NOBLE CHEMISTS AND ARCHAEOLOGISTS:

CHEMICAL ANALYSES OF FOOD RESIDUES FROM ANCIENT MAYA VESSELS

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ABSTRACT

This study of ancient Maya foodways was undertaken in order to better understand changes in economic and social structures that took place in Maya society between the Preclassic (1200 B.C. – A.D. 250) and Classic (A.D. 250 – 900) periods. Two chemical methods were used to identify archaeological food residues that have been preserved in ceramic vessels excavated from several ancient Maya settlements. A second objective of the project was to evaluate the utility of each method of residue analysis for the investigation of ancient Maya foodways in particular, and for the study of ancient foodways and related archaeological questions, generally.

Stable carbon and nitrogen analysis was used to analyse 23 carbonised food residues preserved on the interior surfaces of Middle Preclassic cooking vessels from the site of Cuello, Belize. Isotopically light $\delta^{13}C$ values in all but two vessels indicate that most of the vessels were not used to prepare maize. Elevated $\delta^{15}N$ values in all residues (n=13) with measurable amounts of nitrogen clearly indicate that freshwater fish were prepared in these vessels. Depleted $\delta^{13}C$ values, and the thickness and location of the chars on these same vessels suggest that a starchy C3 plant was cooked along with the fish. Unambiguous evidence that the earliest Maya at Cuello made use of fish from wetland areas near the site is important as other lines of archaeological evidence do not or cannot demonstrate this as clearly. Moreover, these results show that isotopic analysis of charred residues can provide new and different information to investigations of past foodways. Future applications will be restricted only by the small number of carbonised residues recovered, as strong and universal theoretical principles and the

long-term stability of the isotopic signals create potential for widespread utility of the method.

Ancient lipid residues successfully extracted from ceramic vessels from four Lowland Maya sites were analysed by gas chromatography. Fatty acid profiles of the residues contain a record of the former contents of the vessels. Contamination during burial or post-excavation was shown to be minimal except where vessels had been catalogued using nail polish. Direct comparison of the fatty acid profiles of archaeological residues with those of comparative cooked food standards (fresh and degraded) were made difficult by complex processes of degradation that have greatly altered the archaeological residues. However, I suggest that a meat or plant origin can be assigned to most residues based on a ratio of medium:long chain fatty acids <2 for plants and >2 for meats. Freshwater fish residues, in Cuello vessels that had chars, are distinguishable by relatively higher proportions of the odd-numbered fatty acids. In light of these results, and given that faunal and botanical remains are poorly preserved at Lowland sites, the analysis of lipid residues is potentially a useful analytical tool for investigating ancient Maya foodways. The fatty acid criteria suggested for the identification of lipid residues cannot be applied universally as food assemblages from different geographic regions have distinct fatty acid compositions. This fact along with the highly varied and complex processes of degradation, which are currently poorly understood, will serve to limit the development and application of this approach to archaeological studies of foodways.

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Table of Contents

List of Figures

List of Tables

Chapter 1

The Project and Research Goals

1.1 Introduction: the interest in ancient foodways

> Food is the foundation of every economy. It is a central pawn in political strategies of states and households. Food marks social differences, boundaries, bonds, and contradictions. Eating is an endlessly evolving enactment of gender, family, and community relationships...Food is life, and life can be studied and understood through food.
>
> (Counihan and Van Esterik 1997a:1)

This short passage elegantly captures why anthropological investigations of food and foodways are useful for understanding many dimensions of human societies. The term *foodways* refers to food and all of the activities associated with food production, distribution, preparation, and consumption (Welch and Scarry 1995:397). Archaeological food remains have long been used to understand the dietary and subsistence choices of past societies in terms of environmental, nutritional, and economic limitations that would have affected those decisions (Flannery 1976, 1982; Harris 1987; Hastorf 1988). Only recently have archaeologists begun to consider how cultural, social, and political identities and interactions also influence what people decide to eat (Bryant *et al.* 1985:76-77; Costin and Earle 1989:691; Wing and Brown 1979:1, 11-16). The realisation that foodways are connected in many ways to the larger economic, social, cultural, and political systems within which they are set has led to a marked increase in food related research in recent years in archaeology (Brumfiel 1991; Costin and Earle 1989; Hastorf 1991; Hastorf and Johannessen 1993; Johannessen 1993; Hayden 1990; Miller and Burger 1995; Welch and Scarry 1995), sociocultural anthropology (Bryant *et al.* 1995;

Counihan and Van Esterik 1997b; Harris and Ross 1987; Pollock 1992; Weismantel 1988), sociology (Goody 1982), and history (Fiddes 1991; Forster and Ranum 1979; Tannahill 1988). Such a perspective is valuable for archaeology, in particular, because it challenges archaeologists to use food remains in ways that move beyond identifications of the foods which people obtained or produced and ate. It emphasizes that analyses of food can also be used to investigate more complex problems concerning the nature and dynamics of economies, social relationships, and political structures that operated in the past.[1]

1.2 Project objectives: ancient Maya foodways and food residues

In this study, my purpose was to use archaeological evidence of foodways, obtained using chemical analyses (stable isotope analysis and gas chromatography) of food residues from ceramic cooking vessels, to investigate economic and social change in pre-Hispanic Maya society. The project was set up to address the following anthropological and methodological objectives: 1) to explore the dynamic relationship between food preparation, food distribution, food consumption, and other aspects of domestic economies in order to understand how broader societal changes at the end of the Late Preclassic (250 B.C. - A.D. 250) and into the early Classic (A.D. 250 - 900) period impacted Maya households; 2) to establish whether and how food might have played a role in the creation and maintenance of socio-economic and -political hierarchies in Maya society; and 3) to evaluate the usefulness of techniques of residue analysis to the investigation of ancient Maya foodways, in particular, and to the discipline of archaeology, generally.

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[1] Compare for example Hastorf (1988) with Hastorf and Johannessen (1993) and Johannessen (1993).

Rapid growth in Late Preclassic (250 B.C. - A.D. 250) and Classic (A.D. 250-900) period Maya communities resulted in changes in agricultural production (Chase and Chase 1983; Fedick 1989; Harrison and Turner 1978; Killion *et al.* 1989:288-289), and seems also to have affected land tenure and household composition (McAnany 1995). Reorganization of domestic labour and economies undoubtedly accompanied these other changes and may be evident in changes in food preparation, consumption, and/or distribution. Considered along with other evidence for broader economic, social, and political transformations, temporal variation in cooking practices could be informative as to how such larger changes impacted household economies (*cf.* Blanton *et al.* 1981:71-72; Brumfiel 1991) and the day-to-day lives of the Maya. Reconstructing domestic economies from the viewpoint of food preparation and cooking might also afford the opportunity to observe the role of Maya women, in particular, in the evolution of ancient Maya society (Brumfiel 1991:226-227).

Socio-economic and -political hierarchies also emerged in the Late Preclassic as Maya populations increased (Carr 1985; Cliff and Crane 1989; McAnany 1995:55-58; Robertson 1983). These systems became more marked in the Classic period. Yet, the origins of inequality and the nature of elite authority in ancient Maya society are not fully understood (Adams 1970; Ball 1993; McAnany 1993; Sanders and Webster 1988; Webster 1985). As food is often used to establish and maintain social, economic, and political inequalities (Costin and Earle 1989:691-692; Earle 1978:181-183; Hastorf and Johannessen 1993:116-117; Hayden and Gargett 1990; Pollock 1992), an investigation of pre-Hispanic Maya foodways might provide further insights into the nature of the socio-political and socio-economic inequalities which existed. I intended to look for evidence of political feasting and perhaps even the existence of a high status cuisine. Cuisine refers to the cultural construction of meals, knowledge about foods, and the ways in which foods are prepared and combined (*cf.* Weismantel 1988:87). Political feasting is

sometimes used by emergent elites to achieve and maintain prestige through the distribution and presentation of food in a manner that creates asymmetric social and political relations (Hayden 1990; Hayden and Gargett 1990). As their authority becomes more centralized, elites often establish a high status cuisine (*cf.* Goody 1982), distinguishable by differences in the types and quality of foods consumed and by more elaborate methods of food preparation. The different cuisine marks the status differences that exist and symbolizes the power and influence of the elite.

I also consider the utility of food residue analysis from the perspective of an anthropological archaeologist rather than a chemist or an archaeologist whose main interest is archaeometric techniques. Gas chromatography is used to analyse lipid residues (fatty acids) absorbed into the ceramic walls of some vessels. Stable isotope analysis is used for the analysis of carbonized food residues found on the interior of some pots. The value of each approach, and of residue analysis generally, will be considered based on the extent to which it is possible for me to resolve the preceding questions concerning ancient Maya foodways. I expect objections and realize that the questions that I have asked may not be ones that can be answered using residue analysis. Other residue analysts might argue that the techniques are only in the early stages of development and application to the study of ancient organic materials. Yet, I believe that the problems set out are reasonable ones which archaeologists would expect to be able to address using the temporal and spatial patterning of other categories of food remains and artifacts used in the study of foodways. If residue studies are to find wider application in archaeology, the knowledge obtained must offer something to the objectives of the discipline. It must be demonstrated that identifications are reliable, and that the information provided by residue analyses is somehow different and/or better than what can already be learned about ancient foodways through investigations of other types of food remains, artifacts, ethnographic analogy, and/or ethnohistoric

documents. Provocative claims that residue analysis has the potential to provide species or genus level identifications of foods, and of food plants in particular, which are otherwise rarely preserved (Evershed *et al.* 1991) are encouraging. Yet, can this level of identification be achieved with any regularity? Is it reasonable to expect that this level of identification can be attained for residues from a large sample of vessels or are the time and costs involved in the analyses too great? These and other questions regarding the utility of residue analysis to archaeology have yet to be addressed in the published literature.

1.3 Methods and materials

One limitation to reconstructing and understanding pre-Hispanic Maya foodways is that botanical and faunal remains are greatly underrepresented at archaeological sites in the Maya Lowlands. The warm, wet conditions increase the rate and extent of decay of organic materials like bone and seeds. In addition, the physical action of many and large roots effectively destroys most carbonized plant material. Therefore, I elected to investigate the utility of food residue analysis as a different line of evidence for investigating Maya foodways. Two forms of food residues can occur in association with ceramic vessels and both are fairly durable under certain conditions. Lipid residues absorbed into the porous w alls of ceramic vessels during use have been shown to be both relatively resistant to various processes of degradation and to be useful for identifying the original food contents of vessels (Evershed 1993; Heron and Evershed 1993). Gas chromatography was used to analyse fatty acids from this type of residue. Absorbed residues as old as 3000 years have been preserved in ceramic vessels from sites in other tropical areas (Hill *et al.* 1985; Hocart *et al.* 1993). Food may also become charred onto the interior surface of some pots during cooking. These inert carbonised residues are resistant to decay and preserve the stable carbon and nitrogen isotopic

ratios of the original foods allowing identification of particular categories of food plants or animals (Hastorf and DeNiro 1985; Morton 1989). Thus, residue analyses could potentially provide information about foodways at Maya sites where no other food remains exist, or could complement botanical and faunal studies at sites where these types of remains do occur.

As food residues can exist in food preparation vessels and perhaps less frequently in serving vessels, residue analysis will potentially give evidence of household tasks and cuisine that will be useful for addressing questions that interest me. A food residue retained in the ceramic matrix of a vessel is unique in that it combines direct and physical evidence of both the food(s) which was utilized and the activity or process of cooking or serving that food(s). Compared with other types of food artifacts, it might be possible to obtain greater insights into "kitchen" chores and particularly the relative amount of time and labour involved in food preparation tasks. Archaeobotanical and faunal remains often represent parts of foods that were discarded, inadvertently dropped, or destroyed during processing or preparation. The manner in which foods were prepared must be inferred from other indirect lines of evidence or analogy. Residues, however, would give direct evidence for methods used to cook particular foods (see Section 4.2) and of vessel function. Thus, good residue results would be helpful in defining some of the activities that took place in ancient Maya households. In addition, as far as it is possible to determine whether foods were cooked separately in specific vessels, combined, or cooked in sequence, residues might indicate something of the complexity of a cuisine. Increasingly complex cuisines require more time and effort devoted to the organization and execution of food preparation activities in a household as compared to combining many foods in one stew pot. Knowing how much time was spent in the kitchen in any one household at a single point in time, by itself, is not meaningful. However, a sense of how this changed over-time, as Maya society became increasingly complex, or how it

differed between sites or regions might provide insights as to how different or changing economic or socio-political structures affected daily life in typical Maya households.

I contacted archaeologists who had conducted excavations in the Maya Lowlands requesting materials to analyse. Access was given to a number of ceramic collections that would allow me to begin working on the anthropological problems that I set out above. Cuello and K'axob, in northern Belize, are both Preclassic (1200 B.C.-A.D. 250) occupations. Vessels available from collections excavated at El Pilar, Belize and smaller settlements surrounding this centre, spanned the Early Classic (A.D. 250-400) through Late Classic periods (A.D. 600-900). Additional Late Classic materials were obtained from excavations at the centre of Aguateca, Guatemala. Seven late Middle Classic or early Late Classic (ca. A.D. 600) vessels from the small farming village of Cerén, located in the southwestern Maya periphery in El Salvador were also provided for residue analysis. Together, the collections comprise a diachronic sample that could perhaps reveal changes in patterns of food preparation and consumption from the Late Preclassic to the Classic period. Such changes might reflect remodeling of domestic economies. For example, Brumfiel (1991:237-243) suggests that evidence for the preparation of greater amounts of dry food dishes, as opposed to wet gruels and stews, following the Aztec conquest of the Valley of Mexico (A.D. 1430), indicates that people then had to participate in tribute labour for elites which required that they transport and consume more of their food away from the home. Late Preclassic and Classic period population increases are events that might be expected to have impacted the economic activities of Maya households. It has been suggested that at some sites and, in some regions, population increases resulted in the development of larger, extended family households (McAnany 1995) and/or the location of *milpas* at some distance from people's residences (Netting 1978; Sanders 1981:362-363). The former scenario might have resulted in greater repetition of vessels used to prepare the same foods or dishes within the same

residential structure, following the growth of extended family household units; or perhaps preparation of the dishes was simplified in order to accommodate larger numbers of people sharing one meal. The latter outcome of population growth might have required that *milperos* consume more *pozole* (2.4.2), a dry food, away from the house in the fields. As the preparation of *pozole* requires boiling, soaking, and grinding of maize but no further cooking in ceramic vessels, it may be that the number of cooking vessels designated for cooking maize would decrease after such reorganization of agricultural activities. Of course, any number of other responses may also have been made or, perhaps, changes to domestic labour may not have been so great as to require changes to food preparation.

The sample of vessels that was acquired for this project also made it possible to look for differences in food preparation and consumption between different socio-economic groups. Vessels from the Preclassic sites in Belize may be from emergent elite contexts. Vessels from Classic period El Pilar are from elite and non-elite contexts, and those from Cerén and Aguateca are from non-elite and elite residences, respectively. Regrettably, I realized that I did not have sufficient time to analyse all of the vessels that I had gathered. Due to time limitations, and given that less contextual information was available for the El Pilar vessels than for the other collections, a decision was made not to analyse these samples.

The samples that were analysed in this study are described further in Chapter 5 (Section 5.1).

1.4 Preview of chapters

Descriptions of the sites for which residue analyses were completed are given along with the economic, social, and political contexts for the temporal periods and regions in which they existed, in Chapter 2. This chapter also describes the current

understanding of economic and social structures in Maya society during the Late Preclassic and the nature of their transformation as Maya society became increasingly complex into the Classic period.

The value of using food remains and studies of ancient foodways to understand economic, social, and political structures of complex societies is described in Chapter 3 using both ethnographic and archaeological perspectives. This chapter also details what is currently known about ancient Maya foodways from archaeological, ethnohistoric, and ethnographic sources. Subsistence, diet, social and ritual use of food, and cooking and cuisine are covered. Specific attention is given to archaeological information from the sites included in the present study.

Chapter 4 includes a critical review of the current status of food residue analysis in archaeology. The theoretical bases for the analysis of fatty acid residues by gas chromatography, and for stable carbon and nitrogen isotopic analysis of charred residues using mass spectrometry are also given in this chapter.

In Chapter 5, I describe the archaeological vessels and modern comparative food standards that were analysed for this project, and explain why particular samples were selected. Laboratory protocols and instrumentation for gas chromatographic and isotopic analyses are also described.

The results from carbon and nitrogen isotopic analyses, of carbonised residues collected from 23 jars from the site of Cuello, and the interpretation of those results, are provided in Chapter 6.

The results obtained by gas chromatographic analysis of the absorbed lipid residues are given in Chapter 7. In addition to characterizing the fatty acid composition of the archaeological residues, I also describe how I establish whether the residues represent ancient lipids or contaminants from the burial context or from post-excavation handling and storage.

In Chapter 8, I continue to organize, analyse, and evaluate the fatty acid data obtained by the GC analysis of archaeological residues, as well as newly prepared and experimentally degraded cooking water extracts. The chapter includes the results of two separate cluster analyses, one of cooking water extracts and one of archaeological residues, completed in order to identify groups of samples that have similar fatty acid compositions. Results of the cluster analysis of the archaeological residues are ultimately used to look for behavioural patterning in the residue data that reflects something about ancient Maya foodways. Categories of cooked foods that have been characterized by their fatty acid compositions and the fatty acid profiles of a small number of experimentally degraded cooking waters are used to establish criteria for identifying the origins of the archaeological residues on the basis of their fatty acid content. I also describe my efforts to make those identifications. Finally, I consider the reliability of the identifications and discuss some of the shortcomings of the fatty acid approach that became apparent as I assigned identifications to the residues.

In the final chapter (Chapter 9) I discuss what I was able to learn about ancient Maya foodways and society, using residue analysis. I also assess this analytical approach in terms of its value to archaeologists. The evaluation is based upon the results and also my own personal experiences and observations gained while completing the project. A further measure of the approach will be made by comparison of the developmental history and impact which residue analysis has had thus far, with those of another archaeometric technique, isotopic studies of human tissues, which has already found a secure place within the archaeologist's analytical tool box.

Chapter 2

Preclassic and Classic Maya Society: Site Descriptions and Histories

2.1 Introduction

Ancient Maya civilization developed and flourished in first millennium A.D. in the tropical rainforests of lowland Central America, primarily in what is now Belize, Guatemala, and the Yucatán Peninsula of Mexico, and also in the highland region of Guatemala, to the southwest. This chapter includes a brief description of their history from their origins in the Preclassic as egalitarian farming communities through the emergence of social and political complexity, and the development of Classic Maya civilization. The chapter also includes descriptions and histories of the Preclassic and Classic sites from which residues samples were collected for this investigation of ancient Maya foodways.

2.2 A brief history of the lowland Maya: Preclassic to Classic

The Middle Preclassic (ca. 1200 – 350 B.C.)

At the beginning of the first millennium B.C., swidden-maize farmers moved into the forests of the Maya Lowlands and established small, egalitarian hamlets and villages. Unfortunately, the history of these first farmers is not well documented. Population densities were low and settlements, seen archaeologically as the ephemeral remains of pole-and-thatch huts, were relatively scattered and few in number (Andrews 1990:5; Hammond 1991a; see Sections 2.2.1 and 2.2.2). Only a small number of Middle Preclassic sites have been intensively investigated. However, the presence of three

technologically sophisticated ceramic spheres in early Middle Preclassic deposits; Swasey in northern Belize, Xe in the Pasión region, and Eb in the Petén; suggests that several groups of people immigrated to different parts of the lowlands during this period (Andrews 1990:3, 5, 15-16; Kosakowsky and Pring 1998: 55, 57, 64). Comparison of slips and vessel forms, for contemporaneous ceramic assemblages, suggests to Andrews (1990:7) that the people who moved into the Pasión area of Guatemala were non-Maya people from highland Guatemala or Chiapas. The origins of the other two groups are not known. Continued separation and independent developments within the three earliest ceramic spheres imply that the several pioneering populations remained quite discrete before the late Middle Preclassic (Kosakowsky and Pring 1998:64).

The Late Preclassic (350 B.C. – A.D. 250)

What is evident is that these earliest Maya flourished. In the second half of the Middle Preclassic and during the Late Preclassic period (350 B.C.–A.D. 250), the Maya filled the forests of the lowlands with their settlements and farms. As Preclassic populations expanded and settled into the lowlands, the hallmarks and cultural achievements once ascribed to Classic Maya society began to emerge, including the development of elite institutions and perhaps also nascent polities (Freidel 1979:45-49). The reorganization of social and political structures, in the Late Preclassic, is reflected in changing settlement patterns between this period and the Middle Preclassic. There is increased variability in domestic architecture and many settlements were reorganized around a central plaza with public architecture. Two ancient villages in northern Belize, Cuello and K'axob, which are described in some detail in the following section, record this trend from egalitarianism toward increasing social complexity in Maya society from the time of initial settlement through the end of the Late Preclassic period. On a grander scale

are the large, densely populated centres that arose in the northern Petén before the end of the Middle Preclassic, and which reached their peak in the Late Preclassic. At El Mirador and Nakbé, Late Preclassic monumental construction projects dwarf later Classic period architecture at the major centre of Tikal, Guatemala, and include some of the largest structures ever built in the Maya area (Dahlin 1984:18, 19; Matheny 1986). Both the dense population and the massive scale of construction at these sites required the organizing principles of centralized political leaders and they reflect the existence of these at this early date in Maya history.

Indeed, Schele and Freidel (1990:96-129) suggest that the imagery adorning many Late Preclassic temple-pyramids marks the creation of the concept of divine kingship or *ahau* during this early period. They also argue that Maya leaders introduced the concept of kingship in order to rationalize conflicts and contradictions that developed in a formerly egalitarian society with the emergence of social inequality. In claiming descent from gods or important ancestors, Maya rulers constructed a role for themselves as the conduit for communication between the natural and supernatural worlds – represented as the sacred Tree of Life – which was necessary for the well-being and prosperity of the people, community, and polity (Schele and Freidel 1990:87-91, 97-98), thereby explaining and justifying their superior status and the legitimate existence of social hierarchy.

The origins of the social and economic differences in Late Preclassic Maya society are not well understood but surely were related to the larger numbers of people that then inhabited the lowlands, and the diminishing availability of land that was best suited to maize-agriculture. Indeed, there are indications that Maya subsistence economies underwent significant changes in this period. Extensive systems of wetland fields were constructed in southern Quintana Roo, along the upper Candelaria River in Campeche, Mexico, and in northern Belize (Siemens and Puleston 1972; Turner 1974; Turner and Harrison 1981, 1983), suggesting that other marginal agricultural lands were also being

used at this time. In many other parts of the Lowlands, swidden cultivation may already have been supplemented by intensive techniques such as short-fallow fields or intensively cultivated gardens (Fedick 1989:244; McAnany 1995:78; Tourtellot 1993:222). Therefore, it is possible that differences in wealth and status emerged from differential access to quality agricultural lands and uneven abilities to produce subsistence resources. McAnany (1995:78, 91-95) believes that the plots of land were "owned" by lineages and were continuously used by the same lineage for many generations. Land use rights were determined by the principle of first occupancy and legitimized unequal distribution of resources among lineages (McAnany 1995:96, 117, 162). It follows that more established lineages and certain families within these lineages had access to the best agricultural land and probably more land, as well. Using burial patterns, architectural data, and evidence of the emergence of intensification of cultivation at K'axob, Belize, McAnany (1995:114-115) argues that these structures of inequality to resources had their origins in the Late Preclassic and continued through the later Classic and Postclassic periods.

The Classic period (A.D. 250 - 900)

The Classic period, which spans the years from A.D. 250 – 900, is viewed as the time during which ancient Maya society reached its height in terms of social, political, and economic complexity. The temporal boundaries of the Classic period are defined by the several centuries during which powerful Maya lords had Long Count calendar dates carved into limestone monuments, along with the historical and genealogical texts that justified and legitimized both their high status and the political authority that they had attained by this period. Historical events allow us to divide the Classic into Early (A.D. 250-600) and Late (A.D. 600-900) periods (Coe 1996:73).

The first part of the Early Classic likely saw a continuation of processes, already set in motion at the end of the Late Preclassic, which transformed Maya society from a simple agrarian society to a complex civilization. Certainly, by the end of this period at A.D. 600, all of the hallmarks of Classic Maya civilization are evident. Large and small ceremonial centres with temple pyramids and long, range structures or palaces arranged around large, public plazas appear throughout the Lowlands (Potter 1985:142). Accompanying the monumental architecture, and the elite residences and burials, is a set of skillfully crafted material culture, including stone stelae and altars carved with elaborate hieroglyphic texts and royal figures, jade ornaments, and decorative polychrome ceramic vessels, *incensarios* and figurines, all of which have come to typify the Classic Maya. However, the earliest years of the Classic period may also have been a time when rulers and emergent dynasties yet negotiated their rights to the privileges, prestige, and power which they had achieved (*cf.* Gibson 1985; Lincoln 1985:75, 77-78; and Potter 1985:142). Unfortunately, however, because many Early Classic settlements are buried beneath Late Classic constructions at the sites, a better understanding of the evolution and elaboration of Classic Maya society in these early years eludes us yet.

The latter part of the Early Classic period, between A.D. 400 and 600, is distinguished by archaeological and epigraphic evidence for some type of interaction between the Maya and the powerful centre of Teotihuacan, in central Mexico. The influence or presence of Teotihuacan was greatest at settlements in the Guatemalan highlands, particularly at Kaminaljuyú, but is also clearly seen at Tikal, which was the dominant center in the Maya Lowlands at this time (Mathews 1985:31). The nature and extent of the association between the Maya and Teotihuacan is uncertain. One explanation which has found some acceptance among Mayanists is that rather than an actual Teotihuacan presence in the Lowlands or strong economic ties between the two regions, Maya rulers may have manipulated certain of the symbols and elite material

culture of this powerful foreign centre in order to increase their own prestige (Coe 1996:80; Schele and Freidel 1991:163-164). Recent decipherments of historical texts from Tikal, however, do seem to record the arrival of at least a small group of Teotihuacanos who gained control of the Tikal polity by deposing the Maya ruler and his lineage. There is also some evidence for a marriage between one of these foreigners and a Tikal noble woman that might have served to give authority to the new ruling dynasty (Martin and Grube 2000:29-32). The close of the Early Classic period is marked by the cessation of connections between the Maya and Central Mexico, when Teotihuacan's domination of that region came to an end. Coincidently, the centuries-long trend of steady growth in Maya civilization may have been briefly interrupted. During the "hiatus", between the years A.D. 534-593, very few stelae with Long Count dates were produced (Mathews 1985:31) and the construction of monumental architecture also seems to have slowed. In addition, many existing stelae appear to have been intentionally mutilated, suggesting a period of social or political unrest in the Lowland region.

Maya society rebounded from this short perturbation in the subsequent Late Classic period, which marks the zenith of ancient Maya civilization. The numbers of people and settlements in the Lowlands increased quickly and markedly between the years A.D. 600 and 800. Using data from a number of settlement studies completed in the Central Lowlands, Turner (1990: 304, 310) estimates that the Late Classic population peaked at 2.6 to 3.4 million people sometime before A.D. 800, after rising rapidly from just over 1 million people at the end of the previous period. Significant changes in economic, social, and political structures in Maya society certainly were coincident with such a dramatic population increase.

The great population increases of the Late Classic forced changes in land use and the structure and organization of household agricultural production units that may have

already begun in the Late Preclassic, as noted above. In the Late Classic, there is greater evidence for the use of marginal lands and intensive agrotechnologies, including wetland fields, terraced slopes, and urban gardens, all of which were likely cultivated using short fallow periods. The evidence for each of these techniques is described in the next chapter (Chapter 3). Drawing heavily from ethnohistory and using ethnographic examples from Africa and Asia, McAnany (1993:76-82; 1995:120-122) has tried to envision for us how changes in population density and land use affected Maya households once all the available land was claimed. Unable to set up new households, descendants of the household head would have been forced to remain as part of their father's household; some would eventually inherit land and others would not. In addition, land-disenfranchised individuals and their families may have been incorporated into some of these large, multi-family households as servants, craft specialists, and/or tenant farmers. Lineage and household heads could thereby increase their wealth and status by controlling labour as well as access to resources. Thus, both social and economic inequality developed within and between households. Greater variability in Late Classic residences, compared to earlier periods, certainly lends some support for McAnany's model describing the evolution of Classic Maya households.

Of course, more varied residential architecture at this time was not simply a function of the evolution of households as agrarian production units. It was also related to the greater range of social and political status groups that existed in the Late Classic compared to earlier periods. While Classic Maya society can be divided into two broad status groups of elites and commoners (Marcus 1992; Welch 1985) there is evidence from materials associated with residences and burials that several status levels existed within each of these two groups. Indeed, epigraphers have identified several ranks of ruling elites by the various titles recorded in hieroglyphic texts (Houston 1993: 128-134), and McAnany (1993:73-75) has suggested that lower-ranking elites, who had social

power but no direct access to political power, may have been channeled into positions of 'palace artisans' or high-status military and religious positions during the Late Classic. Non-elite craft specialists, too, may have been the lowest status members of their social group. It has been argued that specialization in pottery production was undertaken to supplement poor agricultural returns in marginal areas (Rands and Bishop 1980:42; Webster 1985:390), or by the land disenfranchised who were bound to large heterogeneous households in relationships of dependency (McAnany 1993:76-82).

One indication of a more complex political landscape in the Late Classic is the much larger number of centres that employed emblem glyphs during this period (Mathews 1985:33). Emblem glyphs either name a specific site or territory and/or the ruler that was associated with it, and centres that had their own glyph are generally thought to have been autonomous political units (Culbert 1988:136; Mathews 185:32). The largest political unit, even during the Late Classic, was the polity, which may be likened in some respects to segmentary states or city states (Ball and Taschek 1991:159-161; Culbert 1988:136; 1991:339-341). Each polity was governed by a single lineage, which had jurisdiction over one major centre and perhaps several smaller ones within roughly a 25 km radius (Culbert 1988:146, 150). Larger (40-50 km radius), multi-centre polities did at times exist, such as the ones centred at Tikal and at Dos Pilas, at the end of the Late Classic, but these tended to be unstable and short-lived (Ball and Taschek 1991: 161; Culbert 1988:146, 150; Houston 1993:107-119). Thus, even at its peak Classic Maya society was never politically unified into a larger state. Rather, the numerous polities seem to have been linked by elite interactions, including interpolity alliances, marriages, and gift exchanges that may have occurred during shared ritual and ceremonial activities or obligations (Ball and Taschek 1991:161). Participation in these activities enabled rulers to legitimize and enhance their prestige and their right to rule, by providing them opportunities to publicly display symbols of their status and their genealogical

connections to deities (Schele and Freidel 1990:143). Centralized economic control of production and trade by Maya rulers seems to have been weakly developed (Abrams 1987; Freter 1994:171; Mallory 1986; Webster 1985:387), and appears to have been less important than ideological power in linking polities and Maya society (Culbert 1991:340).

A second indicator that Maya politics were more complicated in the Late Classic, compared to earlier periods, is epigraphic and archaeological evidence of increased warfare between polities (Houston 1993). Through much of the Classic period, the purpose of Maya warfare seems to have primarily been the capture and sacrifice of prisoners (Schele and Matthews 1991:143). However, warfare carried out for the purpose of political or territorial expansion seems to have developed near the end of the Late Classic period (Houston 1993:137-138), and some have argued may have factored into the demise of Classic Maya society in the Central and Southern Lowlands.

2.3 Preclassic site descriptions and culture histories

2.3.1 The site of Cuello: its location and history

Residue samples were collected from two Preclassic sites. The first of these is the ancient village of Cuello, Belize. Cuello sits on a low limestone ridge between the Rio Hondo, roughly 10 km to the east, and the New River, 5 km to the west, in the karstic topography of northern Belize (Hammond 1991b:9; Hammond and Miksicek 1981:260; Figure 2.1). The site is small (3 km^2). A Classic period ceremonial precinct is located in the northeast section of the site. The Late Preclassic site core, consisting of a group of several large platforms, is 300 m to the southwest of the ceremonial precinct, and residential settlement is distributed to the north, west and south (Figure 2.2). The site came to the attention of archaeologists in 1973 during site survey undertaken by the Corozal Project. Subsequent investigations at the site, directed by Dr. Norman Hammond

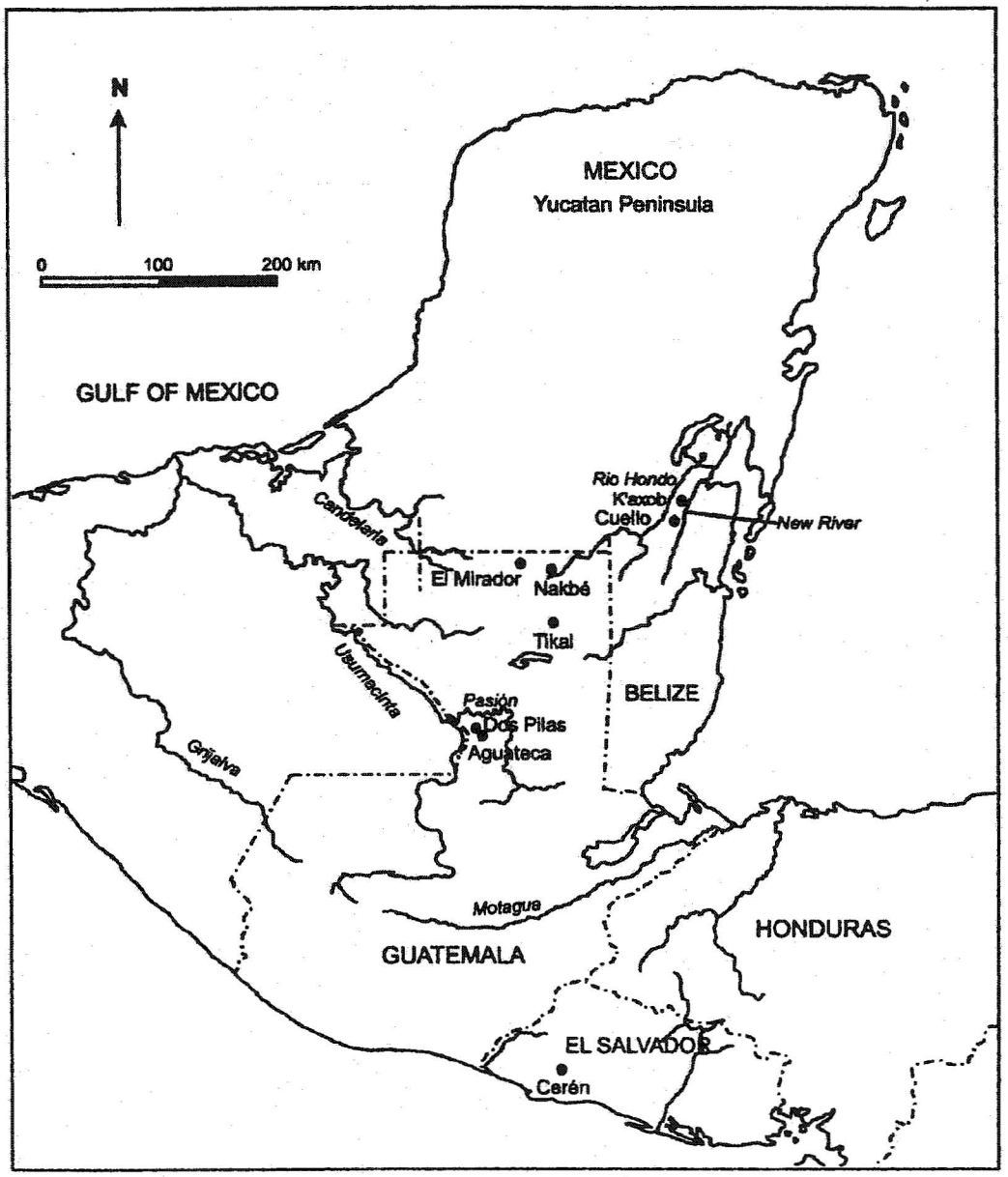

Figure 2.1 Map showing the location of the various sites mentioned in the text.

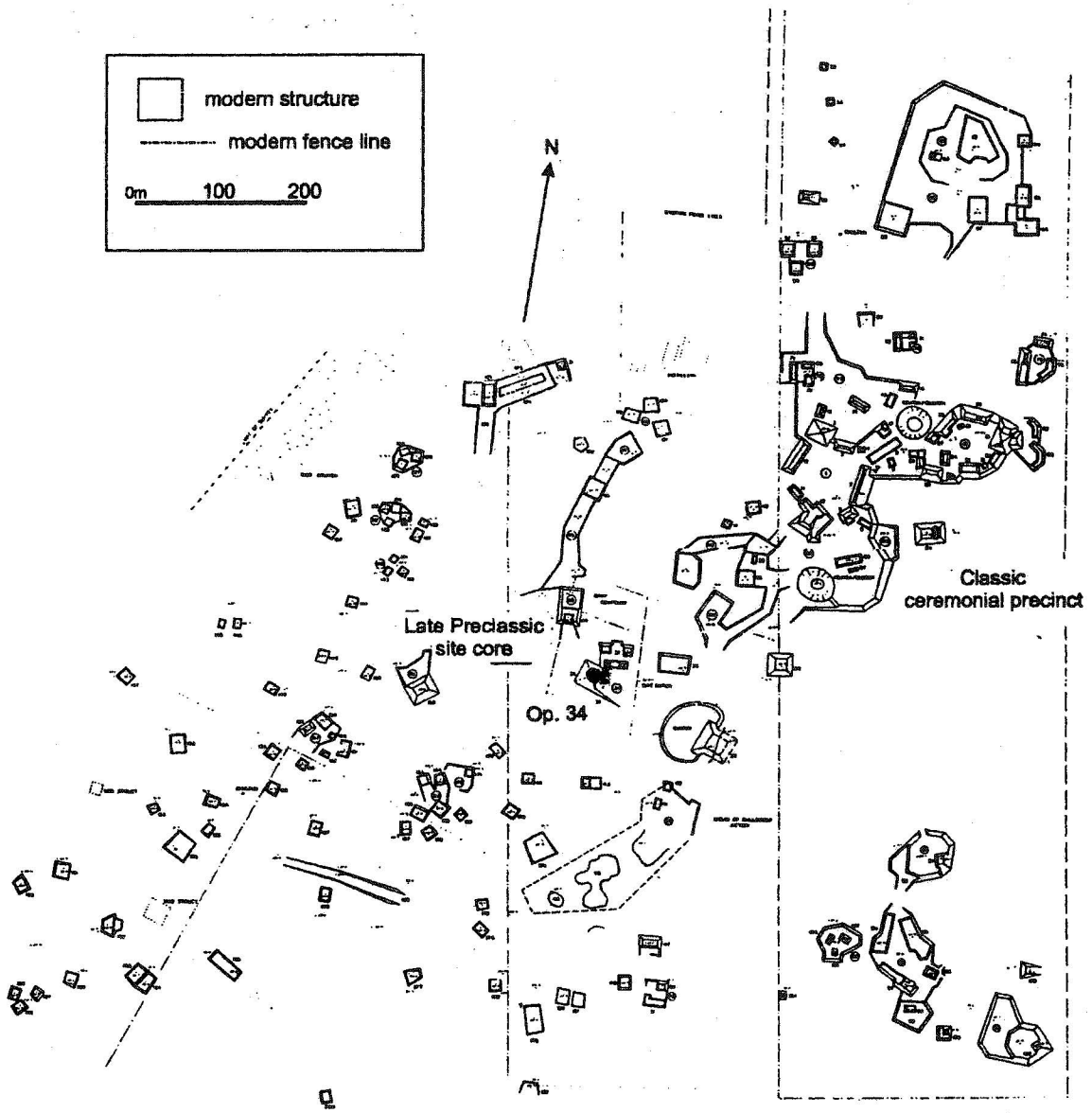

Figure 2.2 Map of the site of Cuello, Belize (from Hammond 1991:10-11).

(Boston University), involved a program of mapping, test-pitting areas between and on house-mounds, and wide-area excavation of a 300 m^2 area centred on Platform 34 within the Late Preclassic site core (Hammond 1977, 1979, 1980, 1985, 1990, 1991a; Hammond and Gerhardt 1990; Hammond *et al.* 1991a, 1991c; Wilk and Wilhite 1991). Cuello's archaeological importance stems from its long occupation history (Figure 2.3), spanning the Preclassic (c. 1200 BC - AD 250) through the Postclassic (c. AD 1000-1250) periods, which chronicles the earliest settlement of the Maya Lowlands (Andrews and Hammond 1990; Hammond *et al.* 1991b) and also mirrors broader changes, more evident at other Lowland sites, which culminated in the complex social and political structures of Classic Maya society (Hammond 1991c:245-246).

Maya Chronology	Ceramic Chronology	Stratigraphic Phase	Date
Middle Preclassic	Swasey	0 to II	1200-900/800 B.C.
	Bladen	III to IIIA	900/800-650/600 B.C.
	Lopez Mamom	IV to IVA	650/600-400/300 B.C.
Late Preclassic	Cocos Chicanel	V to XIII	400/300 B.C.-A.D. 250
Early Classic	Nuevo Tzakol	XIV	A.D. 250-400
Middle Classic	Nuevo Tzakol	XIV	A.D. 400-600
Late Classic	Santana Tepeu	XIV	A.D. 600-1000
Early Postclassic	Tecpec	XIV	A.D. 1000-1250

Figure 2.3. Cuello site sequence (Hammond 1991c:4).

Cuello was initially settled during the late Early, or early Middle Preclassic (Swasey phase c. 1200-900/800 BC) by people who were perhaps among the first sedentary, maize-farmers in the undiminished forests (Miksicek 1991:80) of the northern Maya Lowlands (Andrews and Hammond 1990; Hammond *et al.* 1991b). Four meters below the surface of Platform 34, postholes outline their houses. These were perishable

structures, apsidal in plan, which were constructed atop plaster floors laid on the earth or over a thin layer of *piedrin* (pebbles). By the end of the Swasey phase, residences at this locus were built on very low (0.1-0.2 m) cobble and earth-filled platforms and arranged around a shared patio (Hammond and Gerhardt 1990:464; Hammond *et al.* 1991b:30-33). Additional courtyard groups dating to the first part of the Middle Preclassic have not been located in test excavations at other parts of the site. Settlement survey indicates that the village of Cuello consisted of approximately 53 households (300-370 people) living in dispersed and temporary dwellings (Wilk and Wilhite 1991:126).

In the next 500 years (Bladen [900/800-650/600 B.C.] and Lopez Mamom phases [650/600-400/300 B.C.]), Cuello doubled in size. Palaeoecological data indicate that farmers at Cuello responded by clearing more forest and reducing the fallow cycle (Miksicek 1991:83). Yet the settlement pattern, and by inference the egalitarian organization of the community, changed little before the end of the Middle Preclassic (Wilk and Wilhite 1991:126). The only indication that social differentiation began earlier, at the end of the Bladen phase, are inclusions of large amounts of shell jewelry in burials of children at the Platform 34 locus (Hammond 1991c:242). The courtyard group beneath Platform 34 was more formalized with rectangular, raised house platforms, and relocation of domestic activities, previously located throughout the patio, to its margins and into structures created for these tasks (Hammond and Gerhardt 1990:466-469; Hammond *et al.* 1991b:33-38). Still, the proposed function of the patio group as a residential unit, perhaps for an extended family, remained unchanged from the earlier Swasey phase.

In the Late Preclassic (Cocos Chicanel phase, 400/300 B.C.-A.D. 250), Cuello rapidly reached the size of a small town with an estimated population of 2,600 (Wilk and Wilhite 1991:129, 132). There is evidence that Cuello was, by this period, a socially stratified community (Hammond 1991c:246). Most residences continued to be built on the ground but a larger number were constructed on low, plastered house-platforms than

were in earlier periods. More telling was the transformation of the Platform 34 courtyard group into an elite residential compound and a location for ceremonial and ritual activities. A pyramidal structure was built on the west side of the platform and an uncarved stela and a series of dedicatory deposits were placed at its centre (Hammond and Gerhardt 1990:478; Hammond *et al.* 1991b:41-53). Three additional Late Preclassic platform groups, similar in plan to Platform 34, have been identified. The combined domestic and ritual function of Platform 34 led Wilk and Wilhite (1991:130) to speculate that the four platform groups were occupied by extended families who controlled ritual activities as well as access to land and other resources within their kin group, and thereby had greater status.

Cuello reached its height in the Early Classic (Tzakol phase, A.D. 250-400) and, once more, population growth appears to have been accompanied by changes in the social structures of the community. Greater variation in time and resources invested in residences is reflected by differences in size, construction materials, and elaboration of architectural features, and implies that socioeconomic distinctions between households were more marked in the Early Classic (Wilk and Wilhite 1991:128). Abandonment of the Late Preclassic platform groups, including Platform 34, and creation of a more central ceremonial/administrative core may indicate greater authority of the ruling elite at Cuello. Wilk and Wilhite (1991:128) suggest it might also mark a shift from household to community-level ritual.

In the Late Classic (Tepeu phase, A.D. 600-1000), the population of Cuello declined dramatically, perhaps to Middle Preclassic levels (Wilk and Wilhite 1991:128), and yet it appears that the site was occupied into the Postclassic. The extent and nature of the Postclassic (AD 1000-1250) settlement is not known. Faunal bone associated with construction activity at the Platform 34 locus has been dated to this period (Hammond *et*

al. 1991c) but Postclassic materials were not found in test excavations at other parts of the site (Wilk and Wilhite 1991:129).

2.3.2 The site of K'axob: Its location and history

The second collection of Preclassic vessels used in this study of organic residues and ancient Maya foodways comes from the site of K'axob. K'axob was a small village (84 ha), comprising just over 100 structures, situated on a low and narrow limestone ridge between the southern branch of Pulltrouser Swamp, which bounds the western edge of the settlement, and the New River, 2 km to the east (López Varela 1996:21, 23; McAnany 1995a:7; McAnany and López Varela 1995; White 1990) (Figure 2.1). Survey and excavation have revealed a sequence of occupation for K'axob (Figure 2.4) that spans nearly 2000 years, from the Middle Preclassic to the Postclassic. The site is contemporaneous with Cuello, which lies approximately 8 km to the south-southwest. Further, like Cuello, K'axob is important because its deep deposits of ancient Maya material culture record important transitions that saw the emergence and evolution of complex social, political, and economic structures between the Middle and Late Preclassic periods and into the Classic period (López Varela 1996; McAnany 1995a; McAnany and López Varela 1995).

Settlement survey, site mapping, and test excavations were conducted at K'axob in 1981, as part of the Pulltrouser Swamp Project (B.L. Turner [Clark University] and Peter Harrison [Tulane University], directors). Recent ploughing was found to have heavily impacted the site yet it is recognizable on the landscape by two major residential plaza groups (Figure 2.5) (McAnany 1995a:55; McAnany and López Varela 1995). Plaza A, in the central part of the site, is dominated by a 13 m pyramidal structure constructed during

Maya Chronology	Ceramic Complex	Ceramic Sphere	Construction Phases	Date
Middle Preclassic	Early Chaakkax	Mamom	I – II	800-400 B.C.
	Late Chaakkax		III	
Late Preclassic	Early K'atabche'kax	Chicanel		400-200 B.C.
	Late K'atabche'kax			200-50 B.C.
	Terminal K'atabche'kax			50 B.C.-A.D. 150/250
Early Classic	Nohalkax	Tzakol		A.D. 150/250-?
Late Classic	Witskax			
Early Postclassic	Kimilkax			

Figure 2.4 K'axob site sequence (McAnany and López Varela 1995).

the Late Classic period. Plaza B lies 300 m to the south and predates Plaza A. It is ringed by four low, pyramidal structures (2-6 m in height) and several platforms. The final building phase, which saw the construction of pyramidal Structure 18, occurred during the Early Classic period. Test excavations at the base of Structure 18, however, indicated that Plaza B had been constructed on top of the exact locus of a series of Middle and Late Preclassic domestic structures, which formed the core of the Preclassic hamlet of K'axob (McAnany 1995a:55; McAnany and López Varela 195). A number of smaller, "satellite" groups, consisting of single or multiple residential platforms built on top of larger basal platforms, occur within the vicinity of each of the two main plaza groups (McAnany 1995a; McAnany and López Varela 1995).

The objective of the K'axob Project, directed by Patricia McAnany (Boston University), was to test a model that describes a dynamic relationship between ancestors, lineage organization, and resource rights that may explain the emergence of social and political inequality in ancient Maya communities, by examining temporal transformations in domestic architecture, burial practices, and land use (McAnany 1995a;

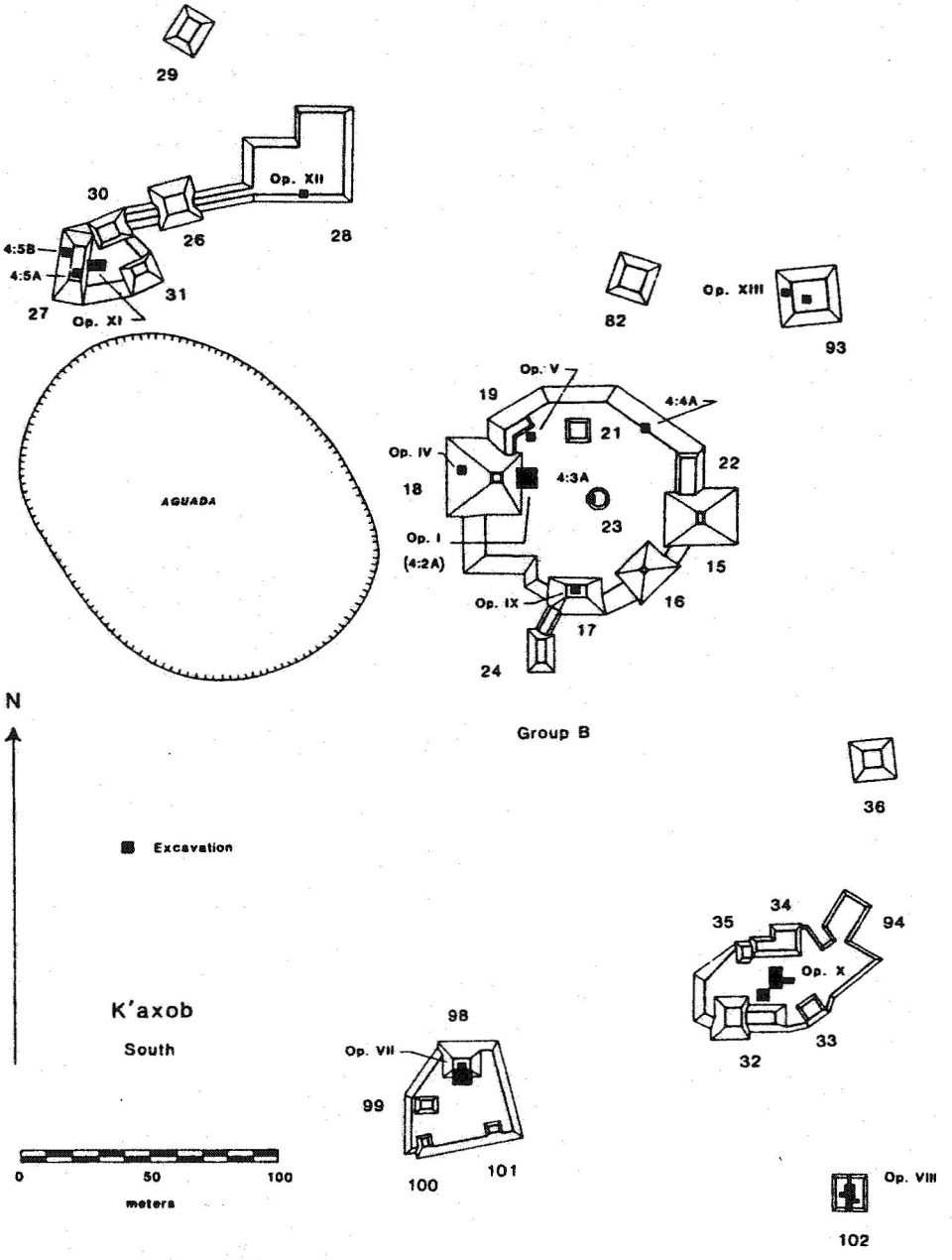

Figure 2.5 Map of the site of K'axob, Belize (from McAnany 1995:54).

Henderson 1994). Therefore, during three seasons of fieldwork, in 1990, 1992, and 1993, excavations were focused on locations at which Preclassic deposits had been noted in test excavations. Excavation at the base of Structure 18 (Operation I), in Plaza B, was of particular importance as this locale contained the only Middle Preclassic deposits identified at the site (McAnany 1995a:55-58; McAnany and López Varela 1995).

Excavations were also completed at a number of satellite groups (Operations VI, VII, X, XI, and XII), all of which lie within 300 m of Plaza B, and which were constructed during the Late Preclassic (McAnany and López Varela 1995).

