q
T.024	12652	7.8	FA	N/A	4040.I
T.026	12652	139.1	FA	N/A	4040.I

T.033	15899	17.7	FA, TAG	N/A	TP.Unass.Gned
T.043	10349	302.7	FA	N/A	4040.H
T.114	N/A	150.2	FA	N/A	Unknown
T.121	N/A	48.4	FA	N/A	Unknown
T.122	N/A	182.3	FA	N/A	Unknown

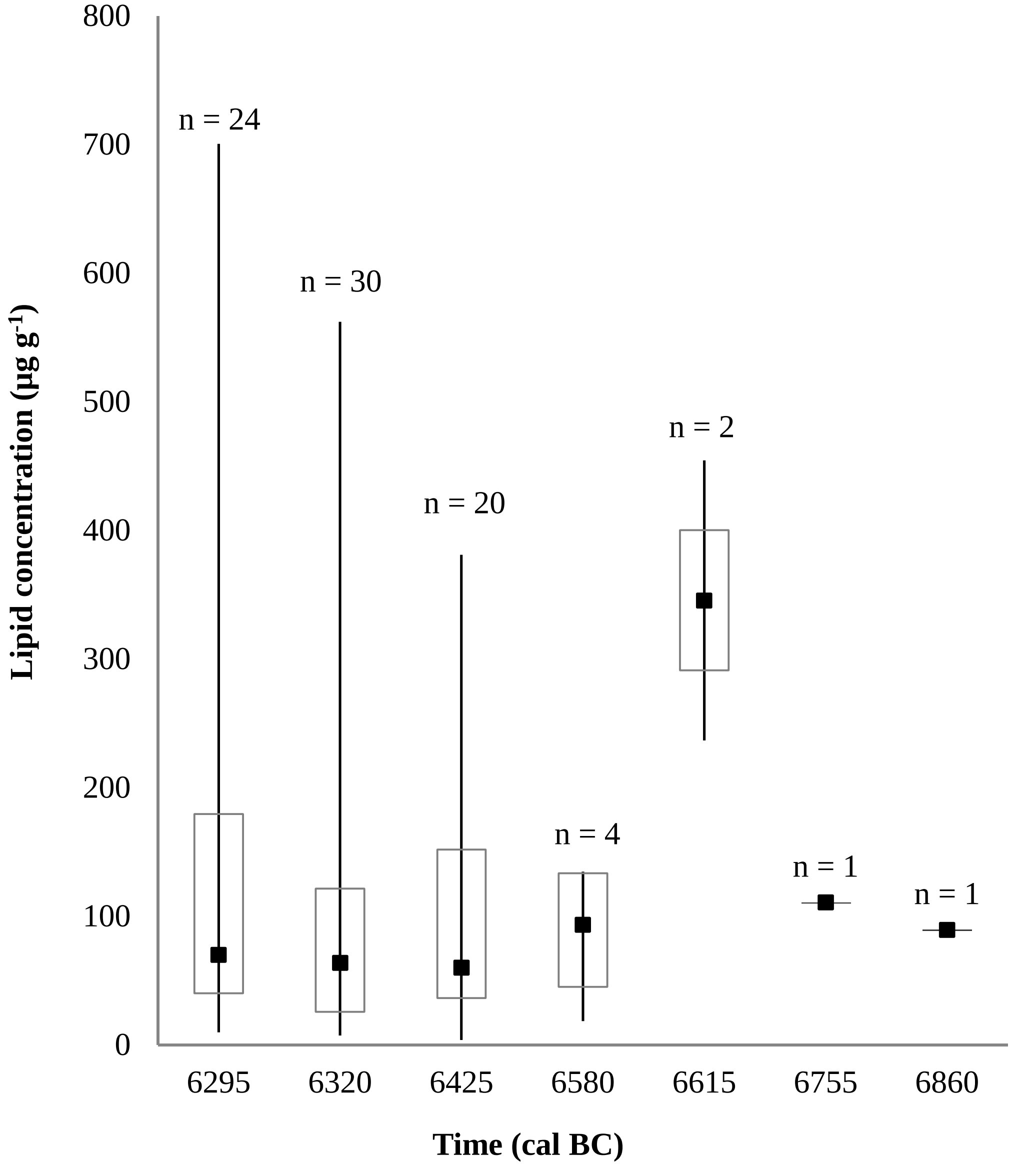

Figure 3.7. Lipid concentrations (µg g^{-1} potsherd) separated by time period. Dates shown are based on radiocarbon dates of the stratigraphic level that each potsherd was excavated from (Cessford et al. 2005). Median values are marked for each time period.

3.4.2 Residues by ware code

In Figure 3.8 the percent of sherds with residue from every ware code category has been depicted. As shown there seems to be a higher abundance of absorbed lipid residues in the dark mineral rather than the cream ware ceramic category. However, many ware code categories only contained one sample due to the rarity of these types of wares (SH, BS, RP and DM.tw). The thin-walled dark mineral wares (DM.tw) are part of the dark line category while the cream wares belong to the light line category as defined by Yalman et al. (*in press*). The light line wares are made with local calcareous, sometimes marly materials from backswamp clay. The non-local materials used to form the dark line wares contained volcanic inclusions from andesitic/dacitic rock fragments and amphiboles (Yalman et al. *in press*).

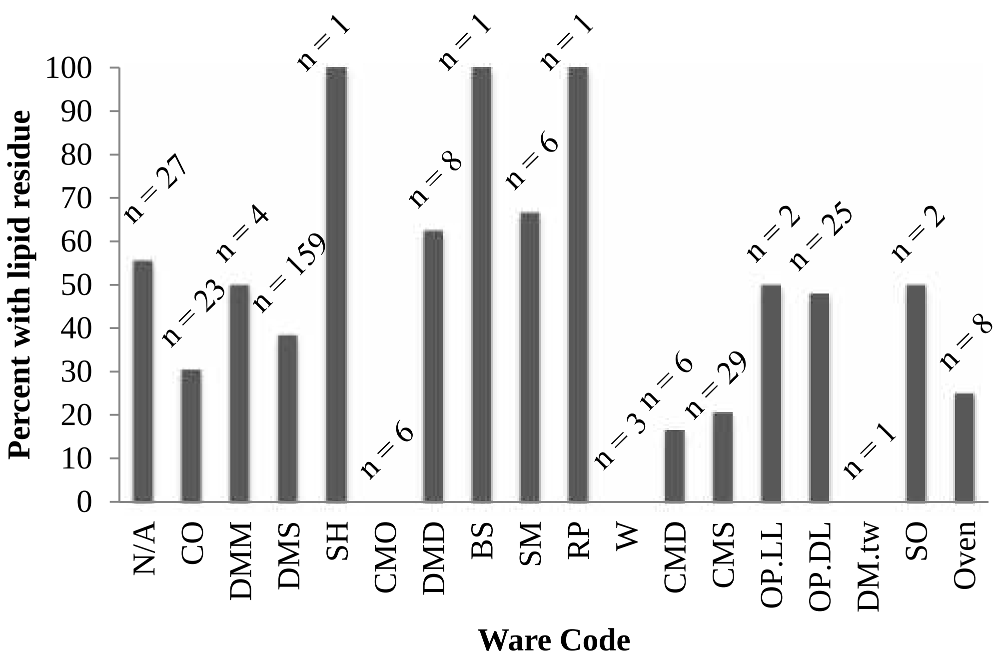

Figure 3.8. Overview of presence of lipids based on general ware code where N/A = samples not assigned a ware code, CO = cream organic, DMM = dark mineral mica, DMS = dark mineral standard, SH = shelly, CMO = cream mineral organic, DMD = dark mineral dense, BS = backswamp, SM = sandy mineral, RP = red paste, W = white wares, CMD = cream mineral dense, CMS = cream mineral standard, OP.LL = orange paste loose OP.DL = orange paste dense, DM.tw = dark mineral thin walled and SO = sandy organic. Further ware code descriptions are available on the Çatalhöyük database (Yalman et al. *in press*).

A more detailed depiction of lipid concentrations based on separate ware types is shown in Fig. 3.9.

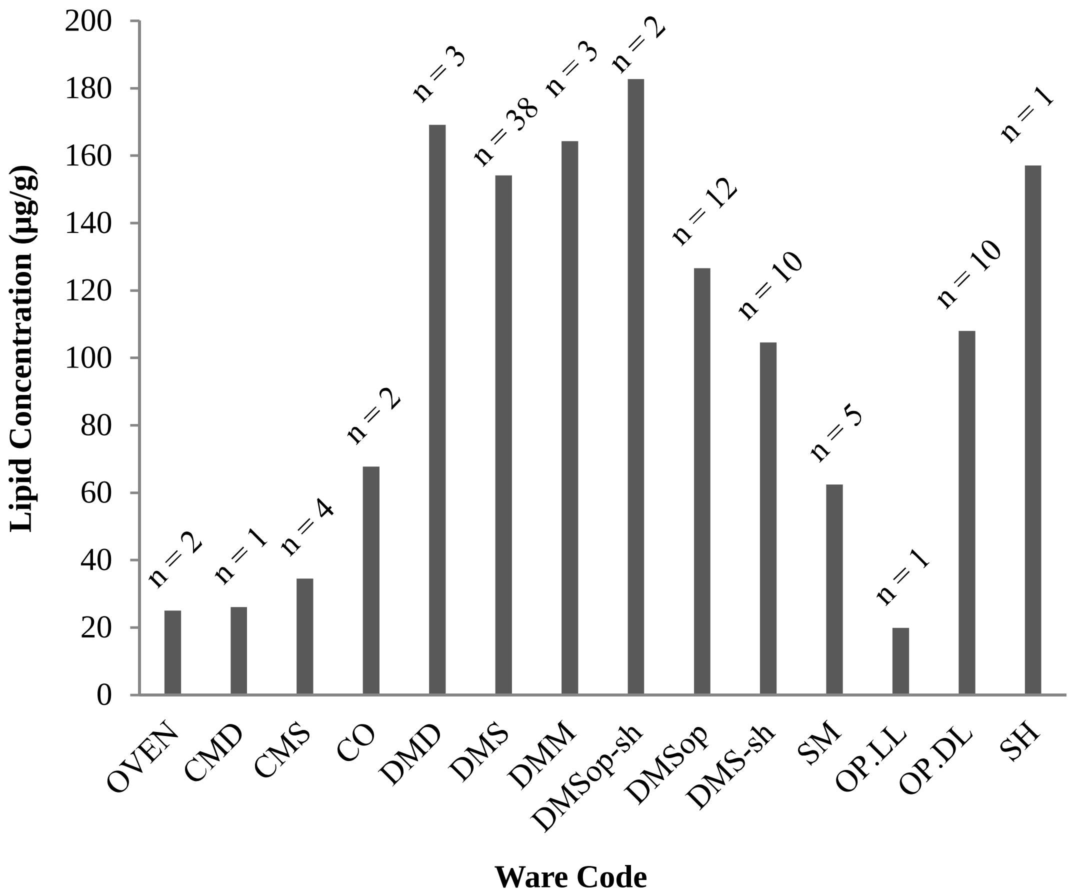

Figure 3.9. Average lipid concentration based on ware type. Detailed descriptions of ware codes may be found in Appendix A.

It must be noted that the dark mineral wares (DM) dominated the assemblage and thus the difference may be due to the relative number of samples collected. A small sampling size may mean that we happen to see potsherds containing higher quantities of absorbed residues in the dark mineral wares rather than cream wares. Due to the limited number of some ware types it was found more useful to combine several categories into two main categories, the dark wares and creamwares. By combining all types of creamwares and comparing them to dark mineral wares it is possible to see that there is still a large distinction between the amount of potsherds found to contain residues in creamwares versus dark mineral wares. Overall 22% of the creamwares and 40% of the dark mineral wares were found to contain residues.

The Wilcoxon test was used to determine whether there was a statistically significant difference between the creamwares and dark mineral wares, as well as between organic tempered and mineral tempered pots. The Wilcoxon test is similar to a t-test, but may be applied to data that does not follow a normal distribution (Wilcoxon 1945). The findings were that the dark mineral wares showed a significantly higher occurrence of residues than the creamwares (p-value = 0.058, H_o = creamwares ≥ dark wares, H_a = creamwares < dark wares) based on the mean percentages of the creamwares (CO, CMO, CMD and CMS) and dark wares (DMM, DMS, DMD and DM) containing residues.

3.4.3 Residues by temper

During the pottery production process materials are often introduced to the raw clay in order to help mold the clay, decrease shrinkage and protect the pottery during the firing process. At Çatalhöyük the types of tempers used varied over time, with much of the early pottery containing organic tempers (grasses/sedges) and the later pottery containing more mineral tempers such as sand or mica (Last 2005). In some cases mineral inclusions may have not been intentionally used, but were rather part of the different materials being used to manufacture pots. Overall, the organic tempered wares displayed a lower abundance of lipid residues with only 24% of organic tempered pots (n = 31) containing residues compared to 40% of mineral inclusion wares (n = 178). Using the Wilcoxon test (Wilcoxon 1945) it was determined that the organic tempered pots (CM, CMO and SO) show significantly fewer occurrences of residue as compared to the mineral tempered pots (DM, SM, DMS, DMM and DMD) (p-value = 0.119, H_o = creamwares ≥ dark wares, H_a = creamwares < dark wares). This may be related to age of the samples as organic tempered pots tend to be older than the mineral tempered pots.

This is understandable due to the thinner walls usually associated with the mineral wares as compared to the thick-walled organic tempered pots. However, it is clear that the organic tempered wares were also used as cooking pots. Surprisingly the orange paste (OP) and sandy (SM) samples had relatively high yields of residue. Further analysis of the pottery materials may shed light on their ability to absorb residues (Chatfield, personal communication 2009). For example, the sandy wares may be more able to absorb lipids due to the larger pore size that would be created with this temper.

3.4.4 Residues by vessel type

Unexpectedly, the presence of lipid residues indicates both bowls and holemouth pots (Fig. 3.10) were used for cooking. This is shown in Table 3.2 along with the types of residues found with specific types of pots. A more detailed description of the types of residues identified may be found in Chapter 4. Base sherds did not yield significant quantities of residue, as is to be expected based on the Charters et al. (1993, 1997) and Evershed et al. (2008b) studies of the distribution of lipids within pots, in which the rims were found to contain the highest concentrations of absorbed lipids. Vessels classified as bowl or holemouth are almost exclusively rim sherds. Additional information on the ware types and vessel types described here may be found in the pottery section by Yalman et al. in the 2012 Çatalhöyük Archive Report.

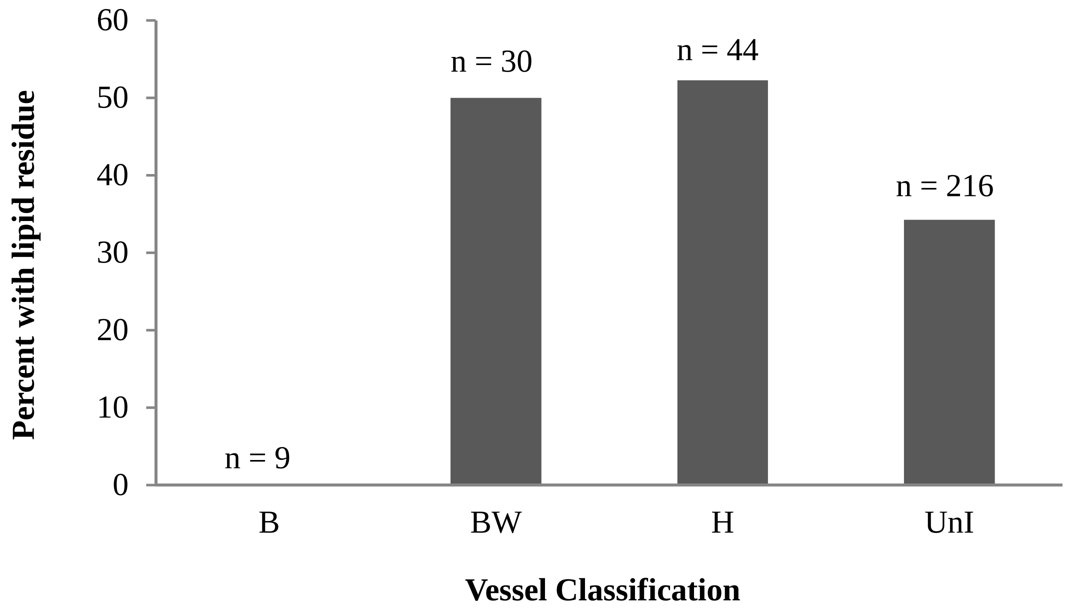

Figure 3.10. Percent of sherds with lipid residue based on vessel classification where B = base sherd, BW = bowl, H = holemouth pot and UnI = unidentified, a category which mainly consists of body sherds.

3.4.5 Clay balls

Also, hand-manufactured, clay cooking balls, varying in size from 40 to 90 mm in diameter (Fig. 3.4), have been collected from levels XII (but not XI) to VII (South.H to South.M) of the East Mound of Çatalhöyük (Hamilton 1996; Atalay 2012). Clay balls are usually found in low numbers; an average of three per unit. Mini balls (40mm), which have not been analysed for residue due to their small size, are found in much higher concentrations, the largest count being n = 443 for one unit (16240). However, clusters of mini balls are not found below South.M. Thus as the use of clay balls was declining there was an increase in the use of mini balls occurring within the time period of South.M, but it is not likely that minis were simply substitutes for the larger clay balls in function. In fact it is likely that mini balls were used as tokens for keeping records, rather than items involved in food production (Atalay 2012).

The regular clay balls may have been heated and placed in baskets to cook or process foodstuffs. Their use predates the development of pottery. It is possible that clay balls and baskets were the primary tools used for cooking in the lower levels prior to the emergence of pots that could withstand temperatures high enough for cooking. It is possible that the improvements seen in ceramic technology may have been the result of increased processing of meats or dairy products.

However, after analyzing a total of thirteen clay balls (data combined from this study and Copley et al. (2005) via GC it was confirmed that there is no evidence of absorbed residues in these materials. The lack of absorbed residues may be due to the balls being used in boiling water or not coming in direct contact with lipid-rich foodstuffs. Visible charring on the clay balls suggests that they were heated, but it is still unclear exactly how they were used.

It is also possible that the clay balls are too compacted to allow for adequate absorption of residues. Scraping the outer layers of the clay balls and analyzing visible residues could provide more information, but the risk of post-depositional contamination is extremely high.

3.4.6 Spatial trends

By categorizing potsherds with organic residue based on the area from which they were excavated it was possible to determine differences in instance of residue as well as lipid concentration across the site as shown in Figures 3.11 and 3.12.

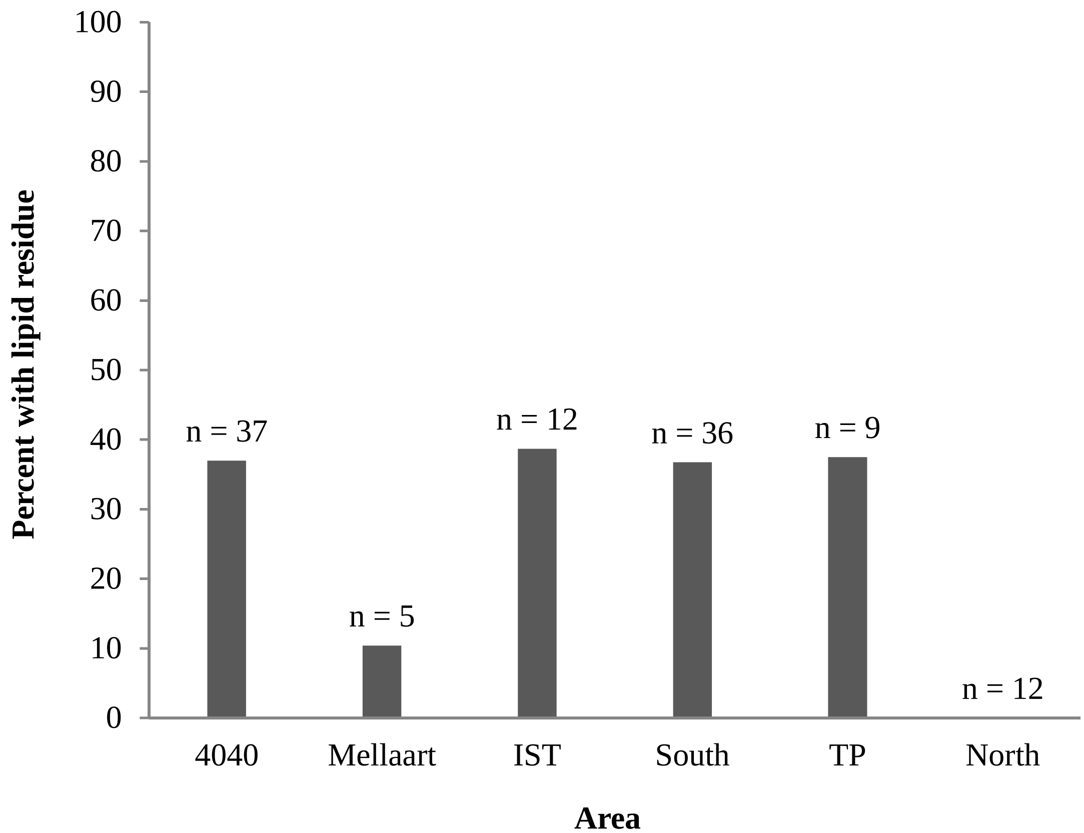

Figure 3.11. Percentages of samples found to contain residues separated by the excavation area they originated from.

The presence of residues was found to be nearly identical in each area of the site, with the exception of the Mellaart excavations and the North (Fig. 3.11). Items collected during the Mellaart excavations would have been kept in storage (plastic bags) for decades, and thus often contained plasticizer contaminants, making it difficult to identify any organic residue remnants. However, it is also likely that variations in pottery material between the older and younger portions of the site would also have a measurable impact on original levels of residue absorption as the older pottery may not have withstood heating (Last 2005; Doherty 2012).

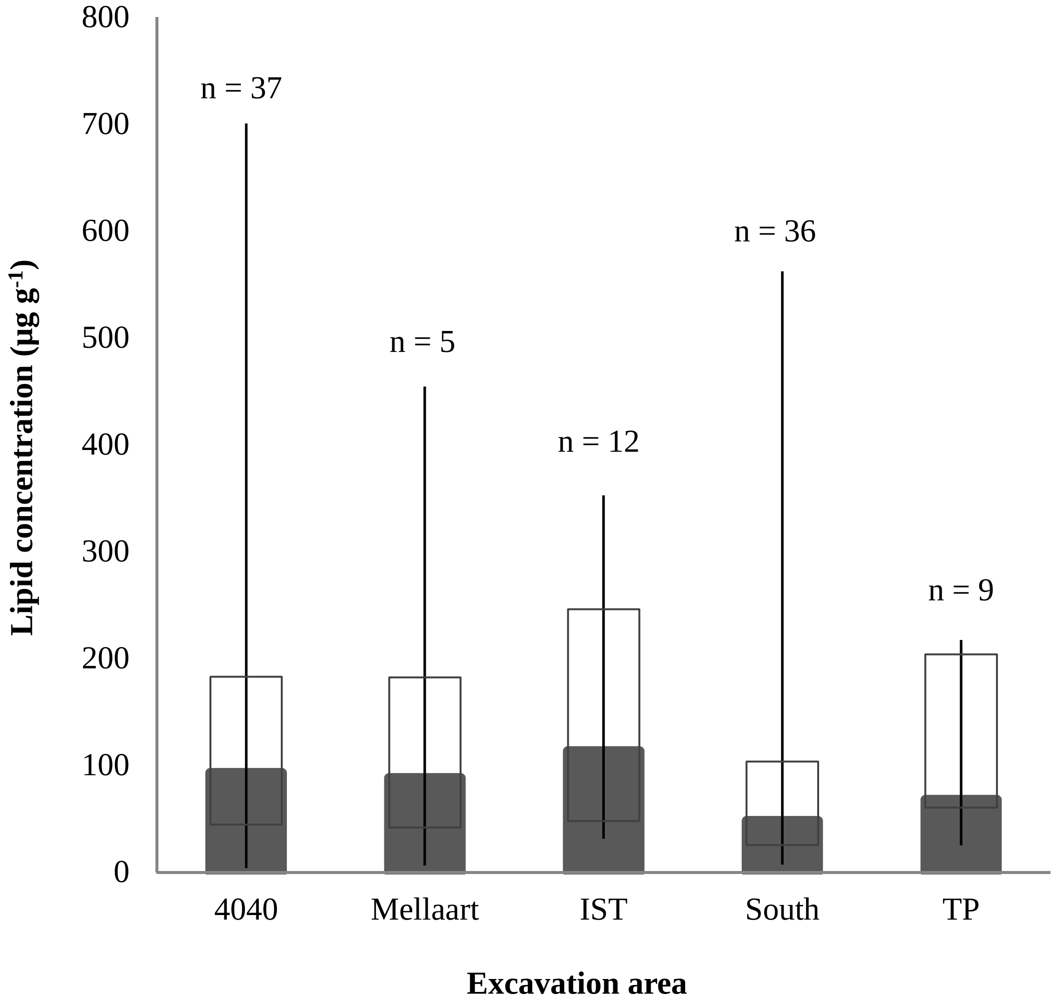

Figure 3.12. Lipid concentration (µg g^{-1} potsherd) based on excavation area of the potsherds sampled. Median values are marked in blue.

It is apparent (Fig. 3.12) that there is not a significant difference between median lipid concentrations of most areas on site. There do seem to be lower concentrations found in the South area, which is understandable as this portion of the site represents the oldest pottery available at Çatalhöyük. Even with a relatively large sample size for the South Area (n = 36) it is still apparent that this region of the site contains the lowest concentrations of lipids on average.

A comparison of the maximum values for each area reveals that the highest lipid concentrations were found in the 4040 area. None of the data distributions for these areas were found to be normal. Therefore the Kruskall-Wallis one-way test of variance was used. By using this test, paired with the Bonferonni correction, it was determined that none of the areas differed significantly from each other in terms of lipid concentration (Kruskal and Wallis 1952; Bonferonni 1936).

3.4.7 Chronologic trends

Figures 3.13 and 3.14 summarize the number of potsherds containing residues for each stratigraphic level according to the Mellaart and Hodder classification schemes respectively. In Figure 3.13 potsherds that were marked as possibly being used over multiple levels (e.g. II–IV) are represented more than once on the graph. Therefore the number of samples containing residue does not represent the actual number of samples for each level, but is rather a combined value of overlapping levels. Where large sample sizes were available there does not seem to be any significant differences in the overall lipid yields based on stratigraphic location.

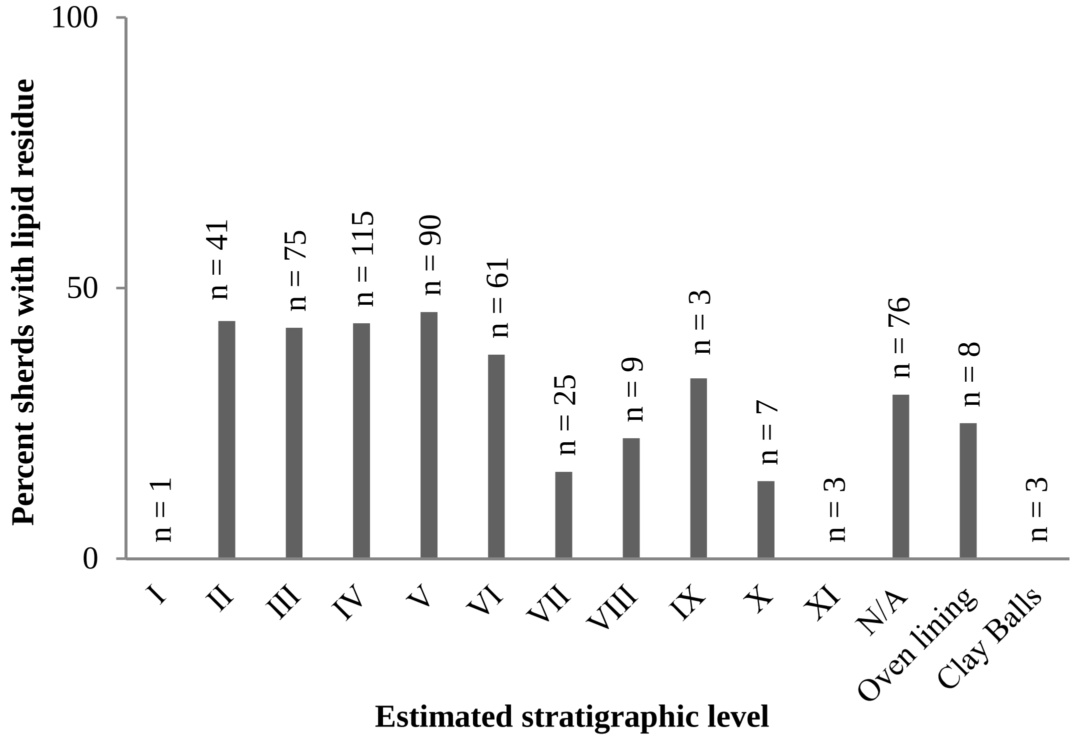

Figure 3.13. Representation of the highest possible percentage (as some sherds overlap levels) of potsherds with residue for each assigned stratigraphic level under the Mellaart chronologic system.

A new stratigraphic classification scheme has recently been implemented for the current excavation project under the direction of Ian Hodder. The new levels correspond to some of the previously classified levels under Mellaart's classification scheme as shown in Table 3.2. Looking at the number of samples with residue under the new Hodder level classification system creates a clearer picture of changes throughout site occupation as pottery can now be classified to more discrete levels (Fig.3.14).

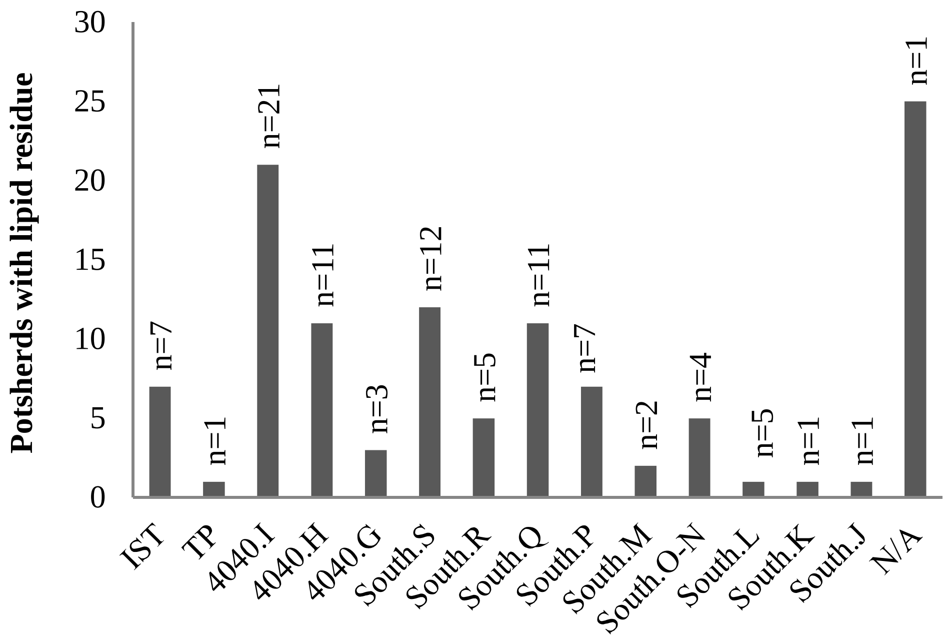

Figure 3.14. Number of sherds with lipid residues for each assigned stratigraphic level under the new Hodder level classification system.

In Figure 3.14 it is apparent that the highest occurances of lipid residue were found at level 4040.I. With 4040 being categorized with the North stratigraphy, this is late in the occupation, most likely around Mellaart level IV. This is around the time increased culling of infantile and juvenile sheep is seen in the faunal record suggesting intensification of sheep/goat herding, perhaps due to a more family-based herding strategy (Russell et al. 2012). This is supported by the bulk $\delta^{15}N$ values obtained from sheep and goat bone, which point towards an increased range of herding locations as seen in increased variation in ranges of $\delta^{15}N$ values found in collagen (Pearson et al. 2007).

The sheep/goat sex ratios change from female dominated, to male-dominated and then return to a female-dominated assemblage towards the end of occupation (Fig. 3.15 from Russell et al. 2012).

