Clay Pot Cookery: Dairy, Diet and Class during the South Levantine Iron Age II Period

Mary K. Larkum
University of Massachusetts Amherst

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Clay Pot Cookery:
Dairy, Diet and Class during the South Levantine Iron Age II Period

A Dissertation Presented

by

Mary K. Larkum

Submitted to the Graduate School of the University of Massachusetts Amherst in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

September 2016

Anthropology
Clay Pot Cookery:
Dairy, Diet and Class during the South Levantine Iron Age II Period

A Dissertation Presented
by
MARY K. LARKUM

Approved as to style and content by:

__________________________________________
Michael O. Sugerman, Chair

__________________________________________
Krista Harper, Member

__________________________________________
Steven T. Petsch, Member

__________________________________________
Jacqueline L. Urla, Chair
Anthropology
For my daughter Emerald and for Mark.

I got you.

“The Bible never purports to provide dietary advice. Even the biblical food laws serve very different purposes than modern nutritional advice. Nevertheless, the Bible has much to say about food that deserves attention, such as the importance of sharing food with those less fortunate than ourselves.”

- Nathan MacDonald
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ABSTRACT

CLAY POT COOKERY:
DAIRY, DIET AND CLASS DURING THE SOUTH LEVANTINE IRON AGE II PERIOD
SEPTEMBER 2016
MARY K. LARKUM, B.A., UNIVERSITY OF MASSACHUSETTS AMHERST
M.Phil., CAMBRIDGE UNIVERSITY
Ph.D., UNIVERSITY OF MASSACHUSETTS AMHERST
Directed by: Professor Michael O. Sugarman

Goody’s (1982) model of cooking and its relation to hierarchy posits a correlation between class and cuisine that is typical of societies practicing intensive agriculture and creating storable surpluses. This archaeological case study tests his model using gas chromatography/mass spectrometry (GC/MS) analyses to investigate ancient food remains (fatty acids) preserved in unglazed clay cooking ceramics from archaeological sites across the Iron Age II period (1000-586 BCE) kingdoms of the southern Levant. These kingdoms are known historically as Ammon, Aram (Aram-Damascus), Edom, Israel, Judah, Moab and Philistia. Samples from this time period and region are suitable for use in this research because archaeological evidence dating to the Iron Age II (1000-586 BCE) indicates socially stratified populations practicing intensive agriculture. Laboratory results suggest differences in south Levantine clay pot cookery related to environment and to social hierarchy.
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CHAPTER 1
INTRODUCTION

Food is an important component of human culture (see, for example, Goody 1982; Levi-Strauss 1970; Mennell et al. 1992; Messer 1984; Tapper and Zubaida 2000; Hamilakis 1999; Samuel 1999). Foods prepared and consumed by societies serve to reinforce social bonds, define identity and mark occasions; considerations above and beyond the provision of basic nutritional requirements. The anthropological study of foodways has a long history of illuminating social processes, examining a varied range of problems in theory and research methods (Mintz and DuBois 2002: 100).

Anthropological studies suggest that eating is an historically and socially constructed practice, an expression of identity and an act of political, economic and social relevance (Bray 2003; Douglas 1987; De Garine and De Garine 2001; Dietler and Hayden 2001; Vives-Ferrándiz 2008; Wilson 2005). The study of food remains from archaeological contexts can contribute to our understanding of ancient food use and its relation to status (Bray 2003; Cool 2006; Grottanelli and Milano 2004; Hastorf 1998b; Wilkins and Hill 2006).

1.1 Common Approaches to the Archaeological Study of Animal Products

Feasting has been the primary focus of case studies examining food and status in Near Eastern archaeological contexts (Altmann and Fu 2014; Aranda Jiménez, Montón-Subías; and Sánchez Romero 2011; Bray 2003; Greer 2013; Kletter and Saarelainen 2014; Smith 2015; Yasur-Landau 2005). Smith (2015: 1216) defines a feast as “a larger-than-quotidian meal that often incorporates distinctive foods, labor-intensive modes of
preparation, and special-purpose serving utensils” (see also Dietler and Hayden 2001b: 3; Hayden and Villeneuve 2011: 434; Twiss 2008: 419).

Smith (2015: 1215-1216) posits that archaeologists focus on feasting for practical reasons. Big meals often leave distinct material signatures such as large middens, unusual food remains, or deposits perceived to have been made during a single episode of activity or comprising large numbers of durable items such as restorable serving vessels and animal bones (see also McNiven 2012; Hayden and Villeneuve 2011: 441).

Archaeologists also focus on feasting because the physical remains of mass-consumption events provides proxy evidence for social and economic activities that are otherwise difficult to elicit from the material record, such as human-environmental dynamics (through the presence or absence of particular wild species and/or domesticates), authority and skill (the size of a kill, the labor required to prepare food), and the location of food consumption relative to other socially meaningful locations such as mortuary contexts, households, and religious structures (Smith 2015: 1216).

Fewer studies have focused on quotidian foodways and hierarchy. Faunal analysis, the study of animal bones from archaeological deposits, is one investigative technique that has been used archaeologically to identify qualitative and quantitative differences in food use that can be ascribed to status. Faunal research includes detailed taphonomic study of large bone assemblages, analysis of bone surface modification and the traces of butchery on bone surfaces, body part description and demographic profiling of herd animals by age and sex (Marom et al. 2009: 56). Analytical results quantify the minimum number of animals present in a deposit, estimate numbers killed by butchering
and their approximate age at slaughter, and assess animal health and species variation (O’Connor 2008: 36-122).

Marom et al. (2009) analyzed animal remains from Tel Rehov, herd species such as sheep and goats, to assess social and economic status on the assumption that wealthier populations consumed better cuts of meat. Sapir-Hen et al. (2016) conducted a similar intra-site analysis investigating Strata VIIA and VIA faunal remains at Megiddo, which date to the LB III and late Iron I respectively. They examined social disparity between the populations of two areas of the city. They discovered a difference in social status and division of labor: a dichotomy between producer-consumers and consumers, who most probably interacted. They concluded that the inhabitants of one sector (Area K) engaged in agriculture and cottage industries, while the people in the other part of the city (Area H), close to the palace, were more affluent, were provisioned with food, and consumed better cuts of (and more) meat.

Domestic cooking has been characterized as conservative by nature because the symbolism invested in foods gives them a kind of ‘cultural inertia’. Food habits usually change gradually and incrementally (Wapnish and Hesse 1998: 124; Mintz 1996: 7). This thesis examines molecular evidence of cooking to investigate whether status differences can be discerned in non-feasting contexts.

The use of faunal analysis to study south Levantine foodways has most commonly addressed questions associated with ethnicity and Israelite dietary laws. An example of this can be seen in the use of faunal analysis, mainly the presence or absence of pig bones within the context of archaeological foodways, as a marker for Israelite and Judahite
ethnicity. For example, Hesse and Wapnish (1998) tabulated pig bone frequencies across sites in the southern Levant and interpreted their results to show a reliance on pig exploitation during the Middle Bronze Age (2200-1550 BCE) with “greatly diminished use” between the Late Bronze Age (1550-1200 BCE) through the Persian Period (586-332 BCE) except in Philistia during the Iron I Period (1200-1000 BCE). Archaeologists have used these results to ascribe Israelite and/or Judahite ethnicity to cultural deposits exhibiting an absence of pig bones, and some consider pig bone frequencies to be a reliable archaeological indicator of regional ethnic difference (Finkelstein 1996: 206; Stager 1995: 334). However, straightforward correlation between ethnic groups and the presence or absence of pig bones in archaeological deposits have been discouraged by the authors themselves (Hesse and Wapnish 1997: 238-270; Wapnish and Hesse 1998: 123-136). They maintain that attempts by archaeologists to use ‘pig avoidance’ to establish an oppositional reference separating the archaeological record of Israel and Judah from that of neighboring populations are confounded by the fact that most other social groups in the region apparently did not eat pork either (Hesse and Wapnish 1997: 262).

Textual sources, such as the Hebrew Bible, frequently mention the production and consumption of meat. Synthetic discussions of Iron Age food use have focused on Israelite and Judahite foodways (e.g., Borowski 1998; MacDonald 2008a, 2008b; Vamosh 2004). These authors confine their discussions of meat consumption to domesticated, ruminant species and source their data from both texts and archaeological faunal analysis. Although Biblical foodways literature has focused on discussions of ruminant exploitation, evidence of cut-marks associated with butchering on camel and donkey bones at Iron Age Hesban, for example, suggests that the range of species eaten
regionally was potentially wide (MacDonald 2008b: 33). Both wild and domestic species were routinely eaten by Mediterranean cultures including horse, donkey, camel and dog. This is in addition to domesticated sheep, goats, cattle and pigs (Wilkins and Hill 2006: 144-150).

Both elites and non-elites had access to wild animals (such as wild boar, deer, gazelle, and small mammals like hare) as well as to numerous species of wild birds (Wilkins and Hill 2006: 150). So there is no reason to assume that ancient peoples only consumed meat from domesticated species raised within a market economy.

There is little consensus among archaeologists about the importance of meat in ancient daily life. Broshi (2001: 133), discussing Roman Palestine (37 BCE-324 CE), maintains that the general population rarely consumed meat, and there is no evidence of animals “having been raised for their meat”. MacDonald (2008a: 75), citing ethnoarchaeological studies of meat consumption in nomadic versus sedentary Bedouin groups in Palestine contends that, as Israel developed and became a centralized and urbanized state, more Israelites became sedentary and may have consumed more meat. The consumption of meat in pre-monarchic times (before the Iron Age II Period) was probably a relatively infrequent event, but “it became more common during the Israelite monarchies – at least in certain circles” (MacDonald 2008a: 75). MacDonald further writes that, during the Iron Age II, animals “may have been increasingly raised with the purpose of supplying meat” (2008a: 71).

Textual sources and ethnoarchaeology have also been used to discuss the ancient use of dairy products. McCormick (2012), for example, uses documentary sources to
discuss ancient dairying across a range of cultures. He notes that there are many problems associated with early documentary sources such as the difficulty of identifying the exact meaning of many of the linguistic terms used in ancient texts. “For instance, early terms for cheese rarely tell us about the nature of a particular cheese”. A second problem concerns content - it varies greatly - and includes financial accounts of Early Mesopotamia, religious hymns of Vedic India, legal texts from Ireland, and Roman agricultural manuals. Moreover, the survival of texts is haphazard and the information is generally partial and often difficult to interpret (McCormick 2012: 100-101).

The earliest documentary evidence for dairy produce comes from Mesopotamia in the centuries before 3000 BCE in the form of late Uruk proto-cuneiform administrative texts (McCormick 2012: 100). Cattle and goats were the main dairying animals in Mesopotamia, and there is less evidence that sheep milk was processed to the same extent (Englund 1995b: 382). As in Jordan, fresh milk quickly turned sour in the hot climate of early Mesopotamia and as a consequence appears not to have been consumed as a liquid to any great extent by adults. It was fed to babies and presented in religious ceremonies as offerings to gods (Stol 1993: 100). Milk was mainly processed to make butter and cheese.

Early Sumerian texts indicate that butter and cheese were made from soured milk (Stol 1993: 101). According to McCormick (2012: 100), the fact that the early sources note that this butter was poured and stored in similar vessels to other liquids indicates that butter was clarified. Butter would first have been produced in solid form and then boiled in order to remove the water content. It is the water in solid butter that causes it to turn rancid but processing increases its life for up to a year (Englund 1995a: 380). Clarified
butter would have had similar uses to olive oil, the latter being little used in early Mesopotamia (Limet 1987:135). Butter was used as an ingredient in cooking (Bottéro 2004: 33) and poured onto bread (Stol 1993: 103). It also had non-culinary uses. An Ur III (2112-2004 BCE) text indicates that it was used for sealing the hulls of boats (Englund 1995b: 409).

Early Sumerian cheese was made from the buttermilk left over from the butter churning process. Stol (1993:105-108) has concluded that the cheese was not true cheese using animal rennet but dried balls of buttermilk that could be crushed to a powder and mixed with water to produce ‘instant milk’. According to Englund (1995: 380b) this powdered-milk type cheese can be kept for years or even decades (Fig. 1: *jamid*).

There is also textual evidence for dairy consumption in neighboring Egypt. McCormick (2012: 103) states that documentary evidence is unclear whether fresh milk was a routine part of an adult Egyptian’s diet. There are many references to milk being used for medicinal purposes in early Egypt either on its own or mixed with other substances (Darby et al. 1977: 771-2). Milk appears to have also been used as an offering.
in religious ceremonies. Milk, along with large quantities of oxen, geese, wine, beer and incense are frequently recorded on stelae as offerings to gods during the Ptolemaic Period while an inscription in the tomb of King Horemheb (c. 1323-1295 BC) calls for grants of milk to be made to the gods for the deceased (Allan 1936: 44-70). Taken as a whole, the evidence from Egypt suggests that milk was rarely consumed by adults but, as in the case of early Mesopotamia, was drunk only by children or used in religious ceremonies (McCormick 2012: 104).

In contrast to Mesopotamia, there is relatively little evidence that the Egyptians processed milk to make butter or cheese. There have been occasional claims that fatty material found in jars is degraded cheese and some suggestions of possible identification of cheese based on iconographic evidence (Curtis 2001: 173; Darby et al. 1977: 733). However, there are no known words designating cheese or butter from the Pharaonic period, the earliest unequivocal evidence for the processing of cheese being from a third century BCE Greek source (Darby et. al. 1977: 733). Perhaps because the Egyptians used a wide range of oils they did not feel it necessary to process dairy fats (McCormick 2012: 104).

MacDonald (2008 a & b) and Borowski (2004: 100) use biblical text to interpret Israelite dairy product processing and use in discussions that closely mirror Palmer (2012), but they come to different conclusions. Borowski (2004: 100) maintains that fresh milk was frequently consumed to quench thirst, as suggested in the story of Jael and Sisera: "He [Sisera] said to her [Jael], 'Give me some water to drink, for I am thirsty.' She opened a skin of milk, (and) gave him a drink" (Judg 4:19). MacDonald (2008a:35), on
the other hand, argues that rapid souring of fresh milk suggests that it was not commonly consumed as a thirst quenching drink.

As with the study of meat use among Bedouin (see above, page 14), ethnoarchaeological case studies of Bedouin dairy product processing and consumption have been used as proxies for ancient practices. Researchers infer that ancient societies used similar techniques as modern counterparts given a similar set of environmental circumstances. An example is Palmer’s 2002 study of traditional wheat and milk products among town dwellers (fallahin) and Bedouin in Jordan. Many everyday, traditional, Jordanian meals are based on mixtures of grain and milk products, combining the dominant pastoral and agricultural elements of local economies (Palmer 2002: 173).

According to MacDonald (2008a: 92), this was also true of the ancient ‘Israelite diet’ of both pastoralists and sedentary town dwellers. However, pastoralists had access to a greater amount of dairy products. Milk is an important component of pastoral economies and, according to calculations by Russell (1988: 74) milk products in groups managing sheep and goats contribute circa 70 to 79% of the calorific productivity of pastoral herds.

However, sheep and goats provide milk for a relatively short period, two to three months in the case of sheep and around four to five months for goats. For sheep and goats, the main season when milk products are made is the spring, from March onwards. Fresh milk curdles quickly in a hot climate. Therefore, milk is rarely consumed fresh, although, during the milking season, it may be consumed warmed and sweetened for breakfast when it is a favorite among children (Palmer 2002: 182).
Figure 2: stages in the milk processing sequence. source Palmer 2002

* Kishk is prepared only in northern Jordan.
Milk is fermented and churned in animal skins and only the preparation of *samn* (clarified butter) involves lengthy boiling in a fireproof container. The relative ease with
which milk and cereal products can be made, using limited material resources and of mostly perishable materials, decreases their apparent importance under archaeological circumstances. There is little evidence for early milk processing in the archaeological record (Betts and Russell 2000: 26). This is probably because early milk processing involved the use of the same perishable equipment. Along with cereal grains, conserved milk products have a long storage life, such that in poor years, there could still be a supply available from the previous year. Milk and cereals were, until recently, the major components of the rural Jordanian diet, and Palmer (2002: 193) contends that it is likely that they were the distant past as well.