In many ways, the historical sequence revealed through excavations at K'axob mirrors that of the contemporary settlement of Cuello, described previously. It, too, records the transformation of a Middle Preclassic hamlet into a stratified, farming village by the Early Classic period. Postholes, fire-pits, sherd-lined pits, and burials intruding into a palaeosol roughly 3.5 meters below the final surface of Plaza B (Op. I, mark the location at which the first residents of K'axob constructed an earthen-floor dwelling during the Middle Preclassic (early Chaakkax complex, *ca.* 800 B.C.) (Bobo 1993; McAnany and López Varela 1995). Shortly thereafter, Structure 1i, a wattle-and-daub house-structure, apsidal in plan, was built atop a low, plastered platform (McAnany and López Varela 1995). Immediately southwest and coeval with Str. 1i are the remains of a series of plaster surfaces, each showing traces of burning, which appear to have been the floors of a kitchen (Str. 4) for the residents of Str. 1i. As at Cuello, this initial site continued as a residential locus for an extremely long time span. The next 400 years saw a series of eight domestic structures built over top of the exact same location.

Resource-rich, riparian and wetland (*bajo*) habitats likely attracted pioneering populations to K'axob and other locations in the river valleys of Northern Belize during the Middle Preclassic period (McAnany and López Varela 1995). Remains of aquatic fauna are abundant in Middle Preclassic deposits at K'axob. On topographical ridges, rich,

drought resistant soils – a mollisol referred to as Pembroke Suite (King *et al.* 1992, cited in McAnany and López Varela 1995) – also would have attracted the maize agriculturalists who settled here. The margins of Pulltrouser Swamp were also the site of raised agricultural fields. Reports on the faunal and botanical remains collected during excavations at K'axob are not yet complete. Therefore, more specific conclusions about the use of resources at K'axob cannot be stated at this time. General observations, however, suggest that these categories of data are less well preserved than they are at Cuello (P. McAnany, personal communication).

Population increase and signs of emerging social complexity characterize the Late Preclassic period at K'axob (McAnany and López Varela 1995). An increasing population may have provoked the initial construction of wetland fields, dated to this period, along the edges of Pulltrouser Swamp. It also resulted in the expansion of the site. Several new residential groups were built within the vicinity of Plaza B during the early K'atabche'kax (400 - 200 B.C.; Operations X and XI) and late K'atabche'kax (200 – 50 B.C.; Operations VI, VIII, and XII). Structure 1 continued to be occupied and was renovated several times during the early K'atabche'kax. However, as K'axob continued to grow in the late K'atabche'kax, the residents of Str. 1 transformed their house from a low, apsidal structure, not unlike other residences at the site, to one set upon a raised, rectangular platform with a stone retaining wall several courses high. A food preparation area that had formerly been observed in the plaza area immediately adjacent to the house disappeared. Presumably it had been moved away from this more imposing residence. Finally, during the late K'atabche'kax (50 B.C.-A.D. 150/250), Operation I and many other residential units were buried under marl-surfaced plazas in order to create large basal platforms that supported multiple house structures. Architectural differentiation at Operation I and other large residential groups, at this time, likely reflects emerging social differences at K'axob (McAnany and López Varela 1995).

Nascent social differences, in the late and terminal K'atabche'kax (50 B.C. – A.D. 150/250) complexes, are accompanied by more elaborate and extended mortuary ritual, and the inception of dedicatory cache deposits (McAnany and López Varela 1995). Primary burials of single or multiple individuals, in extended and later flexed or seated positions, were characteristic of the Middle Classic. At the end of the Preclassic period, however, secondary burials of multiple individuals, who had been interred separately over many years, were more typical. Two such burials - a circular pit and trench that appeared to have been reopened numerous times - had been intruded deep into Plaza B. At the end of the Preclassic, two caches were placed above the trench in the fill that capped this shrine complex. McAnany (1995a:55-60; McAnany and López Varela 1995) argues that such burials include the remains of important ancestors and that these interments, as well as the placement of dedicatory caches, draw attention to the long-term occupation of certain locations and, thereby, legitimize disparity in resource rights and other privileges based upon a principle of original or first use.

During the Early Classic, the pyramidal Structure 18 was built atop Plaza B, ending the construction at this location. K'axob itself, though, continued to expand during the Classic period. Excavations of structures dating to the Classic period were completed during the 1998 and 1999 field seasons at K'axob. Plaza A was built in the central part of the community during the Late Classic period, and numerous residential structures, including individual housemounds and larger residential compounds, were constructed to the north of Plaza B in the Late and Terminal Classic periods. There is also some evidence for activity at K'axob during the Postclassic period. The nature of the occupation or use of the site at that time is not clear, however.

2.4 Classic period site descriptions and culture histories

2.4.1 The site of Cerén: Its location and history

During the late Middle Classic or early Late Classic (A.D. 600), Cerén (Sheets 1992) was a small, rural village situated on the bank of the Río Sucio, in the densely settled Zapotitán Valley of northeastern El Salvador (Figure 2.1). It was just one of an estimated 280 settlements in the valley at that time (Black 1983). The primary centre of the valley region, San Andres, lay just a short distance (5 km) to the northeast of Cerén. The residents of the valley were either Maya or Lenca (Sheets 1992:17, 121-122). As the Zapotitán Valley occurs in a frontier zone between the two culture areas, it has not been possible, and perhaps it would not be appropriate, to associate material remains left at Cerén with one group or the other. However, a number of residential architectural features, and the occurrence of ceramics belonging to the Copador ceramic sphere, which may have originated at the Maya site of Copán, do suggest that the occupants of Cerén were culturally more Maya than Lenca (Sheets 1992:121-122). Despite this uncertainty, as well as Cerén's small size and short occupation history (perhaps only 100 years), the site is of great archaeological interest. Under deposits of volcanic ash several meters thick, it has preserved an extremely rich assemblage of the material culture of several ancient Mesoamerican, agricultural households.

The site of Cerén was first located, in the immediate vicinity of the modern community of Joya de Cerén, in 1976 when a bulldozer cut was made into one of the structures buried beneath the ash (Sheets 1992:11-13). The antiquity of the structure was not immediately appreciated, however, and several ancient structures were subsequently destroyed in the process of leveling an area for the construction of storage silos to be used by Joya de Cerén. In 1978, local residents brought the site to the attention of Payson Sheets (University of Colorado), who was then conducting an

archaeological survey of the Zapotitán Valley. Two lines of evidence allowed Sheets (1992:12) to conclude that a house structure left visible in the cut bank was of some antiquity. First, exploratory excavations into the structure did not uncover any recent cultural material despite the occurrence of well-preserved organic remains, including thatch from a collapsed roof. Second, samples of the roofing thatch that were collected for radiocarbon dating indicated that the structure dated to approximately A.D. 600 (Sheets 1992:12).

Geophysical surveys undertaken in the 1979 and 1980 field season located additional buried structures that were excavated in 1989 and 1990-1991 (Sheets 1992:13). In total, 10 structures, including residences, kitchens and storage buildings (*bodegas*) associated with three separate households, in addition to several structures with specialized functions, have been completely excavated to the final living-floor surfaces (Sheets 1992; Figure 2.6). The specialized structures include a community structure, a sauna, and a building that may have been used by a shaman based on a number of unique architectural features and the assemblage of artifacts left there (Sheets 1992:89-108). Activity areas, walkways, gardens and agricultural fields in proximity to the structures were also extensively excavated.

The subsistence-farming households that comprised the village of Cerén were perhaps typical of many non-elite, rural households in southern Mesoamerica during the Pre-hispanic era. Although they were not of high rank, they seem to have produced abundant and diverse crops, and to have been prosperous farmers (Lentz *et al.* 1996:259; Sheets 1992:123-124). The agricultural basis of this farming village was supported by the fertile soils of the Zapotitán Valley, which had formed by the weathering of volcanic ash deposits laid down in the valley during the eruption of the Ilopango Volcano in A.D. 175 (Sheets 1992:7). Following this eruption, the valley was not settled again until the period in which the settlement of Cerén was established near the

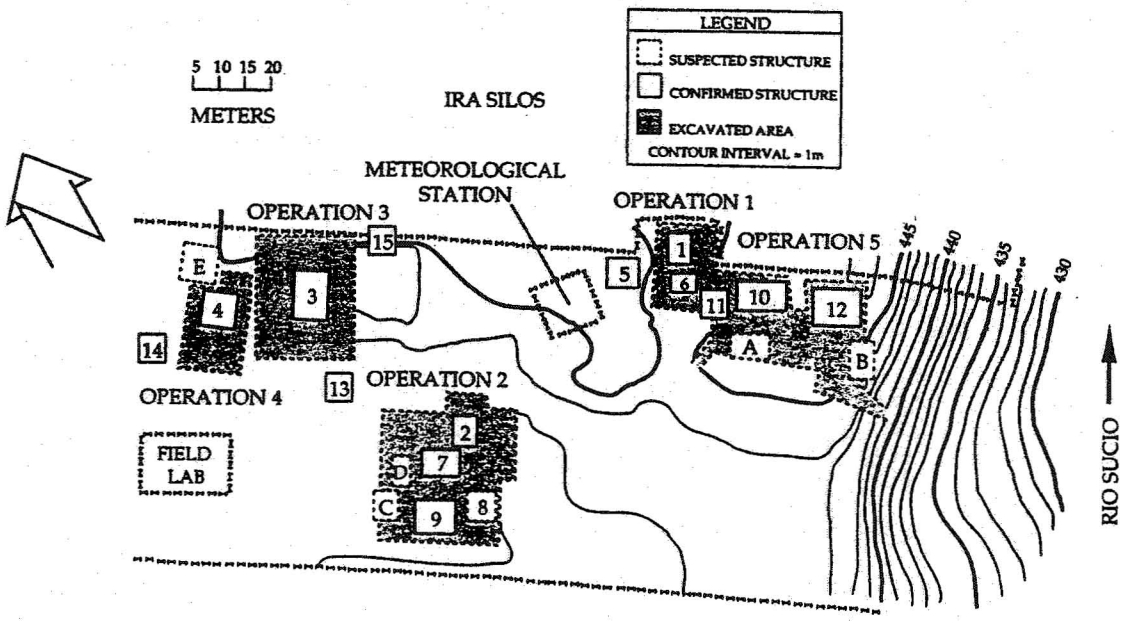

Figure 2.6 Map of the site of Cerén, El Salvador (from Sheets 1992:15).

end of the 6th century A.D. Proof of the productivity of the soil was unearthed during excavations of Cerén. The site was abandoned at the height of the rainy season judging by the abundant and diverse stores of food plants, including *maize*, beans, squash, *coyol* nuts, and *cacao*, which filled storage vessels, baskets, and corn cribs in the houses and *bodegas,* and dried *chiles* hung from the rafters. A second planting of *maize* had just begun to grow (Sheets 1992:111). In fact, the recoveries were so great and varied that Lentz *et al.* (1996:259) have suggested that the farmers of Cerén lived as well as elites at Copán, at least in terms of the diversity of food plants in their diet.

Moreover, game and other resources might have been obtained from several different environmental zones near the settlement. Wood charcoal remains collected from excavations and analysed by Lentz and his colleagues (1996:257-258, 259) indicate that a deciduous tropical forest, although disturbed, remained partially intact, as did a riverine forest along the Río Sucio. Stands of pine apparently grew in areas of the valley that were intermittently burned or on volcanic slopes. *Huaymil* forests and grasslands also existed in areas disturbed by cultivation. *Huaymil* and grassland, and the greater area of forest-edge habitat generally created by clearing forests, would have attracted game, in particular, deer.

The faunal assemblage collected during excavations at Cerén is extremely small (N = 103), however, and does not, in fact, reflect the diversity of habitats that were in proximity to the community. White-tailed deer (*Odocoileus virginianus*) dominates the assemblage (82%) (Brown 1996). A single peccary (*Tayassu* sp.) is the only other game mammal (Brown 1996). The river was a source of aquatic resources, including mollusks and turtle (*Kinosternon* sp.), both of which have been found at the site (Brown 1996). Until very recently, residents of Joya de Cerén caught fish for consumption from the river (Sheets 1992:38). No fish elements occur among the archaeological faunal remains, however. The two remaining animals represented archaeologically, the dog

(*Canis familiaris*) and a duck, likely were raised at the site, although the duck may have been captured. Dogs, largely represented by tooth elements, are the second most common type of animal remains from Cerén. The single duck in the collection had been tethered inside the *bodega* of Household 1 and is represented by a complete skeleton (Brown 1996).

Cerén was occupied for only about one century after which time an eruption of the Laguna Caldera Volcano, located just 1.4 km to the north required the residents of the settlement to suddenly abandon their homes (Sheets 1992:32-36). The eruption devastated an area of just 20 km^2, which included Cerén and probably a number of other sites, rather than the entire valley. It occurred over a number of days and deposited layers of hot, wet ash that were alternately blasted laterally by explosions of steam or which fell vertically from the air (Sheets 1992:33-36). The blasts of heavy wet ash accumulated like drifts, supporting standing-walls and preserving the structural integrity of the architecture at Cerén as the site was buried. The thick deposits also served to seal and protect the ancient settlement from many processes of diagenesis, resulting in the exceptional preservation of organic remains and other artifacts. Moreover, the eruption of the Laguna Caldera contributed to the fortuitous preservation of a virtually complete artifact inventory because it came without warning and left the residents of Cerén with no time to gather their possessions before fleeing.

2.4.2 The site of Aguateca: its location and history

Aguateca is a medium-sized, fortified Late Classic Maya centre in the western part of the Department of El Petén, Guatemala (Inomata 1995:23, 25; Figure 2.1). It is located in the Petexbatún area of the Pasión region. Boundaries for both territories have been defined using geological, geographical, and archaeological parameters together with

historical accounts of political events and interactions recorded on monuments at many of the archaeological sites in these areas (Houston 1993:10-14; Inomata 1995:25-27). The Pasión region (Houston 1993: 10) encompasses more than 5000 km^2 of the drainage systems of the Riós Pasión and Salinas and their tributaries, and extends from the confluence of these two rivers south to the hills of Alta Verapaz (Figure 2.1). Major centres in the region include Altar de Sacrificios, Cancuén, Dos Pilas, Machaquilá, Itzán, and Seibal (Inomata 1995:26). The smaller Petexbatún area (200 km^2) refers to the Petexbatún escarpment or horst and the low-lying wetlands surrounding the Rió Petexbatún and Laguna Petexbatún, which occur atop a down-dropped limestone graben (Inomata 1995:25, 27, 32-33).

Ancient Maya settlements in the Petexbatún occur in the uplands, closely spaced and trending east-west within 1 km of the escarpment edge (Houston 1993:12; Inomata 1995:43-45). These include the centres of Dos Pilas, Tamarindito, Arroyo de Piedra and smaller sites such as El Excavado, La Paciencia, and Los Quetzales. One exception is the fortified centre of Punta de Chimino which is located on a peninsula jutting into Lake Petexbatún. The upland locales met a complex of resource, social, political, and cultural considerations for settlement location (Inomata 1995: 32-36, 43-46). Several ecological zones can be accessed from points close to the escarpment edge (Inomata 1995:46) including the wetlands and various streams, lagoons, and the lake at the base of the escarpment. A series of springs along the escarpment edge clearly influenced settlement location, as surface water is scarce in the karst landscape atop the escarpment. The Rió Petexbatún, too, was a water source but likely also was an avenue for transportation and for communication with other centres and regions. Agricultural and *huaymil* zones occur in immediate proximity to the settlements. Shallow (10-30 cm) but well drained and fertile, forest soils (Rendzina type, Rendolls) are favourable for *milpa* cultivation if care is taken to prevent or minimize erosion (Beach and Dunning

1995:140; Inomata 1995:35, 49), and deeper pockets of soil occur in numerous, well-drained solution sinkholes. Forest zones to the west of the sites lack sufficient surface water for human occupation but support a rich variety of wood, plant, and animal resources. Finally, the escarpment offered defensible settlement locations, which would have been an important consideration during the Late Classic period in the Petexbatún area (see below).

Aguateca is located at a particularly high and steep point on the escarpment that marks the eastern boundary of the site (Figure 2.7). At the foot of the escarpment, 80 - 90 m below the settlement, is a spring-fed pool, which flows into Laguna Aguateca at a short distance east of the site. Running parallel to the escarpment through the central part of the site is the *Grieta*. It is a narrow (5-15 m) but deep (50-60 m) chasm in the limestone that begins at the southern edge of the site centre and ends immediately north of the site. Several natural bridges formed by massive blocks of limestone connect the Main Plaza, which lies west of the *Grieta*, and an elite residential area, which is located between the escarpment edge and the *Grieta*. The southern and western boundaries of the site are bounded by a deep gorge, and a series of sinkholes mark the site's northern limits. Together, the gorge, the *Grieta*, and the steep escarpment face make Aguateca a very defensible location (Inomata 1995:48, 1997:337).

The first archaeological investigations at Aguateca were undertaken by Ian Graham (1967). In the 1950s, he recorded monuments and completed a sketch map of the central part of the site (Inomata 1995:30). Since that time, Houston (1987) has created a compass map of the site's epicentre. He and others (Houston 1987, 1993; Houston and Mathews 1985; Mathews and Willey 1991) also examined the political history of Aguateca and other Pasión centres using the texts recorded on many monuments at the sites in this region. Their work is summarized below.

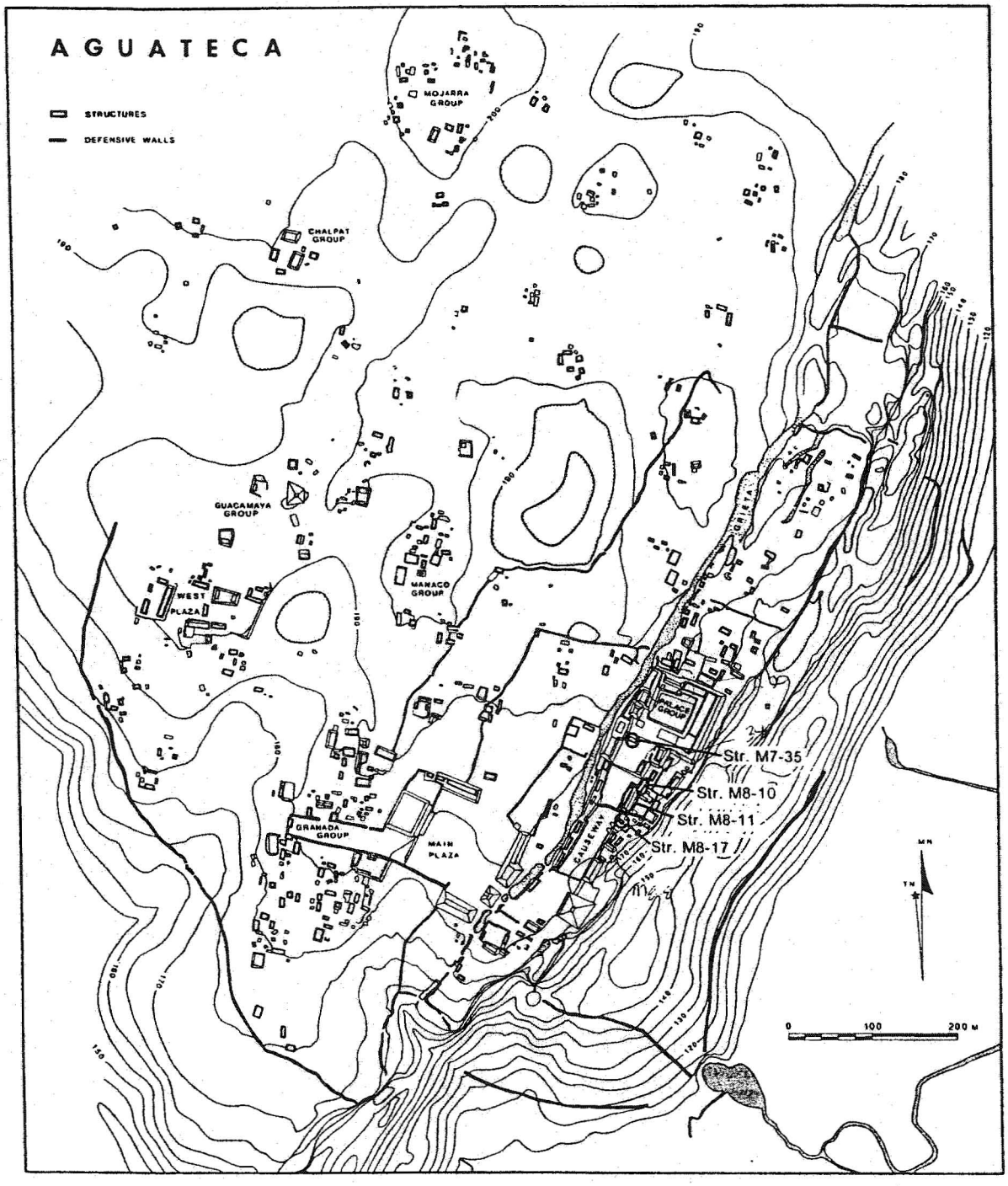

Figure 2.7 Map of the site of Aguateca, Guatemala (from Inomata and Stiver 1998:434).

Full-scale investigations at Aguateca began as a subproject of the Vanderbilt Petexbatún Regional Archaeological Project (Arthur Demarest, director). The research objectives of the project were to understand the breakdown of complex societies and, in particular, the role of warfare in the collapse of Classic Maya society (Inomata 1995:1, 61). Under the direction of Takeshi Inomata, detailed mapping of the site core, settlement survey in the surrounding area, and excavations were carried out during the 1990 through 1993 field seasons (Inomata 1995, 1997). These efforts revealed a well-planned system of defensive walls (Demarest *et al.* 1997:236-238; Houston 1993:51; Inomata 1995:87, 89-93). Several of the walls extend from the escarpment edge to the *Grieta* and would have protected the central part of the site. Below the escarpment, a set of walls protected access to the spring and the lagoon. Excavations also exposed virtually complete artifact assemblages left *in situ* on the floors in and around structures in the elite residential area east of the *Grieta* (Inomata 1995; Inomata and Stiver 1998). Many of the artifacts and the plaster floors of structures showed signs of having been burned. These findings indicate that despite the defensive location and fortifications, elite residents in the central part of the site apparently were forced to flee, leaving behind their possessions, as enemies attacked and burned this part of the settlement.

Given the exceptional circumstances of rapid abandonment at Aguateca, a major goal of the subsequent Aguateca Archaeological Project [Takeshi Inomata (Yale University), Daniella Triadan (Smithsonian Institute), and Erik Ponciano, directors], has been to use the opportunity to better understand domestic activities, and the composition and organization of elite Maya households during the Late Classic period (Inomata *et al.* 1996, 1998). Therefore, excavations during the 1996-1999 field seasons focused on wide-area excavation of several residential structures (Strs. M8-8, M8-10, M8-13, M7-34), including the residence of the royal family (Str.M7-22), located in the site epicentre.

What is known of Aguateca's history derives from archaeological and epigraphic records from this site and other sites in the Petexbatún and the Pasión. Aguateca was a small centre during the Late Preclassic period (300 B.C. - A.D. 350) (Inomata 1997:338). Test excavations into three large platforms (Platforms K6-1, L6-1, L6-2) and a temple-pyramid (Structure K6-1), in the west section of the site centre indicate that they were constructed at this time. There is no evidence for an Early Classic (A.D. 350-600) occupation at the site, however. Other sites in the Pasión, including Dos Pilas (Houston 1993:52) and Seibal (Tourtellot 1988:392-393), appear to have been abandoned or to have had only very small populations at this point, as well.

Based on a small number of ceramics excavated from two groups of mounds (Groups M6-5 and M6-6), it appears that a scattered, rural population lived in the area of Aguateca once again, by the early part of the Late Classic (Tepeu I phase, A.D. 600-700) (Inomata 1997:338, 340-341). Similarities in residential architectural styles and construction offer limited evidence of a connection between the Aguateca population and the contemporary ruling dynasty centred at Tamarindito/Arroyo de Piedra (Inomata 1997:340-341), the only dynasty identified by an emblem glyph in the Petexbatún area for this time period.

Marked changes occur by the Tepeu II phase (A.D. 700-830) of the Late Classic period at Aguateca and in the Petexbatún area (Houston 1993:95-125; Inomata 1997:341). Aguateca burgeoned into a densely settled centre of some importance. Inomata (1997:341) feels that the rapid growth of the settlement, coincident with the appearance of a new domestic architectural style (walls with vertically placed slabs/blocks, room partitions, high benches), reflects the arrival of Maya settlers from other parts of the Pasión region or elsewhere. The site's defensible location probably was a factor in the expansion of Aguateca, as well (Inomata 1997:337), which occurred at a time of recurrent interpolity warfare in the Petexbatún (Demarest *et al.* 1997).

The political context of the Petexbatún area grew more complex through the Late Classic period. A second dynastic lineage seated at Dos Pilas dominated the Petexbatún by the mid-seventh century through the middle of the eighth century A.D. (Houston 1993). The broad influence or connections of this dynasty are reflected in its use of the Tikal emblem glyph, which suggests that the Dos Pilas dynasty originated in the central Petén, at Tikal, or at least claimed descent from that dynasty (Houston 1993:100). Moreover, historical records on monuments tell that Rulers 1 through 4 (A.D. 625 - 761) at Dos Pilas rapidly and aggressively expanded the boundaries of their polity through strategies of elite marriages, the creation of alliances, and warfare (Houston 1993:107-119). At various points during the 100 years that they dominated the Petexbatún, the rulers of Dos Pilas had allied themselves with or had control over the centres of Itzan, Calakmul, Cancuen, El Chorro, Yaxchilan, the "Ik" site, and Seibal (Houston 1993:107-119). Aguateca, too, fell under the hegemony of the Dos Pilas polity. However, Aguateca seems to have been a twin capital with Dos Pilas, at least from the time of Ruler 3 (A.D. 727-741) (Houston 1993:115-116), and perhaps earlier (Demarest *et al.* 1997:236; Inomata 1997:341).

The dominance of the Dos Pilas dynasty was not uncontested. The long-established Tamarandito/Arroyo de Piedra dynasty remained seated just 3 km from Dos Pilas. References to Ruler 2 (ca. 700-726) from Dos Pilas, on a number of monuments at Tamarandito and Arroyo de Piedra suggest that the two centres might have co-existed as allies while Dos Pilas was at its height (Houston 1993:114). Ultimately, though, it seems that the two centres warred and that Tamarandito/Arroyo De Piedra may have captured and killed Ruler 4 of Dos Pilas (A.D. 726-761).

The death of Ruler 4 of Dos Pilas ultimately led to the demise of that centre shortly thereafter and also resulted in the decentralization, or restructuring, of political power in the Petexbatún (Houston 1993:125). Dos Pilas, itself, was abandoned and the Dos Pilas

dynasty apparently splintered. The ruling family may have removed itself to Aguateca, which began to erect more monumental stelae than it had previously (Demarest *et al.* 1997:236; Houston 1993:119). Aguateca thus continued as the capital centre of the Petexbatún as evidenced by numerous references to its rulers at other sites in the area (Houston 1993:119). However, it seems that other branches of the dynasty established themselves at other small centres and struggles for authority likely ensued (Demarest *et al.* 1997:236; Houston 1993:125). Hence, Aguateca's pre-eminence, too, was short-lived as the site fell to enemy attack sometime around A.D. 800. While elite families fled immediately, a non-elite population continued to reside at the site. Aguateca was essentially abandoned by A.D. 830 (Inomata 1997:342).

Chapter 3

The Anthropology of Foodways: Food in Complex Societies

Food is life, and life can be studied and understood through food.

(Counihan and van Esterik 1997a:1)

3.1 Introduction

Food sustains human life; certainly this is the most obvious and basic function of food and eating. No less consequential are the myriad ways in which food and eating are used to create, mediate, manipulate, and communicate interactions and identities in human societies. Knowledge of a group's foodways, which include "the food [people] eat and a whole complex of behaviours by which [they] produce, prepare, present, and consume them," (Welch and Scarry 1995:397) can be used to understand many dimensions of human life. Thus, investigations of ancient foodways have much to contribute to understanding the past, given some knowledge of the variety of factors that can influence people's food choices.

In this chapter, I discuss some of the factors which govern people's food choices including 1) material influences such as environment, technology, nutrition, and cost, and 2) social and political interactions. I focus on how socioeconomic and sociopolitical hierarchies affect food choices in complex societies, drawing attention to the varied types of problems that can be addressed using information from archaeological food remains. At length, my purpose is to justify the application of residue analysis given the importance of food data and the potential that the techniques promise.

In the second half of the chapter, I describe what is known of ancient Maya foodways based on archaeological and ethnohistoric records and ethnographic analogy. I summarize our current understanding of the great complexity and variety in ancient Maya agricultural strategies, which is now well documented archaeologically. The discussion provides context for the reader. It is important, too, because it suggests that we can also expect diversity in what the Maya, in different times and places, chose to eat. Detailed descriptions of Maya foods and cooking are also provided for several reasons. First, they illustrate the variety of foods that were available to and used by the ancient Maya in contrast to the monotonous diets of many impoverished, modern Maya from whom analogies are often drawn. The variety described also contrasts with far more limited archaeological evidence of the foods used by the ancient Maya. Second, the descriptions of Maya foods and dishes include consideration of which foods may or may not be expected to occur as organic residues in archaeological cooking and storage vessels. I hope to show that traditional archaeological food remains and ethnographic analogies do not record the complexity of ancient Maya menus and cuisine. Ultimately, my purpose is to begin to think about how a successful application of residue analysis, as an analytical tool, might fill in some of the remaining gaps and add to our knowledge of ancient Maya foodways, in particular.

3.2 Food is life: Practical concerns and food choices

Anthropologists whose theoretical perspective is that of cultural materialism assume that nutrition (biological requirements) and cost, as determined by environment, technology, demography, and political-economy are the primary factors which influence decisions regarding food production and consumption in every society (Bodley 1983a:86; Harris 1977a, b, 1987:58; Ross 1987). While cultural materialists do not deny that people also select foods to express meaning in social and ritual contexts, the importance of

these processes in shaping food systems is thought to be very peripheral (Harris 1987:60, 61; Ross 1987:19). Further, they hold that even in these contexts, food choices are adaptive to environmental, biological, or economic constraints. The food choices that most people *can* make are certainly bounded by such physical and material parameters. Staple foods, particularly, tend to be those which are locally abundant and economical to produce or procure. A professor in one of my undergraduate courses asked, "Why would Plains people have focused on fish when they could hunt bison?" Perhaps only in the privileged context of the Western industrialized world do local abundance and cost not always govern choices of basic foods (*cf.* Bodley 1983b). Of course, not all foods which people include in their diets are either plentiful or economical. Some are added for flavour, variety and enjoyment despite the relatively poorer returns in time and energy spent gathering or producing them.

Ideally, people's combined food choices, or diet, will meet all their nutritional requirements allowing not just survival but growth and maintenance of the body, and an active and healthy life. Diet refers to the types and proportions of foods which people eat (Weismantel 1988:87). Plants, animals, fishes, insects and other organisms which people do eat are ubiquitous and found nearly everywhere. Hence, at different times and places, many nutritionally successful diets have been created and used over generations and millennia. Examples are the combination of lime-treated maize, beans, and squash in Central America, and diets based on meat and fat in the Arctic (Roe 1973:16; Wing and Brown 1979:3). Not all diets are nutritionally adequate, however. Key foods may be inaccessible for numerous reasons including seasonal food shortages, drought, flooding, crop failure, or lack of economic means to produce or purchase foods. For example, niacin deficiency disease, prevalent in impoverished regions of western Europe, Africa, and the United States in the 18th through early 20th centuries resulted because people

who lacked the economic means to procure additional foods and who had no knowledge of lime-treating corn consumed maize dominated diets (Roe 1973; Katz *et al.* 1974).

3.3 Food and status: creating and maintaining boundaries in a stratified society

Food has the rare capacity to simultaneously create social boundaries which promote solidarity among members of subgroups (e.g. ethnic, gender, religious, or regional groups) and emphasize distance and segmentation between socioeconomic groups or castes within a society (Appadurai 1981:496, 507; Breckenridge 1986:21; Fiddes 1991:33-34; Goody 1982:81-82; Pollock 1992; Weismantel 1988). Fajans (1988:143) argues that food is a transformative material that people manipulate, not just to symbolize changes and differences between groups of people but to enact and maintain these changes. People sometimes adjust their diets (and so food production and preparation) to achieve changes in the social structure of their community or in response to broader social, economic or political changes in the society. Others (Appadurai 1981; Breckenridge 1986:37-38; Manderson 1986:1; Murphy 1986:91; Pollock 1992:232, 235; Weismantel 1988: 5), too, have noted the purposeful use of food to establish individual or group identity and to negotiate or control relationships with other categories of people. In complex societies, the potential for using food to express and negotiate social relations is greater than in egalitarian ones (Appadurai 1981:494; Costin and Earle 1989:691). Populations are larger and more heterogeneous in terms of social, economic, and/or political categories of people. Thus, there are greater numbers and types of interactions and contexts in which food may be used to send messages. There may also be a greater need to establish different identities and boundaries through material symbols, including food, in order to organize and rationalize a more complex social world.

Elite individuals and groups in complex societies are typically in an advantageous position to use food and foodways to negotiate and then legitimize boundaries between

themselves and members of lower-ranking groups within their society. Following Marcus (1983:3), I use 'elite' to refer to the "rich, powerful, and privileged in any society" regardless of whether their elevated status derives from social, economic, or political power. They may do this using one or both of the following strategies: 1) organization and participation in political feasting in order to both create and maintain their privileged rank and; 2) consumption of elite foods and use of high cuisines in order to demonstrate their distinct status.

3.3.1 Feasting: Food in the creation and maintenance of hierarchy

Elites sometimes use feasting to create and then increase or maintain inequalities by ensuring a continued economic base for their political power and social position (Costin and Earle 1989:691-692, 708; Earle 1978:181-183; Hastorf and Johannessen 1993:116-117; Hayden 1990; Hayden and Gargett 1990). Two forms of feasting are commonly used in societies that lack strongly centralized political power (i.e. chiefdoms, incipient states, or expansionist states). Competitive feasting is used by individuals to achieve prestige and wealth through the manipulation of food distribution and presentation in such a way that asymmetric social and political relationships are created through bonds of social debt (Hastorf and Johannessen 1993:116; Hayden 1990). The host of a feast requires many supporters to supply food for the event. Guests from other communities or competing groups will later reciprocate with a more elaborate feast. The original host can then repay his supporters and keep the surplus for himself. Individuals who successfully organize feasts always have outstanding debts and can amply repay supporters and maintain alliances. An example of competitive feasting is the potlatch held by complex hunter-gatherers on the Northwest Coast. In the second type of feasting - political feasting - elites hold feasts in exchange for labour on construction projects, on elite-owned agricultural land, or in warfare, or in return for the allegiance of

their followers. Early historical examples of political feasting include those given by Hawaiian chiefs (Earle 1978:181-183) and by Inka leaders (Hastorf and Johannessen 1993:118-119, 133; Morris 1982 cited in Costin and Earle 1989:698). Reciprocal social or political ties created between elites and commoners during feasting are largely symbolic (*cf.* Costin and Earle 1989:708). Although commoners may be led to believe that they, too, benefit from the leadership and prosperity of the elites, it is nonetheless elites who benefit materially and in terms of privilege.

With more centralized political rule, conspicuous consumption at feasts may move into the context of the court or palace and reciprocal distribution of food with commoners ceases (*cf.* Hayden and Gargett 1990:16; see for example: Corbier 1989:240-242; Díaz del Castillo cited in Coe 1994:74-76; Freeman 1977:157-158). Food is less important for establishing control and more important as a symbol of that control as it is used to legitimize inequality in social structures (*cf.* Freeman 1977:157-158).

Political feasting does not correlate with less stratified societies and conspicuous court consumption with highly stratified societies. Even in strongly centralized societies, individuals and groups manipulate food distribution to enhance prestige or consolidate economic and political control over others (see Breckenridge 1986:37-38; Murphy 1986:108; Pollock 1992:108-109). Further, feasts are not important for consolidating power or justifying social inequality in all complex societies.

3.3.2 Consumption of elite foods and cuisines

The disparity between elite and commoner consumption patterns is most apparent at feasts because of their public nature but it is also typical of day-to-day differences in their diets (see Chang 1977a:15; Goody 1982:113; Khare 1986:170; Revel 1979; van Esterik 1992:184). Elite foods and high cuisine are symbols of elite power and prestige as they reflect the extensive influence, control, and connections of elite members of a

society (*cf.* Goody 1982:97-105; Shafer 1977:128; van Esterik 1992:179). Occasionally, laws or formal dietary prohibitions dictate which foods can and cannot be eaten by members of different social strata (Bryant *et al.* 1985:180; see Sayers 1990:89). However, people's food choices are ultimately bound by their control, or lack thereof, of systems of food production and distribution. Elites generally own more and/or better land, can access technology and labour required in food production, and have the authority to control producers and food distribution to their advantage by collecting tribute or taxes. Elites also have greater access to food through exchange (see for examples: Alcocer 1938:368-369; Coe 1994:102; Corbier 1989:240; C.A. Wilson 1991). Compared to commoners, elites typically have more food, greater variety and quality of foods, more preferred items, and more foods which are costly because they are rare or because they are difficult and/or expensive to acquire, produce, or prepare (Bryant *et al.* 1985:179; van Esterik 1992:178; see for examples: Corbier 1989:239-250; Freeman 1977:150, 153-154, 155; Goody 1982:128; Khare 1986:150, 174). Simply because they can, elites often choose to demarcate their high status by eating foods which non-elites cannot obtain.

Meat is perhaps the category of food that is most difficult for commoners in most complex societies to obtain in quantity and/or on a regular basis (see for examples: Alcocer 1986:174; Murphy 1986: 107; Prakash 1961:129; Revel 1979;44; Sayers 1990:98; Shafer 1977:98; Yü 1977:74). In many societies, meat is esteemed for its nutritional value (essential proteins and fats) and flavour but it can also be costly. The cost of producing domestic animals, in particular, requires that commoners in many societies consume less meaty cuts or meat of smaller and/or older domesticates, or that they hunt game (Fiddes 1991:67, 174; Hémardinquer 1979; Freeman 1977:154; Miller and Burger 1995:447; Revel 1979:44; Sayers 1990:93-98; Shafer 1977: 99; H. Wilson 1988:35), although, game, too, is sometimes a prestigious food item where animal

populations are in decline (Freeman 1977:154). Fiddes (1991) believes that meat also has social value in cultures concerned with marking the culture/nature boundary and control over the wild. By eating meat, humans metaphorically consume an animal's strength and express control over nature. Hence, the widespread preference for meaty cuts. Therefore, Fiddes argues, meat is a 'natural symbol' of prestige and power and is an appropriate elite food item.

Nonetheless, the idea that elites always (now and in the past) have access to greater amounts of meat may be shaped largely by our own cultural and historical perspective, where the costs of producing meat and the differences in wealth between the elite and the very impoverished are much more marked than they were at many times and places in the past. While there are many examples, from different times and different societies, for ample, and even extravagant meat consumption by elites (Fiddes 1991; for other examples see: Coe 1994:74-75; Corbier 1989:240-242; Freeman 1977: 157-158; Sayers 1990:93-98; Shafer 1977: 99), the evidence is typically anecdotal rather than empirical. Two archaeological investigations that document greater use or consumption of meats by elites have been found (Costin and Earle 1989; Wright 1994). However, this dietary privilege of Wanka elites, in Late Prehispanic Peru, is apparent only during the Wanka II period (A.D. 1350-1460) and not in the subsequent Wanka III period (A.D. 1460-1533) (Costin and Earle 1989:696-697); and while Late Classic Maya elites at Altar de Sacrificios and Dos Pilas consumed more meat than commoners at the same sites, (Wright 1994:271, 280) elites at other Maya centres did not share this dietary distinction (White *et al.* 1993:362; White *et al.* n.d.; Wright 1994:271, 278; Wright 1997). Thus, the indications are that elites sometimes but do not always have access to greater amounts of meat in their diets as a result of their privileged status.

Less often is it acknowledged that elite foods often are locally available, favoured food plants (see for examples: Freeman 1977:150, 155; Goody 1982:125, 128, 135; H.

Wilson 1988:11). Some of these foods are made expensive by processing techniques such as white bread in ancient Rome (Mennell 1985 cited in Fiddes 1991:34; Revel 1979:40-41), but many are simply non-staple food plants. In fact, much of the variety typical of elite diets derives from their ability to acquire more types of food plants (Freeman 1977:155; Goody 1982:128, 135; Lentz 1991:128). In many societies, those poor who can access agricultural land devote it to growing just a few staple foods for their own consumption but typically lack means to obtain additional types. The result is that diets of the lowest ranking members of complex societies are generally extremely monotonous.

Elites may also distinguish themselves by the use of a differentiated or "court" cuisine (Goody 1982:98). A differentiated cuisine entails not only more and better foods, but more complex ingredients, dishes, and methods of preparation; the combination of local and foreign ingredients and traditions; culinary specialists and servile labour; and the elaboration and sharing among elites of ideas and attitudes about food and eating (Freeman 1977:144-145; Goody 1982:98-105; van Esterik 1992:185, 188). Goody (1982:97-99, 105) argues that truly differentiated cuisines occur in stratified societies in which the social hierarchy is based upon differences in economic versus political status, and that intensive agriculture is a prerequisite. Centralized social and political control may permit a more complex cuisine because the relative lack of competitive social and political relations makes it possible to mark unambiguous social distinctions (*cf.* Douglas and Gross 1981:2, 32-33). Archaeologists, then, may be able to use evidence for the presence or absence of a differentiated cuisine to predict the basis for social stratification in past societies. However, such a model will not explain the presence or absence of a differentiated cuisine in every stratified society. Unique cultural or historical factors will influence the extent to which elites use food and cuisine, rather than another material, to mark and maintain status differences.

3.4 The analysis of archaeological food remains

The study of archaeological food remains (palaeobotanical and faunal artifacts) developed in the milieu of cultural materialism. Consequently, studies of food have typically centred on economic and adaptive aspects of diets and subsistence systems with the primary goal being to understand the relationship between a group of people and their environment (Brewer 1992:195-200; Lyman 1983: particularly 334-335; Monks 1981:177-180; Munson 1984a:279). Archaeologists have used food remains to establish what was eaten and which foods were most important in palaeodiets to determine which resource zones were most critical to subsistence, and to reconstruct the seasonal scheduling of resource collection or production (Brewer 1992:200, 229-230; Munson 1984a:279). Meeting such objectives typically results in generic descriptions of subsistence systems and palaeo-environments rather than explanations of people's economic behaviours involving food.

Archaeologists have generally neglected to consider cultural and social dimensions of food choices, thereby disregarding human intentionality (Johannessen 1993:182-183; Welch and Scarry 1995:398). It is now apparent that by concentrating solely on the material aspects of life the ability to explain is greatly limited. Responses to questions of why a group ate what they did, or why they began to produce and consume different foods become predictable (e.g. environmental change or increasing population density) and at times are insufficient. People manipulate food in order to identify themselves and to create and legitimize their status. Therefore, archaeologists should also be able to understand patterns and changes in archaeological foodways in terms of social and political as well as economic processes that operated in the past. In doing so, archaeologists will be able to increase and humanize our understanding of these processes, as well (Hastorf and Johannessen 1993:115-117; Welch and Scarry 1995:398). It may be possible, for example, to use archaeological evidence for feasting

or differentiated cuisines to help establish the nature of elite authority in ancient complex societies (Goody 1982:97-99, 105; Hastorf and Johannessen 1993:116-117; Hayden 1990; Hayden and Gargett 1990).

Several recent publications illustrate that considerations of social and cultural factors that shape foodways not only can be incorporated into but will also vitalize interpretations of archaeological food remains and foodways (Costin and Earle 1989; Hastorf and Johannessen 1993; Johannessen 1993; Miller and Burger 1995; Welch and Scarry 1995). Their work is influenced by Chang (1977a, 1977b), Goody (1982), and the *Annales* historians (Forester and Ranum 1979). The *Annalistes*, in particular, whether investigating particular foods, diets, or subsistence systems always consider multiple lines of evidence including environmental constraints, production, cost, distribution, nutritive value, consumption patterns, and attitudes towards food. Further, they stress the importance of addressing questions within a broad geographical and temporal framework, rather than focusing on a single community or time period. The larger perspective allows comparison of food habits with those of earlier and later periods and with other settlements or regions. Consequently, they can better characterise food habits for the place and period with which they are concerned. In bringing diverse types of information together into a strong argument, the *Annalistes* necessarily arrive at multicausal explanations of why certain food choices were made which are particularistic rather than generalizing.

The new approach to studying archaeological foodways, too, stresses the importance of considering multiple lines of evidence when interpreting temporal or spatial patterning of food remains (Hastorf and Johannessen 1993:116) including: settlement data; functional analyses of ceramic vessels and other tools used in food production, processing or preparation; isotopic studies of palaeodiet and consumption patterns; and/or ethnohistoric and ethnographic observations (see: Blitz 1993; Costin and Earle

1989; Hastorf and Johannessen 1993; Johannessen 1993; Miller and Burger 1995; Welch and Scarry 1995). Convincing explanations of changing food data are inevitably the result when changes or stability across time and space in such diverse yet inter-related types of data can be accounted for in a single narration.

In addition, archaeologists (Hastorf and Johannessen 1993: 126-130; Miller and 1995:441-445, 447; Welch and Scarry 1995:407-408) have added new lines of evidence by utilizing the same food remains in different ways that allow them to do more than just itemize what people ate. They show that the distribution of specific faunal elements and plant parts (e.g. joints, nutshells, maize cupules, maize cobs) can be used to investigate activities of food processing and consumption which are shaped by and can inform about past social and political processes by revealing who was producing and/or processing food and who was eating it. For example, the differential distribution of maize cupules (a measure of food processing) at elite and non-elite locations shows that lower-status members of the Moundville polity were shelling more maize. However, the distribution of maize kernels (a measure of maize consumption) indicates that everyone ate similar amounts of maize. Therefore, Welch and Scarry (1995:405, 407-408) are able to suggest that shelled maize was presented to elites as tribute.

Further, by having to account for many lines of evidence, other artifactual remains of foodways (e.g. vessels, *metates*, knives) which are frequently interpreted outside of an 'active' context can be re-associated with the foods and with the economic and social activities for which they were once used. For example, Brumfiel (1991:237-243) describes how political changes that followed the Aztec conquest of the Valley of Mexico (A.D. 1430) impacted women's economic roles in households. A greater ratio of griddles to pots suggests that women responded to additional tributary demands of Aztec rulers by preparing more dry dishes (*tortillas*, toasted seeds *versus* wet stews, beans, *atolli*) for transport and consumption away from home on elite work projects. This

example also illustrates that, by considering that social and political factors interact with and influence foodways in significant ways, it is possible to provide more convincing explanations of economic and political processes, too. (Also see Blitz 1993.)

Archaeological studies of food ordinarily do not make full use of large scales of time and space which are often observable in the archaeological record, and which provide the opportunity to see potentially informative changes, differences, or similarities which otherwise would not be noted. Not uncommonly, single sites are investigated as if they were isolated communities in time and space. However, recent food analysts do recognize the importance of understanding patterns in archaeological food data from the perspective of several different temporal and spatial scales (see: Costin and Earle 1989; Hastorf and Johannessen 1993; Johannessen 1993; Miller and Burger 1995; Welch and Scarry 1995). They also recognize the particular value of long time scales and regional studies. For example, Miller and Burger (1995) found that the distribution of *llama* skeletal elements varied in each of three cultural phases spanning 700 years (900 - 200 B.C.) of occupation at Chavín de Huántar, Peru. Head and foot elements dominate the earliest assemblage. Leg elements increase significantly in the two later phases. Had Miller and Burger looked at data from just one phase, they might not have related the patterning in the faunal assemblage to the particular social, political, and economic structures which existed in each phase, but may have attributed the differences to taphonomic processes. Comparison of the Chavín faunal assemblage with those from contemporary sites at higher altitudes clarified that taphonomic processes were not responsible for the differential preservation of skeletal elements. Differences between sites suggested that, in the later periods, the increasing proportion of leg elements at Chavín is a product of elite demands for the meatiest cuts at this regional capital.

3.5 Preclassic and Classic foodways: Economic and social uses of food

3.5.1 Maya subsistence: Agricultural systems

Maize agriculture was the basis of subsistence at virtually every ancient Maya settlement[1]. This statement of fact, however, does not acknowledge the reality that Maya food production and procurement strategies were extremely complex. Nor does it indicate that subsistence activities varied between sites and regions, being shaped by different social, political, economic, and ecological circumstances (Flannery 1982; Gerry 1993a, 1993b; Harrison and Turner 1978; Pohl 1985c; White 1999a:xiii-xiv, 1999b; Wright and White 1996:172-182). The long-held belief that the ancient Maya were simply swidden (slash-and-burn) farmers seems remote now after several decades of investigation into ancient Maya agricultural systems. The earliest farming households, who settled into small, egalitarian villages during the Early (1800-1000 B.C.) and Middle Preclassic (1000-250 B.C.), may have been the only pre-Conquest Maya to utilize this long-fallow cultivation technique (Cliff and Crane 1989:296, 316; Miksicek 1991:80-83). Swidden cultivation requires that large areas of land remain fallow for 5 to 20 years and, therefore, also necessitates low population densities.

The Maya Lowlands were heavily settled during the Classic and Postclassic, however. Settlement studies completed in the 1960s and 1970s (Ashmore 1981; Ashmore and Willey 1981:16-17) informed archaeologists of this reality and prompted investigations into how the Maya sustained a large and complex society in their tropical forest setting for nearly 2000 years. Long ignored reports of relict agricultural fields (Lundell 1940:9-12; Ower 1927:384; Palerm and Wolf 1957:28), which hinted that the Classic Maya had relied on intensive cultivation strategies, have since been investigated and verified. Systems of wetland fields, either channeled into or built up out of

[1] Coastal sites may be the only exception to this pattern (McKillop 1984, 1994).

seasonally inundated soils along the margins of *bajos*, lakes, or streams, exist in southern Quintana Roo and Campeche, Mexico, and in northern Belize (Siemens and Puleston 1972; Turner 1974; Turner and Harrison 1981, 1983). Botanical remains from some fields indicate that they were used for cultivation of maize and possibly cotton (Wiseman 1983:110, 1990:320-321). Additionally, vast networks of limestone-walled, agricultural terraces have been documented in Quintana Roo, Campeche, and Chiapas, Mexico, in western Belize, and in eastern Guatemala and the Petén (Healy *et al.* 1983:399; Lundell 1940:9-12; Ower 1927:384; Turner 1974:119-121).

Their existence having been established, a number of researchers linked the rise and fall of Classic Maya society to intensive maize cultivation on the wetland fields and terraces (Adams 1980:211; Santley *et al.* 1986:146). Construction of terraced fields does coincide with Middle and Late Classic population growth (Healy *et al.* 1983:407-408; Lundell 1940:11; Puleston 1978:232; Turner 1974:121; White *et al.* 1993:350) and evidently represents efforts to bring marginal lands into cultivation using a system that slows or prevents soil erosion and conserves soil moisture on slopes. Many wetland fields, however, were constructed during the Late Preclassic, centuries prior to the time at which Maya populations were largest (Bloom *et al.* 1985:26; Siemens and Puleston 1972:234; Turner and Harrison 1983:254, 256). They did continue to be used through the Late and Terminal Classic periods. Further, wetland fields are not widely distributed in the Lowlands (Pope and Dahlin 1989) and many large Late Preclassic and Classic centres in the densely settled interior, including El Mirador and Tikal, also lack terracing (Pope and Dahlin 1989:97).

Ancient Maya agriculture is now conceived as having been wonderfully more complicated and flexible, involving a complex understanding and intensive use of the tropical landscape. The specific cultivation strategy developed by each household likely varied greatly according to regional and local setting, and with the amount and quality of

land inherited by the household. Nonetheless, it is yet possible to define "Maya agriculture" as it was practiced across the Lowlands. McAnany (1995a:64-75) offers an elegant and comprehensive model of pre-Hispanic Maya agriculture and land tenure that breathes life into ideas and information gleaned from archaeological, ethnohistoric, and ethnographic sources on the subject. The two main components of the model include fixed-plot variable-fallow cultivation of far fields and continuous cultivation of near fields in the vicinity of residences.

Ideally, each agricultural household would have cultivated a number of scattered plots located in a variety of settings in order to reduce risks of crop damage or loss inherent in growing food. Far fields located at least an hour's walk distant from the residence were likely part of a continuous system of variable-fallow fixed-plot cultivation (McAnany 1995a:69-74, following Killion 1987). These fields would have been important for maize cultivation but maize would have been planted with a mixture of crops including beans, squash, herbs, and protected trees or orchards, as observed ethnographically and ethnohistorically and described by a number of researchers (Atran 1993; Hellmuth 1977:436, 441; Nations and Nigh 1980; Netting 1978:320, 327; Villagutierre 1933, cited in Hellmuth 1977:426; Wiseman 1978:85-89). A mixed-crop strategy prevents soil erosion and nutrient loss, optimizes land use and soil moisture, and prevents or minimizes the risk of crop damage due to disease or insect infestation (Netting 1978:307; Wiseman 1978:87). Far fields were initially cleared from mature forest, cultivated for a number of years and then left fallow for several more. The length of cultivation and fallow would have varied (1-20 years) across time and space according to local environment and soil conditions as well as economic, political, and demographic factors (McAnany 1995a:71-73). Presumably, fallow fields (or *huaymil*) were continually used, however, as protected and planted fruit and palm trees remained to be harvested. The Itzá and Lacandón Maya have used fallow fields in this manner in recent times (Atran 1993:682;

Nations and Nigh 1980:15). Far fields probably were not left to return to high forest before being cleared again, particularly in the Classic period when population levels were highest.