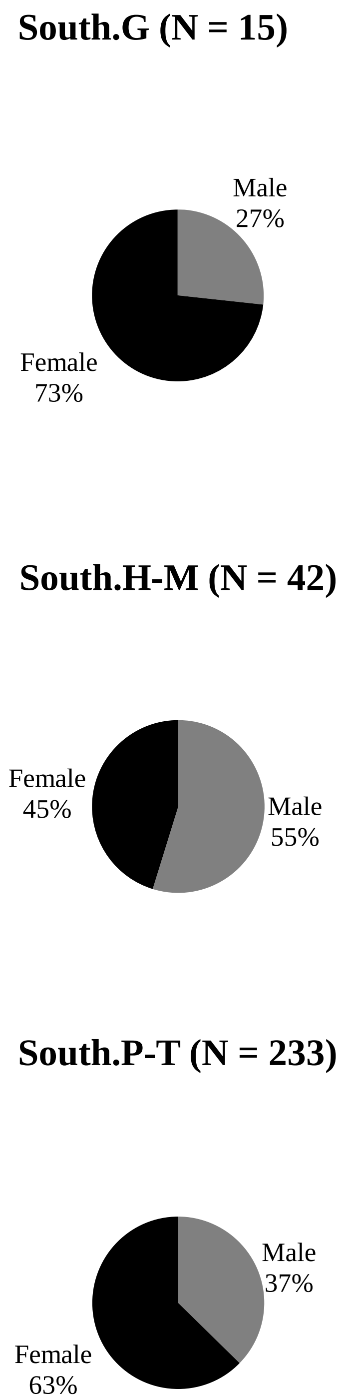

Figure 3.15. Sheep and goat sex ratios based on mature pelves from (a) oldest to (c) youngest (Russell et al. 2012).

3.4.8 Types of lipid residues based on ware and vessel type

Through $\delta^{13}C$ analysis it was also possible to identify specific types of residues and place them into the categories of non-ruminant adipose fats, ruminant adipose fats and ruminant dairy fats. The methods of the GC-C-IRMS analysis required to achieve this level of identification is described in detail in Sections 2.5.3, 2.6.1 and a detailed treatment of the results is presented in Chapter 4. However, it is helpful to see how specific types of residues may be associated with specific types of vessels and thus this information is presented in Table 3.2 for the potsherds that have been classified by ware code and/or vessel type.

Table 3.2 Types of residues found in specific types of pottery

Recording number	Ware code	Vessel code	Residue type
P.034	DMS-sh1	BW3	Non-ruminant adipose
P.068	DMS-sh-op1	BW11	Non-ruminant adipose
P.169	DMS-m1	MdH2	Non-ruminant adipose
P.171	CMB-f1		Non-ruminant adipose
T.001	OPD-1	H2	Non-ruminant adipose
T.073	DMS-sh2		Non-ruminant adipose
T.075	DMS-m6		Non-ruminant adipose
P.038	DMSop-m1	H2	Ruminant adipose
P.043	DMS-m1		Ruminant adipose
P.052	DMS-sh1	SmH2	Ruminant adipose
P.060	DMS-m1		Ruminant adipose
P.081	DMSop-m1	BW3	Ruminant adipose
P.179	DMS-m1		Ruminant adipose
T.004	DM-sh-op1	H7	Ruminant adipose
T.014	DMS-m1		Ruminant adipose
T.059	DMSop-1		Ruminant adipose
T.084	DMSop-1		Ruminant adipose
T.093	DMM-m1		Ruminant adipose
P.033	DMS-m1	H7	Ruminant dairy
P.164	CM-s1	H7	Ruminant dairy
P.175	OPD-f1		Ruminant dairy
T.004	DM-sh-op1	H7	Ruminant dairy
T.087	DMS-sh1		Ruminant dairy
T.097	DMS-m1		Ruminant dairy

More detailed descriptions of the ware code and vessel code schemes are given in Appendix A and Figures 3.1–3.3.

Many of the residues identified derive from dark mineral wares, as is to be expected due to the high occurrence of lipid residues in this ware type. Interestingly, all of the dairy fat residues from identifiable vessels were found in holemouth pots. This would support an interpretation that holemouth vessels were specifically designed for use in processing dairy products. Holemouth pots may have been hung by ropes attached to the lugs on either side of the vessel, and suspended over a fire to boil milk or water (Nurcan Yalman, personal communication 2009). However, the lugs are not particularly strong and thus may simply have been used to hold the pot while pouring substances from the vessel.

3.5 Overview

There do seem to be trends in the appearance of residues in relation to the types of pottery used as well as the time period in which the pots were used. This may be due to several factors or combinations of factors, such as the higher prevalence of dark mineral wares in the later levels of occupation, particularly from Level VII/South.M onwards. This time period corresponds to a time period that seems to include several cultural changes on site, including the development of dairying (based on the organic residue record) and the domestication of cattle (based on faunal evidence). In the next chapter we will see how the presence of dairy fat residues in pottery from these levels ties into the current discussion of whether domesticated cattle were introduced to Çatalhöyük by outsiders, or actually developed at this particular site, independent of outside sources.

During this time there was also a proliferation of pottery styles including the appearance of lugs and many decorative patterns along with the emergence of the expression of animals on pottery. It is also a time marked by the emergence of finer, thin walled, mineral wares. In comparison with the earlier, thick-walled, mainly organic tempered pots this change may have had an effect on the ability of pots to absorb and preserve lipid residues.

Overall lipid residues appeared more often in dark mineral wares rather than cream wares, and also were more apparent in mineral tempered wares. This effect may be due to material properties of the pots (Chatfield 2009; Doherty 2012).

The earliest pottery from Çatalhöyük dates to ca. 7000 cal BC (Hodder 2012). However, based on the evidence provided herein there is no indication of cooking within early pottery based on the presence of absorbed lipid residues until ca. 6860 cal BC ± 90 years. As the pottery present at this site is some of the earliest found in Central Anatolia, the Levant and the Northern Fertile Crescent, these findings may have implications as to the uses of early pottery throughout these regions as well as the reasons for the development of pottery, first as storage vessels and later on as cooking vessels. Thus far the residues found in this study remain some of the earliest found throughout the aforementioned regions (Evershed et al. 2008).

Thus the GC analysis of residues contained in the potsherds gathered from Çatalhöyük revealed the following:

i. Through a careful potsherd collection process that focused on sherds with visible evidence of heating, such as charring, as well as rim sherds residue yields were improved from 26% to nearly 36%.

ii. Older samples were found to contain fewer residues, but no other significant differences based on spatial variation were found. However, the older residues that did contain residues were found to have similar lipid concentrations to those found in potsherds from the later stratigraphic levels.

iii. Lipids were identified for the length of the Neolithic time period for this site. The presence of dairy fats emerging in the residue record was confirmed. This discovery led to further investigation with a comparison to the faunal record as detailed in Chapter 4.

iv. Dark wares were found to be more likely to contain preserved lipid residues as compared to cream wares (40% versus 22% respectively). A Wilcoxon test also revealed that mineral wares were significantly more likely than creamwares to yield residues. Whether this is solely due to material properties or is an actual reflection of more extensive use of mineral wares cannot be determined at this time.

In the next chapter we take a closer look at changes in the faunal record over time and possible links between animal management strategy and trends in the organic residue record through the use of carbon stable isotope analysis.

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Chapter 4 Compound-specific Stable Carbon Isotope Analysis and the Implications on Animal Management Practices

4.1 Introduction

The Neolithic site of Çatalhöyük provides one of the earliest examples of a densely populated agricultural community that exists in the archaeological record, providing a glimpse into early life under an agriculturally based food system. As such, it can provide information on early animal management strategies and the choices that were made that eventually led to the systems in place today. Extensive research has been performed on the faunal remains of the site during the current phase of excavation at Çatalhöyük, beginning in 1993. This information, combined with stable isotope analyses on faunal remains and lipid residues in archaeological ceramics, provides a picture of the animal management strategies likely in place, how they changed over time, and what the possible consequences of these decisions may have been.

Archaeological faunal remains can provide information on a plethora of aspects of animal populations present during site occupation (Russell and Martin 2005; Russell et al. 2012; Henton 2010). Processing marks on bones, or the lack thereof, may make it possible to determine whether meat was boiled or roasted or whether animals were killed or died of natural causes (Russell et al. 2012; Dominguez-Rodrigo 2012). Population demographics of herds provide information on whether animals were used for milk or meat and in some cases whether herds are domestic or wild (Payne 1973; Russell 2004; Zeder 2011).

At Çatalhöyük all of these and many other factors have been considered resulting in a detailed picture of the state of animal populations throughout the site's Neolithic chronology. Due to the thorough dating of the site stratigraphy through the use of radiocarbon analysis, it is possible to view trends over time in the faunal record and translate these into changes in animal management and the uses of wild versus domestic animals on-site (Cessford et al. 2005; Russell et al. 2012).

4.2 Animal management

According to the faunal record, domestic sheep and goats were a major part of life at Çatalhöyük from its inception. Early domestic animals likely travelled with the early settlers of Çatalhöyük, as they were already a part of subsistence throughout southwest Asia (Henton 2010). Until recently the zooarchaeological criteria for determining the appearance of the first domesticated caprines relied on changes in overall body size. However, recent research performed by Melinda Zeder in the Near East and Southern Levant has indicated that reduction of body size alone is a poor determinant of domestication versus changes in hunting practices. Caprine body size is also susceptible to change from one generation to the next based on changes in nutrient availability, temperature variability and changes in sexual demographics. A clearer indication of domestication may be an overall decrease in sexual dimorphism, with males decreasing in size while females maintain roughly the same dimensions as their wild counterparts (Zeder 2011). In Figure 4.1 the overall decrease in cattle size is demonstrated by comparing bone sizes to those of a wild specimen, the Ullerslev cow, the measurements for which have been set as 0.0 on the log size index (LSI) scale (Degerbøl and Fredskild 1970; Russell and Martin 2005; Russell et al. 2012). The faunal remains from earlier levels (Fig. 4.2c and d) show a shift towards smaller cattle compared to the wild Ullersley cow with a median LSI of 0.03 for South G-M (Fig. 4.1a and b) and -0.02 for levels South P–T and 4040 (Fig. 4.1c and d) (Russell et al. 2012).

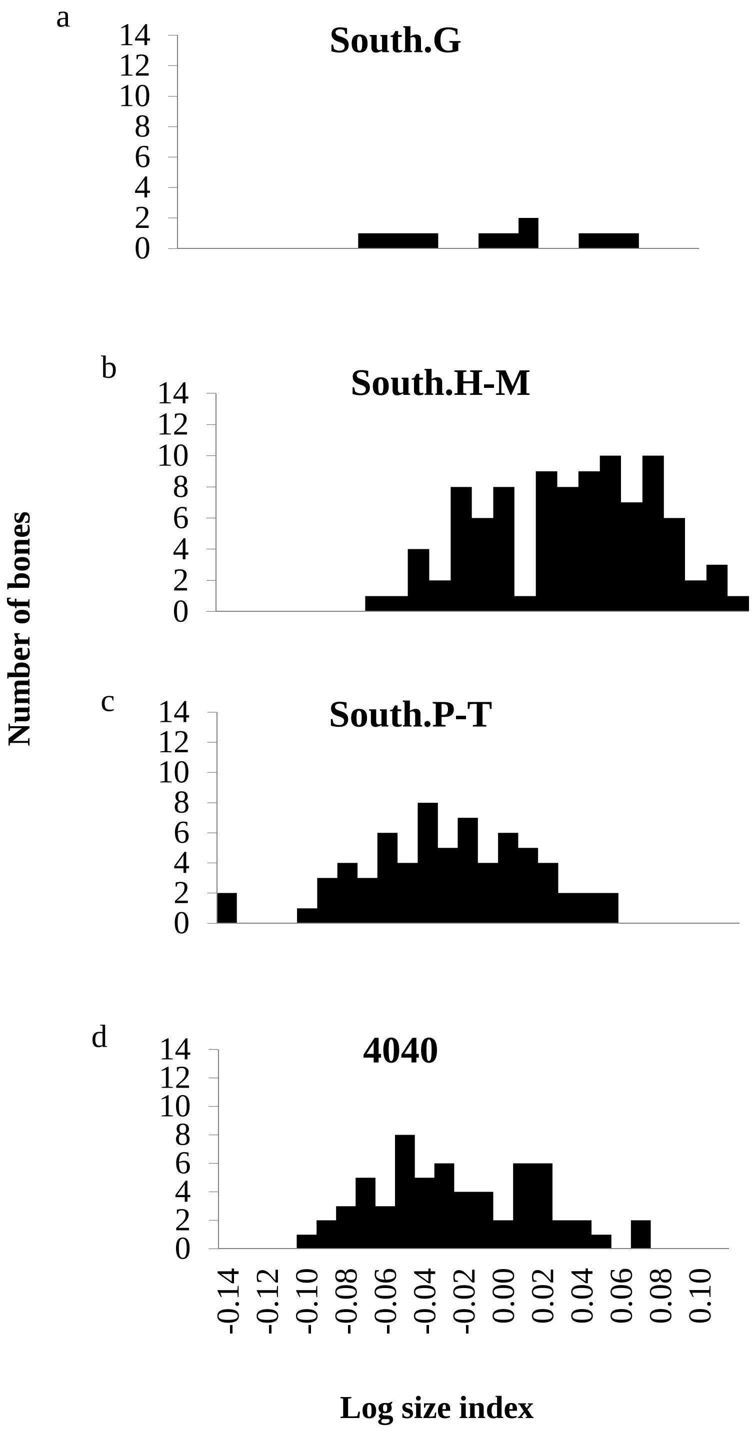


Figure 4.1. Log size index distributions for cattle measurements from oldest levels (a) to youngest (c and d) compared to a wild female standard animal from Ullerslev in Denmark (from Russell et al. 2012).

Herding strategy is also usually indicated by an assemblage biased towards a large population of female adults with juvenile males being culled early for meat (Payne 1973). At Çatalhöyük there is additional evidence for the presence of domesticated caprines on-site in the form of penning structures found in early domestic units in level XI and XII (Russell et al. 2006).

An initial study performed by Perkins (1969) indicated that the remains of cattle from Çatalhöyük provided evidence for the presence of domestic cattle in Anatolia by 5800 B.C., and strongly suggested that cattle were most likely domesticated at least 500 years earlier. At the time this was the earliest known evidence for the domestication of cattle in the Near East. Subsequent reports give varied timing for domestication and some found no evidence for the presence of domestic cattle during the early levels of occupation for this site (Ducos 1988). In fact Ducos (1988) suggested that there was only sufficient evidence for proto-domestication and animal management based on a more extensive examination of the cattle remains at Çatalhöyük. Recent research conducted by the Çatalhöyük faunal team, however, has found that a broad reduction in sexual dimorphism and decreased overall body size of bovine specimens found in later levels are consistent with domestic cattle consumption on-site (Fig. 4.1; Russell et al. 2012).

Despite this evidence there is still the question of whether these later animals were actually domesticated cattle or if there is perhaps another explanation, such as nutritional deficiencies or changes in hunting patterns (Arbuckle 2013). There is also a question of whether cattle were domesticated on-site by the inhabitants of Çatalhöyük, or introduced by outside sources, although it is clear that Central Anatolians could have come into contact with neighbouring cattle herding peoples. Thus, it seems possible that the people of Çatalhöyük may have actively delayed the adoption of domestic cattle to preserve auroch hunting practices (Arbuckle 2013).

4.2 Objectives

According to the faunal record at Çatalhöyük a mixture of wild and domesticated cattle were consumed during the later periods of occupation (Arbuckle and Makarewicz 2009; Russell et al. 2005). Until recently, past faunal population distributions and changes in cattle, goat and sheep specimen sizes via the study of faunal remains were the only means available for estimating approximate timing of the emergence of dairying at this site (Russell et al. 2005) and elsewhere. These studies are limited in how accurately they can define the beginnings of dairy processing in relation to cattle, especially since many factors could potentially contribute to changes in animal population distributions, such as variations in hunting strategies or changes due to environmental rather than management factors (Russell et al. 2005). Thanks to recent studies (Dudd and Evershed 1998; Copley et al. 2003; Evershed et al. 2008), it is now known that there is potential to determine dates for the beginnings of dairy production at Çatalhöyük by analyzing fatty acid residues from cooking pots via GC-C-IRMS and placing them within the chronology of the site based on stratigraphic context. The stratigraphic levels of Çatalhöyük were previously dated via radiocarbon dating (Cessford et al 2005). Evershed et al. (2008) points to a date of ca. 6500 cal yrs BC or around Level VII of the Çatalhöyük stratigraphic sequence (Table 1.1 this thesis) (Cessford et al. 2005). This date significantly differs from the evidence for dairy subsistence practices suggested based upon changes in animal population demographics. Previous estimates based on faunal evidence placed this change in subsistence practices around Level IV or approximately 6200 cal BC (Russell et al. 2005; Cessford et al. 2005).

By utilizing the aforementioned methods of lipid residue analysis and further constraining the timing of the emergence of dairying at Çatalhöyük we hoped to determine whether milk was associated with sheep/goat herding strategies or if the presence of milk could actually provide an indication of cattle herding. This distinction is addressed later. The timing of dairy production found in the organic residue record suggests that domesticated cattle were present at Çatalhöyük around the same time as, and perhaps prior to, those found at Erbaba, a site approximately 100 km east of Çatalhöyük, ca. 6600 cal BC as demonstrated through morphologic and demographic analyses (Arbuckle and Makarewicz 2009).

As mentioned in Chapter 3 in order to compare organic residues from the pottery to the faunal record of Çatalhöyük the following objectives were set:

i. Select animal fat residues from the lipid residues discussed in Chapter 3 based on the high abundances of $C_{18:0}$ and $C_{16:0}$..

ii. Perform GC-C-IRMS analyses on selected FAMEs to obtain $\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$ values to identify types of fats present and investigate the presence of dairy fats.

iii. Compare types of organic residue found (i.e., ruminant adipose, ruminant dairy, non-ruminant adipose) to faunal evidence based on chronology by using $\Delta^{13}C$ values. This will determine whether milk fats in pottery coincide with the appearance of domesticated cattle on-site and if the organic residues reflect any other changes in domestic animal populations (i.e., morphologic and demographic factors) at Çatalhöyük.

iv. Identify any links between stable isotopic data gathered from collagen to animal fat residue findings to confirm broader changes and/or connections between animal management strategy (e.g. wider herding ranges and household based herding).

v. Combine information obtained from GC-C-IRMS with pottery classification to investigate specialisation in use based on the ceramic form or ware type, decorative qualities and vessel type.

vi. Place all the above findings within the sites chronological sequence to glean any consistent patterns or developing trends over time in relation to animal management practices. This will be done by applying the chronological, spatial and technological information assigned to each potsherd at the time of excavation, as well as utilizing data gathered through the study of faunal remains as carried out by the faunal team at Çatalhöyük in order to link changes in the material culture and animal management on-site with changes in food commodities as represented by the organic residues.

4.3 Results and Discussion

As shown in Chapter 3 (Table 3.2) all adipose fats were found in a variety of vessel types. Dairy fats appeared in both dark mineral and cream pots, and interestingly, only in holemouth pots. The shape of these pots, as shown in Figure 3.2, may have been functional, possible being used with a cloth stretched over the top and secured onto the lugs in order to strain milk.

4.4 Compound-specific δ^{13}C analyses of fatty acids

GC-C-IRMS analyses were conducted on 71 fatty acid methyl esters (FAMEs) in order to determine the δ^{13}C values of hexadecanoic and octadecanoic fatty acids ($C_{16:0}$ and $C_{18:0}$) obtained from potsherds (Fig. 1.4). A detailed description of the production of FAMEs from the total lipid extracts (TLEs) is given in the Methods section (Chapter 2). A total of 34 δ^{13}C values are shown here (Table 4.1). Table 4.1 also includes Δ^{13}C values, where $\Delta^{13}C = \delta^{13}C_{18:0} - \delta^{13}C_{16:0}$. By plotting this value against $\delta^{13}C_{16:0}$ values it is possible to determine the types of commodities the fatty acids originate from (Fig. 4.3).

Table 4.1. $\delta^{13}C$ values of fatty acid components of the total lipid extracts of the Çatalhöyük pottery. Residue type assigned based on modern reference animal fats (Copley et al. 2003; Evershed et al. 2008; Dunne et al. 2012).

Recording number	$\delta^{13}C_{16:0}$	$\delta^{13}C_{18:0}$	$\Delta^{13}C$	$C_{16:0}$ stdev	$C_{18:0}$ stdev	cal BC	Fat type
320	-24.5	-26.5	-2.0	0.0	0.1	6295 ± 75	Ruminant adipose
325	-26.9	-28.0	-1.1	0.0	0.2	6295 ± 75	Non-ruminant adipose
327	-26.4	-28.5	-2.1	0.0	0.2	6425 ± 95	Ruminant adipose
330	-25.5	-27.4	-1.9	0.3	0.2	6425 ± 95	Ruminant adipose
331	-27.0	-29.9	-2.9	0.3	0.7	6755 ± 95	Ruminant adipose
333	-23.9	-25.4	-1.5	0.1	0.2	6615 ± 95	Ruminant adipose
352	-26.9	-27.3	-0.5	0.3	0.3	6860 ± 90	Non-ruminant adipose
P.006	-27.3	-25.7	1.6	0.4	0.6	6580 ± 80	Non-ruminant adipose
P.007	-26.8	-26.4	0.4	0.2	0.9	6580 ± 80	Non-ruminant adipose
P.033	-23.4	-28.5	-5.1	0.0	0.0	6580 ± 80	Ruminant dairy
P.034	-25.6	-26.4	-0.8	0.3	0.2	6580 ± 80	Non-ruminant adipose
P.038	-26.7	-28.6	-1.9	0.0	0.1	6295 ± 75	Ruminant adipose
P.043	-24.3	-26.6	-2.3	0.2	0.1	6295 ± 75	Ruminant adipose
P.052	-25.8	-28.8	-3.0	0.0	0.1	6295 ± 75	Ruminant adipose
P.060	-23.9	-26.3	-2.4	0.4	0.1	6320 ± 10	Ruminant adipose
P.068	-25.2	-26.2	-1.0	0.0	0.0	6425 ± 95	Non-ruminant adipose
P.081	-26.0	-27.1	-1.1	0.0	0.0	6320 ± 10	Ruminant adipose
P.109	-24.0	-24.9	-0.9	0.1	0.2	6295 ± 75	Non-ruminant
P.110	-24.0	-26.6	-2.7	0.7	0.8	6295 ± 75	Ruminant
P.111	-22.5	-25.3	-2.8	0.2	0.3	6295 ± 75	Ruminant
P.164	-25.6	-29.4	-3.9	0.5	0.1	6320 ± 10	Ruminant dairy
P.169	-25.6	-25.3	0.3	0.4	0.4	6320 ± 10	Non-ruminant adipose

P.171	-24.8	-24.9	0.0	0.2	0.2	6320 ± 10	Non-ruminant adipose
P.175	-25.4	-29.0	-3.6	0.5	0.2	6320 ± 10	Ruminant dairy
P.179	-24.8	-26.2	-1.4	0.4	0.1	6295 ± 75	Ruminant adipose
T.001	-25.0	-24.9	0.1	0.0	0.0	6320 ± 10	Non-ruminant adipose
T.004	-26.6	-29.9	-3.3	0.1	0.0	6425 ± 95	Ruminant adipose and dairy
T.014	-24.6	-27.0	-2.4	0.2	0.0	6295 ± 75	Ruminant adipose
T.059	-25.1	-26.5	-1.4	0.3	0.3	6295 ± 75	Ruminant adipose
T.073	-28.0	-26.5	1.6	0.1	0.3	6425 ± 95	Non-ruminant adipose
T.075	-26.1	-26.7	-0.6	0.7	0.4	6425 ± 95	Non-ruminant adipose
T.084	-25.6	-27.8	-2.2	0.4	0.2	6320 ± 10	Ruminant adipose
T.087	-26.4	-30.0	-3.6	0.1	0.0	6425 ± 95	Ruminant dairy
T.093	-25.4	-27.5	-2.2	0.2	0.2	6425 ± 95	Ruminant adipose
T.097	-25.2	-29.1	-3.9	0.2	0.1	6425 ± 95	Ruminant dairy

4.4.1 Identification of animal fats

As shown in Figure 4.2, plotting $\delta^{13}C_{16:0}$ versus $\delta^{13}C_{18:0}$ values can provides important information about the types of residues present in a potsherd. However, these values are subject to several factors that affect the identification of animal fats using raw $\delta^{13}C$ values. For example, the $\delta^{13}C$ values of plants are affected by photosynthetic pathways used (CAM, C_3 or C_4), variations in light exposure levels, temperature, soil moisture, interspecies variation, stomatal density of grazing plants, or even the age of the plant (Copley et al. 2005 and references therein). In a recent study of modern ruminant reference fats collected in Libya and Kenya $\delta^{13}C_{16:0}$ were found to have a range from -35 to -15‰ (Dunne et al. 2012). This demonstrates a wide range of C_3 and C_4 plant consumption by livestock. The $\delta^{13}C_{16:0}$ values shown in Table 4.1 fall within this range but are more confined to values between -28 and -22‰ indicating a mixed C_3 and C_4 diet for the grazing animals at Çatalhöyük. The Çatalhöyük $\delta^{13}C_{18:0}$ values obtained ranged from -24 to -30‰. As expected the $\delta^{13}C_{16:0}$ values of these Turkish organic residues reflect higher aridity and C_4 plant contribution to animal diet as compared to modern values of reference fats collected from animals in the UK that were found to have $\delta^{13}C_{16:0}$ values ranging from -24 to -32‰ and $\delta^{13}C_{18:0}$ values from -24 to -36‰ (Copley et al. 2003).

Some work has been done to determine the relationship between bulk $\delta^{13}C$ values of fatty acids in grazing animals as compared to grazing materials (Dungait et al. 2010). In the Dungait study the $\delta^{13}C$ values fatty acids were found to be 7.9‰ lower than those of bulk plant values with a range of 3.1‰ to 11.8‰ difference. Despite an understanding of this relationship between fatty acid $\delta^{13}C$ values and those of bulk plant values it is not possible to determine the original plant isotopic values solely based on the values obtained from the fatty acids. Thus, an additional step must be taken to account for variability caused by environmental conditions as well as variations in plants consumed in order to determine the origins of fatty acids found in ancient pottery.

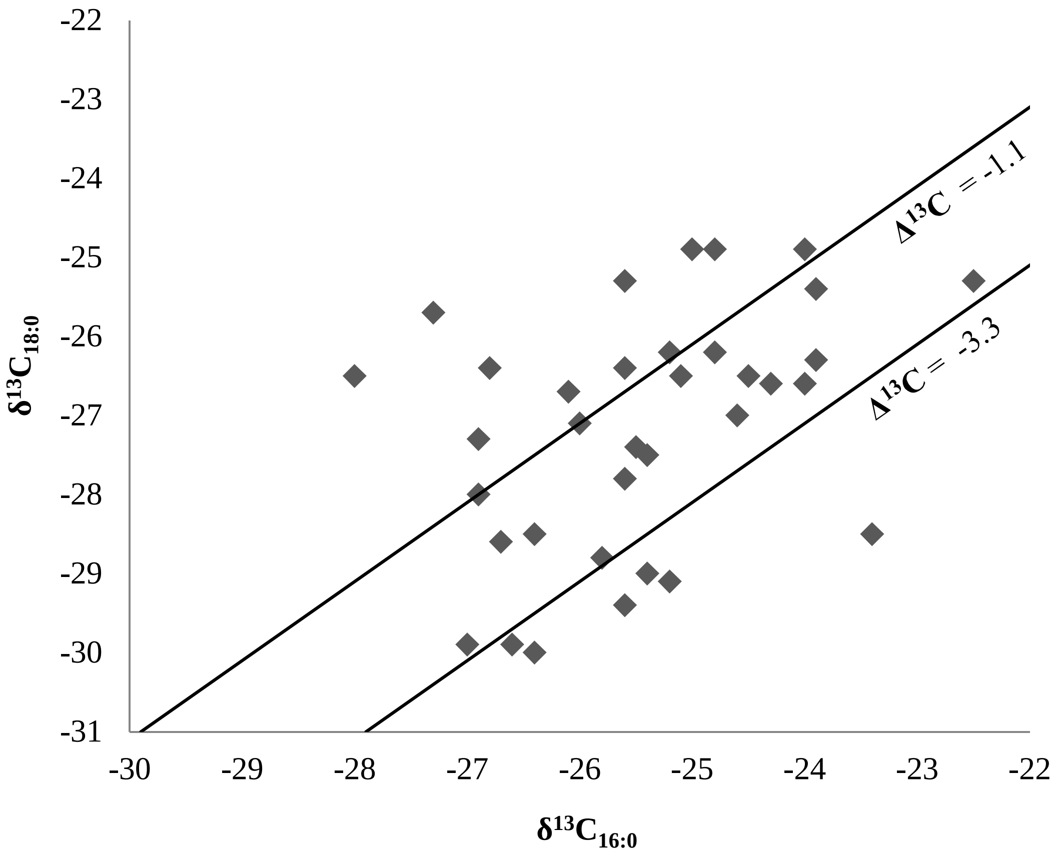


Figure 4.2. Plot of $\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$ values of the FAMEs with the lines $\Delta^{13}C = -3.1$ and $\Delta^{13}C = -1.1$ plotted, where $\Delta^{13}C = \delta^{13}C_{18:0} - \delta^{13}C_{16:0}$. These lines are based on global reference values for the separation of non-ruminant adipose, ruminant adipose and ruminant dairy fats (Dunne et al. 2012).

In order to account for these possible variations in the $\delta^{13}C$ values of the plants consumed, both the $\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$ values are used in defining the term $\Delta^{13}C$. This term can then be used to estimate the C_4 plant or water stressed plant versus C_3 plant contribution to diet in animals. A list of the $\delta^{13}C$ values obtained via GC-C-IRMS analysis may be found in Table 4.1. Consideration of the $\delta^{13}C_{16:0}$ values make it possible to determine the C_4 contribution to animal diet as well as the origin of fats present (Fig. 4.3). For this data set there does not seem to be a clear trend towards C_4 or C_3 diets over time. However, the information presented in Figure 4.3 does not contradict the trend suggested from other stable isotope and faunal records at Çatalhöyük of an increased range of herding areas for the non-ruminant animals (Henton 2010; Pearson et al. 2007; Hodder 2012).

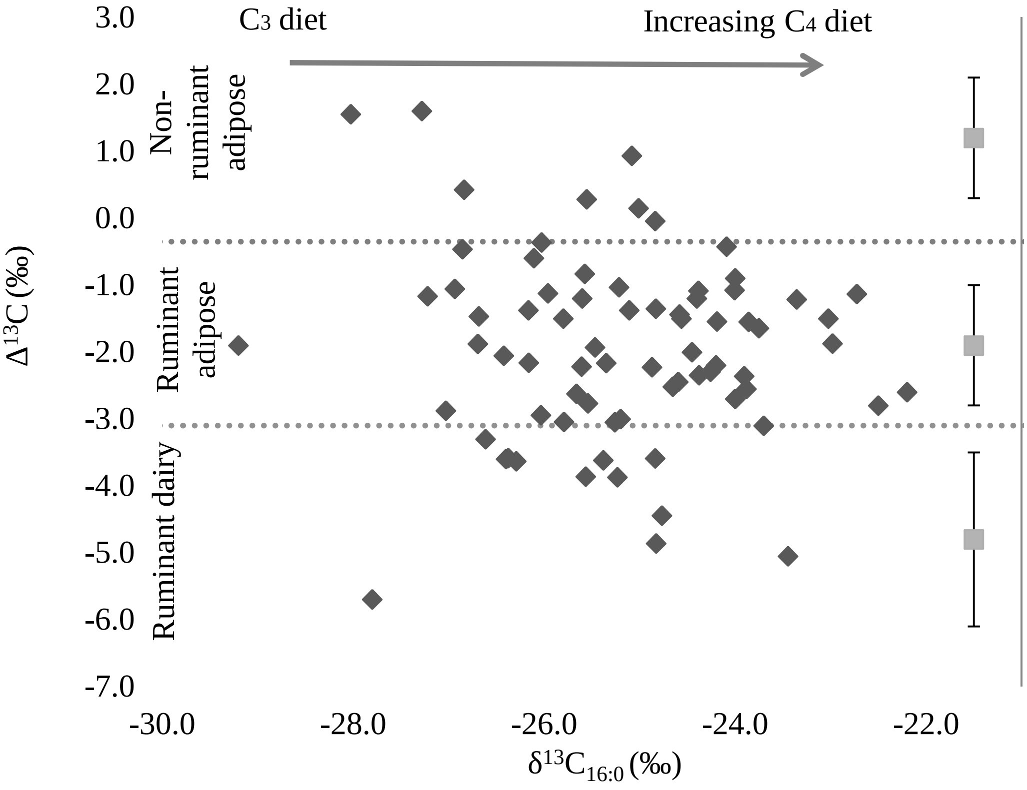


Figure 4.3. Graph of $\Delta^{13}C$ with $\delta^{13}C_{16:0}$ values, where $\Delta^{13}C = \delta^{13}C_{18:0} - \delta^{13}C_{16:0}$, as a way of distinguishing fats of animals consuming primarily C_3 or C_4 vegetation. Points above the $\Delta^{13}C$ value of -1.1 and below a value of -3.1 represent porcine and ruminant dairy fats, respectively. Data falling between the two marked lines are classified as ruminant adipose fats. The values of these lines are based on global reference values gathered from a variety of C_3 and C_4 dominated regions in Europe, Africa and Asia (Dunne et al. 2012). Archaeological data represented on the plot are a combination of values collected during this study and a previous study performed by Evershed et al. (2008).