1.2 Modeling Foodways

In his 1982 book *Cooking, Cuisine, and Class*, Goody argues that differences in food reflect differences in production modes. He posits that the shift from cultivation using simple tools like the hoe to intensive agriculture based on irrigation and the plough created food surpluses necessary for social hierarchy and led, ultimately, to the development of gourmet cuisine (Goody 1982: 208). This premise centers on an opposition between undifferentiated food use of sub-Saharan Africa (‘low’ cuisine) and the elaborate and specialized culinary practices of Europe and Asia (‘high’ cuisine).

Based on research conducted by Goody in northern Ghana between 1949 and 1979, he asks why African societies, specifically the LoDagaa and Gonja, which are hierarchical in other regards do not have hierarchical food customs. He notes that Gonja’s chiefs live like everyone else but simply have more of everything (Goody 1982: 67). Abundance, not exotic ingredients or intricate preparation methods characteristic of
‘high’ cuisine, marked status in 20th century northern Ghana. Food was not used as a means of expressing or increasing social status.

By contrast, Goody’s ‘high’ cuisine is the product of culinary specialists, usually male, using exotic ingredients and foreign cooking techniques to transform everyday foods into an expensive cuisine that separates elites from commoners (Luley 2014:35). This contrasts with meals cooked by commoners that are prepared by non-professional cooks who are, for the most part, women. While Goody used his own fieldwork as the basis for his interpretation of north Ghanaian ‘low’ cuisine, he relied on secondary sources to discuss Eurasian ‘high’ cuisine.

Goody’s model, although hugely influential, is problematic in so far as it 1. posits that inequality is a precondition for surpluses and 2. conflates the foodways of a very large continent. According to Ragavan (2006:7) South Asian traders were importing spices into East Africa as early as the third century BCE. Going back much further in time, archaeological data from pharaonic Egypt, such as grave goods and wall reliefs, indicate trade links between Egypt, the ‘Horn of Africa’, and sub-Saharan Africa. Goody (1982: 99) notes that ancient Egypt enjoyed an haute cuisine but, instead of adopting an Africanist perspective, he discusses this as a component of Europe and Asia. Also problematic is Goody’s idea that ‘haute cuisine’ is universally desirable. According to Ray (2015: 122), in colonial Bengal the Hindu middle class “believed that refined cuisine could only be produced by women” because they were capable of maintaining ritual purity in the kitchen and infused meal preparation with love.
Luley (2014:35) emphasizes that high and low cuisine are not binary opposites nor evolutionarily inevitable. “Even in relatively egalitarian societies certain individuals may receive better cuts of meat than others, fresher produce, higher-quality flour, and so on.” Zooarchaeological studies by Sapir-Hen et al. (2016) at Megiddo, and Marom et al. (2014) at Tel Hazor and Tel Kabri, indicate that the Bronze and Iron I period elite inhabitants of these sites ate more and better cuts of meat than non-elites. Although Goody (1982) does not discuss south Levantine foodways, I argue that his model can be applied to samples from the region because research by Sapir-Hen, Marom, and their colleagues demonstrate hierarchical dietary difference.

1.3 The Goals of This Study

In this thesis I evaluate Goody’s model through the analysis and interpretation of absorbed fatty acids eluted from cooking pottery excavated at sites across the Iron Age II Kingdoms of the southern Levant, known historically as Ammon, Aram (Aram-Damascus), Edom, Israel, Judah, Moab and Philistia. I originally designed my dissertation research to use gas chromatographic analyses and zooarchaeology to test the hypothesis that the study of archaeological foodways is useful for the identification and delineation of ancient ethnic groups. Faunal (animal bone) analysis, especially the presence or absence of pig bones within the context of foodways, has been used as an indicator of ethnic boundaries in the archaeological record of Israel, Palestine and Jordan. I began my project with an expectation that I would find some sort of ethnic differentiation between populations, and I based this assumption on my study of ‘biblical’ foodways (see, for example, Borowski 1987, 1998, 2002, 2003; MacDonald 2008a and
2008b; Vamosh 2004). My data, however, lack significant differences that could be interpreted as ethnic dietary variation. However, samples from this time period and region are suitable for use in research examining the archaeological investigation of diet and class because there is historical evidence for hierarchy and class differentiation within Iron Age II (1000-586 BCE) cultures. This interpretation is based on correlation between archaeological material and textual sources (Herr 1997; Younker 2003). In addition, gas chromato- graphic methods are relatively new and underused analytical tools in south Levantine archaeology. They have the potential to complement routinely used scientific methods such as faunal analysis and palaeoethnobotany to generate new information about ancient diets.

1.4 The Structure of this Study

I examined cooking vessel sherds sampled from sites across the southern Levant, which are located in geographic areas archaeologically associated with historically different cultures. These cultures are the Philistines, whose cities were located in the coastal plain of what is now modern Israel and in the ‘Shephelah’ (foothills) between the coast and highland topography; the Judahites of the southern highlands and northern Negev Desert; the Israelites of the northern highlands and Galilee; the Arameans, a tribal confederacy located in what is now Syria and northern Jordan; the Ammonites, whose territory was located between two seasonal rivers (‘wadis’) the Arnon and Jabok in central Jordan; and the Moabites, who lived inland from the eastern shore of the dead sea; and the Edomites of southern Jordan and the Negev Desert (Map 1: Kingdoms of the Levant circa 830 BCE). I chose to analyze inland sites but I avoided seaports because
they could be atypical in their access to resources and more likely to feature a transient population. Moreover, I prioritized samples from floors in domestic contexts but I sampled from other secure Iron Age II contexts as necessary.

I designed my research project to examine lipids (fatty acids) because they preserve well compared with other organic residues such as carbohydrates and proteins (Rottländer 1990: 37). I focus on foods, primarily animal products, cooked in cooking pots and jugs because this was a common food preparation method. King and Stager describe four types of cooking vessel mentioned in the Hebrew Bible. These are the basin (kiyyôr), the kettle (dûd), the cooking jug (qallahat) and the cooking pot (pārûr). They argue that wide-mouth cooking pots were generally used for meat and stews, and that narrow-necked jugs for soups and gruels (King and Stager 2001:65). However, project sampling focused on the broader category of ‘IA II cooking vessel’ and these typological distinctions were not taken into consideration.
Ten cooking vessel sherds were examined from each of twenty-two sites for a total of two hundred and twenty samples. I determined this number by considering the sample size from the site with the least material available, Tel Miqne/Ekron. This sample size is small although, given the expense and laboratory processing time required for each sample, it is practical for this project, which is a preliminary study. Project data is discussed with reference to laboratory processing numbers for brevity. However, full provenience information is found in the appendices.
2.1 Introduction To Organic Residues, Lipids and Fatty Acids

The term “organic residue” is widely used by archaeologists to describe a variety of amorphous organic remains found in archaeological contexts. The scientific analysis of organic residues covers the study of a wide range of organic deposits such as soils, midden deposits, accretions adhering to lithics, tars and bitumens, and lipids (Heron and Evershed 1993: 250). Organic residues are often found on the internal and external walls of unglazed clay vessels. Both visible surface and invisible absorbed residues have been extracted from pottery used to process and store food, and surface residues have been studied since the nineteenth century (Regert 2011: 177).

Surface residues can be described as deposits or encrustations. They may be visible on both the inner and outer vessel surface. Soot can preserve on the outer surface, caused by placing a pot over a fire. Resinous substances such as pine tar may also be visible on the outer or inner surface, applied to porous vessels as a manufacturing process to reduce permeability (Rice 1987: 163). The burning of cooking ingredients may cause charred encrustations inside vessels. Unglazed ceramics can absorb substantial quantities of residues, particularly lipids (fats and oils), from foodstuffs during storage and cooking. Microscopic pores within the fabric of fired clay function to “trap” and preserve lipids for millennia (Evershed et al. 2001: 332). The cooking of food, for example boiling or roasting, releases organic constituents from the cooking ingredients, facilitating their absorption into the pot wall (Heron and Evershed 1993: 251).

Lipids will normally remain within the sherd unless subjected to severe conditions. They have hydrophobic (“water-averse”) properties, which will limit their
translocation from potsherds by dissolution in waterlogged environments unless the ceramic fabric is severely degraded or structurally altered (Evershed and Connolly 1988; Evershed 1990, 1991). They are composed of hydrophobic molecules with polar parts that are hydrophilic (“water-loving”) and form micelles (membranes) with the hydrophilic parts on the outside, and the hydrophobic parts on the inside, to exclude water from the hydrophobic core (Barnard et al. 2007: 42) (Fig 4: micelle structure).

Figure 5: micelle structure, source www.cheesescience.com

Lipids are fatty acids and their derivatives, and substances related biosynthetically or functionally to these compounds” (Christie 1990: 5). The term lipid has traditionally been used to describe a range of natural products in addition to fatty acids including steroids, terpenes, carotenoids, and bile acids, which have in common solubility in organic solvents such as benzene, hexane and methanol. The principal lipid classes consist of fatty acid (aliphatic monocarboxylic acid) moieties linked by an ester bond to an alcohol, principally the trihydric alcohol glycerol (or by amide bonds) to long-chain bases (Christie 1982:1) (Fig. 6). Lipids are commonly referred to as animal fats, plant oils, waxes, resins, etc., that occur ubiquitously in plants and animals (Evershed and Dudd 2000:155).
Food lipids are normally referred to as fats (solid) and oils (liquid) indicating their physical state at ambient temperatures (McClements and Decker 2007: 156).

![Figure 6: triacylglyceride. source Tro 2006](image1)

Fatty acids are major components of lipids. They contain an aliphatic chain with a carboxylic acid group (Fig. 7). Most fatty acids feature an even number of carbons in an un-branched and straight chain “because of the biological process of fatty acid elongation where two carbons are added at a time” (McClements and Decker 2007: 157).

![Figure 7: fatty acid structure. source Tro 2006](image2)

Exceptions to this are fatty acids with odd carbon numbers, for example heptadecanoic acid (C17:0) and branched chains, which can be found in such sources as microorganisms and ruminant fats. Natural fatty acids most commonly range from fourteen to twenty-four carbons and, while some contain less than fourteen, significant levels of these short chain
fatty acids are usually found only in tropical oils and dairy fats. Fatty acids are mainly
classified as saturated (no double bonds) or unsaturated (at least one double bond)
(McClements and Decker 2007:157) (Fig 8).

![Chemical structures of saturated and unsaturated fatty acids](source Christie 2011)

Fatty acids are described by systematic, common, and abbreviated names.
International Union of Pure and Applied Chemistry (IUPAC) standardized nomenclature
delineates the parent hydrocarbon of a fatty acid based on the number of carbons (e.g.,
ten carbons would be decane). Fatty acids contain a carboxylic acid group, therefore
standardized nomenclature determines that the terminal e in the hydrocarbon’s name is
replaced by oic (e.g., decanoic). Common names exist for most of the even number and
many odd number fatty acids. Common names frequently originate from the source from
where the fatty acid was first isolated (e.g., palmitic acid and palm oil). A numerical
system is used for abbreviated names. The first number in this system designates the
number of carbons in the fatty acid while the second number designates the number of
double bonds (e.g., hexadecanoic acid = palmitic acid = 16:0; cis-9-Octadecenoic acid =
oleic acid = 18:1 cis 9. The second number is always 0 for saturated fatty acids because
they contain no double bonds (McClements and Decker 2007:157). The second number increases to indicate the total number of bonds in unsaturated fatty acids, for example 9,12-octadecadienoic acid = linoleic acid = 18:2 (n-6), where the n-6 indicates that the last double bond is six carbons away from the terminal methyl group (Table 1).

<table>
<thead>
<tr>
<th>Systematic Name</th>
<th>Trivial Name</th>
<th>Shorthand Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanoic</td>
<td>Acetic</td>
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</tr>
<tr>
<td>Butanoic</td>
<td>Butyric</td>
<td>4:0</td>
</tr>
<tr>
<td>Hexanoic</td>
<td>Caproic</td>
<td>6:0</td>
</tr>
<tr>
<td>Octanoic</td>
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</tr>
<tr>
<td>Decanoic</td>
<td>Capric</td>
<td>10:0</td>
</tr>
<tr>
<td>Dodecanoic</td>
<td>Lauric</td>
<td>12:0</td>
</tr>
<tr>
<td>Tetradecanoic</td>
<td>Myristic</td>
<td>14:0</td>
</tr>
<tr>
<td>Hexadecanoic</td>
<td>Palmitic</td>
<td>16:0</td>
</tr>
<tr>
<td>Octadecanoic</td>
<td>Stearic</td>
<td>18:0</td>
</tr>
<tr>
<td>Eicosanoic</td>
<td>Arachidic</td>
<td>20:0</td>
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<tr>
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<td>Behenic</td>
<td>22:0</td>
</tr>
<tr>
<td>Tetracosanoic</td>
<td>Lignoceric</td>
<td>24:0</td>
</tr>
<tr>
<td>9-Octadecenoic n-9</td>
<td>Oleic</td>
<td>18:1 cis-9</td>
</tr>
<tr>
<td>9,12 Octadecadienoic n-6</td>
<td>Linoleic</td>
<td>18:2 n-6</td>
</tr>
</tbody>
</table>

Table 1: nomenclature of some common fatty acids

The analytical study of archaeological residues could be divided into two phases, one before and one after the application of mass spectrometry (MS). As early as the end of the nineteenth century, black organic crusts visible on the surface of ceramic vessels
were thought to contain valuable archaeological information. The first attempts to identify such remnants relied on wet chemistry and basic chemical experiments such as solubility and burning tests (Regert 2011: 177). These types of tests generated the first hypotheses on the presence of birch bark tar (an adhesive produced by heating white birch bark in controlled conditions), dairy products, and different kinds of lipids (Heintzel 1880, 1881; Cotte and Cotte 1917; Grüss 1933).

Infared spectroscopy was used to address archaeological questions during the 1960s (Sandermann 1965; Funke 1969), and the introduction of chromatographic analyses followed during the 1970s. Modern organic residue analysis of archaeological materials began with a publication by Thornton et al. (1970), who investigated the origin and identity of ‘bog butters’, ancient (usually large) waxy lumps of dairy or animal fat that are found buried in peat bogs, using gas chromatography. This paper was the first of several that emerged over the next twenty five years that provided the methodological framework for our understanding of the range of artifacts and archaeological deposits likely to contain organic residues (Condamin et al. 1975, 1976; Rottländer and Schlichtherle 1979, 1983; Evershed et al. 1985, 1990, 1991, 1992, 1994, 1995a,b; Evershed and Connolly 1988, 1994; Connan and Dessort 1989; Rottlander 1990; Oudemans and Boon 1991; Connan et al. 1992; Charters et al. 1993a,b, 1995; Evans and Heron 1993; Heron et al. 1994).

Analysis combining gas chromatography with mass spectrometry began during the 1980s, particularly for the study of terpenoid resins and tars (Evershed, Jerman and Eglinton 1985; Robinson et al. 1987). Pioneering case studies at this time were of great importance because they helped develop systematic research into the examination of
archaeological residues (Condamin et al. 1976; Heron and Pollard 1988). Mass spectrometry (MS) was widely adopted during the 1990s, used in research that aimed to identify archaeological residues and provide spectra that could be related to molecular markers characteristic of specific materials. In addition, major series of archaeological and reference sample studies were conducted, especially by Richard Evershed and colleagues at the University of Bristol in the United Kingdom (for example see Evershed et al. 1992a, b; 1999; 2002; Heron and Evershed 1993; Evershed 1993, 2008a).

A number of natural products have been chemically identified in ancient pottery including beeswax (Heron et al. 1994; Evershed et al. 2003; Regert et al. 2001; Garnier et al. 2002; Regert 2008), wine (McGovern 1998; Garnier et al. 2003; Guasch-Jane et al. 2004, 2006a, b), cacao (Henderson et al. 2007), resins, and tars (Regert and Rolando 2002; Colombini, Modugno and Ribechini 2005; Regert et al. 2008, Stern et al. 2008). Lipids of different origins are probably the most frequently encountered residues in archaeological ceramics (Regert 2011: 178).