In fact, McAnany (1995a:74) suggests that in many areas of the Lowlands during the Classic period the far field component of pre-Hispanic agriculture may have been abandoned because of dense populations and concomitant shortages of cultivable land. She bases her argument on archaeological settlement data that reveal an even and continuous distribution of housemounds across the landscape at that time. Densely populated Classic period settlements may have been supported by intensive, continuous cultivation of land adjacent to residences. The near-field component of Maya agriculture would have included orchards (*cf.* Folan *et al.* 1979 and McKillop 1994) and dooryard gardens, in addition to mixed cropping of lowland fields, terraced slopes, and/or wetland fields (McAnany 1995a:74).

Settlement studies in the Belize River Valley (Fedick 1989) and at Sayil, Mexico (Killion *et al.* 1989; Tourtellot 1993) support the hypothesis that intensive cultivation occurred within urban and rural settlements. Using the amount of labour investment in architecture as a measure of household stability, Fedick (1989:244) observed that Late Classic households in the Belize River Valley that were occupied the longest tend to be located on the best agricultural land. The permanency of these households suggests that intensive cultivation of small plots took place within the vicinity of the residence and that a system of land tenure existed. This pattern seems to originate in the Late Preclassic. At Sayil, elevated concentrations of soil phosphate and low-density ceramic distributions, in the open areas between housemounds, indicate that these areas were fertilized with mulch and kept clear of debris in order to allow intensive gardening within urban centres (Killion *et al.* 1989:288-289; Tourtellot 1993:220-223). Evidence of intensive gardening in the form of small, stone-lined grids, has also been reported from Ixtutz, Petén, Guatemala

(Chase and Chase 1983) and gardens and maize fields, preserved under volcanic ash, have been excavated alongside residential structures at Joya de Cerén, El Salvador (Sheets 1992:76, 120; Zier 1980).

Indeed, ancient housemounds occur on terraces and in close proximity to wetland fields, often only several hundred meters away (Healy *et al.* 1983:402; Turner 1974:120). In Quintana Roo and Campeche, Turner (1974:120) recorded one housemound per 0.75 ha of terracing. Stone walls laid out perpendicular to the terraces have been interpreted as walkways and as mechanisms to control runoff (Turner 1974:120). They may also have served as field boundaries demarcating intensively cultivated plots worked by individual households or lineages. This position differs somewhat from that of researchers who have suggested or implied that construction and cultivation of terraces and wetland fields required the involvement and organization of the ruling class (Cliff and Crane 1989:317; Healy *et al.* 1983:402; Turner and Harrison 1981:399; Wiseman 1983:117). However, centralized direction is not necessary (see Denevan 1982). Further, if McAnany's (1995a, see below) understanding of pre-Hispanic land tenure is correct, it may have been lineage leaders who claimed marginal lands on slopes and at swamp edges and who organized kin for labour during construction and use of terraced and wetland fields.

McAnany suggests that rights to agricultural land and other resources were held by lineages and were obtained, principally, by inheritance from ancestors but also by first occupancy, and by encroaching upon or making a claim (based on ancestral rights) to land held by another lineage (McAnany 1995a:95-96). Long-established lineages in a region, therefore, would have had stronger claims to, and would have held rights to, more and better land (McAnany 1995a:116). Differential access to resources also occurred within lineages (McAnany 1995a:116). Ethnohistoric documents indicate that lineage heads and household heads organized local agricultural production (McAnany

1995a:117) suggesting that, together, these same individuals may also have determined how fields held by the lineage were distributed to member households, perhaps also on the basis of depth of ancestral rights.

3.5.2 Maya comestibles and cuisine

The long-recorded history of maize-dominated diets supplemented by only a few other foods basic to Maya cuisine - beans, squash, and chiles - leaves an impression that Maya diets have varied little over time and across the geography of the Maya realm (see for example Benedict and Steggerda 1936:158; Standley 1946:395). Our knowledge of Maya foodways has been shaped by observations of contemporary Maya diets which include 60-80% maize and much smaller amounts of beans, squashes and, rarely, meat (Benedict and Steggerda 1936:172; Flores *et al.* 1964 and Flores and Reh, cited in Béhar 1968:116; Redfield and Villa Rojas [1934] 1962:37-40; Standley 1946:395, 396, 397). The idea that such modern diets reflect a pre-Hispanic pattern is, in part, the result of earlier literature the authors of which presume, as Standley does, that:

> the highland Indians subsist much as did their remote ancestors... Their diet is probably no better and no worse. They eat little meat now since they have few domestic animals except sheep, whose chief product is not meat but wool. In preconquest days their only edible domestic animals were turkeys and perhaps a few ducks, and except in homes of the upper classes meat must have been a rarity (Standley 1946:395).
>
> It should be emphasized that the "foods" of the Guatemalan Indians were originally and still are maize and beans. Other edible plants, of scant nutriment, are merely *verduras* or "greens", which serve principally like the roughage fed to cattle, or as appetizers. Fruits, likewise, are not considered real food but are eaten because they taste good (Standley 1946:397).

Standley's (1946) description of a "bland" maize and bean diet has been projected backwards into history despite his descriptions of more than 20 additional food plants which he observed to be in use among the highland Maya (see pages 397-400). There

has been little acknowledgment that the same ethnographic literature, which was written in the first half of the 20th century and which emphasizes the importance of maize, also describes a great variety of other foods utilized at that time (Benedict and Steggerda 1936:159, Table 1 lists 60 foods, 161-171; Lundell 1939 describes 47 food plants; Redfield and Villa Rojas [1934] 1962:38-41; Thompson [1930] 1968:184-195). More recently, Alcorn (1984) has recorded the use of 138 different food plants among the Tzeltal Maya, and Atran (1993:641-675) recorded Itzá Maya knowledge of 57 food plants and also lists 59 species of mammals, birds, and freshwater fish known to have been used at present and/or in prehistory.

Earlier ethnographic and ethnohistoric observations have also been used to argue that the ancient Maya, and non-elites in particular, consumed very little meat (Pohl 1985b:141). In truth, the original authors are not clear on this point. A much cited passage from Roys ([1943] 1972:44) states that "...stew contained game or fish often in the homes of the upper class but rarely in those of commoners who are said to have eaten little meat except at festivals." Less often is reference also made to the next passage in which Roys ([1943] 1972:44) continues, saying, "...there was much individual hunting and as we have seen quantities of game were trapped, so the common men probably had frequent opportunities to take meat. The average inhabitant of Chan Kom today eats venison, peccary or agouti about once a week." Tozzer ([1907] 1978:53), too, observed that meat obtained by hunting was second in importance only to maize for the Maya of Yucatán and Chiapas in the early part of this century.

Stable nitrogen isotopic analyses of bone collagen completed to date indicate that although regional variation in dietary protein sources existed in the pre-Hispanic period, meat provided the greatest part of proteins consumed in the majority of ancient Maya diets (Wright and White 1996:176-177). Elevated $\delta^{15}N$ values in bone collagen of inhabitants of the Petén, Guatemala (Wright 1994:255-289, 1997), and of the lowlands in

Belize (Coyston *et al.* 1999: 232; Tykot *et al.* 1996:359; White and Schwarcz 1989:466-467; White *et al.* 1993:360; White *et al.*, in press; White *et al.* 1999) are not unlike those of terrestrial carnivores and indicate that animals were the primary source of dietary proteins for the Maya during the Preclassic through Late and Terminal Classic periods. Further, the nitrogen data also show that members of different socioeconomic status groups which existed within the same settlement often consumed roughly the same proportion of meat proteins in their diets, regardless of their rank (White *et al.* 1993:362; White *et al.* n.d.; Wright 1994:271, 278; Wright 1997). Where differences do exist, they indicate that while elites may have consumed somewhat larger amounts of meat, non-elites were not lacking meat in their diets (White *et al.* 1996; Wright 1994:272, 280, 282). Only the occupants of settlements in the Copán Valley, Honduras, exhibit nitrogen isotopic values that reflect a largely herbivorous diet (Reed 1992, 1999:188, 191).

To some extent, the illusion of a monotonous maize diet for all contemporary and ancient Maya is also a product of the great number of academic papers which are concerned with maize production[2], storage (Smyth 1989, 1990), preparation, nutritional value (Bressani *et al.* 1958; Cravioto *et al.* 1945; Katz *et al.* 1974; Nations 1979; Taube 1989; Ulloa and Herrera 1986), and with measuring maize consumption (Coyston *et al.* 1999; White and Schwarcz 1989; White *et al.* 1993)[3]. The scholarly fascination with maize initially may have been motivated by a need to understand why the introduction of this high yielding and potentially very important economic food plant into Europe, Africa, and into non-indigenous communities in the southeastern United States resulted in malnutrition and disease (Roe 1973) when, for millennia, it had been extremely important to indigenous economies, diets, and cultures in the New World. Whether inadvertent or

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[2] Ultimately every study of ancient Maya agriculture is concerned with the importance and/or impact of maize cultivation in ancient Maya economy and history.

[3] All carbon isotopic analyses of Maya skeletal remains ultimately measure the importance of maize relative to other foods. See sections 4.4.2 and 4.4.5.

intentional, this body of research has contributed to a perception that maize supplemented with beans, which is a minimally adequate diet in terms of nutrition, is also long-standing or traditional, successful and, therefore, acceptable for and desired by modern Maya peoples because it has always been so.

It is very unlikely that it has always been so, however. Infrequently is there acknowledgment that, as Béhar (1968:116; also Ulloa and Herrera 1986:153) realized, the predominantly maize-bean diets consumed by many Maya today are the only option for a group of people who find themselves in disadvantageous economic and social circumstances since the conquest. Today, diets consumed by the Maya lack variety because the people generally have little of the cash and/or land necessary to purchase, produce and/or procure other food plants or animals. This is true for impoverished peoples across time and around the world (Section 3.3.2).

What we can glean from ethnography is, in fact, that diets consumed by the ancient Maya were likely more diverse than those accessible to the most impoverished Maya today. In the pages that follow, I try to describe just some of the variety that almost certainly existed in the diets and cuisine of earlier periods in Maya history, using ethnographic and ethnohistoric analogy as well as archaeological evidence of food and cooking. As far as is possible, I also describe how foods might have been prepared and consider which foods are most likely to have contributed components to organic residues in ceramic storage and cooking vessels excavated from archaeological sites.

maize dishes

The great variety of maize dishes and beverages described in the ethnographic and ethnohistoric literature attest to the importance of this staple food. Most begin with *masa* which is prepared (Redfield and Villa Rojas 1962[1934]:38-39) by first boiling dried maize kernels for a few minutes and then leaving them to soak overnight in the same lime water.

The following morning, the maize is rinsed and the softened maize kernels (*nixtamal*) are ground several times, to produce a fine meal, using a *mano* and *metate*. Two types of maize bread are made from *masa*: *tortillas* and *tamales*. *Tortillas*, which are thin, flat, round cakes cooked on a *comal* (griddle) or in hot ashes, are the form in which most maize is consumed by most Maya, today. However, *tamales*, which are generally only consumed on festive occasions now, appear to have been the most common maize preparation during the Pre-Hispanic era (Taube 1989). *Tamales* are prepared from *masa*, which is strained, cooked until thick, and then mixed with lard (Redfield and Villa Rojas [1934] 1962:39). The maize dough is formed into squares filled with meat, chiles, beans, or squash seeds (Benedict and Steggerda 1936:161; Tozzer [1907] 1978:52). Chicken broth with tomatoes, *achiote*, and salt may be poured over the *tamales* which have been wrapped in leaves and placed in a vessel to be boiled or steamed, or baked in a pit oven (Redfield and Villa Rojas [1934]1962:40; Villa Rojas 1945 cited in Taube 1989:42). *Tamales* are frequently represented in Classic Maya epigraphy as the term *wa* or *wah* and in iconography but *tortillas* are rarely depicted (Taube 1989). Thompson (1938:597), too, noted that *tortillas* are not mentioned in many ethnohistoric texts, including Landa's description of maize dishes (Tozzer 1941:89-90). Further, *comales* do not occur at Lowland Maya sites and appear only infrequently at highland sites in Guatemala before the Protohistoric period (Taube 1989:33). *Tortillas* were likely introduced from Mexico during the 16th century. A myriad of other maize breads are also prepared on religious or ceremonial occasions (Love 1989; Redfield and Villa Rojas [1934]1962:40).

Since *tortillas* and *tamales* are both solid foods, neither may result in the accumulation of a residue that would reflect maize preparation in ceramic jars or *comales*. *Tamales*, too, are sometimes steamed, which would lessen the chances that maize residues would collect in the vessels. Further, waxes from the leaves in which

they are wrapped, whether the *tamales* are boiled or steamed, may produce a greater quantity of residue than the maize (see Section 4.2). However, boiling and soaking corn for the preparation of *masa* is expected to transfer some residue to the walls of cooking jars.

The preparation, storage, and serving of maize beverages or gruels, which were likely consumed more frequently in the past than at present, would also leave residues in the porous walls of ceramic vessels. A number of these beverages or dishes continue to be consumed today in Yucatán and Chiapas. The preparation and ingredients in these dishes have been described by ethnographers (Benedict and Steggerda 1936:160-161; Redfield and Villas Rojas [1934] 1962:39-40). *Atole* is often eaten warm in the morning. What is left-over is consumed cold later in the day. *Atole* is generally made by adding *masa*, honey, and salt to boiling water and allowing it to boil for several minutes. Early in this century, Redfield and Villa Rojas ([1934]1962:39-40) noted that the Maya of Chan Kom, Yucatán, Mexico also prepare several other variations of *atole*. One version is prepared using corn boiled without lime and ground into a gruel and another uses maize ground after it is soaked for several days in water without lime. *Iz ul* and *ahza* are *atoles* made with fresh maize. *Iz ul* is prepared by simply grinding fresh, raw corn and then boiling it with salt and sugar but a number of steps are involved in the preparation of *ahza*. For *ahza*, the maize is crushed and mixed into hot, salted-water. Cold water is added, brought to a boil and the dish is removed from the heat. The next morning, the water is squeezed out, the maize ground, rinsed with cold water, and strained through a cloth. The ground corn is then boiled with sugar and the water that was squeezed from the corn until it thickens.

Pozole is a fermented, non-alcoholic, maize-based gruel frequently consumed away from the home, either in the *milpa* or while traveling (Redfield and Villa Rojas [1934]1962:39; Tozzer 1907:52; Ulloa and Herrera 1986:151-158). Preparation of the

dough used in making *pozole* differs from making *masa* in that the maize is only partly cooked in lime water before being rinsed and boiled again, until fully cooked, in clear water. The resulting *nixtamal* is coarsely ground, formed into balls of dough, and then wrapped in leaves to keep the dough from drying while fermentation takes place. Fermentation is activated by bacteria, yeasts, and molds occurring on the cook's hands and in the food preparation area (Ulloa and Herrera 1986:155). The *pozole* is left from one day to two weeks before the dough is added to water by itself or with salt, sugar, honey, or toasted and ground chiles. In addition to providing a food which remains edible in tropical conditions for a relatively long period, fermentation also improves the nutritional quality of this maize-dish, increasing quantities of lysine and tryptophan as well as the overall protein nitrogen (Ulloa and Herrera 1986:153).

Two maize beverages are made without lime-treating the maize. *Zaca* is made by adding boiled, and ground maize to water (Benedict and Steggerda 1936:161; Redfield and Villa Rojas [1934] 1962:39). This dish is made on ceremonial occasions and offered to deities rather than for meals within the household. *Pinole* (*kah*) is a beverage which, like the *atoles*, is often consumed as the morning or evening meal. Dried maize kernels are toasted with spices (cinnamon, aniseed, pepper), ground, and then boiled as coffee would be or beaten like chocolate drinks (Redfield and Villa Rojas [1934]1962:40).

Many of these same dishes certainly existed in earlier periods of Maya history. Maize-based beverages, described by Fray Diego de Landa in the following passage, were part of 16th century Maya diets and very likely are equivalent to *pozole*[a], *ahza*[b], and *pinole*[c]:

> Their principal subsistence is maize of which they make various foods and drinks, and even drinking it as they do, it serves them both as food and drink... [And] they grind it upon stones, and they give to the workmen and travelers and sailors large balls and loads of the half-ground maize, and this lasts for several months merely becoming sour[a]. And of that they take a lump which they mix in a vase...[and]

> they drink this nutriment and eat the rest, and it is a savory food of great sustaining power. From the maize which is the finest ground they extract a milk and they thicken it on the fire, and make a sort of porridge for the morning[b]... They also parch the maize and grind it, and mix it with water, thus making a very refreshing drink, throwing in it a little Indian pepper or cacao[c] (Tozzer 1941:89-90).

Roys ([1943]1972:43) also notes several maize beverages described in other ethnohistoric sources. That the Classic Maya also used similar maize beverages is indicated by epigraphic evidence from globular, ceramic vessels (Houston *et al.* 1989:722-723). The glyph reading *ul* or *sakha* and meaning *atole* or gruel, has occasionally been found on globular vessels, which are used today by some Maya to keep liquids cool (Reina and Hill 1978 cited in Houston *et al.* 1989:722).

non-maize gruels or beverages

Several other beverage-meals are sometimes prepared instead of maize-based gruels. A beverage prepared with the kernels of *coyol* palm nuts has been described by de Landa (Tozzer 1941:200) as a morning meal that apparently replaced *atole* when food shortages occurred, at least in the Conquest period. That the durable endocarps of the nuts are common in archaeobotanical samples (Lentz *et al.* 1996:257) suggests that this food may have been used more regularly in prehistory. It is possible that *coyol* palm was also a source of oil (Lentz 1991:277; Tozzer 1941:200). However, the importance of *coyol* may have varied regionally. At Copán, for example, *coyol* endocarps are the most common botanical artifact reflecting *coyol* cultivation from the late-Early Classic through the Late Classic (Lentz 1991:273). Yet at Cerén just one kernel occurs. It was made into a spindle whorl indicating that *coyol* may not have been a food source here (Lentz *et al.* 1996:257).

The *coyol* drink and beverages made from *cacao* (*Theobroma cacao*) are expected to produce larger amounts of absorbed lipid residues than maize-based beverages as both these foods contain large amounts of oils. One *cacao* drink is prepared by boiling toasted, ground *cacao* beans and then combining these with maize (Thompson 1968:186; Tozzer 1941:90). The mixture is next frothed in a wooden vessel with a wooden beater (Redfield 1948:89) or by pouring it between two ceramic vessels. de Landa's ethnohistoric account also describes a second *cacao* drink prepared from *cacao* butter and maize (Tozzer 1941:90). *Cacao* drinks probably were not consumed frequently in most Maya households in the past. Today, and during the Conquest period, *cacao* has been a luxury reserved for feasts, festivals, and ceremonies (Redfield 1948:89; Redfield and Villas Rojas [1934] 1962:38; Roys [1943] 1972:40; Thompson 1968:186; Tozzer 1941:90).

Ramón (*Brosimum alicastrum*) nuts, too, are boiled and can be ground and used in the preparation of gruel or *tortillas* (Atran 1993:663; Lundell 1939:41; Roys [1943]1972:40). The nuts are also sometimes roasted and eaten. Puleston (1971, 1982) believed that the *ramón* nut might have been an extremely important part of Classic Maya subsistence. However, ethnohistoric and ethnographic observations record that *ramón* nuts are consumed in place of maize largely during times of famine (Atran 1993:684; Marcus 1982:251; Roys [1943]1972: 40). Further, no *ramón* nuts have been collected in archaeobotanical samples from any archaeological sites (Lentz 1991:277; Miksicek *et al.* 1981:917) suggesting that *ramón* was a famine food in Pre-Hispanic times, as well. As *ramón* nuts are not oily but starchy and proteinaceous, boiling them will likely provide less residual material than *cacao* or *coyol*.

other beverages

There are other beverages, too, which might have absorbed into the walls of ceramic vessels in which they were prepared or served. *Balche* is a ceremonial beverage used during the Colonial period and recently (Redfield and Villa Rojas [1934]1962:38; Roys [1943]1972:42). It is prepared by soaking the bark of the tree *Lonchocharpus longistylus* in fermenting honey-water (Lundell 1939:47; Roys [1943]1972:42). *Balche* would leave residues of terpenoids but lipids may be less likely to remain in detectable amounts. This would also be true for another fermented drink, sometimes referred to as *coyol* wine, prepared from the sap of *coyol* palm (*Acrocomia aculeata* formerly *A. mexicana*) (Lundell 1939:47).

squashes, beans, and other vegetables

A diverse set of food plants, including vegetables, fruits and nuts, are produced and used by the Maya when economic and other circumstances allow. Contemporary groups of Maya eat several types of beans (*Phaseolus vulgaris*) including black, white, and red varieties and lima beans (Benedict and Steggerda 1936:161; Lundell 1939:40). Generally, they are boiled in salt water. *Epazote* (*Chenopodium ambrosiodes*) seeds are sometimes added as flavouring, and lima beans may be mixed with ground squash seeds in a dish called *toczel* (Redfield and Villa Rojas [1934]1962:38,40). The leaf of *epazote* is used to flavour beans in Mexico (Laura Finsten, personal communication). Benedict and Steggerda (1936:161) describe several other ways in which beans are prepared. Boiled beans and *masa* are sometimes mixed together and baked in a pit oven. This dish may be very old as it is also described ethnohistorically (Roys [1943]1972:43). Beans are sometimes boiled with pork, and boiled white beans may be mixed with toasted squash, achiote, and *chile* seeds in a dish called *kol*.

Beans, of course, have been recognized as an important source of proteins in diets presently eaten by the Maya. However, they may have been less crucial as a source of proteins in some Pre-Hispanic diets. As noted above, the stable nitrogen isotopic composition of human bone collagen indicates that but for residents of the Copán Valley, the ancient Maya derived the greater proportion of their dietary proteins from meat and not beans. Carbonized beans have been excavated from a small number of Maya sites. All occurrences are notable, though, given that there are few circumstances in which boiled beans might become charred. The best archaeological evidence for the use of beans comes from two vessels left in a house at Cerén, El Salvador (Sheets 1992:107). A few beans (*Phaseolus* sp.) have also been found at Lamanai, Belize (Pendergast, personal communication to C.D. White) and a seed of a small, wild variety occurred in a cooking area at Copán (Lentz 1991:273, 275).

The present variety of dishes based on maize and beans implies the existence of traditional diets and cuisine that were more complex and varied than just corn and beans until very recently. Of course, squash, too, is noted for its place in the maize-beans-squash triad of food staples in many Central American diets (Berlin *et al.* 1974:477; Mangelsdorf 1974:1-2). There are several species and numerous varieties of squash that are currently used by the Maya. Pumpkin (*Curcurbita moschata*) is the most important of the squashes used by Tzeltal Maya, of Chiapas, Mexico. Berlin and colleagues (1974:421, 422, 477) also record the use of *C. ficifolia* and *C. pepo*, the fruits of which are eaten boiled. Several varieties of *chayote* or *guisquil* (*Sechium edule*) are also favoured. All parts of the *guisquil* plants, including the fruits, rinds, seeds, young leaves, blossoms, and roots are eaten (Lundell 1939:41; Standley 1946:397). The flesh is boiled with salt or roasted in pit ovens (Benedict and Steggerda 1936:161; Redfield and Villa Rojas [1934]1972:41). The very flavourful seeds are eaten a number of ways. Roasted seeds are eaten alone, mixed with honey, or added to the dish *kol* described

above. They are also ground and added to *atoles* and used as fillings for *tamales*. Ethnohistoric sources indicate that squash dishes were just as diverse at the time of the conquest. Landa observed that "...there [were] many different kinds of squashes and gourds, the seeds of some are good for making stews, others for eating roasted or boiled..." (Landa in Tozzer 1941:195-196).

Again, given the variety of dishes and the various forms in which squashes are consumed, it is easy to imagine that squashes were a regular dietary item for the ancient Maya, as well. Nonetheless, the importance of squashes may yet be under-valued, particularly for earlier periods in Maya history; perhaps owing to its infrequent preservation in the archaeobotanical record and its lack of distinctive stable carbon and nitrogen isotopic values. Further, because squash seeds are often ground to be included in other dishes, squash may be less visible than beans, for example, in contemporary diets as well as the archaeological record. Squash seeds have a strong flavour and also contain substantial amounts of oil and proteins and so complement maize-dominated diets. Immature seeds of *chayote* are considered a delicacy (Standley 1946:397). Evidence which suggests that squash and/or squash seeds were not only important but were esteemed by the ancient Maya is the excavation of several seeds of *Curcurbita moschata*, which were found preserved in cinnabar beneath a stela at Copán, Honduras (Lentz 1991:273-274), and which must have been part of the ritual dedication of this stela. That evidence of squash has been found at four of the six sites for which there are palaeobotanical reports also suggests that squash was important. Remains of *Curcurbita* have been found at Cuello, San Antonio and Cerros, Belize, and at Copán, Honduras (Crane and Carr 1994:70, 71; Lentz 1991:273; Miksicek 1990:304; 1991:72). One carbonized seed of *chayote* (*cf. Sechium edule*) has been tentatively identified as such at Copán (Lentz 1991:274).

Squashes contain small amounts of lipids. However, boiling squash fruits or the new leaves may result in the transfer of lipids from protective waxes on the rinds and leaves to ceramic vessels. Toasting the seeds is not likely to produce a residue as the seeds are toasted in their hard seed coats. If ground seeds were added to stews or *atoles*, though, they may well contribute significant quantities of lipids to residues absorbed into vessel walls because they are so oily. Therefore, if food residues were preserved, one would expect to add to the archaeological evidence for the use of squashes by the analysis of absorbed residues from ceramic cooking vessels.

Chiles (*Capsicum annum*) are common as a seasoning in Maya cooking and as a condiment (Benedict and Steggerda 1936:164; Lundell 1939:47; Redfield and Villa Rojas[1934]1972:37). There is little discussion regarding the preparation of chiles other than that they are ground and added to dishes such as *atole* or *tortillas*. A chile sauce for dipping is made by grinding dried chiles with salt and water (Benedict and Steggerda 1936:164). Most chiles and/or chile seeds are dried rather than used fresh, making them suitable for storage and grinding (Thompson [1930] 1968:188). Macro remains of chiles have been found only at Cerén. Here, chile seeds, peduncles, and epidermal fragments were abundant in the botanical collections (Lentz *et al.* 1996:254-255) suggesting that the absence of chiles at other sites is the result of poor conditions for preservation. Residue analysis may expand the archaeological evidence for the manner in which chiles were used in the Pre-Hispanic period. Capsaicin is a chemical compound unique to chiles which makes them "hot" and which is identifiable using chromatographic techniques. This compound may be found in extractable lipid residues should it have been absorbed into ceramic vessels in which chiles were added as a seasoning or in which chile sauces were prepared or served.

Cultivated roots and tubers may also have shown up regularly in ancient Maya menus. Bronson (1966) first suggested that manioc (*Manihot esculenta* [yucca,

cassava]), malanga (*Xanthosoma* spp.), *jícama* (*Pachyrrhizus erosus* and *Calopogonium coeruleum* [yam bean]), and *camote* (*Ipomoea batatas* [sweet potatoes]), which are planted and eaten by Maya today, may have been important in Pre-Hispanic times. Ethnohistoric documents record the use of *camote*, yucca, and *jícama* at the time of the Conquest (Marcus 1982:244-245). However, using linguistic evidence of Maya plant names, Marcus (1982:252) argued that domesticated roots were introduced to the Maya during the Postclassic or Conquest period but that wild types of manioc and malanga may have been used as famine foods prior to this. Root crops never were as important as Bronson believed they might have been (see Cowgill 1971). Nonetheless, there is evidence that roots and tubers were cultivated in the Maya region prior to the Postclassic period. The best evidence are manioc (*Manihot esculenta*) root casts taken from fields at early Middle Classic Cerén (Lentz *et al.* 1996:258) but carbonized fragments of manioc (*Manihot esculenta*) and tentative identifications of malanga (*cf. Xanthosoma* sp.) from Cuello may indicate that roots and tubers were cultivated by the Maya as early as the Middle Preclassic (Hather and Hammond 1994).

Unfortunately, the relative importance of roots and tubers in ancient Maya food systems cannot be determined from plant remains because they are rarely preserved as macro-remains. As the plants lack hard parts, they decay rapidly. Moreover, roots and tubers are prepared by boiling, roasting, grinding with maize to make *masa*, or are eaten raw (*jícama*) (Benedict and Steggerda 1936:161; Lundell 1939:41-42). Therefore, preparation and cooking methods minimize the chances that charred remains would have been produced and preserved at Pre-Hispanic sites. Further, when roots are carbonized they are very difficult to identify (Hather and Hammond 1994). Unless protective waxes of the roots and tubers are present, which is unlikely as the vegetables were likely peeled before being boiled or ground for *masa*, it is not expected that the analysis of

absorbed lipid residues will provide further evidence of past use, as these foods contain few lipids.

The inflorescence of *pacaya* (*Chamaedorea* spp.) (Lundell 1939:42; Standley 1946:398) is eaten as a vegetable today, either raw or boiled and seasoned with oil and vinegar. It may have been consumed in similar fashions in the past. The absence of archaeobotanical evidence for this food is not surprising as there are no hard parts to this food plant.

fruits

The writings of Spanish conquerors and colonizers record the fantastic assortment of fruits which the forests, orchards, and gardens of the Maya produced in the 16th century (Lundell 1939:38, 42-45; Roys [1943] 1972:40). These include the avocado (*Persea americana*), custard apple (*Annona reticulata*), mamey (*Calocarpum mammosum*), zapote (*Achras zapota*), guava (*Psidium guajava*), guayo (*Talisia olivaeformis*), siricote (*Cordia dodecandra*), papaya (*Carica papaya*), hogplum or ciruela (*Spondias purpurea*), the nance (*Byrsonima crassifolia*), and *jauacte* (*Bactris* spp.). More detailed identifications and descriptions of other fruits known to have been used by the Maya in recent times and in the Colonial period may be found in Atran (1993) and Marcus (1982).

Of course, most tree fruits would have been eaten without preparation and will not contribute to organic residues which might be extracted from ceramic storage or cooking vessels. One exception might be avocados if they had been mashed and/or served in a vessel. There is no archaeological evidence for this, of course, nor do ethnographic or ethnohistoric documents discuss how avocados were prepared. Two non-tree fruits that may have been prepared in ceramic vessels are the tomato (*Lycopersicum esculentum*) and tomatillos (*Physalis ixocarpa*), or green tomatoes. They are eaten raw,

cooked with meats - presumably in stews - and made into chile sauce (Alcorn 1984:692; Lundell 1939:40). Therefore, tomatoes and tomatillos may have been used in the preparation of sauces or stews in Pre-Hispanic times, as well. They might have been added to the broth that is poured over tamales, for example. Thus, it is possible that traces of these foods, particularly protective waxes, might occur in organic cooking residues.

verduras or "greens"

A category of food plants which is often overlooked or is not distinguishable in palaeodietary studies based on the study of botanical remains or stable isotopic composition of human bone is the leafy greens or *verduras*. A number of leafy greens commonly used today are *chipilín, macal, hierba mora* or *mucuy* (*Solanum nigrum*), and *chaya* (*Jatropha aconitifolia* or *Cnidoscolus aconitifolius*). In the village of Chan Kom, Redfield and Villa Rojas ([1934] 1972:380) observed that leafy greens were not served as a vegetable but were only added to other dishes as flavourings or were used as condiments. Thus, they did not consider greens as important. However, the writings of other ethnographers suggest that greens are consumed more regularly in other Maya communities (Lundell 1939; Standley 1946; Thompson [1930]1968). Thompson ([1930]1968:186) noted that *chaya*, in particular, was widely cultivated in the Yucatán earlier in this century. He and others (Benedict and Steggerda 1936:164; Lundell 1939:41; Standley 1946:398) observed that *chaya* is boiled and used like spinach. *Hierba mora*, too, is served as a green and is also used as a filling in *empañadas*, which are small turnovers (Standley 1946:399). The shoots, leaves and flowers of *chipilín*, which is collected rather than cultivated, are also boiled and served as a green (Standley 1946:399), as are the buds of the *corozo* palm (*Orbignya cohune*) (Lundell 1939:42). The leaves and flowers (*flor de epazote*) of *epazote* (*Chenopodium ambrosiodes*) and

loroco (*Fernaldia* sp.) add their strong flavour to other dishes and the latter is also used as a green (Benedict and Steggerda 1936:167; Standley 1946:399).

The protective leaf waxes of these greens and quite possibly many others collected from gardens, fields, *huaymil*, and forests, would have been absorbed into the ceramic walls of cooking vessels during repeated cooking events (Evershed *et al.* 1997:91; see sections 4.2 and 4.4.1). Traces of the leaf waxes and other lipids may well remain preserved in archaeological vessels, therefore, and may permit identification of their use in prehistory where no other archaeological evidence exists (Evershed *et al.* 1992:204).

other seasonings: other flowers, seeds and flowers

There are a number of other plants that the ancient Maya may have used as seasonings. As with leafy greens, these, too, might leave residues of protective waxes and other lipids. Chief among these may be the seeds of *achiote* (*Bixa orellana*), which is used in Maya cuisine to give a red colour and to add flavour to stews (Benedict and Steggerda 1936:167; Tozzer 1941:200; Thompson [1930] 1968:184), and which has a high lipid content (Miksicek *et al.* 1981:917). The leaves of allspice (*Pimenta dioica*) are used as seasonings in *atoles* and beans and also make a spicy tea (Alcorn 1984:747, 906). Other seasonings already noted in previous paragraphs are *chiles*, the leaves and flowers of *epazote*, *chipilín*, and loroco.

oily food plants

A number of oily food plants which are more likely to have contributed to absorbed lipid residues than other foods have been noted already. It is generally thought, however, that the ancient Maya did not cook with vegetable oils despite a number of sources available to them (Coe 1994:36). Palm nuts, squash seeds, and perhaps even

avocados - may have been valued for their high fat content - but there is no evidence, other than for *cacao*, that oils, specifically, were purposefully extracted for use in cooking. Recently, however, Lentz (1991:277; Lentz *et al.* 1996:255) has suggested that both *coyol* palm nuts and cotton (*Gossypium hirsutum*) seeds may have been used as sources of vegetable oil at some ancient Maya settlements. In one Cerén household, a handful of cotton seeds were found on the surface of a metate, suggesting to Lentz and his colleagues (1996:255) that the seeds were being ground in order to extract the edible oil. In support of their hypothesis, they cite Alcorn (1984:658) who observed that the Huastec Maya use oil extracted from cotton seeds in just this manner to fry beans.

meats and fishes

The relatively greater lipid content of meats and fishes, compared to food plants, means that these will produce larger amounts of absorbed residues when they are cooked in ceramic vessels. Once again, ethnographic, ethnohistoric, and archaeo-faunal reports record that a wide variety of meats and fishes were accessible and utilized by the Maya in each period of their long history. Only two domesticates, the dog (*Canis familiaris*) and the turkey (*Meleagris gallopavo*), were raised by the ancient Maya to be used for their meat (Clutton-Brock and Hammond 1994; Hamblin 1984:100, 112; Landa in Tozzer 1941:203). The importance of these domesticates is not clear from faunal remains but probably varied geographically and temporally according to the availability of other resources. Game, hunted in the forests and fields, has also been an important part of Maya foodways up to very recent times. Deer (*Odocoileus virginiana* and *Mazama americana*) and peccary (*Tayassu tajacu* and *T. pecari*) are prominent in agricultural ceremonies, are favoured for their meats (Hamblin 1984:122; Pohl 1981; Pohl and Feldman 1982), and occur frequently in archaeo-faunal assemblages at inland Lowland sites (Emery 1999:66-73; Carr 1985:126; Hamblin 1984:122; Olsen 1972:244; Pohl 1981,

1985b:137; Shaw 1999:90; Wing 1975:379; Wing and Scudder 1991:97; Wing and Steadman 1980:331). These animals may sometimes have been protected or raised from a young age by individuals at some ancient Maya settlements (de Landa in Tozzer 1941:127, 204-205; Pohl 1976 cited in Hamblin 1984:132). Other game often represented in archaeo-faunal assemblages include agouti (*Dasyprocta punctata*), paca (*Agouti paca*), tapir (*Tapirus bairdii*), armadillo (*Dasypus novemcinctus*), opossum (Didelphidae), rabbit (*Sylvilagus* sp.), and spider (*Ateles geoffroyi*) and howler (*Alouatta villosa*.) monkeys. Forest birds, including the curassow (*Crax rubra*) and the ocellated turkey (*Meleagris ocelata*) were also hunted. Ducks and doves were kept by the Maya in the early Historic period (Landa in Tozzer 1941:201; Hellmuth 1977:427; Roys 1943:40) and in Pre-Hispanic times (Sheets 1992:37).

Maya women today most commonly prepare meat by boiling it, according to Redfield and Villa Rojas ([1934]1972:40-41). The descriptions of boiled meat dishes, however, may be better thought of as stews because meats are boiled in sauces, such as chile sauces, and cooked along with other vegetables, greens, and seasonings, including *epazote*, onion, garlic, and saffron (Redfield and Villa Rojas [1934]1972:40-41). Boiling would allow for residues of meats to be absorbed into the walls of the cooking vessels but the residues would be complicated by the mixture of foods in stews. The Maya also prepare meats by roasting them over a fire or, more commonly, in an earth oven (*p'ib*) that would not leave any archaeological evidence in the form of residues. The patterning of burned and heat-altered *versus* unaltered animal bone excavated at the coastal island site of Cozumel (Hamblin 1984:42, 116, 136) indicates that the Maya at this Pre-Hispanic settlement often boiled or stewed their meat, including dog, peccary, and fish. However, some dog, peccary and other animal remains also show evidence of having been roasted over fires.

Freshwater fish, turtles (Dermatemydidae, Kinosternidae, Emydidae), and mollusks (*jute* [*Pachychilus* spp.]) taken from streams, lakes, and *cenotes* were also used where they were accessible at inland sites, especially, it seems, in the wetlands of northern Belize (Emery 1999:66-67, 69-70; Healy *et al.* 1990; Moholy-Nagy 1978:71; Roys 1943:42; Shaw 1999:88, 89-93; Wing and Scudder 1991:85). How these foods might have been prepared and eaten in the past may be inferred from ethnographic observations. Turtle remains are common at many sites throughout the Lowlands (Emery 1999:69-70; Hamblin 1984:65-66; Wing and Scudder 1991:85), indicating that they were relatively important and favoured in some ancient Maya foodways. Both recent observations and archaeological evidence of heat-altered bone suggest that the Maya have generally prepared turtles by roasting them (Hamblin 1984:65-66). *Jute* snails are eaten with mashed root crops by the highland Maya at Panajachel, Guatemala (Soustelles 1937 cited in Coe 1994:156) but it is not clear whether the two are cooked together. Fish are dried with or without salt, or they are roasted for storage or transport (Coe 1994:158; de Landa in Tozzer 1941:42). They are also wrapped in palm leaves and roasted in coals or an earth oven (Coe 1994:158). Neither of these methods of preparation would leave a residue. However, Hammond (pers. comm.) has observed that today, in Belize, the Maya also boil fish with root crops and Coe's (1994:159) sources indicate that, like other meats, fish is sometimes added to *atoles*.

Of course, marine fishes and mammals were the primary meat resources at coastal Maya sites (Carr 1985; Hamblin 1984, 1985; McKillop 1984; Wing 1977). There is ethnohistoric evidence that marine resources were traded inland from coastal sites during the Colonial period (de Landa in Tozzer 1941:42). Remains of marine fishes have also been found at archaeological sites located as far as 35 km away from the coast, in Belize (Shaw 1999:91; Wing and Scudder 1991:87), indicating that marine fish were moved inland, at least this distance, during Pre-Hispanic times, as well.

3.5.3 Maya foodways: An instrument of status in Classic Maya society?

The degree to which ancient Maya elites might have used food to mark, justify and/or negotiate their high rank and privileges is a question that has received some attention in recent years. Yet it is a problem which remains unresolved. Based on the isotopic composition of tissues from individuals who lived in three areas of the Lowlands (Belize River Valley, southwestern Petén, Copán), Gerry (1993a:175, 1993b) argues that social boundaries were not marked by significantly different diets during the Classic period. More specifically, he argues that elite and commoner diets were nutritionally equivalent because, although elites may have had more access to deer and larger mammals consumed during rituals (following Pohl 1985b), commoners were able to obtain similar proportions of meat in their diets by hunting smaller mammals, birds, and reptiles. These may often have been hunted by individuals in their *milpa* and fallow fields (Emery 1991; Pohl 1977, cited in Emery 1991; Wiseman 1983:153) using blow guns and perhaps also nets, snares and spears (Pohl 1985b:139). Where Gerry sees equality, Pohl (1994) sees inequality and complexity. She suggests that Maya elites had the authority to restrict access to particular animals (deer, peccary, dog, turkey) that were important elements of agricultural rituals and political feasting. Part of her argument is that through tribute demands, and perhaps also through hunting prohibitions, Maya elites controlled or influenced the production and distribution of preferred foods. Both interpretations have their merits and their weaknesses. A larger body of archaeological data reflects that the truth probably lies somewhere between these two extreme views. A better understanding of this problem would provide further insights into the nature of elite authority and the complexity of ancient Maya society.

Expectations that the Classic Maya valued meat, or particular meats, and that Classic Maya elites, therefore, had preferential access to meat have their origins in

ethnohistoric and ethnographic writings. However, as I have already suggested, ethnohistoric and ethnographic descriptions of meat consumption are ambiguous and inappropriate sources from which to draw analogies in order to understand social uses of food in Classic Maya society. Wright (1997), too, has suggested that the idea that Maya elites must have eaten more meat than commoners, and that meat was of greater social value than maize, may have roots in our own cultural attitudes toward meat as a nutritionally important food item, and our association of maize with poverty in Maya communities today. In fact, as I have outlined, results from analyses of the stable nitrogen isotopic composition of human bone collagen indicate that Maya elites generally did not consume more meat than commoners. To date, the only isotopic confirmation that some Maya elites consumed more meat than their contemporaries comes from two Petén settlements - Altar de Sacrificios and Dos Pilas - and only for the Late Classic period communities at these sites (Wright 1994:271, 280).

There is limited archaeological evidence to support the hypotheses that elites and commoners ate different meats, or that elites had greater access to particular meats (deer, dog, peccary, turkey), and/or different cuts of meat which were important to religious and political ideology and ceremony (Pohl 1985b, 1994). Unfortunately, the validity of each of these hypotheses is difficult to establish with the relatively small number of faunal studies completed to date and given the poor preservation of bone at many sites in the Maya area. Carbon isotopic studies of bone collagen and apatite, however, give some support to these hypotheses. For example, the bones of elites who lived at Lamanai during the Early Classic reveal that the highest ranking male (N9-56/1) ate more C3-fed game, perhaps deer or peccary, and/or freshwater fish than lower-ranking elites (Coyston *et al.* 1999:236-237). At Late Classic Pacbitun, higher-ranking individuals (males, adults, elites) apparently consumed larger amounts of meat from maize-fed domesticates (perhaps dog and turkey) than their lower-ranked counter-parts

(females, juveniles, non-elites) (Coyston *et al.* 1999:238-239). However, these patterns are not universal across the Maya Lowlands or through the Classic period.

Moreover, greater access to certain meats does not necessarily indicate dietary and hunting prohibitions for non-elites in the Pre-Hispanic period but may reflect tribute payments of these meats made to elites. Given the dispersed nature of ancient Maya settlements, it is difficult to imagine how Maya rulers might have prohibited hunting or poaching of deer and peccary, by individuals and households, who hunted game in their maize and *huaymil* fields. Further, remains of these animals are not restricted to elite residential zones at archaeological sites.

All this is not to say that differentiation of social status by diet did not occur in Classic Maya society, as there certainly is evidence that it did. However, there may not have been standard elite and non-elite diets among Classic Maya polities. Foods that were assigned value as symbols of high social status apparently were not the same at each site. Rather, they seem to have varied locally, being determined at each settlement by local availability or accessibility, ritual importance, and/or preference (Coyston *et al.* 1999:240; Wright 1994:288, 1997). As in many complex societies (section 3.3.2), the foods that were assigned social value by the ancient Maya seem often to have been food plants. At Postclassic Topoxté, elite individuals who were buried in the site core ate less maize than their lower ranking contemporaries (Wright 1997). Wright (1997) speculates that elites may have consumed more *cacao* and/or other wild and cultivated non-maize (C3) plants. Elemental composition of human burials from Terminal Classic Dos Pilas also suggests that elites consumed a broader range of plants (Wright 1994:280). Lentz (1991:281), too, found that during the Late Classic period at Copán elites ate a greater variety of food plants than did the average person in the same settlement. Yet, there is evidence that non-elite Maya everywhere did not necessarily eat diets which were poorer, or less varied, than diets accessible to elites in large, urban centres.

During the Middle Classic at Cerén, which was a small, rural, and non-elite settlement, the villagers ate as varied a diet as did the elite ranks of Late Classic Copán, for example (Lentz *et al.* 1996:259). There is no reason to believe that this was not the situation at many other farming villages in the Pre-Hispanic period, as well.

Even the most esteemed beverage - *cacao* - which is frequently assumed to have been an elite food item, seems not to have been restricted to elite consumption. Seeds and peduncles of this plant were also found at Cerén in a bodega associated with an unexcavated house structure (Lentz *et al.* 1996:255-256). Nonetheless, it is plausible that elites, and particularly those who lived in non-*cacao* growing regions, may well have obtained and consumed greater amounts of this valued food item. It may be, however, that status differences were more often communicated through the quality and decoration of the cylinder vases in which this particular drink was served.

Whether or not elite food items were consumed in the context of political feasting or displays of conspicuous consumption is not clear from archaeological evidence. This question of how the ancient Maya elites may have used food to create or maintain their status has not been earnestly investigated. The exception is a study of changing ceramic vessel form and function at Preclassic Cerros completed by Robertson (1983). She suggests that elaboration of vessel forms, including the appearance of very large (supra-family) serving vessels during the Late Preclassic period at the site may be related to the emergence of elites and the consumption of food in ritual contexts (Robertson 1983:128-130, 140-141). Here, too, however, the vessels themselves may have been the material expression of status differences. Although it suggests that food was perhaps used for the same purpose, the elaboration of vessel forms is not necessarily a reflection of this. Crane and Carr (1994:75) do document an increasing diversity of foods used at the site during the same time frame and find that the elite diet was somewhat more diverse than that of non-elites during the Late Preclassic at this

settlement. There is no discussion of whether such patterning in the foodways at Cerros might represent conspicuous consumption by elites or political feasting as a strategy used by emergent elites.

3.6 Summary

The first part of this chapter relates how and why archaeological evidence of food and ancient foodways is an invaluable source of information about many aspects of past lifeways. Food is sustenance; it is also an aspect of subsistence, and so it has a central role in the inter-connected economies of societies, communities, and households. A view into one aspect of an ancient foodway - domestic food storage and preparation - will make it possible, then, to learn about not only household economies but also the larger economic structures of the communities and societies in which the households existed. Food also has a part in many social and political interactions and people consciously negotiate and manipulate these relationships through their food choices. Elites, in particular but not exclusively, also accomplish this through their control of food production and distribution. The patterning in food remains over time or at different locations (e.g. residential units, settlements, regions) will reveal patterns of food distribution, and similarities or differences in food consumption, which can help us to reconstruct the organization of social and socio-political groups. Considering what can be learned by studying food, then, and given the poor preservation of faunal and botanical remains at most Maya sites in the tropical lowlands of Central America, a successful application of chemical analyses of food residues could further our understanding not just of ancient Maya foodways but also of changing economic and socio-political structures between Preclassic and Classic Maya society.

There are several additional and more specific contributions that the research reported on in this dissertation may make to the study of Maya foodways. First, it might

be expected that residue analysis will provide another line of evidence to complement existing data, which show that few major distinctions were made between elites and non-elites in ancient Maya foodways. It will not be possible to establish whether or not elites and commoners ate different types of meat (see Section 4.3.1) or different cuts of meat using residue analyses. However, identification of the vessels contents should make it possible to compare the proportion of vessels from elite and commoner residential contexts that were used to prepare food dishes that contained meat. This would allow us to further evaluate the possibility that ancient Maya people from different status groups ate diets with similar proportions of meat, as stable nitrogen isotope measurements of human bone collagen indicate to us already.

Should identifications of specific plants, or plant food categories, prove to be possible, residue analysis might also provide direct archaeological evidence for the variety of foods which undoubtedly were included in Preclassic and Classic Maya diets. The poor conditions for organic preservation at lowland Maya sites means that we can expect that most foods used by the ancient Maya have left no archaeological trace. However, ethnohistoric and ethnographic descriptions of foods used by the Maya in more recent times have led me to argue that ancient Maya diets were at least as diverse, and likely more varied, than those accessible to many people in Central America today. Chemical analysis of cooking residues potentially offers a method by which we can evaluate this argument.

Beyond documenting the variety of foods that might have been used by the Maya in the past, the possibility of being able to trace the use of certain foods that are believed to have been significant in ancient Maya foodways in terms of their economic, nutritional, cultural or social roles, and which are otherwise essentially invisible archaeologically is an important one. Some examples of such foods are beans, squash, palm nuts, and cacao. The relative importance of squash and squash seeds, in particular, is poorly

documented in the archaeological record but these foods may well have been economically, nutritionally, and culturally important to the ancient Maya (section 3.5.2). Moreover, if we can identify certain foods in cooking residues, it will be possible to determine the significance of the foods in the context (residential, economic, social) in which they were prepared and used by examining the contexts from which the vessels were excavated.

Chapter 4

Chemical Analysis of Archaeological Food Residues Using Gas Chromatographic and Isotopic Techniques

4.1 Introduction: Archaeologists, archaeometry, and the development of organic residue analysis

> [O]rganic residue analysis is still a relatively romantic area to study. It is possibly the last of the archaeological sciences where the noble chemist can go forth and slay molecular dragons and so rescue the "beautiful" archaeologist in distress.
>
> (Evans 1990:7)

It is true that there is an element of romance surrounding the investigation of organic residues found at archaeological sites. Organic residues have been found adhering to stone tools and wooden artifacts, in ceramic vessels, with mummified remains, and in contexts such as middens and shipwrecks (Evans and Heron 1997; Heron and Evershed 1993; Loy 1990; Morgan *et al.* 1984). Archaeologists have always carefully scraped and wrapped and collected into vials, little foil packets, film canisters, and plastic bags the unrecognizable bits of residue and resin that they have encountered during their excavations. These ancient organic remnants, already remarkable because they have survived centuries or millennia, are collected because they might provide a rare opportunity to extract some valuable, but unknown, evidence of human activities in the past. It is that *potential* which is intriguing.

Since the end of the 19th century, chemical techniques have been used sporadically to identify the origins of organic residues (Heron and Evershed 1993:249;

Oudemans and Boon 1991:197; examples are Biek 1963:129-130; Lucas 1948:36-37, 380; von Stokar 1938:85). Nonetheless, most residues are not analysed. Identifications provided by the earliest analyses were general and tenuous, which did not encourage further applications. Only recently, with the development of more efficient chemical extraction techniques and analytical instrumentation capable of resolving individual components from trace amounts of complex mixtures such as organic residues, has there been an increase in the number of residue studies (Bethell *et al.* 1994:229-230; Evershed 1993:75; Heron and Evershed 1993:249-250). In the last 20 years, several researchers have used this technology to investigate food residues found in ceramic vessels (Evershed *et al.* 1990, 1994; Hill *et al.* 1985; Hurst *et al.* 1989; Rottländer 1990; Rottländer and Hartke 1982). Their results have been encouraging enough to attract the attention of others wishing to develop and apply methods of food residue analysis, in particular (e.g. Charters *et al.* 1995, 1997; Dudd and Evershed 1998; Malainey 1997; Raven *et al.* 1997; Sherriff *et al.* 1995).

Despite these successes, organic residue analyses have not yet become standard techniques in the archaeologist's analytical toolbox, and the number of applications remains small. Further, residue analysis has not been as readily accepted as other archaeometric techniques have been following their introduction. Isotopic analysis of human bone for palaeodietary studies, for example, has been more widely applied since its introduction to archaeologists by Vogel and Van der Merwe (1977) twenty-five years ago. The principal reason for this situation is, I suggest, that although current analytical methods have been shown to be sound, the utility of residue analysis for investigating foodways of ancient societies has not yet been adequately demonstrated. I support this statement through a critical review of published reports on food residue analyses, in

which I examine the stated goals and objectives of previous projects, and the identifications and conclusions offered as the final results.

This chapter also includes a description of the two analytical methods, gas chromatography (GC) and isotopic analysis, used to analyse absorbed lipid residues and charred surface residues, respectively, in this study of ancient Maya foodways. The theoretical bases of each of these techniques, the specificity of identifications that they permit, and their limitations are discussed. I begin, though, by describing what food residues are and how they are believed to form in ceramic vessels.