The outliers at points (-29.2, -1.9) and (-27.8, -5.7) may be explained by the degree of mixing (or lack of mixing) occurring in a particular vessel (i.e., cooking non-ruminant and ruminant fats in one pot) as $\delta^{13}C$ values reflect accumulated fats in each pot. Also variations in C_3 versus C_4 diets account for differences in $\delta^{13}C_{16:0}$ as C_3 dominated plant regimes yield more depleted $\delta^{13}C$ values.

Of the FAMEs containing lipid residues 49 were found to contain ruminant adipose fats and 16 originated from non-ruminant adipose fats (Tables 4.2 and 4.3).

Although some mixing is evident, as indicated by residues with $\delta^{13}C$ values close to boundaries between types of commodities, approximately 61% of the FAMEs were from a predominantly ruminant adipose source. Nearly 20% of the FAMEs analysed via GC-C-IRMS (n = 71) were found to originate from ruminant dairy fats. Non-ruminant fats accounted for ca. 20% of the lipid residues detected.

It was expected that the ruminant dairy fats would primarily come from sheep/goat considering the prevalence of caprines in the Çatalhöyük faunal remains. However, the timing of the appearance of milk seems to correspond with the possible introduction of domestic cattle on-site; a total of 16 milk residues have now been detected in the pottery from Çatalhöyük (Table 4.1).

The earliest milk residues to date, 4 of the 16 found, have been assigned to stratigraphic level North.G (Fig. 4.3 and 4.4). According to the latest chronological scheme North.G most likely corresponds to South.N–O. The levels after South.M demonstrate a shift towards smaller cattle likely associated with a higher proportion of female animals, which may suggest herding (Russell et al. *in press*). Potsherd sample T.004 was determined to contain a mixture of ruminant adipose and dairy fats (Table 4.1).

There was no difference found in the average lipid concentrations of bowls versus holemouth pots (0.14 mg g^{-1} for both). A closer look at the lipid concentrations for each commodity reveals an average of 0.06 mg g^{-1} for dairy fats, 0.07 mg g^{-1} for ruminant adipose fats and 0.07 mg g^{-1} for non-ruminant adipose fats found in the pottery. The ranges of lipid concentrations for each of these commodities are illustrated in Figure 4.4. However, as shown, the range of lipid concentrations for dairy fats is much narrower (0.01–0.13) than those resulting from ruminant or non-ruminant fats with upper limits of 0.38 and 0.29 respectively.

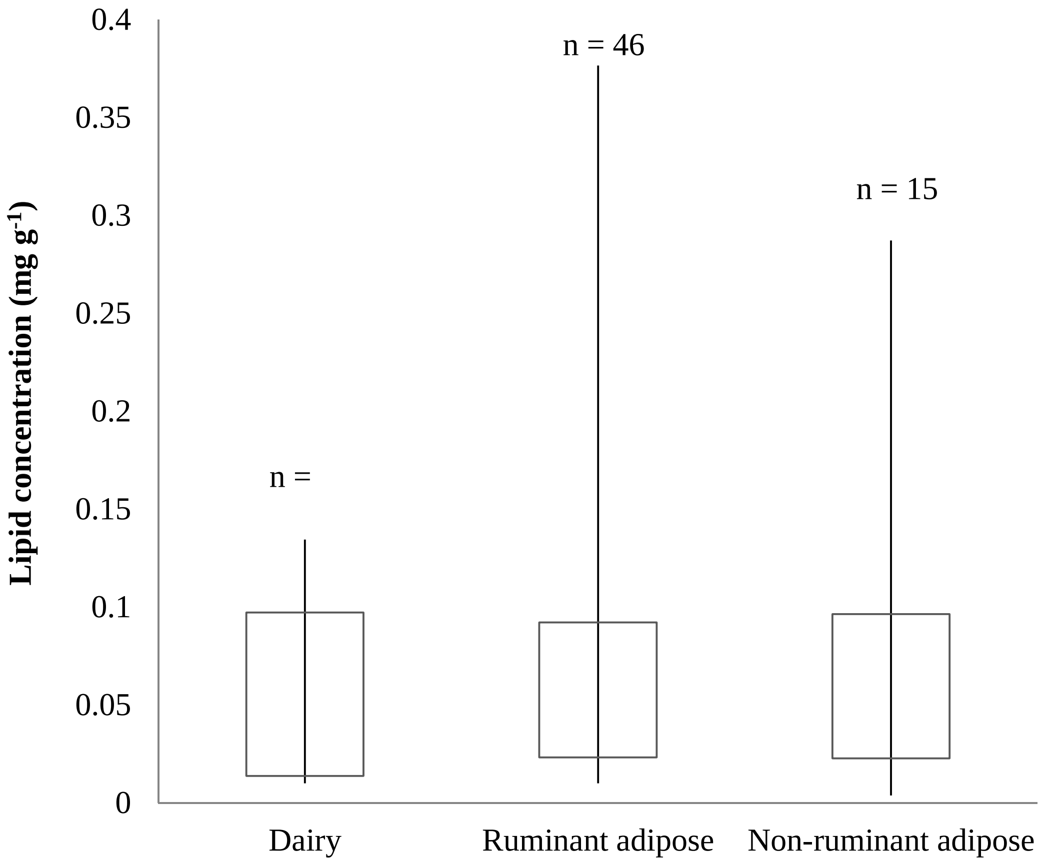


Figure 4.4. Interquartile range, maximum and minimum values of lipid concentrations (mg g^{-1}) for dairy, ruminant adipose and non-ruminant adipose fats found in the pottery of Çatalhöyük.

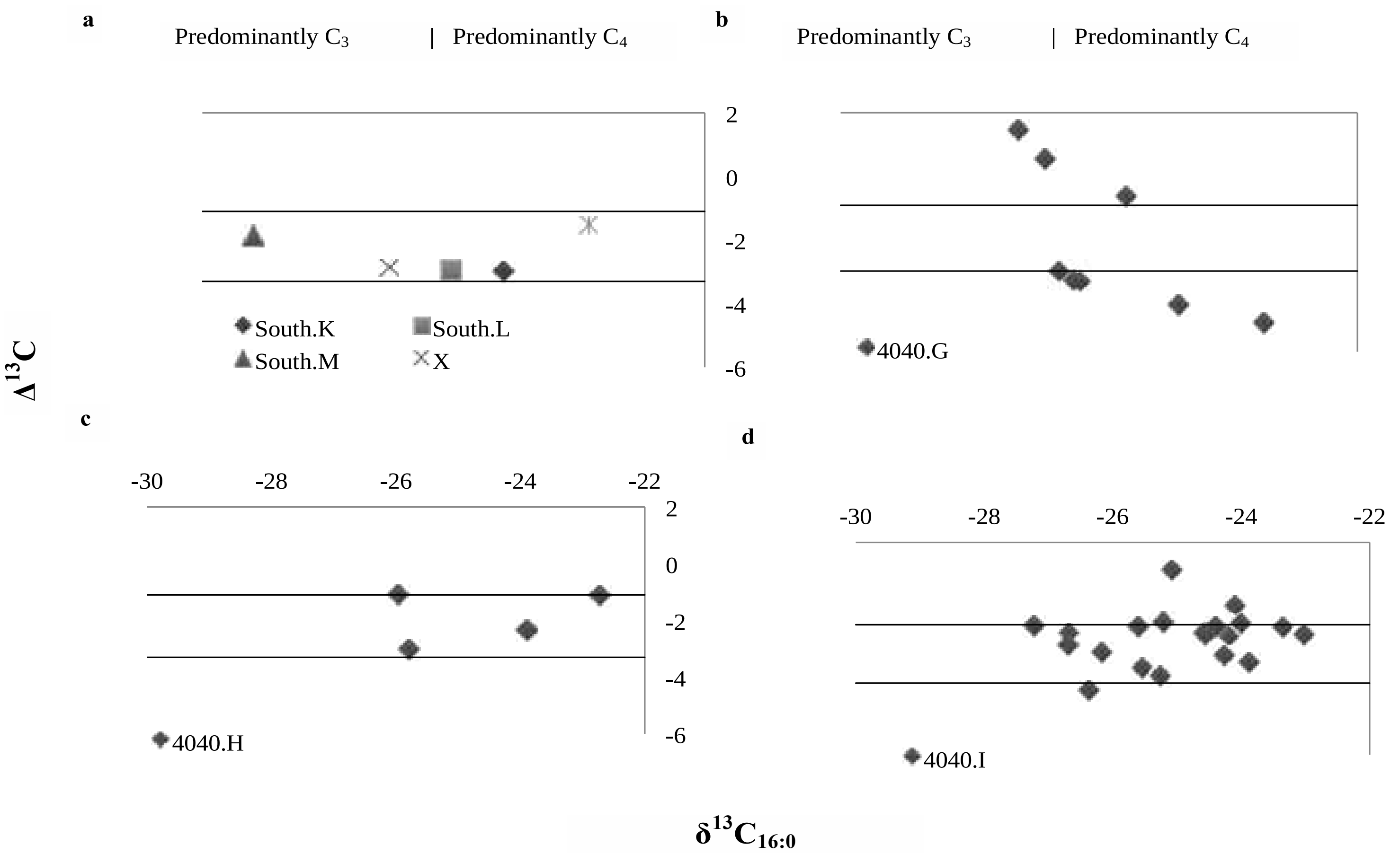
It is possible that milk was thus used to make very specific commodities such as yogurt from fermented milk and possibly that some of the fat was removed in the process. This would have allowed for easier digestion, which would have been necessary as it is not likely that lactase persistence had developed at this time (Brüssow 2013).

Based on the data presented above we can construct a chronological record of animal product processing at Çatalhöyük using the estimated timeline of the stratigraphic levels presented in Table 1.1. This is the most detailed record of its kind for any archaeological site investigated to date and is only possible due to the long chronological record of occupation.

4.4.2 Variations in carbon stable isotope values through time

Due to the wide range of potsherd samples collected it was possible to determine changes in stable carbon isotopic composition over time in both $\delta^{13}C_{16:0}$ and the $\delta^{13}C_{18:0}$ values. These variations are shown in Figure 4.5.

According to the organic residue record animals appear to have grazed on a mixture of C_3 and C_4 plants (Fig. 4.5). It should also be noted that the lipid residues from early levels indicate that ruminant animals dominated the types of meat processed at Çatalhöyük at the beginning of the occupation, which is confirmed by the faunal record (Russell et al. 2005). Phytolithic evidence at Çatalhöyük also confirm that C_4 plants would have been available throughout site occupation as they appear in small quantities within the macrobotanical remains (Fairbairn et al. 2005). Isotopic analysis of animal collagen also reveals an increasingly mixed diet that most likely included C_4 plants (Pearson et al. 2007).


a
Predominantly C3 | Predominantly C4
b
Predominantly C3 | Predominantly C4
2
0
-2
-4
-6
South.K
South.L
South.M
X
4040.G
Δ13C
c
d
-30
-28
-26
-24
-22
4040.H
4040.I
δ13C16:0

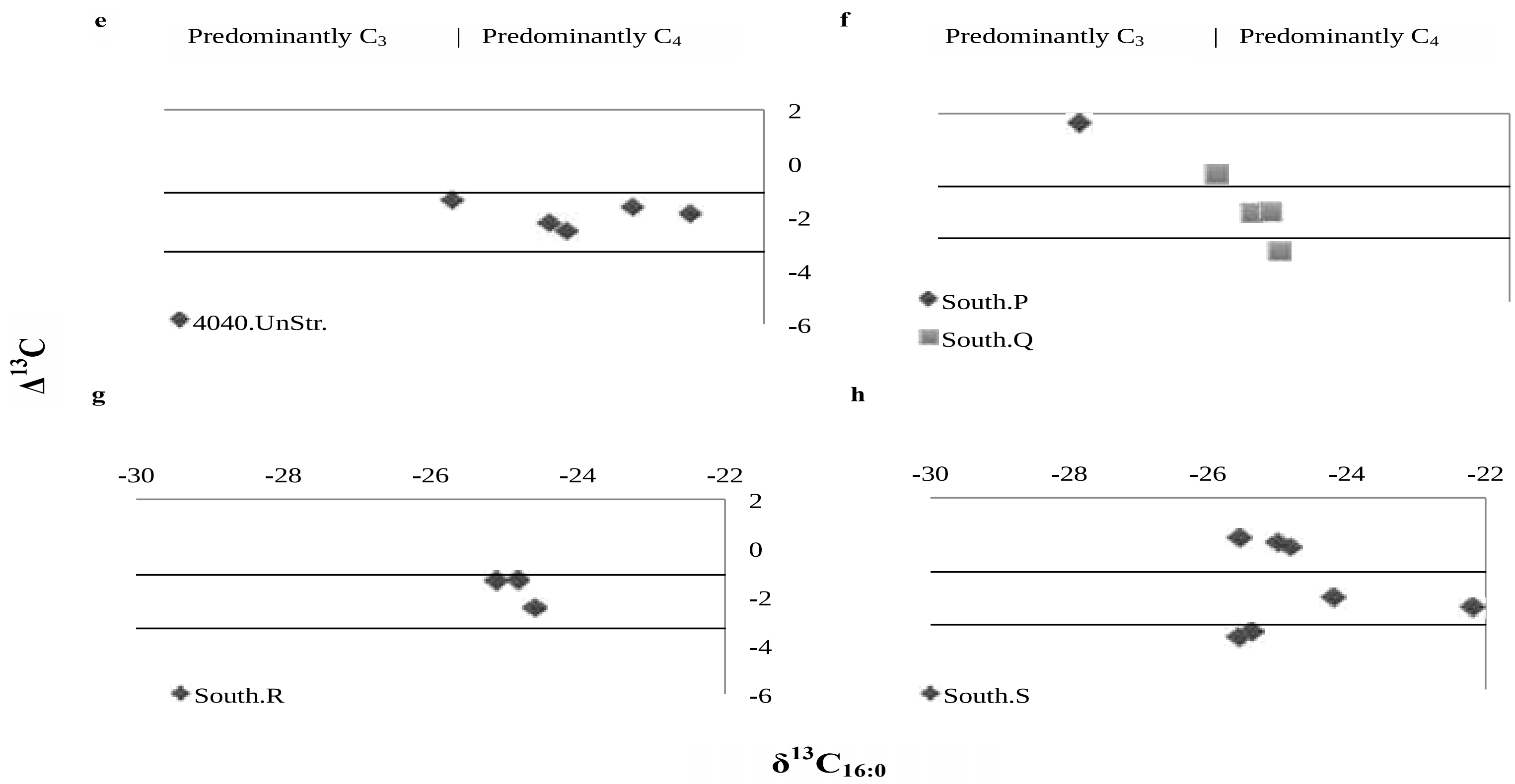


Figure 4.5. a-h) Plot of $\delta^{13}C_{16:0}$ values versus $\Delta^{13}C$, where $\Delta^{13}C = \delta^{13}C_{18:0} - \delta^{13}C_{16:0}$. Demonstrating changes in ruminant versus non-ruminant consumption, the emergence of dairy production, and changes in grazing of C_3 versus C_4 plants over time from early occupation (a) to the end of the Neolithic occupation (h). Levels 4040.G-H (c-d) overlap levels South.P-R (e-g) in time (Table 1.1).

Figure 4.6 shows the amount of potsherds containing organic residue per stratigraphic level for ruminant adipose and dairy fat. As expected ruminant adipose fat dominates the assemblage with the exception of potsherd samples collected from 4040.G. This is of particular interest as it is the timing of the first appearance of domesticated cattle for this site (Russell et al. 2012).

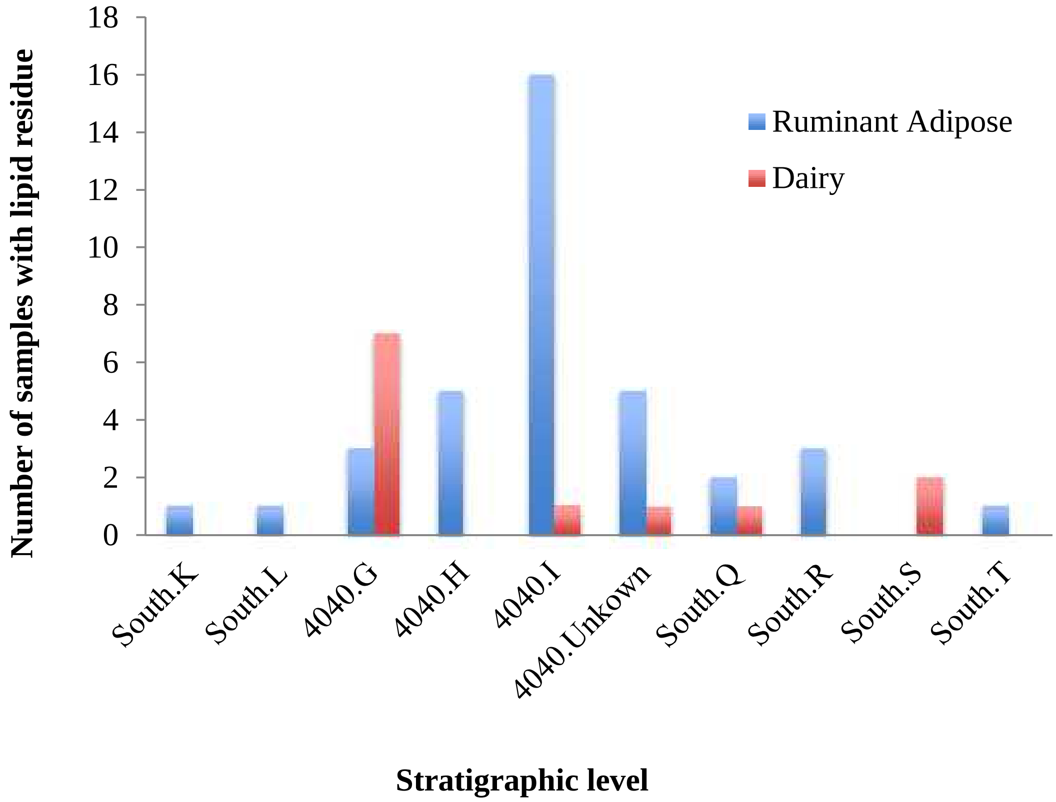


Figure 4.6. Presence of ruminant adipose and ruminant dairy fats in the lipid residue record organized by time from oldest to youngest (left to right) stratigraphic level.

As shown in Figure 4.7 ruminant adipose fats dominate the organic residue assemblage throughout occupation, with the acception of level South.P, which only contained one potsherd with organic residue that was found to have originated from non-ruminant adipose fat.

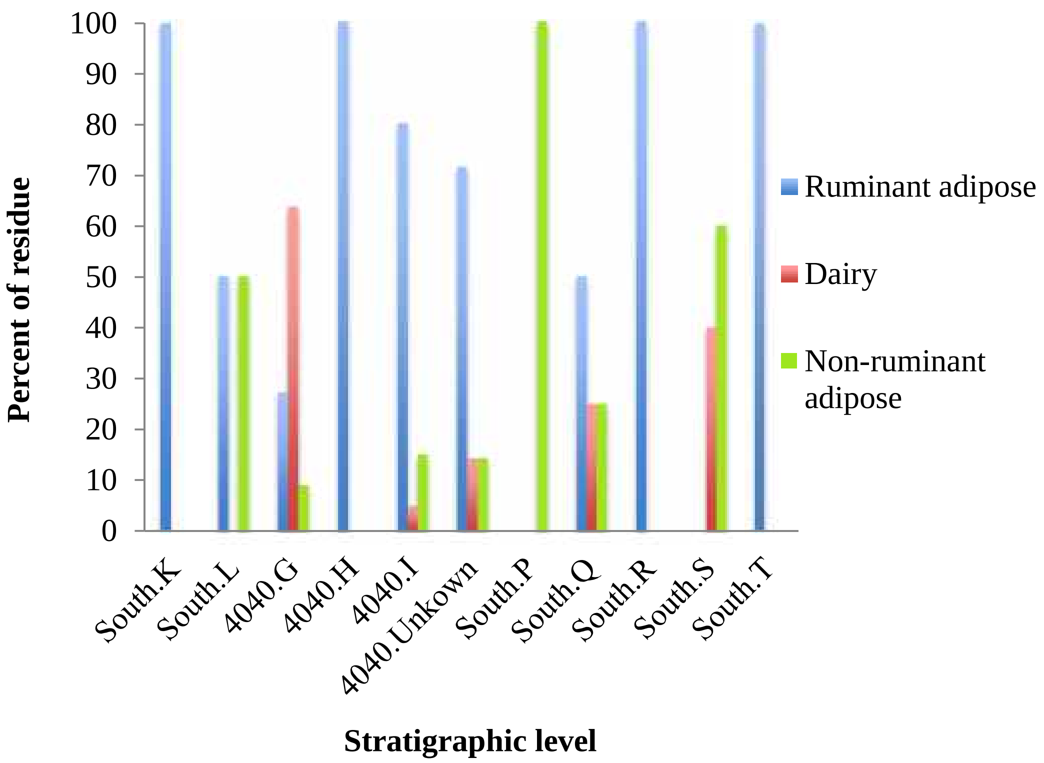


Figure 4.7. Percent of the residues from each stratigraphic level that were ruminant adipose, dairy or non-ruminant fats.

At this time information is lacking on cattle remains for levels South.N-O, but by South.P it appears that domestic cattle were present at Çatalhöyük. The relationship between North.G and South.P-O is not yet entirely clear and further analysis is needed to clarify the presence of domesticated cattle in South.P. The transition from hunting wild aurochs to the presence of domestic cattle may have been gradual or sudden. The rate of this change has yet to be determined (Russell et al. 2012). However, the lack of dairy residues prior to North.G when domestic sheep/goats would have been the likely source suggests that this commodity was not utilized during the early levels of occupation and instead was introduced along with the introduction of cattle management. The low yield of milk obtained from sheep compared to their meat production most likely contributed to the decision to raise sheep solely for meat (Dickerson 1970). The amount of meat produced from sheep would also be more manageable without access to long-term meat preservation. In comparison the milk produced from a cow over a lifetime may exceed the caloric output of its body mass. It could then also be used for traction and eventually meat (Brüssow 2013). If further faunal analysis reveals the development of domesticated cattle on-site it could mean that the appearance of dairy in the residue record happens simultaneously with the development of domesticated cattle.

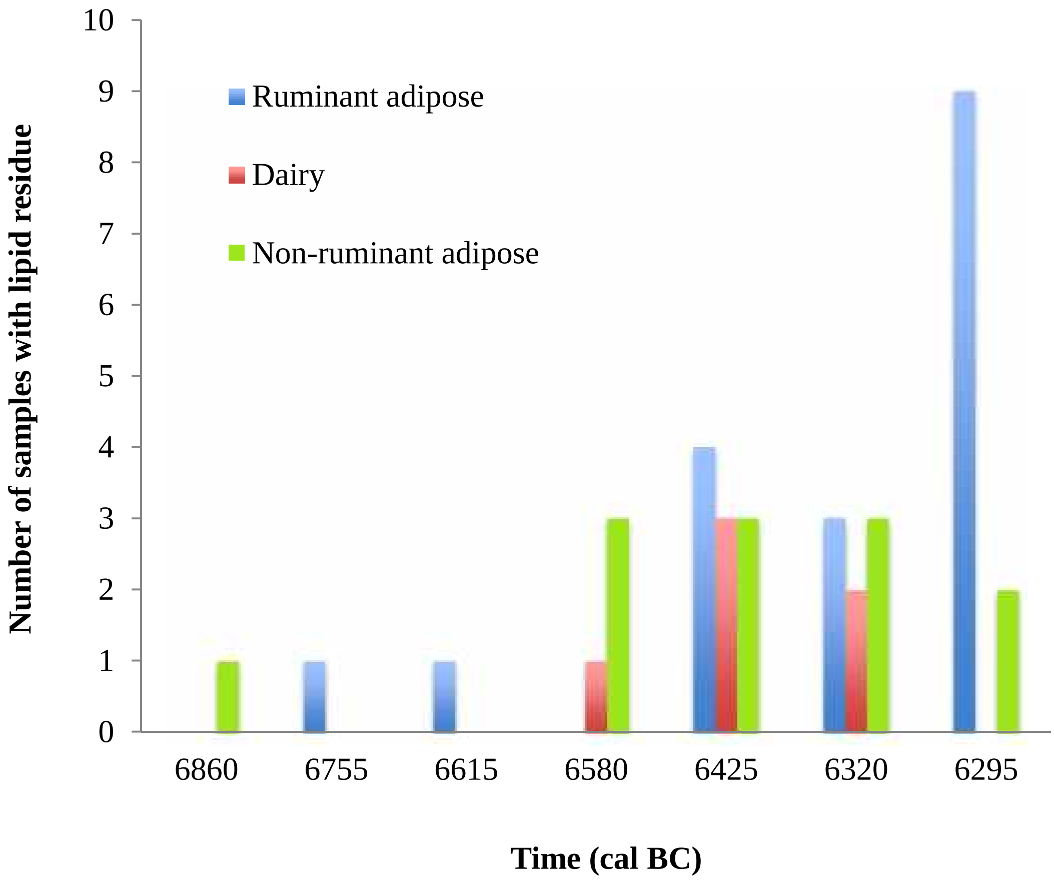


Figure 4.8. Presence of ruminant adipose, non-ruminant adipose and ruminant dairy fats in the lipid residue record organized by time from oldest to youngest (left to right) based on cal BC radiocarbon dates (Cessford et al. 2005).

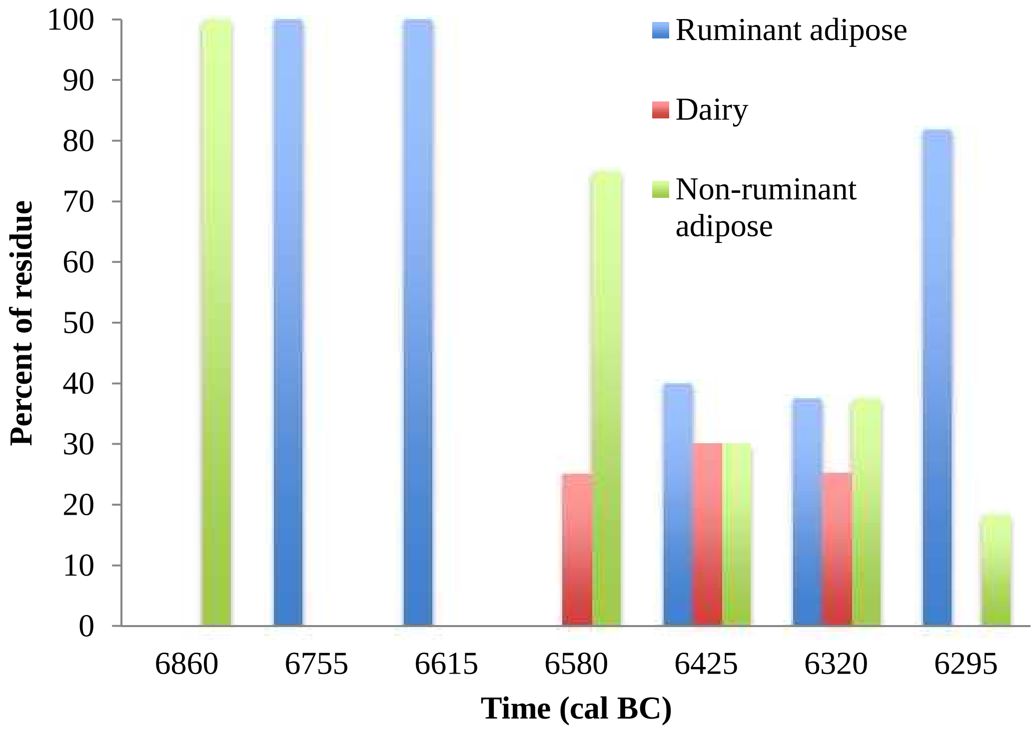


Figure 4.9. Percent of the residues that were identified as ruminant adipose, dairy or non-ruminant fat from each radiocarbon dated stratigraphic level.

Figures 4.6 and 4.7 are further summarized in Figures 4.8 and 4.9, which show the presence of different commodities based on radiocarbon dates. Again we see the late arrival of dairy products. Strangely dairy products are missing from the latest level at 6295 cal BC. Perhaps a look at the West Mound of this site would reveal more information about the decline of dairy products found in the later levels of the East Mound.

There are also several trends in the faunal record that indicate a return to older traditions of animal management, similar to the earliest levels of occupation. This idea is explored further towards the end of this chapter (Figure 4.12).

As shown in Figure 4.10 the carbon isotope compositions are fairly uniform throughout the site chronology, with a slight trend towards less-depleted values. This trend is more pronounced in the $\delta^{13}C_{18:0}$ values, which are more directly related to environmental changes compared to $\delta^{13}C_{16:0}$. The $\delta^{13}C_{16:0}$ values are more likely to be affected by other factors such as individual animal metabolism rates (Stear 2008). This trend is more pronounced in the stable hydrogen isotope record as explained in Chapter 5 of this thesis.

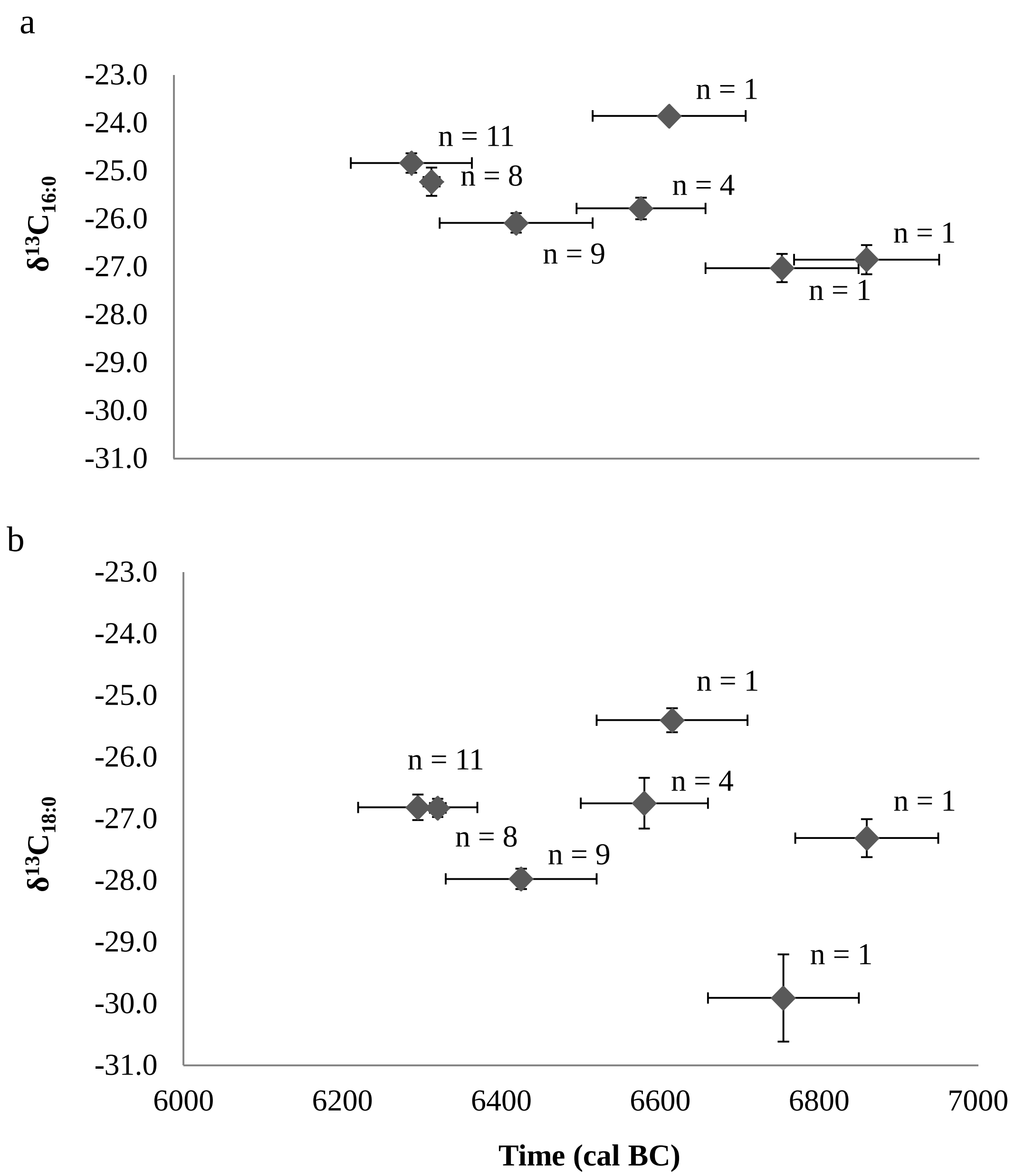


Figure 4.10. Mean of combined $\delta^{13}C$ values from Evershed et al. (2008) and this study for: a) $C_{16:0}$ and b) $C_{18:0}$ fatty acid values. Vertical error bars represent standard deviation or instrument error depending on number of residues studied per level. Error bars associated with age are based on 1 standard deviation from the plotted median age based on radiocarbon dates (Cessford et al. 2005).