Gas chromatography (GC) and, particularly, gas chromatography combined with mass spectrometry (GC/MS) are useful techniques for analyzing ancient organic residues because they separate and identify compounds from complex mixtures using very small quantities of archaeological material. Gas chromatography/mass spectrometry is a two-step process. The gas chromatograph separates compounds based on differing affinities for a stationary phase (a temperature controlled capillary column) and a mobile phase (a carrier gas). Molecules with greater mass weight are retained for a longer period of time and, if gas chromatography is used alone, identification is based on these retention times. When coupled with mass spectrometry, individual compounds are transported from the
GC column to the mass spectrometer where they are bombarded with electrons, forming characteristic ion fragments. The result is a mass spectrum (Fig. 9). Compounds may then be identified by ion fragmentation patterns as well as retention times. In addition, mass spectral libraries in the form of software, for example the library issued by NIST (National Institute of Standards and Technology, www.nist.gov) can be used to aid identifications. Molecules are typically identified using all the above as well as comparison with reference standards.

Figure 9: mass spectrum, Tell en-Nasbeh Room 513 x33, x10, background removed

2.2 Sample Collection

All pottery samples were collected from excavation stores in fifteen different locations in the United States, Canada, Israel and Jordan, including the Israel Antiquities warehouse in Bet Shemesh, Israel. I used an unbranded tile cutter purchased in a Jerusalem hardware store to cut sub-samples from vessel sherds. The tile cutter was
cleaned with Kim Wipes and distilled water between each sample and I wore unpowdered laboratory gloves during sampling. After cutting, each sample was stored in an uncontaminated plastic sample bag. Most vessels had been stored in plastic bags prior to sampling.

All samples were taken from the top third of each vessel for two reasons. (1) Vessel rims are important typological indicators. They aid in distinguishing vessels of differing time periods and forms. (2) Studies have shown that the abundance of absorbed lipids is greater in the top third of cooking vessels. The concentration of lipids in pottery rim sherds may be ten times higher than in body sherds, and thirty times higher than the concentration of lipids in vessel base sherds (Charters et al. 1997: 1–7). This makes sense given the structural characteristics of lipids—their hydrophobicity and density. It is generally assumed that residues in cooking pots were likely formed by boiling, i.e., cooking foods in water at a temperature of at least 100°C. Lipids, being less dense than water, normally rise and form a separate layer at the surface. Therefore, the greatest concentration of lipids would naturally occur at the surface of a liquid in the cooking pot. Malainey (2011:203) notes that cooking pots may not always be filled to the rim, and evaporative water loss during boiling may reduce a pot’s liquid level. So the neck and shoulder of cooking pottery, the top third of the vessel, should be the best candidates for sampling.
2.3 Laboratory Processing

All samples were processed by gas chromatography/mass spectrometry analysis (GC/MS) in the University of Massachusetts Geosciences Biogeochemistry Laboratory using the following methods. Non-powdered laboratory gloves were worn throughout processing and changed whenever they became wet with solvent or ripped. The outer, potentially contaminated, surface of each potsherd was removed using a Dremel hand sander fitted with a disposable half inch sixty grit sandpaper band. The Dremel was cleaned between each sample firstly with dry Kim Wipes and, secondly, with methanol on Kim Wipes. In addition, the sandpaper band was replaced between each sample. Aluminum foil, used to cover samples during processing, laboratory sand used to fill ASE cells (see below), and all glassware were combusted at 500 degrees centigrade for a minimum of four hours prior to use to remove potential lipid contamination.

After outer surface removal, the remaining sherd was ground to a powder using a mortar and pestle, which were also wiped initially with dry Kim Wipes and then rinsed sequentially with hexane, methanol and dichloromethane between each sample. All spatulas, syringes, and other processing tools used to transfer ground pottery into ASE cells and subsequently into processing vials were wiped and subsequently rinsed, three times each, with hexane, methanol and dichloromethane between samples.

Approximately 1.57 grams of ground potsherd were weighed and processed for each sample. This weight was determined in consideration of the approximate weight represented by the smallest samples within the dataset. One “blank” sample, composed of combusted sand only, was processed and derivatized along with each set of ten ceramic samples.
Twenty microliters (µL) of 1.065 mg/ml C36 n-alkane (n-hexatriacontane) in toluene was added to each sample as an internal standard. All samples were processed using Accelerated Solvent Extractor (ASE) technology (Dionex Corporation 1999). ASE extraction processing accommodates up to twenty-three samples and a reference blank in one run and minimizes opportunities for laboratory contamination that could occur during manual sonication and pipetting. Pottery samples were packed into metal cells with combusted sand, to a total combined weight of 15 grams per cell, and then loaded into the ASE machine. An internal oven within the machinery heats to one hundred and fifty degrees centigrade, and each cell is individually processed through the oven where it is heated and flushed with solvent solution. Lipids are extracted using dichloromethane/methanol (9:1 v/v) and collected into receiving vials within the machinery. After ASE processing, this solvent is removed under a gentle stream of nitrogen.

Derivatization of samples was accomplished by adding one hundred microliters of N,O-bis(trimethylsilyl) trifluoroacetamide trimethylchlorosilane (BSTFA/TMCS) in hexane and heating sample vials at seventy degrees centigrade for twenty minutes. This solvent was removed under a gentle stream of nitrogen before reconstitution using two hundred microliters of hexane. One hundred and fifty microliters were then transferred into glass inserts inside two-milliliter vials for gas chromatographic processing.

Gas chromatographic analysis was performed on a Hewlett Packard 6890 gas chromatograph using a temperature program with an inlet temperature of three hundreds degrees centigrade and a maximum heater temperature of three hundred and twenty centigrade. Gas chromatographic conditions were as follows: temperatures within the GC
were raised from an initial 50° C to 320° C at a rate of 20° C per minute, with the final 320° C temperature held for ten minutes. Sample flow was set to one milliliter per minute for a split-less run using Helium as the carrier gas. Samples from Rehov, Pella, Megiddo, Batash, Es-Safi/Gath, Qiri, and Tel en-Nasbeh were processed with a 5 % phenyl methyl siloxane column (30m with a 0.25 mm inner diameter and a 0.25 μm film). Samples from Beersheva, Zira’a, Lachish, Malhata, Ira, Abila, Yokne’am, Khirbat al-Mudayna, Jawa, Mione/Ekron, Jalul, Shechem, and Halif were processed on a 60m column with a 0.25 mm inner diameter and 0.1 μm film. The gas chromatograph is attached to a Hewlett Packard 6890 mass selective detector. To test for contamination, vials containing hexane were processed at the start of each run and after every fifth sample.

Background contamination, recorded in mass spectra, is a common problem in gas chromatographic analysis. Contamination in the gas chromatograph typically comes from column or septum bleed (degradation), a dirty injection port, the injection port liner, a contaminated syringe, poor quality carrier gas, dirty carrier gas tubing, or fingerprints (improper handling of clean parts). Contamination originating in the mass spectrometer usually comes from an air leak, cleaning solvents and materials, foreline pump oil, or fingerprints (improper handling of clean parts) (Agilent 2016). Common contaminants recorded in CSV reports and mass spectra are silane and siloxane from column or septum bleed; phthalates (plasticizers) that may be from vacuum seals or laboratory gloves; silicon oil that may be pump oil; and benzene, a cleaning solvent.

Mass spectral interpretations are based on known fragmentation times of organic compounds. Each sample has been compared with reference spectra of laboratory grade
saturated and unsaturated fatty acids from Supelco reference kits (Sigma Aldrich 2016) that were derivatized and processed using the same gas chromatographic program as used for ceramic samples. Samples were interpreted with reference to both Wiley 275 (Wiley 2016) and National Institute of Standards and Technology (NIST) (National Institute of Standards and Technology 2016) spectral libraries. Spectrum matches with quality ratings of 90% and above were considered to be acceptable for this study. Detailed reports were generated along with spectra, providing peak areas for all molecules (Appendices 8 and 9). The fatty acids in mg per g total lipids were quantified in relation to the internal standard, n-hexatriacontane using the equation (\(X/SM = AIS/ISM\))/mg per g where: \(X\) = Area of TMS ester; \(AIS\) = internal standard area; \(SM\) = sample mass; and \(ISM\) = Internal standard mass, and mg per g = sample weight. Results are expressed in mg fatty acids/g total lipids.

Areas of all extant tetradecanoic acid (C14:0) in the dataset \((N = 16)\) were compared with their corresponding internal standard areas to assess whether instrumentation was a factor in the numerical variation of internal standard areas across samples. A strong linear correlation indicates a positive relationship between the two \((.766 = 87\% \text{ of } N, \text{ or } 14 \text{ out of a total of } 16 \text{ samples})\). The gas chromatograph underwent a process of fine-tuning throughout sample processing, including column replacement. However, human error may also be a minor factor in internal standard variation (Fig. 10).
### Table: Pearson Correlation Coefficients

<table>
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<th>Sample area</th>
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<td></td>
</tr>
<tr>
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</tr>
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<td>N</td>
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<tr>
<td>IS area</td>
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<td>Sig. (2-tailed)</td>
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</tr>
<tr>
<td>N</td>
<td>16</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>

**Correlation is significant at the 0.01 level (2-tailed).**

Figure 10: Pearson Correlation Coefficients of C14:0 and Internal Standard

#### 2.4 Site Descriptions

Descriptions of sampled sites summarize archaeological data that are relevant to this study, i.e., the Iron Age. Sites are ordered according to geographical region and descriptions include a brief history of excavation, overview of Iron Age strata, and my reason or reasons for including the site in my project.

**Northern Negev:**

**Malhata**

The Arabic name of the tel, Tell el-Milḥ (‘Hill of Salt’), apparently indicates an association with the production of salt from the Dead Sea area, and the town may have been a major trading center for imported salt (Beit-Arieh 2015: 14-15). The Iron Age
name for this town is unknown. However it was known as ‘Molatha’ during the Roman Period when the site was home to a fort.

Tel Malḥata is located in the Arad–Beersheva Valley in the northeastern Negev Desert of Israel, on the eastern bank of Wadi Malḥata near its confluence with Wadi Beersheva (Beit-Arieh 2015:11). The site is midway between Arad and Beersheva (Negev and Gibson 2001: 309).

The first Iron Age settlement (late Iron IIA, Stratum V) parallels Judahite sites in the Beersheva Valley, such as Beersheva Strata VI–IV and Arad Stratum XI. The material culture of Tel Malḥata had become an admixture of Judahite, coastal and Edomite influences By Stratum IV of the Iron IIB, and mainly in Stratum IIIA dated to the end of the Iron Age. The site was destroyed at the end of the Iron Age (Late IA II, stratum V) during the Babylonian conquest of Judah. Approximately 25% of pottery from this destruction level is typically Edomite. I chose to include this site in the dataset because of the Edomite cultural influence and because of its location in the northern Negev.

Beersheva

Tel Beersheva is identified with Tell es-Saba’ (‘Well of the Oath’), a mound located approximately four kilometers (2.5 miles) east of the modern Israeli city of Beersheva (Stern et al. 1993: 167; Laughlin 2006: 46). The site was first excavated during 1969-75 by Yohanan Aharoni on behalf of Tel Aviv University. Ze’ev Herzog conducted a follow-up season during 1976. Traces of the earliest settlement at the site
date to the Chalcolithic Period (3400-3100 BCE). There are nine strata of occupation dating from the Iron Age I (13th – 11th BCE) through the beginning of the Islamic Period (7th – 8th centuries AD).

Excavators uncovered nine strata of occupation. The earliest occupation levels (strata IX-VI) date to the Iron Age I Period (1200-1000 BCE) and consist of unfortified settlements containing scattered dwellings and silos (Negev and Gibson 2001: 73). It has been estimated that the population of the site would have been approximately 120-200 people during this time period. Strata V-II date to The Iron Age II Period (1000-586 BCE). The final stratum (I) has been dated to the early seventh century and represents an “unsuccessful attempt to revitalize the city of Stratum II” (Laughlin 2006: 48).

The mound reached its largest area of habitation during the Iron Age II Period (1000-586 BCE), reaching approximately 2.8 acres. Although small, it was a “well-planned administrative center” fortified by at first by a solid wall (Str. V-IV) followed by a casemate wall (Str. III-II) with entry through a four chambered gate system (Laughlin 2006: 49).

The Iron Age II town featured sophisticated town planning, in the form of well-laid-out streets, a large plaza circa forty by sixty-six feet in size, and public buildings identified as storehouses (Laughlin 2006: 50). This town was destroyed at some point during the Iron Age although the date and circumstances of its destruction are unknown to date. There is archaeological evidence of human activity at the site following the destruction, but Beersheba never achieved its former importance as an administrative
center. Beersheva was included in the dataset because of its importance during the Iron Age II period and its location in the northern Negev.

Tel ‘Ira

Tel ‘Ira is located in the Beersheva Valley at the summit of a steep hill, 514m above sea level, a position that allowed ‘Ira to control the road through the valley. David Alon first surveyed the site in the early 1950s. Yohanan Aharoni also surveyed during 1956. Excavations were conducted from 1979 through 1987, first by the Israel Department of Antiquities and then by Tel Aviv University and the Nelson Gluek School of Biblical Archaeology, Hebrew Union College. The site’s Biblical identification is unknown. Nine strata were identified, dating from the 27th century BCE to the early Arab period (8th century CE). The richest finds came from the Iron Age and Byzantine periods. Although seven areas were excavated, the area uncovered is less than 1/20th of the total area of the tel (Hebrew Union College 2016).

After brief occupation in the Early Bronze Age III, a thriving city and its large cemetery stood at Tel ‘Ira until destroyed at the end of the Iron Age. The earliest settlement is dated to the Early bronze III (stratum IX). There was a small, temporary settlement dating to the 10th-9th centuries BCE (stratum VIII). The main city with buildings and a casemate wall over 5m thick, including a gateway, is dated to the first half of the 7th century BCE (stratum VII). Public buildings were uncovered in the eastern section of the tel that date to this time period. The site was destroyed and rebuilt during the second half of the 7th century BCE (stratum VI), but this stratum was destroyed at the
beginning of the 6th century BCE. I chose this site because of its location in proximity to Beersheva.

Tell Halif

The Arabic name for Tell Halif, ‘Khuweilifeh’, translates as ‘Little Caliph’. The site has been identified as a number of Biblical settlements with En-Rimmon being the most likely match (Negev and Gibson 2001: 213). It is a three-acre site approximately eight kilometers (five miles) southwest of Tell Beit Mirsim, located at the juncture of the Judean Hills, the Shephelah and the Negev in a valley near the modern Kibbutz Lahav (Laughlin 2006: 139, Negev and Gibson 2001: 213). Fieldwork was conducted at the site from 1976 through 1993 as a part of the ‘Lahav Research Project’ directed by Joe D. Seger of Mississippi State University. Seventeen strata of occupation were identified dating from the Chalcolithic (fourth millennium BCE) through the nineteenth-twentieth century CE, when the town was called Khirbat Khuweilifeh (after 1937).

The Iron Age I settlement is represented by living surfaces on which stone tools and pottery were found, including what excavators termed “degenerate-style Philistine potsherds” (Seger 1993: 557). The town expanded during the Iron Age II period (Str. VIB-VIA) as evidenced by a large cemetery dating to the ninth-eight century BCE. However, the town was destroyed again at the end of the eighth century, possibly by Sennacherib. I chose this site because it was a Judahite town in the northern Negev.
Shephelah:

Es-Safi/Gath

Tell es-Safi/Gath, which translates from the Arabic as ‘the White Hill’ is identified with Philistine Gath (‘Winepress’). The site is located on the southern banks of the Wadi ‘Ajjur, thirty-five kilometers (twenty-two miles) northwest of Hebron. It is roughly five miles south of Miqne/Ekron on the eastern edge of the so-called ‘Philistine Coastal Plain’ (Laughlin 2006: 124). Archaeological excavations at the site reveal that it had been continuously inhabited since the 5th millennium BCE.

Tell es-Safi was first excavated by F.J. Bliss, with the aid of R.A.S. Macalister, in 1899 (Bliss 1899a; 1899b; 1900; Bliss and Macalister 1902: 28-43). Several soundings were conducted in various parts of the summit. Rich Iron Age II occupation levels were uncovered and were assigned by Bliss to what he labeled as the 'Jewish Period', which he dated to 800-300 BCE. Albright (e.g., 1960: 30) corrected this date to 1000-587 BCE. I chose this site because of the ‘rich’ Iron Age II period Philistine occupation levels.