4.2 The character and formation of absorbed and charred residues

Two types of food residues found with ceramic vessels are absorbed residues and surface residues (Heron and Evershed 1993:250). The surface residues, or encrustations, may be either charred or uncharred and are readily visible on the interior and/or exterior surfaces of a vessel. For surface residues, I am concerned only with charred residues found on the interior walls of some ceramic vessels. Therefore, the description that follows is limited to charred food residues.

absorbed residues

When liquid or semi-liquid foods and beverages are stored, processed, or cooked in unglazed ceramic vessels, organic and inorganic components (e.g. lipids, proteins, carbohydrates, phosphate, salts) permeate the porous vessel walls (Cackette *et al.* 1987; Evershed *et al.* 1995a:88; Heron and Evershed 1993:250-251). Cooking foods, in particular, liberates constituents allowing them to be more readily transferred and absorbed into the ceramic (Charters *et al.* 1993:218; Evershed *et al.* 1995a; Heron and Evershed 1993:251). For the various classes of lipids (fatty acids, fatty alcohols,

alkanes, triacylglycerols, waxes, etc.), at least, this is a non-selective process (Evershed *et al.* 1995a:88, 91). Absorbed materials continue to accumulate as long as a vessel is in use (see Evershed *et al.* 1995a:91). Once use has ended and/or the vessel is discarded, the various compounds absorbed into the ceramic will begin to be removed or be altered by a variety of diagenetic processes. Relatively more water-soluble compounds, including proteins and carbohydrates are generally leached away first[1] whereas lipids, which are hydrophobic, will be more resistant to leaching and other forms of diagenesis (Evershed 1993:77; see sections 4.4.1 and 4.4.2). For this reason, analyses of absorbed residues have focused on the extraction and identification of lipids. I analyse absorbed lipid residues in this study of Maya food and cooking.

In theory, any food that is cooked or processed in a ceramic vessel can produce an absorbed lipid residue. All plant and animal tissues used as foods contain lipids (section 4.4.1). Yet, it can reasonably be expected that foods which contain a larger proportion of lipids, such as meats, dairy products, or oily nuts and seeds will produce a larger quantity of absorbed material, more likely to be preserved through archaeological time. Residues produced by cooking meats are, in fact, the most frequently identified residues in archaeological ceramics (Charters *et al.* 1995; Evershed *et al.* 1990; Malainey *et al.* 1999:430; Raven *et al.* 1997:268). Repeated cooking of food plants, and in particular those which produce protective waxes, such as leafy greens, also results in a significant quantity of absorbed lipid material, however (Evershed *et al.* 1997:91). Some vegetables, grains (e.g. maize) and seeds (e.g. legumes) also have protective waxes that might contribute to residues. Starchy plants, including other grains and root crops, are expected to leave the smallest amount of residue (Hill and Evans 1987:92).

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[1] Polysaccharides have been identified in charred residues (Oudemans and Boon 1991) and amino acids have been identified in charred and uncharred surface residues (Oudemans and Boon 1991:216 and Hurst *et al.* 1989:286, respectively) collected from archaeological vessels, however.

Clearly, analyses of absorbed residues do not have the potential to provide evidence of all foods that were once cooked or consumed by a particular group in the past. Like palaeobotanical and faunal studies, which are left with only the most durable remains, organic residue analysis is also limited by differential preservation and recovery (Heron and Evershed 1993). In addition to the bias towards fatty foods, many foods would not have become incorporated into residues if they were eaten raw (fruits and berries, nuts, some greens) or were prepared in ways that did not involve cooking in ceramic vessels (e.g. roasting in pits or over a fire, boiling in hides).

Absorbed lipids do not always accumulate uniformly throughout a vessel but may be relatively more concentrated in the rim/neck, body, or base (Charters *et al.* 1993; Evershed *et al.* 1995a). The distribution of a residue is influenced by the former contents of the vessel, the manner of use (i.e. food storage versus preparation and cooking) and, for cooking pots, the method of cooking (Charters *et al.* 1993:218-219; Evershed *et al.* 1995a). Residues produced by boiling foods are concentrated at the rim/neck, as lipids float to the surface, and gradually decrease towards the base where the residues are least concentrated as a result of thermal degradation during cooking (Charters *et al.* 1993:216; Charters *et al.* 1997:6; Evershed *et al.* 1995a: 90, 91). Stewing mixtures of foods should produce a similar pattern. A greater density of lipids at the base of a vessel may suggest that foods were roasted (Charters *et al.* 1993:218) or fried, while a more evenly distributed residue may indicate the use of fat as a postfiring treatment to seal the vessel, the storage of oil (Charters *et al.* 1993:218), or the cooking or storage of more viscous foods.

The mechanism for preservation of absorbed residues is unknown. However, it has been suggested that the physical entrapment of organic molecules within the pores of the ceramic serves to inhibit losses through leaching and microbial attack (Bethell *et al.*

1994:232; Evershed 1993:77; Heron and Evershed 1991:253; Hill *et al.* 1985:126). Adsorption of lipid molecules onto surfaces of the clay may also limit their availability to microorganisms (Evershed 1993:77; Heron and Evershed 1991:253). Personal observations suggest that charred residues on the interior surfaces of a pot also aid in the preservation of absorbed residues, presumably by sealing the porous surface of the ceramic. Lipid residues are also known to preserve within charred surface residues, presumably as food materials were trapped in small vesicles produced during carbonisation and subsequently having been protected from degradation by an inert wall of carbon (Hill *et al.* 1985:126).

charred surface residues

Charred or carbonised residues are brown-black to black encrustations found on the surfaces of some ceramic vessels (Figure 4.1). Charring on exterior surfaces is typically soot or resinous material produced by setting the vessel over a wood fire. In this project, I analyse only charred residues adhering to the interior walls of ceramic vessels as a result of over-cooking food. Formation of carbonised residues occurs at points of intense heat where water is not present in the vessel walls (Skibo 1992:148) and is dependent, in part, upon the composition and consistency of foods cooked in the vessel.

Charred food residues may form on the interior of the rim/neck, body, or base of a vessel. The position of the residue is related to the method of food preparation, the type of food cooked, and vessel morphology. For example, when cooking mixtures of vegetables and meat, food material caught on the vessel wall above the level of the liquid sometimes becomes charred in a band (Kobayashi 1994:165). In pots used by the Kalinga to cook mixtures of vegetables and meat, this point was at the middle of the

vessel (Kobayashi 1994:165) but a similar process is likely responsible for the zone of charring found around the rims of some archaeological vessels from the Northeastern Plains (personal observation). Rice cooking pots used by the Kalinga also develop a carbonised residue on the body of the vessels that eventually spreads down to the bottom of the vessels (Kobayashi 1994:148-151). Such chars develop below the surface of this thick, starchy dish at 'hot spots' in the vessel wall when much of the water has evaporated from the food and the vessel. The burnt area that forms cannot be removed completely when (or if) the vessel is washed and it grows with subsequent cooking events (Kobayashi 1994:150). The vessels from Cuello, Belize analysed in this study also have carbonised residues that occur as a band on the body and near the base of the vessels (Figure 4.2).

The physical properties of residues produced experimentally (one cooking and burning episode) and in ethnographic contexts (multiple cooking events) also vary with the type of food cooked (Kobayashi 1994:166-168; Sherriff *et al.* 1995:103, 108). Starchy plant foods (wild rice, rice, bulrush tubers) produce a thick, even, and dull residue. Meat and fish generate a thick, glossy residue that adheres more strongly to the ceramic. Many vegetables produce little or no residue (Skibo 1992:151), particularly those that have little starch. Further, as noted for absorbed residues, not all foods that were utilized in the past were cooked in ceramic vessels and, therefore, the isotopic composition of charred residues does not necessarily reflect that of the whole diet.

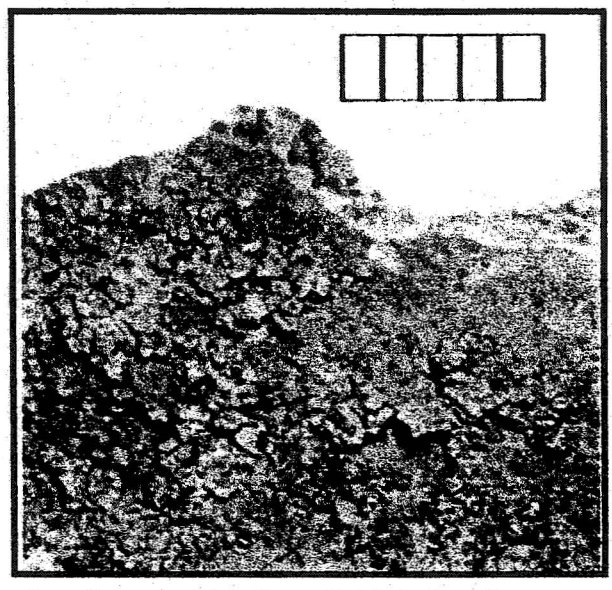


Figure 4.1 Carbonised surface residue from the interior of a ceramic vessel. The scale provided is in millimetres.

Figure 4.2 Distribution of charred residue on the interior body of a cooking vessel from Cuello, Belize. The scale provided is in centimetres.

4.3 Previous applications of food residue analysis

Early methodological goals

Archaeologists and chemists really only began to seriously consider the possibilities of organic residue analysis in the past thirty years. Publications from the early part of this period reflect the exploratory nature of a new analytical approach. Of course, the primary concern of the first studies was to examine and establish suitable analytical techniques and analytes, which would provide accurate identifications of the residues. A variety of different approaches were evaluated including: determination of trace elements (Fie *et al.* 1990; Hill and Evans 1982:226-228), in particular, phosphorous (Cackette *et al.* 1987; Duma 1972; Dunnell and Hunt 1991); infrared spectroscopy (Hill and Evans 1982:224; Hill *et al.* 1985:126); stable carbon and nitrogen isotope analysis of charred residues (Hastorf and DeNiro 1985; Morton 1989; Morton and Schwarcz 1988; Morton *et al.* 1990); and the analysis of lipids, especially fatty acids, using various chromatographic techniques (Bowyer 1972; Condamin *et al.* 1976; Deal and Silk 1988; Evershed *et al.* 1990; Gurfinkel and Franklin 1988; Hill and Evans 1982:224-226; Hill *et al.* 1985:126-128; Ohshima *et al.* 1993; Patrick *et al.* 1985; Rottländer and Hartke 1982). While each of these provides some information as to the original food contents of a vessel, only isotopic analysis and gas chromatographic analysis of lipids continue to be used with any regularity, as they allow for the most satisfactory identifications (see sections 4.4 and 4.5). The exploratory and methodological nature of the first group of residue studies is also apparent in the tendency to analyse only one or several vessels (exceptions include Hastorf and DeNiro 1985; Morton 1989; Morton *et al.* 1990). Recognizing that the intent was not there, it is nonetheless unfortunate that as a result, the findings cannot be used to address many questions of anthropological interest, regardless of the degree of accuracy of the identifications.

current directions: primary goals

Despite this unfavourable circumstance, the primary goals of residue analysis have not changed over time. The two reasons given most frequently for undertaking either the development or application of methods for analysing residues associated with ceramic vessels are first, the determination of the original contents of a vessel (Bowyer 1972:330; Condamin *et al.* 1976:195; Dudd and Evershed 1998; Evershed *et al.* 1997; Hocart *et al.* 1993; Hurst *et al.* 1989:287; Rottländer and Hartke 1982) and second, the related problem of defining vessel function (Biers *et al.* 1988:34; Cackette *et al.* 1987; Charters *et al.* 1993:212, 222; 1995:113, 114; 1997:2; Evershed *et al.* 1990:1339, 1995a:85, 1997:402; Hill *et al.* 1985:125; Malainey *et al.* 1999; Ohshima *et al.* 1993:3225; Raven *et al.* 1997:284). Despite improved analytical techniques and instrumentation in recent decades, however, identifications are often still restricted to broad categories of foods (e.g. plant, animal fat, freshwater or marine fish, dairy; see sections 4.4.4, 4.5.2, and 4.5.3). Further, the method of cooking can generally only be assumed to have been boiling. Still, the desire to know exactly what a particular vessel or vessel form once contained, and how it was used continues to shape the direction in which the field of residue analysis is evolving. Consequently, rather than assigning residues to general categories of food and increasing the number of archaeological applications the majority of work with residues continues to be in the area of method development, designed to refine both interpretations of vessel contents (Dudd and Evershed 1998; Evershed *et al.* 1990, 1992, 1994, 1997; Regert *et al.* 1998) and the 'mode' of use (Charters *et al.* 1993, 1995, 1997; Evershed *et al.* 1995a; Kobayashi 1994; Raven *et al.* 1997; Skibo 1992). Results from this latest body of research are not without merit, of course, and do suggest ways in which residue analyses might proceed in the future, potentially

contributing new and different information to archaeological investigations of food and foodways.

The studies which are most often cited as examples of the potential of residue analysis are those few in which it was possible to infer the genus or species of the foods preserved as a residue. In each case, the researchers began with clues as to which foods the vessels might have contained, and successfully used chromatographic techniques to detect particular components characteristic of the foods that they sought to identify. The identifications of theobromine and caffeine in four vessels from a tomb at Río Azul, Guatemala confirmed that the vessels once held cacao (*Theobroma cacao*), as glyphs on one of the vessels indicated (Hall *et al.* 1990; Hurst *et al.* 1989). The presence of the lactones yangonin and methysticin in two archaeological vessels indicated that they once contained a traditional drink consumed in Oceania which is made using the root of the kava plant (*Piper methysticum*) (Hocart *et al.* 1993). The archaeological vessels were selected for analysis based on similarities in form to modern kava bowls. Finally, Evershed and colleagues (1992:203-204, 1994:912) determined that several Late Saxon/Early Medieval vessels from the West Cotton site, Britain were used to cook cabbage or turnip leaves (*Brassica* sp.) and leeks (*Allium porrum*). Long-chain alkyl compounds previously identified in the residues suggested that they compare the residues to extracts of epicuticular leaf waxes of modern cabbage in order to make the identification. The novelty of the identifications makes them interesting, as does the latent potential of using residues of epicuticular waxes, which are prevalent in plants (Gurr and Harwood 1991:281, Section 4.4.1), in order to identify the use of food plants that are rarely or never preserved as macro-botanical remains at most archaeological sites (e.g. roots and leafy greens) (Evershed *et al.* 1992:204; Hocart *et al.* 1993:222). Before this is to happen, however, much time and effort will have to be spent determining whether

relatively diagnostic biomarkers exist for the many foods used by each group of people in prehistory.

Investigators have also been working towards tighter classifications of meats. It has been suggested that differences in the carbon isotopic composition of particular lipids, measured using a combined gas chromatograph-mass spectrometer, can be used to distinguish between residues left by ruminant versus non-ruminant fats (Dudd *et al.* n.d.; Evershed *et al.* 1997:405), and between milk and meat fats (Dudd and Evershed 1998:1480). Therefore, it may now be possible to obtain direct evidence for the cooking of meat as well as animal husbandry or dairying even at sites where faunal remains are badly preserved or not preserved (Dudd *et al.* n.d.; Evershed *et al.* 1997:402). It is not yet possible, however, to identify specific animal species.

Another focus of residue analyses in recent years has been discerning how processes of cooking and post-depositional diagenesis contribute to the formation and composition of archaeological food residues. The expectation is that the information gained may be used to make more informed interpretations of both vessel contents and vessel function. Section 4.2 includes a summary of the information derived from a number of these studies describing how certain physical characteristics of the residue, including whether the residue is charred or absorbed and how it is positioned or distributed in a vessel, can inform about cooking methods used in the past (Charters *et al.* 1993, 1997; Evershed *et al.* 1995a; Kobayashi 1994; Sherriff *et al.* 1995:103, 108-109; Skibo 1992:148-151). Residue analysts are now also looking at the chemical characteristics of residues in order to establish which vessels were used for cooking and which were used for other tasks such as storage (Raven *et al.* 1997; Regert *et al.* 1998). Raven and colleagues (1997:284) demonstrate that the presence of homologous series of long-chain ketones (29-35 carbon atoms) identified in some archaeological

residues can be explained by ketonic decarboxylation of free fatty acids and triacylglycerols during cooking (Raven *et al.* 1997:277, 283, 284). This condensation reaction occurs when these lipids are pyrolysed (heated) in an inorganic matrix (i.e. ceramic), and in the presence of an inorganic catalyst (e.g. iron oxide, magnesium oxide, calcium carbonate) that originates from the clay or from foods cooked in the vessels (Raven *et al.* 1997: 270, 277, 281, 283). They also hint at the feasibility of estimating cooking temperature, as heating triacylglycerols and free fatty acids at higher temperatures (800°C) produces characteristic secondary pyrolysis products (homologous series of minor ketones, methylketones, methyl esters, alkanes, and alk-1-enes) not formed at lower temperatures (350-450°C) (Raven *et al.* 1997:284). Residues of cooking vessels should also contain lipid oxidation products, including dicarboxylic and hydroxy acids, which form during cooking and perhaps following burial (Regert *et al.* 1998:2030). These low molecular weight oxidation products are relatively soluble in water, however, and they are frequently leached from ceramics by groundwater except at arid sites (Regert *et al.* 1998:2029, 2030). Therefore, they are not commonly identified in lipid residues extracted using organic solvents but they have been extracted by base treatment of insoluble residues (carbonised) (Regert *et al.* 1998:2029, 2030).

It is important to consider that each methodological innovation and the additional information which it may access nonetheless requires increased commitment in terms of time and expense devoted to laboratory work and to interpretation of the chromatograms generated, both of which can be significant. For example, defining cooking methods using the spatial distribution of lipids within a single vessel requires processing one or two additional samples from each vessel (Charters *et al.* 1993; Evershed *et al.* 1995a), while establishing vessel function by the presence/absence of lipid oxidation products (Regert *et al.* 1998) requires the additional step of a base extraction from the insoluble fraction of the residue. At some point, therefore, archaeologists will have to make a

decision as to whether the return, in terms of the amount and type of information gained by the varied analyses now available, warrants the time and expense involved in processing and interpreting the residue samples. In making such a decision, we have to consider whether or not the same or similar, but sufficient answers might not already be accessible through the study of other material remains of foodways, including faunal and botanical remains and artifacts used in the preparation and distribution of foods. For example, in many cases, the identification of a food residue in addition to morphological characteristics of a vessel should provide enough information to decide whether a particular vessel was used for storage or cooking without having to identify lipid oxidation or pyrolysis products in the food residues.

Current directions: secondary goals

Residue analysts reason that the value of identifying vessel contents and vessel function from food residues is that the information provided may ultimately be used to investigate various aspects of ancient economies. These include palaeodiet, subsistence, and trade. The role of residue analysis in palaeodietary reconstructions is seen not only as a source of direct evidence for the use of particular foods (Charters *et al.* 1993:212; Evans and Hill 1982; Evershed *et al.* 1994:909, 1995a:85, 1997:402; Hill *et al.* 1985:125; Morton and Schwarcz 1988:84), but as a method by which it might be possible to identify foods which are not typically preserved in faunal and botanical assemblages (Evershed *et al.* 1992:204; Hocart *et al.* 1993:222). Residues are also proclaimed as a source of information related to subsistence activities or strategies (Dudd *et al.* n.d.; Patrick *et al.* 1985:231). More specifically, it has been suggested that food residues may be an appropriate source of evidence for detecting the use and/or introduction of particular crop plants (Hall *et al.* 1990; Hill *et al.* 1985:125; Hill and Evans 1987; Hocart *et al.* 1993) or domestic animals (Evershed *et al.* 1997:403) where botanical

or faunal remains are lacking. Finally, it has been proposed that knowing the contents of ancient vessels, and amphorae in particular, will contribute to understanding the trade of ancient commodities such as wine and oils (Badler *et al.* 1990; Condamin *et al.* 1976:195; Evershed *et al.* 1997:405). Understanding ancient economies clearly remains a secondary goal, however. The studies cited here merely suggest the *potential* of using residue analyses for understanding activities related to the use or trade of food in prehistory. Most researchers have, in fact, made no attempt to incorporate their results into explanations of past economic activities. The very few examples that do utilize residue analyses in reconstructions of palaeodiet or subsistence are Hastorf and DeNiro (1985), Hastorf and Johannessen (1993), Malainey (1997), and Malainey *et al.* (1999).

I have already argued that residue analyses cannot be used to resolve questions about any aspect of human societies in the past as long as only one or a handful of vessels are analysed. The dilemma that currently exists is that although the continued use of small sample sizes may be justified by methodological goals, it does not encourage applications to archaeological reconstructions of past economies or foodways. This is a result of the failure to demonstrate that residue analysis can be undertaken on the scale required to address such a task. Perhaps a further result of not applying residue analyses to questions of anthropological interest is that investigators disassociate the pots from the people who cooked and ate the foods that the vessels once contained. Research interests are not directed towards understanding why people in a particular time and place chose to prepare that food, among others, in their cooking vessels. Thus, investigators have overlooked the potential for residue analyses to provide valuable information about temporal and spatial differences in cooking practices that could provide insights into the organization of domestic economies (section 3.1). Nor have most investigators considered how food residues might provide insights into social and political structures of past societies by informing about social uses of food (section

3.2). Therefore, further development of residue analysis as an analytical technique for archaeologists may in fact be hindered by the current goals of residue analysts.

There are only four examples in which archaeologists have made an effort to incorporate information from residue studies into explanations of foodways in the past (Hastorf and DeNiro 1985; Hastorf and Johannessen 1993; Malainey 1997; Malainey *et al.* 1998; Morton 1989; Morton *et al.* 1990). Of these, the work by Hastorf and her colleagues (Hastorf and DeNiro 1985; Hastorf and Johannessen 1993) is perhaps the best example of how it is not necessary to wait until species specific identifications are possible before employing the results of residue studies to investigations of prehistoric economic, social, or political systems. Non-specific results can be informative particularly when they are obtained within the framework of well-defined research questions, and when their significance is considered in the context of other archaeological information related to foodways or the social and political organization of human groups in the past. For example, isotopic analysis of residues charred onto 71 vessels from sites in the Mantaro Valley, Peru, only distinguished maize from other plants (quinoa and tubers) (Hastorf and DeNiro 1985). Nonetheless, the sample of residues recorded a temporal shift in maize preparation between the Wanka I (A.D 900-1300) and Wanka II (A.D. 1300-1430) periods, which, along with other lines of evidence for changes in food processing and preparation, allowed Hastorf and Johannessen (1993:124-131) to infer that increased consumption of the maize beverage, *chicha*, accompanied local political changes and feasting during Wanka II times. Obviously, the significance of such general identifications cannot be understood without a relatively large sample of residues that can reveal differences in food preparation across time or geographical locations.

Malainey (1997; Malainey *et al.* 1999) also integrates the results of residue analysis with data from faunal and tool analyses into an understanding of the different subsistence and settlement strategies utilized by prehistoric hunter-gatherers from the

plains, parkland, and boreal-forest zones in western Canada. By comparing the fatty acid composition of more than 200 archaeological sherds from eighteen sites to those of experimentally produced cooking residues, Malainey (1997:184, 210, 212; Malainey *et al.* 1999:426, 429-432) was able to assign most of the residues to one of seven identifications: large herbivore, marrow of large herbivore with plant, plant, plant with traces of large herbivore, fish or corn, fish or corn with plant, and beaver. The patterning apparent in the cooking residues, faunal remains, and tools each indicated that plains groups had a less varied diet, consisting primarily of large herbivores (bison) than people who occupied the parklands and forests (Malainey 1997:210). The unique contribution of residue analyses was that the residues provided direct archaeological evidence for the greater utilization of food plants, and a more varied diet, by parkland and forest groups compared to plains groups (Malainey 1997:198-199, 212-213).

Other applications have not addressed questions as broad as those attempted by Hastorf and DeNiro (1985) and Malainey (1997). Morton (1989; Morton *et al.* 1990:807) and Whitney (1992:7) each hoped to detect the introduction of C4 crops, into southern Ontario (maize) and southern Somalia (sorghum), respectively, using the carbon isotopic composition of carbonized residues found in cooking vessels. For different reasons, this was not possible in either study. Whitney's entire sample (N=24) from Somalia postdates the introduction of sorghum (Whitney 1992:100). Morton's results indicate that maize was not routinely cooked in the vessels analysed from Ontario (Morton 1989:165; Morton and Schwarcz 1988:92; Morton *et al.* 1990:808).

The particular insights gained into prehistoric cooking practices in southern Ontario were unexpected. The carbon isotopic composition of bone collagen of people from the same region and temporal period (A.D. 1100 - 1725) as the vessels indicates that the diets consumed by these people contained between 33 and 50% maize (Morton and Schwarcz 1988:92; Schwarcz *et al.* 1985:200). In order to understand the divergent

results of the two studies, Morton (1989; Morton and Schwarcz 1988:92) suggested that the maize consumed might have been prepared by roasting or as bread, rather than being boiled. It is also possible that maize is under-represented in the residues due to differences in the formation and/or preservation of food residues (see Sections 4.2 and 4.4.3). In either case, it is important to note that the information obtained from the analysis of cooking residues is likely to be very different from that derived from isotopic analyses of human tissues as the residues do not reflect patterns of food consumption but rather the activities of food processing, preparation, and perhaps food distribution/ serving. It is also important to recognize that Morton would not have been able to offer the interpretation that she did had she not also considered the isotopic data from bone collagen. Whitney was less successful in trying to make sense of her residue data, I believe, as she has not used other lines of archaeological evidence to understand the significance of the residue results which she did obtain.

I think that it is important to consider that both Hastorf and Malainey may have been able to utilize results from their residue studies because, in addition to sampling a large number of vessels, they view the type of information obtainable from residues as independent from, but not more important, valid, or useful than other material remains which archaeologists traditionally use to investigate economic, social, and political structures of past societies. Thus, residue results are not presented apart from analyses of other artifact classes, nor is the significance of residue identifications offered without considering what is known from other types of archaeological data.

4.4 Gas chromatography: analysis of absorbed lipid residues

4.4.1 Lipids as biomarkers

The term lipids refers to a large, chemically heterogeneous group of substances which are insoluble in water but are soluble in organic solvents such as chloroform,

ether, and alcohols (Gurr and Harwood 1991:1; Kates 1986:1). Lipids occur in all living organisms, serving structural, energy storage, and metabolic functions (Gurr and Harwood 1991:1, 4-9; Kates 1986:1). They comprise fatty acids, long-chain hydrocarbons, fatty alcohols, and aldehydes, which are building blocks for more complex classes of lipids such as acylglycerols, waxes, steroids, glycolipids, and phospholipids (Kates 1986:1; Lehninger 1986:56, 303, 315). The characteristic water-insolubility of lipid molecules is a function of their chemical structure, which may be either a straight or branched, aliphatic hydrocarbon chain in fatty acids and fatty alcohols, or a sterol ring system (Gurr and Harwood 1991:4-5; Lehninger 1986:303; Lehninger *et al.* 1993:242).

Lipids are an appropriate biomarker for the identification of archaeological residues, therefore, as they exist in all food plants and animals and their insolubility in water inhibits or slows their loss from potsherds and other archaeological contexts by water leaching (Bethell *et al.* 1994:232; Evershed 1990, 1993:75; Heron and Evershed 1993:254; Rottländer 1990:37). Furthermore, lipids are resistant to degradation by heat, surviving temperatures as high as 400°C (Rottländer 1990:37). Preservation of lipids in archaeological contexts can be expected to be greater than that of proteins and carbohydrates which are more soluble in water (Heron and Evershed 1993:253).

For a number of practical but important reasons, fatty acids have been and continue to be the most frequently analysed class of lipid in the investigation of archaeological residues, despite an understanding that identifications based solely on the fatty acid composition of a residue can be problematic (Bethell *et al.* 1994:241; Evershed *et al.* 1992:203; Heron and Evershed 1993:268; section 4.4.3). In fact, sterols and waxes can potentially provide more specific information. Cholesterol is found only in animals and campesterol and sitosterol are characteristic of plants. Protective plant waxes may provide more unique biomarkers and should at least allow for identifications of plant families, if not species (Evershed *et al.* 1991). However, many foods that were used in

prehistory have not continued to be (widely) used into the present and, therefore, have not been analysed for their lipid composition. As such, unique or relatively unique biomarkers (waxes, sterols or otherwise) have not been identified for most foods of interest in studies of ancient foodways. Further, given the need to investigate a large number of vessels for which the original contents are a complete unknown it is not practical to begin to look for individual biomarkers (*cf.* Malainey 1997:101); *this is a lifetime of work.* Determination of fatty acid composition may provide general characterizations of residues that can be used to direct efforts towards more specific identifications if time and finances allow. Further, analysis of fatty acids using gas chromatography (GC), versus the identification of unique compounds by gas chromatography/mass spectrometry (GC/MS) may be more accessible to archaeologists in terms of time and costs involved in learning the method and accessing equipment. This is crucial; for any archaeometric technique to find wide application, there must be a base of archaeologists who can understand and undertake the analyses themselves. The difficulties in finding chemists willing to devote time and resources to large-scale archaeological projects are long-standing and are not likely to go away.

Fatty acids are the primary category of lipid analysed by GC in this study.

4.4.2 Fatty acids, triacylglycerols, and waxes

Fatty acids contain a linear chain of carbon atoms surrounded by hydrogen atoms and a carboxyl group (–COOH) at one end (Kretchmer *et al.* 1997:19; Lehninger 1986:303; Figure 4.3). They may be saturated or unsaturated. The carbon atoms in saturated fatty acids are completely loaded with hydrogen atoms (Figure 4.3a). In unsaturated fatty acids, some of the hydrogen atoms are missing and where this occurs along the hydrocarbon chain, carbon–carbon double bonds are formed (Figure 4.3b). Polyunsaturated fatty acids contain more than two double bonds. Plants and animals

synthesize fatty acids by condensation of two-carbon units. In nature, therefore, fatty acids typically have an even number of carbon atoms (2-30) (Gurr and Harwood 1991:24, 40). The most commonly occurring fatty acids have 12 - 24 carbon atoms (Gurr and Harwood 1991:24; Lehninger 1986:304; Lehninger *et al.* 1993:241).

Fatty acids are the building blocks of most lipids and, therefore, do not typically exist as free fatty acids (Gurr and Harwood 1991:24). In foods, most fatty acids occur as part of triacylglycerols that are esters of the alcohol, glycerol, and three fatty acid molecules (Gurr and Harwood 1991:1; Lehninger 1986:303, 306; Figure 4.3c). Triacylglycerols are the principal component of the storage and depot fats of plants and animals. The fatty acids in archaeological residues, generally, are no longer part of triacylglycerols but have been separated from the glycerol molecule during decomposition and do exist as free fatty acids.

Another source of fatty acids in foods is the protective waxy coatings that occur at the surfaces of organisms (skin, hair, leaves and stems), preventing water loss and also providing a barrier between an organism and its environment (Gurr and James 1980:124; Lehninger 1983:309). These protective surface coatings are actually a mixture of true waxes, free fatty acids and alcohols, and long chain hydrocarbons (Gurr and James 1980:124). The true waxes are esters of long chain fatty acids (10-30 carbon atoms), which may be saturated, unsaturated, branched or cyclic, and long chain alcohols (10-30 carbons). The long chain hydrocarbons in the waxy coatings are odd-numbered *n*-paraffins that are believed to form by the successive addition of 2-carbon units to an existing long chain fatty acid (generally C16:0 or C18:0). Odd-numbered *n*-paraffins, with 21-35 carbon atoms, are ultimately produced by the decarboxylation of these very long hydrocarbons. Some of the very long chain fatty acids (20-28 carbon atoms), however,

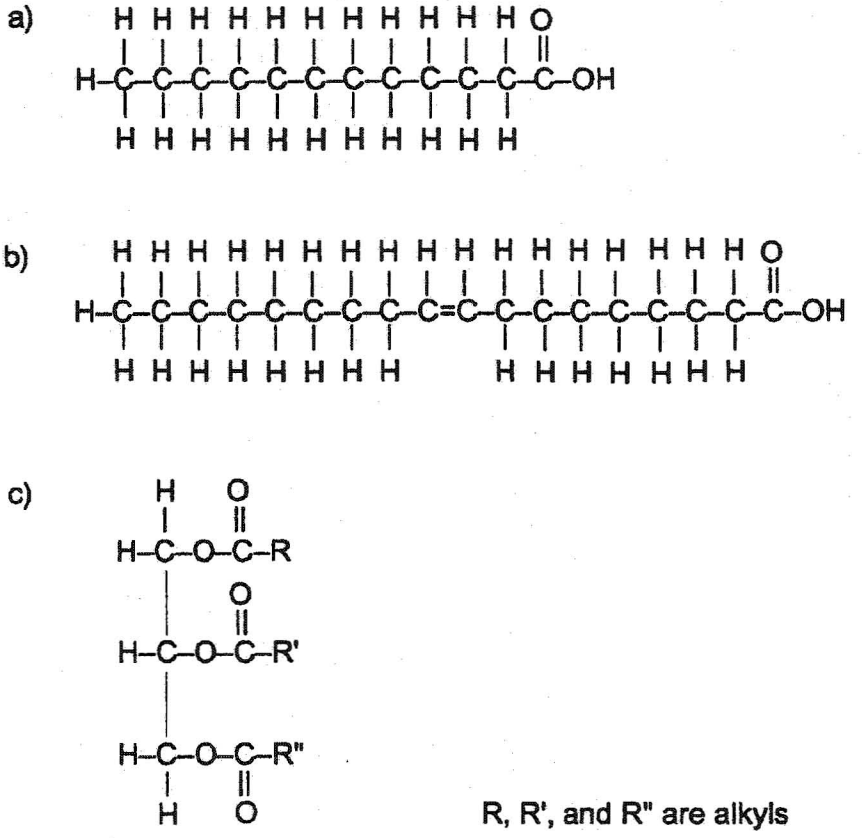


Figure 4.3 The structures of a) straight-chain saturated fatty acid, b) straight-chain unsaturated fatty acid, and c) a triacylglycerol.

which are intermediate products of the elongation-decarboxylation pathway, are not decarboxylated and may be esterifed into glycerides or phospholipids.

4.4.3 Decay of lipids in archaeological vessels

Fatty acid profiles, or the particular combinations of fatty acids and their relative proportions in vegetable oils and animal fats, are quite distinctive for different foods when the foods are fresh (Heron and Evershed 1993:268; Marchbanks 1989:98-99; Rottländer and Hartke 1982:219; Skibo 1992:87, 89). Additionally, "signature" fatty acids,

which occur rarely and only in trace amounts in a small number of foods, can also be useful in identifying some fats and oils (Skibo 1992:87). Identifications, however, can sometimes be difficult. The small number of major fatty acids limits the amount of possible variability (Heron and Evershed 1993:268). Moreover, the fatty acid composition within a single species can vary according to diet or body part in animals, and with soil, climate, and processing method for plant oils (Evershed 1993:84; Heron and Evershed 1993:268). Unfortunately, the fatty acid composition of fats and oils becomes more similar through a number of degradative processes making it even more difficult to identify archaeological lipid residues (Heron and Evershed 1993:268).

Decomposition processes that began with food storage and cooking and continued subsequent to burial of the vessels or sherds determine the composition of archaeological food residues. The major types of degradation that affect lipid residues are hydrolysis, various forms of oxidation, and, in some archaeological contexts perhaps, the formation of adipocere.

hydrolysis

Hydrolysis of ester linkages is the primary process through which fatty acids are removed from triacylglycerols of storage fats, the esters being cleaved to form -OH groups and fatty acids (Evershed *et al.* 1992:196). Heat, chemical (acids, bases) and enzyme initiators will promote hydrolysis in foods during storage, cooking, and following burial (Evershed *et al.* 1992:195; Dugan 1994:168). In archaeological contexts, enzyme initiators can originate from microorganisms (Gunstone *et al.* 1986). Hydrolysis is not a major form of decomposition of free fatty acids. Once fatty acids are hydrolysed, however, they are more available to microbial enzymes, to further chemical reactions, and they are more soluble in water (Eglinton and Logan 1991:318). Although fatty acids can undergo decomposition while bound to glycerol *ex vivo*, it is expected that due to

insolubility in water the process would be relatively slower than for free fatty acids (Jack Rosenfeld, personal communication).

oxidation

Oxidation processes *ex vivo*, particularly peroxidation and thermal oxidation, are likely to have the greatest effect on the final composition of lipids remaining in archaeological ceramics (see Evershed *et al.* 1992:197-199 and Malainey 1997:109-113). Overall, oxidation results in a reduced number of fatty acids and especially polyunsaturated fatty acids that readily react with oxygen. However, monoenoic and saturated fatty acids will also oxidize at higher temperatures (Mead *et al.* 1986:83). In fact, oleic acid (C18:1) is commonly the only unsaturated fatty acid identified in archaeological lipid residues (Evershed *et al.* 1992:199) although linoleic acid (C18:2) is also sometimes present (O'Donoghue *et al.* 1996:544; Ohshima *et al.* 1993:3225; Malainey 1997:164; Priestly *et al.* 1981; Skibo 1992:91-92).

Foods exposed to oxygen at ambient temperatures are subject to several types of peroxidation processes that cause degradation of lipids as well as proteins and vitamins (Gurr and Harwood 1991:96-99; Gurr and James 1980:80). In autoxidation, the lipids themselves have a role in catalysing the reactions involved, which increase in rate as the reactions proceed. Haematin compounds (e.g. haemoglobin, myoglobin, cytochromes) catalyze another type of chemical peroxidation. Lipid peroxidation is also catalyzed by the enzyme lipoxygenase, which occurs in a variety of plants and animals but is most abundant in peas, beans, cereals, and oil seeds. Autoxidation is probably the most important of these (Dugan 1976:169).

Autoxidation involves a free radical chain-reaction that occurs in three stages - initiation, propagation, and termination - and results in the production of primary, secondary, and tertiary products (deMan 1976:58-67; Dugan 1976:169-179; Gurr and

Harwood 1991:96; Mead *et al.* 1986:83-87). The oxidation reaction begins when an unsaturated lipid loses a hydrogen atom to form a free radical (Figure 4.4a). Hydrogen loss is initiated by conditions of heat, ultraviolet light, or ionizing radiation, or by traces of peroxides or transition metals. Oxygen can then combine with the free radical to form a peroxy radical on the fatty acid substrate (Figure 4.4b). Propagation occurs when this free radical abstracts a hydrogen atom from another unsaturated fatty acid, producing hydroperoxide and yet another free radical. The radical is available to react with another unsaturated molecule in what becomes a chain reaction process (Figure 4.4c). Hydroperoxides are the major, primary product of lipid oxidation processes. Termination occurs when the free radicals combine with each other, which does not yield other free radicals (Figure 4.4d). Figure 4.5 (from Dugan 1976:173-174) illustrates the autoxidation of a polyunsaturated fatty acid. A hydrogen atom from a carbon at a double bond is lost because the electron distribution at double bonds makes them less stable than single bonds. Hydrogen abstraction during the initiation stage may occur on either side of the double bond and results in a shift in the position of the double bond and the formation of isomeric hydroperoxides (Figure 4.5).

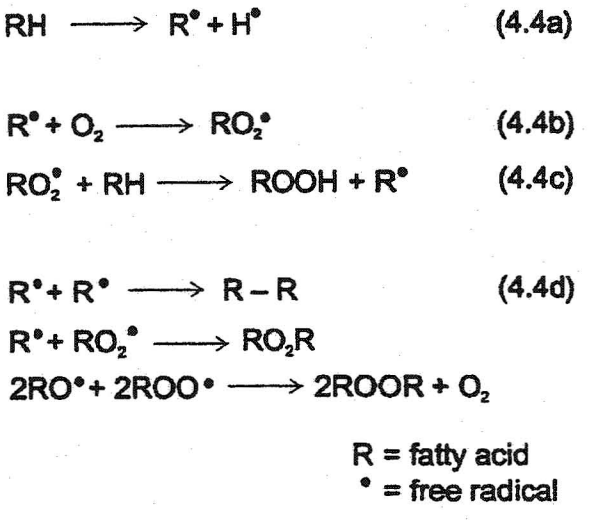
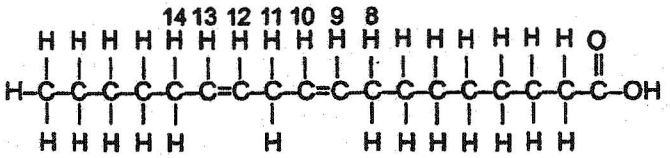


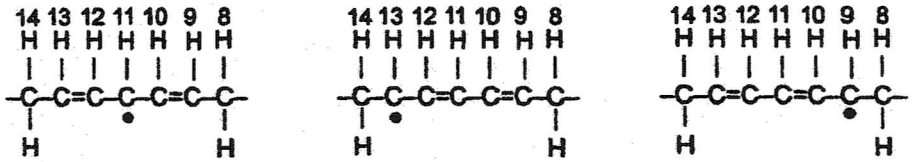
Figure 4.4 The stages of autoxidation of lipids: a) and b) initiation, c) propagation, and d) termination (Adapted from deMan 1976:58, 59).

a)



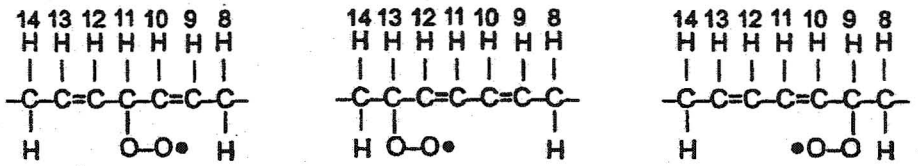
A polyunsaturated fatty acid.

b)



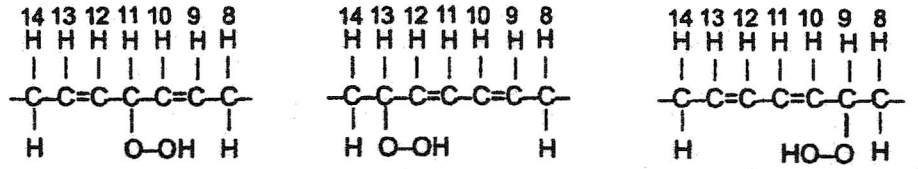
Hydrogen is abstracted from C-11 resulting in the formation of one of three possible isomeric radicals.

c)



Peroxy radicals form with the addition of oxygen.

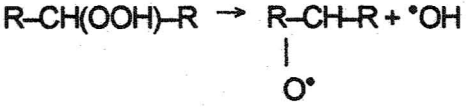
d)



Peroxyl radicals can abstract a hydrogen atom from another unsaturated fatty acid to form isomeric hydroperoxides.

Figure 4.5 (a-d) Autoxidation of a polyunsaturated fatty acid (Dugan 1994:173-174).

Hydroperoxides are also very reactive and will contribute to a variety of subsequent reactions (deMan 1976:62-64; Dugan 1976:170-171, 175-178; Evershed *et al.* 1992:197, 199). Heat, radiation, enzymes or metals (including Cu^{2+}, Fe^{2+}, Fe^{3+}) also catalyze degradation of hydroperoxides. The products of hydroperoxide degradation are considered to be secondary products of lipid autoxidation. Hydroperoxides can break down to alkoxy and hydroxy free radicals:



Alkoxy radicals may fission, creating volatile and non-volatile aldehydes, or they can abstract hydrogen from other molecules to form alcohols. Ketones are produced if alkoxy radicals combine with other free radicals. Hydroperoxides may also recombine to produce peroxy dimers. Many of the products of these reactions are also volatile and are readily lost. Tertiary products of lipid oxidation include fatty acids produced by oxidation of the aldehydes, and ketones converted from alcohols. The effect of peroxidation, then, is the formation of an extremely varied group of end products which can give no indication of the particular fatty acids from which they derive (Malainey 1997:111).

Thermal oxidation during events such as cooking increases the rate of decomposition. It results in many of the same products as autoxidation (Malainey 1997:112).

microbial degradation

Numerous microorganisms are very active in the soils from which archaeological ceramics are usually excavated. Their role is to remove detritus from soils and they are

very efficient as they metabolize about 99% of the organic matter deposited in sediments (Jorgensen 1983, cited in Eglinton and Logan 1991:322). Microorganisms contribute enzymes that can initiate degradation processes in lipids (Gunstone *et al.* 1986). Freezing and drying can dramatically slow the work of microorganisms but they will continue to promote oxidation and hydrolysis (Eglinton and Logan 1991:322). Therefore, it is important to acknowledge that microbial degradation very likely is a factor in the preservation and/or loss of lipid residues from ceramic sherds.

adipocere formation

Adipocere was first described following exhumations of recent human graves. It is degraded depot fat which has altered to a greyish-white, waxy substance and is composed almost entirely of saturated fatty acids, dominated by palmitic (C16:0) and stearic (C18:0) acids (den Dooren de Jong 1961:338, 342). Lipids buried in wet, oxygen-depleted or anaerobic conditions change to adipocere in a process initiated by bacteria originating in the dead organism and/or the soil (den Dooren de Jong 1961:359, 361). den Dooren de Jong (1961:342-343) compared the decomposition pathway (Figure 4.6) to β-oxidation of lipids. β-oxidation is the process through which stored fat is converted to energy in living organisms. It is the successive loss of 2-carbon units (acetyl-CoA) from the carboxyl end of a fatty acid chain, in a repeating series of enzyme-catalyzed reactions in cell mitochondria and sub-cellular microbodies (Gurr and Harwood 1991:78-89; Lehninger 1982:511-521). The products include acetyl-CoA, which is converted to an energy-rich molecule (adenosine triphosphate, ATP), and a fatty acid shorter by two carbon atoms (Lehninger 1982:515). The transformation of lipids to adipocere is less well understood but it is clear that unsaturated fatty acids are replaced by saturated fatty acids with two fewer carbon atoms (den Dooren de Jong 1961; Morgan *et al.* 1973). For example, oleic acid (C18:1) is replaced by palmitic acid (C16:0), and palmitoleic (C16:1) by

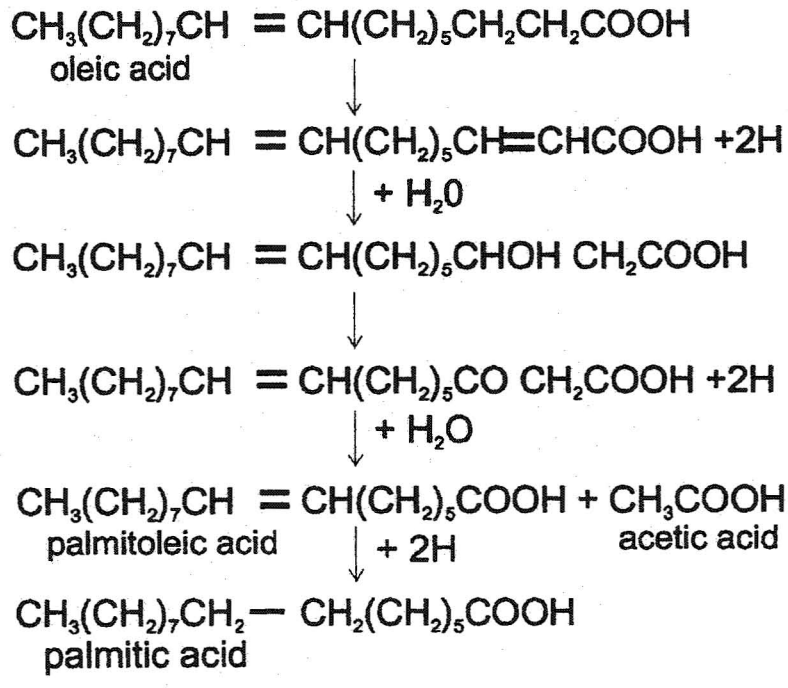


Figure 4.6 Proposed chemical pathway for the formation of adipocere from storage fats (den Dooren de Jong 1961:343).

lauric (C14:0). Glycerol, acetic acid, and the hydrogen liberated in the reactions become available to continue the degradation cycle (den Dooren de Jong 1961:343).

Some have proposed that adipocere formation plays a role in the degradation and preservation of lipid residues in ceramic vessels and should be considered when interpretations of fatty acid data are made (Deal and Silk 1988:111-112; Skibo 1992:98).

Malainey (1997:109) disagrees arguing that, because of the specific enzymic and environmental requirements for adipocere formation, it may not be a factor in food residue studies. It would not be unreasonable to suggest that this degradative process may, in fact, have a role in the decomposition of unsaturated fatty acids where sherds have been buried under meters of midden, overburden, or soil at wet, tropical sites.

4.4.4 Interpretation of food residues using fatty acids

The overall effects of fatty acid decomposition are reductions in the amount and number of fatty acids so that the distributions and relative percentages of the fatty acids are entirely changed from their original food source. Essentially all of the polyunsaturated fatty acids, many of the monounsaturated fatty acids, and some of the saturated fatty acids are lost. The original fats all tend to become more similar to each other over time. Therefore, when only fatty acid data are available identifications will be difficult and can be expected to be limited to general categories of food such as plant, animal, fish, marine mammal, and dairy (Bethell *et al.* 1994:241; Evershed 1993:85; Heron and Evershed 1993:268, 269).

Despite the obvious difficulties which decomposition processes contribute to interpreting the origins of lipid residues, some analysts continue to argue the utility of fatty acid analysis (Deal *et al.* 1991; Malainey 1997; Malainey *et al.* 1999; Skibo and Deal 1995). Malainey and her co-workers (1999:425-426) provide a good overview of the various methods that have been used to compare the fatty acid composition of degraded residues to modern food references. Through boiling and experimentally degrading modern seal tissue, Patrick and colleagues (1985:233) discovered that the ratio of oleic and vaccenic acid (C18:1, n-9/C18:1, n-7) may not be greatly altered over time by these processes. Similar ratios of these C18:1 isomers for seal and for a residue from a South African vessel, along with faunal remains at the site, suggested that seal may have been

cooked in the vessel (Patrick *et al.* 1985:233). The strength of the "seal" identification is lessened by the fact that the residue was only compared to seal and anchovy. Further, vaccenic acid is a major bacterial fatty acid (Gunstone *et al.* 1986, cited in Deal *et al.* 1991:191). It is not clear when its presence in a residue may be attributed to this source.

Skibo (1992:88, 89) was able to distinguish between modern examples of uncooked rice, vegetables, and meat using the ratios of some of the most common fatty acids (C18:0/C16:0 and C18:1/C16:0) and a small number of "signature" fatty acids. The fatty acid profile of residues produced in rice cooking pots used by the contemporary Kalinga, specifically for Skibo's study, matched that of modern rice (Skibo 1992:94). However, characterizing the residues was found to be more difficult when more than one food had been cooked in the same vessel. It was not always possible to establish that meat had been cooked in the vegetable/meat pots used by the Kalinga. Also, specific types of vegetables or meats could not be identified (Skibo 1992:96). Processes of degradation, which increased the amount of C16:0 and so altered the fatty acid ratios used to interpret the residues, also made it difficult to identify the origins of residues extracted from 10 Kalinga archaeological sherds of unknown age (Skibo 1992:97).

Marchbanks (1989:68) used the following equation to characterize the parent material of lipid extracts according to the amount of saturated *versus* polyunsaturated fatty acids present:

$$\%S = C18:2 + C18:3 / C12:0 + C14:0$$

In doing so, he attempted to avoid some of the interpretive problems introduced by fatty acid degradation. Marchbanks (1989:66, 68-69) reasoned that it should be possible to characterize different categories of food on the basis of the relative percentage of two saturated fatty acids - lauric acid (C12:0) and myristic acid (C14:0) - because animals

tend to have high proportions of saturated fatty acids whereas plants typically have much higher proportions of polyunsaturated fatty acids and very few saturated fatty acids. He chose not to use palmitic (C16:0) or stearic (C18:0) acid in the calculation as both of these are known to increase during decomposition. Although C18:2 and C18:3 are known to decrease through oxidation, plant lipids frequently comprise large concentrations of C18:2 and no C18:3 (Marchbanks 1989:68-69). Therefore, they were included in the calculation because of their diagnostic potential. An analysis of modern foods indicated that the %S value does separate the categories of plant, terrestrial animal, and fish into distinct groups, based on their saturated and unsaturated fatty acid distributions (Marchbanks 1989:95). Marchbanks (1989:75-81) was also able to use the %S values of archaeological residues to suggest which vessels may have been used to cook or store foods which were mostly vegetables, mixtures of plants and animals, or animal products. However, because of the expected rapid loss of polyunsaturated fatty acids from archaeological residues, interpretations of animal origins may sometimes be made in error.

Skibo (1992:89, 90) found that he could not calculate %S in his study as many of the foods used by the Kalinga do not contain either C12:0 or C14:0. Therefore, it may be that there is no one method suited to interpreting fatty acid data from ceramic vessels from every archaeological site. Some methods rely on too few fatty acids to make identifications while other methods require that specific fatty acids be present. Unfortunately, owing to differences in the original fatty acid profiles of the foods/dishes, and to differences in the factors responsible for preservation and degradation of the residues, key fatty acids required for each method are not always present in residues from every site or region.

Two other studies (Deal *et al.* 1991; Morgan *et al.* 1984) consider the cumulative percentage of those fatty acids remaining in the archaeological residues analysed,

normalized to 100%, and also look for the presence of signature fatty acids in order to suggest identifications for the residues. These fatty acid distributions are then compared to the cumulative percentages of the same saturated and monoenoic fatty acids in modern reference materials. In both studies, it was expected that some type of marine animal was the source of the lipid residue. Therefore, the researchers selected very specific and a very narrow range of comparative samples in order to make the comparisons and identifications. This interpretive technique can be expected to be much more difficult to apply starting with unknown residues, a large collection of archaeological vessels, and a greater number of comparative food standards. Nonetheless, the "qualitative-feel" to this approach may be useful for rapid characterization of a large number of samples.