4.5 Faunal evidence

The abundance of faunal remains at Çatalhöyük allows a detailed analysis of changes in proportions of the various species consumed on-site. In particular changes in herding and culling patterns as well as changes in sheep/goat and cattle populations have been determined through extensive analysis of remains throughout the site chronology (Russell et al. 2012). For this study the main focus is on sheep/goat and cattle remains. Figure 4.11 shows changes in proportions of ungulates consumed based on special (e.g. feasting) versus daily consumption practices. Although the older levels (South H-M) do show a significant use of cattle in daily consumption, it is likely that most or all of these specimens would have been wild (Fig. 4.11). In the 4040 region however, cattle were still part of daily consumption, but a mixture of wild and domesticated specimens are likely. This is the stratigraphic level where the first dairy fat residues have been detected (Fig. 4.8, 4.9, 4.11).

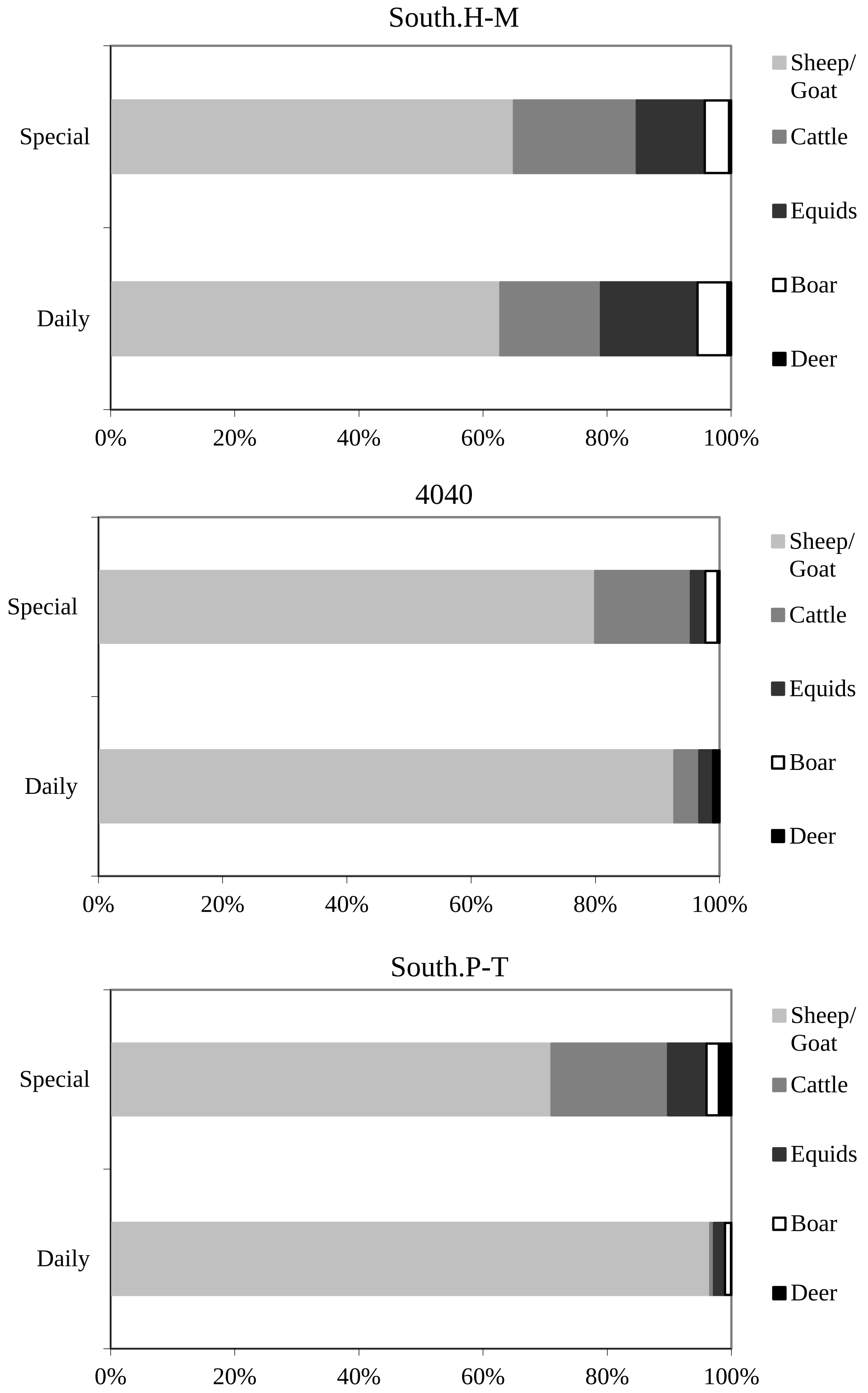


Figure 4.11. Proportions of major ungulate taxa for South.H-M, South.P-T, and 4040 daily and special consumption contexts, based on diagnostic zones (Russell et al. 2012).

4.5.1 Sheep intensification

Domesticated sheep and goat specimens are apparent from the time of early settlement at Çatalhöyük (Russell and Martin 2005). Early penning structures indicate that these early domesticates were sometimes kept within living areas on-site (Russell and Martin 2005; Matthews 2005). The overall sizes of sheep/goats do not drastically change at any point during occupation of the East Mound. There is a trend towards larger sheep on the West mound, but further organic residue analysis is necessary to make a comparison between the effects on dairy production and the relative importance of dairy during the latest levels of occupation. However, based on increased numbers of sheep remains found in the later levels, as well as isotopic evidence of larger herding areas being utilized for sheep grazing, there does seem to be an intensification in the daily use of sheep (Fig. 4.11 4040 and South.P-T) (Russell et al. 2012; Henton 2010; Pearson et al. 2007). There are also subtle changes of young versus older specimens, as well as male versus female distributions. A few wild specimens also seem to be present within the assemblage, suggesting a mixed diet of wild and domesticated varieties. A summary of these changes in the faunal record along with changes in the organic residue record are presented in Table 4.2.

For the early levels (South.H-M) mature males seem to have been kept nearby with females taken further away for much of the year. Another possible interpretation is an intensification of meat production (Russell et al. 2012). In the later levels a possible shift in the seasonality of herd movements is indicated with the culling of slightly younger sheep/goats seen on-site. Assessment of the pathologies and sex ratios of sheep over the course of the Neolithic portion of the site reveal that flocks were possibly segregated based on household or multi-household flocks with mixed sexes and ages, rather than larger combined flocks segregated by age and sex (Russell et al. 2012).

In the organic residue record the older levels show the presence of non-ruminant and ruminant adipose fats. The oldest animal fat residue found was from a ruminant adipose source (Fig. 4.6, Fig. 4.7). According to the organic residue record the emergence of dairy production begins at the end of the South.H-M period and drops off again before South.P. However, it should be noted that no residues were found in the pottery from levels South.S and T (the latest levels of occupation). For the latest time periods of occupation a further exploration of potsherds from the West Mound is necessary. The most recent time period (ca. 6295 cal BC) shows a dominance of ruminant adipose fats. This may reflect the intensification in the use of sheep and cattle.

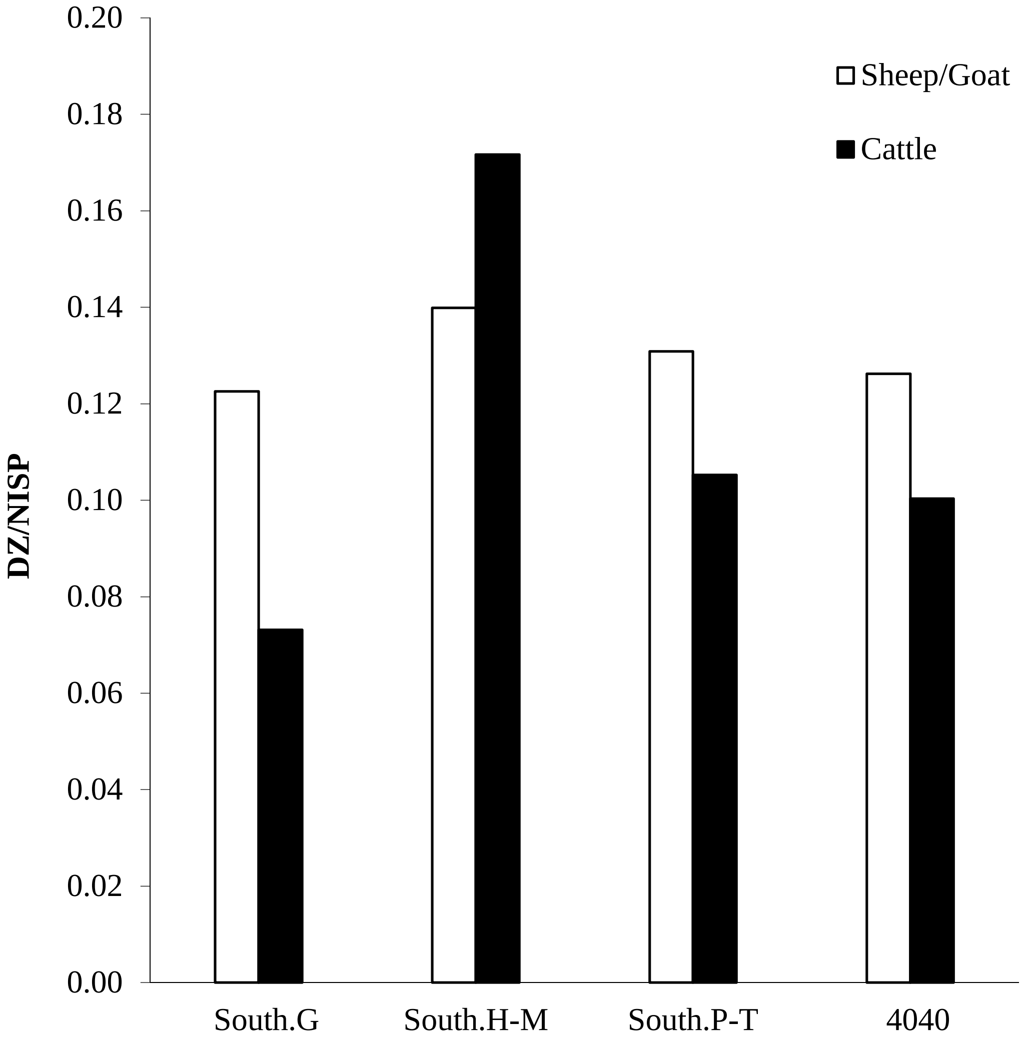


Figure 4.12. Fragmentation of sheep/goat versus cattle bone through time where a high diagnostic zone to number of identified specimens ratio (DZ/NISP) represents lower bone fragmentation (from Russell et al. 2012).

The higher fragmentation of cattle bones in the later levels may reflect increased feasting as well as an increased use of bone marrow and extraction of grease from fragmented bones (Russell et al. 2012; Outram 2001). The increased use of cattle bones for decorative displays in the houses may also have been the result of increased competition in feasting rituals (Russell et al. 2012). In the later levels cattle dung is also used in addition to the traditional caprine dung, which is consistent with the appearance of domesticated cattle on-site (Russell et al. 2012).

4.5.2 Cattle domestication

The switch from a bimodal to a more normal distribution of sizes of cattle suggests an overall decrease in sexual dimorphism, which is consistent with domestication, or a mixed wild and domesticated population with wild females overlapping with domestic males (Helmer et al. 2005; Russell et al. 2012). The shift from a bimodal distribution to a normalized distribution seems to occur between Levels South H-M and South P-T. If we assume that the gap between levels South N and O correspond to North.G (also referred to as BACH or 4040.G in some contexts) then a clearer picture of the tempo of the shift from a purely wild to a most likely mixed cattle population may be seen. While smaller cattle do not appear up in large enough quantities to affect the distribution until 4040.H, small animals that were probably domestic and display horn cores of domestic morphology appear in North/4040.G (Russell et al. 2012). The dramatic decrease in overall size combined with increases in relative amounts of juvenile (76%) and female (89%) (Fig. 4.13 and 4.14) specimens suggests a sudden appearance of domesticated cattle ca. level VI (4040.G) (Arbuckle 2013). Interestingly, 4040.G is also the earliest level in which dairy fats have been detected (Fig. 4.5 b). Demographic shifts are also not apparent until 4040.H. Levels 4040/North/BACH.G (and possibly South.N-O, as yet unstudied) thus seems to be a transitional time when domestic cattle are introduced but remain rare. The demographic shifts occurring alongside the introduction of dairy fats in the lipid residue record may be the result of an increased number of female specimens being kept for milk production on-site

(Fig. 4.14). Interestingly, the older levels show a dominance of male specimens, most likely associated with hunting preferences. The 4040 region shows a preference for female specimens (Fig. 4.14) that is then also seen in the latest levels (South P-T). The milk residues also appear first in the 4040 area, and are not seen in the south area lipid residue record until later (South.Q) (Fig. 4.6, 4.7; Table 1.1).

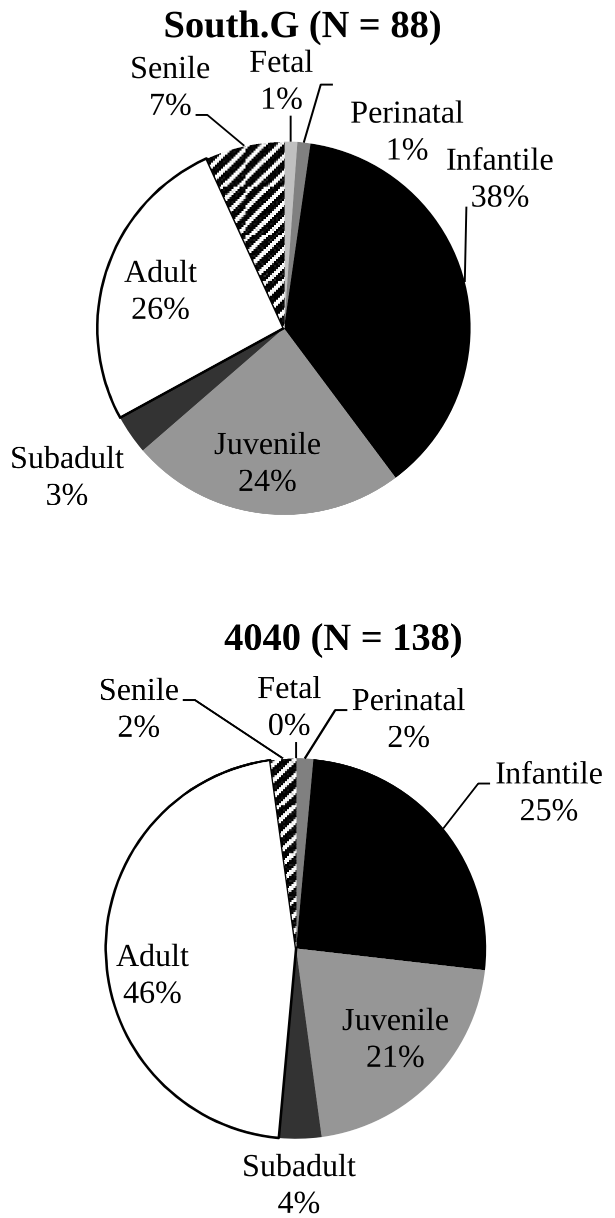


Figure 4.13. The distribution of cattle specimens based on age at the time of death representing a) the demographics for the oldest cattle specimens and b) the overall distributions for the more northern mound from dates starting around 6700 cal BC. The 4040 samples include remains of wild and later, domesticated cattle (Russell et al. 2012).

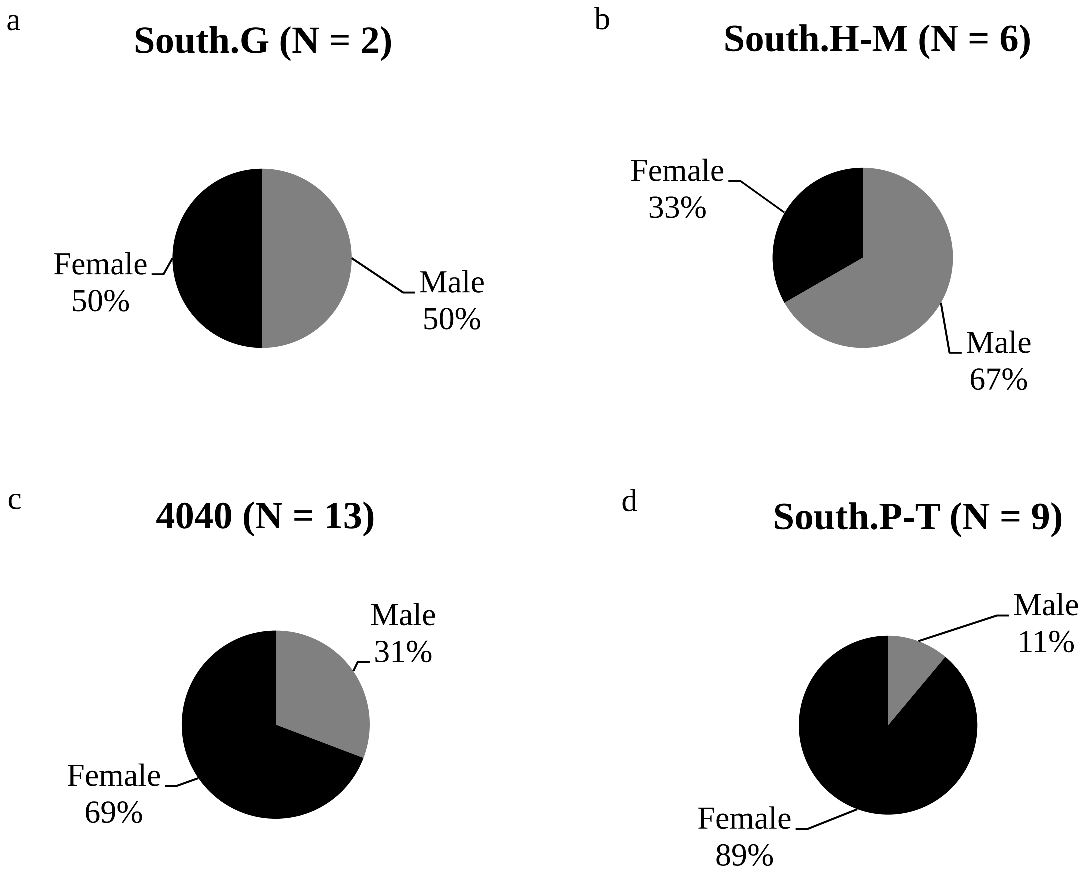


Figure 4.14. Cattle sex distributions over time from oldest (a) to youngest (d) with some overlap of 4040 and South P-T (refer to Table 1.1 for dates) (Russell et al. 2012).

Pathological changes in the cattle populations also indicate an increase in nutritional deficiencies as well as stress related osteological ailments towards the later levels (Russell et al. 2012). Perhaps these conditions are also indicative of stresses associated with domestication.

The timing of the changes seen in the cattle faunal remains that reflect less intensive meat production combined with a slight shift towards a population profile similar to that expected in an early dairying population seen within the caprine specimens still leaves the question open of whether the milk residues detected at Çatalhöyük were solely produced by cattle, sheep/goats or a combination of these.

The question of whether domestic cattle were introduced from an outside source or developed on-site requires further investigation of the faunal remains from Levels South.N and O.

4.5.3 Summary of faunal evidence and organic residue findings

For the purpose of creating a clear picture of changes in the faunal record and the organic residue record several data sets have been combined into a single table (Table 4.2). In order to describe the organic residue record in a way that lines up chronologically with the faunal data the residues obtained from the North/4040 stratigraphic levels have been combined. As in the faunal report (Russell et al. 2012) the 4040 levels are assumed to roughly cover South.N-T. The other categories present are South.P-T and South.H-M where South.H is the youngest and South.T is the youngest level. The earliest level represented in the organic residue record is South.J. All of the stratigraphic levels are summarized in the Introduction (Table 1.1) of this thesis.

Table 4.2 Organic residue classifications and faunal demographic changes through time.

Time (cal BC)	Ruminant adipose	Dairy	Non-ruminant adipose	Faunal levels	Cattle female (%)	Sheep female (%)
6860	0	0	1	South H-M	33	45
6755	1	0	0	South H-M	33	45
6615	1	0	0	South H-M	33	45
6580	0	1	3	4040	33	45
6425	4	3	3	South N-O, 4040	69	63
6320	3	2	3	4040	69	63
6295	9	0	2	South P-T, 4040	89	54

Table 4.3 Summary of carbon stable isotope values of collagen and organic residues through time

Radiocarbon dates (cal BC)	**6295 ± 75**	**6320 ± 10**	**6425 ± 95**	**6580 ± 80**	**6615 ± 95**	**6755 ± 95**	**6860 ± 90**	**6955 ± 115**
Collagen $\delta^{13}C$	N/A	N/A	N/A	-18.5	-18.0	-18.6	-16.0	-19.5
Organic Residue $\delta^{13}C_{16:0}$	-24.8	-25.2	-26.1	-25.8	-23.9	-27.0	-26.9	N/A
Organic Residue $\delta^{13}C_{18:0}$	-26.8	-26.8	-28.0	-26.8	-25.4	-29.9	-27.3	N/A

Table 4.4 Carbon stable isotope values of collagen and organic residues through time

Radiocarbon dates (cal BC)	**6425 ± 95**	**6320 ± 10**	**6295 ± 75**	**6580 ± 80**	**6615 ± 95**	**6755 ± 95**	**6860 ± 90**	**6955 ± 115**
Collagen $\delta^{13}C$	N/A	N/A	N/A	-18.5	-18.0	-18.6	-16.0	-19.5
Organic Residue $\delta^{13}C_{16:0}$	-26.0	-25.2	-24.7	N/A	-23.9	-27.0	N/A	N/A
Organic Residue $\delta^{13}C_{18:0}$	-28.3	-27.1	-26.9	N/A	-25.4	-29.9	N/A	N/A

4.6 Stable Isotope Evidence

Through the work of Pearson et al. (2007) it is possible to extrapolate further the development of various animal management strategies utilized during the Neolithic portion of Çatalhöyük's past. Stable isotope analysis was performed in order to obtain $\delta^{13}C$ and $\delta^{15}N$ values of caprine bone collagen collected from Çatalhöyük as well as nearby Aşıklı Höyük. Although stable isotope analysis focuses on individual variation, by looking at collected values from different points in time it is possible to make generalizations about what may have caused differences in the distribution of isotope values. Table 4.3 shows a comparison of the $\delta^{13}C$ values obtained from collagen versus those found in the organic residues from the time period corresponding to the beginning of the pottery record at Çatalhöyük (ca. 6955 cal BC). The dip in the average $\delta^{13}C$ values from the collagen record ca. 6860 cal BC is not reflected in the average $\delta^{13}C$ values of the organic residues. However, the collagen samples were all obtained from sheep/goat remains (Pearson et al. 2007). Thus, if we look at only the organic residues obtained from ruminant adipose fat (Table 4.4) we do see a matching increase in $\delta^{13}C$ values for all three proxies from 6615 cal BC to 6755 cal BC. Unfortunately, there are too few corresponding dates between the ruminant adipose organic residues and the collagen samples. Obtaining more ruminant animal residues from the oldest levels of occupation would be difficult. But further collagen analysis of materials from the younger stratigraphic levels may shed more light on any possible links between these values.

In the record of Çatalhöyük it is clear that isotope values from later periods of occupation cover a wider range of values. It has been suggested that this may be the effect of increased land use area in terms of where specimens, in this case sheep, were allowed to graze (Pearson et al. 2007, 2010).

At Çatalhöyük a trend towards larger scale management associated with raising caprine specimens is seen in increased variation of the $\delta^{13}C$ and $\delta^{15}N$ values obtained from bone collagen (Pearson et al. 2007). There is a known variation in the average range of $\delta^{13}C$ values for C_3 (approx. -34‰ to -22‰) and C_4 plants (approx. -20‰ to -10‰) (O'Leary 1988). Increasing ranges of $\delta^{13}C$ and $\delta^{15}N$ values suggest that greater amounts of C_4 plants were added to the diet of the caprine specimens at this site and that there is increased diversity of diet over time for these specimens (Pearson et al. 2007; Pearson, personal communication). Palaeobotanical analyses have shown that there was an increase in forestland, dominated by deciduous oak, in the area surrounding Çatalhöyük, and a decrease in the grasslands seen towards the end of occupation (Asouti 2009).

4.7 Conclusions

In light of new faunal evidence and the research presented above it is apparent that domesticated cattle were present at Çatalhöyük, whether they were domesticated on site or brought in from elsewhere (Russell et al. 2012). Due to the limitations in distinguishing sheep, cattle and goat milk products through organic residue analysis it remains unclear whether early dairy production was a product of milking sheep, goat or cattle. However, the combination of several proxies does provide a clearer picture. The domestication of cattle is now believed to have occurred before Level South.P, but after South.M. At this time there is a gap in information for levels South.N and South.O, which may include the development of domestic cattle (Russell et al. 2012). It is as yet unclear how quickly this process may have occurred or whether it is possible that cattle were not domesticated at this site, but were rather introduced from outside. Thus far it appears that the introduction of domestic cattle is the most likely explanation according to the faunal remains (Russell et al. 2012). The changes in the demographic profiles of bovine and caprine specimens support the organic residue findings that the beginnings of dairy production were likely to have occurred at stratigraphic level 4040.G ca.6580-6425 cal BC.

Overall the carbon stable isotope analysis revealed the following:

i. High preservation of residues well into the early pottery record as identified through HT-GC analysis confirms the presence of cooked animal fats as early as 6860 cal BC (South.J). Pottery prior to this stage was most likely not used for cooking.

ii. The earliest organic residue identified originated from the heating of non-ruminant adipose fat, most likely from equid or boar meat due to the prevalence of these in the early faunal record.

iii. Dairy fats do appear concurrently with the appearance of known domestic cattle on-site ca. 6580 cal BC (4040.G). Thus it seems likely that cattle were the source of milk and milk products rather than sheep and goats. This may be due to higher yields produced from cows as compared to the caprines. However, the apparent decline in the use of dairy in later stratigraphic levels should be further investigated by extending the residue record to cover the West Mound to include data from the Chalcolithic period.

iv. Stable carbon isotope values of the organic residues appear to be in agreement with the collagen stable isotope record in terms of increased variation of $\delta^{13}C$ values suggesting wider herding areas towards the end of occupation. This also supports the assertion that herds were managed by groups rather than as one population for the entire site.

In the next chapter the hydrogen stable isotope analysis will be explained in order to shed light on environmental changes that would have been occurring at the same time as the changes described in Chapters 3 and 4 of this thesis.

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Chapter 5 Hydrogen Stable Isotope Analysis

Adapted from Geochimica et Cosmochimica Acta publication (in review):

Fatty acid deuterium isotope analysis of organic residues in archeological ceramics from Çatalhöyük, Turkey: Evidence for past environmental and cultural change

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Abstract

Compound-specific stable carbon isotope analysis, via gas chromatography-combustion-isotope ratio mass spectrometry (GC-C-IRMS), of $C_{16:0}$ and $C_{18:0}$ fatty acids has been used extensively in the study of organic residues in archaeological pottery to identify the specific origins of animal fat residues. However, until recently, δD values of fatty acids have not been utilized in palaeoenvironmental reconstruction despite the wealth of information that could be gained by applying it directly to archaeological contexts. By utilizing gas chromatography (GC), high temperature-GC/mass spectrometry (HT-GC/MS) and GC-thermal conversion-IRMS (GC-TC-IRMS) the first well-dated stratigraphic record of compound-specific δD values of $C_{16:0}$ and $C_{18:0}$ fatty acids has now been established from ceramics at the Neolithic site of Çatalhöyük in central Turkey. This site was occupied from ~7300 to ~6200 cal BC, during a period of generally wetter climate and repeated river flooding. The origins of the fatty acids were determined based on their $\delta^{13}C$ values as arising largely from ruminant adipose and dairy fats. A δD record was constructed, based on a subset of ruminant adipose fats only, which showed most negative isotopic values from ~6900 to 6600 cal BC indicative of wet conditions, followed by a drying trend which reached a maximum at or just after 6280 cal BC, coincident with the 8.2 ka (~6200 cal BC) cold, dry climate event. The drying trend is consistent with that observed in the $\delta^{18}O$ record from the nearby lake Eski Acıgöl carbonates. Thus, we demonstrate that δD analysis of archaeological residues may be useful in assessing broader environmental and climatic changes directly from cultural residues.

Keywords: Palaeoclimate; archaeology; pottery; organic residues; animals fats; lipids; fatty acids; $\delta^{13}C$; δD.

5.1 Introduction

Hydrogen stable isotopes incorporated into plant and subsequently animal tissues reflect the stable hydrogen isotope composition of groundwater (Yapp and Epstein 1982). The hydrogen isotope composition of groundwater is dependent on several factors including latitude and altitude (constant for a specific site), temperature and precipitation, all of which are underpinned by the fact that $^{1}H_2{}^{16}O$, the lightest isotopic form of water is more susceptible to evaporative loss compared to the heavier forms (Dansgaard, 1964). Thus, the hydrogen signal can vary spatially or temporally due to changes in climate or geography. While all biological tissues contain abundant hydrogen, lipids offer particularly attractive candidates for study since much of the hydrogen they contain is non-exchangable at environmental temperatures and generally have fast turnover rates in living organisms (Chivall 2007). Hobson et al.

(1999) provided important evidence for drinking water contributing to the hydrogen isotope composition of both non-lipid and lipid tissues of birds, with approximately 20% of hydrogen in metabolically active tissues deriving from drinking water. Thus, lipids hold considerable potential for use in investigating changes in past environments or animal behaviors underpinned by changes in source water recorded in deuterium isotope values. The recent development of gas chromatography-thermal conversion- isotope ratio mass spectrometry (GC-C-IRMS) allows facile access to the deuterium isotopic compositions of individual lipids, e.g. fatty acids, which has opened the way for the development of molecular-based deuterium isotope records in a range of environments on various timescales (Chivall et al. 2012).

Around two decades of research have demonstrated the utility of organic residues preserved in archaeological pottery as indicators of past diet and vessel use. Degraded animal fats are the most common class of residue observed since the fatty acyl components of animal products become absorbed into the matrix of unglazed, ceramic pottery during “cooking”, and are protected from degradation and contamination from the burial environment. The preservation of fatty acids in archaeological pottery has allowed extensive analysis of past subsistence practices of ancient civilizations. Carbon isotope analyses of fatty acids in particular have been extensively employed in the investigation of prehistoric dairying in ruminant animals (Copley et al. 2003; Evershed et al. 2008). $\delta^{13}C$ values of $C_{16:0}$ and $C_{18:0}$ fatty acids have been widely used in organic residue analysis in archaeology to determine the origins of fats preserved in a range of contexts, most commonly in unglazed pottery vessels, used for food processing.

A recent example of this was the use of compound-specific stable hydrogen isotope analysis of fatty acids to investigate early horse domestication in the Eurasian Steppe (Outram et al. 2009; Stear 2008). This study exploited seasonal differences in the deuterium isotope value of precipitation that allowed different fat types, adipose and milk, to be distinguished. This was possible due to the fact that a seasonal signal could be identified from the δD values of $C_{16:0}$ and $C_{18:0}$, which recorded the >100‰ difference in δD values between the summer and winter precipitation signals, with adipose fats recording an integrated annual signal and dairy fats only recording the spring/summer signal. These proxy data were used with a range of bone metrics to provide the earliest evidence of horse domestication in the Eurasian steppe (Outram et al. 2009). The study also revealed differences between modern and ancient horse fat δD values consistent with climatic differences between the present and past southern Siberia, suggesting that the δD values of lipids in archaeological pottery may also have additional utility in the reconstruction palaeoclimate records linked to environmental and cultural changes in the human past.