Tel Miqne/Ekron

The Arabic name for the tel, ‘Khirbet el-Muqanna’, has been transliterated into Hebrew as ‘Tel Miqne’ (Laughlin 2006: 111). The site has been identified as Philistine Ekron. It is located thirty-five kilometers (21 miles) south of Jerusalem and eighteen kilometers (eleven miles) north of Tell es-Safi/Gath at the eastern edge of the Philistine Coastal Plain near the Sorek River. The site is approximately sixty acres in size.
Excavation of Ekron/Tel Miqne began in 1981 under the direction of Trude Dothan of Hebrew University and Seymour Gitin, Director of the Albright Institute of Archaeological Research in Jerusalem. Some Chalcolithic remains dating to the fifth-fourth millennium BCE were discovered in addition to eleven identified strata dating from the Middle Bronze Age (stratum XI) through the end of the seventh century BCE (Stratum I) (Laughlin 2006: 113). The site was continuously occupied from the Middle Bronze Age to the Iron Age II period.

The city expanded and contracted several times. Only the acropolis (Field I) covering 2 ½ acres at the northern end of the tel was there material evidence of occupation throughout all catalogued archaeological periods. There was a four hundred year gap in occupation of the lower city (40 acres in size) between the end of the Middle Bronze Age and the Iron Age I (circa 1200 BCE). Another gap of two hundred and fifty years occurred again before reoccupation during the eighth century BCE.

The first Philistine city dates to the Iron I period (1200-1000 BCE). A large amount of Philistine bichrome pottery, twenty-five pebble hearths, and a megaron date to this period (Laughlin 2006: 114). A megaron is a rectangular building that features a pillared porch and a large central hearth. They are commonly found at Mycenaean sites but they are rare in Israel. The stratum IV Philistine city was destroyed around 1000 BCE.

Only the ten-acre upper city was occupied during the Iron Age II, between 1000 and 700 BCE. However, under Assyrian domination, the city became large and prosperous. One hundred and fifteen olive presses were uncovered during excavation,
which indicate that Ekron was the largest olive oil producing center known in the ancient
world. The town was destroyed by Nebuchadnezzar in 603 BCE and remained
abandoned until a small Roman settlement was built at the northern edge of the tell
(Dothan & Gitin 1993: 1057). I chose this site because of its Philistine material culture
and its large size.

Tell ed-Duweir/Lachish

Tell ed-Duweir has been identified as the Iron Age city of Lachish. The tell is
located in the foothills of the Judean Hill Country (the Shephelah) forty-eight kilometers
(thirty miles) southwest of Jerusalem and twenty-four kilometers (fifteen miles) west of
Hebron (Laughlin 2006: 176). The mound is hidden between low hills near the valley of
Nahal Lachish (Wadi Ghufir) surrounded by deep valleys that provided a natural defense.
The top of the tell is 273m above sea level and 50m above the valley on its north side.
The site is a large mound approximately thirty acres at its base narrowing to eighteen
acres at its summit.

An excavation of the site was begun in 1932 under the directorship of J.L. Starkey
but was halted during 1938 by his untimely death (Negev and Gibson 2001: 288). It was
David Ussishkin of the Institute of archaeology, Tel Aviv University, who carried out
long-term excavation at the site from 1973 through 1987. Pottery finds during this
excavation helped clarify chronological questions, especially with regards to lmlk
(‘belonging to the king’) stamped jar handles (Laughlin 2006: 177.)
The earliest Iron Age remains date to the 10th century BCE. They are Palace A (stratum V), built on the ruins of a Late Bronze Age palace, and an eighteen foot thick wall (stratum IV). Numerous lmlk handled jars were found close by Palace A. The stratum III city was heavily fortified by an eighteen-foot inner wall made of brick that encircled the hill summit. It was surrounded by a seventeen-foot high outer wall made of bricks on a stone foundation. The city gate is located on the west side of the hill, where it was protected by a large bastion measuring 83 feet by 68 feet (Negev and Gibson 2001: 289).

The city of stratum III was destroyed and covered by a three-foot layer of ash. This probably occurred when Sennacherib attacked the city in 701 BCE. On the southwest side of the hill, Ussisshkin’s excavation discovered a large ramp, identified as an Assyrian siege platform, made from unhewn stone bound with mortar. It is the earliest known siege ramp in the Near East (Negev and Gibson 2001: 291).

A new city (stratum II) of eight hectares (20 acres) was built above the ruins although house masonry at this level is of poor quality and the palace was abandoned. The wall and gate were rebuilt. This city was also destroyed, probably by Nebuchadnezzar in 597 BCE. I chose to sample Lachish because of its Judahite material culture and its location in the Shephelah.
Tell el-Jezer has been identified as Gezer. At thirty-three excavated acres, the site was one of the largest and also one of the most important settlements in pre-Roman Palestine. The mound is located thirty-two kilometers (twenty miles) northwest of Jerusalem on a crossroads of the Via Maris (the ‘Way of the Sea’). It is situated on the last ridge of the Judean foothills as they slope down to join the Shephelah (Negev and Gibson 2001: 196).

The tell was first identified with ancient Gezer in 1871 by Charles Clermont-Ganneau, an identification corroborated by boundary inscriptions dating to the Herodian Period that read “boundary of Gezer” (Laughlin 2006: 127). R.A.S. Macalister first excavated the site on behalf of the Palestine Exploration Fund between 1902 and 1909. His team uncovered a wall system made up of four walls – a middle wall possibly dating to the Early Bronze Age (3330–3050 BCE), and inner wall with a triple gateway dating to the Middle Bronze Age IIC (1650-1550 BCE), and outer wall dating to the Late Bronze Age (1550-1200 BCE), and a casemate wall with a four-entrance gateway typical of the Iron Age (a so-called Solomonic gate) (Laughlin 2006: 196).

More recent excavations began during 1964 by the Hebrew Union College Biblical and Archaeological School in Jerusalem in conjunction with the Harvard Semitic Museum. G.E. Wright directed the first season with subsequent seasons led by W.G. Dever. J.D. Seger directed the 1972 – 74 seasons, and Dever returned for the final season, sponsored by the University of Arizona, during 1984 (Negev and Gibson 2001: 197).
Dataset samples from Gezer were uncovered during this excavation. I chose to sample pottery from Gezer because of its size and regional importance during the Iron Age.

Tel Batash/Timnah

Tel Batash has been identified as Timnah. It is situated in the Sorek Plain six kilometers (four miles) west of Beth Shemesh and eight kilometers (five miles) south of Gezer. The description of the southern border of Judah in Joshua 15: 10-11 mentions that Timnah is situated between Ekron and Beth Shemesh along the Sorek Valley. Tell Batash is the only possible candidate for this location.

Excavations were conducted at the site between 1977 and 1989 under the direction of G.I. Kelm of the Southwestern Baptist Theological Seminary in Fort Worth, Texas and A. Mazar of the Hebrew University of Jerusalem. Their team uncovered a total of twelve strata dating for the Middle Bronze Age (c. 1700 BCE) through the Persian Period (sixth century BCE) (Mazar and Kelm 1993: 152). The mound itself is square in shape and each side is six hundred feet long (Negev and Gibson 2001: 69). The construction of an earthen rampart during the Middle Bronze Age created the unusual shape. The rampart was topped by a massive mud-brick wall.

Originally a Canaanite and then a Philistine settlement, it is posited to have come under Judean control at some point during the tenth century due to the presence of characteristic red slipped, hand burnished pottery (Laughlin 2006: 229). A large building that may have been a palace was excavated at the southern end of the mound (stratum IV) although the town may not have been heavily built up since buildings were not found in
all excavated areas. This town may have been destroyed during the Egyptian invasion of the country by Sheshonq.

The town was not rebuilt until the eighth century (stratum III) perhaps under the reign of Uzziah, King of Judah (Negev and Gibson 2001: 69). A large stone wall and double gate were constructed at this time. One of the most important discoveries from this stratum was a storehouse containing over thirty ‘lmlk’ (‘belonging to the king’) handled jars providing clear evidence of Judean activity at this time period (Negev and Gibson 2001: 69). This town was destroyed by the Assyrians in 701 BCE. I chose to collect samples from Tel Batash because of the site’s Judahite material culture.

Hill Country/Highlands:

Tell En-Nasbeh

Tell en-Naṣbeh is generally identified as biblical Mizpah (Laughlin 2006: 188). The site is located on a limestone ridge 848 m (2762’) above sea level about 12 km (eight miles) north of the Old City of Jerusalem and immediately south of the modern Palestinian city of Ramallah (Zorn 2014: 2). The site is approximately 250 meters north to south and 160 meters east to west. It covers an area of 3.2 hectares (circa 8 acres), though the area inside the fortifications only amounts to about 2.4 hectares and the actual area occupied by houses is only a little over 1.7 hectares. At its height in Iron Age II it probably had a population of about 900.
The site was excavated during five seasons from 1926 through 1935 by W.F. Badè of the Pacific School of Religion in Berkeley, California (Zorn 2014: 4). Stratigraphical techniques (i.e. excavating according to debris layers) were not commonly used during the early 20th century, and site interpretation was hampered because of this. Badè excavated the site as a series of ‘rooms’. In addition, the recording method used at Tell en-Naṣbeh was adopted from the system used by Clarence S. Fisher, an early adviser of Badè. If no floor level could be determined for a room all artifacts from the tops of the room’s walls, to the base of its walls were reported as coming from one homogenous unit. If some indication of a floor could be determined for a room artifacts from below that level would be given a separate designation within the room. For this reason it is usually impossible to determine which sherds (and most of the ceramics from the rooms are sherds, not complete forms) were floating in debris high above floor level in redeposition, which were found on or at least close to a floor, and which came from below a floor. Such an approach to recording makes any chronological or contextual study of the artifacts virtually impossible (Zorn 2014: 9) and ceramic analysis must be based on typological form.

Work undertaken by Jeffrey Zorn in his dissertation (1993) considerably revised and clarified site stratigraphy. The revised stratigraphy uses Arabic numerals in order to avoid confusion with the Roman numerals used in the 1947 report. Some Chalcolithic remains were recovered, but the first real settlement is Stratum 5 in Early Bronze Age I (ca. 3200 BC). After that, the site was abandoned until the Iron Age I (ca. 1200 BC) when Stratum 4 was established. This was followed by Stratum 3, which was continuously occupied and rebuilt from the tenth to the beginning of the sixth century. Stratum 3, which initially
represents a modest rural agricultural settlement but came to take on the role of a Judean border fortress as well, is divided into three sub-phases.

The original Stratum 3C settlement of three- and four-room houses was protected by a casemate-like wall. Subsequently in Stratum 3B a massive offset-inset wall with an inner-outer gate complex was constructed slightly down slope from the 3C town, most likely in the ninth century. Stratum 3A represents additional modifications to the town plan subsequent to the construction of the fortifications. In order to construct the new Judean administrative center of Stratum 2 the previous settlement was leveled, filled in, and built over. In other words, Stratum 3 was “destroyed” as a result of a program of peaceful urban renewal, not sudden destruction by some enemy (Zorn 2014: 13). I chose to collect samples from this site because of its highland location and Judahite material culture.

Tell Balât'ah/Shechem

The site of Tell Balât'ah has been identified with ancient ‘Shechem’, meaning ‘shoulder’ or ‘saddle’ in Hebrew, a reference to the tel’s configuration. The mound is ten to twelve acres in size and located between Mount Gerizim to the south and Mount Ebal to the north. It was one of the most important Canaanite towns and capital of the divided kingdom of Israel (Negev and Gibson 2001: 459).

Shechem was first identified with Tell Balât'ah in 1903 by Heinrich Thiersch, and excavated between 1913 and 1934, albeit with interruptions, by Ernst Sellin. However, most current knowledge about Shechem is based on results of the Drew University-
McCormick Theological Seminary Archaeological Expedition, which dug at the tel and surrounding area between 1956 and 1973 under the direction of G.E. Wright (Negev and Gibson 2001: 460, Laughlin 2006: 206).

The earliest Israelite town (stratum X, c. 975-920 BC) was unwalled and consisted of small houses. The situation changed in stratum IX. The MB IIC fortifications were rebuilt and the houses were built with a carefully planned use of space (continuing to stratum VII around 920-724 BC). This recovery is possibly to related to King Jeroboam I’s initiative (1 Kgs. 12:25). The final destruction of Israelite Shechem is attribute to Shalmaneser, who conquered the Israelite kingdom in 722 BC (Negev and Gibson 2001: 461). I chose to include Shechem ceramics in the dataset due to its importance as the capital of the divided Kingdom of Israel.

**Jezreel Valley:**

**Tell Qeimun/Yokne’am**

Tell Qeimun has been identified as ancient, Yokne’am a natural hill of ten acres overlooking the junction connecting the Via Maris road of the coastal plain with the route across the Jezreel Valley. It is approximately ten miles southwest of Nazareth. Yoqne’am was inhabited almost continuously for nearly 4500 years from the Early Bronze Age I (c. 3000 BCE) through the Mamluk Period (1500 CE) (Laughlin 2006: 231). It is mentioned in the Karnak inscription recording the campaign of Thutmosis III into Canaan (c. 1468 BCE).
Conder and Kitchener conducted the first survey of the archaeological remains at the site during the 1870s. The tel was excavated by Amnon Ben-Tor on behalf of the Hebrew University between 1977 and 1988. The remains of a house with installations for olive oil production belongs to the Iron Age I (1200-1000 BCE, Strata XVII, XVIIIa-b). Strata XI-XVI consist of a city with a casemate fortification system dating to the 10th century BC. That fortification was replaced by a double wall during the 9th century BCE. This wall appears to have been destroyed during the late 8th century, perhaps during the Assyrian conquest of northern Israel (Negev and Gibson 2001: 550). I chose to sample vessels from Yokne’am because of its Israelite material culture and location in the Jezreel Valley.

Tell Qiri

Tell Qiri is located on the slopes of Mount Carmel near the junction of the mountain and the Jezreel valley. As a result, Qiri does not have the typical shape of a mound, even though it is one. It does not rise above its surroundings, and appears to be a continuation of the natural slope of the mountain. The western edge of the site is covered with a forest planted during the mid- to late twentieth century. In the east, where the site slopes steeply towards the Shofet River, damage was caused by the digging of military positions during the Arab-Israeli war of 1948. The southern part of the mound was severely damaged by bulldozers that leveled the area for the construction of new houses. Nine areas were excavated between 1975 and 1977. The location and size of each of the areas of excavation were determined by such factors as limitations of time, the extent of previous
damage, the location and ground plan of the houses to be constructed at the time, and
“not necessarily by purely archaeological considerations” (Ben-Tor et al. 1987: 3).

Almost 50 percent of Tell Qiri’s original size was still visible in 1975, but is now
completely covered with houses of Kibbutz Hazorea (Ben-Tor et al. 1987: 3). The
Hebrew University excavation directed by Amnon Ben-Tor was the first archaeological
excavation to be carried out at the site. Previous knowledge of Qiri was derived solely
from chance finds and surveys (Ben-Tor et al. 1987: 3). These surveys revealed pottery
of “all periods,” mainly Neolithic, Chalcolithic, Early Bronze I, Middle Bronze I, Late
Bronze and Iron Age (Ben-Tor et al. 1987: 4). The “small, damaged and unimpressive
site of Tell Qiri yielded an astonishingly rich and varied quantity of remains of different
periods” (Ben-Tor et al. 1987: 3).

The site was a small agricultural settlement composed of residential buildings,
installations for agricultural industries and public buildings, whose plans are often
identical to ordinary houses (Ben-Tor et al. 1987: 53). Tell Qiri existed continuously
throughout the whole of the Iron Age. The archaeological remains from that period
consequently predominate in most excavation areas and at the site as a whole (Ben-Tor et
al. 1987: 53). I chose to collect samples from Tel Qiri because it was a modest
agricultural settlement in the Jezreel Valley. I thought it would be an interesting
comparison with Megiddo and Yokne’am.
Tell al-Mutesellim/Megiddo

Tell al-Mutesellim (‘The Hill of the Governor’) has been identified as ancient Megiddo. It is a mound in northern Israel near Kibbutz Megiddo, about 30 km (19 miles) southeast of Haifa. The site is known for its historical, geographical, and theological importance, especially under its Greek name ‘Armageddon’. Megiddo was an important city-state strategically located at the head of the Aruna Pass through the Carmel Ridge overlooking the Jezreel Valley from the west, where the city was able to control access to the Via Maris, which was the main international highway connecting Egypt to Syria, Anatolia and Mesopotamia. It is one of the most impressive tells in the Levant. Epic battles that decided the fate of western Asia were fought nearby. The site was mentioned for the first time in the annals of Thutmosis III, who in 1468 BC defeated a Canaanite army near here (Negev and Gibson 2001: 327).