The approach that I use to characterize the residues in this study of Maya ceramics follows Malainey (1997; Malainey *et al.* 1999). Malainey analysed the fatty acid distribution of 19 experimental residues that she prepared by cooking and decomposing modern food standards in replica vessels. Six food categories were defined on the basis of the relative percentages of medium chain fatty acids (C12:0, C14:0, C15:0), C18:0, and C18:1 isomers in the degraded residues (Malainey 1997:184-185; Malainey *et al.* 1999:426). Malainey (1997:185-195) argues that the identification criteria are valid as they are supported by the results of hierarchical cluster analysis and principal component analysis which were used to group the archaeological residues from vessels found at sites in the northern Plains, parkland, and southern boreal forest of Western Canada. She found strong correspondence between the statistical groupings and the archaeological residue identifications made within each group. For example, all of the residues within one of three major clusters are identified as large herbivore or large herbivore with plant (Malainey 1997:185; Malainey *et al.* 1999:432-434). Further, the residue identifications are supported by faunal and tool assemblages at the different sites

(Malainey *et al.* 1999:435). Malainey and her colleagues (1999:437) imply that these same criteria may eventually be applied outside her study area. However, the initial fatty acid composition of foods in other study areas may differ, as might conditions for preservation and degradation. Therefore, I expect it will be necessary to establish unique criteria using degraded cooking residues of foods from the Maya area.

4.5 Isotopic analysis of charred residues

Isotopic analysis was added to the archaeologist's repertoire of techniques for reconstructing past foodways twenty years ago (Vogel and van der Merwe 1977; van der Merwe and Vogel 1978). Determining patterns of food consumption in antiquity using measurements of the ratios of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ in ancient human tissues is now routinely done due, in part, to the fact that the theoretical principles are easily understood, laboratory procedures are not complicated, and the results are consistently reliable. Isotopic analysis can also be used to investigate food preparation, serving (or distribution) and consumption patterns by measuring the carbon and nitrogen isotopic composition of charred residues found cooked onto the interior surfaces of some ceramic vessels (Hastorf and DeNiro 1985). To understand how isotopic analysis can be used to identify the former contents of ceramic vessels, it is essential to know how and why stable carbon and nitrogen isotope ratios divide foods into different groups. In the sections that follow, I explain the theoretical principles of isotopic analysis and describe the isotopic composition of foods eaten by Preclassic and Classic Maya.

4.5.1 Stable isotopes, fractionation, and delta values

In this section, terms and concepts necessary for understanding isotopic analysis of charred residues are defined. O'Leary (1981), van der Merwe (1982), and DeNiro (1987) have written useful review articles which provide more detail than is given here.

In studies of ancient diets and foodways, the elements of interest are stable (non-radioactive) isotopes of carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$) in human tissues (DeNiro 1987; van der Merwe 1982) and charred organic cooking residues (Hastorf and DeNiro 1985; Morton 1989). Isotopes are atoms of the same element that have the same number of protons and electrons but different numbers of neutrons. Therefore, isotopes have different atomic weights. For example, ^{13}C has 6 protons and 7 neutrons and an atomic weight of 13 whereas ^{12}C has just 6 neutrons and an atomic weight of 12. Consequently, isotopes react in the same manner but at different rates in a chemical reaction. This can result in fractionation, which is a change in the isotopic ratio between the original substance and the product in a reaction. It is significant, in terms of isotopic studies of past foodways, that carbon isotopes are fractionated during plant photosynthesis and nitrogen is fractionated as it passes between consumers in a food chain.

4.5.2 Classification of edible plants using carbon and nitrogen isotope ratios

Two groups of terrestrial plants are distinguished by their carbon isotope ratios. The distinction exists because plants using different photosynthetic pathways discriminate against ^{13}C to different degrees as they incorporate and convert atmospheric CO_2 to carbon during photosynthesis (Park and Epstein 1960; Smith and Epstein 1971). C3 plants use the enzyme ribulose biphosphate carboxylase (Calvin and Benson pathway) to convert atmospheric CO_2 to a three-carbon compound (O'Leary 1981:554; Park and Epstein 1960; Smith and Epstein 1971). Their $\delta^{13}C$ values range from -20‰ to -35‰ and average -26.5‰. Adapted to low light and moist conditions, the majority of wild and cultivated food plants are C3 plants. Some examples are roots and tubers, vegetables, and many fruits, nuts, and grains including rice and wheat (Ambrose 1993:86; DeNiro 1987:183; van der Merwe 1982:597). C4 plants fix atmospheric CO_2

using phosphoenol pyruvate carboxylase (Hatch and Slack pathway) converting it to a four-carbon compound (Hatch and Slack 1970:148-150; O'Leary 1981:554; Smith and Epstein 1971). They discriminate less against $^{13}CO_2$ and have higher $\delta^{13}C$ values which vary from -6 to -19‰ and average -12.5‰, although maize is typically heavier (-11.5‰, Tieszen and Fagre 1993:35). C4 plants are adapted to arid and semi-arid regions with strong sunlight and high temperatures during the growing season (Ambrose 1993:86; van der Merwe 1982:598). Maize, sorghum, millets, sugar cane, and some amaranths and chenopods are examples of edible C4 plants (Bender 1968: 468; DeNiro 1987:184; van der Merwe 1982:597). Succulents utilize crassulacean acid metabolism (CAM) meaning they use the C4 pathway under some conditions but the C3 pathway under others (Nalborcyzyk *et al* 1975, cited in O'Leary 1981:553). Their $\delta^{13}C$ values may be similar to either C3 or C4 plants. Edible CAM plants are rare and of secondary importance in only a few human diets. They include agave, yucca, pineapple, piñuela, and prickly pear (DeNiro 1987:184; van der Merwe 1982:597).

In prehistory, $\delta^{13}C$ values of C3 and C4 plants were probably closer to -25.5‰ and -11.5‰, respectively. Recent burning of fossil fuels has introduced large amounts of ^{13}C-depleted CO_2 into the atmosphere, lowering the $\delta^{13}C$ value of atmospheric CO_2 (to about -7.8‰; Keeling 1961:281; Marino and McElroy 1991:127, 131) and that of the plants growing in it by as much as 1.5‰ (DeNiro 1987:183; Smith and Epstein 1971:380). For example, $\delta^{13}C$ values of archaeological maize have been found to be heavier than modern varieties ($\delta^{13}C$ = -8.7 to -9.3‰) (Schwarcz *et al.* 1985; Tieszen and Fagre 1993:36; Wagner 1988, cited in Tieszen and Fagre 1993:36).

Nitrogen isotope ratios also separate terrestrial plants into two groups (DeNiro 1987:184; Virginia and Delwiche 1982). Legumes have $\delta^{15}N$ values of roughly +1‰ and non-legumes, grown without the use of isotopically depleted chemical fertilizers, have higher $\delta^{15}N$ values averaging +2 to +4‰. The isotopic separation between legumes and

non-legumes occurs because legumes fix nitrogen from both atmospheric N_2 ($\delta^{15}N \cong 0‰$) and from soil, whereas non-legumes derive nitrogen only from nitrate (NO_3^-) and ammonium (NH_4^+) ions in the soil. Nitrogen in natural soils originates from decaying plant matter (Létolle 1980:417) and then undergoes numerous fractionations during processes of denitrification by bacteria, oxidation of ammonia to nitrate, and discrimination against ^{15}N enriched NH_4^+ by some soil organisms (Ambrose and DeNiro 1986:396; Létolle 1980:416, 417; Rennie *et al.* 1976:44). The rate and extent to which each of these processes occurs is a factor of local conditions of climate and environment. Thus, $\delta^{15}N$ values of soils vary considerably (-1 to +17‰) but generally are higher than atmospheric N_2, averaging about +7‰ (Cheng *et al.* 1964; Létolle 1980:417; Rennie *et al.* 1976:46).

Considered together, $\delta^{13}C$ and $\delta^{15}N$ values separate terrestrial plants into three groups: non-leguminous C3 plants ($\delta^{13}C$ = -25.5‰, $\delta^{15}N$ = +2 to +4‰), non-leguminous C4 and CAM plants ($\delta^{13}C$ = -11.5‰ [-9‰ for maize], ($\delta^{15}N$ = +2 to +4‰), and C3 legumes ($\delta^{13}C$ = -25.5‰, $\delta^{15}N$ = +1‰) (Figure 4.7).

4.5.3 Classification of animals (meat) using carbon and nitrogen isotope ratios

An animal's diet is the primary determinant of the carbon and nitrogen isotopic composition of its tissues (Bender *et al.* 1981; DeNiro and Epstein 1978, 1981). Fractionation can occur during metabolism and tissue synthesis. For example, the $\delta^{13}C$ value of bone collagen is roughly 3 to 5 ‰ more positive than that of the diet (DeNiro and Epstein 1978:503; van der Merwe 1989:114; Vogel 1978:299). Controlled diet experiments have shown that fractionation of $^{13}C/^{12}C$ ratios between diet and muscle (meat) is somewhat unpredictable with $\delta^{13}C$ values of muscle being within ±2‰ of an animal's diet (Bender *et al.* 1981:347; DeNiro and Epstein 1978, 1981; Tieszen *et al.* 1983:33). On average, however, the $\delta^{13}C$ value of muscle is about 1‰ more positive

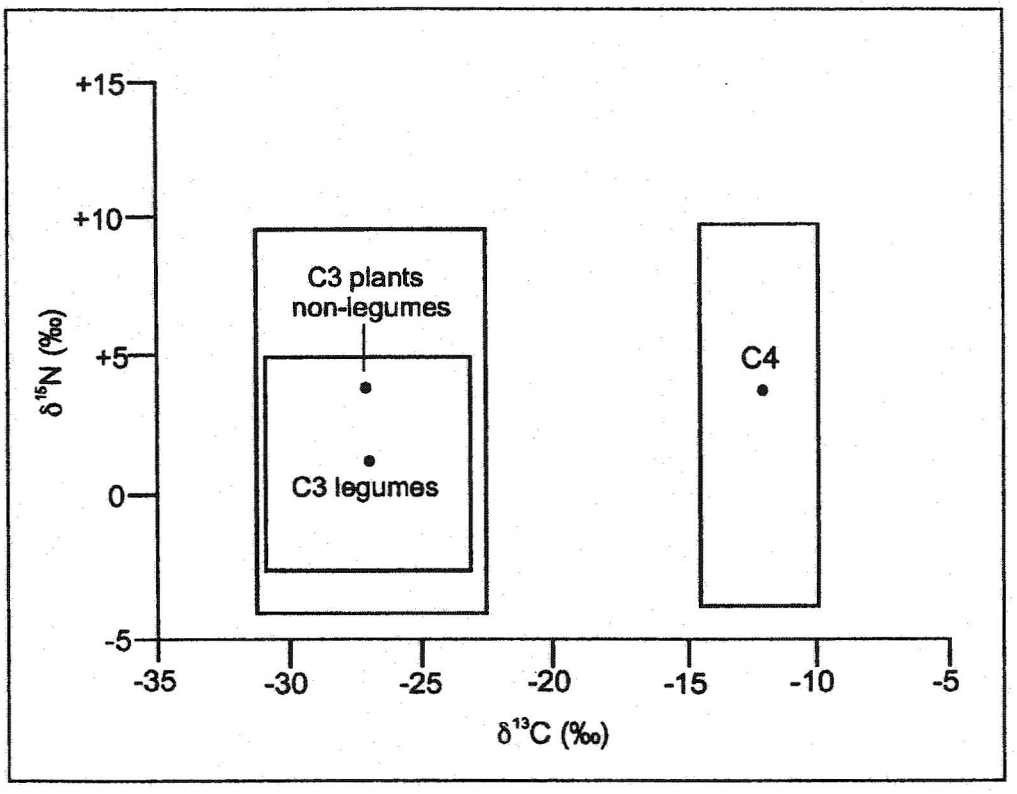


Figure 4.7 Separation of terrestrial plants into three groups: non-leguminous C3 plants, non-leguminous C4 and CAM plants, and C3 legumes by their $\delta^{13}C$ and $\delta^{15}N$ values.

than that of the diet. The $\delta^{15}N$ values of an animal's muscle and collagen are both enriched by 3‰ relative to the diet so that increasingly elevated $\delta^{15}N$ values exist in the tissues of animals at higher trophic levels in both terrestrial and marine food webs (DeNiro and Epstein 1981:344, 345; Schoeninger 1985).

Plants and, in some marine habitats, chemoautotrophic bacteria are the primary producers in a food web which ultimately provide carbon and nitrogen to all higher order consumers. Plants in various food webs make use of different sources of carbon and

nitrogen and, therefore, animals from each food web have a distinctive pattern of carbon and nitrogen isotope ratios. The categories of animals that can be identified based on their isotopic composition are terrestrial herbivores and carnivores, marine animals, coral reef fish and shellfish, and freshwater fish (Figure 4.8).

terrestrial herbivores and carnivores

Terrestrial animals cannot be distinguished from other categories of plant or animal foods by their carbon isotopic composition. Their sources of carbon are the edible plants discussed in preceding paragraphs. Thus, $^{13}C/^{12}C$ ratios found in terrestrial animals are quite variable (Figure 4.8). The $\delta^{13}C$ values do allow distinctions to be made between terrestrial animals that consume C3, C4, or a mix of C3 and C4 resources. However, a C3, C4, or mixed C3-C4 signal in a charred residue or human bone could not be attributed to the use of either plants or animals because the amount of ^{13}C enrichment between trophic levels is extremely small (≤ 1‰) (Schoeninger 1985:516; Schoeninger and DeNiro 1984:636).

Terrestrial animals are characterized by their nitrogen isotopic composition (Figure 3.3). Terrestrial herbivores have $\delta^{15}N$ values of +5 to +7‰ (Schoeninger 1985:523; Schoeninger and DeNiro 1984:631) that are more positive than the range of +1 to +4‰ observed in terrestrial plants. Terrestrial carnivores typically have $\delta^{15}N$ values of +9‰ or higher (Schoeninger 1985:523).

temperate marine animals

Temperate marine animals have a pattern of relatively heavy $\delta^{13}C$ values and some of the most elevated $\delta^{15}N$ values (Chisholm *et al.* 1982; Schoeninger and DeNiro 1984; Tauber 1981) (Figure 4.8). A $\delta^{13}C$ value of -18‰ has been measured for the flesh of marine animals (Chisholm *et al.* 1982:1132). A similar value is suggested by the average

$\delta^{13}C$ value (-13‰) of bone collagen of marine animals (Schoeninger and DeNiro 1984:635) remembering that carbon isotopes are fractionated by -3.7‰ (Keegan and DeNiro 1988:329) between the diet and collagen and that the carbon isotopic composition of the flesh differs from that of the diet by only ≤1‰. The 5.5‰ separation between terrestrial and temperate marine animals (Schoeninger and DeNiro 1984:632) arises from the different sources of carbon in the two food webs. The sources of carbon in most temperate marine food webs, dissolved bicarbonate and carbonic acid (≅ 0‰) produce $\delta^{13}C$ values in marine plants (-10 to -18‰) which are roughly 7.5‰ more positive than those of terrestrial C3 plants (Tauber 1981:332). Elevated $\delta^{13}C$ values will indicate use of temperate marine resources in circumstances where terrestrial C4 foods, or a mixture of C3 and C4 foods were not used, as these foods have $\delta^{13}C$ values similar to those of marine resources (Chisholm *et al.* 1982:1132; Tauber 1981:332). This limitation can be overcome by also using nitrogen isotopic data.

Temperate marine plants fix nitrogen from dissolved nitrate and ammonium. The nitrogen isotopic composition of these sources varies widely according to local ocean conditions (Sweeney *et al.* 1978:18-19). Therefore, the isotopic composition of the plants also varies but has a mean $\delta^{15}N$ of +7‰. Coastal peoples tend to eat relatively few marine plants, however, focusing instead on marine fish, shellfish, and mammals. Marine food chains are longer than terrestrial ones. Therefore, marine carnivores are at higher trophic levels and have enriched $\delta^{15}N$ values (mean = +15‰ [Schoeninger and DeNiro 1984:631]) compared to their terrestrial counterparts due to additional trophic level increases in ^{15}N (Schoeninger and DeNiro 1984). Therefore, it is possible to distinguish between the utilization of marine fauna and terrestrial resources. While their $\delta^{15}N$ values may overlap with those of freshwater fish (see below), marine animals have more positive $\delta^{13}C$ values compared to freshwater fish.

coral reef animals

Marine fauna from Caribbean coral reef habitats are distinguishable by a combination of elevated $\delta^{13}C$ values and depleted $\delta^{15}N$ values (Keegan and DeNiro 1988; Tykot *et al.* 1996:357; van der Merwe *et al.* 1994) relative to fauna from other marine habitats. Flesh of reef molluscs and fishes collected in the Bahamas has an average $\delta^{13}C$ value of -11‰, and $\delta^{15}N$ values of +3‰ for molluscs, +7.5‰ for fish, and +9.5‰ for secondary fish carnivores (Keegan and DeNiro 1988:330, 331). Nearly identical values are obtained when bone collagen measurements for reef fish caught off the coast of Belize ($\delta^{13}C$ = -7.3±2.0‰; $\delta^{15}N$ = +6.8±1.4‰) (Tykot *et al.* 1996:357; van der Merwe *et al.* 1994) are converted to values for flesh using fractionation factors of -3.5‰ for $\delta^{13}C$ and +1.6‰ for $\delta^{15}N$ reported by Keegan and DeNiro (1988: Table 3 p. 326, 329) for modern fish from a Bahamian reef. Belizean reef molluscs $\delta^{13}C$ = -13.3‰; $\delta^{15}N$ = +3.5‰) (Tykot *et al.* 1996:357; van der Merwe *et al.* 1994) are also similar in isotopic composition to those from the Bahamas. The isotopic pattern seen in reef animals originates at the base of the food chain with blue-green algae, seagrasses, and corals. Blue-green algae (cyanobacteria) fix N_2 as well as nitrate and ammonia and supply isotopically depleted nitrogen ($\delta^{15}N$ = 0‰) within reef communities (Capone *et al.* 1977; Stewart 1978:171; Wada and Hattori 1976, cited in Wada 1980:380, 393). Seagrasses utilizing this source of nitrogen also have low $\delta^{15}N$ values ranging from -1.9 to +2.3‰ (Goering and Parker 1972, cited in Wada 1980:393). The $\delta^{13}C$ values of seagrasses are similar to those of C4 plants (-11.4‰) because they use the C3 photosynthetic pathway in a unique, closed system to fix dissolved inorganic carbon in sea water (-10.3‰) (Benedict *et al.* 1980; Fry and Sherr 1984:19).

freshwater fish

Freshwater fish typically have very low $\delta^{13}C$ values and high $\delta^{15}N$ values (Figure 4.10) although, in fact, their isotopic values vary widely and can overlap with the lowest $\delta^{13}C$ values and the most elevated $\delta^{15}N$ values observed in terrestrial animals (Schoeninger and DeNiro 1984:632). Reported $\delta^{13}C$ values for flesh of freshwater fish range from -36 to -18‰ (France 1996; Fry 1991; Hamilton *et al.* 1992; Keough *et al.* 1996:141; Schoeninger and DeNiro 1984:632) and $\delta^{15}N$ values span +5 to +16‰ (France 1995, 1996; Fry 1991; Hamilton *et al.* 1992:327; Keough *et al.* 1996:142; Minagwa and Wada 1984:1136; Schoeninger and DeNiro 1984:632). The wide range of $\delta^{13}C$ values may be explained by the fact that the principal source of food for freshwater fish is phytoplankton (Hamilton *et al.* 1992; Keough *et al.* 1996). Typical $\delta^{13}C$ values for phytoplankton range from -24 to -30‰ but can be as low as -35 to -45‰ in some small lakes (Fry and Sherr 1984:35; Keough *et al.* 1996:141, 142). Initially, phytoplankton obtain carbon from dissolved CO_2, the isotopic composition of which varies locally according to the relative contributions of atmospheric CO_2 and CO_2 respired from decaying organic matter in the water (Hamilton *et al.* 1992:326). The diverse $\delta^{15}N$ values in freshwater fish also originate with phytoplankton, which vary between -1 and +6.5‰ (Hamilton *et al.* 1992:327; Keough *et al.* 1996:142; Minagwa and Wada 1984:1136) and then are amplified because fish occupy more than one trophic level within freshwater food webs.

4.5.4 Preservation of the isotopic signal in charred organic residues

Isotopic analysis can be used to identify which group[s] of food contributed to the formation of a charred residue because the original carbon and nitrogen isotopic composition of the foods is altered little during cooking and charring processes. Experiments in which modern examples of plant and animal foods were processed (fermented, maize soaked in lime), cooked (boiled, roasted), or carbonized show that $\delta^{13}C$

and $\delta^{15}N$ values shift by only ±2‰ (DeNiro and Hastorf 1985; Marino and DeNiro 1987; Sherriff *et al.* 1995:101). DeNiro and Hastorf (1985) also demonstrate that similar isotopic shifts occur in archaeological examples of carbonized plant remains and argue that the isotopic values are essentially unchanged by processes of cooking, charring, and diagenesis. None of the reported changes are large enough to mask the isotopic separation of the different categories of foods. Therefore, it is possible to use the isotopic composition of carbonized residues to identify the preparation of any of the categories of food discussed in the preceding section, or to suggest combinations of foods which would produce similar isotopic ratios, using knowledge of the types of foods that were available to a group of people at a particular time in the past.

4.5.5 Isotopic categories of Ancient Maya foods

To arrive at reliable interpretations of isotopic data, it is important to be able to compare the results of an analysis to the isotopic composition of foods from the study area. Therefore, as researchers began to investigate what the ancient Maya ate using isotopic analysis of human bone collagen, they also began to categorize the foods available in the Maya area by measuring the carbon and nitrogen isotopic composition of archaeological and modern examples (Gerry 1993:215-217; Tykot *et al.* 1996:357; White 1986; White and Schwarcz 1989:46; Wright 1994:202, 207-208). The results of their work are presented in Figure 4.8, an isotopic model of Maya foods, and are summarized here.

The Maya used plants from each of the isotopic categories C4, C3 non-legumes, C3 legumes, and CAM in Pre-Hispanic times. The staple crop maize (*Zea mays*) is a C4 plant, as are the grains goosefoot (*Chenopodium ambrosioides*, or *quinoa, epazote*) and amaranthus (*Amaranthus* sp.) (Schwarcz *et al.* 1985:195; Smith and Epstein 1971:381).

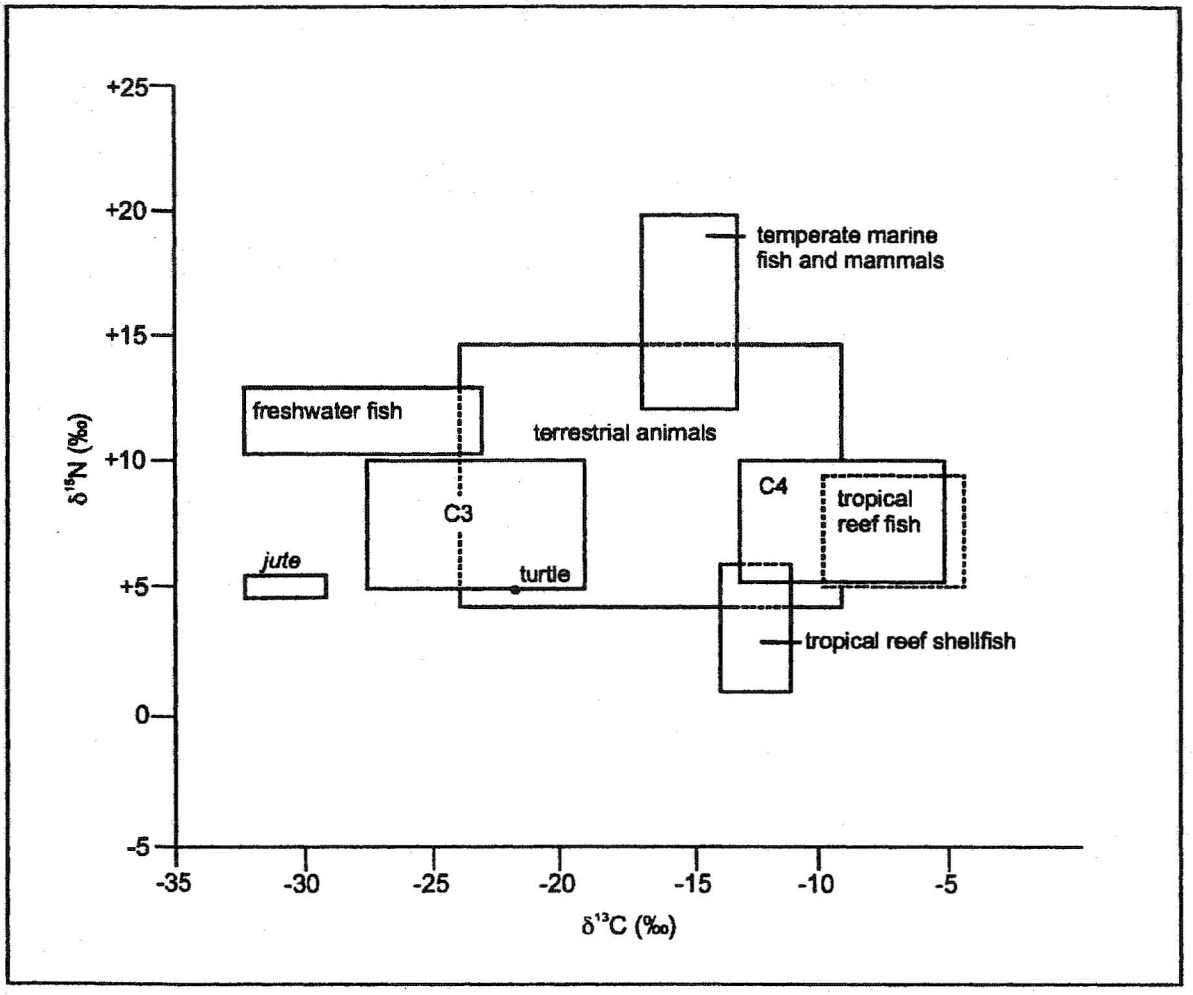


Figure 4.8 Isotopic model of Maya foods (data from Gerry 1993:215-217; Tykot *et al.* 1996:357; White 1986; White and Schwarcz 1989:46; Wright 1994:202, 207-208).

The $\delta^{13}C$ values of modern maize from locations in Belize and Guatemala range from -10.7 to -11.2‰ (n=3) suggesting a prehistoric value of -9 or -10‰. Two CAM plants available in some parts of the Maya area, *piñuela* (*Bromelia karatas*) and nopal cactus (*Opuntia* spp.) also have been shown to have a C4-like signature (Wright 1994:203). Beans (*Phaseolus vulgaris*) are C3 legumes and virtually all of the other cultigens, including squashes and roots and tubers, along with wild greens, fruits, and nuts are non-leguminous C3 types. The average $\delta^{13}C$ value for modern C3 food plants reported in the

literature is -27.4±3.6‰ (range -34 to -25‰). The small amounts of nitrogen present in plants make it difficult to measure $\delta^{15}N$ values. However, the few numbers obtained by Wright (1994:204) range from 0.5 to 5.5‰.

In the Maya area, two isotopically distinct groups of terrestrial mammals were utilized - game and maize-fed domesticates. The average $\delta^{13}C$ value of terrestrial game animals is -20.9±2.4‰ and a mean $\delta^{15}N$ value of 4.5±3.1‰ reflecting the consumption of diets that consist largely of C3 plants from the tropical forest. These values were obtained from analyses of archaeological bone collagen, primarily from remains of deer (brocket and white-tailed deer) and peccary but also paca, tapir, and armadillo excavated at sites in the Pasion region of Guatemala (Gerry 1993; Wright 1994), northern Belize (Tykot *et al.* 1996; White 1986; White and Schwarcz 1989; White *et al.* 1999), and Copán (Gerry 1993). To this point, no archaeological remains of deer have carbon isotopic compositions that indicate that the Maya fed them maize. Rather, consistently low $\delta^{13}C$ measurements for collagen of archaeological deer bone, excavated from sites in the Petexbatún region in Guatemala ($\overline{X}$ = -20.6‰), and from Colhá, in Belize ($\overline{X}$ = -21.1), are more consistent with a diet of C3 forest browse (Emery *et al.* 2000:542; White *et al.* 2001:102). Domestic dogs were, however, fed maize. This is reflected in elevated $\delta^{13}C$ values of -11.7±3.5‰ (data from Gerry 1993; Tykot *et al.* 1996; White and Schwarcz 1989; White *et al.* 1998). Similar values might also be expected for domestic turkeys but none have been analysed. The mean $\delta^{15}N$ value for dogs (+7.8±1.6‰) is also higher than for game animals suggesting omnivorous diets as compared to the herbivorous diets of game.

Of course, exceptions to this game *versus* domesticate division can be expected where game, such as armadillo or peccary, scavenged maize from *milpas*, and as bone from a greater number of species is analysed the carbon isotopic separation, at least, may become more blurred. In addition, turtles, which were relatively important at some

inland settlements (Emery 1990; Pohl 1985; Wing and Scudder 1991), have isotopic compositions very similar to terrestrial game ($\delta^{13}C$ = -23.8±2.1‰, $\delta^{15}N$ = +6.1±1.4‰) (data from Tykot *et al.* 1996; White and Schwarcz 1989; Wright 1994) and their potential input should be considered when interpretations of isotopic data are made.

Two isotopic categories of fish were also accessible at some of the Lowland Maya sites. Coral reef fish were certainly caught along the Caribbean coast. Modern examples of fish from Belizean waters have an average $\delta^{13}C$ value of -7.3±2.0‰ and a mean $\delta^{15}N$ value of +6.8±1.4‰ (Tykot *et al.* 1996:357). Shellfish from the same habitat have values of -13.3±1.8‰ and +3.5±1.3‰ for carbon and nitrogen, respectively (Tykot *et al.* 1996:358). Freshwater fish were available at some inland sites, including sites in the Pasíon region where modern fish have mean isotopic ratios of -29.2±3.1‰ for carbon and +11.2±1.4‰ for nitrogen (Wright 1994:208).

Finally, there are snails that do not fit neatly into any of the other isotopic groups. Snails have depleted $\delta^{13}C$ values, similar to freshwater fish (-31.8±2.5‰, n = 2), but lower $\delta^{15}N$ values (+5.2±0.2‰, n = 2) that are within the range expected for terrestrial herbivores (values are for *Pachychilus glaphyrus* from Wright 1994:208). Snails, however, are not expected to have made a major contribution to ancient Maya diets (Healy *et al* 1990).

4.6 Summary

Despite significant developments in analytical techniques in recent years, food residue analyses are still undertaken infrequently. One reason for this, I suggest, is that although it has been shown that the analytical methods are sound, as are some of the identifications, the utility of residue analysis for investigating foodways of ancient societies has not yet been adequately demonstrated. A review of the food residue literature (Section 4.3) reveals that, with few exceptions (e.g. Hastorf and DeNiro 1985;

Malainey 1997), only one or several vessels are analysed (Evershed *et al.* 1992:189) and the identifications of the vessel contents have not been incorporated into interpretations of human activities in the past (e.g. Biers *et al.* 1988; Charters *et al.* 1995; Evershed *et al.* 1994; Hurst *et al.* 1989, among others). This circumstance is due, in part, to the fact that any new approach must start small. However, another factor is the role which many archaeologists assign to archaeometry, one that is alluded to in the quote from Evans (1990) cited at the beginning of this chapter. There is a tendency for archaeologists involved in residue projects to hope or believe that "the noble chemist" can provide information that they themselves cannot access. Therefore, this information may be different and perhaps even more valid than what can be gained by studying the material remains of foodways collected at archaeological sites. Thus, the answer to the only question that the chemist really can contribute to ("What was in the pot?") has sometimes become an end in itself. Although the answer is often not uninteresting, it is typically not satisfactory.

In addition, the preceding description and discussion of the techniques used to analyse and identify absorbed lipid and charred surface residues clearly states that a great majority of identifications of the original contents of archaeological vessels will be limited to general categories of food (i.e. animal, plant, fish, dairy, C3 or C4 plant). In most cases, the identifications are less specific and more tenuous than identifications made using faunal and botanical remains. Identifications of genus and species, while not out of the realm of possibility in some cases, will be very rare. There simply is not enough knowledge of unique or specific biomarkers for so many of the foods used in prehistory and it will take many decades to acquire this information. Consequently, given the time and expense required, many archaeologists remain hesitant to undertake residue projects themselves.

Of course, more general identifications are not entirely uninformative as was apparent in a number of residue studies, and in the success of isotopic studies of human bone. Given the time and costs involved in sample preparation, running samples, and interpreting the results, for lipid analyses in particular, the following question should be asked. Does the quality of the information obtained through residue analyses justify further application to investigations of concern to archaeology and the study of ancient foodways? This is a question that I will explore in the chapters that follow.

Chapter 5

Methods:
Sample Selection, Laboratory Protocols, Instrumentation, and Calculations

5.1 Introduction

The first part of this chapter is a discussion of how archaeological vessels and modern, comparative food standards were selected for this study of food residues. The sample of vessels obtained from each site is also described. The following sections include descriptions of the laboratory protocols used to prepare samples for gas chromatographic and isotopic analyses, as well as the parameters of the analytical instruments (gas chromatograph and mass spectrometer) used. The final part of the chapter explains how the fatty acids were identified, as well as several calculations that were used to organize and interpret the residue data.

5.2 Criteria for the selection of archaeological sherd and soil samples

The selection of archaeological sherds for residue analysis was governed by a number of considerations. The main concern was to obtain a sample of vessels from each site in the study that might be informative about Maya foodways and household economies. Therefore, the sherds selected represent vessel forms including small to medium jars and large bowls that might have been used as cooking or serving vessels. Most vessels were excavated from domestic contexts including residences or their associated storehouses, storerooms, middens, yards or patios, and *chultunob*. Sites used in the study include the Preclassic settlements of Cuello and K'axob, Belize,

and the Classic period communities of Aguateca, Guatemala, and Cerén, El Salvador (sections 2.3 and 2.4). The ceramic collections from Cerén and Aguateca were viewed as potentially very valuable since both of these Classic period sites were abandoned suddenly. As a result, they contain identifiable vessel forms (often complete vessels) that were left in the exact locations in which they were used (Sheets 1992; Takeshi Inomata personal communication). Moreover, because the sites sampled include both Preclassic and Classic period settlements, the opportunity existed to examine temporal changes in patterns of food preparation related to remodeling of domestic economies. Of course it may sometimes be difficult to distinguish between temporal change and geographic differences in cooking practices, given the spatial and temporal distances between the sites included in the study.

Most sherds chosen for the analysis of lipids are from the rim, neck, or shoulder area of the vessels where such residues tend to accumulate (Charters *et al.* 1993; 1997:4-6). Many of the sherds from bowls are described as body sherds, however the bowls are quite shallow and the sherds were taken from the upper half of the vessels. Several examples of body sherds were also selected from jars that have waxy, blackened interiors that suggest carbonized foods once adhered to the surfaces rather than blackening by fire clouding. All of the sherds provided by Norman Hammond for the isotopic analysis of charred encrustations are body sherds.

Only the vessels from Aguateca were excavated during the course of this project. Therefore, only these sherds were handled in a manner ideal for residue studies. The sherds were immediately wrapped in foil upon excavation without being handled, washed, or stored in plastic. As soon as it was possible, the sherds were placed in a freezer for storage until they could be analysed. In contrast, vessels from Cuello, K'axob, and Cerén had been excavated several years prior to analysis for residues. The sherds had been handled, washed, catalogued, analysed, and stored, at times in plastic

bags, and the vessels from Cerén had also been reconstructed. It was a conscious decision to use curated ceramic collections in this project. Such collections are readily available and if residue analysis is ever to be a technique that is routinely used, I expect that archaeologists will hope that it can be applied to materials that they have already excavated.

One advantage of taking residue samples during an excavation is that samples of the soils from which the sherds are excavated can also be collected for analysis. Soils from Aguateca were collected in a similar manner as the sherds in order to test for possible contamination of the ceramic material with soil lipids (Heron *et al.* 1991:657). It was not possible to obtain soil samples from the other sites. This is not expected to be a problem, however, as investigations have shown that the movement of soil lipids into archaeological ceramics is negligible (Heron *et al.* 1991).

5.2.1 Descriptions of the samples

Cuello

Fifty-one vessels from Cuello, excavated from Middle Preclassic (N=36) and Late Preclassic (N=15) occupations, were analysed. The Middle Preclassic sample includes 23 unslipped, utilitarian vessels represented by one or multiple body sherds covered with charred encrustations on much of the interior surfaces. Initially, only these vessels were to be analysed but the sample was expanded to include ceramics without surface residues, and a wider variety of vessel forms in order to understand the role that charred residues might have in the preservation of absorbed lipids. This group of ceramics (n=29) includes unslipped jars as well as slipped bowls, dishes, and one bottle-top. All vessels are from residential contexts including yards (living surfaces covered with thin sheets of midden outside of house structures) and refuse swept into two *chultunob*

Table 5.1. Descriptions of vessels included in the sample from Cuello, Belize.

Sample	Vessel	Form	Sherd Type	Char	Context	Description
Swasey (1200-900 BC):						
CU99.17	4569	unid.	body	√		Not identified
Swasey/Bladen:						
CU99.22	2952-1	bowl	rim		refuse	Bowl; Consejo Red: Consejo Variety
CU99.9	2952-2	bowl	rim, body		chultun	Bowl; Backlanding Incised: Grooved Incised Variety
Bladen Phase I (900-800 B.C.):						
CU99.13	4063.01.40	jar	rim, neck		refuse	Large open-mouthed jar; Chicago Orange: Nago Bank Variety
CU99.8	4357.01.01	jar	neck,shoulder		refuse	Jar; Tiger Buff: Cut and Throw Away Variety
CU99.23	4357.01.12	bowl	rim		refuse	Bowl; Machaca Black: Wamil Variety
CU99.27	4358	bowl	base, body		chultun	Bowl; Consejo Red: Estrella Variety
CU99.4	4566-1	olla/jar/bowl	body	√		Large, open-mouthed olla/jar/bowl with rounded bottom† Chicago Orange: Nago Bank Variety
CU99.5	4566-2	unknown	body	√		Form unknown but likely similar to Chicago Orange Tiger Buff: Cut and Throw Away Variety
CU9.19	4623-1	olla/jar/bowl	body	√		Large, open-mouthed olla/jar/bowl with rounded bottom Honey Camp Brown: Honey Camp Variety
CU99.20	4623-2	unknown	body	√		Not identified
CU99.21	4623-3	unknown	body	√		Not identified
CU99.18	4631	olla/jar/bowl	body	√		Large, open-mouthed olla/jar/bowl with rounded bottom† Chicago Orange: Nago Bank Variety
CU99.7	4639	olla/jar/bowl	body	√		Large, open-mouthed olla/jar/bowl with rounded bottom Tiger Buff: Cut and Throw Away Variety
CU99.15	4682	unknown	body	√	chultun	Chicago Orange: Nago Bank Variety

† Compare with Figure 4.18 in Kosakowsky 1987:39.

Table 5.1. (continued)

Sample	Vessel	Form	Sherd Type	Char	Context	Description
Bladen Phase Ia (900-800 B.C.):						
CU99.14	4585	olla/jar/bowl	body	√		Chicago Orange: Nago Bank Variety
---	4627-1	bottle	bottle top	√		Bottle top, possibly of a monopod bottle Chicago Orange: Nago Bank Variety
CU99.16	4627-2	olla/jar/bowl	body	√		Large, open-mouthed olla/jar/bowl with rounded bottom† Chicago Orange: Nago Bank Variety
---	4630	unknown	body	√		Not identified
CU99.24	4632	olla/jar/bowl	body	√		Large, open-mouthed olla/jar/bowl with rounded bottom† Chicago Orange: Nago Bank Variety
---	4634	unknown	body	√	chultun	Not identified
CU99.12	4649	olla/jar/bowl	body	√	chultun	Large, open-mouthed olla/jar/bowl with rounded bottom† Chicago Orange: Nago Bank Variety
CU99.26	4661-1	olla/jar/bowl	body	√	chultun	Large, open-mouthed olla/jar/bowl with rounded bottom Honey Camp Orange-Brown: Honey Camp Variety
CU99.28	4661-2	olla/jar/bowl	body	√	chultun	Large, open-mouthed olla/jar/bowl with rounded bottom Tiger Buff: Cut and Throw Away Variety
CU99.29	4661-3	unknown	body	√	chultun	Form unknown but likely similar to Chicago Orange Copetilla Unslipped: Gallon Jug Variety
CU99.25	4691	olla/jar/bowl	body	√	chultun	Large, open-mouthed olla/jar/bowl with rounded bottom† Chicago Orange: Nago Bank Variety
Lopez-Mamom (650/600-400/300 B.C):						
CU99.31	2393	dish	body nr. base		refuse	Dish; Guitara Incised: Grooved Incised Variety
CU99.32	2415	dish	base		refuse	Dish; Muxanal Red on Cream: San Lazaro Variety
CU99.2	2466	*tecomate*	neck		refuse	Tecomate; Chicago Orange: Warrie Camp Variety
CU99.10	2978	jar	neck, shoulder		chultun	Large open-mouthed jar; Chicago Orange:Warrie Camp Variety
CU99.36	4079 [4079.01.40]	jar	neck,shoulder		chultun	Large open-mouthed jar; Chicago Orange:Warrie Camp Variety

Table 5.1. (continued)

Sample	Vessel	Form	Sherd Type	Char	Context	Description
Lopez-Mamom (continued):						
CU99.33	4104/5.01.1	dish	base		refuse	Dish; Muxanal Red on Cream: San Lazaro Variety
CU99.17	4621-1	unknown	body	√		Not identified
CU99.6	4621-2	olla/jar/bowl	body	√		Large, open-mouthed olla/jar/bowl with rounded bottom† Chicago Orange: Nago Bank Variety
CU99.37	5077.01.04	bowl	rim,body		refuse	Bowl; Chicago Orange: Warrie Camp Variety
CU99.30	5270	unknown	body	√		Not identified
Cocos Chicanel (400/300 B.C.-A.D. 250):						
CU99.38	2075	bowl	rim and body		refuse	Bowl; Sierra Red:Ahuacan Variety
CU99.44	2084	bowl	body nr. base		refuse	Bowl; Sierra Red: Big Pond Variety
CU99.43	2094	bowl	base		refuse	Bowl; Sierra Red: Sierra Red Variety
CU99.11	2112-1	jar	neck, shoulder		refuse	Large open-mouthed jar; Chicago Orange: Chucun Variety
CU99.45	2112-2	bowl	body		refuse	Bowl; Society Hall Red: Society Hall Variety
CU99.42	2113-1	bowl	base		refuse	Bowl; Society Hall Red: Society Hall Variety
CU99.1	2113-2	jar	neck		chultun	Jar; Sierra Red: Sierra Red Variety
CU99.40	2369	bowl	rim and body		refuse	Bowl; Sierra Red: Sierra Red Variety
CU99.39	2675	bowl	body		refuse	Bowl; Society Hall Red: Society Hall Variety
CU99.47	3108-1	jar	body		chultun	Large open-mouthed jar; Chicago Orange: Chucun Variety
CU99.35	3108-2	bowl	body		chultun	Bowl; Polvero Black: Polvero Variety
CU99.41	3108-3	jar	rim		chultun	Large open-mouthed jar; Chicago Orange: Chucun Variety
CU99.34	3149-1	jar	body nr. base		chultun	Jar; Sapote Striated: Variety Unspecified
CU99.46	3149-2	bowl	body		chultun	Bowl; Sierra Red: Sierra Variety
CU99.3	2963	jar	neck			Large open-mouthed jar; Chicaco Orange: Chucun Variety

(Hammond, personal communication). Type:variety designations and identifications of vessel form were provided by Dr. Laura Kosakowsky, Boston University, and are provided in Table 5.1.

K'axob

Sherds from 42 vessels excavated from K'axob and a single sediment sample from a sherd-lined pit were selected for analysis of lipid residues. The sample spans the Middle Preclassic (N=19) and Late Preclassic (N=22) periods. One additional vessel comes from a Proto-Classic deposit. The majority of vessels selected are wide-mouthed, utilitarian jars that have been typed as Chicago Orange by Sandra López Varela. These are the most likely candidates for cooking vessels at K'axob (McAnany, personal communication) although some of these may also have been used for storing and serving food. The nature of the deposits from which the sherds were excavated was a primary concern when samples were chosen for analysis. As much as possible, construction fill contexts were avoided. A few sherds were associated with living floors but most are from primary or re-deposited middens (Table 5.2). Rim/neck sherds were not always available from the contexts that were of interest for sampling. Therefore, the K'axob sample has a greater proportion of body sherds than samples from other sites included in this study. Also, unique to K'axob are ten samples taken from sherd-lined pits which are thought to have been used for steam cooking, maize soaking, stone boiling, and as hearths (Kobza 1994:81-82). A small number of sherds (N=5) have charred or other encrustations on their interior surfaces but these have not yet been analysed.

Cerén

Permission was obtained to test seven vessels from Cerén, one from each household unit excavated and one from the communal structure (Structure 3). The

Table 5.2. Descriptions of vessels included in the sample from K'axob, Belize.

FS #	Zone	GC #	Provenience	Form	Vessel Type	Sherd	Context
Middle Preclassic, Early Chaakkax:							
Op I, Phase Ib:							
FS 460	Z63	KX99.40	SQ J N6004 E1996	jar	Chicago Orange	rim	midden
FS 463	Z63	KX99.3		jar	Chicago Orange	neck	midden
		KX99.2		jar	Chicago Orange	body	midden
FS 501	Z63	KX99.7	SQ A	unknown	Chicago Orange	body	midden
FS 505	Z63	KX99.1	SQ B N 6008 E1996	jar	Chicago Orange	neck	midden
FS 526	Z233	KX99.45	SQ F N6006 E1996	jar	Chicago Orange	body	
FS 531	Z63	KX99.24	SQ F	jar (?)	Chicago Orange	neck	midden
Op. I, Phase II:							
FS 432	Z59	KX99.19	SQ J N6004 E1996	jar	Chicago Orange	rim	midden
		KX99.43		jar	Chicago Orange	body	
FS 435	Z59	KX99.12	SQ E N6006 E1994	jar	Chicago Orange	neck	midden
		KX99.21		jar	Chicago Orange	rim	
		KX99.20		jar	Chicago Orange	body	
FS 438	Z59	KX99.13	SQ A N6008 E1994	jar	Chicago Orange	neck	midden
		KX99.14		jar	Chicago Orange	body	
FS 444	Z59B	KX99.11	SQ B N6008 E1996	jar	Chicago Orange	body	midden
Middle Preclassic, Late Chaakkax:							
Op. I, Phase III:							
FS 371	Z57	KX99.23	N6008 E1994	jar	Chicago Orange	rim	subfloor fill
		KX99.41		jar	Chicago Orange	rim	

Table 5.2 (continued)

FS #	Zone	GC #	Provenience	Form	Vessel Type	Sherd	Context
Op. I, Phase III:							
FS 373	Z57	KX99.16	N6008 E1996	jar	Chicago Orange	neck	subfloor fill
		KX99.22	N6008 E1996	jar	Chicago Orange	neck	
		KX99.17	N6008 E1996	jar	Chicago Orange	body	
FX403	Z57	KX99.18	N6008 E1994	jar	Chicago Orange	neck	subfloor fill
Late Preclassic, Early K'atabche'kax:							
Op. I, Phase IV:							
FS 411	Z151	KX99.49	subzone 151 B		unknown	body	sherd-lined pit
Op. I, Phase VII:							
FS 125	Z87	KX99.25		jar	Chicago Orange	neck	midden
FS 243	Z87	KX99.27		jar	Chicago Orange	neck	midden
		KX99.28		jar	Chicago Orange	neck	
Op. X, Phase I:							
FS 35	Z17	KX99.33		jar	Chicago Orange	body	midden
		KX99.42		jar	Chicago Orange	body	
Op. X, Phase II:							
FS 23	Z11	KX99.29		jar	Chicago Orange	body	
		KX99.38		jar	Chicago Orange	rim	
		KX99.39		jar	Chicago Orange	rim	

Table 5.2 (continued)

FS #	Zone	GC #	Provenience	Form	Vessel Type	Sherd	Context
Op. XI, Phase Ia:							
FS 1162	Z83	KX99.48	SQ B		unknown	body	sherd-lined pit
Op. XI, Phase Ib:							
FS ?	Z85	KX99.47	SQ B		unknown	body	sherd-lined pit
Op. XI, Phase II:							
FS 1125	Z69	KX99.5	SQ B	jar	Chicago Orange	neck	living surface
		KX99.6		jar	Chicago Orange	neck	
		KX99.4		jar	Chicago Orange	rim	
FS 1128	Z69	KX99.8	SQ C	jar	Chicago Orange	neck	living surface
		KX99.9		jar	Chicago Orange	rim	
Late Preclassic, Late K'atabche'kax:							
Op. VII, Phase I:							
FS 335	Z27	KX99.26		sediment	unknown		sherd-lined pit
Op. VIII, Phase I:							
FS 3	Z9	KX99.35		jar	Chicago Orange	body	midden
FS 4	Z9	KX99.34		jar	Chicago Orange	body	midden

Table 5.2 (continued)

FS #	Zone	GC #	Provenience	Form	Vessel Type	Sherd	Context
Op. XII, Phase III:							
FS 956	Z20	KX99.36	SQ C	jar	Chicago Orange	rim	trash pit?
		KX99.37		jar	Chicago Orange	rim	
		KX99.32		jar	Chicago Orange	neck	
		KX99.31		jar	Chicago Orange	body	
Op. XII, Phase IV:							
FS 897	Z44	KX99.44			unknown	body	sherd-lined pit
Op. XII, Phase IV?:							
FS 861	?	KX99.10				body	
FS 960	Z10C	KX99.30			unknown	body	sherd-lined pit
Proto-Classic, Terminal K'atabche'kax:							
Op. I, Phase IX:							
FS 148	Z25	KX99.15	N6006 E2000	jar		rim	

majority of vessels selected for analysis were small jars and open bowls or basins excavated from primary (*in situ*) contexts suggesting that they had been used either to cook or store food (Table 5.3). The exception is the very large open-mouthed jar (height = 60 cm, diameter = 65 cm) found in the communal structure which, it has been suggested, was too large for storage and, given the context may have been used for dispensing a beverage (Sheets 1992:95). All of the vessels date to the early Middle Classic period.

Aguateca

Ceramic sherds were collected for residue analysis during excavations at Aguateca during the 1996 through 1998 field seasons. Like Cerén, the site of Aguateca presented a rare opportunity to collect samples from vessels found *in situ*. The greater contextual information accessible in such a situation will be useful in interpreting vessel contents and function as activity areas can be defined with more confidence than for other archaeological sites. In total, 21 sherds and 4 soils were analysed (Table 5.4). Small to medium "cooking" jars have not been identified in the ceramic assemblage from Aguateca. It has been suggested that the large, shallow, monochrome bowls may have been the vessel form used in food preparation at this site (D. Triadan, personal communication) and in the Petexbatún region of the Petén (Foias 1996:994). Therefore, these bowls (N=8) were sampled. Large jars (N=10) were also sampled although they may be more representative of food storage. A sherd from a single incensario, which was covered with a charred residue on the interior surface, was also sampled. All of the vessels were excavated from elite residences, including the palace, where they had been left *in situ* when the site was rapidly abandoned. Many of the vessels were found within the structures in living spaces and storage areas. A number of sherds were also

Table 5.3 Descriptions of the vessels included in the sample from Cerén, El Salvador.

Lab #	Vessel	Vessel Form	Sherd Type	Context	Comments
CRN2	295-3-17	large open-mouthed jar	neck	Str. 3 communal building	*chicha* jar
CRN7	295-8-96		shoulder	Str. 10 on hearth	cream slip
CRN1	295-1-258	globular jar	neck/shoulder	Str. 11 on hearth	red slipped area sampled
CRN5	295-1-258	globular jar		Str. 11	
CRN4	295-2-283	jar	body	Str. 7	storage vessel with beans
CRN6	295-1-255	open bowl/basin	neck/shoulder	Str. 11	sampled 6-7cm below rim
CRN3	295-5-10	open bowl/basin	neck/shoulder	Str. 12	shaman's structure
CRN8	295-1-61	globular jar	base	Str. 1 storage in roof	interior, base is blackened

Table 5.4 Descriptions of the vessels included in the sample from Aguateca, Guatemala.