The present study takes the previous investigation of Outram et al. (2009) a step further by creating a long-term record of past moisture availability via δD analysis of ancient adipose fats in pottery from the archaeological site of Çatalhöyük in South-central Turkey. Çatalhöyük provides a rich and well-dated material record of life during the Neolithic and early Chalcolithic periods (Hodder 2006). The large collection of pottery spanning occupation at the site provides the opportunity for undertaking comprehensive investigations of changes in subsistence practices, through the study of biomarkers preserved within ceramic materials. In fact, Çatalhöyük is the location from which some of the oldest Neolithic preserved fatty acid residues, dating to approximately 7000 cal BC, have been revealed via organic residue analysis (Evershed et al. 2008). The extensive range and depth of research performed at this site also provides information needed to test the validity of the results of stable isotope and other analyses. For instance palaeoenvironmental reconstructions that have been created through studies of the off-site geological stratigraphy, phytolith assemblages and faunal record of Çatalhöyük and the surrounding area, provide information that can be compared to data gathered on the δD values of fatty acids preserved within pottery on site (Boyer et al 2006; Roberts and Rosen 2009; Jenkins 2005; Asouti and Hather 2001; Newton and Kuniholm 1999).

Archaeological evidence suggests that differences in settlement patterns over the chronology of Çatalhöyük were linked to environmental as well as cultural changes. During the pre-pottery Neolithic period prior to ~7500 cal BC the population took advantage of both dry and marshy areas of the alluvial Çarşamba river fan for settlement, for example at the site of Boncuklu north of Çatalhöyük (Baird et al. *in press*). By contrast during the Ceramic Neolithic occupation of the east mound at Çatalhöyük there was a shift towards a more nucleated settlement (Roberts and Rosen 2009; Asouti 2009). The Chalcolithic marked a return to a more fractionated settlement pattern ca. 6200 cal. BC when the occupants of Çatalhöyük moved across the Çarşamba River to form a new site a mere 150 m to the west of the South mound (Fig. 5.1).

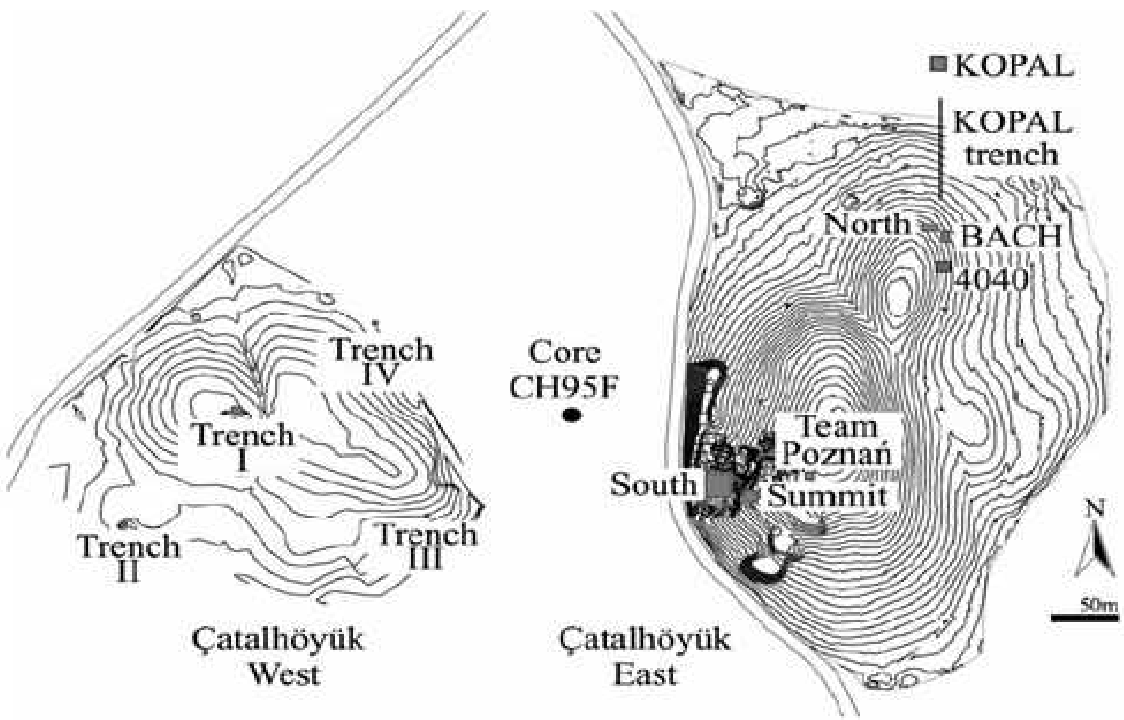

Figure 5.1. Contour map compiled from survey points depicting Çatalhöyük trench sites as well as the spatial separation of the east and west mounds (Hodder 2007).

Deposition of backswamp clay, indicative of regular and widespread seasonal river flooding, occurred throughout the Neolithic occupation of Çatalhöyük. This depositional activity ended ca. 7300 to 6680 cal BC associated with soil formation and drier conditions in the locality (Boyer et al. 2006; Roberts and Rosen 2009). The archaeobotanical record suggests a shift towards plants adapted to drier conditions ca. 7000 cal. BC (Asouti and Austin 2005). The macro-charcoal record at this time indicates a proliferation of juniper wood, which would not have grown well in the marshy environment of Çatalhöyük and must have been imported from further afield. Plausibly, this may reflect the exhaustion of locally available supplies of wood from around Çatalhöyük.

Changes in seasonality, specifically a shift from winter to spring precipitation would result in less negative δD values. Such a shift has been suggested as a possible explanation for an increase in $\delta^{18}O$ values during the mid-Holocene from calcareous sediments studied in Lake Zeribar, Iran (Stevens et al. 2001). However, Jones and Roberts (2008) bring into question the ability of seasonality changes alone to explain the observed shift in the stable isotope record, which also occurred at other lake sites, such as Eski Acıgöl in central Anatolia and which is included in this study. Other factors such as changes in precipitation/evaporation ratio, temperature, the amount of available ground or surface water, and the isotopic composition of the source water from the Mediterranean Sea (c.f. Calvert and Fontugne 2001) could also have impacts on δD values of ingested water, which in turn would be expressed in the fatty acids of the animals represented by the residues studied herein. A study performed by Kirsanow et al. (2008) demonstrated that the relationship between seasonal changes in local hydrological δD values were reflected in the δD values of dentinal collagen obtained from ovicaprids. As discussed above such seasonal variations were also detectable in the individual fatty acid δD values of modern and ancient equids (Outram et al. 2009; Stear 2008).

In this study the combination of GC-C-IRMS and GC-TC-IRMS have been utilized in order to identify the origins of fats in archaeological pottery ($\delta^{13}C$ values) from the Neolithic archaeological site of Çatalhöyük, Turkey, and to begin evaluate the use of δD values of fatty acids as long term climate recorders. This site is of particular value due to its excellent radiocarbon chronology spanning ca.7400 to 6220 cal BC (Cessford et al. 2005). The east mound site occupation thus covers not only the development of pottery in Anatolia, but also runs up to and includes the initial response to the widespread 8.2 ka climatic event (Alley and Ágústsdóttir 2005; Walker et al. 2007). This global climatic event is thought to have occurred between 6700-5800 cal BC with a peak of negative isotopic values appearing in North Atlantic records ca. 6200 cal BC (Daley 2011, OxCal 4.2). Some authors (e.g. Turney and Brown 2007; Weninger et al. 2006) have proposed that this climatic event triggered important demographic stresses, which led to the expansion of Neolithic farming populations out of Anatolia and across South-east Europe. The results reported here represent the first well-dated compound-specific δD palaeoenvironmental record using archaeological residues. The 830 to 1220 year long time span (95% confidence) covered by Neolithic pottery samples from Çatalhöyük provides a particularly useful chronological framework for such an investigation (Cessford et al. 2005). The overall aims of this study are to: (i) identify the compounds present in the pottery of Çatalhöyük, Turkey in order to extend previous analyses (Copley et al. 2005; Evershed et al. 2008), (ii) place the lipid residues in a chronologic context linked to changes in Neolithic subsistence practices at this particular site, (iii) create a well-dated δD record using archaeological residues, and (iv) compare this δD record against geologic and archaeological evidence of environmental and cultural change to identify possible connections between the different proxies as well as confirm the validity of the proxy developed within this study.

5.2 Materials and methods

5.2.1 Archaeological materials

Potsherd samples were chosen in order to maximize coverage of pottery throughout the Neolithic portion of Çatalhöyük, across distinctive archaeological contexts and time periods. Of the potsherds collected from identifiable contexts 48% were from middens. Potsherds from building and room fills, which are more secure contexts in terms of being constrained to a shorter period of time of possible use, accounted for another 38% of the samples chosen for δD analysis. Potsherds containing residues chosen for δD analyses were collected from non-mixed strata, whether from midden, building or room fills to ensure maximum constraint on context and timing of usage.

Dates for each stable isotope sample were based on a large number of radiocarbon ages for the different stratigraphic levels of human occupation. Date ranges represent radiocarbon dates for the stratigraphic level a pot has been assigned to based on where it was found during excavation. Pottery from this site does not show evidence of repairs and thus it is assumed that the length of time a pot was used would have been very brief and well within the confines of the errors associated with radiocarbon dates for each stratigraphic level. Radiocarbon dates were determined largely through analysis of charred plant remains as well as combined radiocarbon and dendrochronological dating of charcoal remains and are reported herein to 95% probability (Cessford et al. 2005). These dates were compared to geological radiocarbon and other dates gathered on site (Roberts et al. 1999).

5.2.2 Sample preparation

Lipid analyses were performed according to an established protocol (Evershed et al. 1990; Charters et al. 1993). Archaeological pottery fragments from Çatalhöyük, Turkey (n = 35) were prepared for $\delta^{13}C$ analysis (Table 1). A selection from the same group of pottery fragments (n = 34) was prepared for δD analysis (Table 2). Radiocarbon dates assigned to pottery are based on stratigraphic level assignments as explained in section 2.1. Fragments with assigned radiocarbon dates were chosen for δD analysis whereas potsherds prepared for $\delta^{13}C$ analysis had to meet the additional criteria of falling into a specific ware type.

The potsherds were cleaned using a modeling drill (Como Mini Drill, MFA Como Drills) in order to remove exterior contaminants and surface lipids that may have attached to the sherd via deposition or handling. The cleaned portion of the sample was removed using a hammer and a dichloromethane (DCM) rinsed chisel. An internal standard (*n*-tetratriacontane, 20 µl) was added to each sample of 2.0 g ground sherd. The 2.0 g of ground sherd was ultrasonicated (2 x 15 min) in chloroform: methanol (2:1 *v/v* 2 x 10 ml). Each sherd represents a separate vessel. Total lipid extracts (TLEs) were separated from pottery material via centrifugation and filtration through furnaced (4 h at 450ºC) HPLC grade silica.

5.2.3 Trimethylsilylation procedure

An aliquot (ca. 50 µl) of the TLE was then derivatized with *N*,*O*-bis(trimethylsilyl)-trifluoroacetamide (BSTFA; 40 µl; 70ºC, 1 h). The trimethylsilyl (TMS) derivatives were then screened for the presence of lipids via GC and HT-GC/MS.

5.2.4 FAME preparation

Aliquots of potsherd lipid extracts or reference animal fats were saponified using sodium hydroxide in methanol and double distilled water (9:1 *v/v*; 0.5M; 2 ml; 70°C, 1 h). FAME derivatives of the free fatty acids were prepared by heating with 100 µl BF_3-methanol (14 % *w/v*; Sigma Aldrich Company Ltd.) at 70°C for 1 h Double distilled water was added (1 ml) and the FAME derivatives were extracted with chloroform (3 x 2 ml) and the solvent removed under nitrogen. The addition of hexane (50-250 µl) to FAMEs was made prior to analysis by GC and GC-TC-IRMS. A detailed description of the preparation of FAMEs for $\delta^{13}C$ analysis appears in Mottram et al. (1999) and for δD analysis in Chivall et al. (2012).

5.2.5 Instrumental analyses

TMS derivatives were analysed on a Hewlett Packard 5890 series II gas chromatograph coupled to a PC with Clarity software. In some instances further analyses were performed on a Perkin Elmer Turbomass Gold equipped with a fused silica capillary column (J&W; DB1-HT; 15 m x 0.25 mm i.d.; 0.1 μm film thickness) with a GC interface maintained at 350°C in order to verify the identification of $C_{16:0}$ and $C_{18:0}$ fatty acids. In all of the FAMEs studied for δD and $\delta^{13}C$ values the $C_{16:0}$ and $C_{18:0}$ fatty acids were clearly identified as they are most often the only long-chain fatty acids preserved in archaeological samples (Fig. 5.2).

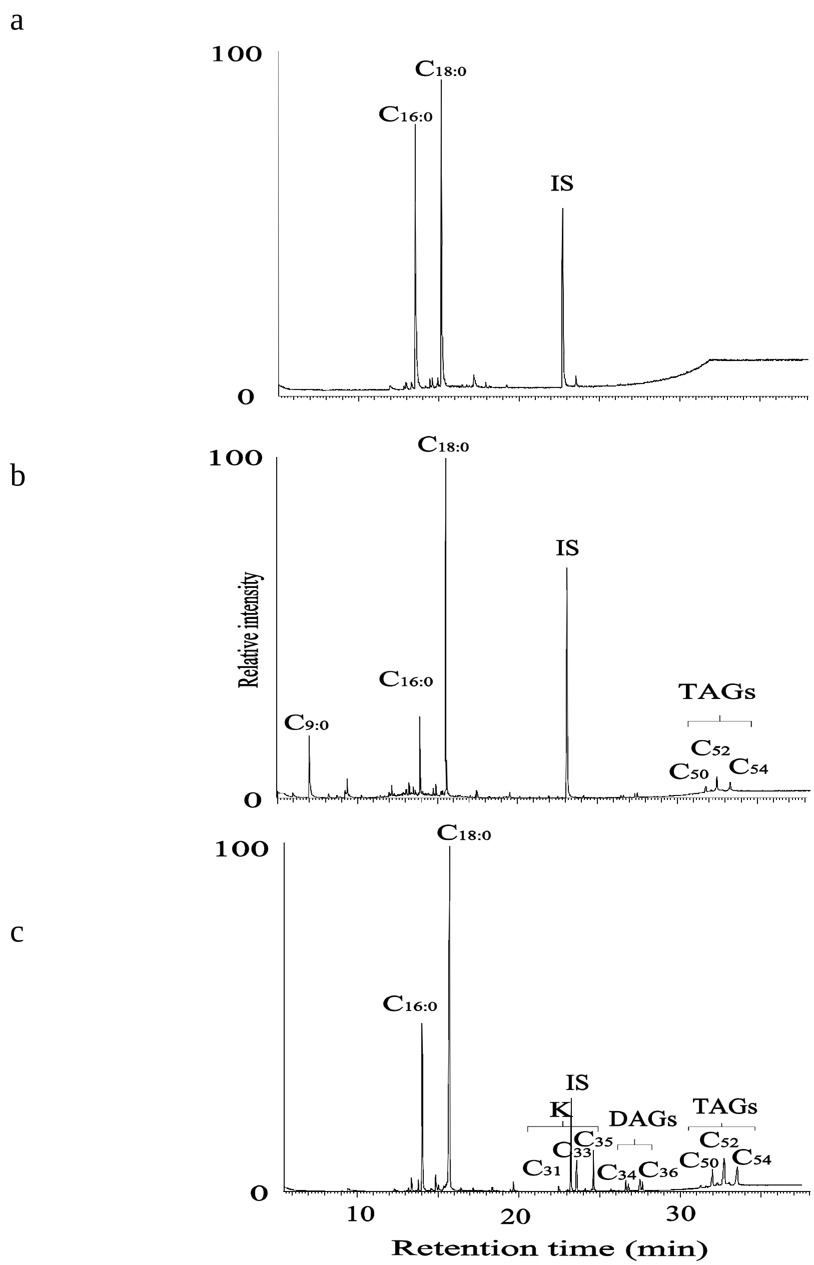

Figure 5.2. a) Typical gas chromatogram of the assemblage at Catalhoyuk with only $C_{16:0}$ and $C_{18:0}$ fatty acids preserved. b) Unusual gas chromatogram of a sample featuring nonanoic acid $C_{9:0}$ in addition to the long chain fatty acids typically seen in residues originating from animal fats ($C_{16:0}$ and $C_{18:0}$). c) Example of HT-GC profile of a sample containing a variety of compounds. This combined with mass spectra identifies specific types of compounds within the lipid assemblage such as fatty acids (e.g. $C_{16:0}$ and $C_{18:0}$), diacylglycerols (DAGS), ketones (K), triacylglycerols (TAGS) as denoted here.

GC-C-IRMS analyses were performed on fatty acid methyl ester derivatives (FAMEs) of 35 residues determined as being pure animal fats using a Finnigan MAT Delta S in order to determine the $\delta^{13}C$ values of the palmitic and stearic acids present. A detailed description of the preparation of FAMEs appears in Chivall et al. (2012).

Carbon GC-C-IRMS analyses were performed using a Varian 3400 GC coupled to a Finnigan MAT Delta S IRMS (standard error ± 0.3‰) via an extensively modified Finnigan MAT type I combustion interface with Cu and Pt wires (0.1 mm o.d) in an alumina reactor (0.5 mm i.d). The reactor temperature was maintained at 860°C and the mass spectrometer source pressure was 6 x 10^{-6} mbar. Faraday cups were used for the detection of ions of *m/z* 44 ($^{12}C^{16}O_2$), 45 ($^{13}C^{16}O_2$ and $^{12}C^{17}O^{16}O$) and 46 ($^{12}C^{18}O^{16}O$). The GC column was a Factor Four VF-23ms column (Varian Chrompack 60 m x 0.32 mm i.d, 0.15 µm film thickness) and the temperature program consisted of an isothermal period of 1 min at 50°C followed by an increase to 240°C at a rate of 10°C min^{-1} followed by an isothermal period of 10 min at 240°C.

GC-TC-IRMS analyses of FAMES were performed on a ThermoFisher Scientific Delta V. A standard of 15 *n*-alkanes of known isotopic composition (Schimmelman B Standard) was used to verify instrument error between each run. Instrument error was maintained between 2–7‰ error.

The lake carbonate samples analysed at the NERC Isotope Geosciences Laboratory (Keyworth, UK) were treated with 5% sodium hypochlorite for 24 h to oxidize organics and disaggregate the sediment, sieved through an l80 µm sieve cloth on to Whatman quartz microfibre filter paper and washed with deionized water. The <80 Am fraction, within which carbonates were dominated by authigenic aragonite crystals, was collected on the filter while coarser material including derived carbonates was retained in the sieve cloth. The filter paper was dried and the carbonate removed and ground to a fine powder. Following this 10 mg of $CaCO_3$ was reacted with anhydrous phosphoric acid in vacuum overnight at a constant temperature of 25°C (McCrea, 1950). The liberated CO_2 was separated from water vapour and its stable isotope content measured on a VG Optima mass spectrometer. Results are reported in 6180 and 3C notation in per mil (‰ C) versus VPDB. based on calibration of the laboratory standards against NBS-19. Analytical reproducibility is better than 0.1‰ (2 σ) for both isotopes.

5.2.6 Isotope value correction

$\delta^{13}C$ values of fatty acid methyl ester were corrected for the added derivative carbon according to Mottram et al. (1999).

δD values were obtained by manual processing the raw data from GC-TC-IRMS analysis in the following equation as established by Chivall (2007) and Chivall et al. (2012):

$$\delta D_{FA} = \frac{(n_{FAME}\delta D_{FAME} - 3\delta D_{MeEffective})}{(n_{FA})} \tag{1}$$

where n_{FAME} is the total number of hydrogen atoms of the fatty acid methyl ester measured (34 or 38 for $C_{16:0}$ and $C_{18:0}$ respectively), n_{FA} is the number of non-exchangeable hydrogen atoms of the fatty acid and δD_{FA} is the corrected δD value of the fatty acid. The values for $\delta D_{MeEffective}$ were calculated using sodium stearate and sodium palmitate of known δD values and the equation below to determine the effects of derivatisation on the δD_{FAME} values.

$$\delta D_{MeEffective} = \frac{(n_{FAsalt}\delta D_{FAsalt} - n_{FAME}\delta D_{FAME})}{3} \tag{2}$$

Equation (1) above thus corrects for changes in the δD value resulting from BF_3MeOH derivatisation (Chivall et al. 2012).

5.3. Results

5.3.1 Lipid identification

$C_{16:0}$ and $C_{18:0}$ are the most prevalent compounds found in the lipid extract of archaeological potsherds, indeed in most cases these are the only compounds found in residues from the pottery of Çatalhöyük (e.g. Fig. 2a). A few extracts were found to include short-chain fatty acids, such as *n*-nonanoic acid (Fig. 2b). In some cases a wider range of compounds was present, such as ketones, diacylglycerols and triacylglycerols (Fig. 2c). This shows a high level of preservation for the residues at Çatalhöyük. The presence of mid-chain ketones indicate high heating (ca. 300^{o}C) during the use of the vessels (Evershed et al. 1995; Raven et al. 1997). In addition to free fatty acids, monoacylglycerols (MAGS), diacyldlycerols (DAGS), and triacylglycerols, (TAGS) were present in some extracts evidence of a high degree of preservation for residues of this age. Lipid concentrations varied from 0.004 to 0.700 mg g^{-1} potsherd, sufficient for GC-C-IRMS analysis.

$\delta^{13}C$ values were determined for a selection of (n=35) residues with each sample run in duplicate. $\delta^{13}C$ values combined with $\Delta^{13}C$ values, where $\Delta^{13}C = \delta^{13}C_{18:0} - \delta^{13}C_{16:0}$, provide information about the origin of fats identified, as well as the relative contribution of C_4 versus C_3 plants to the animal diet (Fig. 5.3). Since sheep/goat remains dominate the faunal assemblage, followed by cattle, as was expected ruminant adipose fats dominated the lipid assemblage. The animal origin of the residues are summarised in Tables 1 and 2 with some pots showing evidence of having been used in the preparation of mixtures of animal products.

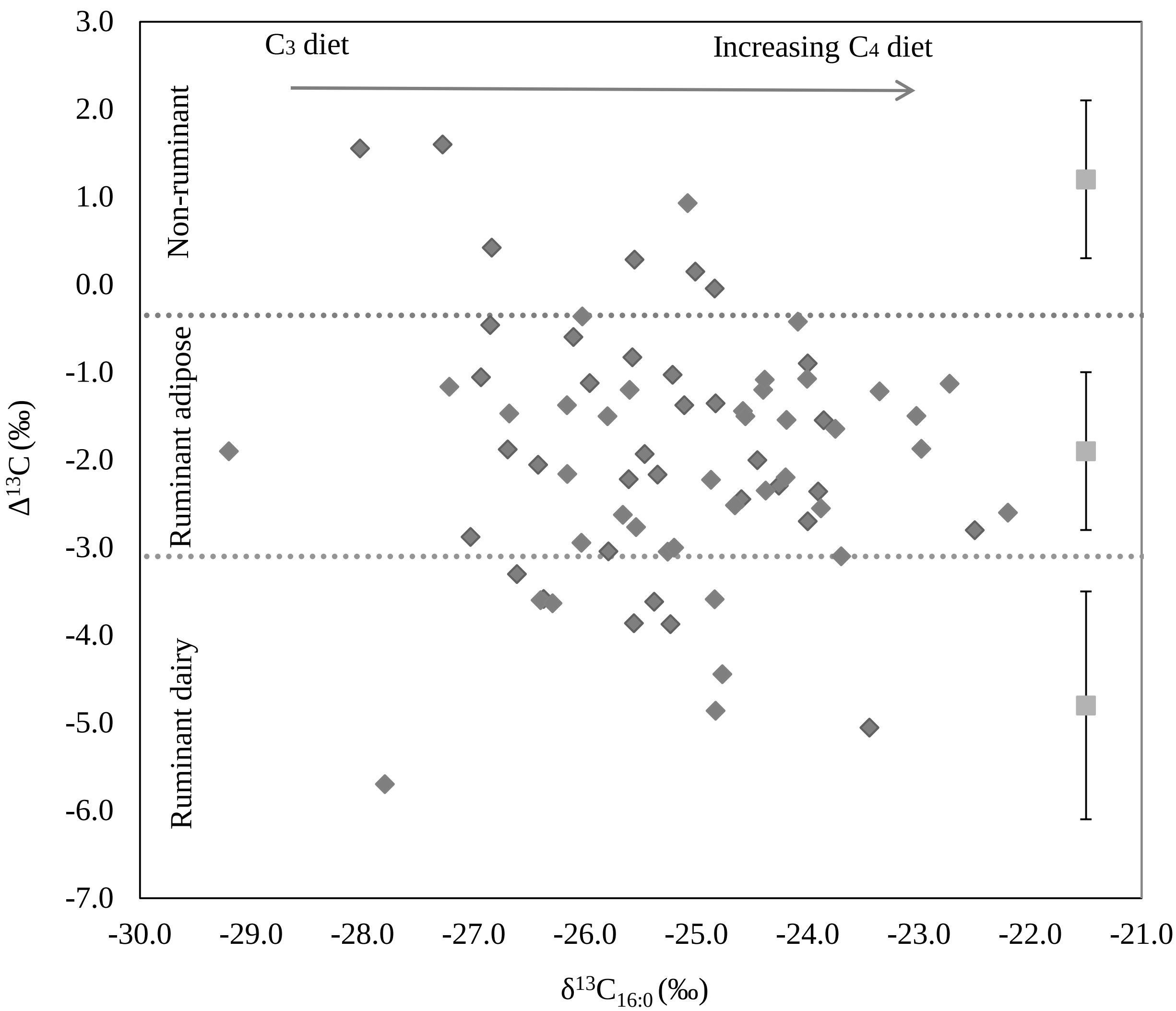

Figure 5.3. Graph of $\Delta^{13}C$ with $\delta^{13}C_{16:0}$ values, where $\Delta^{13}C = \delta^{13}C_{18:0} - \delta^{13}C_{16:0}$, as a way of distinguishing fats of animals consuming primarily C_3 or C_4 vegetation. Points above the $\Delta^{13}C$ value of -0.3 and below a value of -3.1 represent porcine and ruminant dairy fats respectively. Data falling between the two marked lines are classified as ruminant adipose fats. The ranges shown are based on reference values gathered for a global database comprising modern reference ruminant animal fats from Africa, the UK (animals raised on a pure C_3 diet), Kazakhstan, Switzerland and the Near East and represent the mean ± 1 standard deviation of the $\Delta^{13}C$ values (Dunne et al. 2012). Archaeological data represented on the plot are a combination of values collected during this study and a previous study performed by Evershed et al. (2008).

Table 5.1. $\delta^{13}C$ values of fatty acid components of the total lipid extracts of the Çatalhöyük pottery. Residue type assigned based on modern reference animal fats (Copley et al. 2003; Evershed et al. 2008).

Recording number	$\delta^{13}C_{16:0}$	$\delta^{13}C_{18:0}$	$\Delta^{13}C$	$C_{16:0}$ stdev	$C_{18:0}$ stdev	cal BC	Residue type
320	-24.5	-26.5	-2.0	0.0	0.1	6295 ± 75	Ruminant adipose
325	-26.9	-28.0	-1.1	0.0	0.2	6295 ± 75	Non-ruminant adipose
327	-26.4	-28.5	-2.1	0.0	0.2	6425 ± 95	Ruminant adipose
330	-25.5	-27.4	-1.9	0.3	0.2	6425 ± 95	Ruminant adipose
331	-27.0	-29.9	-2.9	0.3	0.7	6755 ± 95	Ruminant adipose
333	-23.9	-25.4	-1.5	0.1	0.2	6615 ± 95	Ruminant adipose
352	-26.9	-27.3	-0.5	0.3	0.3	6860 ± 90	Non-ruminant adipose
P.006	-27.3	-25.7	1.6	0.4	0.6	6580 ± 80	Non-ruminant adipose
P.007	-26.8	-26.4	0.4	0.2	0.9	6580 ± 80	Non-ruminant adipose
P.033	-23.4	-28.5	-5.1	0.0	0.0	6580 ± 80	Ruminant dairy
P.034	-25.6	-26.4	-0.8	0.3	0.2	6580 ± 80	Non-ruminant adipose
P.038	-26.7	-28.6	-1.9	0.0	0.1	6295 ± 75	Ruminant adipose
P.043	-24.3	-26.6	-2.3	0.2	0.1	6295 ± 75	Ruminant adipose
P.052	-25.8	-28.8	-3.0	0.0	0.1	6295 ± 75	Ruminant adipose
P.060	-23.9	-26.3	-2.4	0.4	0.1	6320 ± 10	Ruminant adipose
P.068	-25.2	-26.2	-1.0	0.0	0.0	6425 ± 95	Non-ruminant adipose
P.081	-26.0	-27.1	-1.1	0.0	0.0	6320 ± 10	Ruminant adipose
P.109	-24.0	-24.9	-0.9	0.1	0.2	6295 ± 75	Non-ruminant
P.110	-24.0	-26.6	-2.7	0.7	0.8	6295 ± 75	Ruminant adipose
P.111	-22.5	-25.3	-2.8	0.2	0.3	6295 ± 75	Ruminant adipose
P.164	-25.6	-29.4	-3.9	0.5	0.1	6320 ± 10	Ruminant dairy
P.169	-25.6	-25.3	0.3	0.4	0.4	6320 ± 10	Non-ruminant adipose
P.171	-24.8	-24.9	0.0	0.2	0.2	6320 ± 10	Non-ruminant adipose
P.175	-25.4	-29.0	-3.6	0.5	0.2	6320 ± 10	Ruminant dairy
P.179	-24.8	-26.2	-1.4	0.4	0.1	6295 ± 75	Ruminant adipose
T.001	-25.0	-24.9	0.1	0.0	0.0	6320 ± 10	Non-ruminant adipose

T.004	-26.6	-29.9	-3.3	0.1	0.0	6425 ± 95	Ruminant adipose and dairy
T.014	-24.6	-27.0	-2.4	0.2	0.0	6295 ± 75	Ruminant adipose
T.059	-25.1	-26.5	-1.4	0.3	0.3	6295 ± 75	Ruminant adipose
T.073	-28.0	-26.5	1.6	0.1	0.3	6425 ± 95	Non-ruminant adipose
T.075	-26.1	-26.7	-0.6	0.7	0.4	6425 ± 95	Non-ruminant adipose
T.084	-25.6	-27.8	-2.2	0.4	0.2	6320 ± 10	Ruminant adipose
T.087	-26.4	-30.0	-3.6	0.1	0.0	6425 ± 95	Ruminant dairy
T.093	-25.4	-27.5	-2.2	0.2	0.2	6425 ± 95	Ruminant adipose
T.097	-25.2	-29.1	-3.9	0.2	0.1	6425 ± 95	Ruminant dairy

Table 5.2. δD values of fatty acids of the Çatalhöyük pottery. Only ruminant adipose fats were used to construct deuterium record (Fig. 5.6). Residue type based on δ^{13}C values (Table 5.1).