Tel Megiddo was excavated in the beginning of the 20th century by a German team and again by the Oriental Institute of the University of Chicago. In the 1960s Yigael Yadin from the Hebrew University of Jerusalem conducted further excavations. An extensive excavation campaign has been carried out at the site by Israel Finkelstein and David Ussishkin from Tel Aviv University, Israel since 1994.

Excavations have unearthed 26 strata, indicating a long period of settlement. Megiddo was inhabited almost continuously, with no substantial occupational gaps, and succeeding settlements were built one top of the other, creating a typical multi-layered mound. The absolute chronology of Tel Megiddo is well established by ceramic typology, dozens of radiocarbon samples, and historical records (Finkelstein and
Piasetzky, 2010; Regev et al., 2014; Toffolo et al., 2014). Most significant are several
destruction layers, dated by a large number of radiocarbon data, which make the
backbone of the Megiddo chronology (Finkelstein and Piasetzky, 2009; Regev et al.,
2014). At least one destruction layer is also securely dated historically, the one caused by
the Assyrian king Tiglath- Pileser III in 732 BCE (Shaar et al. 2016: 173). Megiddo was
an important regional center, first as a Canaanite city-state, and later as an administrative
center of the Northern Kingdom of Israel. It is represented by a complete sequence of
occupation until its destruction in 732 BCE (Str. III-II). I chose to collect samples from
Megiddo because of its importance, location, and the fact that it has been so thoroughly
investigated using modern excavation and dating techniques.

Jordan Valley:

Tell es-Sarem/Rehov

Tell es-Sarem / Tel Rehov (‘street’ in Hebrew) is the largest mound in the Beth-
Shean Valley. Located in the alluvial plain, it is approximately six kilometers (four miles)
west of the Jordan River, three kilometers (two miles) east of the Gilboa ridge and five
kilometers (three miles) south of Tel Beth Shean. The tel dominates the north-south road
along the Jordan Valley. Its total size is 10.2 hectares (40.8 acres) and the summit of the
mound is 116 m below sea level. The site includes an upper mound and a lower mound to
its north of approximately five hectares each. The upper mound rises to twenty meters
above the surrounding plain, while the lower mound rises eight meters. A ravine
separates the lower and upper mounds. A gate may have been located in this ravine, at the
eastern side of the mound, during antiquity.

Tel Rehov was identified by P. Abel in the early 1920’s. The identification is based
on historical sources (including Pharaoh Shishak’s list of conquered cities, ca. 925
B.C.E., that mentions Rehov at number 17 after “The Valley” and before Beth Shean), on
the preservation of the name in the Byzantine Jewish town ‘Rohob’ located at Hurvat
Parva (Khirbet Farwana) north-west of the mound, and in the Islamic tomb of  esh-
Sheikh er-Rihab, which is south of the mound. W. F. Albright, A. Biran and N. Zori’s
survey of the mound indicated occupation during the entire Bronze and Iron ages (Mazar
2008: 203).

The excavations at Tel Rehov, directed by A. Mazar, were conducted on behalf of
the Institute of Archaeology of the Hebrew University and sponsored by Mr. J. Camp.
Nine seasons of excavations at Tel Rehov from 1997 through 2008 uncovered successive
occupational layers from the Late Bronze Age and Iron Age I (12th - 11th centuries BCE)
and well-preserved buildings from three occupation layers dating to the 10th - 9th
centuries BCE. Two of these cities were destroyed.

Strata VI-IV of the Iron Age IIA signify the development of the city during the
early Israelite Monarchy. This period must have lasted through most of the 10th and 9th
centuries B.C.E. A conflagration which destroyed parts of Stratum V may indicate
conquest by Shishak, while the violent end of Stratum IV, and abandonment of the Lower
City, may be related to one of the events during the mid-9th century B.C.E., possibly the
Aramean wars after the end of the Omride Dynasty.
The final two Iron IIA cities (Strata V-IV) were prosperous; and Rehov maintained trade relations with Phoenicia, Cyprus and Greece. A “variety of cult objects, seals, ivory objects, etc., indicate that Canaanite/Phoenician and northern Syrian traditions were retained by the local population”. Although the city was a part of the Israelite Kingdom, much of the population could have been descendants of the previous Iron I Canaanites (www.rehov.org). An important discovery dating to the IA II is the industrial apiary uncovered in Area C, the only ancient beehives discovered in archaeological excavations (Mazar and Panitz-Cohen 2007).

During the late 9th and 8th centuries (Stratum III) the city was restricted to an area of five hectares on the upper mound and was surrounded by an immense fortification wall. This city survived until the Assyrian conquest of 732 B.C.E., which is documented by archaeological evidence of site destruction and slaughter in the houses. Two graves with Assyrian pottery and few additional remains (Stratum II) are indications for a short period of activity after the Assyrian conquest, but the site was abandoned around this time period (www.rehov.org). I chose to analyze samples from Rehov because of its location in the Jordan Valley and its Israelite material culture.

Tabaqat Fahl/Pella

Tabaqat Fahl has been identified as ancient Pella. The Jordanian Department of Antiquities, the University of Sydney, Australia, and Wooster College, USA began jointly excavating the site in 1979. Since 1985, Pella has been excavated by the Jordanian Department of Antiquities and the University of Sydney under the direction of Stephen J.
Bourke. It is an expansive, ten-hectare, site in the Jordan Valley region of northwestern Jordan, 27.4 kilometers (seventeen miles) south of the Sea of Galilee and 130 kilometers (80 miles) north of Amman. Pella was one of ten Decapolis cities founded during the Hellenistic period. The city expanded to its largest state during the reign of the Roman Empire although the site has been continuously occupied since c. 8000 BCE. As a result, the tel contains over 20 meters of occupation debris spanning the past 10,000 years.

Excavations by the University of Sydney have uncovered many important discoveries, including: Neolithic housing (ca. 6000 BC); Early Bronze Age stone defensive platforms (ca. 3200 BC); massive Middle Bronze Age mudbrick city walls (ca. 1800 BC); Late Bronze Age residences, some with clay tablets (ca. 1350 BC); large areas of the Hellenistic city (destroyed by war in 83 BC); the theatre, baths and fountain-house of the Roman city (ca. 150 AD); three Byzantine churches (ca. 550 AD); an early Islamic city destroyed by an earthquake (ca. 750 AD); and many other finds that bring Pella’s history up to the present day.

For several seasons since 1997, excavation focused on investigating a series of superimposed Bronze and Iron Age temple structures located on a slight rise on the southern side of the main mound. During this time the dig team excavated three distinct Bronze Age (ca. 1700-1200 BCE) and one Iron Age (ca. 900 BCE) stone walled temples.

Between 2003 and 2009 the University of Sydney excavated significant parts of three earlier mudbrick temples (ca. 1900-1700 BCE), the uppermost displaying a white plaster floor. All were located immediately below the floor of the central room of the stone-built temples. Excavation of a multi-room Iron Age administrative building, located
immediately west of the temples, began during the 2003 season. This building contained distinct room assemblages in each of the 26 rooms excavated between 2003-2005, and again in 2015, “all preserved below the thick layers of burnt debris that sealed the Iron II complex, when it was destroyed around 800 BCE (University of Sydney 2016). I chose to sample ceramics from Pella because of its proximity to Rehov.

Northern Jordan:

Zira’a

Tall Zira'a is a large mound 4.5 kilometers (2.8 miles) south-west of the ancient Decapolis city of Gadara in northern Jordan. It is situated at the confluence of the Wadi el-'Arab and its tributary, the Wadi az-Zahar. The site is approximately two hectares in size and rises 25 meters (82 feet) above the surrounding area. It is 240 meters (790 feet) in diameter at its base. The plateau measures 160 meters (520 feet) in diameter. Occupation layers are between 12 meters (39 feet) and 15 meters (49 feet) thick.

Gottlieb Schumacher surveyed the Wadi el-'Arab during 1885 and mentioned Tall Zira'a. Nelson Glueck visited the site during 1942. In March 1978, a two-day archaeological rescue investigation was initiated by the Department of Antiquities prior to the Wadi el-'Arab dam project. This was followed up by a brief archaeological survey supervised by J. W. Hanbury-Tenison in the Wadi el-'Arab during September 1983.

Recent excavations were part of the “Gadara Region Project”, an interdisciplinary study of the regional history of Gadara. The long-term archaeological project (2001–
2015) investigated the Wadi el-'Arab region, an area extending over 25 square kilometers (9.7 square miles). The Biblical Archaeological Institute Wuppertal conducted a survey on Tall Zira' and in its surroundings during August 2001, directed by Dieter Vieweger. He started the first excavation campaign in September 2003. Since 2004, the project has continued with two campaigns a year since 2004. It is a co-operative project of the Biblical Archaeological Institute Wuppertal and the German Protestant Institute of Archaeology in Amman. The excavation is directed by Vieweger and Dr. Jutta Häser (Zira’a 2016). I included samples from Zira’a in the dataset because of the site’s location in northern Jordan.

Abila

Abila is fifteen kilometers (nine miles) to the north of Irbid, two kilometers (one mile) east of Hartha, and five kilometers (three miles) south of the Yarmouk River. The site is surrounded by agricultural fields near the modern Ain Quweilbeh spring. Archaeological evidence indicates that the site was occupied during the Bronze Age (Early, Middle, and Late), Iron Age, Hellenistic Period, Roman Period, Byzantine Period, Umayyad Caliphate and Abbasid Caliphate. Four regional transect surveys demonstrated the presence of suburban communities, cemeteries, quarries, agricultural fields, aqueducts, farmsteads, and nomadic campsites. The most intensive use of the countryside occurred during the Byzantine/Umayyad Period when the population reached its maximum.
The first European explorer to examine Abila was Ulrich Seetzen, a German scholar best known as the "discoverer" of Gerasa (Jerash). C.E. Gottlieb Schumacher visited the site during February of 1888. The site had been generally known by the local Bedouin as ‘El Kueilby’ (Kueilby being the diminutive form of the Arabic word for "well." Hence the name means "small/little well"). Nelson Glueck included Abila in his extensive survey of Transjordan in the 1930's and 40's. Glueck's collection and identification of the sherds from Abila is his major contribution to the investigation of the site.

The American Expedition to Abila of the Decapolis began fieldwork with a systematic survey of the site during 1980. Fieldwork at Abila was directed from 1980 until 2004 by Dr. Harold Mare of Covenant Theological Seminary in St. Louis. Research in the painted Roman Period tombs has been conducted by French archaeologists. Surface survey conducted during 1980 by Dr. Harold Mare and team revealed that Abila's history extended to the Early Bronze Age. At present, the Greco-Roman, Byzantine and Islamic periods are the main focus of investigation. Dr. Harold Mare died in a car accident at Abila during the summer of 2004. Responsibility for the project passed to Dr. David Chapman at Covenant Theological Seminary, then to Dr. David Vila (www.jbu.edu/abila/). I decided to study samples from Abila because of its location in northern Jordan and proximity to Zira’a.
Madaba Plains:

Jalul

Tall Jalul is located five kilometers (three miles) due east of the modern town of Madaba. At eighteen acres, it is the largest tel site in the central Jordan plateau. It occupies the highest point in the immediate region, making it the most imposing feature on the western side of the Madaba Plain. The mound is oblong, measuring approximately 300 meters east-west and 240 meters north-south, and covers about seventeen acres. Excavation began during 1992 as a part of the larger, multi-site Madaba Plains Project (Madaba Plains Project 2016) under the co-direction of Randall Younker and David Merling of Andrews University. From 2011, the Jalul Excavation has been under the leadership of Randall Younker (director), Constance Gane (co-director), Paul Z. Gregor (co-director), Paul J. Ray, Jr. (co-director), and Reem Al-Shqour (director of Jalul Islamic Village project).

Pottery sherds discovered by surface survey and excavation indicate habitation from the Middle Bronze Age through the Ottoman Period. The ceramic horizon at Jalul suggests that the earliest Iron Age settlements in both Cis- and Transjordan occurred in the Madaba Plains. The appearance of Manasseh bowls, collared-rim store jars, and flanged cooking pots typologically seriated to the earliest Iron IA points to “a close connection with the slightly later appearance of these forms to the west of the Jordan River” (Younker et al. 2011:64). Ashy lenses over one meter in thickness found under the early Iron II remains suggesting that a major conflagration occurred towards the end of the Iron Age I.
Inscriptional evidence (seals and ostraca), iconographic evidence, and other aspects of material culture at Jalul, as well as nearby Hisban and ‘Umayri, indicate that the Ammonites were in firm control of the Madaba Plains Region by the middle of the Iron Age II. During the Iron IIB period, Jalul was along the southernmost bastion of the Ammonite cultural sphere. The growing strength of the Ammonite presence is supported by a settlement pattern that shows a consistent increase in the number of settlements from LB to Iron II with the peak occurring towards the end of the Iron IIB period (Younker et al. 2011: 64). I chose to sample cooking pottery from Jalul because of its Ammonite and Moabite material culture.

**Tall ‘Umayri**

Tall al-‘Umayri is a small, but densely occupied, multi-period site located on a natural ridge fifteen kilometers (nine miles) south of the outskirts of Amman. Until recently, a natural spring at the northern foot of the site was the only natural water source between Ras al-‘Ayn (Amman) and the town of Madaba. Excavations on the tel discovered constructed water facilities such as drains, channels that date to the Iron II period, the Roman period, and the Byzantine era. The immediate area of the site was occupied almost continuously from the Neolithic Period to the present. The top of the site is lower than the immediately surrounding hills to the north, west, and south. Watch towers would have been necessary on surrounding hills to provide an early warning system against attack. The site’s “strategic” value was command of the water source (Herr 2011: 28).
The site was first mentioned by Charles Warren in a report on an 1867 travel itinerary to Transjordan, in which he spells the name “el-‘Ameireh”. He referred to the site as a district with three tels. There is no indication that archaeologists visited the site again until it was re-discovered by the Hisban survey team in 1976 (Ibach 1987: 31). No road traveled through the immediate region until the construction of the airport highway and the rolling hills of the area did not allow explorers to glimpse the site in the distance. Even Nelson Glueck missed the site as he traveled the Madaba road farther to the east passing by Jawa and Yaduda (Herr 2011: 28).

Large-scale excavations began in 1984 by the Madaba Plains Project sponsored by Andrews University in cooperation with the Department of Antiquities of Jordan and the American Center of Oriental Research. The dig is ongoing and is now sponsored by La Sierra University in consortium with Andrews University School of Architecture, Canadian University College, Mount Royal College, Pacific Union College, and Walla Walla University. Lawrence T. Geraty was the initial Director of the project with Larry G. Herr as the Chief Archaeologist. In 2008, Geraty is listed as Founding Director, with Herr and Douglas R. Clark as Co-directors. (Herr 2011: 30)

Excavations show that the site was occupied by 21 separate settlements, with strata stretching from Early Bronze Age I to the Islamic Period, but the primary periods of occupation were the Bronze and Iron Ages. The best-preserved remains come from the Late Bronze Age and the LB/Iron I transitional period.

Four strata of Iron I occupation (counting the two transitional strata) probably saw settlement throughout the period, though the second stratum was the most important with
major fortifications, a city gate, and well-preserved domestic buildings. A major characteristic of the site is the excellent preservation of the architectural finds. Walls stood over one meter high in Strata 14 (Late Bronze Age), Strata 12 (Transitional Late Bronze/Iron I), and Strata 7 (late IronII/Persian). Some walls were 1.5 to 2.0 meters high. Another characteristic is the way significant settlements are visible horizontally in a panorama across the site, rather than simply in a top-to-bottom relationship. A visitor to the site standing at a spot to the east can see Middle Bronze II remains in the northwest; a Late Bronze palace/temple to the north; a partially reconstructed four-room house from the transitional Late Bronze/Iron I period in the northern center; a late Iron II/Persian administrative complex in the center and south; and a late Iron I courtyard sanctuary to the southwest (41). I included samples from Tall ʿUmayri in the dataset because of its Ammonite material culture.