Lab #	Vessel #	Form	Type	Sherd type	Provenience	Context	Comments
AG99.7†	VS152c	unidentified	cacao vessel	body	14B-13-1-3	midden	not analysed
AG99.13	VS26	jar	Pantano	body	20A-8-3-1		#439-441; soil AG99.14
AG99.11	VS3	jar	Cambio	body	20A-3-3-1/2	interior floor	#187-189; soil AG99.11
AG99.8	VS44	jar	Tinaja rojo	body	20A-13-3-3	Str. M8-8, north addition	#603-605; soil - AG99.9
AG99.10	VS45	jar	Encanto	body	20A-13-3-3	Str. M8-8, north addition	#606-608
AG99.15	VS33	bowl	Chaquiste	body	20A-4-3-2	interio floor	#487-489; soil AG99.16
AG99.27	VS375	incensario		body	21A-16-3-4	bulk ceramics	
AG99.1	VS152	bowl	Chaquiste	rim	14B-13-1-3	midden	soil - AG99.6
AG99.25	VS152	bowl	Chaquiste	rim	14B-13-1-3	midden	bulk ceramics
AG99.26	VS152	unidentifed	unidentified	body	14B-13-1-3	midden	bulk ceramics
AG99.5	VS152	jar	Tinaja rojo	shoulder	14B-13-1-3	midden	bulk ceramics
AG99.2	VS152	jar	Encanto	body	14B-13-1-3	midden	bulk ceramics
AG99.4	VS152	jar	Encanto	body	14B-13-1-3	midden	bulk ceramics
AG99.3	VS152	bowl?	unidentified	body/shoulder	14B-13-1-3	midden	bulk ceramics
AG99.17	VS152	unidentified	unidentified	body/shoulder	14B-13-1-3	midden	bulk ceramics
AG99.21	VS384	bowl	Chaquiste	body*	22A-10-2-5	collapse in front of bench	
AG99.24	VS384	bowl	Chaquiste	body*	22A-10-2-5	collapse in front of bench	
AG99.20	VS387	jar	Pantano	body	22A-10-2-5	collapse in front of bench	
AG99.18	VS395	bowl	Chaquiste	body*	22A-10-2-5	collapse in front of bench	
AG99.19	VS390	bowl	Chaquiste	below rim*	22A-10-2-5	collapse in front of bench	
AG99.23	VS654	jar	Pantano	body	22A-14-2-6		
AG99.22	VS777	jar	Pantano	body	22A-14-3-2		

* blackened interior
† not analysed

collected from a midden associated with house Structure M8-13. No vessels were found in contexts that would clearly suggest cooking. In fact, no hearths or kitchen structures have been identified, although other artifacts, such as *manos* and *metates*, attest to food preparation activities having taken place in and around the residences. All of the vessels date to the Late Classic occupation of the site.

In the 1998 field season, samples were taken from vessels found in a sealed room in the Str. M7-22, in the Palace Group, and numerous sherds were taken from the midden associated with residential Structure M8-13. The aim was to sample contexts other than floors of residential structures in order to understand the possible effect of different burial contexts on the preservation of absorbed lipid residues. The sample from K'axob should also be useful in this regard. The single sherd from an incensario (VS375, 1998) recovered from Structure M8-4 at Aguateca was chosen as we were interested in knowing whether or not the presence of a charred surface residue has any role in the preservation of absorbed lipid residues.

5.3 Procedures for lipid extraction from sherds, soils and cooking waters

5.3.1 Extraction of lipid residues from archaeological sherds and soils

Total lipid residues were extracted from archaeological ceramics using a method adapted from Evershed *et al.* (1990). The size of sherd utilized ranged from roughly 2 to 44 g, averaging approximately 15 g. Sherds were prepared for extraction by removing all surfaces with a scalpel and then grinding the ceramic material to a fine powder using an agate mortar and pestle. As the vessels from Cerén are complete and of museum quality, sample sizes were restricted to less than 1 g and were collected by scraping the sherd material from a 1 cm^2 area on the vessel interior using either a scalpel or dental drill. The powdered sherd was weighed and transferred to a 40 ml screw-top glass vial with a

Teflon-lined cap and stored in a freezer until the lipid residue was extracted within the next two days.

Heptadecanoic acid (C17:0; 5 µg) was added to each sample as an internal standard as it, like other odd-numbered fatty acids, occurs infrequently in fresh foods; with freshwater fish being an exception. Lipids were extracted by adding chloroform-methanol (2:1; 2 x 15 ml) to each vial and placing the vials in an ultrasonic bath for 20 minutes. The samples were centrifuged briefly, the solvents decanted and filtered under a slight vacuum using a Millipore filter (GVP, 0.25 µm) to remove all clay-sized particles. The solvent-extracts were transferred to round bottom flasks (25 ml) and the solvents were removed by rotary evaporation. When the extracts were nearly dry, they were transferred to pre-weighed 2 ml screw-top glass vials with Teflon-lined caps, using a Pasteur pipette and a small volume of diethyl ether (1.5 ml), rinsing the flask 6 times. The diethyl ether was evaporated under a gentle stream of nitrogen and the vials re-weighed to obtain the weight of the total lipid extract. The samples were then redissolved in 100 µl of ether and stored in a -20°C freezer under a blanket of nitrogen.

The following day, fatty acids were converted to methyl esters. Methylation is an analytical derivatization reaction that replaces the hydrogen of the carboxyl group (CO_2H) of a fatty acid by a methyl group (CH_3). The result is increased volatility of the fatty acid. Greater volatility of the fatty acids improves their chromatographic detectibility by decreasing their interaction with the solid phase of the column, allowing for better peak separations and peak shapes (Knapp 1979:2-3). Fatty acid methyl esters were produced by the addition of 1.5 ml of an ethereal solution of diazomethane to the total lipid extracts. Diazomethane was prepared following Fieser and Fieser (1967:191-192). The sample was left to react for one half hour following which the diazomethane was evaporated under a gentle stream of nitrogen. The lipid extracts were re-dissolved in

100 µl carbon disulfide (CS_2) and 1 µl was injected for analysis on the gas chromatograph.

Lipids were extracted from soil samples (roughly 2 g) using the same extraction procedure. Soils were not ground but pebbles were removed prior to extraction.

Glassware (vials, beakers) used in the extractions had been degreased by soaking in chromic acid ($H_2Cr_2O_7$) overnight or by rinsing clean glassware (filters, filter paper, flasks, caps) with chloroform (2x) and methanol (1x). Chloroform (6x) and methanol (1x) rinses were used to clean the fritted glass Millipore filter between samples.

5.3.2 Selection and preparation of modern, comparative food standards

Selection of modern, comparative food standards

Ethnohistoric, archaeological, and ethnographic sources were used to establish which modern foods needed to be collected for use as comparative food standards (Chapter 3, section 3.3). Efforts were made to include as many cultigens as possible, in addition to plants that may have been collected from the forests, fallow fields, or *milpas*. The final collection of reference foods is not comprehensive, however, and there are some important omissions of meats, in particular. Examples of turtle, fish, dog, and *jute* snails, for example, were not obtained from the field.

Comparative samples of cultivated food plants were purchased from markets in the Lowlands and Highlands of Guatemala and in El Salvador during the 1997 and 1998 field seasons. Many of these foods were purchased dried, others were partially dried in the sun until they could be placed in a freezer and later transported to McMaster. Unfortunately, a number of the leafy plants acquired in 1997 developed mould before they could be frozen and were, therefore, discarded. In 1998, a food dehydrator was used to desiccate all food plants collected in the field and markets. A small number of plants

which the ancient Maya might have gathered from the forest or protected in milpas and fallow fields were collected at Aguateca with the help of Candelario Paau López, and at Tikal with the assistance of José Ernesto Macz. The ancient Maya are expected to have used far more forest plants during Prehispanic times than are represented in the sample. Unfortunately, because of extremely dry conditions in the 1998 dry season many of the herbs, which may have been eaten in the past, could not be found in the forest understory. Examples of game (deer, *tepesquintle*, armadillo, and turkey) were donated by the restaurant - *La Mesa de los Mayas* - in Flores, Guatemala in 1997 and purchased there in 1998. The armadillo and turkey meat had been cooked at the restaurant. The foods were immediately placed in a freezer at McMaster upon my return to Canada at the end of each season, and were stored there until they were analysed for their lipid content. In total, 26 examples of food plants and 4 meats were obtained for lipid analysis. A list of the foods and the locations from which they were purchased or collected may be found in Table 5.5.

Preparation of experimental cooking water extracts

Thermal and oxidative degradation during cooking markedly alter the quantities and distribution of fatty acids in foods (Malainey 1997:158-163). Consequently, it is useful to prepare experimental cooking extracts using modern food references, to aid the interpretation of archaeological cooking residues (Charters *et al.* 1997; *cf.* Fankhauser n.d.).

Experimental cooking extracts (designated as CKG) were prepared on a laboratory hot plate by boiling 1 to 20 g (average wt. = 4 g) of food and 300 ml deionized water in a glass beaker covered with aluminum foil. The foods were boiled for one half hour. The foil was removed and cooking continued until roughly 50 ml of liquid remained. The cooking water was filtered into a flask, under a slight vacuum, using a Büchner funnel

and filter paper. The bottom of a beaker was used to press the water out of the cooked food. The beaker, filter, and remaining food were rinsed with 30 ml chloroform-methanol (1:1). The mixture of cooking water and solvent was then transferred to a graduated cylinder and the total volume was recorded. Subtracting 30 ml from this total gave the volume of the cooking water. The mixture was transferred to a separatory funnel and the lipid fraction was separated by adding chloroform and methanol in volumes that produced a ratio of 2:2:1.8 for chloroform:methanol:water (Bligh and Dyer 1959:912). The water-solvent mixture was left to separate into two phases overnight. The following day, the lower chloroform layer containing the lipids was collected into round-bottom flasks and the solvents were removed using a rotary-evaporator. The extracts were transferred to 2 ml screw-top glass vials with Teflon-lined caps, using a Pasteur pipette and a small volume of ether (1.5 ml), rinsing the flask 9 times. The ether was then evaporated under a gentle stream of nitrogen. The samples were then redissolved in 400 µl of ether and stored in a -20°C freezer under a blanket of nitrogen. The cooking water extracts were methylated the following day using 1 ml diazomethane. After one half hour, the diazomethane and ether were evaporated under a gentle stream of nitrogen. The lipid extracts were re-dissolved in 400 µl CS_2. An aliquot of 100 µl was removed and diluted to 200 µl with the addition of 100 µl of CS_2 containing 200 µg C17:0 methyl ester as an internal standard. One microlitre was injected for analysis on the gas chromatograph.

Maize was prepared as it is traditionally done in Mesoamerica, by using alkali processing (Bancroft 1888:76; Bressani *et al.* 1958:770; Katz *et al* 1974). The maize was boiled in a 1% solution of calcium hydroxide [$Ca(OH)_2$]) in deionized water for 30 minutes and then allowed to soak overnight. The cooking water was removed the following day and was processed in the same manner as other cooking water extracts.

The foods prepared as cooking extracts are listed in Table 5.5.

Table 5.5 Modern Comparative Foods Prepared as Cooking Waters.

Sample	Food	Taxonomic Name	Part	Location
CKG.6.FRJ	black beans	*Phaseolus vulgaris*	seeds	Antigua
CKG.7.CRZ	*corozo* palm	*Orbignya cohune*	nut	Aguateca
CKG.8.CHI*	*chiles*	*Capsicum annuum*	fruit	Sololá
CKG.9.BLD*	*blédo*		leaves	Tikal
CKG.10.CPL*	*chipilín*	*Crotolaria maypurensis* or *C. guatemalensis*	leaves	Tikal
CKG.11.PCYA	*pacaya*	*Chamaedorea tepejilote*	infloresence	Guatemala City
CKG.12.GÜI*	*güicoy*	*Curcurbita pepo*	fruit	Guatemala City
CKG.13.MAC*	*macal*		leaves	Tikal
CKG.14.CHY	*chaya*	*Cnidoscolus chayamansa*	leaves	Tikal
CKG.15HM	*hierba mora*		leaves	Tikal
CKG.16.SM	*Santa Maria*		leaves	Tikal
CKG.17.PMNT	*pimienta*	*Pimenta dioica*	leaves	Tikal
CKG.18.RdJ	*rosa de Jamaica*	flower	Antigua	
CKG.19.HB	*hierba buena*		leaves	Tikal
CKG.20.CMT	*camote*		root, peeled	Tikal
CKG.21.CAC	cacao	*Theobroma cacao*	seeds	Santa Elena
CKG.22.GÜL	*güisqui/chayote*	*Sechium edule*	leaves	Tikal
CKG.23.YCA	yucca		root, peeled	Antigua
CKG.24.RB	red beans	*Phaseolus vulgaris*	seeds	Antigua
CKG.25.ACH	*achiote*/annatto	*Bixa orellana*	seeds	Joya de Cerén
CKG.26.KB	flat red beans	*Phaseolus vulgaris*	seeds	Antigua
CKG.27.MNT	*hierba buena*		leaves	Sololá
CKG.28.SQ*	squash	*Curcubita sp.*	seeds	Antigua
CKG.29.LOR	*loroco*	*Fernaldia pandurata*	flower	Santa Tecla
CKG.30.FdEP	*flor de epazote*	*Chenopodium ambrosiodes*	flower	Guatemala City
CKG.31.PMNT*	*pimienta*/allspice	*Pimenta dioica*	leaves	Aguateca
CKG.32.TMO	*tomatillo*		fruit	Winnipeg
CKG.33.TOM	tomato		fruit	USA
CKG.34.CRC	squash	*Curcurbita*	seeds	Antigua
CKG.35.MZ	maize	*Zea mays*	seeds	Antigua
CKG.36.MZ	maize	*Zea mays*	seeds	Antigua
CKG.37.TEP*	tepescuintle		flesh	Flores
CKG.38.DR*	deer		flesh	Flores
CKG.39.TRK	turkey		flesh	Flores
CKG.40.ARM*	armadillo		flesh	Flores
FD.1.AVC†	avocado	*Persea americana*	fruit	USA

*signifies that these samples were also analysed as degraded cooking water extracts.
† The sample of avocado was not cooked but the extraction was done using a fresh fruit.

Solvents used in cooking water extractions were all of reagent grade. Chloroform (2X) and methanol (1X) rinses were used to clean all glassware and filter paper prior to the extractions.

Degradation of cooking water extracts

Fatty acid distributions were obtained for several examples of degraded cooking water extracts, as it was anticipated that the fatty acid distributions of extracts from the cooking water extracts might not be comparable to the degraded, archaeological residues. Another expectation was that the criteria given by Malainey (1997:100; Malainey *et al.* 1999:426) for identifying archaeological residues on the basis of their fatty acids might not be applicable to the Maya pots. Not only did the ancient Maya cook different plant and animal foods compared to prehistoric peoples in Western Canada, but also the plants grew under different environmental and soil conditions and the animals consumed these different plants. Therefore, it is reasonable to expect that the tissues, even of the same type of plant (maize, for example) or animal (deer, for example), from the two regions might have different lipid compositions.

After they were analysed on the GC, many of the cooking water extracts were degraded under low-light conditions, in a 60°C oven, for a period of one year. The meat samples, as well as one sample each of maize and squash (CKG.34 and CKG.35), were degraded for a much shorter period of three months. It would have been preferable to degrade these for a longer period. There is evidence, however, that the greatest changes due to degradation occur very rapidly (Malainey 1997:158). Further, all of the samples had previously been methylated, which makes the fatty acids more volatile (J. Rosenfeld, pers. comm.) and is expected to have accelerated the loss of the lower molecular weight acids. Therefore, the samples left for the shorter period should still provide much useful information about the changes that result from decay. All samples,

whether degraded for three months or a year will provide imperfect comparative parameters as neither group of samples has been degraded under conditions that truly replicate the burial environment and climate at a Lowland Maya site. One final complication is that the cooking samples left to degrade included the C17:0 that had been added as an internal standard. To correct for this, degraded cooking blanks that contained the internal standard were also run in order to see how the degradation conditions affected the C17:0.

Thirteen degraded cooking samples were analysed. They were selected by taking two or three samples from each food category identified by the cluster analysis of the cooking-water extracts. They are indicated with an asterisk (*) in Table 5.5.

5.3.3 Preparation of analytical blanks

Analytical blanks were prepared for each batch of 8 – 10 samples so that it would be possible to identify and correct for any contaminants that might be introduced with the distilled water and chemicals used in the extractions. The blanks were prepared following the same procedures for extraction and methlylation described above for sherds, soils and cooking waters but without any ceramic, soil, or food material.

5.4 Analysis of lipid extracts by gas chromatography

Separation and identification of fatty acids and other lipids in archaeological food residues and modern cooking extracts are accomplished using chromatography. Chromatographic techniques involve the distribution of a substance(s) between two immiscible phases (Gurr and Harwood 1991:13-17; Hanrahan *et al.* 1988:61-62). A mobile phase continuously moves a sample through an inert, microporous stationary phase. Phase pairs commonly used are gas-liquid and liquid-solid combinations.

Substances interacting with a phase-pair divide between the two phases, eventually reaching equilibrium, which is referred to as the partition coefficient. The particular chemical and physical properties of each substance in a mixture, such as a total lipid extract, influence its solvent-solute interactions with the two chromatographic phases and produce a distinct partition coefficient for each compound. Consequently, the various substances in a sample move at different velocities relative to the mobile phase and so become separated as the mobile phase moves them through the chromatographic system (Gurr and Harwood 1991:13). For example, a substance with a greater affinity for the solid phase will spend more time in that phase and move more slowly through the system than one that has a greater affinity for the mobile phase.

Gas chromatography (GC) and gas chromatography-mass spectrometry (GC/MS) are the methods preferred for analysis of relatively volatile organics such as lipids are (Gurr and Harwood 1991:14, 17; Hanrahan *et al.* 1988:61). The mobile phase is a carrier gas, hydrogen or helium, which passes through a wall-coated-open-tubular (WCOT) or capillary column made of fused silica. These columns are long and thin (30 m x 0.25 mm id) in order to allow for high resolution (or separation) of complicated mixtures of compounds (Gurr and Harwood 1991:14). The stationary phase is a thin film of liquid (< 1 µm) coated onto the interior surface of the column.

In the gas chromatograph, the column is heated in an oven. The temperature of the oven may be fixed (isothermal operation) or, if separation of components with a wide range of molecular weights is necessary, the column temperature is programmed to increase over the time of a sample run (temperature programming or gradient operation) (Gurr and Harwood 1991:16). The sample is injected into a heated injector port (Figure 5.1) where it is vaporized before reaching the column. The vaporized sample moves through the column with the carrier gas. Its various components separate according to

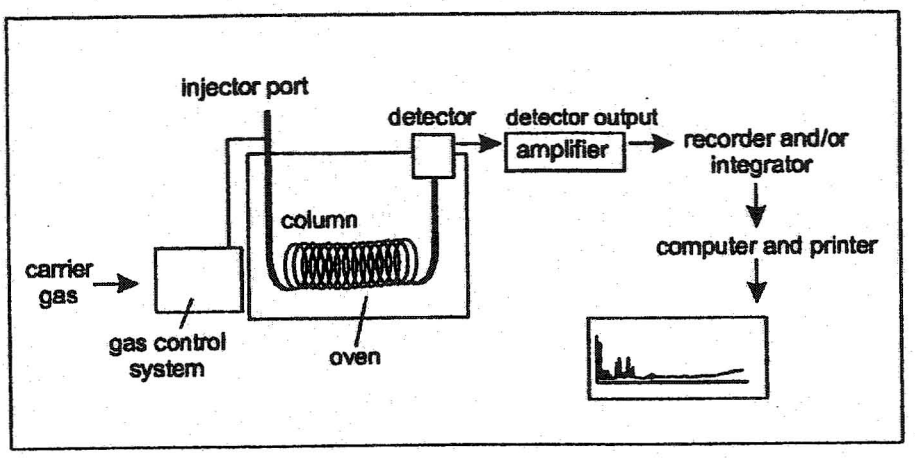


Figure 5.1 Schematic of a gas chromatograph (modified after Gurr and James 1980:13).

differences in volatility, chain length, functional groups, number and position of double bonds, and affinity for the stationary phase (Hanrahan *et al.* 1988:61; Malainey 1997:114). More volatile substances move through the column more rapidly. For fatty acids, those with short or branched carbon chains will elute sooner than saturated, straight-chain fatty acids with the same number of carbon atoms. Using the particular column used in this project, unsaturated fatty acids with one or two double bonds elute before saturated fatty acids with the same number of carbon atoms.

The separated compounds are quantified at a detector (Figure 5.1) as they emerge from the column. A flame ionization detector (FID) is generally used for lipid analysis. It has a highly sensitive response to almost all organic compounds, and a low signal-to-noise ratio, allowing for the detection of even trace quantities (10^{-12} g/ml) of material (Gurr and Harwood 1991:16; Hanrahan *et al.* 1988:62). The signal measured by the detector (millivolts, mV) is transferred to a data acquisition system equipped with programs to integrate the data. The program used in this project is Waters' Millennium,

which records the retention time (RT) and response (mV), calculates the height, area, and percent area (% area) for each peak, and also creates a chromatogram for each sample run (Figure 5.2 a and b).

Samples were analysed on a Varian gas chromatograph connected to a SATIN data collection system. The column was a polyimide clad 30 m x .32 mm i.d. fused-silica capillary column coated with DB-1 stationary phase (immobilized dimethyl polysiloxane, 0.25 µm film thickness; J&W Scientific). Samples were manually injected into an injector set at 300 °C where they are volatilized to a gas before they enter the column. Hydrogen was the carrier gas used to move the sample through the column at a linear velocity of *ca.* 107 cm/second. Temperature programming of the GC oven and column was from 115 to 300 °C, increasing 5 °C/minute. The temperature was held at 300 °C for 6 minutes. At the end of the column the sample gas was passed through a flame ionisation detector (FID) set at 300 °C.

5.5 Methods used to identify fatty acids and absorbed lipid residues

Fatty acids present in the cooking waters and archaeological residues were identified on the basis of their retention times (RT) normalized to that of the C17:0 internal standard. These relative retention times (RRT) were used to make the identifications, rather than just the retention times, as the samples were injected onto the column manually rather than by an automated injector. Manual injection results in slight differences in the timing and volume of injections between samples. The use of relative retention times corrects for minor differences that result in the retentions times for the same fatty acids, between injections.

The distinctive retention times for each of the fatty acid peaks were established using a mixture of known fatty acid methyl ester standards, purchased from Supelco (FAME mix catalogue no. 47885-u). Each day that a group of samples was run, the

Sample Information

SampleName	CU99.19	Sample Type	Unknown
Vial	1	Date Acquired	8/31/99 1:06:11 PM
Injection	4	Acq Method Set	GC1
Injection Volume	1.00 ul	Processing Method	Sherd Extracts
Channel	SATIN	Date Processed	8/31/99 2:05:16 PM
Run Time	43.0 Minutes		

Integration Results

	Name	RT	Start Time	End Time	Area	Height	% Area	Int Type
1		1.116	1.102	1.133	201	268	0.17	bb
2		3.101	3.072	3.135	136	74	0.12	bb
3		3.539	3.483	3.575	318	107	0.27	BB
4		3.613	3.575	3.663	536	290	0.45	BB
5		3.768	3.733	3.803	153	79	0.13	bb
6		3.891	3.853	3.943	815	364	0.69	BB
7		4.116	4.073	4.165	634	304	0.54	Bb
8		4.278	4.233	4.363	1798	779	1.52	bB
9		4.461	4.412	4.525	218	77	0.18	bb
10		4.686	4.633	4.773	1255	350	1.06	BB
11		4.827	4.785	4.913	374	107	0.32	bb
12		4.969	4.928	5.015	1046	474	0.88	bb
13		5.078	5.023	5.133	227	87	0.19	bV
14		5.193	5.133	5.253	1420	520	1.20	VV
15		5.299	5.255	5.403	437	101	0.37	bb
16		5.660	5.583	5.712	217	58	0.18	bb
17		5.750	5.713	5.795	111	49	0.09	bb
18		5.899	5.845	6.033	599	107	0.51	bb
19		6.100	6.043	6.153	405	100	0.34	BB
20		6.219	6.163	6.267	2510	899	2.12	bb
21		6.304	6.272	6.345	292	126	0.25	bb
22		6.692	6.635	6.742	1775	615	1.50	bb
23		6.852	6.747	6.922	3614	657	3.06	bb
24		6.970	6.932	7.030	228	87	0.19	bb
25		7.172	7.127	7.208	425	187	0.36	bb
26		7.292	7.260	7.338	659	274	0.56	bb
27		7.558	7.492	7.630	986	284	0.83	bb
28		7.701	7.657	7.752	489	176	0.41	bb

Figure 5.2 a) Example of raw data generated in the analysis of lipid extractions using gas chromatography.

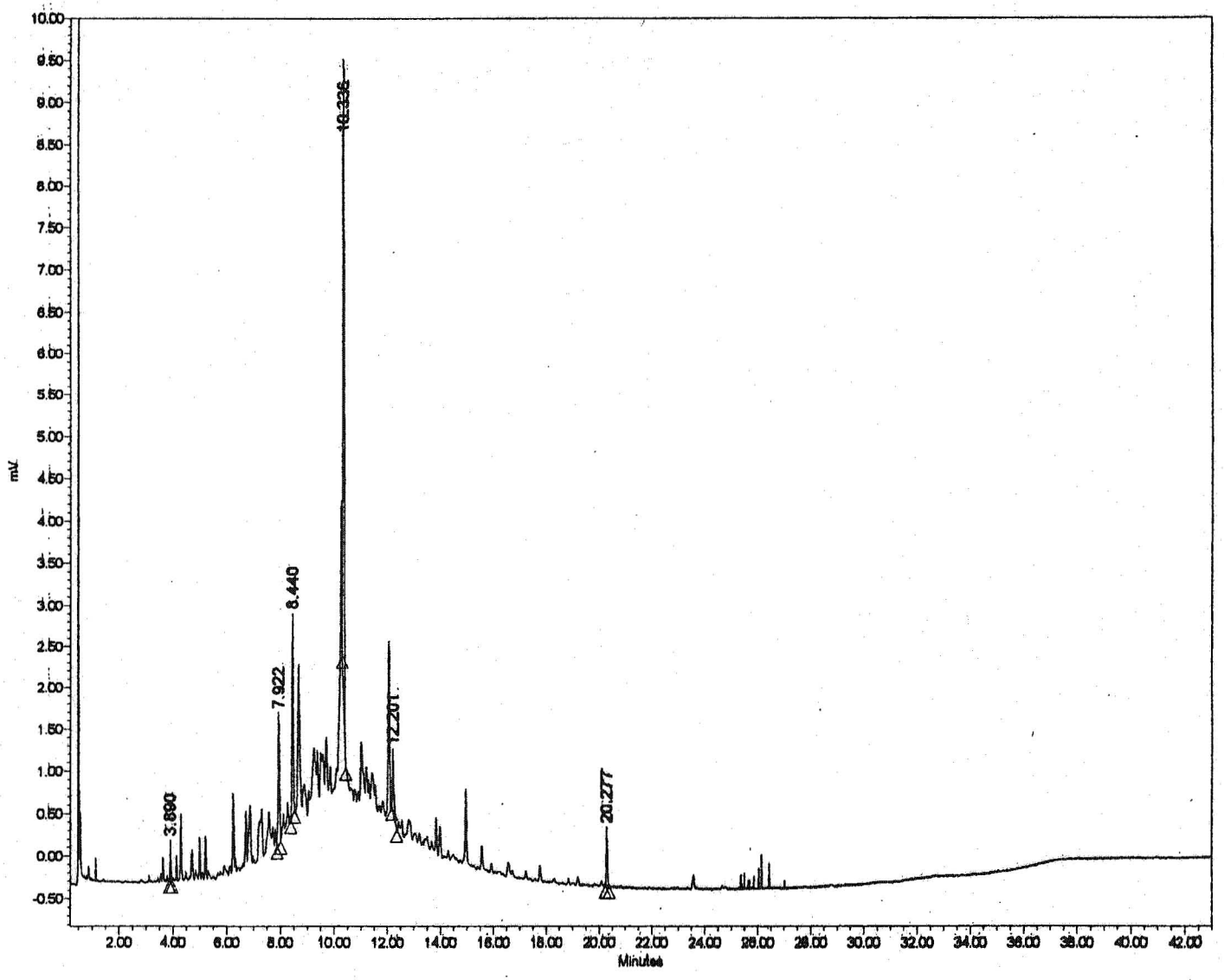


Figure 5.2 b) Example of raw data generated in the analysis of lipid extractions using gas chromatography.

standards were also run on the GC under the same column conditions and temperature programming. An example of the chromatograph and results table for the FAME standard mix is shown in Figure 5.3. The relative retention time for each fatty acid in the standard mix was then calculated by dividing its retention time by that of C17:0. For example, for the injection illustrated in Figure 5.3, heptadecanoic acid (C17:0) has a RRT = 1.000, lauric acid (C12:0) has a RRT =.314, and lignoceric acid (C14:0) has a RRT = 1.913. The relative retention time of each peak produced by the injection of a sample or blank was determined in the same way. The fatty acids present in these extractions could then be identified by comparison to the relative retention times of the fatty acids in the FAME standard mix. Note that any fatty acids not included in the standard mix would not, then, be identified in a sample. This does not mean, however, that other fatty acids were not extracted from the sherds or modern foods.

Similarly, the relative peak area for each fatty acid identified in the samples and blanks was calculated by comparison with the peak area of the C17:0 internal standard. This standardization of the peak areas made it possible to correct for any fatty acid contaminants that occurred in the blanks run with each sample batch by subtracting the relative area of the contaminant from the equivalent fatty acid peak in the sample. The relative peak areas are used in statistical analyses once they have been transformed, either to concentrations of fatty acid in the ceramic material (µg/g) or to relative percent area of all fatty acids identified in a sample.

Several replicate analyses (two separate injections run on the same day) of both standards and lipid extracts were made in order to establish the reproducibility of the measurements made by the GC. The relative retention times of the fatty acids are extremely consistent between sample runs. Four injections of the FAME mix, run on 3 different days, showed that the relative retention times of the various fatty acids differ by just $3x10^{-4} \pm 3x10^{-4}$%, on average. Over the course of the project, the relative retention

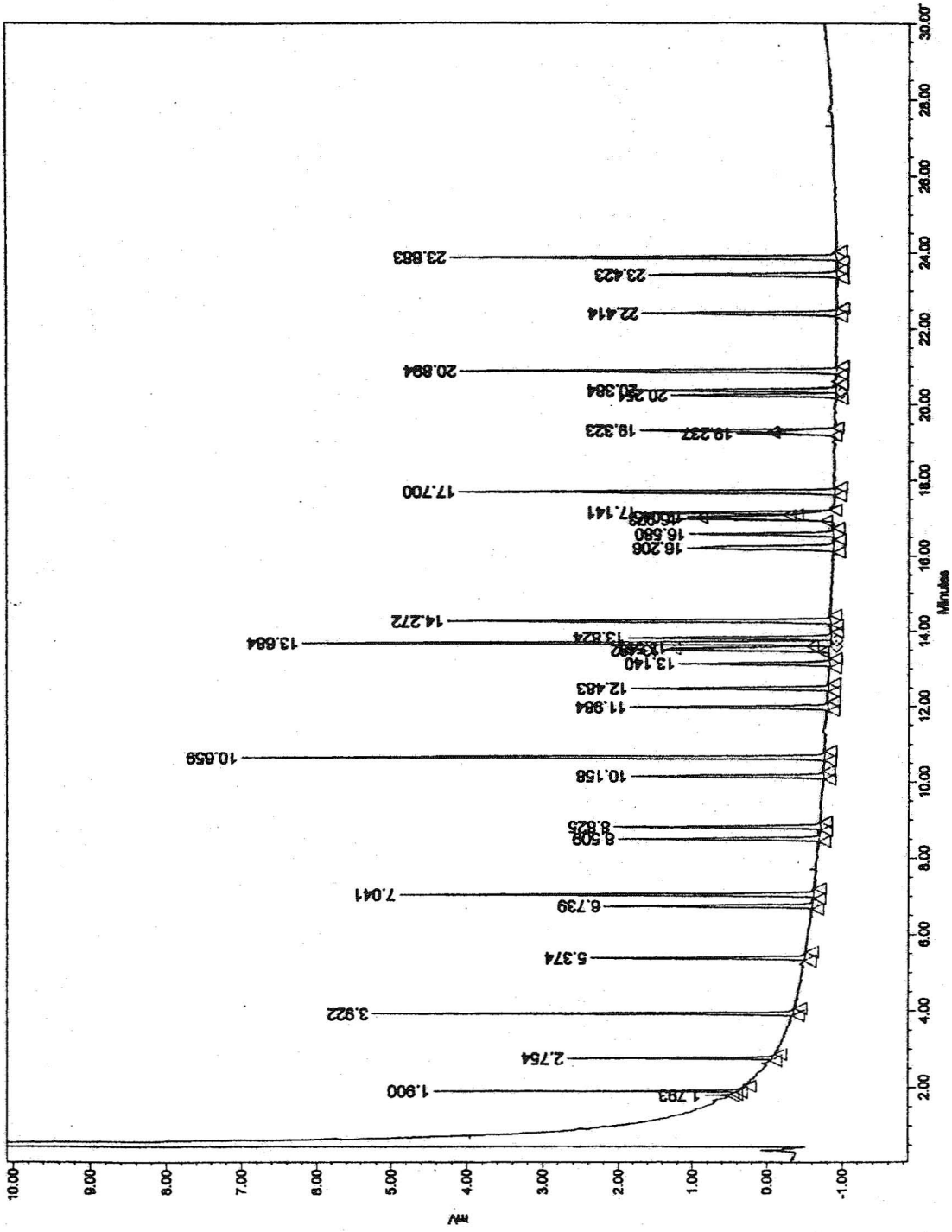


Figure 5.3 Chromatograph of the mix of fatty acid laboratory standards (47885-u).

times of the individual fatty acids were essentially invariable for injections of both standards and fatty acid extracts. The reproducibility of the relative peak areas for duplicate analyses of the FAME standard mix run on the same day (n=48 fatty acid peaks) is 0.6 ±0.8%. The reproducibility of the relative peak areas is not as good, however, for four runs of the standard mix made over a period of three days (4.3 ±8.7%, n=92 fatty acid peaks). The relative peak areas of eight fatty acids that were identified in duplicate analyses of a degraded cooking water extract (CKG.38), run on the same day, had a reproducibility of 0.8 ±1.0% (range: 0.01 to 2.8%). Like the FAME mix, the relative peak areas of the fatty acids (n=18), in repeat analyses of the degraded cooking water extract (CKG.37) run on different days, were not as reproducible (7.3 ±14.1%; range: 0.005 to 47.7%). The differences may be attributed to changing column conditions on different days.

5.6 Comparing extracts: fatty acid compositions and concentrations

The fatty acid compositions of the samples (archaeological residues, cooking water extracts, and degraded cooking waters), which are described by the relative proportions of each of the fatty acids identified in the samples, were used to group and compare the samples to each other. The relative percentage of each fatty acid in a sample was calculated by dividing its relative peak area (normalized to the area of the C17:0 peak) by the sum of relative peak areas for all fatty acids identified in that sample, and then multiplying that result by 100 percent. Converting the data in this way to relative percentages makes it possible to compare the fatty acid compositions of different types of samples that might have very different concentrations or amounts of lipid material, for example, long degraded archaeological food residues and recently degraded lipid extracts from modern foods.

However, transforming the relative peak areas to relative percentages creates other problems for comparing the different types of samples. When the quantity of each fatty acid component of a sample is represented as a percentage of the total (100%), a change or difference in the quantity of one fatty acid component will necessarily change the amounts (percentages) of all other fatty acids present, regardless of whether their actual amounts have changed or whether they differ greatly between samples. This effect is most problematic when specific fatty acids, which are frequently present in most samples, are absent or are present at levels that are atypically high or low in a particular sample. The result is that the relative percentages of all other fatty acids are also dramatically affected so that they are different (greater or smaller) or changed from what they are perhaps expected to be. When this happens, it becomes very difficult to compare the fatty acid composition of that sample to others. At two points in the analysis of data for this thesis the limitations of using relative percentages to characterize the fatty acid profiles of the samples became apparent. First, a contaminant peak introduced into many K'axob residues (Chpt. 7, section 7.7.2) exaggerated the apparent amount of C16:0 present and probably resulted in lower than actual, relative percentages of all other fatty acids that were identified in those samples. Conversely, the absence of a number of key fatty acids from some of the archaeological residues resulted in inflated proportions of other fatty acids identified in those residues (Chapter 8, section 8.6).

One way to work with this limitation of using relative percentages is to compare ratios of particular fatty acids or groups of fatty acids, which are deemed to be significant for characterizing the fatty acid profiles and for identifying the origins of the archaeological food residues.

The archaeological vessels were also compared in terms of the concentrations (µg/g) of the identified fatty acids extracted from each sherd. The purpose was to discover whether or not different concentrations of fatty acids remaining in the vessels

might correlate to vessel form, function, vessel type, or burial context (see Chapter 6) and thereby provide some information related to vessel use and/or the origins of the residues. It was possible to calculate the concentrations of the fatty acid residues using the following pieces of information: the known weight (0.05 µg) of the internal standard (C17:0) injected with each 1 µl injection of a sample; the known weight of each fatty acid present in a 1 µl injection of the FAME standard mix (0.2, 0.4, or 0.6 µg); and the corresponding peak areas of each fatty acid identified in the samples and the FAME mix normalized to C17:0 (RPA=relative peak area). Let $M_{i,r}$ equal the mass of fatty acid *i* (in µg) in a residue *r*. Then we can see that

$$M_{i,r} = \left[\frac{0.25 M_{i,\,FAME}}{X(RPA_{i,\,FAME})}\right] RPA_{i,r} \qquad \text{(i)}$$

where RPA is the relative peak area. The factor 0.25 takes account of the fact that the amount of C17:0 added as an internal standard (0.05 µg/g) is four times smaller than the amount used for the FAME standard mix (0.2 µg/g). We can then calculate the total concentration of all fatty acids in the sherd $[FA]_{r,\Sigma,(ppm)}$ (in ppm) from

$$[FA]_{r,\Sigma,(ppm)} = 100\left(\frac{\sum_{i=1}^{k} M_{i,r}}{Msh}\right) \qquad \text{(ii)}$$

where M_{sh} is the mass (g) of the sherd analysed. The factor 100 represents the ratio of the volume of solvent used to dissolve the fatty acids from the residue to the volume used to dissolve the FAME standard mix.

5.7 Procedures for carbon and nitrogen isotopic analysis of charred residues

Charred residues were removed from the interior surfaces of sherds using a metal spatula. The residues were then stored in glass screw-top vials with Teflon-lined caps. The Teflon prevents contamination with plasticizers that can interfere with other types of chemical analyses that might be done in the future.

The method used to prepare the charred residues for isotopic analysis is adapted from DeNiro and Hastorf (1985:98) and Morton (1989:15-18). Aliquots of each residue are sampled for carbon (10 mg) and nitrogen (30 mg) analyses. The aliquots were put into centrifuge tubes with 10 ml of 1M HCl (hydrochloric acid) and left to soak 24 hours to allow the removal of any carbon that might have originated as contaminants from soil. Samples were rinsed three times with distilled water to remove the HCl and then dried overnight in a 90° C oven. Charred residues removed from the surface of vessels from Cuello reacted vigorously with the HCl and the sample size was greatly reduced - often to half the original weight - following this chemical pre-treatment. Treatment with HCl can be omitted if archaeological sediments or soils do not contain calcium carbonate. Morton (1989) began with much smaller samples, as the pots from Ontario did not require pre-treatment with HCl. Aliquots of HCl treated residues were removed (3 mg for carbon analysis and 10 mg for nitrogen analysis[1]) and put into Vycor[1] tubing (6 mm diameter)

[1] Frequently, it is not possible to obtain sufficient amounts of N_2 to be measured on the mass spectrometer. Loss of nitrogen occurs during burial (Whitney 1992:82). Unfortunately, this problem cannot be corrected by increasing the size of the aliquot for nitrogen analysis. An aliquot of residue larger than 10 mg can produce a volume of CO_2 large enough to explode the tube.

with an excess of cupric oxide (CuO). Prior to this, the Vycor tubing and the CuO had been purified by heating to 900°C. The tubes were sealed under vacuum to ensure that carbon from atmospheric CO_2 did not affect the results. Samples were then burned at 900° C for a minimum of 2 hours, releasing oxygen from the CuO that reacts with the organic sample and forms CO_2, N_2, and H_2O.

The tubes were then cracked under vacuum while connected to a V.G. 602D Micromass mass spectrometer, releasing the gases produced during the reaction with CuO. The H_2O is removed using a dry ice and alcohol slush trap. For analysis of carbon, CO_2 is isolated in a liquid nitrogen trap while all other gases are pumped away. In the analysis of nitrogen, it is N_2 which is isolated by freezing the CO_2 in the sample tube prior to cracking the tube. The different atomic weight of each isotope also allows the separation, collection, and quantification of the isotopes on the mass spectrometer, which measures the ratios of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ in the gases. Because $^{13}C/^{12}C$ and $^{15}N/^{14}N$ ratios vary by extremely small amounts between materials, and because most fractionations are also very small, the ratios are expressed relative to those of universal standards as delta values ($\delta^{13}C$, $\delta^{15}N$), in parts per mil (‰), to make them more readily understood (DeNiro 1987:182; van der Merwe 1982:596). Delta values are calculated using the equation:

$$\delta_{sample} = \left[\left(\frac{R_{sample}}{R_{standard}}\right) - 1\right] \times 1000‰$$

where R_{sample} is the ratio of $^{13}C/^{12}C$ or $^{15}N/^{14}N$ measured in the sample and $R_{standard}$ is the ratio of $^{13}C/^{12}C$ or $^{15}N/^{14}N$ measured in the standard. The standard for carbon is a marine

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[1] Because of the high temperatures (900°C) required to react the carbonized samples and the CuO, Vycor rather than Pyrex tubing is required. The latter will melt at this temperature.

carbonate (Peedee Belemnite). AIR (atmospheric N_2) is the standard used in nitrogen analyses. The precision of analysis is ± 0.1‰.

Chapter 6

Isotopic Analysis: Results and Interpretations

6.1 Introduction

This chapter is a presentation of the results and interpretations of the isotopic data obtained by the analysis of carbonised residues from 23 jars excavated from the site of Cuello. Isotopic analysis is a well-established analytical method in studies of ancient foodways. Specifically, isotopic analyses can be used to determine the presence of major nutrient types in the vessels, such as maize, fish, beans, and meat. In the chapters that follow, I will contrast the isotopic results and interpretations, as well as the analytical approach itself, to similar aspects of the analysis of lipid residues by gas chromatography.

6.2 Charred residues: Results and interpretation of isotopic analyses

Carbon and nitrogen isotopic analyses were performed on 18 Bladen Phase vessels and two vessels from contexts dated to the Bladen/Lopez Mamom transition at Cuello. The results are presented in Table 6.1 and Figure 6.1. The $\delta^{13}C$ values range from -12.9 to -23.9‰ with a mean value of -21.1 ± 2.1‰ (n = 21). The $\delta^{15}N$ values range from +7.7 to +11.9‰ with a mean of +9.3 ± 1.2‰ (n = 13). Those samples for which there are carbon but no nitrogen data did not contain measurable amounts of nitrogen.

Table 6.1 $\delta^{13}C$ and $\delta^{15}N$ Values of Charred Residues from Vessels from Cuello, Belize.

Vessel	GC#	Phase	Date	Context	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
4569		O	1200-900 BC	Old land surface	-22.2	8.3
4566-1	CU99.4	I	900-800 BC	Yard 1	-19.2	--
4566-2	CU99.5	I	900-800 BC	Yard1	-23.8	11.9
4623-1	CU99.19	I	900-800 BC	Yard 1	-21.3	8.6
4623-2	CU99.20	I	900-800 BC	Yard 1	-19.2	9.1
4623-3	CU99.21	I	900-800 BC	Yard 1	-22.5	--
4631	CU99.18	I	900-800 BC	Yard 1	-23.4	11.2
4639	CU99.7	I	900-800 BC	Posthole	-20.7	--
4682	CU99.15	I	900-800 BC	Chultun	-20.5	10.1
4627-1		Ia	900-800 BC	Yard 2	-20.3	8.1
4627-2	CU99.16	Ia	900-800 BC	Yard 2	-21.5	7.7
4630		Ia	900-800 BC	Yard 2	-19.4	9.5
4632-1	CU99.24	Ia	900-800 BC	Yard 2	-16.2	--
4634		Ia	900-800 BC	Chultun	-19.7	8.9
4649	CU99.12	Ia	900-800 BC	Chultun	-19.1	--
4661-1	CU99.26	Ia	900-800 BC	Chultun	-20.1	10.4
4661-3		Ia	900-800 BC	Chultun	-20.7	9.1
4691	CU99.25	Ia	900-800 BC	Chultun	-24.0	--
4621-1	CU99.17	IV	600-500 BC	Yard	-23.9	8.6
4621-2	CU99.6	IV	600-500 BC	Yard	-24.0	--
5270	CU99.30			south trench	-12.9	--

Very light $\delta^{13}C$ values in all but two vessels indicate that the majority of vessels in the Cuello sample did not contain substantial amounts of maize. Only vessel 5270 appears to have contained a substantial amount of maize, or perhaps the meat of maize-fed dogs and armadillo (Clutton-Brock and Hammond 1994; Tykot *et al.* 1996:361). Vessel 4632-1 probably contained smaller amounts of maize or C4-consumers in the isotopic mixture of foods cooked in the pot. Nitrogen data, which could be used to sort out whether the C4 contribution to the residues is from maize or animals, are not available for either of these vessels. Knowing that maize was the most important food staple for the ancient Maya, and having evidence that it was included in a great variety of dishes,

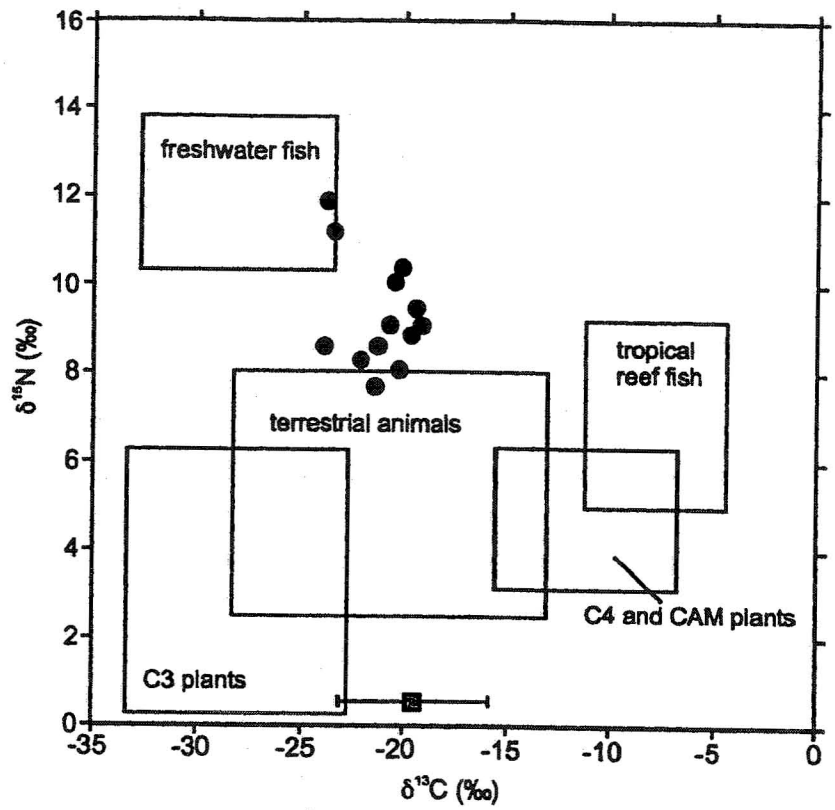

Figure 6.1 Carbon and nitrogen isotope ratios of charred residues from Cuello vessels compared to the isotopic model of Maya foods. The symbol ■ indicates the mean $\delta^{13}C$ value (-19.8±3.9 ‰) of charred residues for which no nitrogen data are available. (References: van der Merwe *et al.* 1994; White *et al.* 1993; Wright 1995.)

the near absence of evidence for maize preparation in the vessels from Cuello was somewhat unexpected. Carbonized residues on archaeological vessels from Southern Ontario also fail to record a C4 signal, although the people who used the pots are known to have consumed considerable amounts of maize (Morton 1989:165; Morton and Schwarcz 1988:92). Perhaps maize was prepared in such a way that burning was infrequent. For example, it may have been boiled for a short period, left to soak overnight, and then never returned to the fire to simmer.

Beans are a second food that was important in many ancient Maya diets but which has not left an isotopic trace in the carbonized residues from the Cuello vessels. The $\delta^{15}N$ values of the chars are much higher than would be expected for beans.

The pattern of depleted $\delta^{13}C$ values and elevated $\delta^{15}N$ values indicates that freshwater fish were prepared in many of the vessels from Cuello. Freshwater fish caught in the Petén have $\delta^{13}C$ values of –29.2±3.1‰ and $\delta^{15}N$ values of 11.2±1.4‰ (Wright 1994:208). Although the $\delta^{15}N$ values of terrestrial carnivore meat are also similar to those measured in the residues, the Maya probably did not consume terrestrial carnivores in any quantity. Figure 6.1 clearly illustrates, however, that freshwater fish was not the only food prepared in the vessels, as the $\delta^{13}C$ values are more positive and the $\delta^{15}N$ values are slightly lower than would be expected for just the fish. The cooking of any other food(s) whether C3 plants, animals that consumed C3 or C4 foods (dogs, armadillos), tropical marine fish, or maize could have produced such isotopic shifts. Remains of foods from all of these food categories have been found at Cuello. The location of the residues on the vessels at the middle and near the base of the body, however, suggests that the other food was a starchy vegetable (Kobayashi 1994:148-151; see section 4.2), possibly a C3 root or tuber, and perhaps also a very small amount of corn. A fish stew or soup was perhaps prepared in these vessels. Norman Hammond (personal communication) notes that a fish stew that includes manioc is consumed in Belize today. Also, carbonised remains of manioc have been identified in the botanical remains from the site (Hather and Hammond 1994; section 3.5.2). There is really no way, however, of knowing whether the foods were cooked together or in separate cooking events.

There is also reason to suggest that at least six of the eight residues for which no nitrogen data are available (excluding vessels 5270 and 4632-1) also contained fish.

Figure 6.1 illustrates that the $\delta^{13}C$ values ($\overline{X}$=-19.8±3.9 ‰) of these charred residues are the same as those residues identified as fish by their stable carbon and nitrogen isotopic compositions. In addition, these residues exhibited very similar physical properties and positioning on the interior body and base of the vessels. Therefore, it might be argued that 19 of the 21 carbonized residues from Cuello vessels represent food dishes that contained freshwater fish.

A conclusion drawn from faunal remains is that freshwater fish was not an important part of the Preclassic diet at Cuello despite its accessibility at the site (Tykot *et al.* 1996:358-359, 361; Wing and Scudder 1991:85). It is of some interest, then, that the analysis of carbonized food residues highlights the use of freshwater fish at Cuello. Of course, the identification of fish in 13 cooking vessels does not mean that fish was as important as maize-fed dog (Tykot *et al.* 1996:361). The carbonized residues do, however, suggest that the use of fish has been somewhat overlooked. A number of factors may have contributed to this situation. To start, small fish bones may have been missed during excavations and lost through the 1/4" mesh used to screen the archaeological soils and sediments (Wing and Scudder 1991:84). Second, Wing and Scudder (1991:85) rely heavily on weights of bone recovered for each species in order to assess the relative importance of different animals in the diet, which will mean that fish are underrepresented because of the small size and low weights of fish bones.

The charred residues provide good evidence for the use of fish by Preclassic Cuello residents. In contrast, however, are the nitrogen isotopic compositions of human bones, which do not strongly indicate that these people consumed a significant amount of fish. The average $\delta^{15}N$ value of the human bone collagen is 8.9±1.0‰ (Tykot *et al.* 1996:359), which is lower than expected for a diet dominated by freshwater fish ($\delta^{15}N$=12 to 15‰). The $\delta^{15}N$ values of the bone, however, neither refute nor support the

evidence for fish found in the vessels, as consuming nitrogen from other food sources (terrestrial animals and plants) would lower the $\delta^{15}N$ values and mask any nitrogen signal contributed by a smaller portion of fish in the diet. Therefore, as is true for archaeological faunal remains, nitrogen isotopic analysis of bone collagen does not allow us to measure the relative importance or quantity of fish in the diets consumed at Cuello. The fact that the carbonized residues from 13 pots do clearly show that fish was cooked at Cuello is an important demonstration that Preclassic residents at the site very likely made regular use of this food resource. The residue results also provide no measure of the amount of fish that was used relative to other types of food. This should not be unexpected as food residues in ceramic vessels represent meals and food preparation activities. They do not record patterns of food consumption. Moreover, as we have seen in Chapter 4 (section 4.2), the formation of carbonised residues depends upon the types and consistency of the foods that were cooked in the vessels. Many foods consumed in the past never produced charred residues. Therefore, this category of food evidence cannot be used to reconstruct paleodiets.

Reviewing what has been learned from different lines of archaeological evidence regarding food use at Cuello, it is possible to speculate about how particular foods were prepared at this site during the Preclassic period. The isotopic signatures of some of the charred residues that are dominated by the signal for freshwater fish suggest that certain pots were reserved specifically for cooking fish, perhaps to avoid transferring a fishy-taste left in the porous walls of the ceramics to other dishes. It is possible but not necessarily true that other vessels were designated for the preparation of particular foods or dishes, as well. The fact that maize, dogs, and deer did not leave strong isotopic signatures in the chars does not mean that these foods were never cooked in ceramic vessels. They may not have been cooked in ways that left charred residues.

However, their absence might also reflect that the meat of deer, dog, and armadillo was roasted or baked more frequently than it was stewed.