Recording number	δD $C_{16:0}$	δD $C_{18:0}$	cal BC	Residue type
320	-273	-276	6295 ± 75	Ruminant adipose
325	-286	-290	6295 ± 75	Non-ruminant adipose
327	-268	-285	6425 ± 95	Ruminant adipose
330	-291	-295	6425 ± 95	Ruminant adipose
331	-283	-297	6755 ± 95	Ruminant adipose
333	-282	-297	6615 ± 95	Ruminant adipose
352	-288	-294	6860 ± 90	Non-ruminant adipose
P.033	-258	-274	6580 ± 80	Ruminant dairy
P.034	-286	-285	6580 ± 80	Non-ruminant adipose
P.038	-284	-301	6295 ± 75	Ruminant adipose
P.043	-265	-283	6295 ± 75	Ruminant adipose
P.052	-257	-267	6295 ± 75	Ruminant adipose
P.060	-265	-266	6320 ± 10	Ruminant adipose
P.066	-274	-265	6425 ± 95	Ruminant adipose
P.068	-278	-281	6425 ± 95	Non-ruminant adipose
P.081	-278	-277	6320 ± 10	Ruminant adipose
P.109	-231	-249	6295 ± 75	Non-ruminant adipose
P.110	-200	-220	6295 ± 75	Ruminant adipose
P.111	-274	-264	6295 ± 75	Ruminant adipose
P.164	-268	-297	6320 ± 10	Ruminant dairy
P.169	-283	-275	6320 ± 10	Non-ruminant adipose
P.171	-271	-279	6320 ± 10	Non-ruminant adipose
P.175	-279	-312	6320 ± 10	Ruminant dairy
P.179	-291	-278	6295 ± 75	Ruminant adipose
T.001	-289	-291	6320 ± 10	Non-ruminant adipose
T.004	-278	-299	6425 ± 95	Ruminant adipose and dairy
T.014	-261	-270	6295 ± 75	Ruminant adipose
T.059	-277	-282	6295 ± 75	Ruminant adipose
T.073	-326	-306	6425 ± 95	Non-ruminant adipose
T.075	-280	-279	6425 ± 95	Non-ruminant adipose
T.084	-284	-288	6320 ± 10	Ruminant adipose
T.087	-276	-301	6425 ± 95	Ruminant dairy
T.093	-264	-271	6425 ± 95	Ruminant adipose
T.097	-264	-289	6425 ± 95	Ruminant dairy

$\delta^{13}C$ and δD chronologic records were constructed to allow comparison of trends. Comparisons between these two records allow distinctions to be drawn between stable isotopic trends that could be attributed to biological rather than environmental factors. Each point (Fig. 5.4) represents the average, where possible, of several pottery samples based on period of usage. Errors presented on date ranges show the level of uncertainty associated with radiocarbon dates to 95% probability for the stratigraphic levels from which pottery samples were collected (Cessford et al. 2005).

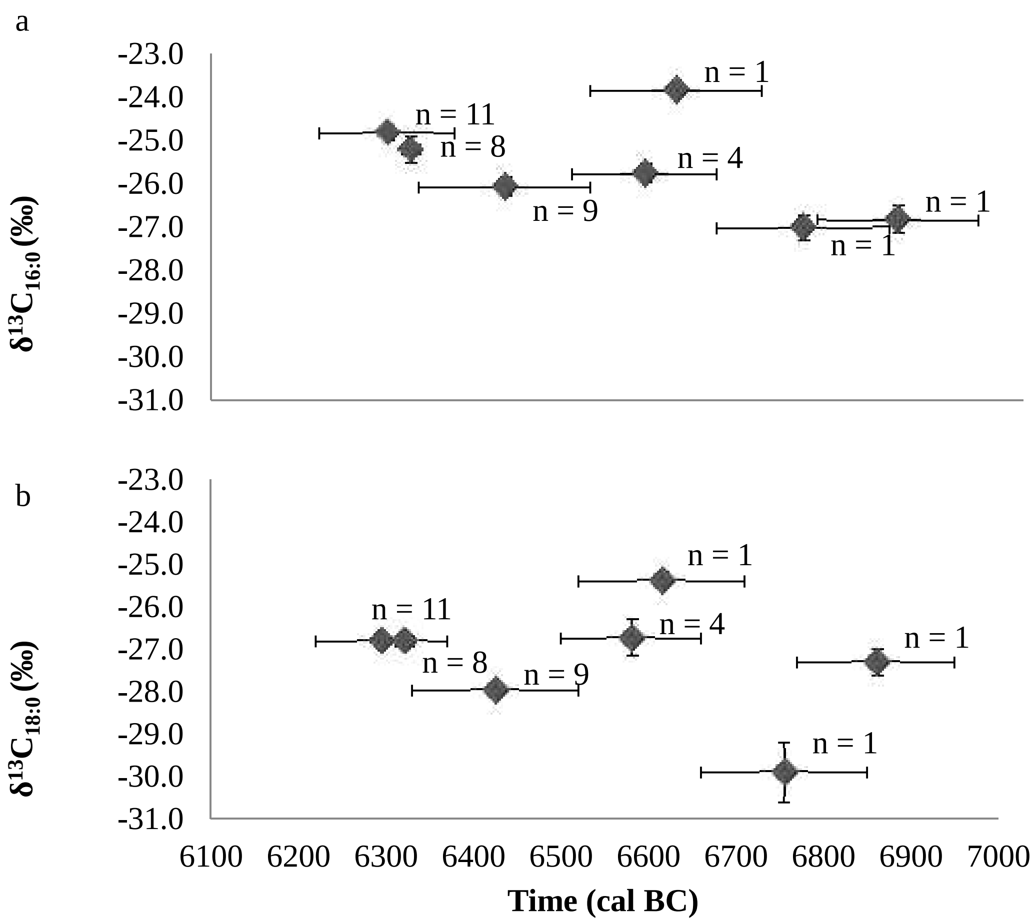

Figure 5.4. Mean of combined $\delta^{13}C$ values from Evershed et al. (2008) and this study with a bias towards the oldest possible dates of origin for the pottery sampled for: a) $C_{16:0}$ and b) $C_{18:0}$ fatty acid values. Vertical error bars represent standard deviation or instrument errordepending on number of samples available per level. Error bars associated with age are based on 1 standard deviation from the plotted mean age based on radiocarbon dates (Cessford et al. 2005).

5.3.2 δD of $C_{16:0}$ and $C_{18:0}$ fatty acids

δD values were obtained for the same archaeological pottery samples (n = 34) that were analysed via GC-C-IRMS for $\delta^{13}C$ values. Results of GC-TC-IRMS δD analysis are shown in Figure 5.5. Average values are based on samples combined by stratigraphic level. Calculated averages of each sample were also determined as δD values of both $C_{16:0}$ and $C_{18:0}$ were measured a minimum of three times per sample.

a

b

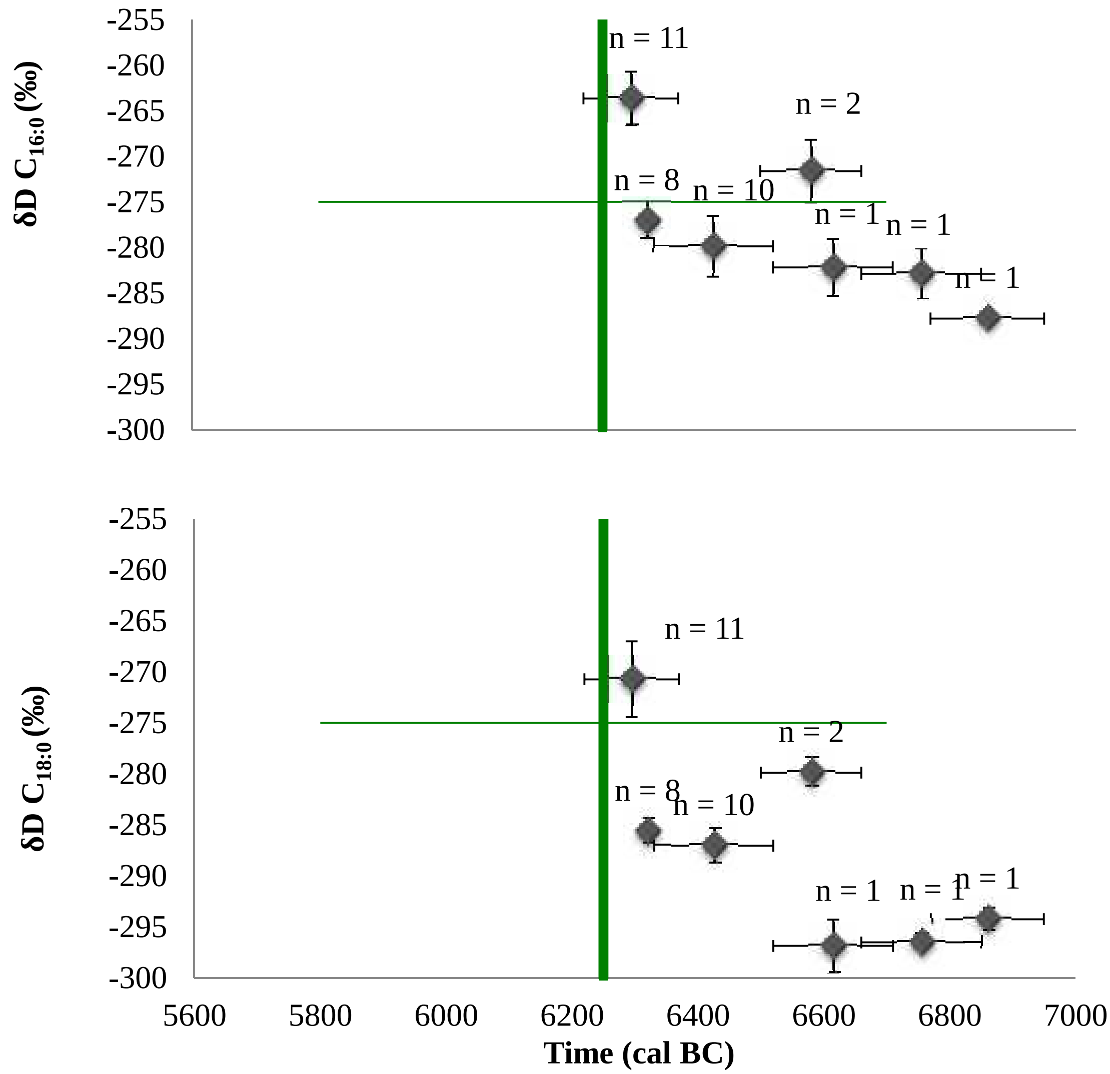

Figure 5.5. Average δD values of: a) hexadecanoic ($C_{16:0}$), and b) octadecanoic ($C_{18:0}$), acid components derived from sherds through time. Vertical error bars represent standard deviation or instrument error depending on number of samples available per level. Error bars associated with age are based on ranges of error with 95% probability from the plotted mean age based on radiocarbon dates (Cessford 2005). Green lines denote estimated timing of the 8.2 ka event (Daley 2011, OxCal 4.2).

Due to biofractionation, δD values of fats vary greatly in absolute values as compared to environmental water values. δD values of fatty acids are typically significantly depleted compared to environmental values (Stear 2008). Thus, it was no surprise that the mean weighted δD value for Ankara precipitation is -54 ‰, whereas those for modern fatty acids are ca. -200 ‰ (-212‰ for $C_{16:0}$ and -183 ‰ for $C_{18:0}$). The latter values are consistent with the mean δD values recorded for the ancient fats were -274 ‰ ± 3 and -282 ‰ ± 2 for $C_{16:0}$ and $C_{18:0}$. The fractionation mechanism(s) causing such large differences between δD values of animal fats and ingested water is not well understood but is well-known (Hobson et al. 1999). However, trends in δD values of fatty acids are indicative of real changes in moisture values and may also be linked to changes in temperature, such as the seasonal differences seen by Outram et al. (2009) in horse milk and body fats in the Eurasian Steppe.

Tables 1 and 2 list the stable isotope compositions of the extracts containing significant quantities of acyl lipid (>0.003 mg g^{-1}) for isotopic analysis. In total, thirty-four archaeological fatty acid extracts were chosen for δD analysis using GC-TC-IRMS. The low recovery rates of residues present in the ancient potsherds, as well as constraints on the number of potsherds available for analysis, greatly limited the final number of fatty acid samples available in the older levels (~6860-6615 cal BC).

5.3.3 δD values through the Çatalhöyük chronologic record

Utilization of the established radiocarbon chronology of Çatalhöyük allowed creation of a δD record through time up to and including the 8.2 ka climatic excursion (~7740-6604 cal BC) (Cessford et al. 2005; Daley et al. 2011). Grouping of the older (ca. 6900 to 6600 cal BC) and the younger stratigraphic levels (ca. 6600 to 6280 cal BC) demonstrates a pronounced shift in relative humidity levels during site occupation

(Fig. 5.5). The resulting record demonstrates average conditions becoming isotopically less negative (i.e., drier) after ca. 6600 cal BC, particularly in the $C_{18:0}$ record.

5.3.4 Geological δ^{18}O data

The combination of δD and δ^{18}O analyses allows a more detailed overview of past climatic trends. Figure 5.6 demonstrates a palaeoenvironmental reconstruction from δ^{18}O values obtained from calcium carbonates of the nearby lake Eski Acıgöl, focusing on the time span that corresponds to occupation at Çatalhöyük (Roberts et al. 2001; Jones et al. 2007). It shows an abrupt shift to more positive δ^{18}O values between ~6300 and 6050 cal BC marking the onset of the 8.2 ka climatic event. The dating precision of the Eski Acıgöl sequence, based primarily on U-series ages, is limited to approximately ± 200 yr.

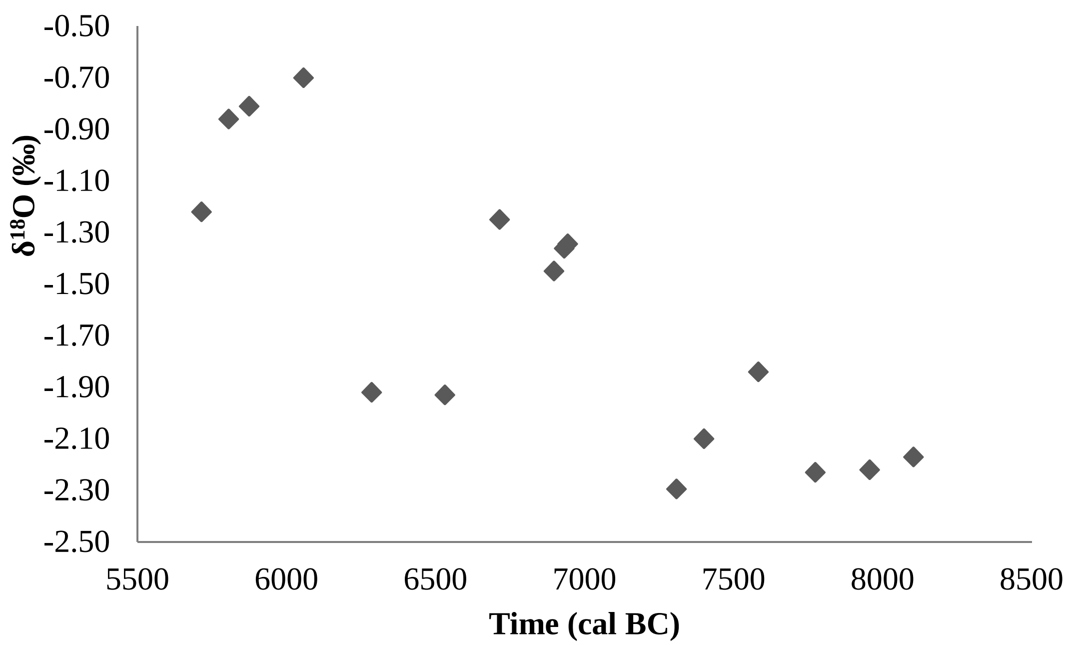

Figure 5.6. Oxygen values gathered by Jones et al. (2007) from lake Eski Acıgöl carbonates.

5.4. Discussion

Unlike the $\delta^{13}C$ record of the same residues the δD record demonstrates a clear pattern of change during the ceramic Neolithic period at Çatalhöyük. Although a limited number of potsherds with residue were available from the older levels (~6860-6615 cal BC), when the available samples for these levels are grouped together a clear drying trend is seen. All of the potsherds sampled were mostly linked to undisturbed midden fills, which are considered secure archaeological contexts.

Although the distinction between older and younger levels of occupation is difficult due to the limited number of older (>6600 cal BC) potsherds available, the analyses revealed an overall drying trend for much of the site chronology particularly from ca. 6600 to 6300 cal BC in both $C_{16:0}$ and $C_{18:0}$. This is consistent with bio-archaeological finds from Çatalhöyük, and also with geo-archaeological evidence for a shift from frequent river flooding to dry ground conditions by ~6200 cal BC. No correlation was found between $\delta^{13}C$ and δD values, with r^2 values of 0.30 and 0.09 for δ^{13} $C_{16:0}$ and δ^{13} $C_{18:0}$, respectively, compared to r^2 values of 0.56 and 0.53 for the δD values of $C_{16:0}$ and $C_{18:0}$, supporting the interpretation that the δD record is reflecting primarily environmental changes associated with varying precipitation/evaporation levels. This trend is more pronounced in $C_{18:0}$. Although it is unclear what may cause the differential expression of less negative isotope values between the δD values of $C_{16:0}$ and $C_{18:0}$, it has been previously suggested that this phenomenon may be due to a more direct environmental contribution to δD values of $C_{18:0}$. The biosynthetic pathway of uptake of hydrogen in the formation of $C_{16:0}$ is more greatly influenced by several factors (i.e., trophic level, host metabolism, etc.) whereas hydrogen isotope contribution to $C_{18:0}$ formation is more directly related to meteoric water isotopic values (Stear 2008). Further analysis will allow clarification of such biosynthetic preferential uptake of environmental hydrogen as well as more detailed assessments of the palaeoenvironmental record for Çatalhöyük and other archaeological sites.

Differences in species physiology may also contribute to differences in δD values between different residues. Çatalhöyük is dominated by sheep/goat specimens, which make up approximately 70% of the total faunal remains of the site whereas remains identified as originating from cattle specimens only compose 23% of the total remains according to the number of identified specimens (Russell et al. *in press*). These are the only ruminant animals associated with the site, apart from deer (which are rare), making up only ~1% of the faunal remains. Thus, it is highly likely that the data reported represents a rather robust marker of palaeoenvironmental change rather than metabolic effects.

Currently δD values obtained through stable isotope analysis of fatty acids only demonstrate hydro-climatic trends, not absolute values that could be compared directly to modern values. Further analysis of differences between isotopic values of metabolically active tissues of ruminant animals, such as fats, and environmental values from surface water due to fractionation is needed in order to quantify the extent of climatic changes in past environments.

The end of the occupation at Çatalhöyük's east mound coincides with the 8.2 ka cold, dry climate event that was felt widely across the Northern Hemisphere. This abrupt but short-lived climatic cooling was triggered by the collapse of the residual Laurentide ice sheet over Hudson Bay and subsequent rise in sea levels after ca. 8450 ± 44 BP (7580-7480 cal BC, 95% probability) (Hijma and Cohen 2010). Turney and Brown (2007) constrained this to 8350-8230 cal. BP (~7490-7180 cal BC, 95% probability) using sea-level index points, while Daley et al. (2011) compared multiple, independently-dated stable isotope records from the circum-North Atlantic region that show this abrupt climatic event occurring between ca. 7740 and 6604 cal BC (IntCal09). The beginning of this time period is covered in the chronology reported herein for Çatalhöyük, with two uppermost sampled levels (IV and V) having ages of ~6320 ± 10 and 6295 ± 75 cal BC (95% probability) (Cessford et al. 2005).

Although there are currently not enough data points to allow exact correlation over time, the separate δD values of fatty acids and $\delta^{18}O$ values obtained from lake sediments do show similar excursions towards increasingly positive values at the time of the 8.2 ka climatic event. Both of these values indicate a drying trend, reaching a drought maximum around 6300-6200 cal BC. A slight chronological offset between the two is probably due to the dating impression in the Eski Acıgöl lake record. A more significant difference appears to be in the timing of the initial onset of the drying trend. In the Çatalhöyük δD record from animal fats this drying trend occurs earlier, from ~6600 cal BC, either gradually ($\delta D_{16:0}$) or more abruptly ($\delta D_{18:0}$). This implies that the initial change in δD values may not have been directly climatic in origin, but was instead caused by a local change in hydrological regime. This could have related to a shift in the deposition centre down the Çarşamba alluvial fan causing a gradual decline in river flooding around Çatalhöyük, a possibility that clearly deserves further investigation.

Another possible explanation for the drying trends seen in the δD record are fluctuations in seasonal trends over time. There is a strong seasonal signal seen in the $\delta^{18}O$ values of freshwater mollusk *Unio* shells (Bar-Yosef Mayer et al. 2011). Thus, shifts seen in the δD record would have been influenced by changes in local hydrology as well as changes in precipitation composition. Changes in isotopic composition of precipitation in Central Anatolia would most likely not have been significant enough to demonstrate the trends seen in the fatty acid δD record. More evidence is needed to determine whether the shift in δD values is more directly related to variations in local hydrology or in the precipitation/evaporation regime of this region.

Interestingly there is no clear pattern of change of vegetation during the 8.2 ka climatic event within central Anatolia (Asouti 2009), and therefore the impact of the drying trend on subsistence practices is still questionable. The stability of the plants available to Neolithic farmers at the time in question suggests that climate change may not have been the main driving force in the incorporation of alternative food sources or the main limiting factor in the spread of farming into Europe.

There is also currently a project underway with the goal of defining a more constrained chronology for Çatalhöyük. The new dates will be based on radiocarbon dates of articulated bones in order to improve upon the previous dates, which were based largely on charred plant material (Bayliss and Farid 2010). This will provide a more accurate chronological record and thus constrain the timing of inferred environmental change at this particular site.

5.5. Conclusions

The results presented herein represent the beginnings of the development of a palaeoenvironmental proxy from on-site archaeological materials that may be used to shed light on local climatic and environmental change. This may be particularly useful when trying to couple site-specific changes in past human society with global climatic variations. Although such studies are limited to areas of established human occupation and material culture, particularly the presence of unglazed pottery, this tool provides a useful mechanism for studying environmental changes, whether natural or anthropogenic in origin.

In the case of Çatalhöyük this information may help to explain the delay in the uptake of agriculture between Anatolia and Europe after its initial extension from the Levant. Similarly, the record shown here seems to indicate that drier conditions allowed the community at Çatalhöyük to move locations across the Çarşamba River, which implies a possible link between environmental forcing and settlement changes. Further organic residue analysis of pottery from the settlement of Çatalhöyük West will provide a clearer picture of the persistence of the drying record after the 8.2 ka event.

Drying conditions may have also encouraged an increase in the variety in the types of foodstuffs exploited, leading to the incorporation of new subsistence resources into the diet of Çatalhöyük's population. Such a trend towards increased biodiversity in consumption may have included the development of dairying at Çatalhöyük, a site from which the earliest chemical evidence for dairying has been established (Evershed et al. 2008).

The use of compound specific δD analysis allows a detailed, time-constrained palaeoenvironmental proxy that adds to, and complements, previous methods. However, when implementing this method of analysis it is important to gather pottery from secure stratigraphic contexts with well-constrained chronologies whenever possible. This method of analysis also relies heavily on the accuracy of dating methods when looking at specific climatic episodes such as the short-lived 8.2 ka event. Thus, the combination of several proxies, particularly involving collaboration prior to artifact and data collection, will allow for a more precise assessment of local climatic, environmental and cultural changes, linked directly to past anthropogenic activity.

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Chapter 6 Conclusions

6.1 Addressing project aims

Although there are many changes occurring throughout the site chronology at Çatalhöyük, it seems that there are several technological, faunal, and subsistence practice changes occurring around South.M-South.P (Hodder, *in press*). Thus, most of the conclusions presented herein focus on this specific time period ranging from ca. 6770 cal. BC to 6500 cal. BC (Cessford et al 2005). As presented at the beginning of this thesis the main project aims were to 1) to produce accurate estimates of the timing of dairy production at this particular site in order to shed light on the probable timing of the secondary products revolution in the Near East. 2) To define the technological, environmental and social elements that were changing contemporaneously with the emergence of dairy production at Çatalhöyük, 3) to determine how these factors influenced the decision to raise domesticated animals for milk production rather than meat production and 4) to determine whether stable isotope analysis (particularly hydrogen stable isotope ratio analysis) of fatty acid residues is a viable palaeoenvironmental proxy.

6.1.1 Changing technologies

The extensive record of materials used at Çatalhöyük show several trends through time. Focusing on South.M-South.P we see many changes occurring. The disappearance of clay balls along with the emergence of refined pottery seems to suggest changes in cooking technologies (Atalay 2012; Last 2005). The major proliferation of pottery styles seen at South.M certainly reflects increased specialization, and may be an indication of the separation of groups within the site.

The increased specialization of pottery over time hints at the possibility of groups separating within the site. It is difficult to say what may have caused these further distinctions amongst groups. Düring (2007) suggests that at Çatalhöyük spatially segregated areas of the site created neighbourhoods consisting of several houses grouped together (e.g. 36 buildings in one neighbourhood within Level VI or ~North.G) most likely in order to make the population easier to manage (Düring 2007). Smaller, household groups would have provided the economic organization at Çatalhöyük and have been estimated to incorporate roughly six houses. This estimate is based on findings of large clusters of burials found in specific houses, while 80% of buildings lack burials. On average it is suggested that neighbourhoods at Çatalhöyük would have contained approximately 150-250 people, but up to as many as 600 people. Clustered neighbourhoods seem to mainly occur from levels XII to VI, with up to roughly 53 neighborhoods present at the height of population density, and then disappear in later levels (Düring 2007).

6.1.2 Animal management

As previously mentioned, major changes are seen in the faunal record around South.M through South.P (ca. North.G-H) just as is seen in several other areas of study at Çatalhöyük. The extensive stable isotope analyses of both collagen and residues for this site reveal quite a bit about changes in animal management strategies during the Neolithic. The bone collagen $\delta^{13}C$ and $\delta^{15}N$ records suggest that herds were grazing over increasingly larger, more spread out areas towards the end of the Neolithic sequence (Pearson et al. 2007; Henton 2010). Taking into account the $\delta^{13}C$ values of $C_{18:0}$ and $C_{16:0}$ of the 35 residues from cooking pots it is also suggested that the introduction of dairying was taking place ca. South.M, with the earliest dairy sample coming from 4040.G, which roughly corresponds to South.N-O (Chapter 4 this thesis).

This information is supported by the faunal remains, which show intensification of the smaller ruminants (sheep and goats) and the appearance of domesticated cattle, along with decreases in the size of cattle (Fig. 4.2) and changes in the demographic compositions of cattle (Fig. 4.7 and 4.8) (Russell et al. 2012). The first non-ruminant adipose lipid residues are also seen during stratigraphic level 4040.G (Fig. 4.3b). It is not clear why non-ruminant adipose fats would be less prominent during the earliest levels.

According to Düring (2007) the appearance of streets and alleys at Çatalhöyük takes place around Level V (~South.P or North.H). Perhaps this spatial separation was the result of increased competition of goods between households or the disintegration of the neighbourhood system (further discussed in section 6.2 of this thesis). Düring also points out that the space used at Çatalhöyük decreases at this time and smaller settlements appear in the surrounding area so that Çatalhöyük is no longer the sole settlement on the Konya Plain. Perhaps the population reached a critical tipping point ca. Level VI (4040.G/South.N-O) after which it became difficult to maintain the sharing of resources and the control of behavior so that it became necessary to break the population into smaller groups. With the appearance of milk also occurring during the height of population density it does seem possible that some level of scarcity was present that may have encouraged the incorporation of dairy into the diet of the peoples of Çatalhöyük.

Although it is still not clear whether cattle domestication occurred on-site or was the result of influences from outside sources it is hoped that further analysis of the faunal data will make this clearer. However, it does appear that the adoption of domesticated cattle was quite sudden, with a dramatic reduction in specimen size occurring along with an increase in the relative juvenile (79%) and female remains (86%) ca. level VI (Arbuckle 2012; Russell et al 2012). Despite this wild auroch (bovine) specimens still appear on site as the result of continued hunting practices, particularly in feasting environments (Arbuckle 2012).

6.1.3 Palaeoenvironmental proxy

The utilization of GC-TC-IRMS allowed for the acquisition of δD values of 34 residues, along with 6 modern plant samples as an approximate reference for current local ground water δD values, has provided a record of changes in precipitation levels during the Neolithic occupation of Çatalhöyük (Chapter 5 this thesis). It is argued in this thesis that GC-TC-IRMS analysis of of $C_{18:0}$ and $C_{16:0}$ fatty acids retained in archaeological pottery do provide δD values that reflect palaeoenvironmental changes in local hydrology. More work is needed to fully understand absolute value changes of this nature, however the current method of assessment does provide an adequate tool for studying relative precipitation level trends of the past. A deeper understanding of metabolic and kinetic effects on δD values during biosynthetic processes occurring within ruminant animals could help establish a method for assessing absolute value changes in comparison with groundwater δD values.

The results of this project suggest that during the Neolithic Çatalhöyük experienced a drying period with an onset occurring ca. 6600 cal BC (Fig. 5.6 of this thesis). It is possible that this is a reflection of a local hydrological response to the 8.2 ka cooling event, which has not previously been confirmed as having a great affect in this region. This global climatic event is thought to have occurred between 6700-5800 cal BC with a peak of negative isotopic values appearing in North Atlantic records ca. 6200 cal BC (Daley 2011). In fact Douglas Baird (2012) recently pointed to the stability of settlement structures in Anatolia as an indication that there were no significant impacts of the 8.2 ka cooling event in the region, particularly noting relative stagnation in pottery design. However, at Çatalhöyük, as outlined throughout this thesis, we do see many shifts in various cultural elements including the proliferation of decorative pottery as well as changes in subsistence practices that may tell another story. Although it may not seem that these changes are quite as significant as the transition from the Neolithic to the Chalcolithic, they are worth noting.

However as seen in Figure 6.1 (adapted from Fleitmann et al. 2009) it does appear that the records shown here show similar dips around the same time as the record produced from the δD values of the fatty acids at Çatalhöyük. In figure 6.1 this wiggle is most pronounced in the Botuvera Cave record (Fig. 6.1g). The estimated peak for this anomaly (ca. 8150 BP) has been marked in yellow (Daley 2011).

By comparing several proxies it is possible to further test the proxy developed herein. If compound-specific stable hydrogen isotope analysis of the fatty acyl components of lipid residues is found to be a robust palaeoenvironmental proxy, it stands to greatly expand the amount of information that can be gleaned from archaeological materials.

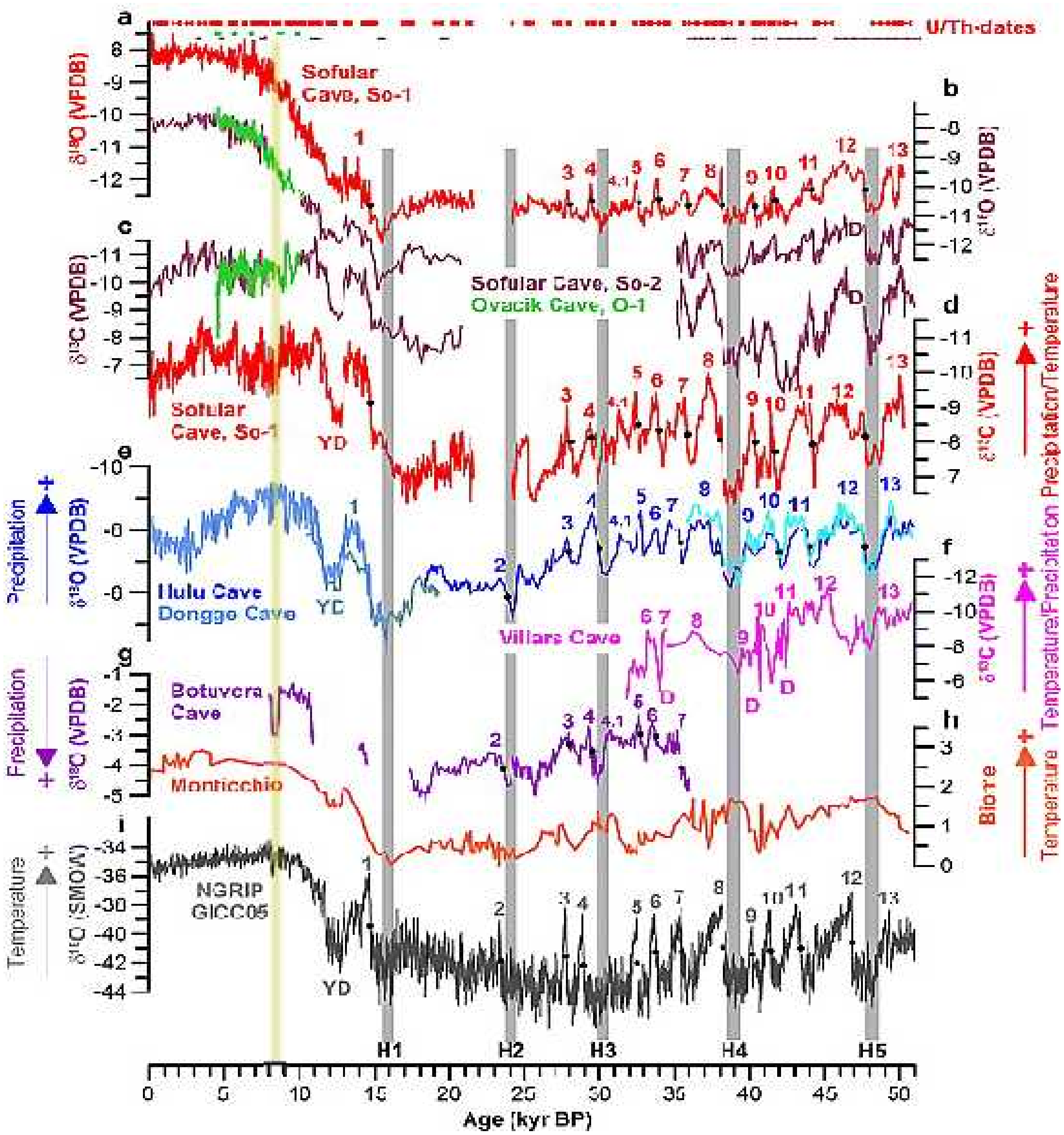

Figure 6.1. Stable isotope records of Sofular and Ovacık Caves in Turkey (a-d) as well as caves from China (e), France (f) and Brazil (g) with pollen from southern Italy (h) and the Greenland ice core record (i) adapted from Fleitmann et al. 2009 with the estimated peak of the 8.2ka climatic event marked in yellow ca. 8150 BP (Daley et al. 2011).