Khirbat al-Mudayna

Khirbat al-Mudayna is located on the eastern edge of the Karak plateau in south-central Jordan (biblical Moab), approximately nineteen kilometers (12 miles) northeast of al-Karak. The site is relatively large, occupying approximately 2.2 hectares on a promontory overlooking the juncture of the Wadi al-Mukhayris and the main southern extension of the Wadi al-Mujib.

Archaeological investigations at the site have been limited. There are at least six sites in south-central Jordan named ‘Khirbat al-Mudayna’, and these have often been confused with one another in the scholarly literature. N. Glueck visited (this) Khirbat al-
Mudayna in 1933, publishing both a sketch plan and a photograph of the site (Glueck 1934: 52-53). However, as is clear from several subsequent references to "Kh. el-Medeinyeh" in Glueck's ASOR publications, he seems to have conflated several of the sites he visited by that name. A clear understanding of the location and identity of the site was not established until the late 1970s.

A project of mapping and small-scale excavation at the site of Khirbat al-Mudayna was begun by Routledge during 1994 and was carried out over three very brief seasons in 1994, 1996, and 1998. Architectural remains at Khirbat al-Mudayna cover the entire promontory, measuring about 375 meters in length by 30-110 meters in width. The most prominent feature on the site is its defensive architecture, which surrounds the perimeter of the promontory and conforms to its topography in shape. The inhabited portion of the site is enclosed by a casemate wall measuring between 4.0 and 4.6 meters wide, and most of the buildings visible on the surface at Kh. al-Mudayna are attached directly to this wall system.

Using wall lines visible on the surface of the site, it is possible to estimate perhaps 35-45 dwelling units at Kh. al-Mudayna, occupying approximately one hectare of the site's surface area. These dwellings are consistent with the typical ‘four room house’ plan but also include ‘L-plan’ units that have broad rooms that are perpendicular to the long axis of the house and are located at the end most distant from the entrance. These rooms are equivalent in every respect to broad rooms in four-room houses. I sampled ceramics from Kh. al-Mudayna because of the site’s Moabite material culture.
**Tall Jawa**

Tall Jawa stands at an elevation of 928 meters (3,045 feet) above sea level, located west-northwest of the modern city of Jawa, 10.9 kilometers (6.8 miles) south of modern Amman.

The site was known to nineteenth-century travellers and explorers. Nelson Glueck conducted the first archaeological survey on site in 1933 and modern day excavations commenced in 1989. No other research is known to have taken place between Glueck's survey and the start of modern excavations. Tall Jawa underwent six seasons of research and excavations, first as part of the Madaba Plains Project and, after 1992, as the Tall Jawa Excavation Project. Lawrence T. Geraty (Project Director, Madaba Plains Project) was in charge of the excavations during 1989 and 1991. Michèle Daviau oversaw them from 1992 to 1995.

The earliest settlement on site dates back to the Iron Age I period (1100-900 BCE). After the destruction of the Iron Age I village, excavations revealed the existence of a fortification wall and a multi-chambered gate dating to mid-late Iron Age II. The majority of the ceramic material found date primarily to Iron Age II, putting the site within the range of Iron Age II residential towns. Items excavated include artifacts of daily life such as ceramics, ground stone tools, jewelry, figurative objects, coins, seals and marine shells (Daviau 2003). I included Jawa cooking vessels in this analysis because of the site’s Ammonite material culture.
CHAPTER 3
ANALYSIS BY GAS CHROMATOGRAPHY/ MASS SPECTROMETRY

3.1 Introduction
The study of organic residues from ancient cooking vessels can be an analytical challenge because of the range of molecules that may be present and because of the damage affecting lipid products through the degrading action of time (Evershed et al. 1992a; Skibo 1992). This is compounded by the fact that gas chromatographic methods cannot distinguish between cooking events, so food residues preserved in pottery must be interpreted as representing ceramic use life—a palimpsest of everything cooked in a vessel during its use life.

The use life of an Iron Age cooking vessel is undeterminable. However, ethnoarchaeological studies provide analogies to predict the length of time ancient vessels were typically used prior to breakage and discard (DeBoer 1974; Foster 1960; Nelson 1991). For example, the Kalinga Ethnoarchaeology Project conducted fieldwork to track the use life of utilitarian ceramics among the Kalinga society of the Philippines between 1975 and 1988 (Tani and Longacre 1999). Using ethnographic interviews, inventories and documentation of vessel breakage, researchers tracked a total of 1,160 cooking pots, calculating a mean vessel use life of 2.2 years. This expected mean is similar to results from comparable ethnographic case studies recorded cross-culturally (Nelson 1991: 177). So the accumulation of fatty acids within the fabric of a cooking vessel potentially occurs over a period of approximately two years of use. However, as mentioned above, whether fatty acid accumulation actually represents the initial use of a pot—a vessel’s “seasoning,” represents numerous cooking episodes over time, or represents the final use of a vessel before breakage and discard, cannot be determined.
Fatty acid distributions are complicated by factors such as non-specific usage and lipid profiles that may represent contributions from a variety of foodstuffs; for example, the use of a range of ingredients in recipes will yield complex lipid profiles. Interpretation of GC/MS spectra is also complicated by the redundancy of many fatty acids, “multiple sources of mixtures, and the variations in the way fatty acids are damaged, e.g., unsaturated fatty acids, such as C18:1 are damaged much more quickly than saturated ones, such as C16:0” (Evershed et al. 1991: 206).

It is important to note that the lipids detected in ancient pottery represent only a fraction of the organic material absorbed into the fabric during vessel use. The typical figure for all ceramic assemblages has been estimated at approximately one per cent survival (Evershed 2008: 28). The preservation of this small percentage of molecules is presumed to be due to the absorption and physico-chemical binding of lipids into the microscopic pores within fired but unglazed clay, providing some level of protection from micro-organisms (Evershed 2008: 29). Nevertheless, lipids and all other organic compounds will degrade to a lesser or greater degree depending on the biochemical nature of the original residue, the mode of vessel use, and their discard and depositional histories (Heron and Evershed 1993: 253).

The entrapment of molecules in geological material such as clay enhances the possibilities of survival by inhibiting access by microorganisms capable of degrading organic matter. Moreover, although clay as a material contains microorganisms that produce fatty acids, they are not considered to be a potential source of contamination. Fatty acids are stable in temperatures up to two hundred degrees centigrade. They rapidly oxidize between two hundred and two hundred and fifty degrees centigrade. This is much
lower than the usual firing temperature of pottery, which is between five hundred and eight hundred degrees centigrade (Barnard et al. 2007: 91). So the fabric of a new cooking vessel should be devoid of fatty acids. In addition, analyses of potsherds and adhering burial soil indicate that lipids migrating from burial soil are not a serious source of contamination (Deal and Silk 1988, Heron et al. 1991b). The first analyses of residues in archaeological ceramics examined soils surrounding and adhering to pottery using the same laboratory protocols to assess the possibility of sherd contamination by biomolecular constituents naturally present in the burial environment. Results of these studies show that lipids identified in vessels and in soils differ, and that vessel lipids can be interpreted as the result of human activities related to their use unrelated to migration of lipids from the sedimentary matrix. This can be explained by the hydrophobic properties of lipids that limit their transfer from soil into ceramics and vice versa (Regert 2007: 62; 2011: 181).

The aliphatic nature of most lipids results in low water solubility and, therefore, high preservation potential. Nevertheless, they do degrade when exposed to oxygen and water, and these processes are accelerated by higher temperatures, for example during boiling in a cooking vessel. Some alteration, such as the enzymatic and chemical hydrogenation of double bonds and loss of functional groups, may take place during use life as well as after vessel discard and subsequent burial depending on environment. Once hydrolyzed, free fatty acids are more water soluble and “readily utilized by microbial enzymes and chemical reactions that require aqueous conditions” (Eglinton and Logan 1991: 318). For example, oleic acid can undergo enzymatic hydrolysis followed by dehydrogenation to give the alpha/beta-unsaturated free acid followed by oxidative
scission of the carbon-carbon double bond (C=C). Hydrogenation of the 9,10 double bond would take place. However, why this beta scission halts, in nature, after two carbons are cleaved and why reduction of the original C=C takes place is unclear (White 1992: 5). This would result in oleic acid chain shortening to saturated hexadecanoic acid (C16:0), potentially making tentative identifications based on C16:0 to C18:0 (octadecanoic) ratios problematic.

Oxidation is the most frequently observed degradative process in food lipids. From a food science perspective, many of the tastes and smells associated with rancidity are byproducts of oxidative fatty acid degradation. Long-chain saturated fatty acids form shorter-chain fatty acids and volatile aromatic compounds as they break down. Humans are evolutionarily predisposed to recognize the “off” smells and flavors resulting from this decomposition as unhealthy because toxic-compound-producing bacteria live on rancid foods. Food science research has shown that the processes of decomposition are complex, producing a diverse range of organic compounds. Fatty acids decompose to shorter derivative compounds that break down into unstable and short-lived compounds, which may further degrade into other compounds (Eerkens 2007: 91). The process is imperfectly understood and its relevance to archaeology is unclear because these processes occur over short timespans and only relatively stable end products will preserve in the archaeological record. For example, an experiment simulating the decay of milk fat soaked into unglazed ceramics found greater than ninety five percent reduction in triacylglycerols, and a resulting degradation to free fatty acids, after only ten days under oxic conditions (Dudd et al. 1998).
Archaeologists have taken two analytical approaches to link foods to these end products. One approach identifies distinct biomarkers posited to be characteristic of particular genera and/or species. This approach compares the properties of the individual compounds or mixtures of compounds (i.e. the biomarkers) present in archaeological residues to those occurring in reference materials derived from contemporary plants and animals. “This principle is largely analogous to that which has been applied in the fields of molecular organic geochemistry and biomolecular palaeontology to determine the nature of biological inputs into sedimentary materials, and in the assessment of palaeoenvironments” (Evershed 1993: 78). For example, gas chromatography/mass spectrometry has been used to identify biomarkers such as abietic acid (coniferous resins) and betulin (from birch bark) from di- and triterpenoid resins (Mills and White 1994; van Bergen et al. 1997b; Serpico and White 2000a,b), thermally altered forms of natural resins (Evershed et al. 1985; Hayek et al. 1990; Dudd and Evershed 1999; Regert et al. 2003a; Stern et al. 2003; Regert 2004), and beeswax (Heron et al. 1994; Charters et al. 1995; Evershed et al. 1997b, 2003; Regert et al. 2005).

Analysis of animal and plant lipids pose a greater challenge because major components such as polyunsaturated fatty acids rarely, if ever, survive in the archaeological record, leaving only “rather undiagnostic n-alkanoic acids” derived from the degradation of triacylglycerols (Evershed 2008: 899). Identification of alkenoic biomarkers relies on carbon specific isotope analysis. For example, \( \delta^{13}C \) values of hexadecanoic and octadecanoic that survive in degraded animal fats can differentiate their sources due to metabolic differences between different animals and carbon sources utilized in biosynthesis of fat types, distinguishing ruminant from non-ruminant “meat”
fat as well as ruminant carcass fat from dairy fat (Dudd and Evershed 1998; Mottram et al. 1999; Copley et al. 2003, 2005b–e; Craig et al. 2005; Mukherjee et al. 2007; Evershed 2008, Evershed et al. 2008b). This is rarely possible by GC/MS analysis of fatty acid compositions alone.

Another approach assumes that different families or genera of animals and plants produce differing quantities of fatty acids. For example, certain plant families may produce greater relative quantities of long chain fatty acids than others or categories of food, such as meat, which may produce more saturated than unsaturated fatty acids. (Eerkens 2007:92). This method is potentially problematic because, for it to be effective, fatty acids must decay at the same rate so that their relative percentages will stay the same and can be calculated and compared. However, as discussed above, fatty acids decompose at different rates, with short- and long-chain compounds (with less than fourteen and greater than eighteen carbons) oxidize more rapidly than medium-chain compounds (fourteen to eighteen carbons), and unsaturated fatty acids degrade quicker than saturated ones. Moreover, the rate at which lipids decompose depends on the relative densities of individual compounds combined with environmental factors such as temperature, the availability of oxygen, and of water (Eerkens 2007: 92).

Species identifications based on the distribution of saturated fatty acids should be made with caution, owing to the possibility of double-bond reduction and chain shortening of fatty acids. However, dairy products are readily recognizable by the presence of short-chain fatty acids with less than twelve carbons (Evershed et al. 1992: 203). “Broad classifications, e.g. 'animal fats', 'dairy products', 'vegetable oils' and
'fish/marine oils', are probably the best that can be achieved at present on the basis of the fatty acid content of archaeological fats and oil residues” (Evershed 1993: 85).

3.2 The Dataset

The project dataset consists of two hundred and twenty samples processed using GC/MS (Appendix 1). Eighty-six samples (39%) preserved fatty acids, leaving a total of one hundred and eleven samples (50%) devoid of fatty acid inclusions (Appendices 2 and 3). Lipid preservation was poor in samples from sites located in the northern Negev and throughout Jordan, with the exception of Tall Umayri (Map 1). For the purpose of this study, sites with poor preservation are defined as having fifty percent of samples or less with fatty acid content. In other words, good preservation is defined as six or more samples out of ten eluting fatty acids that are not the product of modern contamination. A combined total of one hundred and ten samples were processed from sites in these two areas (the northern Negev and Jordan). However, only nineteen samples contained fatty acids. Tall Umayri was the only site with good preservation, with nine out of ten samples eluting fatty acids.

Map 2: sites with poor preservation of fatty acids
Fatty acids were absent from all Abila, Tel Ira, Tall Jawa, and Shechem potsherds, a total of forty samples. A number of factors may account for the absence of preserved lipids in cooking vessels including degradation before and/or after discard and deposition, use for a purpose other than cooking, and non-use. A new and unused cooking vessel would not, a priori, preserve food lipids. Storage conditions and length of time since excavation seem to be irrelevant to residue preservation within the dataset. Samples from Tell en-Nasbeh, for example, were excavated between 1926 and 1935. They are stored unbagged in curatorial shelving units. Nevertheless, all samples eluted fatty acids. Ceramics devoid of fatty acids from these four excavations have been stored in different conditions and for differing lengths of time (Map 2) (Appendix 3) (Table 2).

Map 3: sites devoid of fatty acids
<table>
<thead>
<tr>
<th>Site</th>
<th>Excavation</th>
<th>Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abila</td>
<td>1980 – current</td>
<td>unbagged in trays</td>
</tr>
<tr>
<td>Tel Ira</td>
<td>1979 – 1987</td>
<td>unbagged in trays</td>
</tr>
<tr>
<td>Tall Jawa</td>
<td>1989 – 1995</td>
<td>unbagged in trays</td>
</tr>
<tr>
<td>Shechem</td>
<td>1956 – 1964</td>
<td>enclosed in plastic bags</td>
</tr>
</tbody>
</table>

Table 2: sites devoid of fatty acids

A further twenty-three samples (11%) contained fatty acids but were excluded from further analysis because they were found to be contaminated with isopropyl myristate, a commercially manufactured compound that is produced through the esterification and distillation of myristic acid combined with isopropanol (Appendix 4). This compound is used in personal care products such as lotions and sunscreens to aid skin absorption, and in household products such as laundry detergents and dishwashing liquids (PubChem 2016).

All samples were collected in an identical manner. Isopropyl myristate contamination may have occurred when the samples in question were excavated, cleaned after excavation, or examined prior to and/or during storage rather than during sampling or laboratory processing since gloves were worn and all equipment was carefully cleaned.