Perhaps more important to understanding the early settlement and adaptation of the Maya Lowlands is that thirteen of the carbonised residues give good evidence that freshwater fish and the wetlands around the site were utilized, at least by the Middle Preclassic residents of Cuello, where previously there had been only scant faunal evidence for this economic activity. Twenty of the twenty-three vessels that had carbonised residues, and twelve of the thirteen vessels that were identified as having contained fish, were excavated from the very earliest occupation levels (Swasey Phases 0, I and Ia), which have all been dated to the first part of the Middle Preclassic period (1200-900/800 B.C). The vessels were found in yards and *chultunes* that appear to be associated with two different household locations. Just two of the vessels, including one with a fish signal, are from later Lopez Mamom (Phase IV) contexts at the end of the Middle Preclassic (650/600-400/300 B.C.). None of the vessels that have chars date to the Late Preclassic or Early Preclassic phases at the site.

Whether this pattern is significant and what it might mean is unclear. The apparent temporal shift in the formation of carbonised residues can be interpreted in several different ways. One possibility is that in later periods food preparation activities took place in areas that fell outside the excavation trench and that activity areas within the excavated area were different. In fact, early in the Late Preclassic the residences at this location were transformed into an elite residential compound that also had ceremonial and ritual functions. Alternatively, the absence of cooking vessels with charred residues might reflect a decline in the use of fish and root crops after the Swasey Phase or it might also indicate a change in the way that these foods were cooked so that they no longer became charred onto the vessels. As there are so few carbonised residues, and because they are not representative of the diversity of foods used by the Maya at Cuello,

it will be necessary to use additional lines of evidence to explain the temporal patterning in the data. Unfortunately, there is isotopic data for only one human individual who lived at Cuello during the Swasey Phase (Tykot *et al.* 1996:). Therefore, we cannot contrast the consumption patterns of the Swasey Phase with later periods, to see if the amount of freshwater fish consumed might have decreased. The faunal remains do show a slight increase in the percentage of fish remains among the vertebrate remains excavated from levels dated to the Lopez Mamom Phase compared to the combined Swasey and Bladen Phase occupation levels (Wing and Scudder 1991:97). This suggests that the use of fish did not decline after the time that carbonised residues are no longer found and that a change in food preparation might be a better explanation. However, the counts of fish bones include peripheral and marine species in addition to freshwater fish, and so the temporal patterning in the use of freshwater fish cannot be ascertained from these data. At this point, no explanation can be offered for the lack of carbonised residues in later deposits.

The carbonised residues do not provide much additional information about the subsistence activities and foodways of the residents at Cuello. There are several reasons why this is so. Given that many foods will never leave a charred residue, the information that can be obtained by the analysis of chars is very narrow and is not representative of the variety of foods that were used in the past. Isotopic analysis of the Cuello chars made it possible to identify just one dish, which appears to have been a fish and manioc stew, for example. Carbonised food residues are also quite rare. All of the carbonised residues that were collected during the excavations at Cuello have been analysed for this project. The shortcomings associated with having a small number of samples are exaggerated by the fact that many of the chars will not have enough nitrogen preserved to obtain a reliable measurement of the $^{15}N/^{14}N$ ratio. Without both a

$\delta^{13}C$ value and a $\delta^{15}N$ value, is not possible to identify the isotopic category (maize, beans, C3 plant, fish, meat) of the food that produced the residue. All these factors conspire to hinder our ability to look for temporal and spatial patterns in food preparation and use, based on the results of isotopic analyses of carbonised residues.

6.3 Chapter Summary

Carbon and nitrogen isotopic results for charred residues from thirteen Preclassic jars from Cuello, Belize indicate that dishes prepared with freshwater fish were cooked in the vessels. Other unidentified foods were also cooked in the vessels either together with the fish or in separate cooking events. The location and thickness of the chars are indications that a starchy plant food was cooked along with the fish. Depleted $\delta^{13}C$ values reflect that this plant food was very likely a root, rather than maize. As well, the elevated $\delta^{15}N$ values of the chars give no indication that beans, another starchy food, were cooked in any of these vessels. Just two vessels (4632-1 and 5270), for which there is no nitrogen data available, have $\delta^{13}C$ values that suggest the preparation of either maize or the meats of an animal that fed upon substantial amounts of this food.

The identification of freshwater fish in the residues was an unexpected result. I would have predicted that the residues would be dominated by the carbon isotopic signals of maize. Maize was certainly the most important food for the ancient Maya and the carbon isotopic composition of the bone collagen of the Preclassic residents of Cuello shows the importance of this food in their diet (Tykot *et al.* 1996). In addition, the nitrogen isotopic composition of their bones does not indicate that these people consumed large amounts of fish. The apparently contradictory finding of fish in the vessels can be explained however, by the fact that the nitrogen isotopic composition of bones reflects that of a mixture of different protein sources in their diets including fish, meat and plant

foods such as beans and squash seeds. In addition, the archaeological food residues do not record long-term dietary patterns. Rather, individual residues are very short-term records of the preparation of specific dishes or meals. Nonetheless, the results obtained by isotopic analysis of the cooked food residues are very important as the identification of freshwater fish in thirteen vessels provides clear evidence for the use of fish by the Preclassic Maya at Cuello. Thus they contribute to our understanding of Maya diet and diet variety, though not to our knowledge of the bulk subsistence contribution of dietary elements.

Chapter 7

GC Analysis of Lipid Residues: Part I, Results

7.1 Introduction

Owing to the complexity of the data, the results of the gas chromatographic analysis of the absorbed lipid residues are presented in this chapter and the next. In this chapter, I first describe the fatty acid composition of the archaeological lipid residues in a very general way. Having done this and discovered some unusual patterns in the data, and considering that the amount of extractable residue is extremely small, I then felt that it was necessary to establish whether the residues represent traces of the original contents of the vessels, or contaminants from the burial context or from post-excavation handling and storage. In the balance of the chapter, I describe how I sorted out these problems and the conclusions that I reached.

7.2 Lipid residues: Results of GC analyses

7.2.1 Archaeological residues: some general comments

Twenty-four different fatty acids were identified in the total lipid residues extracted from the archaeological vessels. The most frequently identified fatty acids are C12:0, C14:0, C16:0, C18:0, the C18:2 isomers, and C24:0. Those that regularly occur in proportions ≥ 5% are C14:0, C16:0, C18:0, C18:2n6t, and C24:0.

There are differences between vessel collections in terms of the total number of fatty acids identified and their frequencies. Twenty or more fatty acids were identified in

the collections from Cuello (n=24) and Aguateca (n=23), and 19 were identified in 14[1] vessels from K'axob. Only 13 fatty acids were identified in pots from Cerén. The difference may reflect that fewer vessels from Cerén were analysed and that much smaller amounts of ceramic material (< 1 g) were sampled from these vessels. [It has not been possible to determine whether this also reflects different extents of degradation, as well.] Besides having the greatest number of identified fatty acids, the residues extracted from Cuello vessels have a larger number of fatty acids (n=12) that regularly occur (≥ 40% of the vessels). Vessels in other ceramic collections have markedly fewer fatty acids that occur frequently. Six fatty acids are regularly identified in vessels from K'axob and Aguateca, and just three occur in ≥ 40% of the Cerén vessels.

The fatty acid distributions of many of the archaeological residues are, in several respects, typical of degraded organic residues described in other studies (section 4.4.3). Fewer fatty acids are identified in the majority of the archaeological samples ($\overline{X}$=8.2±4.3; Tables 7.1-7.4) compared to the cooking water references ($\overline{X}$=10). Decreased variability and amounts of fatty acids are anticipated outcomes of oxidation processes that are expected to have occurred during cooking, use, and burial of the vessels. Note, however, that many vessels from the Cuello collection defy this trend. The average number of fatty acids identified per vessel ($\overline{X}$=10.3) in this collection is equivalent to that for the cooked foods. Many of the archaeological residues from all the collections also contain significant amounts of C16:0 and/or C18:0. Large proportions of these fatty acids occur in adipocere, a substance produced when lipids degrade under wet, low oxygen conditions. Malainey (1997) frequently identified C16:0 and C18:0, in varying proportions, in vessels from the Northern Plains that were not

[1] Only 14 vessels from the K'axob collection were unaffected by contaminants. Problems with contamination are described below.

Table 7.1 Relative proportions of individual fatty acids identified in archaeological residues, total peak areas (Vmin.), and residue concentrations (µg/g) for vessels from Cuello, Belize.

	SAMPLE:											
FA	CU99.1	CU99.2	CU99.3	CU99.4	CU99.5	CU99.6	CU99.7	CU99.8	CU99.9	CU99.10	CU99.11	CU99.12
C8:0											8.03	
C10:0		1.44	0.38		2.13			0.84	9.39	0.24	6.89	1.10
C11:0		0.64	1.21		2.13	1.65	1.70		4.43	0.13	2.40	
C12:0	22.02	3.43	8.39	7.54	4.64	3.53	4.19	4.60	20.20	0.51	11.49	
C13:0	3.11	0.76	1.21		3.03	6.46	3.28		1.95	0.21	1.52	
C14:1	14.51	0.64	2.49			2.12			4.01	0.10	28.35	5.34
C14:0	36.40	9.85	14.74	44.72	41.12	51.29	40.50	11.44	34.65	3.25	19.22	
C15:1	5.96				2.90	7.54					12.98	44.01
C15:0		1.71	6.42						2.27	1.13	0.49	
C16:1	5.44			7.12	11.06	9.33	9.70			0.31		
C16:0		56.78						24.00		58.10		
C17:1										0.48	0.57	
C18:2n6c			8.47		16.71				7.07			19.71
C18:2n6t			17.91					7.29		7.06		
C18:2				12.27								
C18:1			4.91									
C18:0	4.27	21.57	2.49	2.24	5.55	8.33	24.25	26.25	5.38	22.85	6.74	22.10
C20:1			15.19							1.31		
C20:0		1.18						6.45		1.73		
C21:0								0.00		0.29		4.42
C22:1			4.31		2.16		2.62	17.44		0.06		
C22:0										1.28		
C23:0										0.34		3.31
C24:1								1.68				
C24:0	8.29	2.01	11.87	26.11	8.58	9.76	13.76		10.65	0.61	1.33	
sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Vmin.	43.8	53.4	167.4	80.8	92.1	108.6	150.7	52.6	49.6	647.9	250.4	138.3
µg/g	0.403	3.850	0.262	1.823	2.479	1.786	0.900	0.445	0.926	3.310	2.253	0.334

Table 7.1 continued

	SAMPLE:											
FA	CU99.13	CU99.14	CU99.15	CU99.16	CU99.17	CU99.18	CU99.19	CU99.20	CU99.21	CU99.22	CU99.23	CU99.24
C8:0	1.49			4.58								
C10:0	3.22	0.39								3.52	0.58	
C11:0	5.33	0.66	1.84							3.28	0.45	
C12:0	12.27	1.44	3.68	3.77	4.69		3.32	1.89	1.50	16.12	2.19	0.70
C13:0		1.25	2.70		33.38		30.62	13.37	34.52	0.90	0.81	2.28
C14:1	9.05		6.75							7.39		
C14:0	36.31	8.84		62.53	9.50			17.74	12.21	29.14	7.02	1.19
C15:1	1.73	0.76	28.10	6.92			16.19	0.49		5.48		0.29
C15:0	1.12							32.60		1.72	1.61	
C16:1		1.46	20.12			0.79					1.36	
C16:0		77.34				61.30					38.24	
C17:1	10.41					5.10	4.36	1.53	5.03	0.69		
C18:2n6c	3.97	1.89		18.42		7.04	12.35	4.65	6.15	1.58	4.13	4.20
C18:2n6t								0.81		0.02	0.96	19.70
C18:2												
C18:1								5.99		1.04		5.27
C18:0	10.16	5.07	26.26	3.77	8.47		15.99	3.78	3.71	29.11	17.40	3.31
C20:1	4.96											52.55
C20:0						7.21					0.64	
C21:0												
C22:1							3.97	1.66	5.92		22.43	2.24
C22:0						18.56		12.24				0.30
C23:0												
C24:1											2.15	0.38
C24:0		0.90	10.55		43.96		13.20	3.25	30.95			7.60
sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Vmin.	291.1	155.5	336.3	65.9	82.2	16.4	115.2	269.6	166.2	475.7	195.6	178.7
µg/g	0.223	4.720	0.462	1.904	4.254	0.752	1.130	2.852	1.488	15.055	4.000	6.873

Table7.1 continued

SAMPLE: FA	CU99.25	CU99.26	CU99.27	CU99.28	CU99.29	CU99.30	CU99.31	CU99.32	CU99.33	CU99.34	CU99.35	CU99.36
C8:0												
C10:0									0.04	1.85		
C11:0										0.09	0.18	
C12:0	1.59	3.53	7.59		3.02	0.98	5.28	3.89	0.64	29.99	2.26	2.81
C13:0	13.10	39.33		17.96	30.31	24.98	2.79	0.68	0.34	2.65	0.57	
C14:1		1.52	7.24		1.72	0.61	3.94	3.43			2.00	1.53
C14:0	31.88		10.29			10.36	34.95	5.56		35.81	4.70	5.15
C15:1	1.59	13.00		15.77	13.81				0.08		1.66	1.39
C15:0			2.34				1.52	0.59	0.27	2.94	0.46	0.41
C16:1	6.75				11.11	2.50					0.60	
C16:0	0.00								6.41		44.73	77.11
C17:1	2.91				1.55	2.42	1.27	0.84	0.81	1.23	0.25	0.13
C18:2n6c	8.60	11.80				5.04	5.34	2.92	0.21	6.54	2.28	1.03
C18:2n6t			2.02				4.55	7.74	1.87	0.95	2.14	
C18:2												
C18:1								14.42				
C18:0	8.33	18.62	17.85	14.17	15.44	10.48	11.71		85.28	8.67	16.07	2.47
C20:1												
C20:0					2.04			0.97	1.48		1.02	
C21:0									0.32			
C22:1	3.97	3.29	3.77	7.39	10.46	3.97			0.12		0.41	0.54
C22:0	3.84								0.27		0.29	
C23:0	2.65								0.13			
C24:1												
C24:0	14.81	8.91	48.90	44.71	10.54	38.66	28.64	58.95	1.72	9.28	20.36	7.42
sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Vmin.	166.7	201.4	72.8	83.4	385.9	200.9	112.4	286.1	542.5	397.5	223.8	716.9
µg/g	0.771	0.926	2.835	0.488	0.711	1.380	0.426	1.229	4.589	1.061	3.192	2.677

Table 7.1 continued

SAMPLE:											
FA	CU99.37	CU99.38	CU99.39	CU99.40	CU99.41	CU99.42	CU99.43	CU99.44	CU99.45	CU99.46	CU99.47
C8:0											
C10:0	0.76	0.05			0.33			0.34			0.17
C11:0	1.99	0.25	1.07	0.98	1.28						2.67
C12:0	15.58	0.74	4.70	8.47	12.52	1.85	22.09	1.64	2.00	7.44	6.64
C13:0	3.09	0.30		1.55	1.85						
C14:1	3.21	0.34	1.64		14.33	42.55			38.39	15.56	67.77
C14:0	28.48	4.69	16.61	19.17	28.94	3.32	29.07	4.89	4.61	3.88	10.35
C15:1		0.22		2.52	10.20			1.05	1.20		5.65
C15:0	3.25	0.94	0.93	1.30	2.18		2.90				
C16:1	1.25										
C16:0	0.94	69.26						84.65		26.62	1.41
C17:1	0.69	0.14	1.07	0.53	2.18						
C18:2n6c	4.30	0.58		10.74	7.97						
C18:2n6t	2.34	11.92		5.98	1.04		7.15	0.74			
C18:2											
C18:1	2.67	3.30			1.00						
C18:0	16.02		6.56	7.45	12.29	2.50	17.15	2.65	2.24	32.09	5.34
C20:1			1.64								
C20:0	1.06	3.27		0.69	1.09					1.71	
C21:0											
C22:1	3.98		2.57	1.02	2.80						
C22:0	0.86	0.78									
C23:0		0.08									
C24:1	0.46										
C24:0	9.07	3.16	63.22	39.60		49.78	21.64	4.05	51.57	12.70	
sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Vmin.	672.2	1,355.3	210.1	408.6	760.7	63.4	202.5	470.2	158.6	87.3	139.2
µg/g	6.883	3.404	0.552	0.643	0.744	1.867	0.715	6.188	2.185	1.281	1.657

Table 7.1 continued (CHARS)

	SAMPLE:			
FA	CHAR2	CHAR3	CHAR4	CHAR5
C8:0				
C10:0				
C11:0		0.03		
C12:0	3.427	16.61	0.88	37.71
C13:0				
C14:1		0.77		
C14:0	15.97	23.78	4.59	37.29
C15:1				
C15:0		0.77	2.10	
C16:1	44.86		0.88	
C16:0	35.75	54.02	46.12	
C17:1				
C18:2n6c				12.43
C18:2n6t			4.39	
C18:2				
C18:1				
C18:0			10.74	12.57
C20:1				
C20:0			0.44	
C21:0		2.48		
C22:1			0.88	
C22:0				
C23:0				
C24:1				
C24:0		1.54	29.0	
sum	100.00	100.00	100.00	100.00
Vmin.	2.305	3.756	2.049	0.716
µg/g	34.893	22.817	20.237	22.813

Table 7.2 Relative proportions of individual fatty acids identified in archaeological residues, total peak areas (Vmin.), and concentrations (µg/g) of fatty acid residues for vessels from K'axob, Belize.

	SAMPLE:									
FA	KX99.1	KX99.2	KX99.3	KX99.4	KX99.5	KX99.6	KX99.7	KX99.8	KX99.9	KX99.10
C8:0					25.77	3.95	1.86			
C10:0					16.29					
C11:0										
C12:0	1.59					7.41		3.35	3.96	0.16
C13:0										0.20
C14:1									2.32	0.08
C14:0	16.51	0.13	3.78		15.05	5.19	10.43	25.45		27.89
C15:1		0.19	2.97			16.79		18.66	21.53	0.43
C15:0	4.68		2.81			4.44	6.89			0.30
C16:1			0.94			3.21				
C16:0		98.89							2.51	62.15
C17:1			2.48			8.64		8.97	4.73	0.53
C18:2n6c	4.28	0.16				8.15		5.34	17.47	0.18
C18:2n6t	15.51		7.38			13.09	4.10	3.53	16.60	0.15
C18:1			3.21							
C18:0	43.47	0.42	63.12	100.00	42.89	29.14	59.03	23.82	30.89	6.88
C20:1			4.42							
C20:0								1.36		0.45
C21:0										
C22:1										
C22:0	6.87		4.87							0.47
C23:0	2.50									0.14
C24:1								9.51		
C24:0	4.59	0.22	4.02				17.69			
sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Vmin.						46.7				
µg/g						0.155				

Table 7.2 continued.

	SAMPLE:									
FA	KX99.11	KX99.12	KX99.13	KX99.14	KX99.15	KX99.16	KX99.17	KX99.18	KX99.19	KX99.20
C8:0					0.33					
C10:0										
C11:0										
C12:0			4.47	0.08	8.29				0.28	2.28
C13:0										
C14:1										3.19
C14:0		31.88	11.46	1.95	26.08		19.13		93.70	
C15:1	57.63		4.95	0.08			14.78		0.45	16.40
C15:0			2.51	1.38	5.20	0.33	5.22	7.69	0.11	
C16:1	42.37			0.54						
C16:0				67.19		97.27				
C17:1			4.47	0.46					0.20	
C18:2n6c						0.26	14.78	8.85	1.54	23.01
C18:2n6t			35.24	2.47	34.28	0.15	8.70	10.77	0.73	5.24
C18:1			1.88	1.80						
C18:0		68.12	28.49	21.86	25.18	1.18		51.92	1.86	32.35
C20:1										
C20:0			2.90	1.32		0.35				10.02
C21:0				0.24						
C22:1										
C22:0			3.61	0.57		0.46				5.24
C23:0										
C24:1							8.70			
C24:0				0.60	0.65		28.70	20.77	1.13	2.28
sum:	100.00	100.00	100.00	100.54	100.00	100.00	100.00	100.00	100.00	100.00
Vmin.	120.1		49.7		70.9		156.1			
µg/g	0.016		0.035		N/A		0.034			

Table 7.2 continued

	SAMPLE:									
FA	KX99.21	KX99.22	KX99.23	KX99.24	KX99.25	KX99.26	KX99.27	KX99.28	KX99.29	KX99.30
C8:0								100.00	4.37	
C10:0						4.33				
C11:0										
C12:0						10.75				
C13:0										
C14:1										
C14:0						72.19				
C15:1	1.13	45.65								
C15:0										
C16:1						12.73				
C16:0				99.65						
C17:1		25.85								
C18:2n6c	48.59								95.63	
C18:2n6t	7.91									
C18:1										
C18:0	22.03	28.50		0.35	100.00					
C20:1										
C20:0	3.67									
C21:0										
C22:1										
C22:0										
C23:0										
C24:1										
C24:0	16.67						100.00			
sum	100.00	100.01	0.00	100.00	100.00	100.00	100.00	100.00	100.00	0.00
Vmin.						62.8				32.8
µg/g						0.797				0.000

Table 7.2 continued

	SAMPLE:									
FA	KX99.31	KX99.32	KX99.33	KX99.34	KX99.35	KX99.36	KX99.39	KX99.44	KX99.45	KX99.49
C8:0							0.64	3.37	100.00	1.66
C10:0								4.40		
C11:0										
C12:0							1.38			4.28
C13:0										
C14:1										
C14:0		24.00	91.61	28.95			25.96	13.99		19.24
C15:1										
C15:0										
C16:1										
C16:0					99.03	97.85				
C17:1										
C18:2n6c			1.96					39.64		
C18:2n6t			3.63	71.05		0.84	29.82	11.66		6.18
C18:1										
C18:0		76.00	2.80		0.97	1.31	32.57	26.94		68.65
C20:1							9.63			
C20:0										
C21:0										
C22:1										
C22:0										
C23:0										
C24:1										
C24:0										
sum	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Vmin.							226.5	57.9	81.5	131.3
µg/g							0.230	1.798	0.108	0.942

Table 7.3 Relative proportions of individual fatty acids identified in archaeological residues, total peak areas (Vmin.), and residue concentrations (µg/g) for vessels from Aguateca, Guatemala.

	SAMPLE:									
FA	AG99.1	AG99.2	AG99.3	AG99.4	AG99.5	AG99.8	AG99.10	AG99.11	AG99.13	AG99.15
C8:0						9.43	35.17			
C10:0						4.48				
C11:0										
C12:0			0.05						2.37	
C13:0			0.02					9.26		
C14:1	1.31		0.03						5.10	
C14:0	9.49	5.35	0.03	17.09	6.13				4.01	7.38
C15:1			0.02							
C15:0	1.94		0.13	3.42						
C16:1	3.55		0.12							
C16:0	42.87	70.84				41.98	64.83	26.68	4.74	54.03
C17:1	4.41			5.65						
C18:2n6c	6.28		1.31	7.09	27.20				19.13	16.12
C18:2n6t	12.89	5.35		21.69				14.16	27.32	22.48
C18:2										
C18:0	8.96	13.60		26.00	29.80	21.93		13.98	16.94	
C20:1			0.85						1.64	
C20:0			14.20						4.74	
C21:0									2.00	
C22:1					15.57				2.91	
C22:2			0.03							
C22:0			3.93						6.19	
C23:0		1.06	1.22	2.68				7.62		
C24:1										
C24:0	1.68	3.81		16.20	21.31	22.17		28.31		
sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Vmin.	66.6	45.3	9,215.7	64.2	25.6	79.7	13.0	18.1	176.1	42.6
µg/g	0.925	1.087	11.804	0.133	0.158	1.646	1.071	0.288	0.449	0.163

Table 7.3 continued

	SAMPLE:								
FA	AG99.17	AG99.18	AG99.19	AG99.20	AG99.23	AG99.24	AG99.25	AG99.26	AG99.27
C8:0						8.28	0.07		
C10:0									
C11:0									
C12:0	0.26						0.10		4.51
C13:0									2.82
C14:1							0.11		
C14:0	0.68						0.16	4.08	16.01
C15:1									4.02
C15:0	0.35						0.15		
C16:1							0.37		3.46
C16:0	17.02	6.22		16.24		46.48	68.54	3.62	9.10
C17:1							0.13	6.61	
C18:2n6c	0.67						2.03	12.83	20.73
C18:2n6t	10.15	5.42		72.47		21.64		29.35	18.41
C18:2									
C18:0	69.25	4.88		11.29	100.00	23.60		16.40	13.26
C20:1							0.88		
C20:0							17.11		
C21:0							0.55		
C22:1									
C22:2									
C22:0	0.57						7.86		
C23:0							1.95		
C24:1									
C24:0	0.47	83.48						28.08	7.69
sum	100.00	100.00	0.00	100.00	100.00	100.00	100.00	100.00	100.00
Vmin.	129.5	63.1	0.000	4.0	26.6	18.4	2,198.3	513.0	25.6
µg/g	6.025	1.057	0.000	0.054	0.115	0.427	6.483	0.245	N/A

Table 7.4 Relative proportions of fatty acids identified in lipid residues, total peak areas (Vmin.), and residue concentrations (µg/g) for vessels from Cerén, El Salvador.

	SAMPLE:					
FA	CRN1	CRN2	CRN3	CRN4	CRN5	CRN6
C8:0						1.02
C10:0						
C11:0						
C12:0	3.39					
C13:0						
C14:1						
C14:0		3.57		3.48		
C15:1						
C15:0						
C16:1						
C16:0		17.86	100.00	26.09	9.52	12.19
C17:1						
C18:2n6c					19.05	
C18:2n6t	3.39	64.29		52.17	42.86	
C18:2						
C18:1				0.87		
C18:0		7.14		17.39		17.13
C20:1						
C20:0						6.68
C21:0						
C22:1	93.22					
C22:0						11.61
C23:0						9.00
C24:1						
C24:0		7.14			28.57	42.38
sum	100.00	100.00	100.00	100.00	100.00	100.00
Vmin.	79.4	0.9	14.9	26.3	6.7	15.4
µg/g	0.192	0.083	0.023	0.069	0.126	N/A

buried under anaerobic conditions, however.

Yet, the archaeological residues examined in this study also exhibit some unanticipated patterns in their fatty acid distributions, given that they have been buried for centuries at tropical sites. In particular, the regular occurrence of both unsaturated fatty acids and long-chain fatty acids in this group of Maya vessels is not typical of archaeological lipid residues (Tables 7.1-7.4). All of the polyunsaturated fatty acids are generally expected to have been lost, although linoleic acid (C18:2n6c) has been identified in a number of residue studies. Evershed *et al.* (1992:199) have found that C18:1 is often the only unsaturated fatty acid that remains (see section 4.4.3). Yet, both linoleic (C18:2n6c) and linolelaidic acid (C18:2n6t) are very common and often are relatively abundant in vessels from all four collections of Maya ceramics. Moreover, in addition to C18:1, several other monoenoic acids are not infrequent in the collections from Cuello, K'axob, and Aguateca, including C14:1, C15:1, and C17:1. The odd numbered fatty acids do not occur in most fresh, uncooked foods. It is also surprising that long-chain fatty acids (≥20 carbons) are often present in the archaeological residues. They are particularly frequent in the vessels from Cuello. The most common of these is C24:0. Malainey (1997:178) found that both unsaturated and saturated fatty acids with chain lengths of 20 or more carbons were lost very rapidly from experimentally degraded cooking residues. The experimental cooking residues represent only one cooking episode in the vessels, however. It is possible that longer chain fatty acids remain in the Maya vessels because repeated cooking events in prehistory initially left greater concentrations of these fatty acids.

The somewhat atypical fatty acid distributions in the Maya archaeological residues were puzzling, and I wondered for a long time, "are they real?" I wondered whether the

presence of the long-chain and the unsaturated fatty acids might reflect a source of contamination from the burial environment or from excavation, storage, or processing of the sherds. These issues will be elaborated on below.

My concern regarding what the lipid extracts represented was exacerbated by the fact that the extractable quantities of the total lipid residues were extremely small. What was I seeing in the chromatogram? Certainly, the residues were not visible without the chromatogram[2]. Indeed, the peaks on the chromatogram were only visible at high scale factor settings. Unfortunately, most other studies of ancient lipid residues do not report absolute concentrations of fatty acids in their samples nor do they indicate the scale of their chromatograms. Malainey (1997:131) used only those samples that totaled a minimum of 100,000 units [sic], for the sum of the fatty acid peaks. However, the sum of all the peak areas (fatty acids and other lipids) in the chromatograms produced for the Maya residues often does not approach 100,000 mV/min (or 100 Vmin.). The mean for the sum of just the fatty acid peaks in the Aguateca residues is 12.4 ± 20.7 Vmin. (excluding two outliers: AG99.3 and AG99.25). The average for the Cuello residues is 27.9 ± 20.4 Vmin., not including eight samples that have fatty acid sums greater than 100 Vmin. ($\overline{X}$= 281.0 ±145.8 Vmin.). This supports my contention that the amounts of residue extracted from the Maya ceramics are extremely small, even for archaeological residues.

Malainey's constraint of 100,000 units may have been set arbitrarily but likely reflects some informed understanding of her residue samples. Given that many of the

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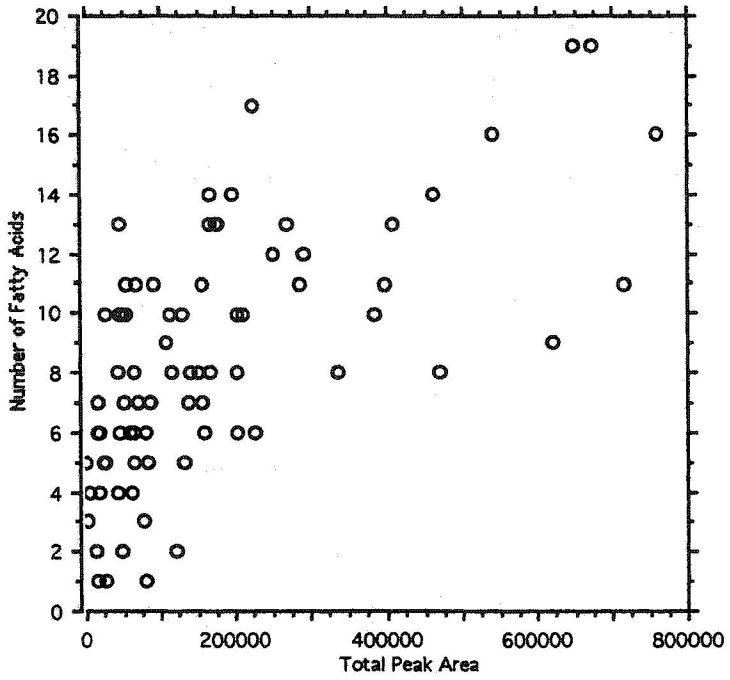
[2] Much different were residues extracted from three archaeological vessels from southwestern Ontario. These were readily visible as a strongly yellow-coloured, viscous substance in the bottom of a GC vial. A slight yellow colouration was also noted for the extracts from K'axob vessels as the sample, dissolved in CS_2, was drawn into the injection syringe. However, the colouration was determined to reflect the presence of nail polish, as a contaminant.

Maya vessels do not meet the criterion of 100 Vmin., a regression analysis was completed in order to discover whether the amount of extractable residue (measured by total peak area) determines the number of fatty acids that can be identified in a sample. The regression analysis excludes three outliers that have extremely large total peak areas (AG99.3, AG99.25, CU99.38), as well as a large number of sherds from K'axob that are contaminated (see below). The results show that there is a fairly strong, positive correlation between the number of fatty acids identified in a sample and the total peak area (Y=5.511+1.555E-5*X; r^2 = .408) (Figure 7.1). In other words, the number of fatty acids identified tends to increase with the amount of residue extracted and is a function of the amount of residue extracted. It is possible that a greater number of fatty acids is present in at least some of the smaller residues but they are not present in amounts large enough to produce a signal that rises above the baseline of the chromatogram.

The scatter of points in Figure 7.1 gives no indication that this relationship breaks down above a certain total peak area. The conclusion that must be drawn from this is that it would be preferable to use just those samples with the largest amounts of extractable residue in subsequent statistical analyses. Samples with ever-smaller amounts of extractable lipids can be assumed to provide less complete and less accurate information about the fatty acid compositions of the residues. Further, it follows that the chances of not being able to identify a residue, or of misidentifying it, will increase as the amount of residue extracted decreases. Therefore, a decision has to be made regarding which samples to include and exclude from statistical tests. Looking at the scatter plot, there appears to be a jump in the number of fatty acids identified around the 100-150 Vmin. mark. Certainly, the initial steep rise in the curve plotted on the graph begins to level out considerably at this point and beyond. Residues with total



Y = 5.511 + 1.555E-5 * X; R^2 = .408

Figure 7.1 Results of a regression analysis showing the relationship between the numbers of fatty acids identified in a sample and the total peak area.

peak areas of <100 Vmin. do have significantly fewer fatty acids ($\overline{X}$= 5.8 ±3.2, n=42) than residues with total peak areas of ≥100 Vmin. ($\overline{X}$= 10.4 ±4.1, n=41). There is a good deal of overlap between the two groups, however. Therefore, the decision to include only those samples with total peak areas of ≥ 100 Vmin. and/or with eight or more identified fatty acids in a later cluster analysis is an arbitrary one. Following these parameters resulted in 32 residues being excluded from the cluster analysis, including all six residues from Cerén, 12 of 16 residues from Aguateca, 6 of 14 uncontaminated

residues from K'axob (see below), and 8 of 52 residues from Cuello vessels, including 2 of the 5 charred residues analysed for their lipid content.

7.2.2 Problems with contamination of the K'axob collection

The analysis of many of the sherds from the K'axob collection has been hindered by contamination of the residues with nail polish used in cataloguing the sherds. The major contaminant peak from nail polish, which may be a compound from resins used in the manufacture of nail polish, occurs at approximately the same retention time as C16:0. Its presence is a problem because the peak is so large and broad that it obscures any C16:0 that might be in a given sample. Therefore, it is impossible to establish whether and how much C16:0 might be present in an archaeological residue. Hexadecanoic acid (C16:0) is very common and often is relatively abundant in lipid archaeological residues. If C16:0 is present but not recognized in a particular sample calculations of the relative proportions of all other identified fatty acids will be inaccurate, and data obtained for that sample will not be comparable with data for other samples or collections.

The problem of nail polish contaminants apparently cannot be corrected for. Once the source of the contaminant was identified, the section of the sherd that had been striped with nail polish was snapped off prior to extracting the residue. This does not appear to have removed all of the contaminant, however. As Figure 7.2 illustrates, removing the section of the sherds that has been painted with nail polish dramatically decreases the area of the contaminant peak. For quite some time, it appeared that removing the painted section of the sherd had eliminated this contaminant. However, a closer look at the data reveals that where this peak can be identified in sherds that were

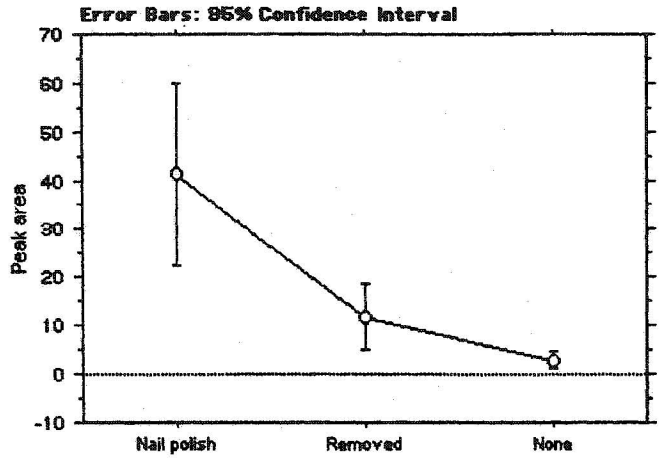


Figure 7.2 Results of an analysis of variance indicate that removing the nail polish only reduces the amount of the C16:0-like contaminant.

not striped with nail polish the peak area is significantly smaller still. It may be that solvents (toluene, for example) that are also components of the nail polish are very mobile and may have carried dissolved resins and perhaps other lipid contaminants deeper and further into the porous ceramic than is marked by the visible luster of the nail polish.

The problem with contamination can only serve to further complicate subsequent data analyses and attempts to identify the residues, and so a decision has been made to exclude data for all the K'axob vessels that had been catalogued with nail polish from all statistical analyses. In total, thirteen of the twenty-eight residues extracted from K'axob jars were contaminated.

7.2.3 But are they real? Establishing the origins of the lipid extracts

Considering the extremely small quantities of residue that were extracted, and given some unexpected patterns in the fatty acids identified, it is important to establish that the extracts are "real" artifacts of the vessels' previous contents rather than contaminants that might have originated either from the burial environment or from handling during or subsequent to excavation. There are several lines of evidence that suggest that most of the residues are, in fact, "real".

The variability observed in the fatty acid distributions of the extracts within and between collections (Tables 7.1 through 7.4) immediately suggests that they might be ancient residues. Differences in vessel function and contents, and variable processes of degradation and preservation are expected to result in residues with diverse fatty acid distributions. The same variability is not an expected outcome of contamination. If the fatty acids in the sherds came from archaeological sediments, greater uniformity might be expected among samples from the same site. Similarly, contamination by handling is likely to produce fatty acid distributions that are more similar, both within and among sites, than is apparent in the results. For example, the repeated occurrence of a very large peak, always at the same retention time, led to the realisation that many residues in the K'axob collection have been contaminated by nail polish used in cataloguing the sherds.

Results of the analysis of paired sherd and soil samples from Aguateca give further evidence that the fatty acid distributions seen in archaeological residues cannot be accounted for by migration of soil lipids into the sherds. An assumption made in interpreting the data is that no fatty acids are preferentially absorbed by the ceramics during burial, just as absorption of different lipids during cooking has been shown to be a

Table7.5 Relative percentages of fatty acids identified in sherd and soil pairs from Aguateca, Guatemala.

FA	sherd AG99.8	soil AG99.9	sherd AG99.11	soil AG99.12	sherd AG99.13	soil AG99.14	sherd AG99.15	soil AG99.16
C8:0	9.65	1.27						
C10:0	4.47			1.17				
C11:0								
C12:0					2.37			
C13:0			9.26					
C14:1					5.10	1.02		
C14:0		3.71		1.91	4.01		7.38	2.52
C15:1								
C15:0		2.05		1.38		1.71		3.29
C16:1						0.80		
C16:0	41.88	20.61	26.68	13.03	4.74	22.71	54.03	16.89
C17:1		4.49		3.64		4.12		3.77
C18:2n6c		3.71		2.98	19.13	4.70	16.11	
C18:2n6t		14.84	14.16	14.98	27.32	21.16	22.48	10.26
C18:1				1.81	2.91	3.80		
C18:0	21.88		13.98	9.05	16.94	8.90		4.37
C20:1					1.64			
C20:0				0.45	4.74	0.94		
C21:0				0.57	2.00	0.45		
C22:1					2.91			
C22:2		5.37		5.26		6.43		13.94
C22:0		4.98		5.95	6.19	4.05		7.15
C23:0		7.32	7.62	8.17		3.15		5.80
C24:1								
C24:0	22.12	31.64	28.31	29.65		16.06		32.27
sum	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.3

non-selective process (Evershed *et al.* 1995a:88, 91). The data presented in Table 7.5 show that there are clear differences in the types and amounts of fatty acids present in extracts taken from the pairs of sherds and soils. Furthermore, although the soil samples do not have identical fatty acid compositions, they are not as diverse as the archaeological residues. Nine fatty acids (C14:0, C15:0, C16:0, C17:1, C18:2n6t, C22:2,C20:0, C23:0, and C24:0) occur in all of the soil samples in similar proportions.

Only C16:0 occurs in varied proportions in all four archaeological residues. This evidence suggests that fatty acids present in the sherds have not been absorbed from the soils.

A comparison of the concentrations of identified fatty acids for sherds buried in middens *versus* living floor contexts reinforces the conclusion that lipids in the sherds do not originate from the soils and sediments in which they were buried. If ceramics do absorb lipids from their burial environments, then sherds that had been tossed into organic rich middens are expected to have greater concentrations of fatty acids than sherds that had been left on living floors. Using the Aguateca collection, a comparison of the fatty acid concentrations for 8 vessels from middens and 11 vessels from living floors shows that this is not the case. A Mann-Whitney U statistical test ($U=24$, $N1=8$, $N2=10$, $p=0.1551$, $\alpha=0.05$) indicates that there is no significant difference between the fatty acid concentrations in vessels from the two different contexts. A similar result and the same conclusion are obtained when the comparison is extended to include all vessels, from midden/refuse and living floor contexts, from all sites ($U=333.50$, $N1=30$, $N2=29$, $p=0.1238$, $\alpha = 0.05$).

Two of the fatty acids that characterize the soil samples, C18:2n6t and C24:0, have already been noted to occur regularly and unexpectedly in the larger sample of Maya vessels analysed in this study. It is fair, then, to question whether their presence in the archaeological sherds is not related to their prevalence in the soils. If there is a relationship, it is not the result of fatty acids being transferred from soils to the sherds, as has already been argued. Certainly C18:2nt6 and C24:0 are present in many but not all of the ancient residues. Consider, however, that the lipids that are present in soils derive largely from decaying plant detritus. Perhaps, then, there is a relationship if the

repeated occurrence of these two fatty acids in the archaeological residues also reflects a plant origin for some of the residues.

There is some reason to believe that the fatty acids which are unexpectedly present in the archaeological residues (C24:0, the C18:2 isomers, and several monoenoic fatty acids) are not contaminants acquired during storage or curation. Not only do they occur in sherds that have been curated in archaeological collections for a number of years (e.g. Cuello and K'axob) but they have been extracted from vessels from Aguateca, too. The sherds from Aguateca were collected specifically for residue analysis during excavations at the site and have been carefully handled in the field and in the lab to avoid contamination. These sherds have always been handled with latex gloves and have not been washed, stored in plastic bags, catalogued or glued in vessel reconstructions. Therefore, the likelihood of post-excavation contamination is minimal.

Twenty-five blanks that were prepared along with the archaeological extractions typically contain several fatty acids in trace amounts. Frequently identified fatty acid contaminants include: C10:0 (12 times), C11:0 (7), C16:0 (13), C18:0 (11), and C24:0 (13). It is possible, therefore, that the C24:0 in the samples originates in the chemicals used in the extractions. Subtraction of the contaminants identified in the blanks was designed to correct for this, however. Moreover, other long chain and unsaturated fatty acids, which were unexpected components of the archaeological lipids, are not present in the blanks.

A final line of evidence, which indicates that the lipid extracts originate with previous vessel contents rather than contamination, comes from a search for use- or activity-related patterns in the data. Before doing the cluster analysis, I looked for a simple way to establish whether the residues were "real" or "not real". I decided to

compare the concentrations of residues extracted from groups of vessels that were behaviourally meaningful. The residue concentrations of bowls and jars from all sites were compared with the expectation that there might be a difference between the two vessel forms because of their different functions. Twenty-two bowls (7 from Aguateca, one from Cerén, and 14 from Cuello) and 37 jars (9 from Aguateca, 4 from Cerén, 11 from Cuello, and 13 from K'axob) were included in the analysis. Bowls and jars were found to have significantly different concentrations of the identified fatty acids (U=205.500, N1=22, N2=36, p=0.0023, α=.05). The data illustrated in Figure 7.3, along with the sample means and standard deviations, indicate that more bowls have elevated concentrations of the identified fatty acids ($\overline{X}$= 2.68 ± 3.49 µg/g, n=22) than jars. The concentrations of fatty acids in the jars ($\overline{X}$= 0.66 ± 0.81 µg/g, n=36) are less variable and cluster at the lower end of their range. Therefore, it appears that the residues do record a difference between bowls and jars that may be a function of their different uses or contents.

There are indications, however, that differences in the porosity of the vessels, and perhaps also surface treatment, may have a greater influence on the amount of residue that is present or preserved. The bowls from Cuello are fine paste serving bowls and they are far less porous than other vessels included in this study. The bowls from Cuello also have the greatest concentrations of identified fatty acids ($\overline{X}$ = 3.55 ± 3.86 µg/g) compared to all other vessels, including not just the coarse-grained jars but the bowls from Aguateca, as well (Figure 7.4 a and b). In fact, the concentrations of residues in the Aguateca bowls ($\overline{X}$ = 1.33 ± 2.31 µg/g) are not significantly different from those of the Aguateca jars ($\overline{X}$ = 0.56 ± 0.57 µg/g) according to the results of a Mann-Whitney U test (U = 29, N1 = 7, N2 = 9, p = 0.7913, α=.05). This finding is consistent with the

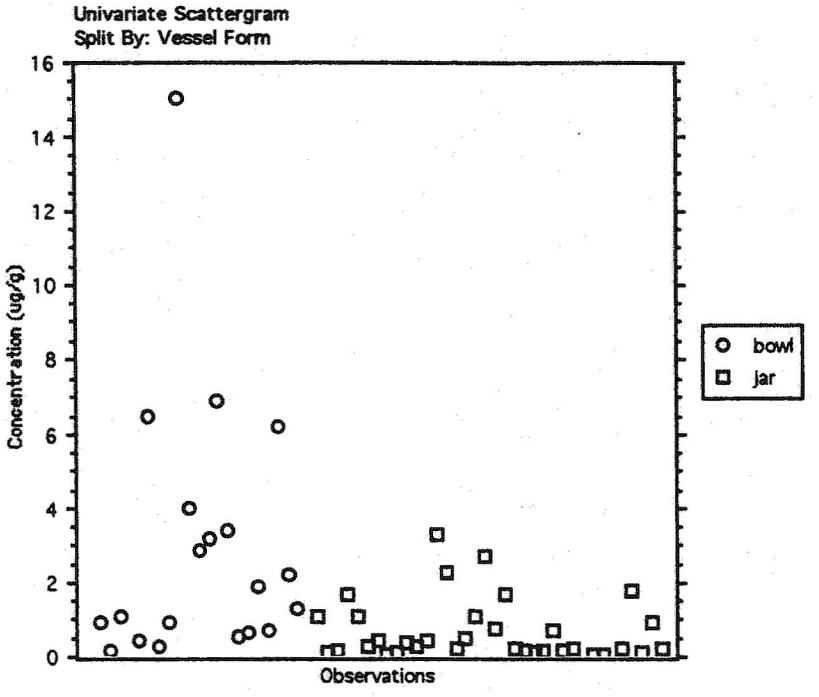


Figure 7.3 Scattergram showing the different concentrations (µg/g) of identified fatty acids in residues from bowls and jars from all sites.

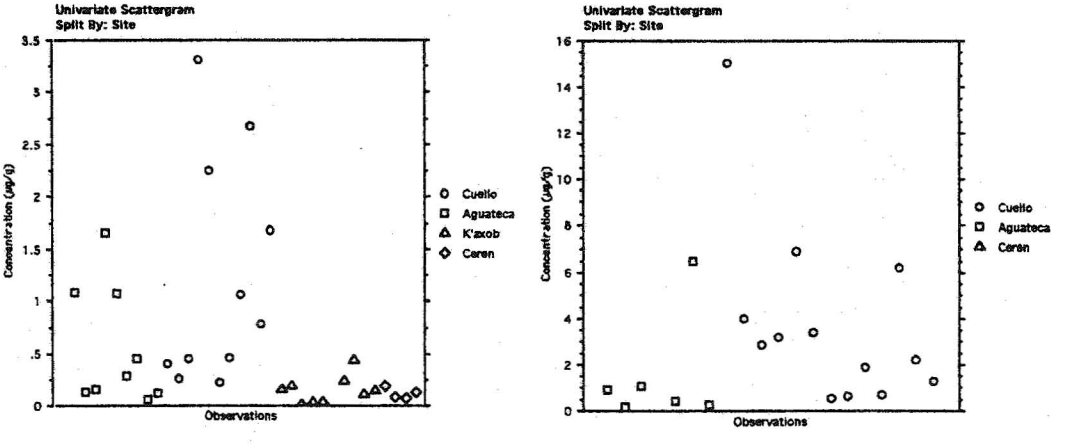


Figure 7.4 Scatterplot showing concentrations (µg/g) of identified fatty acids in a) jars and b) bowls from each site.

hypothesis that the large bowls found at Aguateca were used as utilitarian cooking vessels.

Although there appears to be a relationship between vessel porosity and the concentration of residue that is extracted, I do not know whether the bowls from Cuello, which are less porous, absorbed more residues during the time that they were used or whether the smaller pore size favoured the preservation of the lipids after discard and burial. I can only speculate that the smaller pore size perhaps slowed degradation by reducing the extent to which the lipids were exposed to oxygen, moisture, or microorganisms. Perhaps the slips, which have not eroded from the Cuello bowls as they have from all of the other vessels analysed, also minimized the loss of the lipids in some way. It is also possible that the better conditions for the preservation of organics, generally, which are known to exist at the site of Cuello, are a factor in the preservation of the relatively greater concentration of the lipid residues, in the bowls from that site. Indeed, the average concentration of the identified fatty acids for all of the vessels from Cuello ($\overline{X}$ =2.35±2.59 µg/g, n=47) is both larger and significantly different than the average concentration of fatty acids in the vessels analysed from each of the other three sites (Appendix A). The mean concentration of the residues from the Aguateca vessels is 1.79 ± 3.14 µg/g (n=18), while the average concentrations of the K'axob ($\overline{X}$ = 0.34±0.55 µ/g, n=11) and Cerén ($\overline{X}$ = 0.10±0.06 µg/g, n=5) residues are much lower.

7.3 Chapter discussion and summary

Ancient lipid residues were successfully extracted from archaeological vessels that had been excavated from several sites in the Maya Lowlands. Various lines of evidence indicate that many of the residues likely originate with some former contents of the

vessels rather than as contaminants from the burial environment or from post-excavation handling and storage. First, the fatty acid profiles of sherds and soil samples collected as pairs at the site of Aguateca differ in the types and number of fatty acids that were identified, indicating that lipids are not being absorbed into the ceramic material from the surrounding sediments. More evidence of this is that sherds that had been discarded into organic-rich midden contexts at Aguateca and Cuello do not have greater concentrations of residue compared to sherds left on living surfaces. If lipids did migrate from sediments into the sherds, I would expect that sherds excavated from middens would have greater concentrations of residue. Further, my concerns that the unsaturated and long chain fatty acids in the archaeological residues resulted from post-excavation handling were allayed by the finding that these same fatty acids were as common in residues extracted from Aguateca sherds, which were collected specifically for residue analysis and handled very little, as they were in sherds that had been curated for several years. Unsaturated and long chain fatty acids are sometimes identified as contaminants in experimental blanks, but they occur less frequently and in much smaller quantities compared to residues. Overall, in fact, the fatty acid profiles of the blanks do not resemble those of the archaeological residues. Therefore, the fatty acid composition of the residues also cannot be explained by contamination of the samples during the extraction process in the laboratory.

There is a large group of samples (n=26) from K'axob, however, that were catalogued, as archaeologists generally do, by writing the catalogue number in ink, over a stripe of clear nail polish. Unfortunately, a contaminant from the nail polish, which is possibly a resin, occurs at approximately the same retention time as C16:0. As a result, it was necessary to exclude all of the sherds that had been striped with nail polish from

statistical analyses. Further, it would not be worthwhile to attempt to identify these contaminated residues. A far-reaching implication of this finding is that ceramic collections that have previously been excavated and catalogued with nail polish will not be suitable for lipid residue analysis.

Having discounted contamination as the source of the remaining archaeological residues, I can make the argument that the variability and patterning observed in the fatty acid profiles of the residues is related, at least in part, to the various ways in which people used and/or manufactured the vessels in the past. Variability in the fatty acid composition of the residues may reflect that the vessels once held different foods or dishes (mixes of foods). In addition, if the vessels were used for a variety of functions- some for storage, some for cooking, and others for serving foods - the fatty acid profiles of the residues also would have been made diverse by the different processes of thermal and/or oxidative degradation to which each vessel had been exposed during its use-life.

Differences in the amount of residue preserved may also indicate that the vessels once held a variety of contents. However, it seems that distinct physical properties, which were dictated by differences in vessel functions, might also have affected the amount of lipid residue that was absorbed and preserved. The fact that bowls, and the bowls from Cuello in particular, have significantly greater concentrations of the identified fatty acids than jars may simply reflect that these two vessel forms held different foods. Perhaps the bowls contained a more fatty food, for example. It is likely not coincidental, however, that it is the fine-paste serving bowls from Cuello, which still have well-preserved interior and exterior slips, that have the greatest concentrations of identified fatty acids. It is not just the porous, coarse-grain, utilitarian jars from all the sites that have significantly lower concentrations of the residues. In fact, the utilitarian bowls from

Aguateca, which are thought to have been used for cooking, and which are much more porous than the bowls from Cuello, also have significantly lower concentrations of the identified fatty acids compared to the Cuello bowls.

Better conditions for the preservation of organics at Cuello may also factor into the greater concentrations of the absorbed residues found preserved in Cuello vessels, generally, compared to vessels from Aguateca, K'axob, and Cerén.

Unfortunately, it is impossible to evaluate the extent to which any factor – the original vessel contents, various degradative processes, and vessel morphology - played a role in creating the variation that is apparent in the archaeological residues analysed in this study. This is problematic. Consider a very over-simplified example of a particular food plant that was repeatedly cooked in a jar and then always served in the same fine-paste bowl. The residue in the cooking jar, which would eventually return to the fire, would be exposed to additional thermal degradation while that in the bowl would not. Once the vessels were no longer used, it seems possible that the residues in the two vessels would be exposed to different amounts and/or types of degradative processes. Therefore, it is very possible that two different residues of the same cooked food would not be recognizable as the same food on the basis of their fatty acid profiles.