6.1.4 Factors influencing subsistence practices

The drying trend detected via δD analysis may have had implications for animal management strategies as detected in the faunal record through osteological and stable isotopic analysis. Both cattle faunal remains and caprine remains could be reflecting the development of dairying. The emergence of dairy production around South.G (roughly equivalent to South.N-O) may have been induced by the drying trend seen in the palaeoenvironmental record along with increased population pressure (Hodder *in press*, Chapters 5 this thesis). These increased pressures on the previously established food resources may have encouraged the exploration of additional food sources. Milk products would have been an excellent source of fat and protein that had the potential to be used year-round. Thus far it also seems as though lactose intolerance would have been prevalent in this population at this time. Recent models show lactose intolerance developing near the central Balkans (Fig. 6.1) ca. 7500 ya or around 6300 cal BC whereas the dairy lipid residues from Çatalhöyük are estimated to be from ca. 6580 cal BC (Itan et al. 2009; Cessford et al. 2005).

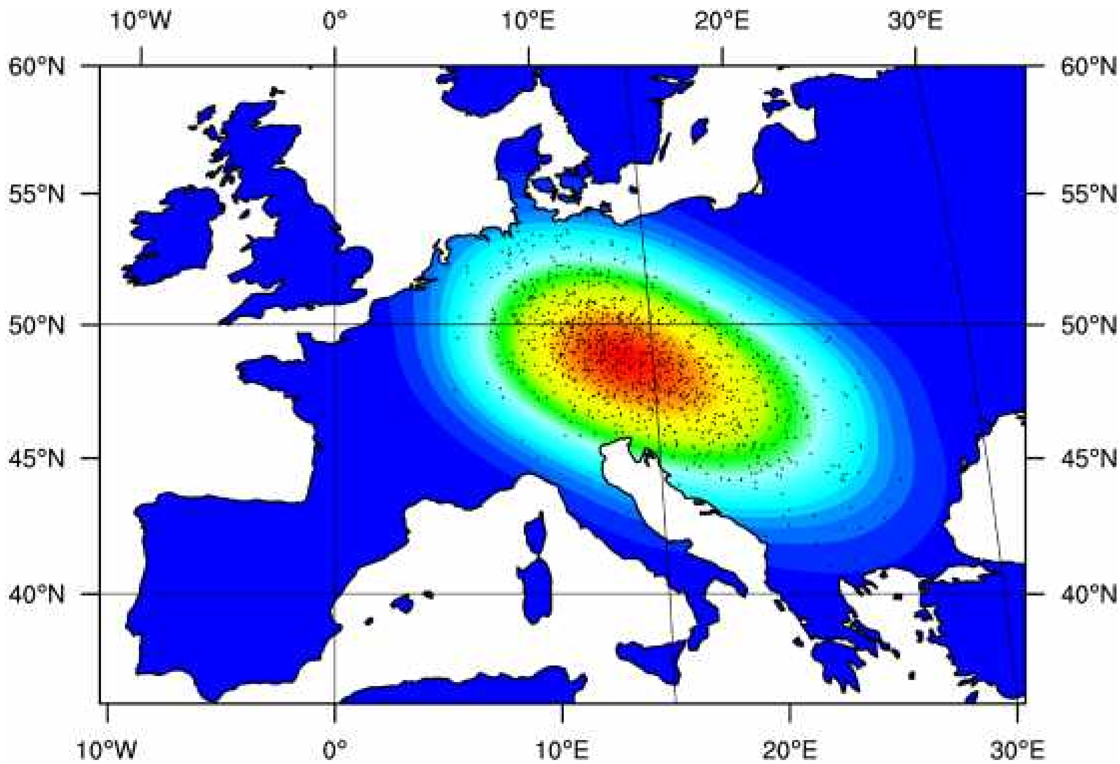

Figure 6.1. Estimated epicenter of the origin of the *−13,910*T* allele (from Itan et al. 2009**).**

6.2 Suggested future work

This particular project focused on the Neolithic portion of Çatalhöyük. After reviewing the palaeoenvironmental record as well as changes in subsistence practices during the Neolithic it is logical that similar analysis should be extended through the full chronology of site occupation. It is likely that many of these trends continue into the Chalcolithic. With an extension of the aforementioned analyses it is possible new information about the full effects of the 8.2 ka paleoclimatic event on this local area would be revealed.

The implications of this project are also that the production of similar, extensive organic residue records for other archaeological sites could reveal a wealth of information that has not previously been uncovered. With training archaeologists could provide carefully selected unwashed pottery samples from the rims of pots to laboratories equipped with HT-GC/MS, GC-C-IRMS and GC-TC-IRMS. Analyses following the protocols outlined in this thesis could provide additional information about the types of foods consumed, changes in the past environmental climate and changes in the intensification of specific types of foodstuffs as was demonstrated in this particular study of Çatalhöyük. The field of archaeology stands to benefit greatly from the use of such scientifically rigorous methods, which complement previously established methods of archaeological analysis. By combining all of these methods it is likely that much more will be understood about past civilizations. It is possible that a wider study of the development of agricultural management strategies and the forces driving change in subsistence practices of the past may help us understand how modern agricultural methods can and will be shaped in the future.

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Appendix A: Ware code descriptions

Rough English translations from the original Turkish provided via Google Translate.

*** DARK WARE ***

DMS - Dark Mineral Standard Ware

Dark mineral standar grubu mallar genellikle büyük kaplar oldukları için incelik ve kalınlık farkına göre yapılan ayrımlar yanıltıcı olabilmektedir. Bu nedenle Fine,Medium,Coarse (F, M, C) ayrımları katkı ve yüzey işlemine göre yapılmıştır. Buna göre;

Dark mineral standard group of large vessels grouped according to the fineness and the thickness although the distinctions can be misleading. For this reason, Fine, Medium, Medium (F, M, C) are distinctions made with respect to the surface. According to this:

DMS- fine (Özenli yapım) : Temiz bir hamur ve parlak/ parlakça açkılı

DMS- f 1 - Burnished
DMS- f 2 - Unburnished
DMS- f 3 - Slipped
DMS- f 4 - Mottled
DMS- f 5 - Painted
DMS- f 6 - Polished

DMS- medium (Sıradan yapım): Mevcut katkı orta yoğunlukta. Donuk, izli ve yer yer açkılı, nadiren açkısız (özellikle küçük parçalarda kabun tamamını göremediğimiz için arada bir açkısızların gelmeside mümkün).

Contribution to the existing medium density. Pale, burnished-track and from place to place, rarely without burnishing (especially for small parts cannot see the whole shell, it is possible for them to occassionally come without burnishing).

DMS- m 1 - Burnished
DMS- m 2 - Unburnished
DMS- m 3 - Slipped
DMS- m 4 - Mottled
DMS- m 5 - Painted
DMS- m 6 - Polished

DMS- coarse (kaba yapım): Mevcut katkı yoğun ve iri partiküller halinde ayrıca katkı genellikle yüzeyede yansıyor.Yüzey işlemi donuk , izli ve katkının yüzeye yansıması sonucu bozulmuş.

Dense and coarse particles also contribute in the current contribution is usually dull surface also its side.Processed dull surface and marred as a result of additives to the surface.

DMS- c 1 - Burnished
DMS- c 2 - Unburnished
DMS- c 3 - Slipped
DMS- c 4 - Mottled
DMS- c 5 - Painted

DMS- c 6 - Polished

DMS-sh- Dark Mineral –*shell like*- Thin Walled: Hamur temiz ve ince ise Dark mineral standart / fine grubuna dahil edilmekte. Bu yüzden shell like adı verilen grupta katkı belirgin ve ince yapılıyor. Buda brittle özelliği katıyor. Fine grubuyla shell like gurubunu ayıran bu brittle özelliği, yani ince ve brittle olması. Belirgin nitelikli bir grup olduğu için Fine,Medium,Coarse olarak ayrılmamıştır.

Clay is clean and fine minerals present. Dark standard / groups are fine. Shells present, whether obvious or subtle. Brittle features add to this group too. Grouped in a distinctive feature of the brittle shell, like a group of fine, thin and brittle to be so. If significant specimens may also be grouped as Fine, Medium, Coarse as listed.

DMS-sh 1 - Burnished
DMS-sh 2 - Unburnished
DMS-sh 3 - Slipped
DMS-sh 4 - Mottled
DMS-sh 5 - Painted
DMS- sh 6 - Polished

DMS-op- Dark Mineral Standart – *Orange Paste :* Bazı DMS’lerde daha kırmızımsı/ turuncumsu bir hamur rengi ile karşılaşılmakta. Bu durum hamur renginin pişme sırasındaki koşullarla değişmesi ile ilgili olabileceği gibi kilin doğal rengindende kaynaklanmış olabileceği düşünülmektedir. Kaynak analizleri ve pişme ile ilgili deneysel çalışmalar sonucunda daha fazla bilgi edinilmesi umulmakla birlikte DMS-op kabın genel mantığı açısından (ağırlık, katkı, yüzey işlemi, form) DMS grubundan çok farklı değildir. Böyle bir grup yapılasının nedeni sadece gelecek çalışmalarda kolaylık sağlamasıdır. Fine, medium, coarse ayrımı DMS kriterlerine göre yapılmıştır.

Some of DMS are more reddish / orange color depending on type of clay used. This is the color of the clay during baking and may be related to changes in conditions, such as the clay is thought to be caused by natural colors. As a result of resource analysis and experimental studies gather more information about cooking with the DMS-op is to be expected the general logic (in terms of weight, additives, surface treatment, the form of the container) this group is not very different from the DMS group. This group can only be defined by these factors in the future. Fine, medium, coarse distinction is made according to criteria of the DMS.

DMSop –f Dark Mineral Standart *orange paste* - fine

DMSop-f 1 - Burnished
DMSop-f 2 - Unburnished
DMSop-f 3 - Slipped
DMSop-f 4 - Mottled
DMSop-f 5 - Painted
DMSop-f 6 - Polished

DMSop –m Dark Mineral Standart *orange paste* - medium

DMSop-m 1 - Burnished
DMSop-m 2 - Unburnished
DMSop-m 3 - Slipped
DMSop-m 4 - Mottled
DMSop-m 5 - Painted

DMSop-m 6 - Polished

DMSop –c **Dark Mineral Standart *orange paste* - coarse**

DMSop-c 1 - Burnished
DMSop-c 2 - Unburnished
DMSop-c 3 - Slipped
DMSop-c 4 - Mottled
DMSop-c 5 - Painted
DMSop-c 6 - Polished

DMC – Dark Mineral Calcite

Ana çamur yapısı ve yüzey rengi açısından DM grubuna dahil. Ayrılma nedeni içindeki çarpıcı katkının calcite olduğunu düşündüğümüz iri ve orta boyutlardaki parçalar. Genellikle kenar kalınlıkları medium olan bu grup parçaların arasında zaman zaman ince parçalarlada karşılaşılmaktadır. Bu mal özelliklerine sahip profil veren parça olmadığından parçanın kabın neresinden olduğunu bilmemekteyiz. Bu yüzden şimdilik Fine,Medium,Coarse ayrımı yapılmamıştır. Zira mal grubu kabalığıyla tanımlanmaktadır. Bununla ilgili (F,M,C) kodlama sistemi karşımıza çıktıkça verilmektedir. İleride birer ayrım oluşturma olasılıkları nedeniyle yeterli parça olmadığından bu kıstaslar standartlaşmamıştır.

DM in terms of structure and surface color of the main clay groups. Reason for leaving outstanding contribution in the large and medium-sized parts that we think is Calcite. Generally, this group of medium thickness of the edge from time to time among the items encountered in thin parçalarlada. This cost is not piece of track, which features profiles of the place, do not know the container. This is why Fine, Medium, Coarse separation have been performed. Because goods are defined kabalığıyla. However, the (F, M, C) coding system as they are encountered. Creating a distinction in the future because of the possibilities of this criterion is not enough standardized parts.

DMCop – Dark Mineral Calcite *orange paste :* Aynı mal grubu özelliklerine sahip fakat daha dikkat çekici sarımsı, turuncumsu rengi nedeniyle önlem olarak ayrılmıştır.

DMM - Dark Mineral Mica

Bu mal grubuda DM özelliklidir.Ayrılma nedeni içindeki çarpıcı yoğunluktaki mika katkıdır. Bu mal grubunun tüm tip özellikleri bilinmediğinden Fine.Medium,Coarse kıstası olarak şimdilik kenar kalınlıkları dikkate alınacaktır. Çünkü bu konuda bir varyasyon varlığı sezinlenmiştir. Bu mal grubunda gözlenen bir diğer varyasyon mika boyutlarındaki farklılıklardır. Ancak küçük parçalar olduğundan bunun kabın geneline nasıl bir dağılım yaptığı henüz bilinmemektedir.Bu büyüklük farkının anlamlandırılması uzmanlık gerektirdiğinden ayrı bir ayrıma gidilmemiştir.

DMM-fine (fine ware , thin walled)

DMM-f 1 - Burnished
DMM-f 2 - Unburnished
DMM-f 3 - Slipped
DMM-f 4 - Mottled
DMM-f 5 - Painted
DMM-f 6 - Polished

DMM-medium (standard , medium size)

DMM-m 1 - Burnished
DMM-m 2 - Unburnished

DMM-m 3 - Slipped
DMM-m 4 - Mottled
DMM-m 5 - Painted
DMM-m 6 - Polished

DMM-coarse (coarse ware , thick walled)

DMM-c 1 - Burnished
DMM-c 2 - Unburnished
DMM-c 3 - Slipped
DMM-c 4 - Mottled
DMM-c 5 - Painted
DMM-c 6 - Polished

DMO - Dark Mineral and Chaff Tempered Ware (Late Levels)

DMO-f Fine Ware:

DMO-f 1 - Burnished
DMO-f 2 - Unburnished
DMO-f 3 - Slipped
DMO-f 4 - Mottled
DMO-f 5 - Painted
DMO- f 6 - Polished

DMO-m Medium Ware:

DMO-m 1 - Burnished
DMO-m 2 - Unburnished
DMO-m 3 - Slipped
DMO-m 4 - Mottled
DMO-m 5 - Painted
DMO-m 6 - Polished

DMO-c-Coarse Ware:

DMO-c 1 - Burnished
DMO-c 2 - Unburnished
DMO-c 3 - Slipped
DMO-c 4 - Mottled
DMO-c 5 - Painted
DMO- c 6 - Polished

DO-Dark Organic Tempered Ware (Early levels)

DO-f- Fine Ware:

DO-f 1 - Burnished
DO-f 2 - Unburnished
DO-f 3 - Slipped
DO-f 4 - Mottled
DO-f 5 - Painted
DO- f 6 - Polished

DO-m- Medium Ware:.

DO-m 1 - Burnished
DO-m 2 - Unburnished
DO-m 3 - Slipped
DO-m 4 - Mottled

DO-m 5 - Painted
DO- m 6 - Polished

DO-c- Coarse Ware:.

DO-c 1 - Burnished
DO-c 2 - Unburnished
DO-c 3 - Slipped
DO-c 4 - Mottled
DO-c 5 - Painted
DO- c 6 - Polished

*** LIGHT WARE ***

CM-Cream Mineral Ware (middle & late levels)

Genellikle homojen bir hamur yapısına sahip. Bu nedenle Fine,Standart,Coarse ayrımı kap boyutunu belirleme olasılığından dolayı kenar kalınlıklarına göre yapılmıştır. Çünkü daha çok çükük boyutlu kapların (tüm kaplarda incelik kalınlık kontrasının fazla olmadığı kapların) olduğu bir gruptur.

CM-f- Fine Ware,

CM-f 1 - Burnished
CM-f 2 - Unburnished
CM-f 3 - Slipped
CM-f 4 - Mottled
CM-f 5 - Painted
CM-f 6- Polished

CM-s- Standard (medium size or thin walled,)

CM-s 1 - Burnished
CM-s 2 - Unburnished
CM-s 3 - Slipped
CM-s 4 - Mottled
CM-s 5 – Painted
CM-s 6- Polished

CM-c-Coarse (thick walled, powdery, light in weight).

CM-c 1- Burnished
CM-c 2- Unburnished
CM-c 3- Slipped
CM-c 4- Mottled
CM-c 5- Painted
CM-c 6- Polished

CMC- Cream Mineral Calcite Ware

İçinceki çarpıcı calcite yoğunluğu nedeniyle ayrılan bu grupta Fine,Medium,Coarse özelliklerinin katkıyla değişmediği gözlemlendi bu nedenle bu kıstaslar kenar kalınlıklarına göre yapıldı.

Allocated due to the stunning intensity of calcite in this group sizes inside Fine, Medium, Coarse contribution does not change the properties observed in the thickness of the edge, so this was done according to the criteria.

CMC-f- Fine ware

CMC-f1	Burnished
CMC-f2	Unburnished
CMC-f3	Slipped
CMC-f4	Mottled
CMC-f5	Painted
CMC-f6	Polished

CMC-s- Standart , Medium

CMC-s1	Burnished
CMC-s2	Unburnished
CMC-s3	Slipped
CMC-s4	Mottled
CMC-s5	Painted
CMC-s6	Polished

CMC-c- Coarse ware (thick walled)

CMC-c1	Burnished
CMC-c2	Unburnished
CMC-c3	Slipped
CMC-c4	Mottled
CMC-c5	Painted
CMC-c6	Polished

<u>CMM- Cream Mineral Mica Ware</u>

İçinceki çarpıcı mica yoğunluğu nedeniyle ayrılan bu grupta Fine,Medium,Coarse özelliklerinin katkıyla değişmediği gözlemlendi bu nedenle bu kıstaslar kenar kalınlıklarına göre yapıldı.

Due to the density of mica separated this group sizes inside a stunning Fine, Medium, Coarse contribution does not change the properties observed in the thickness of the edge, so this was done according to the criteria.

CMM-f- Fine ware

CMM-f1	Burnished
CMM-f2	Unburnished
CMM-f3	Slipped
CMM-f4	Mottled
CMM-f5	Painted
CMM-f6	Polished

CMM-s- Standart , Medium

CMM-s1	Burnished
CMM-s2	Unburnished
CMM-s3	Slipped
CMM-s4	Mottled
CMM-s5	Painted
CMM-s6	Polished

CMM-c- Coarse ware (thick walled)

CMM-c1	Burnished
CMM-c2	Unburnished
CMM-c3	Slipped
CMM-c4	Mottled
CMM-c5	Painted
CMM-c6	Polished

CO-Cream Organic Tempered Ware : (early levels)

CO-f Thin walled, finer ware

CO-f 1 - Burnished
CO-f 2 - Unburnished
CO-f 3 - Slipped
CO-f 4 - Mottled
CO-f 5 - Painted
CO-f 6 - Polished

CO-s Standart , Medium size,

CO-s 1 - Burnished
CO-s 2 - Unburnished
CO-s 3 - Slipped
CO-s 4 - Mottled
CO-s 5 - Painted
CO-s 6 - Polished

CO-c- Thick walled, coarse ware

CO-c 1 - Burnished
CO-c 2 - Unburnished
CO-c 3 - Slipped
CO-c 4 - Mottled
CO-c 5 - Painted
CO-c 6 - Polished

CMO-Cream Mineral Organic Ware : (early levels)

CMO-f Thin walled, finer ware

CO-f 1 - Burnished
CMO-f 2 - Unburnished
CMO-f 3 - Slipped
CMO-f 4 - Mottled
CMO-f 5 - Painted
CMO-f 6 - Polished

CMO-s Standart

CMO-s1 - Burnished
CMO-s 2 - Unburnished
CMO-s 3 - Slipped
CMO-s 4 - Mottled
CMO-s 5 - Painted
CMO-s 6 - Polished

CMO-c- Thick walled, coarse ware

CMO-C 1 - Burnished
CMO-c 2 - Unburnished
CMO-c 3 - Slipped
CMO-c 4 - Mottled
CMO-c 5 - Painted
CMO-c 6 - Polished

Appendix A

OP- Orange Paste Ware

Bu grup hamur yoğunluğuna göre 2 gruba ayrılmıştır.
This group is divided into two subgroups

OPD – Orange Paste Dense : Sık dokuludur. F,M,C ayrımı yüzey işlemi ve katkı boyutları gözönüne alınarak yapılmıştır. Dense textures. F, M, C

Orange Paste Dense Fine ware

OPD-f 1 - Burnished
OPD-f 2 - Unburnished
OPD-f 3 - Slipped
OPD-f 4 - Mottled
OPD-f 5 - Painted
OPD-f 6 - Polished

Orange Paste Dense Medium ware

OPD-m 1 - Burnished
OPD-m 2 - Unburnished
OPD-m 3 - Slipped
OPD-m 4 - Mottled
OPD-m 5 - Painted
OPD-m 6 - Polished

Orange Paste Dense Coarse ware

OPD-c 1 - Burnished
OPD-c 2 - Unburnished
OPD-c 3 - Slipped
OPD-c 4 - Mottled
OPD-c 5 - Painted
OPD-c 6 - Polished

OPL – Orange Paste Loose : Daha gevşek dokuludur. Bu boşluğun nedeninin içindeki bitkisel katkı haricindeki organik katkılar olduğu düşünülmektedir. F,M,C ayrımında yüzey işlemi, katkı boyutu ve bunun yanısıra kenar kalınlığı dikkate alınmıştır. Loose grubu Cream Ware gibi daha homojen yapılıdır.

Looser texture. This is the reason for the gap in the organic section. Additives are thought to be non herbal supplements. Fine, medium, coarse surface differentiation process, contribution to the size and thickness as well as the edges of the walls are taken into account. Cream wares have a more homogenous structure.

Orange Paste Loose Fine ware

OPL-f 1 - Burnished
OPL-f 2 - Unburnished
OPL-f 3 - Slipped
OPL-f 4 - Mottled
OPL-f 5 - Painted
OPL-f 6 - Polished

Orange Paste Loose Fine ware

OPL-m 1 - Burnished
OPL-m 2 - Unburnished
OPL-m 3 - Slipped
OPL-m 4 - Mottled
OPL-m 5 - Painted
OPL-m 6 - Polished

Appendix A

Orange Paste Loose Coarse ware

OPL-c 1 - Burnished
OPL-c 2 - Unburnished
OPL-c 3 - Slipped
OPL-c 4 - Mottled
OPL-c 5 - Painted
OPL-c 6 - Polished

RP-Red Paste Ware :

RP- f - Red Paste Fine

RP -f 1 - Burnished
RP -f 2 - UnBurnished
RP -f 3 - Slipped
RP -f 4 - Mottled
RP -f 5 - Painted
RP -f 6 - Polished

RP- m - Red Paste Medium

RP -m 1 - Burnished
RP -m 2 - UnBurnished
RP -m 3 - Slipped
RP -m 4 - Mottled
RP -m 5 - Painted
RP -m 6 - Polished

RP- m - Red Paste Coarse

RP -c 1 - Burnished
RP -c 2 - UnBurnished
RP -c 3 - Slipped
RP -c 4 - Mottled
RP -c 5 - Painted
RP -c 6 - Polished

W-White Ware (late levels):

Separated into Fine , Medium , Coarse based on wall thickness

W-f White Ware Fine

W-f 1 -Burnished
W-f 2 -UnBurnished
W-f 3 -Slipped
W-f 4 -Mottled
W-f 5 -Painted
W-f 6 -Polished

W-f White Ware Medium

W-m 1 - Burnished
W-m 2 - UnBurnished
W-m 3 - Slipped
W-m 4 - Mottled
W-m 5 - Painted
W-m 6 - Polished

W-c White Ware Coarse

W-c 1 -	Burnished
W-c 2 -	UnBurnished
W-c 3 -	Slipped
W-c 4 -	Mottled
W-c 5 -	Painted
W-c 6 -	Polished

<u>S-Sandy Ware</u>

S- Sandy Ware Fine

S-f 1	-	Burnished
S-f 2	-	Unburnished
S-f 3	-	Slipped
S-f 4	-	Mottled
S-f 5	-	Painted
S-f 6	-	Polished

S- Sandy Ware Medium

S-m 1	-	Burnished
S-m 2	-	Unburnished
S-m 3	-	Slipped
S-m 4	-	Mottled
S-m 5	-	Painted
S-m 6	-	Polished

S- Sandy Ware Coarse

S-c 1	-	Burnished
S-c 2	-	Unburnished
S-c 3	-	Slipped
S-c 4	-	Mottled
S-c 5	-	Painted
S-c 6	-	Polished

TrH Transitional shelly ware

Includes landsnail shells in the paste.

Appendix B: Partial high temperature gas chromatograms

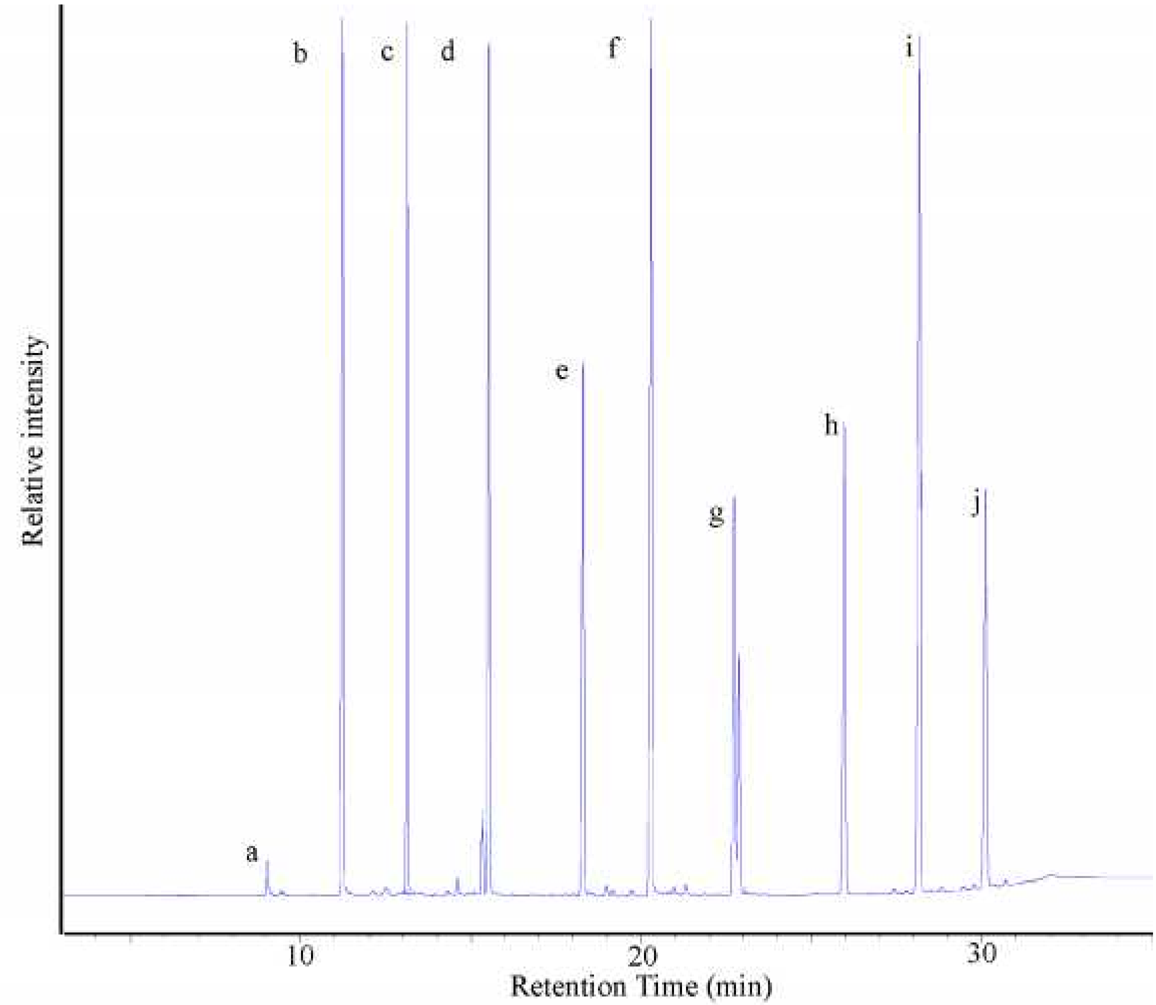

Figure B-1. Partial high temperature gas chromatogram of standard used for HT-GC analysis consisting of a mixture of known compounds: a) C_9 dicarboxylic acid, b) palmitic acid ($C_{16:0}$), c) stearic acid ($C_{18:0}$), d) 1-monopalmitoylglycerol ($C_{16:1}$), e) cholesterol, f) tetratriacontane, g) 1,2-dipalmitoylglycerol ($C_{16:2}$), h) trimyristin ($C_{14:3}$), i) tripalmitin ($C_{16:3}$), and j) tristearin ($C_{18:3}$).

Using the same labeling the following figures show examples of other partial high temperature gas chromatograms of potsherd samples run as part of this dissertation project. Palmitic acid (b) and stearic acid (c) are the most prevalent fatty acids present. Tetratriacontane (f) is the internal standard used to judge the concentrations of fatty acids found.

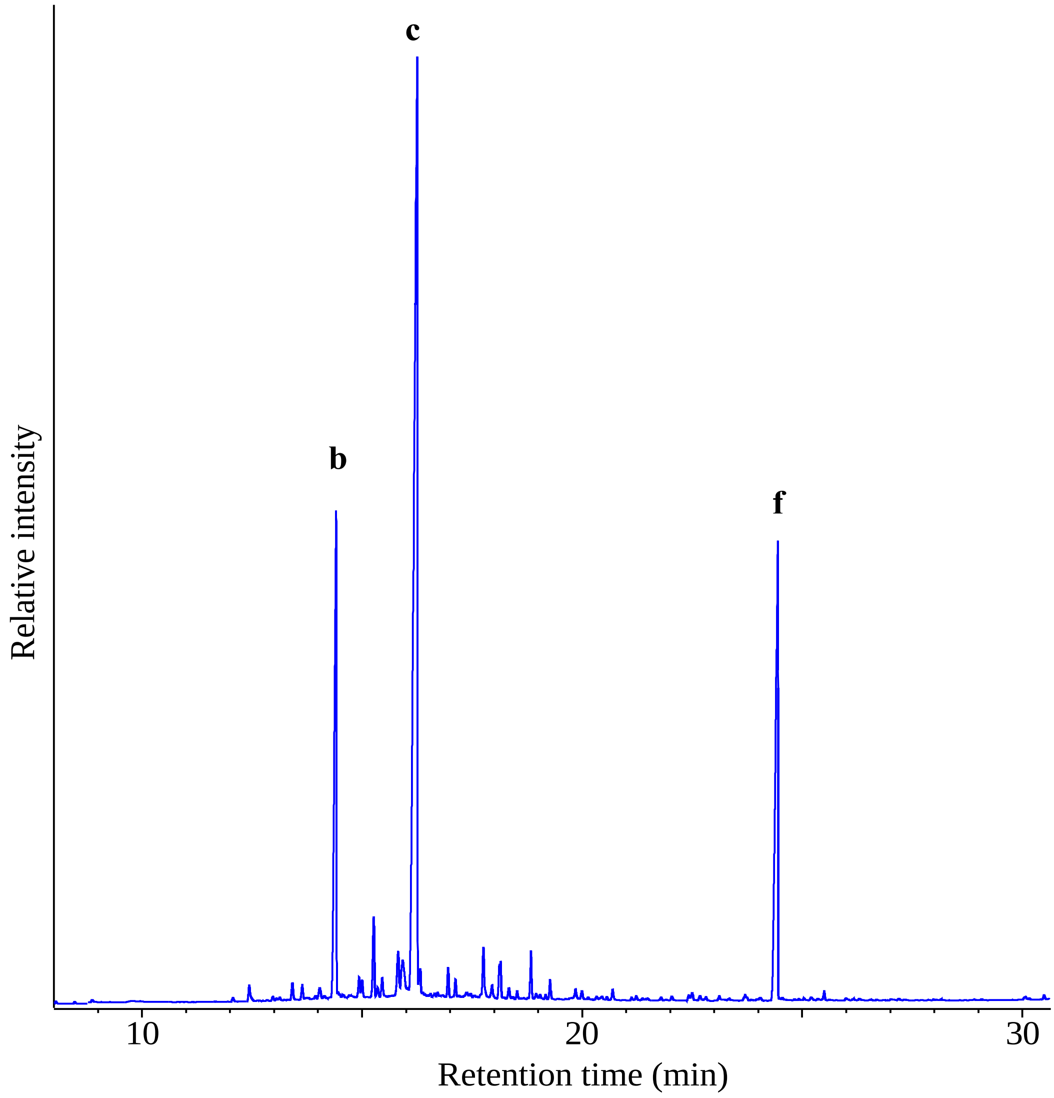

Figure B-2. Partial high temperature gas chromatogram of potsherd number P084 containing b) palmitic acid ($C_{16:0}$), c) stearic acid ($C_{18:0}$) and f) tetratriacontane.