Newly excavated ceramics are often soaked in buckets of water to remove encrusted sediments, and then cleaned in water using a brush. Archaeological excavators frequently wear sunscreen while working outdoors. Excavators wearing sunscreen would
have an opportunity to introduce isopropyl myristate onto ceramics during excavation, into water buckets along with the sherds, and also during the brushing process. The fact that only twenty-three, out of two hundred and twenty samples were contaminated in this way adds to the likelihood that contamination did not occur during sampling or laboratory processing. None of these samples have been included in fatty acid counts.

A range of Iron Age II period cooking vessel types were sampled for this project. Residue data suggest that there is no relationship between vessel form, rim style, or vessel size, and fatty acid preservation or content. Preserved fatty acids from uncontaminated samples are all within a restricted range from decanoic acid (C10:0) through Docosanoic acid (C22:0). Unsaturated fatty acid content is limited to oleic acid (18:1 n-9). Heptadecanoic acid (C17:0) is the only odd-chain fatty acid in the dataset.

Decanoic acid (C10:0) was found in samples from cis-Jordanian sites, that is, from sites located in what is now Israel and Palestine, and in one sample from Pella, a trans-Jordanian site, located in what is now the modern country of Jordan (“Pella 10”). This fatty acid is absent from sites in the northern Negev and trans-Jordanian sites other than Pella (Map 4) (Appendix 1).
Dodecanoic acid (C12:0) is also present in samples from cis-Jordanian sites and it was found in the one fatty-acid eluting sample from Tall Zira’a and in one sample from Khirbat al-Mudayna (Map 5) (Appendix 2).
Tetradecanoic acid (C14:0) was found in samples from all sites except Gezer, Halif, and Tall Jalul. Samples from Tel Batash, Khirbat al-Mudayna, Tel Malhata, and Yokne’am preserved tetradecanoic acid (C14:0) and hexadecanoic acid (C16:0), but no other fatty acids (Map 6) (Appendix 2).

![Map 6: sites with samples preserving only tetradecanoic and hexadecanoic acids](image)

Hexadecanoic acid (C16:0) was found in all samples. Heptadecanoic acid (C17:0) eluted from samples from the Jezreel Valley (Megiddo, Qiri, Yokne’am), the Jordan Valley (Pella), Hill Country (Tell en-Nasbeh), the Madaba Plains (Tall Umayri), the Shephelah/Judean Foothills (Tel Batash, Tel Miqne/Ekron, Tell es-Safi), and the northern Negev (Tell Halif) (Map 7) (Appendix 2).
Oleic acid (18:1 n-9), like decanoic acid, is present primarily in samples from cis-Jordanian sites although it was found in one sample from Pella (“Pella 3”) and two samples from Tall Umayri (“Umayri 1” and “Umayri 4”) (Map 8) (Appendix 2). Unsaturated fatty acids degrade more rapidly than straight chain, saturated fatty acids. Samples from Tel Batash, Megiddo, Tel Miqne/Ekron, and Tall Umayri preserved oleic acid but did not contain short-chain fatty acids C10:0 and C12:0.
Octadecanoic acid (C18:0) is one of the most commonly occurring fatty acids found in nature along with hexadecanoic acid and oleic acid. It is present in samples from all sites except Gezer and Tel Malhata. However, results for these two sites were hampered by isopropyl myristate contamination (Gezer) and poor preservation (Tel Malhata). Saturated, long chain fatty acids are uncommon in the dataset. Eicosanoic acid (C20:0) was found only in samples from Tell en-Nasbeh, Tall Umayri, Tell Qiri, and Yokne’am (Map 9) (Appendix 2).
Docosanoic acid (C22:0) is the fatty acid with the largest mass in the dataset. It eluted from samples from Tell en-Nasbeh, Tell es-Safi/Gath, and Tell Qiri (Map 10) (Appendix 2).

Map 10: sites with samples containing docosanoic acid

Hexadecanoic acid (C16:0) and octadecanoic acid (C18:0) are two of the most commonly occurring saturated fatty acids found in nature. Although they derive from both plant and animal lipids, a greater abundance of octadecanoic acid (C18:0) in any ratio of C16:0 to C18:0 has generally been interpreted as indicating an animal fat in published case studies (Gregg et al. 2009; Dudd et al. 1998). However, C16:0 has been shown to be more abundant than C18:0 in studies of modern, un-degraded porcine adipose fat (lard) and marine fish (Regert 2011: 190), as well as in fresh ruminant milk (Hilditch 1956: 133-137).

A Pearson Correlation using SPSS was conducted to test for significant differences in the means of all fatty acids in the dataset. Based on the results of this study,
strong positive correlations were found between the following fatty acids (p = 0.05 for all values):

C10:0 and C12:0  r = .989  
C16:0 and C17:0  r = .871  
C16:0 and C18:0  r = .911  
C16:0 and C18:1   r = .998  
C17:0 and C18:0  r = .848  
C18:0 and 18:1     r = .861

This indicates that these variables increase or decrease at the same rate. However, causation cannot be determined using this test. In addition, a one-way ANOVA was conducted to test the effect of site difference on fatty acid means. All sites were arranged alphabetically and assigned a number between one and twenty-two. No significant differences between sites were recorded at the p = .05 level. Post hoc comparisons using the Tukey HSD and Bonferroni tests show harmonious subsets with no significant difference at r = 0.05 across all samples (harmonic mean sample size = 8.917) although results do show that site 17, Tel Qiri, was different than the others in having smaller (but still not significant) r values (Appendix 6).

When examining levels of these fatty acids qualitatively, there appears to be a difference in the distribution of hexadecanoic and octadecanoic acids across the region. All samples contain hexadecanoic acid (C16:0). Of the eighty-six uncontaminated samples that preserve lipid residues, nine preserved no octadecanoic acid (C18:0) (Appendix 2). Six of these nine samples contain short to medium chain fatty acids
ranging from decanoic acid (C10:0) through hexadecanoic acid (C16:0). The remaining three samples preserve only hexadecanoic acid (C16:0).

Seventy-seven samples feature both hexadecanoic acid (C16:0) and octadecanoic acid (C18:0) (Appendix 2). Of these seventy-seven samples, fifty-two (68%) feature a greater abundance of C16:0 when compared with C18:0. Forty-three of these samples (84%) are from sites with annual precipitation above 400mm (Map 10).

Map 11: sites with samples containing a higher ratio of C16:0 to C18:0

Twenty-one of the forty-three samples (49%) also feature decanoic acid (C10:0) (Appendix 2). Decanoic acid (C10:0) is present in samples from sites located in the Jezreel Valley, Jordan Valley, Hill Country, and Shephelah/Judean Foothills. It is absent from samples located in northern Jordan, the Madaba Plains, and the northern Negev. It is also absent from all Batash, Miqne/Ekron, and Megiddo samples. Decanoic acid is present in only one out of a total of six samples from Tell es-Safi/Gath. All ten samples from Tell en-Nasbeh, and eight out of ten samples from Tell Qiri, contain this fatty acid. Tell en-Nasbeh is in the Judean Hill Country and Tell Qiri is situated in the Jezreel
Valley on the slopes of Mt. Carmel. Both sites received a minimum of 600 mm of precipitation per annum during the Iron Age (Hesse 1990).

There are eight samples with more C16:0 than C18:0 from sites with isohyet levels between 300 and 400 mm, representing only ten percent of the seventy-seven samples (Appendix 2) and only two of these samples also feature decanoic acid (“Pella 10” and “Lachish 5”). Lipid preservation was poor in ceramic samples from sites with annual precipitation below 300 mm, all located in the northern Negev. Of a total of forty processed samples, only four preserved lipid residues (“Beersheva 1”, “Tell Halif 10”, “Tel Malhata 3”, “Tel Malhata 6”). Only one sample, from Beersheva, eluted more hexadecanoic acid (C16:0) than octadecanoic acid (C18:0) (Appendix 2). Malhata samples did not contain octadecanoic acid. The sample from Halif has more octadecanoic acid (C18:0). Decanoic acid (C10:0) was absent from all of these samples.

Of the original seventy-seven samples containing both hexadecanoic acid (C16:0) and octadecanoic acid (C18:0), fifty-two samples contain more C16:0 than C18:0, twenty-three samples feature more C18:0 than C16:0. Two samples from Tell Qiri exhibit equal abundance of these two fatty acids. The twenty-three potsherds with more C18:0 than C16:0 were sampled from sites located in the Jezreel Valley, northern Jordan, Jordan Valley, Madaba Plains, Shephelah/Judean Foothills, and northern Negev (Map 11). The bulk of them, however, came from just two sites; eight out of a total of nine samples from Tall Umayri and four out of nine samples from Megiddo eluted more C18:0 than C16:0 (Appendix 2).
3.3 Conclusion

Fatty acids in the dataset are restricted to a limited range from decanoic acid (C10:0) through docosanoic acid (C22:0), including heptadecanoic acid (C17:0) and oleic acid (C18:1). Absorbed residues preserved poorly in samples from sites in areas with isohyets between 100 and 300 mm per annum. Decanoic acid (C10:0) was found in samples from cis-Jordanian sites and in one sample from Pella, a trans-Jordanian site in the Jordan Valley. All of these sites received, on average, more than 300 mm of precipitation per annum during the Iron Age (Map 12).
TMS esters in the dataset are characteristic of highly degraded lipid residues. Saturated fatty acids are restricted to a limited range from decanoic acid (C10:0) through docosanoic acid (C22:0). The absence of short-chain fatty acids with fewer than ten carbons is related to instrumentation. With an inlet temperature of 300ºC and temperature program used (described above page 32), these low mass weight fatty acids would elute within the solvent peak at the start of processing and be undetectable (S. Petsch, pers. comm., 9/1/16). Oleic acid (C18:1) is the only extant unsaturated fatty acid. Results also suggest a connection between fatty acid preservation and environment because preservation is poor in samples excavated at all but one arid site, Tall Umayri. Despite this, results show variation in the distribution of fatty acids between sites. The main differences are relative abundance of C16:0 verses C18:0 and the presence or absence of decanoic acid (C10:0).

Samples eluting decanoic acid were found only at sites with greater than 300 mm of annual precipitation. The majority of these samples eluted more C16:0 than C18:0. By
contrast, not only was decanoic acid absent from sites with less annual precipitation, the majority of these samples contained more C18:0 than C16:0. Oleic acid preservation within the dataset is unrelated to environment, and samples that eluted oleic acid lacked decanoic acid. Unsaturated oleic acid is more susceptible to degradation than straight-chain, saturated decanoic acid, so these results suggest differences in cuisine rather than preservation.

As discussed above, absorbed residues preserved poorly in samples from sites in areas with less than 300 mm of precipitation per annum - most of Jordan and the northern Negev. This hampered regional interpretation, and Tall Umayri is the only site exhibitinglipid preservation comparable with sites that receive greater annual precipitation. Seven out of a total of nine Umayri samples (78%) eluted more octadecanoic acid (C18:0) than hexadecanoic acid (C16:0). The one sample from Tell Halif (northern Negev) that preserved both of these fatty acids, one from Tall Zira’a (northern Jordan), one from Khirbat al-Mudayna (Karak Plateau in west-central Jordan), and one from Pella (Jordan Valley), also have more C18:0 than C16:0.

Out of a total of nineteen samples from Jordan and the northern Negev that preserved both C16:0 and C18:0, eleven (58%) eluted more C18:0 than C16:0. Forty-two percent eluted more C16:0. Of the fifty-nine cis-Jordanian samples (not including the northern Negev) that preserved both fatty acids, 48 (81%) eluted more C16:0, and eleven (19%) more C18:0. The ratio of C16:0 to C18:0 has been used to identify animal fats and distinguish them from plant oils. Content of C16:0 lower than C18:0 is generally interpreted as characteristic of animal fat (Aillaud et al. 2001; Dudd et al. 1998). However, fatty acid composition tables for fresh ruminant milk (bovine, ovine and
capric), pork lard, and marine fish feature C16:0/C18:0 ratios with lower C18:0 (Regert 2011: 190; Hilditch 1956: 133-137). Of the samples eluting decanoic acid, eighty-nine percent, twenty-four of the total of twenty-seven samples had C16:0/C18:0 ratios with lower C18:0 (Appendix 2).

Decanoic acid was absent from samples originating in the northern Negev and Jordan, with the exception of one Pella sample. Neither was it found in samples from Tel Batash, Tel Miqne/Ekron, and Megiddo. Samples from these three sites preserved oleic acid (18:1), however, and all are located in areas with 400 mm or more precipitation per annum. When considered with regard to fatty acid degradation, the absence of decanoic acid is probably not a factor of preservation. Instead, I interpret this as indicating a difference in foods cooked within sampled vessels (Map 14).

Map 14: sites with samples containing C18:1 but no C10:0 or C12:0
Unfortunately, the identification of cooking ingredients using analysis by gas chromatography/mass spectrometry alone is problematic because most of the fatty acids recorded in the dataset are common to several animal and plant genera. For example, the suite of fatty acids C14:0, C16:0, C18:0, C18:1, and C20:0, are present in pork lard and ruminant tallow (bovine, ovine and capric), and also in wheat (CyberLipid 2016). C10:0, C12:0, C14:0, C16:0, C18:0 and C18:1 are found in ruminant dairy fat (Ai).

Heptadecanoic acid (C17:0) is an odd chain fatty acid found in microbial species. It is abundant in lipids derived from bacterial activity in the digestive tract of ruminant animals. It is found in both adipose and dairy fat at 1 – 1.5%. It is also present in non-ruminant species typically at < 0.5%. However, it is absent from poultry and vegetal fats including grains such as wheat and barley (Christie 2011).

According to Evershed et al. (1992a: 203), dairy product residues are readily recognizable by the presence of “short-chain fatty acids with less than twelve carbons” (also see Rottländer and Schlichtherle 1979). Decanoic acid is a minor component of most milk fats, including those of non-ruminants, but significant amounts are not found elsewhere in animal tissues. It is absent from vegetal oils apart from coconut, palm kernel, and Cuphea sp., none of which are indigenous to western Asia (Christie 2011). The presence of decanoic acid in sixty-eight percent of cis-Jordanian samples is consistent with the use of cooking vessels to process dairy products and/or prepare milk-based recipes.

Goats and to a lesser extent, sheep, provided fresh milk during spring/summer and fresh milk could not be stored without spoiling. Typically, thick sour milk called laban
was drunk. It curdled quickly because it was kept in skin containers (Borowski 1998: 54-55; MacDonald 2008a:35-36; McCormick 2012: 101; see also Palmer 2002). Milk could not be stored without processing. This was done by churning, using a goatskin or clay container to separate the butterfat and whey. Clarified butter was produced by boiling and cooling butterfat. Soft cheese was made using cloth bags filled with soured milk. The liquid component drained through the cloth and soft cheese remained in the bag. A hard cheese was made from fermented soured milk. Milk was poured into molds where it curdled and dried, hardening in the sun. The sap of fruit trees, such as figs, was used to harden cheese - a method still used by Bedouin (Palmer 2002).

Ethnoarchaeological case studies of modern Bedouin record that fresh milk, butter, cheese and yoghurt are dietary staples. A dry type of yoghurt called ‘jamid’ is made by removing the liquid, mixing in salt, and forming the mixture into small balls, which are then sun dried to a hard consistency. They preserve for up to a year without refrigeration, are portable, and can be used in a variety of ways. They can be eaten as is, often with dried fruit. The yoghurt balls can also be crumbled into water to create a milky soup base or sauce. So the processing of dairy products used a variety of methods and equipment.

The preservation of oleic acid in two samples from Tall Umayri, and a total lack of short-chain fatty acids, suggests that milk products may have been processed and consumed in ways that did not require a cooking vessel. Unlike cis-Jordan, where decanoic acid is common and the majority of sherd samples eluted more C16:0 than C18:0, elevated C18:0 and the lack of decanoic acid may indicate that cooking vessels were used to prepare meat based meals and not to process clarified butter or create milk-based soups or stews.
Samples from three cis-Jordanian sites also lack decanoic acid – Tel Batash, Tel Megiddo, and Tel Miqne/Ekron. Three samples from Batash, seven from Megiddo, and one from Miqne/Ekron preserve oleic acid (Appendix 2). All are multi-period sites with more than 300 mm of precipitation per annum. Ceramic samples from all three sites are from excavated areas interpreted as high status/elite, areas with both domestic and public/monumental architecture. An elite context in archaeology is one that features location, architecture, and/or artifacts that can be interpreted as characteristic of the upper echelons within a hierarchical society.