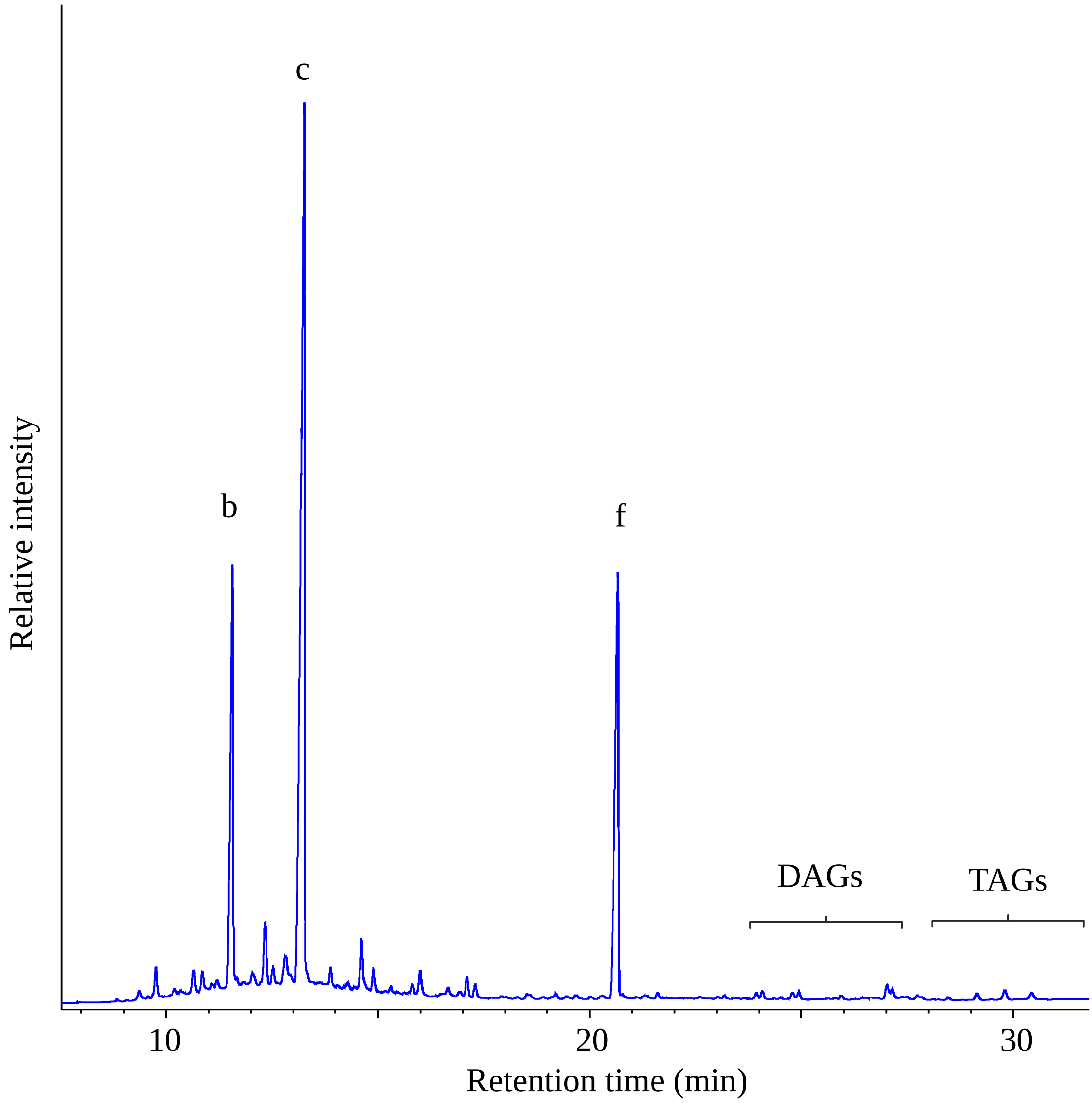

Figure B-3. Partial high temperature gas chromatogram of potsherd number 337 (Mellaart collection) containing b) palmitic acid ($C_{16:0}$), c) stearic acid ($C_{18:0}$), f) tetratriacontane and very low concentrations of DAGs and TAGs.

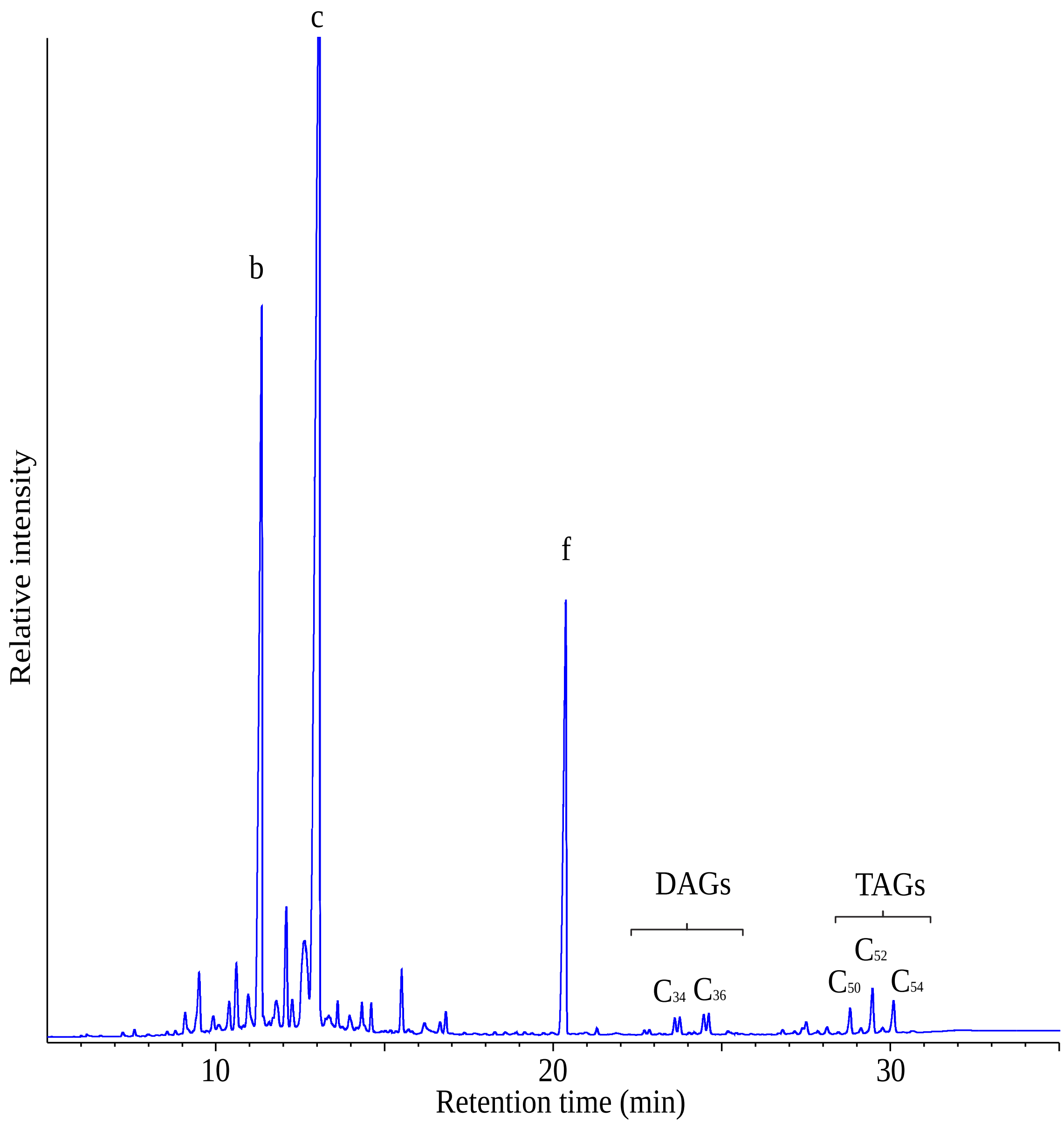

Figure B-4. Partial high temperature gas chromatogram of potsherd number T055 containing b) palmitic acid ($C_{16:0}$), c) stearic acid ($C_{18:0}$), f) tetratriacontane and low concentrations of DAGs and TAGs.

Appendix C: Radiocarbon data

Tables from Cessford et al. 2005

Table C-1. Radiocarbon determinations from the South Area of Çatalhöyük.

Lab. No.	Unit	Level	Building/ Space	Context	Material Dated	Reliability	Age (uncal BP)	SD	$\delta^{13}C$	Age (cal BC) to 1 S.D.	Age (cal BC) to 2 S.D.
P-796	N/A	II	A.II.1	Bin or hearth	Grain	High	7521	77	Unk	6440-6250	6480-6220
P-774	N/A	III	A.III.1	Unknown	Charcoal	Low	7531	91	Unk	6460-6250	6570-6210
A-18104	N/A	IV	E.IV.1	Post	Charcoal, juniper	Low	8065	50	-23.5%	7140-6830	7300-6750
A-18105	N/A	IV	E.IV.1	Post	Charcoal, juniper	Low	7710	100	-23.9%	6650-6450	7050-6250
A-19344	N/A	IV	E.IV.1	Post	Charcoal, juniper	Low	7620	50	-22.3%	6500-6415	6590-6380
A-19345	N/A	IV	E.IV.1	Post	Charcoal, juniper	Low	7626	52	-23.0%	6505-6420	6600-6380

A-19346	N/A	IV	E.IV.1	Post	Charcoal, juniper	Low	7670	50	-23.1%	6590-6440	6640-6420
A-19347	N/A	IV	E.IV.1	Post	Charcoal, juniper	Low	7998	54	-23.7%	7060-6820	7070-6690
A-19348	N/A	IV	E.IV.1	Post	Charcoal, juniper	Low	7982	52	-23.2%	7060-6770	7060-6690
A-19349	N/A	IV	E.IV.1	Post	Charcoal, juniper	Low	7944	65	-23.1%	7040-6690	7060-6650
A-19350	N/A	IV	E.IV.1	Post	Charcoal, juniper	Low	7918	54	-23.2%	7030-6680	7040-6640
A-19351	N/A	IV	E.IV.1	Post	Charcoal, juniper	Low	7747	65	-23.9%	6640-6480	6690-6440
P-775	N/A	IV	E.IV.1	Post	Charcoal, juniper	Low	8037	96	Unk	7120-6710	7350-6650
P-776	N/A	V	E.V.4	Post	Charcoal, juniper	Low	7640	91	Unk	6600-6400	6650-6250
P-1361	N/A	V	F.V.1	Hearth	Charcoal, juniper	Medium	7499	93	Unk	6440-6240	6500-6090
P-769	N/A	VIA	E.VI.A.25	Unknown, probably storage bin	Grain	High	7505	93	Unk	6440-6250	6510-6090
P-1365	N/A	VIA	E.VI.A.70	Ladder	Charcoal, juniper	Low	7729	80	Unk	6640-6460	6770-6410
P-1362	N/A	VIB	E.VI.B.27	Post	Charcoal, elm	Low	7904	111	Unk	7040-6640	7100-6500
P-797	N/A	VIB	E.VI.B.28	Post	Charcoal, juniper	Low	7629	90	Unk	6590-6390	6650-6250
P-777	N/A	VIB	E.VI.B.10	Post	Charcoal, juniper	Low	7704	91	Unk	6640-	6850-

										6450	6350
P-1364	N/A	VIB	E.VI.B.70	Post	Charcoal, elm	Low	7936	98	Unk	7040-6690	7100-6500
P-827	N/A	VI	E.VI.1	Burial	Charred human brain	High	7579	89	Unk	6510-6260	6600-6230
P-781	N/A	VI	A.VI.1	Roofbeam	Charcoal, oak	Low	7524	90	Unk	6450-6250	6510-6100
P-770	N/A	VI	A.VI.1	Roofbeam	Charcoal, juniper/oak	Low	7912	94	Unk	7030-6650	7100-6500
P-772	N/A	VI	E.VI.1	Post	Charcoal, oak	Low	7572	91	Unk	6500-6250	6600-6220
P-1375	N/A	VI	E.VI.25	Post	Charcoal, elm	Low	7661	99	Unk	6640-6420	6700-6240
P-1363	N/A	VI	E.VI.49	Beam	Charcoal	Low	7911	103	Unk	7040-6650	7100-6500
PL-972431A	1091	VII	Space 105	Fill of wall cut	Charred seeds, *Cerealae*	Medium to low	7810	80	-22.7%	6760-6480	7050-6450
AA-27980	1091	VII	Space 105	Fill of wall cut	Charred seeds, *Cerealae*	Medium to low	7790	60	-24.4%	6680-6500	6900-6450
PL-972431A and AA-27980 combined	1091	VII	Space 105	Fill of wall cut	Charred seeds, *Cerealae*	Medium to low	7797	48	N/A	6680-6500	6750-6470
PL-9800565A	1532	VII	Space 107	Construction	Charred seeds, *Cerealae*	Medium to low	8050	70	-22.6%	7140-6820	7300-6650
PL-980561A	1084	VII	Space 108	Floors	Charred seeds, *Cerealae*	Medium to low	7850	80	-22.3%	6990-6530	7050-6450

PL-9800507B	2701	VII	Space 109	Oven construction	Charred seeds, *Cerealae*	Medium to low	7850	90	-24.1%	7030-6530	7050-6450
PL-9800563A	1888	VII	Space 112	Hearth base	Charred seeds, *Cerealae*	Medium to low	7760	90	-22.4%	6660-6460	7050-6400
PL-9800570A	2730	VII	Space 112	Fill of scoop	Charred seeds, *Cerealae*	Medium to low	7800	90	-23.3%	6750-6470	7050-6450
PL-980520A	2704	VII	Space 112	Hearth base	Charred seeds, *Cerealae*	Medium to low	7780	80	-25.0%	6690-6470	7050-6400
PL-980519A	2703	VII	Space 112	Hearth lining	Charred seeds, *Cerealae*	Medium to low	7760	80	-22.5%	6650-6470	6900-6400
PL-980518A	2310	VII	Space 113	Floors	Charred seeds, *Cerealae*	Medium to low	7840	80	-24.0%	6980-6510	7050-6450
P-778	N/A	VII	E.VII.24	Unknown, probably storage bin	Grain	High	7538	89	Unk	6460-6250	6570-6210
P-1366	N/A	VII	E.VIII.45	Building fill	Charcoal	Low	7684	90	Unk	6640-6440	6700-6260
PL-980513A	2732	VIII	Space 115	Finely bedded midden	Charred seeds	Medium	7850	100	-22.2%	7050-6500	7050-6450
PL-9800566A	1579	VIII	Space 115	Coarsely bedded midden	Charred seeds	Medium	7820	90	-22.9%	6820-6500	7050-6450
PL-980560A	1587	VIII	Space 115	Finely bedded midden	Charred seeds, *Cerealae*	Medium	7910	80	-22.3%	7030-6650	7060-6590
PL-980511A	1883	VIII	Building 4, Space 151	Building fill	Charred seeds, *Cerealae*	Medium	7800	100	-22.9%	6800-6460	7050-6400
PL-980512A	2348	VIII	Building 4, Space 151	Building fill	Charred seeds, *Cerealae*	Medium	7860	100	-19.9%	7030-6590	7050-6500

P-1367	N/A	VIII	E.VIII.45	Hearth	Charcoal, elm/oak	Medium	7853	97	Unk	7030-6530	7050-6450
PL-980410A,B	2328	IX	Building 2, Space 117	Dump	Charcoal	Medium	7815	60	-24.4%, -24.5%	6730-6500	7050-6450
PL-9800568A	1889	IX	Building 2, Space 117	Bin fill	Charred seeds, *Cerealae*	Medium	7880	90	-21.9%	7030-6610	7100-6500
P-779	N/A	IX	E.IX.8	Floor and fill	Charcoal	Low	8190	99	Unk	7450-7060	7550-6800
P-1369	N/A	X	E.X.29	Midden	Charcoal	Medium	7937	109	Unk	7040-6680	7150-6500
P-1371	N/A	X	E.X.29	Midden	Charcoal	Medium	7844	102	Unk	7050-6500	7050-6450
P-1372	N/A	X	E.X.29	Midden	Charcoal, elm	Medium	7915	85	Unk	7030-6650	7060-6590
P-1370	N/A	X	E.X.28	Hearth	Charcoal, elm	Medium	8036	104	Unk	7140-6700	7350-6600
P-782	N/A	X	E.X.1	Hearth	Charcoal	Medium	8092	98	Unk	7310-6820	7450-6650
OxA-9774	4715	XI	Space 198	Penning deposit	Charred seeds, *Scirpus*	High	7935	50	-23.2%	7030-6690	7050-6650
OxA-9946	4715	XI	Space 198	Penning deposit	Charred seeds, *Scirpus*	High	7980	55	-23.3%	7050-6770	7060-6690
OxA-9774 and OxA-9946 combined	4715	XI	Space 198	Penning deposit	Charred seeds, *Scirpus*	High	7955	37	N/A	7040-6710	7050-6690
P-1374	N/A	XII	E.XII.29	Building fill	Charcoal, elm	Low	7757	92	Unk	6660-	7050-

										6460	6400
OxA-9947	4822	XII	Space 199	Penning deposit	Charred seeds, *Triticum/Hordeum/Scirpus*	High	7985	50	-22.4%	7060-6820	7060-6690
OxA-9775	4826	XII	Space 199	Burning event	Charred seeds, *Triticum/Scirpus*	High	8090	55	-20.5%	7290-6860	7320-6820
OxA-9948	4826	XII	Space 199	Burning event	Charred seeds, *Triticum/Scirpus*	High	8090	50	-20.7%	7290-6860	7310-6820
OxA-9775 and OxA-9948 combined	4826	XII	Space 199	Burning event	Charred seeds, *Triticum/Scirpus*	High	8090	37	N/A	7180-7040	7300-6860
OxA-9949	4848	Pre XII.A	Space 181	Burning event	Charred seeds, *Pisum*	High	8050	50	-21.7%	7080-6820	7300-6700
OxA-9950	5276	Pre XII.B	Space 181	Lime burning	Charred seeds, *Triticum/Pisum*	High	8030	50	-21.4%	7080-6820	7090-6700
OxA-9776	5292	Pre XII.B	Space 181	Fill of scoop	Charred seeds, *Scirpus*	High	7985	55	-23.5%	7060-6770	7060-6690
OxA-9892	5317	Pre XII.C	Space 181	Burning event	Charred seeds, *Lens*	High	8150	50	-23.7%	7300-7060	7330-7050
OxA-9777	5323	Pre XII.C	Space 181	Coarsely bedded midden	Charred seeds, *Lens*	High	8160	50	-23.9%	7300-7070	7330-7050
OxA-11267	5323	Pre XII.C	Space 181	Coarsely bedded midden	Silicified/ Calcified seeds, *Celtis*	High	8050	60	-10.1%	7120-6820	7300-6700
OxA-9778	5324	Pre XII.D	Space 181	Alluviated dump	Charred seeds, *Triticum/Pisum*	High	8240	55	-21.4%	7450-7080	7480-7080
OxA-9893	5329	Pre	Space 181	Alluviated	Charred seeds,	High	8155	50	-22.0%	7300-	7330-

		XII.D		dump	*Triticum/Scirpus/Cerealae*					7070	7050
PL-980525A	N/A	?Pre XII.D	Core ÇH94A	Unknown	Charcoal	Medium	8390	90	-24.0%	7580-7330	7600-7180
AA-27982	N/A	?Pre XII.D	Core ÇH94A	Unknown	Charcoal	Medium	8195	80	-24.0%	7320-7070	7480-7050
PL-980525A and AA-27982 combined	N/A	?Pre XII.D	Core ÇH94A	Unknown	Charcoal	Medium	8283	60	N/A	7480-7180	7520-7080

Table C-2. Radiocarbon determinations from the North Area of Çatalhöyük.

Lab. No.	**Unit**	**Phase/ subphase**	**Context**	**Material dated**	**Reliability**	**Age (uncal BP)**	**SD**	**δ^{13}C**	**Age (cal BC) to 1 S.D.**	**Age (cal BC) to 2 S.D.**
OxA-11046	3810	B5.B	Packing against wall	Charred seeds, *Triticum dicoccum*	Medium	7730	50	-21.3	6640-6470	6650-6460
OxA-11043	2166	B1.1B	General fill	Charred seeds, *Triticum dicoccum*	Low	7680	50	-22.8	6590-6450	6640-6430
OxA-11042	2165	B1.1B	General fill	Charred seeds, *Triticum/ Hordeum*	Low	7785	45	-23.1	6650-6500	6690-6470
PL-980558A	2181	B1.1B	General fill	Charcoal	Low	7910	80	-23.2	7030-6650	7060-6590
PL-972424A	2198	B1.1B	General fill	Charred seeds, *Cerealae*	Low	7940	80	-24.0	7040-6690	7070-6640
OxA-11052	2529	B1.1B	Skeleton	Human bone, old man	High	7860	45	-18.3	6820-	7030-

									6610	6570
OxA-11045	3036	B1.E	External fill	Charred seeds, *Lens*	Medium	7620	45	-21.0	6480-6420	6590-6390
OxA-11268	3036	B1.E	External fill	Calcified seeds, *Celtis*	Medium	7630	50	-9.4	6500-6420	6600-6390
OxA-11044	3030	B1.E	External fill	Charred seeds, *Lens*	Medium	7680	50	-21.0	6590-6450	6640-6430
OxA-11269	3030	B1.E	External fill	Calcified seeds, *Celtis*	Medium	7530	45	-11.4	6440-6260	6460-6240
PL-972126A	1442	B1.2A	Fill of basin	Charred seeds, *Cerealae*	Medium	7830	80	-22.4	6820-6450	7050-6450
PL-9800562A	1416	B1.2	Floor sequence	Charred seeds, *Cerealae*	Medium	7640	90	-22.7	6590-6400	6650-6250
AA-27979	1416	B1.2	Floor sequence	Charred seeds, *Cerealae*	Medium	7700	60	-23.5	6590-6460	6650-6440
OxA-11079	1429	B1.2B	Floor sequence	Charred seeds, *Cerealae*	Medium	7590	60	-22.6	6480-6385	6570-6250
OxA-11176	1417	B1.2B	Floor sequence	Charred seeds, *Cerealae*	Medium	7465	75	-21.6	6400-6240	6460-6100
OxA-11040	1459	B1.2B	Floor sequence	Charred seeds, *Cerealae*	Medium	7640	45	-21.7	6505-6430	6600-6410
OxA-11051	2115	B1.2B	Skeleton	Human bone, old woman	High	7855	45	-18.5	6810-6590	7030-6560
PL-972425A	2124	B1.2B	Grave fill	Charcoal	Low	8070	80	-24.3	7290-6820	7350-6650
OxA-11028	1226	B1.2B	Fill of scoop	Charred seeds, *Cerealae*	Medium	7780	40	-22.6	6650-6500	6690-6470
OxA-11078	1415	B1.2C	Floor	Charred seeds, *Cerealae*	Medium	7515	60	-22.2	6440-	6460-

			sequence						6250	6230
OxA-X-1084-07	1424	B1.2B	Skeleton	Inhaled particulate carbon	Low	7190	140	-23.0	6220-5910	6400-5750
OxA-X-1045-13	1456	B1.2C	Floor sequence	Animal bone, sheep and cattle sized fragments	Medium	7850	110	-18.9	7050-6500	7050-6450
OxA-11032	1456	B1.2C	Floor sequence	Charred seeds, *Cerealae*	Medium	7765	40	-22.0	6650-6500	6650-6470
OxA-11155	1454	B1.2C	Floor sequence	Charred seeds, *Cerealae*	Medium	7710	50	-21.6	6590-6460	6640-6450
OxA-11049	1959	B1.2C	Skeleton	Human bone, juvenile	High	7760	50	-19.4	6650-6500	6660-6460
OxA-11050	1960	B1.2C	Skeleton	Human bone, juvenile	High	7775	50	-19.3	6650-6500	6690-6460
OxA-11049 and 11050 combined	1959/ 1960	B1.2C	Skeletons	Human bone, juveniles	High	7768	35	N/A	6650-6500	6650-6470
OxA-11029	1332	B1.3	Storage	Charred seeds, *Lens*	High	7730	45	-24.1	6600-6470	6650-6460
OxA-11712	1332	B1.3	Storage	Charred seeds, *Lens*	High	7705	55	-23.0	6590-6460	6650-6440
OxA-11077	1344	B1.3	Storage	Charred seeds, *Lens*	Low	7540	60	-23.3	6460-6260	6470-6230
OxA-11713	1344	B1.3	Storage	Charred seeds, *Lens*	High	7755	55	-23.5	6640-6500	6690-6460
OxA-11029, OxA-11712 and OxA-11713	1332 / 1344	B1.3	Storage	Charred seeds, *Lens*	High	7730	29	N/A	6600-6480	6640-6460

combined										
OxA-11182	1344	B1.3	Storage	Animal bone, wild goat horn core 1344.X4	Medium	7535	45	-15.5	6450-6260	6460-6250
OxA-11041	2142	B1.3	Fill of posthole	Charred seeds, *Hordeum vulgare var.*	Medium	7655	45	-22.6	6530-6430	6600-6420
PL-9800521A	2142	B1.3	Fill of posthole	Charred seeds, *Cerealae*	Medium	7820	90	-22.9	6820-6500	7050-6450
OxA-11075	1400	B1.3	General fill	Animal bone, cattle skull with horncores 1400.X3	Medium	7725	75	-17.9	6640-6460	6700-6420
PL-972139A	1349	B1.3	Fill of basin	Charred seeds, *Cerealae*	Medium	7710	70	-23.0	6600-6460	6660-6420
AA-27978	1349	B1.3	Fill of basin	Charred seeds, *Cerealae*	Medium	7710	70	-22.1	6600-6460	6660-6420
PL-972139A and AA-27978 combined	1349	B1.3	Fill of basin	Charred seeds, *Cerealae*	Medium	7710	49	N/A	6590-6460	6640-6450
OxA-11031	1390	B1.4	Stakehole	Charred seeds, *Cerealae*	Medium	7675	50	-23.2	6590-6440	6640-6430
OxA-11545	1391	B1.4	Stakehole	Charred seeds, pulses	Medium	7670	40	-22.8	6590-6440	6600-6430
OxA-11183	1366	B1.4	Base of hearth	Charred seeds, *Cerealae*	Medium	7750	45	-21.6	6640-6500	6650-6460
OxA-X-1042-22	1358	B1.4	Floor sequence	Animal bone, sheep sized fragments	Medium	7870	60	-17.8	6990-6640	7050-6500

OxA-11030	1358	B1.4	Floor sequence	Charred seeds, *Triticum dicoccum*	Medium	7685	40	-23.5	6590-6450	6640-6440
OxA-11048	1466	B1.4	Skeleton	Human bone, adult man	High	7800	50	-17.7	6690-6500	6800-6450
OxA-11047	1378	B1.4	Skeleton	Human bone, old man	High	7790	50	-17.9	6660-6500	6750-6460
OxA-X-1084-08	1378	B1.4	Skeleton	Inhaled particulate carbon	Low	7330	75	-24.7	6250-6070	6390-6020
OxA-11007	1334	B1.5B	Pit fill	Animal bone, worked point 1334.X14, sheep/goat metacarpal	Medium	7630	45	-18.4	6500-6420	6590-6400

Table C-3. Radiocarbon determinations from the KOPAL Area of Çatalhöyük.

Lab. No.	Unit	Phase	Material Dated	Age (uncal BP)	SD	$\delta^{13}C$	Age (cal BC) To 1 S.D.	Age (cal BC) To 2 S.D.
PL-9800526B	2410 =6020/ 6086	Buried soil horizons and land surfaces	Charcoal	7180	80	23.0%	6200-5920	6220-5880
AA-27983	2410 =6020/ 6086	Buried soil horizons and land surfaces	Charcoal	7015	55	-23.2%	5980-5810	6000-5740
PL-9800526B and AA-27983 combined	2410 =6020/ 6086	Buried soil horizons and land surfaces	Charcoal	7069	45	N/A	6000-5840	6020-5810
OxA-10092	6020 =6086	Buried soil horizons and land surfaces	Charred seeds, *Triticum*	7185	65	-22.2%	6160-5920	6220-5910
OxA-9980	6020 =6089	Buried soil horizons and land surfaces	Charred seeds, *Triticum*	7955	75	-19.4%	7040-6700	7060-6650
OxA-9980 and OxA-10092 combined (X-Test fails at 5%)	6020	Buried soil horizons and land surfaces	Charred seeds, *Triticum*	7543	49	N/A	6460-6260	6470-6240
OxA-9771	6013	Renewed natural backswamp clay formation	Charred seeds, *Triticum*	7965	55	-21.8%	7040-6770	7060-6690
OxA-9943	6013	Renewed natural backswamp clay formation	Charred seeds *Triticum*	7910	55	-22.1%	7030-6650	7040-6640
OxA-9771 and OxA-9943 combined	6013	Renewed natural backswamp clay formation	Charred seeds, *Triticum*	7938	39	N/A	7030-6700	7040-6680
PL-9800522A	2412 =6010	Quarry pits and related activities	Charred seeds, *Cerealae*	7830	90	-22.4%	6980-6500	7050-6450

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OxA-9772	6075	Quarry pits and related activities	Charred seeds, *Triticum*	8025	55	-21.0%	7070-6820	7140-6690
OxA-9944	6075	Quarry pits and related activities	Charred seeds, *Triticum*	7975	50	-20.9%	7050-6770	7060-6690
OxA-9772 and OxA-9944 Combined	6075	Quarry pits and related activities	Charred seeds, *Triticum*	7998	37	N/A	7060-6820	7060-6700
AA-47057	6025	Quarry pits and related activities	Animal bone, cattle phalanx	8085	66	-18.2%	7300-6830	7350-6750
OxA-9945	6079	Unknown	Charred seeds, *Scirpus*	7775	50	-23.0%	6650-6500	6690-6460

Table C-4. Radiocarbon determinations from the BACH Area and cores from Çatalhöyük.

Lab.Ref.	Area	Unit	Context	Material Dated	Age (uncal BP)	SD	$\delta^{13}C$	Age (cal BC) to 1 S.D.	Age (cal BC) to 2 S.D.
PL-980514A	BACH	2215	Building fill	Charred seed	7810	100	-24.7	6810-6470	7050-6450
PL-980559A	BACH	2255	Building fill/midden	Charcoal	7730	80	-24.4	6640-6460	6770-6410
AA-27976	BACH	2255	Building fill/midden	Charcoal	7780	55	-24.6	6650-6500	6750-6460
PL-980559A and AA-27976 combined	BACH	2255	Building fill/midden	Charcoal	7764	45	N/A	6650-6500	6660-6460
PL-980515A	BACH	2256	Building fill	Charred seeds	7620	100	-23.6	6600-6270	6650-6230
PL-980524A	Core ÇH96W	N/A	Unknown	Charcoal	6940	80	-24.4%	5890-5720	5,990-5660
AA-27981	Core ÇH96W	N/A	Unknown	Charcoal	7040	40	-24.8%	5990-5840	6,000-5800
PL-980524A and AA-27981 combined	Core ÇH96W	N/A	Unknown	Charcoal	7024	37	N/A	5980-5840	5,990-5800
Beta-90022	Core ÇH95F	N/A	Unknown	Organic matter	6760	80	-24.2%	5730-5560	5,800-5510