All samples from Tel Batash come from three areas (D, E, H) from stratum IV (10th century BCE) and III (eighth century BCE). A combination of location and artifacts identify the three areas as high status (Table 3). Material from Stratum III Area D Building 737, the “LMLK Jars Building” includes the secure sample locus 737 from the stone floor in Squares J-30-32 comprised of Loci 734, 737, and 748. Most of the lmlk jars (Fig. 11) were found smashed on this floor (Mazar 1997: 3). The ancient Hebrew lmlk - lamed-mem-lamed-kaf, commonly pronounced l’melekh translates as "belonging to the king". Jars with lmlk seal impressions were manufactured from the late eighth to early seventh centuries BCE and are primarily associated with the reign of King Hezekiah of Judah. They have been interpreted as royal stamps on large storage jars, the contents of which may represent military rations, religious tithes, or government tax payments.
Stratum III floors in the western part of Area E are probably a part of the Building 737 (LMLK Building) complex (Mazar 1997: 3). Dataset samples come from Loci 702 (Square L-K-25) and 709 (Square K-25). Locus 702 is a patchy pebble surface above Strata IV-V fill (Locus 708), which might represent a street running between Walls E713 and E822. Locus 709 is a plaster floor south of Wall 628. Storage jars, kraters and a scoop, were found along with cooking pots in these loci. A scoop is an asymmetrical bowl that was probably used for filling storage jars.

Stratum IV Area H has been interpreted as domestic structures located next to an administrative complex and the city gate (Mazar 1997: 6). Samples were excavated from debris below both sides of Stratum III Wall H868. The top of this debris may include material belonging to Stratum III (8th century BCE). A sample from locus 865 was excavated from a white plaster and pebble floor in Squares DD-EE-37 (Loci H807, H816, H865) along with a large collection of sherds and several whole vessels. This floor
appears to have been first laid in Stratum IIIB, and continued in use in Stratum IIIA, both eighth century BCE.

Samples from Megiddo were excavated from floors and occupation debris in Area H. This area has been interpreted as domestic structures near a Bronze Age palace, the city gate, and the water system. It has been interpreted as high status because of its location. According to Sapir-Hen et al. (2016: 66), Area H was home to an administrative class employed by the palace during the Bronze Age and Iron Age I. Its inhabitants did not process food but, instead, received provisions from other areas of the city. Faunal remains from this time period show that provisions included better cuts of, and more, meat (Sapir-Hen et al. 2016: 63). No artifacts indicative of elite status were excavated from Iron II period strata, but the area was always a “favorable place to live” (Finkelstein, pers comm, March 30, 2016).

Level H-7 features two architectural units (00/H/66; 06/H/26), domestic in nature, built around an open space (06/H/34). Building 00/H/66 is the major structure of Level H-7. The living surfaces of this phase are characterized by a thick accumulation (ca. 20-25 cm) of beaten earth and phytolith floors. Shahack-Gross et al. (2009) interpret Megiddo phytolith floors to be the accumulation of household waste. Level H-7 “seems to represent the growth of Iron IIA Megiddo into a real city” because it contains a variety of architectural features and is better organized than previous levels (Arie 2013: 265). The thick accumulation of floors and the changes in the courtyard may suggest that the time span of this level was significant. Level H-3 consists of domestic structures immediately below Assyrian Building 1853 and the open courtyard to the north of Assyrian Palace 1369 (Joffe et al. 2000: 143).
Samples from Tel Miqne/Ekron came from two contexts, a stratum III street cut by a stratum II drain in Field I, the Acropolis (Strata III-II, 8th century BCE) and the Lower Temple Auxiliary Building of Field IV the “Elite Zone” (Stratum I, 7th century BCE). Domestic and public/monumental architecture have been uncovered in both areas, and both areas have been interpreted as elite, based on architecture and excavated artifacts.

The lower part of the Iron Age I city was abandoned during the tenth century BCE following destruction by Pharaoh Siamun or the Israelites (Dothan and Gitin 2012: 4). Only the upper city was occupied in Strata III–II (8th century BCE). Ekron became an Assyrian vassal city-state following the Assyrian conquest of the 8th century and was re-urbanized in Stratum I (7th century BCE). The Iron Age II city of strata III-II was built over a series of massive stone foundations that ran east–west up and across the top of the acropolis, forming part of a monumental system of terraces and platforms (Dothan and Gitin 2012: 7). The primary architectural feature of Stratum III was a re-paved Stratum IV street with flanking walls. The general plan of Stratum III continued in the monumental architecture of Stratum IIA–B, with the addition of a series of rooms, probably shops or market stalls, that opened onto the street, to which a stone-lined central drainage system was added in Stratum IIB (Dothan and Gitin 2012: 7). Three lmlk stamped jar handles, associated with the end of the 8th century BCE, were uncovered in stratum II. One four-winged example bears the inscription lmlk hbrn (“belonging to the King of Hebron”), dating to a brief period when the Judean King Hezekiah ruled Ekron (Dothan and Gitin 2012: 8). A silver hoard consisting of 21 pieces, including a silver
medallion depicting the goddess Ishtar standing on a lion, came from the Field I Summit/Acropolis (Dothan and Gitin 2012: 9).

Temple Auxiliary Buildings produced concentrations of two unique categories of finds—inscriptions and silver hoards. The former are represented by sixteen inscriptions on storage jars, including, among others, *kdš lʾšrt* (“dedicated to[the goddess] Asherat”), *lmqm* (“for the shrine”), and the letter *tet* with three horizontal lines below it (probably indicating 30 units of produce set aside for tithing). The word *bt*, designating a capacity of ca. 32–35 liters, also occurs, as do inscriptions indicating storage jar contents, such as *šmn* (“oil”) and *dbl* (“a cluster of figs”). Three silver hoards amounting to 220 pieces, including ingots, cut pieces, and broken pieces of jewelry were discovered here. “This large quantity reflects the use of silver as currency in Phoenician maritime trade, an important element in the economy fostered by the Neo-Assyrian Empire” (Dothan and Gitin 2012: 9).
Table 3: sample provenience

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<th>File No.</th>
<th>Locus &amp; pottery plate</th>
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<tbody>
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<td>Batash 2</td>
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<td>H8571/1 [82:23]</td>
<td>dwellings next to admin. complex near gate</td>
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<td>Batash 3</td>
<td>1002235.D</td>
<td>H8605/1 [87:26]</td>
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<td>Batash 5</td>
<td>1002237.D</td>
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<td>Batash 7</td>
<td>1002239.D</td>
<td>E7069/2 [25:14]</td>
<td>prob. part of “LMLK Jars Building”</td>
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<td>06/H/13 VS 10</td>
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<td>Megiddo 3</td>
<td>1003183.D</td>
<td>94/H/57 VS7</td>
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<td>Megiddo 4</td>
<td>1003184.D</td>
<td>94/H/57 VS8</td>
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<td>Megiddo 5</td>
<td>1003185.D</td>
<td>06/H/78 VS18</td>
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<td>Megiddo 6</td>
<td>1003186.D</td>
<td>06/H/2 VS 10</td>
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<td>Megiddo 7</td>
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<td>96/H/57 VS1</td>
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<td>Fld. 1 street cut by Str. II drain, acropolis</td>
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<td>Miqune/Ekron 3</td>
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<td>L28110 ISW.28.287.12</td>
<td>Fld. 1 street cut by Str. II drain, acropolis</td>
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<td>Miqune/Ekron 5</td>
<td>120923-17.D</td>
<td>L3021.1 INW.3.094.20</td>
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<td>Miqune/Ekron 7</td>
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<td>Fld. IV Lower Temple Aux. Bldg., “Elite Zone”</td>
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<td>Fld. 1 street cut by Str. II drain, acropolis</td>
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4.1 Implications Regarding Ancient Cooking

Analytical results suggest differences in cooking based on environment and on status. Samples from arid sites (< 300 mm isohyet) eluted no decanoic acid (C10:0) and preserved more octadecanoic acid (C18:0) than hexadecanoic acid (C16:0). This ratio was reversed in samples from non-arid sites. Decanoic acid was present in samples from non-arid sites (>300 mm isohyet) with three exceptions, Tel Batash, Megiddo and Tel
Miqne/Ekron. Samples from these three sites were excavated from contexts interpreted as elite. By contrast, every sample from Tell en-Nasbeh contained decanoic acid as did nine out of ten samples from Tel Qiri. Neither site preserved features or material culture associated with hierarchy (public/monumental architecture, symbols of authority).

However, it would be unrealistic to broadly interpret cooking and diet based on a small number of samples—ten in total from each site—and by studying only one cooking method. There were many cooking methods employed by ancient south Levantine populations that are potentially more difficult, if not impossible, to trace in the archaeological record—e.g., grilling, roasting, drying, and parching. Food was also eaten raw. With these caveats in mind, this initial study does offer preliminary information about clay pot cookery during the Iron Age II period.

4.1.1 Evaluating the Model

Goody theorizes that a ‘high cuisine’ is typical of societies that are politically stratified, with the “allocation of specific foods to specific roles, offices or classes”. His “low” cuisine is characterized by local and undifferentiated food shared by all groups in society. Although differences can exist in terms of the quantity of food served to different people, in a low cuisine there are no significant differences in terms of the quality or the nature of the food consumed by different social groups (Luley 2014: 35).

There is evidence of agricultural surpluses in the south Levantine archaeological record, for example lmlk handled jars and scoops. However, fatty acids within the dataset fall within a restricted range and, with the exception of oleic acid, are all saturated. The
presence of decanoic (C10:0) and heptadecanoic (C17:0) acids suggests a reliance on ruminant fats. There is nothing in the dataset that points to the use of exotic ingredients, such as imported spices, typical of Goody’s ‘high’ cuisine. In addition, the limited number of samples available for analysis, ten from each site, may be insufficient to produce statistically significant results. The absence of decanoic acid in samples from elite contexts implies a difference in clay pot cookery that may be linked to status. Further analysis is needed to better understand this difference. Therefore, I argue that there is insufficient data to evaluate Goody’s model. This study can be seen as a pilot project and testing a larger dataset, sampled from targeted areas within sites with large exposures, has the potential to yield more information. In addition, combining gas chromatographic analysis with another method like carbon specific isotope analysis could lead to a more robust interpretation of the dataset.

4.1.2 Methodological Implications

Carbon specific isotope analysis (GC-C-IRMS: gas chromatography-combustion-isotope ratio mass spectrometry) is typically used to differentiate plant from animal lipids, ruminants from monogastric animals. Gas chromatography/mass spectrometry (GC/MS) is a useful tool to identify compounds and determine which samples are suitable for isotopic analysis. It is a valuable ‘first step’.

This study was hampered by poor preservation and sample contamination. Greater care with regards to handling and storage of samples during and after excavation could improve this. The shared use of laboratory facilities also increases the probability of contamination during processing. Greater delineation of laboratory equipment, for
example using a new GC/MS column for each project and not sharing solvents, could minimize this problem.

4.2 Suggestions for Future Research

Analysis using (GC-C-IRMS) gas chromatography-combustion-isotope ratio mass spectrometry has the potential to add further information to the dataset. GC-C-IRMS analysis follows an established protocol (Dudd and Evershed 1998; Dudd et al. 1999). This approach uses δ13C values of C16:0 and C18:0 saturated fatty acids to characterize the origins of animal fat recovered from archaeological pottery (Evershed et al. 2002b). Different plant and animal groups exhibit differing δ13C values, enabling classification of archaeological food lipids (Evershed et al. 2001: 332), for example distinguishing between porcine and ruminant-derived adipose fats extracted from ceramic vessels (Mukherjee et al. 2008: 2063) and distinguishing between ancient adipose and milk fats (Evershed et al. 2002a: 666). Specifically, differing consumption of foods can be inferred from stable carbon isotopic composition of fats.

The carbon isotope composition of plants, and plant products, is linked to the process of photosynthetic CO2 fixation (Spangenberg et al. 2006: 2). The C3 and C4 pathways of plant photosynthesis are important atmospheric CO2-fixing reactions. Plants from temperate regions feature C3 pathways, this includes most vegetables, fruit and domesticated grasses such as wheat and barley (Spangenberg et al. 2006: 2). C3 plants use the Calvin cycle for CO2 fixation, and their δ13C values fall into a range between -34 and -22%. Conversely, C4 plants are adapted to hot and arid environments and are typically tropical genera such as millet, maize and sugar cane. They use the Hatch-
cycle, and are relatively enriched in $^{13}C$ (-16 to -19%), and they feature lower isotope fractionation compared with C3 plants (Spangenberg et al. 2006: 2). Animals (including humans) who consume mainly C3 plants will have $\delta^{13}C$ values below -22%, while those eating primarily C4 plants will have values close to, or above, -12%. The lower $\delta^{13}C$ values indicate that the diet of the individual in question derived from C3 plants, or by consuming meat and dairy products from animals that subsisted on a diet of C3 plants (Spangenberg et al. 2006: 2).

Evershed et al. (2002b: 74) posit that animals raised in antiquity would have consumed a reasonably restricted diet, so the dietary contribution of $\delta^{13}C$ to tissues would be fairly constant. Variation to this may arise in non-ruminant domesticates due to the inclusion of food supplements such as food processing waste that may contain a large protein component, for example meat scraps or whey from cheese production. Enrichment of $\delta^{13}C$ in species further up the food chain has been noted and, in non-ruminant animals, direct routing (as opposed to routing through the rumen) of dietary fats to storage organs as adipose means that the isotopic signal of the dietary lipids consumed is retained and reflected in the isotopic composition of the adipose fat (Evershed et al. 2002b: 74). However, plant lipids ingested by ruminant animals undergo extensive microbial transformation in the rumen, with short-chain fatty acids as an end product (Spangenberg et al. 2006: 8). Ruminant dairy fats (milk, butter and cheese) have “higher $\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$ values than those of adipose fats”, facilitating their identification (Spangenberg et al. 2006: 9), Comparing $\delta^{13}C$ values of archaeological animal fat residues with values from modern reference fats from animals consuming primarily C3
plants can characterize the origins of animal fats recovered from south Levantine archaeological pottery to enrich GC/MS differentiation between plant and animal fats.

Combining GC/MS and GC-C-IRMS to the study of a greater number of samples from sites with ongoing excavations has the potential to generate more detailed data resulting in a more nuanced interpretation.

Figure 12: GC-C-IRMS, carbon specific isotope analysis. source: Evershed 2008
CHAPTER 5
RESULTS SUMMARY

Qualitative dataset analysis revealed three main discoveries relating to ethnicity, social hierarchy, and environment. This dissertation project began as an investigation into south Levantine Iron Age II period cooking and ethnicity. However, results indicate that there is no variation between samples that can be ascribed to ethnic difference. Instead, all well-preserved lipid profiles are characteristic of animal fats and, in particular, ruminant dairy and meat fats. Fatty acid preservation was poor in samples from arid areas of Jordan and the northern Negev. Controlled laboratory experimentation has the potential to help us better understand this phenomenon. Hierarchical and environmentally mediated differences in the dataset are outlined in table four. They raise new questions about food and class in Iron Age Israel as well as meat consumption in arid areas. I foresee at least three future research projects stemming from this research.
<table>
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<tr>
<th>FINDINGS</th>
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<tr>
<td>Environment</td>
<td>Data suggest that populations living in arid conditions did not use dairy products in clay pot cookery and, instead, prepared meat-based meals. By contrast, vessels from populations living in areas with the most annual precipitation also had the greatest amount of data to suggest that cooking vessels were used for the processing of dairy products (e.g., clarified butter) and/or preparing milk-based recipes.</td>
</tr>
<tr>
<td>Hierarchy</td>
<td>The absence of a fatty acid biomarker for dairy products, decanoic acid, from the elite areas of three sites (Tel Batash, Tel Miqne-Ekron, and Tel Megiddo) indicates that high status populations did not use cooking pottery to process dairy products and did not cook milk-based meals. Decanoic acid was present in all but one vessel sample from sites without archaeological remains interpreted as elite (Tell en-Nasbeh, Tel Qiri). This result is independent of environment. All five sites receive in excess of 600 mm of precipitation per annum.</td>
</tr>
</tbody>
</table>

Table 4: results summary
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