The amount of organic residue preserved in the Maya vessels, which have long been buried at these tropical sites, is extremely small. The quantity of residue that can be extracted is very small even by comparison to lipid residues extracted from archaeological vessels found at sites in the temperate latitudes of Western Canada and Southern Ontario. In fact, many of the residues (n=58) from the Maya vessels were deemed to be too small to be useful after it was realized that a positive correlation exists between the number of fatty acids that can be identified and the amount of residue that

is extracted, as measured by the total peak area (Vmin.). As the number of fatty acids identified in each residue is clearly a function of the amount of residue that is extracted, we can predict that it would be possible to see and identify additional fatty acids that were already present but below the limits of detection, either by concentrating the residue or by extracting the same residue from a larger sherd. Furthermore, we can expect to obtain incomplete fatty acid profiles when we analyse very small amounts of archaeological lipid residues, by GC analysis. It is also important to remember, though, that the ≥ 100 Vmin. criterion for including residues in the cluster analysis is an arbitrary one. Therefore, it is not necessarily true that we can obtain complete fatty acid profiles by GC analysis for these relatively larger residues.

Ultimately, an incomplete or inaccurate description of the fatty acids in a residue will hinder efforts or make it impossible to identify a residue. Archaeological residues are characterized based on the relative proportions of the fatty acids, or the ratios of one fatty acid to another. If one or several fatty acids are present but not at detectable limits in a very small residue, then the ratios or proportions calculated for those that are identified will not be accurate or true. It is plausible, therefore, that ancient residues of the same food might produce very different fatty acid profiles, depending on how much of the residue was preserved. Further, because fatty foods (meats, oily/waxy food plants) will produce more residue, we can expect that they will be identified more often and perhaps more readily than less fatty food – such as starchy food plants - that might not always leave enough residue to produce a completely detectable fatty acid profile. In the next chapter, I work through the process of identifying the origins of the archaeological residues.

Chapter 8

GC Analysis of Lipid Residues: Part II, Identifications

8.1 Introduction

Having established that many of the lipids extracted from the vessels do originate with their past contents and not with contaminants, and having recognized and eliminated those sherds from the K'axob sample that are contaminated, efforts were then focused on identifying the foods that left the residues. This chapter describes the process of identifying the residues, as well as the findings.

8.2 Comparing and grouping samples: Hierarchical cluster analysis

Hierarchical agglomerative cluster analysis was used to find patterns that exist in the fatty acid compositions of both cooking extracts and archaeological residues. The way in which fatty acid compositions or fatty acid profiles of the samples were determined is described in Chapter 5 (Section 5.6). Cluster analysis groups individuals (or samples) that are more similar to each other than they are to samples in other clusters (Baxter 1993:140). In hierarchical agglomerative methods, each sample is initially considered to be a separate cluster. At the next and at each successive stage the most similar samples and/or clusters are merged into ever-larger clusters until all of the samples are included in a single, large cluster (Baxter 1993:141; Shennan 1997:221-222, 235). Therefore, the first clusters that are formed contain samples with a high level of similarity while subsequent clusters incorporate samples that are increasingly dissimilar.

The Euclidean distance coefficient is the similarity measure used in this study to describe the relationships between samples. It is defined by the following equation:

$$d_{ij} = \sqrt{\sum_{k=1}^{p} (x_{ik} - x_{jk})^2} \qquad \text{Eq. 7.1}$$

where i and j are two individuals (samples) that are described by p variables (x) (Shennan 1997:223-224). The variables that were subject to cluster analysis are the relative proportions of each of the fatty acids identified in each of the samples. The resulting matrix of similarity/distance coefficients describes the relationships between all individuals in a data set. The closer *dij* is to zero, the more similar two samples are to each other. The most dissimilar samples in a data set will have the largest value of *dij* (Shennan 1997:224).

The Euclidean distance coefficient is preferred over other similarity measures for use with the average-link clustering algorithm, applied to the fatty acid data in this study, as it is less distorting (Wright 1989, cited in Baxter 1993:156). In measuring similarities and dissimilarities between samples, Baxter (1993:157) notes that it places more emphasis on large differences between samples than some other measures but less so than the squared Euclidean distance coefficient.

The average-link (or within groups) clustering algorithm was used to group similar samples. Similarity between samples and clusters is measured by the arithmetic average of the distances between pairs of individuals or groups (Baxter 1993:155; Shennan 1997:239-240):

$$\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} dij}{n \pi j}$$

where *dij* is the distance between a sample in group *i* and a sample in group *j*, and *n* is the number of samples in a group (Shennan 1997:239-240). When groups contain more than one sample, the average distance is calculated for the sum of distances between each member of the first group paired with each member of the second group. As the clustering analysis proceeds in stages, pairs of samples and/or groups that are most similar are linked together at ever-greater distances.

The results of hierarchical cluster analysis are visually represented in a dendrogram. The researcher must then decide upon the appropriate number of clusters, keeping in mind that the appearance of the dendrogram can be misleading (Baxter 1993:161). Cluster analysis does impose patterning on the data (Shennan 1997:22). While there are formal statistical rules that can be used, most decisions as to the number of clusters are made subjectively, using logic to the extent that it is possible (Baxter 1993:163-164). Any patterns identified in the clusters should ideally be verified using another type of multivariate analysis or a second method of cluster analysis. Given the difficulties encountered in identifying the residues in this study, a supplementary analysis was considered to be unnecessary.

8.3 Results of cluster analysis of cooking water extracts

Fatty acid compositions were determined for 35 cooking water extracts that were used as comparative standards when identifying the archaeological residues taken from Maya vessels. The cooking water standards were prepared by boiling modern examples of foods from the Maya area. The fatty acid compositions of the cooking water extracts

were not expected to be directly comparable to those of the archaeological residues, which are more extensively degraded. It was anticipated that a cluster analysis of the cooking water extracts would facilitate the definition of categories of cooked foods, which are distinguishable by their fatty acid profiles, that might continue to be relevant for the degraded archaeological residues. In other words, it was anticipated that cooked foods within each cluster or category might degrade in similar ways and so continue to share important fatty acid characteristics as degraded archaeological food residues.

Twenty-five different fatty acids were identified in the cooking waters using their relative retention times and those of the FAME standards (see Section 5.4.1). Eleven fatty acids that occur in 40% or more of the cooking waters, in descending order, are: C24:0, C18:2n6t, C18:2n6c, C16:0, C18:0, C22:0, C12:0, C14:0, C15:0, and C16:1. Of these, the C18:2 isomers, C16:0, C18:0, and C24:0 occur in the greatest proportions (8-31%). Notably absent from these lists are C17:1 and C18:1. As it was used as an internal standard, C17:0 could not be identified as having originated in the cooking waters or archaeological residues.

The fatty acid compositions of 35 cooking waters were compared using average link cluster analysis. The dendrogram generated by the analysis is shown in Figure 8.1. The results, which are described in the following pages, are summarized in Table 8.1 and are presented in more detail in Appendix B. The cluster analysis can be considered to have been successful as it is possible to identify very general "fatty" attributes that are common to most of the cooked foods in each cluster. The categories of foods that can be distinguished in the cooking water extracts are: maize and other starchy plant foods, meats and squash seeds, oily and waxy plant products, and leafy greens.

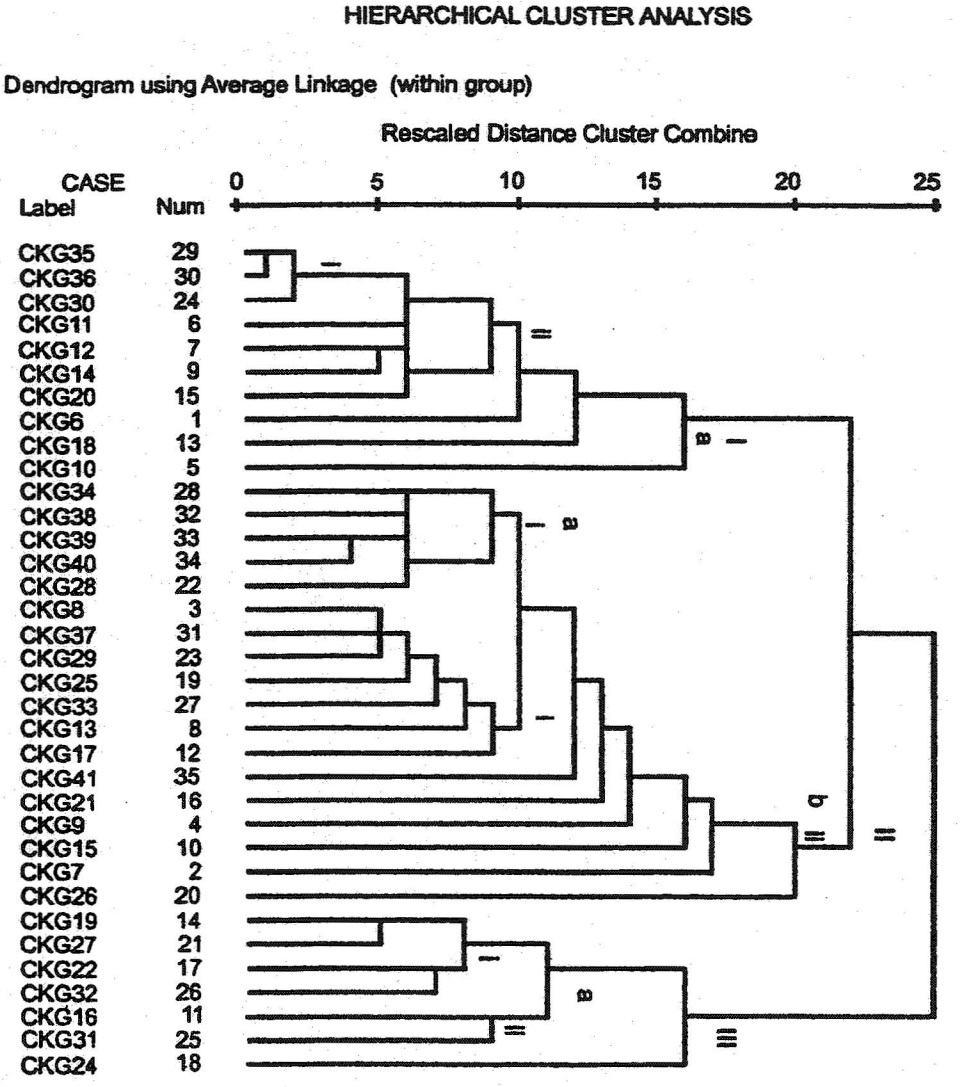


Figure 8.1 Dendrogram of hierarchical cluster analysis of cooking water extracts.

Table 8.1 Characteristic fatty acid compositions of cooked food groups identified by cluster analysis.

Cluster/FA:	Mean relative % ≤ C15	C16:0	C18:2n6c	C18:2n6t	C18:1	C18:0	≥ C20
Maize and starchy food plants:							
Cluster I	2.67 ±4.88	18.32 ±7.46	62.73 ±6.35	9.93 ±9.39	0.17 ±0.29	1.43 ±2.10	4.35 ±3.18
Meats and squash seeds:							
Cluster II(a)	3.00 ±5.21	22.79 ±2.80	32.47 ±7.31	22.10 ±7.75	0.75 ±1.27	15.72 ±9.79	1.43 ±1.71
Oily/waxy plant products:							
Cluster II(bi)	4.82 ±5.96	25.51 ±6.21	35.09 ±8.05	10.51 ±5.40	1.13 ±2.48	10.87 ±6.13	12.00 ±3.13
Cluster II(bii)	8.26 ±1.58	12.88 ±9.55	11.40 ±15.20	24.20 ±14.22	0.57 ±1.28	25.07 ±21.70	16.34 ±13.44
All of II(b)	6.32 ±10.63	20.25 ±9.82	25.22 ±16.38	16.22 ±11.78	0.90 ±2.01	16.78 ±15.66	13.81 ±12.27
Leaves and leafy plant greens:							
Cluster III(ai)	2.32 ±0.87	67.93 ±8.75	5.09 ±6.74	4.14 ±3.47	0.47 ±0.56	8.99 ±4.02	10.58 ±5.50
Cluster III(aii)	1.88 ±2.65	51.12 ±0.86	0.00 ±0.00	19.29 ±5.33	0.00 0.00	9.67 ±2.71	18.05 ±9.83
All of III(a)	2.17 ±1.39	62.33 ±11.02	3.40 ±5.84	5.70 ±8.61	0.31 ±0.49	9.22 ±3.36	13.07 ±7.23

The guidelines given in Figure 8.2 are used to describe and compare the relative percentages of the various fatty acids that characterise the samples within a cluster. The same parameters are also used to describe the fatty acid compositions of the degraded cooking extracts and the archaeological residues. Of course, some fatty acids tend to occur always in either very large or very small proportions of the total fatty acids. Therefore, the levels of particular fatty acids are also described in terms of the range of

Amount of Fatty Acid	Relative Percentage Present
trace	≤1%
low	2-5%
moderate	6-15%
high	16-35%
very high	≥36%

Figure 8.2 Guidelines for describing the relative percentage of the various fatty acids present in a lipid extract or residue.

values measured for that fatty acid in all of the cooking water extracts or all of the archaeological residues.

Cluster I comprises mainly starchy foods that have a low lipid content including two samples of maize, the florescence of *pacaya*, the squash, *güicoy*, the root of *camote*, and black beans. *Epazote* flowers and a leafy green, *chaya*, are also part of this cluster. Samples in this cluster tend to have extremely high proportions of C18:2n6c (62.7%), high percentages of C16:0 (18.3%), moderate amounts of C18:2n6t (9.9%), low percentages of C18:0 (1.43%), and the medium (≤ C15; 2.67%) and long chain (≥ C20; 4.4%) fatty acids, and only trace amounts of C18:1 (0.17%) (Table 8.1). Considering the range of values measured for each fatty acid present in just the cooking water extracts, the amount of C16:0 in the Cluster I cooking waters can otherwise be described as being present in relatively low-moderate proportions, as would C18:2n6t and the medium- and long chain fatty acids (for ranges, see Table 8.1).

Cluster II comprises meats and food plants that are more fatty than the foods in other clusters whether referring to fats, oils, or protective waxes. This cluster divides

into subclusters (a) and (b). Cooking Cluster II(a) includes three of the four meat samples (deer, turkey, armadillo), and two different samples of squash seeds. These cooked meats have high proportions of the C18:2 isomers (32.5% and 22.1%), and C16:0 (22.8%). Relative to other cooked foods, however, the amounts of C16:0 present are low to moderate. Overall, stearic acid (C18:0) is present in moderate amounts (15.7%), and the medium (3.0%) and long chain fatty acids (1.4%) occur at low levels. Just traces of C18:1 (0.8%) were measured in the cooked meat samples. In comparison to other cooking waters, this amount of C18:1 might be described as moderate-high.

Cluster II(b) is more diverse than both Cluster I and Cluster II(a). The core of this cluster [subcluster b(i)] includes a mix of *tepescuintle* meat, *achiote* seeds, *loroco* flowers, *chile*, tomato, a leafy green (*macal*), and *pimienta* leaves. More distantly linked to this group, and to each other, is an assortment of food plants [b(ii)] that includes two leafy greens and three very oily plant products: avocado fruits, *cacao* beans, and *corozo* palm nuts. Overall, samples in Cluster II(b) have high levels of C16:0 (20.3%), C18:2n6c (25.2%), C18:2n6t (16.2%), and C18:0 (16.8%). Both the medium- (6.3%) and long chain (13.8%) fatty acids are present in moderate proportions. Once again, C18:1 typically occurs in trace amounts. However, relative to the fatty acid composition of other cooking water extracts, the cooked foods in Cluster II(b) have large amounts of C18:0 and C18:1 as well as the medium- and long chain fatty acids, whereas the levels of C16:0 and the two C18:2 isomers are low-moderate and moderate, respectively.

The cooked foods in Cluster II(b), comprising mainly oily and waxy plant products, are separated from the meats and squash seeds, in Cluster II(a), by their lower proportions of C16:0 and C18:2n6c, and greater amounts of C18:2n6t, C18:0, and the longer-chain fatty acids (Table 8.1).

Cluster III is a grouping of leaves, leafy greens (*hierba buena*, *guisquil* leaves, *Sta. Maria*, *pimienta*), and *tomatillo*. Extremely high levels of C16:0 (62.3%), moderate levels of C18:0 (9.2%) and fatty acids with 20 or more carbons (13.1%), and low levels of C18:2n6c (3.4%), C18:2n6t (5.7%), and the medium chain fatty acids (2.2%) describe the fatty acid distributions of these cooked foods (Table 8.1). Compared to other clusters of cooking waters, Cluster III might otherwise be described as having just moderate-high levels of the long chain fatty acids and moderate, rather than trace amounts of C18:1.

Rosa de jamaica, *chipilín*, *macal*, and two of three examples of beans (CKG 24 and CKG 26) do not readily cluster with any other samples.

An interesting pattern that appears in the fatty acid data for the cooking water samples suggests that it might be possible to distinguish between residues produced by cooking waxy (leafy greens or vegetables) or oily plant foods *versus* other foods (meats and starchy food plants) based on their markedly different proportions of the long chain fatty acids. The leaves, greens, vegetables, and oily fruits (avocado, *corozo* palm nuts) in Clusters II(b) and III have the greatest proportions of the long chain fatty acids, averaging 13.8% and 13.1%, respectively. Lignoceric acid (C24:0) predominates but C22:0 and C20:0 are also common in samples belonging to these clusters. Two cooking water residues in Cluster II(b), *cacao* and *tepescuintle*, do not readily fit this pattern. They have much lower percentages of the long chain fatty acids. In fact, the proportion of long chain fatty acids in tepescuintle (0.2%) is more similar to those of other cooked meats, which group together in Cluster II(a), and average 0.9% of the fatty acids identified (see Appendix B). Maize and other starchy food plants (Cluster I) have

intermediary levels of the long chain fatty acids ($\overline{X}$= 4.4 ±3.2%), as does the cooking water extract for squash seeds[1] (Appendix B, CKG.34), in Cluster II(a).

Although waxy and oily plants analysed for this project tend to have greater proportions of the long chain fatty acids compared to starchy food plants, there is considerable variation in the former group. Therefore, a more reasonable expectation might be the possibility of predicting that a residue resulted from cooking meat, as opposed to food plants, based on levels of long chain fatty acids ≤ 4%. There is a potential problem with this reasoning, however. The long chain fatty acids in the food plants, and particularly the leafy greens and vegetables, may derive from protective waxes that coat the leaves and fruits (see section 4.4.2). Protective waxes also occur in the skins and hair/fur of animals. The examples of meats cooked in this study included just muscle tissue and, therefore, may contain fewer long chain fatty acids than meats cooked with the skin tissue. Although some animals, deer for example, may often have been skinned prior to cooking, other meats such as turkey may not have been. Therefore, without additional fatty acid analyses of a greater variety of meats and animal tissues it cannot be concluded with certainty that all residues with proportions of long chain fatty acids ≥ 4% are the result of cooking plants and not meat.

Moreover, long chain fatty acids are also common in low to moderate proportions in freshwater fish (Henderson and Tocher 1987:292-293). It can be expected that some of these might continue to exist after cooking and following degradation in archaeological burial contexts, although there is no evidence for this at this time. Malainey (1997:289) did not identify long chain fatty acids in her cooked and experimentally degraded fish residue but she also did not identify long chain fatty acids in any other experimentally

[1] Another example of cooked squash (CKG.28, Appendix B) has no long chain fatty acids.

degraded food residues. Moreover, the fatty acid composition of the temperate latitude fish that she analysed is not necessarily representative of freshwater fish from the tropical Maya area. Various factors, including environmental temperature, diet and the fatty acid profile of a particular aquatic food chain, season, and fish species, all influence the fatty acid composition of freshwater fish (Henderson and Tocher 1987:292, 327-328, 330-332).

Owing to the many factors that affect the lipid and fatty acid composition of freshwater fish (Henderson and Tocher 1987), it is difficult to describe a "typical" fatty acid profile for this category of food when it is fresh. Cooking and degradation will only complicate efforts to predict what the fatty acid profile for freshwater fish would look like in an archaeological residue; this is a problem that will be addressed again in a later section (section 8.6). Henderson and Tocher (1987:292-294) do, however, describe some general characteristics of the fatty acid composition of the total lipid of freshwater fish. Unsaturated fatty acids dominate fish lipids. Monoenoic acids comprise 15%-50% of the total lipid. Of the major monoenes, C18:1 occurs in the greatest proportions followed by C16:1 and then C20:1. Several others (C14:1, C15:1, C17:1, C22:1, C24:1) tend to be present in low proportions (<2%). The principal dienoic acid is C18:2 (18.5% and lower). Freshwater fish lipids are also characterized by a variety and abundance of polyunsaturated fatty acids with 18, 20, and 22 carbons, which tend to occur in low to moderate proportions. Saturated fatty acids are not necessarily minor components of fish lipids, however. In freshwater fish from temperate environments, they comprise 9%-36% of the total lipid. Tropical freshwater fish generally have greater proportions of saturated fatty acids, as high as 45% of the total lipid. The most abundant saturated acid is C16:0 (moderate to high) > C18:0 > C14:0 >C12:0 (low). Long chain, saturated

fatty acids (C20:0 and C22:0) are only minor constituents when they do occur. What is interesting and perhaps also important (section 8.5), is that odd numbered fatty acids (C13:0, C15:0, C17:0, C19:0) and especially C15:0 and C17:0 are not uncommon in the lipids of freshwater fish, although they tend to account for less than 2.5% of the total lipid.

8.4 Fatty acid composition of the degraded cooking waters

The fatty acid distributions of twelve experimentally degraded extracts were determined by GC analysis. The results are provided in Appendix D and are described in this section. Seven of these samples had been left to degrade for a period of one year. Five others, including extracts from the meats, maize (CKG.35), and one squash extract (CKG.34), were degraded for just three months. Obviously, the extracts left for a full year are more extensively degraded. The internal standard has disappeared completely or is present in just trace amounts in these samples, whereas substantial amounts of the C17:0 remain in the extracts decomposed for the shorter period. Nonetheless, the fatty acid distributions of all the degraded cooking water extracts are very different from those obtained when the cooking water extracts were freshly prepared (see graphs in Appendix D), indicating that much degradation has already occurred in all the samples.

Still, as is true for archaeological residues in this study (section 7.2.1), the fatty acid distributions of the decomposed cooking extracts differ in some important ways from those of experimentally degraded food residues produced by Malainey (1997), using cooked foods from Western Canada and degraded for 80 days. In particular, a variety of unsaturated fatty acids (C14:1, C15:1, C16:1, C17:1, the C18:2 isomers,

C18:1, C22:2, C22:1, and C24:1) remain and are frequently identified in the degraded samples of Maya foods and the archaeological residues. Most of the unsaturated fatty acids occur at trace to low levels (see Appendix C) but a number of them are present at moderate to high relative percentages in the samples (the C18:2 isomers, C22:2, and C22:1). As well, various long chain fatty acids are common and they occur in low to moderate proportions in both the degraded food extracts (Appendix C) and the archaeological residues (Appendix D). Moreover, the diversity of identified fatty acids in the degraded extracts remains comparable to the variety identified in "fresh" cooking extracts, rather than having decreased as the samples decomposed. Twenty-four fatty acids were identified in the twelve degraded samples, and the decayed extracts have an average of 10.8 identified fatty acids per extract. Fifteen of the identified fatty acids occur in 40% or more of the extracts. Those most frequently identified are C24:0, C18:0, C18:2n6c (frequency ≥80%), and C23:0, C16:0, C15:0, C14:0, and C10:0, which each occur in 75% of the degraded extracts. The fatty acids that tend to occur in the greatest relative proportions are C16:0 ($\overline{X}$=32.6±16.4%), C18:0 ($\overline{X}$=19.2±13.1%), C18:2n6t ($\overline{X}$=16.2±8.9%), C18:2n6c ($\overline{X}$=15.5±16.9%), and C22:1 ($\overline{X}$=12.3±31.1%). Each of C20:0, C22:2, and C24:0 also have mean relative proportions that are greater than 5%.

The differences between the fatty acid profiles of the degraded Maya foods and archaeological residues *versus* those of degraded foods and archaeological residues from Western Canada and specifically the more frequent occurrence of unsaturated and long chain fatty acids in the former may be significant. Malainey (1997) shows that the absence of unsaturated and long chain fatty acids in her samples is a result of thermal and oxidative degradation. However, because both of these categories of fatty acids remain in cooking extracts left to decompose for an entire year and in the archaeological

residues that have degraded for several hundred years in tropical conditions, it seems unlikely that their absence from Malainey's samples is only a result of degradation. I believe that the different fatty acids in the Maya and Canadian residues can, in part, be explained by the different lipid compositions of the original foods (or food assemblages) from the two different regions. The implication that follows from this is that fatty acid profiles developed from a geographically specific set of modern food standards, in order to identify the origins of archaeological residues, will not be useful for identifying residues from vessels excavated from sites in another part of the world where a dissimilar group of foods was available. This assumes that experimentally degraded food extracts can provide useful criteria for identifying the origins of archaeological residues on the basis of their fatty acid distributions.

One limitation is that the degraded samples selected to represent a particular cluster (e.g. maize and starchy plants, oily/waxy plant products) are not useful for predicting the fatty acid profiles of other foods that had belonged to the same cluster of cooking water extracts. Freshly cooked foods that share similar fatty acid profiles, as identified by cluster analysis (Appendix B), do not always have similar fatty acid compositions once the cooked food extracts have degraded (Appendix C). For example, degraded lipid extracts from squash and meat (deer and armadillo) are markedly different, though they had been grouped together in Cluster II(ai), and degraded extracts from maize and *guicoj* [Cluster I(ai)] have also diverged.

The fatty acid profiles obtained for just twelve degraded cooking water extracts suggest that four categories of food – maize, squash seeds, meat, leafy greens/plants – might be discernible by their degraded fatty acid residues (Table 8.2). The degraded lipid extract from maize is dominated by high levels of C18:2 isomers, moderate

Table 8.2 Criteria for archaeological residue identification based on experimentally degraded cooking residues of foods from the Maya Lowlands.

FA/Identification:	maize	squash seeds	meat	leafy greens/plant
Medium chain	trace	5 to 7%	2 to 15.5%	5 to 13%
C16:1	none	trace to 1.5%	trace to 2.5%	0 to 2%
C16:0	~10%	none	17 to 50%	48 to 57%
C17:1	none	0 to ~1%	none	none
C18:2n6c	57%	0 to 11.5%	11 to 25%	trace to 8.5%
C18:2n6t	~25%	none	15 to 30%	0 to 15%
C18:1	trace	none	trace to 2.5%	0 to 1%
C18:0	~1%	none	12 to 32.5%	trace to 22.5%
Long chain	6.5%	80 to 93%*	trace to 4%	2.5 to 38%

* dominated by either C20:0, C22:2, and/or C22:1.

proportions of C16:0 and the long chain fatty acids. Unlike many other degraded extracts, maize has just trace amounts of the medium chain fatty acids. Two degraded lipid extracts from cooked squash seeds are characterized by extremely large proportions of the long chain fatty acids (especially C20:0, C22:2, and/or C22:1). They are also lacking fatty acids with 16 and 18 carbons and have only low to moderate amounts of the medium chain fatty acids.

Degraded lipid extracts from meats and other plant foods have a greater diversity of fatty acids than do those of degraded samples of maize and squash seeds (Table 8.2; Appendix C). The relative proportions of several fatty acids used to characterize the fatty acids profiles (medium chain, C16:1, C16:0, C17:1, C18:1, C18:0) overlap for degraded extracts from meats and leafy greens/plants. However, plant extracts nearly always have larger percentages of the long chain fatty acids. The fatty acid profiles of degraded maize and squash seed extracts also have greater relative proportions of the

long chain fatty acids than do those of meats. Long chain fatty acids comprise less than 4% of all the identified fatty acids in degraded lipid extracts from meats. In degraded plant extracts, they account for 6.5% to 93% of the fatty acids, tending toward the higher end of the range. The vegetable, *guicoj*, is the only exception. Degraded lipid extracts of meats are further distinguished from those of leafy greens/plants by higher proportions of the C18:2 isomers and C18:0 (Table 8.2). Although maize also has large proportions of the C18:2 isomers, degraded meat extracts exhibit a greater diversity of fatty acids, higher percentages of C18:0, and much smaller proportions of the long chain fatty acids.

It is necessary at this point to comment on the reliability of the criteria presented in Table 8.2 as a method of distinguishing between the foods from which degraded lipid extracts originated. The extracts used to establish the criteria included only eleven different foods, and just one or a few examples from each of the categories. It is possible that the samples selected for analysis are not representative of the variation in fatty acid compositions that exists for foods within each category. That there are degraded foods that do not fit into any of the defined categories suggests this might be the case. For example, the degraded lipid extract of *tepescuintle* has a much lower percentage of C18:2n6c compared to other degraded meat extracts, whereas degraded *chile* has levels of the C18:2 isomers that are comparable to degraded meats. *Chile* has a greater proportion of long chain fatty acids (7.7%) than is expected for meats, however. Therefore, criteria provided for identifying archaeological lipid residues on the basis of their fatty acids should only be considered to be guidelines. They will not provide secure identifications and additional lines of evidence to support any identification that is offered would be ideal if not essential.

Perhaps the most certain distinction that can be made based on fatty acid distributions alone is that between meat and plant, as indicated by different proportions of long chain fatty acids. However, without any information on the fatty acid composition of cooked and degraded freshwater fish, even this is not certain. Given some broad similarities in the fatty acid composition of freshwater fish and plants, with reference to moderate to high proportions of C16:0 and C18:0 as well as abundant unsaturated and long chain fatty acids, it is possible that the fatty acid composition of degraded fish is not unlike that of some degraded plants.

8.5 Results of cluster analysis of archaeological residues

The decision to eliminate 32 residues, on the basis of total peak areas <100 Vmin., and to exclude 13 more samples because of problems with nail polish contaminants left just 59 samples to include in a hierarchical analysis of archaeological residues. The cluster analysis identified five clusters (Clusters I –V) and a number of subclusters (Figure 8.3). The average fatty acid compositions of the samples in each of the clusters and subclusters are given in Table 8.3. Data for individual samples, organized by cluster and subcluster, are presented in Appendix D.

Cluster I is a loose grouping of 12 residues. Seven of these, including three charred residues, are from Cuello vessels (five jars, one large, open-mouthed vessel, and one unidentified form), three more are from Aguateca vessels (two jars and one incensario), and two residues were extracted from K'axob jars. These residues are distinctive because they exhibit a fairly even distribution of the identified fatty acids. On average, each of C16:0 ($\overline{X}$=12.6%), C18:2n6c ($\overline{X}$=7.3%), C18:2n6t ($\overline{X}$=11.1%), and C18:0 ($\overline{X}$=11.7%) occur in moderate proportions. The remaining fatty acids tend to be

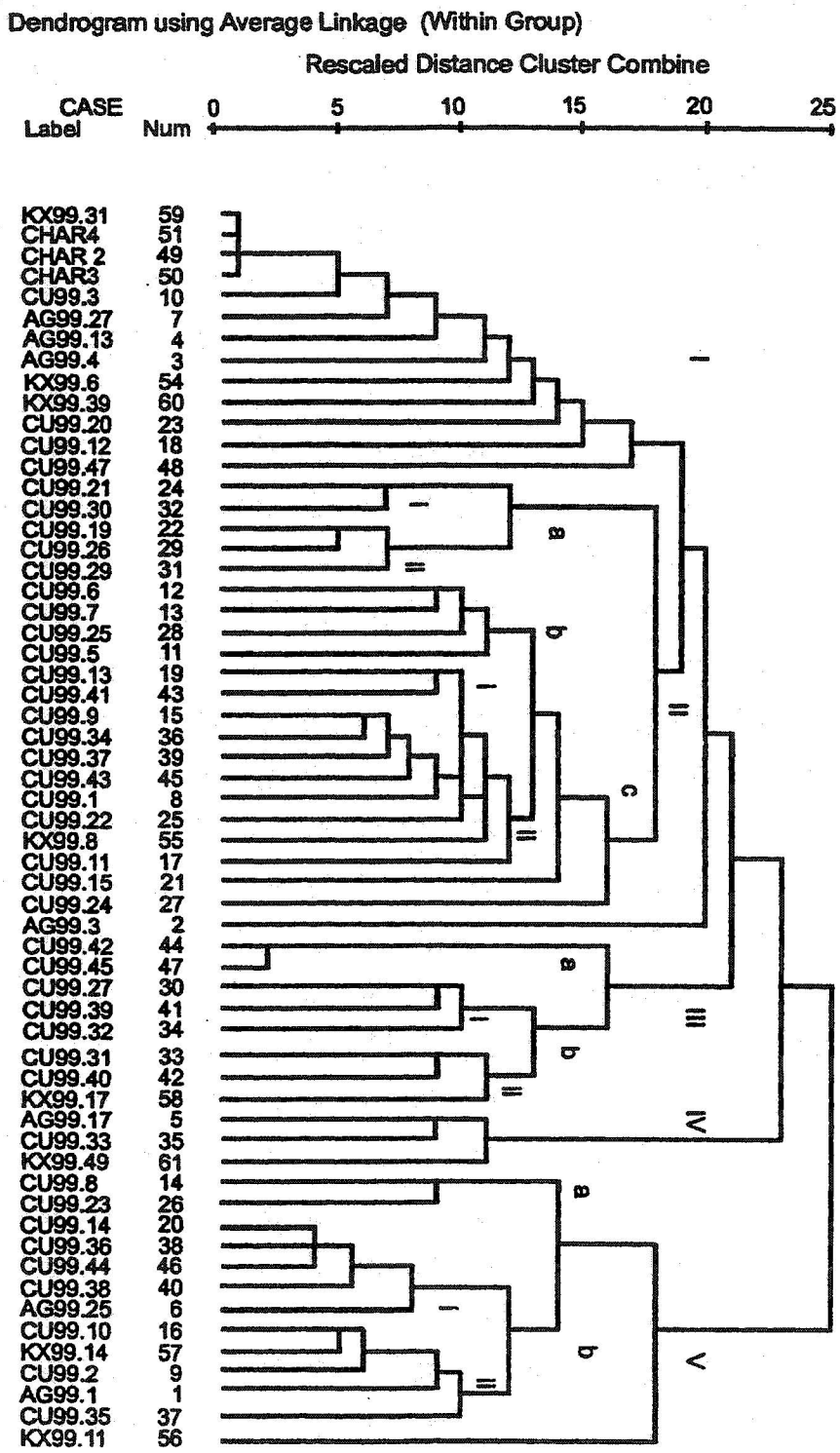


Figure 8.3 Dendrogram of hierarchical cluster analysis of archaeological residues.

Table 8.3 Characteristic fatty acid compositions of archaeological residues identified by cluster analysis.

	Mean relative %						
Cluster/FA:	≤ C15	C16:0	C18:2n6c	C18:2n6t	C18:1	C18:0	≥ C20
Cluster I(a)	3.49	12.59	7.34	11.12	1.15	11.69	1.68
(n=11)	±4.18	±20.29	±8.26	±11.57	±2.19	±11.96	±1.32
Cluster II(a):							
Cluster II(ai)	4.73	0.00	5.60	0.00	0.00	7.10	4.42
(n=2)	±0.89	±0.00	±0.79	±0.00	±0.00	±4.79	±0.45
Cluster II(aii)	5.79	0.00	8.05	0.00	0.00	16.69	1.94
(n=3)	±0.55	±0.00	±6.98	±0.00	±0.00	±1.70	±0.60
All of II(a)	5.37	0.00	7.07	0.00	0.00	12.85	2.93
(n=5)	±0.82	±0.00	±5.13	±0.00	±0.00	±5.90	±1.44
Cluster II(b):	6.29	0.00	6.33	0.00	0.00	11.61	1.73
(n=4)	±1.24	±0.00	±8.02	±0.00	±0.00	±8.52	±0.79
Cluster II(c):							
Cluster II(ci)	7.90	0.00	5.97	0.52	5.24	11.22	0.49
(n=2)	±0.09	±0.00	±2.83	±0.74	±7.41	±1.50	±0.08
Cluster II(cii)	7.26	0.13	3.55	2.00	0.53	14.92	1.21
(n=7)	±1.44	±0.36	±3.01	±2.65	±1.02	±9.40	±0.74
All of II(c)	7.41	0.10	4.09	1.67	1.58	14.10	1.05
(n=9)	±1.28	±0.31	±2.99	±2.40	±3.46	±8.32	±0.71
Cluster III(a):	5.22	0.00	0.00	0.00	0.00	2.37	5.63
(n=2)	±0.12	±0.00	±0.00	±0.00	±0.00	±0.19	±0.14
Cluster III(b):							
Cluster III(bi)	2.47	0.00	0.98	3.25	4.81	8.14	6.67
(n=3)	±0.79	±0.00	±1.69	±4.01	±8.33	±9.03	±0.82
Cluster III(bii)	4.50	0.00	10.29	6.41	0.00	6.39	3.98
(n=3)	±0.82	±0.00	±4.74	±2.11	±0.00	±5.93	±0.72
All of III(b)	3.49	0.00	5.63	4.83	2.40	7.26	5.32
(n=6)	±1.33	±0.00	±6.01	±3.35	±5.89	±6.90	±1.63
Cluster IV:							
(n=3)	1.03	7.81	0.29	6.07	0.20	74.39	0.19
	±1.53	±8.59	±0.34	±4.14	±0.34	±9.44	±0.23

Table 8.3 (continued)

Cluster/FA:	Mean relative % ≤ C15	C16:0	C18:2n6c	C18:2n6t	C18:1	C18:0	≥ C20
Cluster V(a):							
(n=2)	1.64 ±0.33	31.12 ±10.07	2.07 ±2.92	4.13 ±4.74	0.00 ±0.00	8.70 12.30	4.28 ±2.09
Cluster V(b):							
Cluster V(bi) (n=5)	0.90 ±0.54	75.38 ±6.65	1.11 ±0.86	2.53 ±5.26	0.66 ±1.47	2.04 ±2.13	0.99 ±1.27
Cluster V(bii) (n=5)	1.27 ±0.76	53.93 ±10.10	1.71 ±2.74	4.91 ±5.15	0.68 ±0.94	18.26 ±5.84	0.77 ±0.96
All of V(b) (n=10)	1.09 ±0.65	64.66 ±13.89	1.41 ±1.94	3.72 ±5.06	0.67 ±1.16	10.15 ±9.50	0.88 1.07

present at low percentages. Yet, compared to archaeological residues in other clusters, the relative percentages of C18:1 ($\overline{X}$=1.2%), the medium chain fatty acids ($\overline{X}$=4.1%), and the long chain fatty acids ($\overline{X}$=1.5%) can also be described as moderate. The medium chain fatty acids are dominated by C14:0 ($\overline{X}$=13.0 ± 8.2%) and C12:0 ($\overline{X}$=4.5 ± 4.8%). Low-moderate levels of C24:0 ($\overline{X}$=5.8±9.1%) mark the long chain fatty acids.

There really is no "average" fatty acid composition for the residues in Cluster I. The mean relative percentages of the different fatty acids are somewhat misleading. As the standard deviations indicate (Table 8.3), the proportions of any particular fatty acid vary considerably among the samples in this cluster. The variation may be explained by the fact that each residue in the cluster is linked at an ever-increasing distance, rather than being linked at roughly the same distance (see Figure 8.3).

Cluster II comprises 18 residues - 17 from Cuello and one from K'axob - distributed between three smaller subclusters (a, b, and c). Cluster II(a) includes five residues

extracted from Middle Preclassic vessels from Cuello. The vessel forms either could not be identified or are recognizable only as large, open-mouth vessels. Four of the vessels belong to the Bladen ceramic complex and one to the Lopez-Mamom ceramic complex. All five vessels had charred residues on their interiors. Residues in Cluster II(a) have no C16:0, C18:2n6t, or C18:1. They tend to have high levels of C13:0 ($\overline{X}$=31.9 ± 5.34%) and moderate levels of C15:1 ($\overline{X}$=8.6±7.9%), which dominate the medium chain fatty acids, and high percentages of C24:0 ($\overline{X}$=20.5 ±13.5%), which dominates the long chain fatty acids. Although these residues have low percentages of the medium ($\overline{X}$=5.4%) and long chain ($\overline{X}$=2.9%) fatty acids, overall these are present in moderate amounts compared to residues in other clusters. Stearic acid (C18:0, $\overline{X}$=12.9%) and C18:2n6c ($\overline{X}$=7.1%) also occur in moderate proportions.

Cluster II(b) includes three large, open-mouth Bladen vessels and one unidentified Lopez-Mamom vessel, all from Cuello. All four of these vessels had charred residues on their interior surfaces. Similar to the Cluster II(a) residues, the Cluster II(b) residues have no C16:0, C18:2n6t, or C18:1 and they also have moderate proportions of C18:2n6c ($\overline{X}$=6.3%) and C18:0 ($\overline{X}$=11.6%). However, the Cluster II(b) residues have relatively large amounts of the medium chain fatty acids ($\overline{X}$=6.3%), compared to residues in Cluster II(a) (and other clusters), and lower proportions of the long chain fatty acids ($\overline{X}$=1.7%) The distribution of the medium and long chain fatty acids in Cluster II(b) is also different. Very high levels of myristic acid (C14:0, $\overline{X}$=41.2 ±7.9%) dominate the medium chain fatty acids, and the level of C13:0 is much lower ($\overline{X}$=6.5 ±4.5%). The percentage of C24:0, too, is much lower ($\overline{X}$=11.7 ±3.0%), which accounts for the smaller amounts of long chain fatty acids, overall.

The occurrence of odd-numbered fatty acids (C13:0, C15:1, and C15:0) in many of the residues in Cluster II(a) and Cluster II(b) may be related to the presence of the carbonised residues on many of the vessels. Lipid residues from virtually all of the Cuello vessels that had charred surface residues, including those that were excluded from the cluster analysis, contain some C13:0, and C15:1 or C15:0. Most also have large amounts of C24:0. At this point, it is not possible to explain why this relationship exists. It may be that the odd numbered fatty acids exist in these residues because of the types of foods cooked in the vessels. In particular, we might suspect the presence of fish, which are characterized by the occurrence of these odd-numbered lipids. Alternatively, the char itself may have created different and/or unique conditions for preservation/degradation of the lipid residue within the walls of these vessels.

Eight residues in Cluster II(c) are from Cuello and one is from K'axob. The three bowls and five jars from Cuello include Middle Preclassic (Swasey/Bladen, Bladen, Lopez-Mamom) and Late Preclassic (Cocos-Chicanel) vessels. All are from refuse contexts and *chultunes*. The single jar from K'axob dates to the Late Preclassic. The Cluster II(c) residues are distinctive because of the relatively high proportion of medium chain fatty acids ($\overline{X}$=7.4%) compared to residues in other clusters. The medium chain fatty acids are again dominated by C14:0 ($\overline{X}$=31.6 ±4.1%) but C14:1 is also present at low-moderate levels ($\overline{X}$=5.8 ±5.8%) and the mean percentage of C12:0 is 18.5 ±8.2%. Stearic acid tends to occur in moderate amounts ($\overline{X}$=14.1%), and C18:2n6c (4.1%) and the long chain fatty acids (1.1%) occur in low proportions. The fatty acids with ≥ C20 are dominated by low levels of C24:0 ($\overline{X}$= 6.6±7.4%). Unlike residues in Clusters II(a) and (b), C16:0, C18:2n6t, and C18:1 are present but at just trace to low levels (Table 8.3).

Cluster III(a) has just two residues. Both were extracted from bowls found in Late Preclassic refuse contexts at Cuello. These residues contain no C16:0, no C18:1, and neither of the C18:2 isomers. Stearic acid (C18:0) is present only in low amounts ($\overline{X}$=2.4%). The proportions of the medium chain and the long chain fatty acids are also low ($\overline{X}$=5.2% and $\overline{X}$=5.6%, respectively). However, relative to other clusters, these two groups of fatty acids are present in fairly high amounts. The Cluster III(a) residues are dominated by very high proportions of C14:1 ($\overline{X}$=40.5 ±3.0%) and C24:0 ($\overline{X}$=50.7 ±1.3%). Among the medium chain fatty acids, myristic acid (C14:0) and lauric acid (C12:0) also tend to be present at low levels.

Residues in Cluster III(b) were extracted from three bowls and two dishes from Cuello, and a single Middle Preclassic jar from K'axob. The Cuello vessels date to the Middle Preclassic (Bladen and Lopez Mamom) and Late Preclassic. Four are from refuse deposits and one is from a *chultun*. The K'axob jar was found in subfloor fill that is believed to have been re-deposited midden. Residues in Cluster III(b) also have no C16:0. They do have low proportions of the C18:2 isomers ($\overline{X}$=5.6%, $\overline{X}$=4.8%) and C18:1 ($\overline{X}$=2.4%). In fact, relative to other residue clusters, these residues have moderate-high amounts of these fatty acids. The proportion of the medium chain fatty acids is not only lower than for Cluster III(a) but C14:0 ($\overline{X}$=17.6±10.11%) rather than C14:1 ($\overline{X}$=2.7 ±2.8%) dominates this group of fatty acids. Like residues in Cluster III(a), these residues also tend to contain relatively high proportions the fatty acids with ≥20 carbons compared to residues in other clusters. This reflects the very high relative percentage of lignoceric acid (C24:0, $\overline{X}$=44.7 ±14.9%) in these six residues.

Cluster IV contains three residues. The residues were extracted from an unidentified vessel excavated from a midden at Aguateca, a Lopez-Mamom dish from a

refuse deposit at Cuello, and a body sherd from a Late Preclassic sherd-lined-pit at K'axob. These residues are marked by anomalously high percentages of C18:0 ($\overline{X}$=74.4±9.4%) and trace levels of the long chain fatty acids ($\overline{X}$=0.2±0.2%) that reflect that the amount of C24:0 ($\overline{X}$=0.7±0.9%) is much lower than for residues in other clusters already described. Cluster IV residues also have low percentages of the medium chain fatty acids ($\overline{X}$=1.0%), which are dominated by C14:0 ($\overline{X}$=19.9±10.9%) and C12:0 ($\overline{X}$=1.7±2.2%), moderate levels of C16:0 ($\overline{X}$=7.8%) and C18:2n6t ($\overline{X}$=6.1%), and trace amounts of C18:2n6c ($\overline{X}$=0.3%) and C18:1 ($\overline{X}$=0.2%).

Cluster V(a) includes two residues extracted from a jar and a bowl from Bladen phase refuse contexts at Cuello. High levels of C16:0 ($\overline{X}$ =31.1±10.1%) and a distinct distribution of the long chain fatty acids mark the residues. These are present at low percentages ($\overline{X}$=4.3%). Yet, compared to other residue clusters their proportions are high. Lignoceric acid does not dominate the long chain fatty acids. Instead, C20:1 ($\overline{X}$=26.3±18.6%), C22:1 ($\overline{X}$=19.9±3.5%), and C24:0 ($\overline{X}$1.9±0.3%) contribute to higher percentages for the long chain fatty acids. The proportion of medium chain fatty acids is low ($\overline{X}$=1.6%). Lauric acid (C12:0, $\overline{X}$=3.4±1.7%) and C14:0 ($\overline{X}$=9.2±3.1%) are the major fatty acids in this group. Stearic acid (C18:0) tends to occur at moderate levels ($\overline{X}$=8.7±12.3%) while C18:2n6c and C18:2n6t are present in low amounts ($\overline{X}$=2.1 ±2.9%, $\overline{X}$=4.1±4.7%, respectively). Oleic acid (C18:1) is not present.

Cluster V(b) is a relatively large group of 12 residues. Seven of the residues were extracted from Cuello vessels (3 bowls, 1 *tecomate*, 3 large, open-mouth vessels) that date to Middle (1 Bladen, 3 Lopez-Mamom) and Late Preclassic periods at the site. Two more residues were extracted from bowls excavated from a Late Classic midden at Aguateca. The final residue comes from a Middle Preclassic jar from K'axob. The

residues in Cluster V(b) are characterized by a very high proportion of C16:0 ($\overline{X}$=64.7±13.9%) and trace-low amounts of the long chain fatty acids ($\overline{X}$=0.9±1.1%). Among these, C24:0 averages 3.6±6.3% and C20:0 has a mean of 2.6±5.2%. Oleic acid, too, is present in only in trace amounts ($\overline{X}$=0.7±1.2%), the C18:2 isomers ($\overline{X}$=1.4±1.9% and $\overline{X}$=3.7±5.1%) and the medium chain fatty acids ($\overline{X}$=1.1±0.7%) in low-moderate proportions, and C18:0 averages 10.2±1.2% of the identified fatty acids. Several medium chain fatty acids are present; C14:0 is the major fatty acid in this group ($\overline{X}$=5.3±3.2%) while others are present in trace-low proportions (C12:0 [$\overline{X}$=1.8±1.6%], C15:1 [$\overline{X}$=0.5±0.7%], C15:0 [$\overline{X}$=0.8±0.7%]).

Seven residues, designated as outliers (Appendix D), have fatty acid distributions that do not readily cluster with any other of the archaeological residues.

8.6 Identification of the archaeological residues: results and evaluation

Using the fatty acid profiles of several experimentally degraded cooking water extracts (Table 8.2), attempts were made to identify the origins of the archaeological lipid residues extracted from ancient Maya vessels. The effort was fraught with difficulties and successes were few. Nonetheless, the process of trying to classify the archaeological residues revealed some of the limitations of the technique itself. This section of the chapter includes the few identifications that were possible and also a discussion of what was learned through some specific problems that were encountered during the process of identifying the residues.

8.6.1 Identifications of plant *versus* meat

Nine of the twelve archaeological residues in Cluster I cannot be identified using the experimentally degraded, comparative standards (Table 8.2). Two residues (AG99.27, AG99.13) may be plant residues, as suggested by their relatively high proportions of long chain fatty acids and the presence of C16:0, the C18:2 isomers, and C18:0. In fact, AG99.13 is very similar to the experimentally degraded residue of *chiles*. A more certain identification of plant can be suggested for CHAR4 based not just on the types and amounts of the fatty acids present but also on their ratios to each other within the sample. This sample was also analysed by isotopic methods (Table 6.1). However, the sample contained an insufficient amount of nitrogen to obtain a measurement and, therefore, there is no nitrogen data to confirm the identification of "plant".

Most of the nine residues in Cluster I that were not assigned an identification have proportions of the long chain fatty acids >4%. However, each of these is completely lacking in C16:0, the C18:2 isomers, and/or C18:0. All of these, and C16:0 in particular, are important components (low - very high percentages) of the experimentally degraded plant residues. It follows that the relatively large proportions of the long chain fatty acids do not necessarily reflect a plant origin for the archaeological residues. Rather, the high percentages of the long chain fatty acids are a function of there being little or no C16:0, C18:2, and/or C18:0 in the residues. The same explanation can be given for the much larger proportions of the medium chain fatty acids observed in these archaeological residues compared to all categories (maize, squash, meat, leafy green/plant) of the experimentally degraded residues.

Indeed, this same problem or a similar problem was encountered again and again as efforts were made to identify the archaeological residues in each of the clusters. The

difficulties, which are created either by the absence of an important fatty acid, such as C16:0, C18:2, and or C18:0, or by the presence of one or more of these same fatty acids in proportions that are far greater than expected, are inherent to the use of relative percentages to compare different samples (Chapter 5, section 5.6). Comparing the ratios of specific fatty acids is one way in which to work with this limitation. However, fatty acids with 16 and 18 carbon atoms, which were important to characterizing the different types of samples, no longer exist in many of the archaeological residues. Therefore, the possibility that the ratio of medium chain fatty acids:long chain fatty acids might be used to distinguish between ancient plant and meat residues was tested. The ratio calculated compares the sum of the relative percentages of all of the medium chain fatty acids identified in a sample, to that of that of all of the long chain fatty acids identified (Equation 8.1).

$$R = \frac{\sum \text{rel\% medium FAs}}{\sum \text{rel \% long FAs}} \qquad \text{(Eqn. 8.1)}$$

First, the ratios of medium to long chain fatty acids were calculated for the modern comparative food standards (freshly prepared and degraded) (Appendix E). The result of a Mann-Whitney U-test (U=6, *z*-value= -2.868, *p*=0.0041, N_1=29, N_2=4) indicates that the ratios of medium:long chain fatty acids in freshly prepared cooking water extracts are in fact significantly different. The mean ratio of the plant samples is 0.46±0.75 (n=29), while that of the meats is 8.37±8.37 (n=4). The ratios are not significantly different (U=12, *z*-value= -1.768, *p*-value=0.0771, N_1=9, N_2=6) between degraded cooking extracts of plants and meats although they appear to be very different judging by their

average ratios (plants: $\overline{X}$=0.69±1.69, n=9; meats: $\overline{X}$=8.69±12.99, n=6). This may reflect the small number of degraded samples for which data are available, as a Mann-Whitney U-test (U=47, *z*-value= -3.63, *p*-value=0.0003, N_1=38, N_2=10) comparing the ratios of all plant and meat standards (freshly prepared and degraded) indicates that there is a very strong statistical difference between the ratios of medium chain:long chain fatty acids for the two different categories of food.

We are therefore presented with the possibility that we can make the distinction between meat and plant origins for archaeological lipid residues, based on the ratio of the relative proportions of the medium chain fatty acids to those of long chain fatty acids in each sample. It is suggested here that a ratio of <2 may indicate a plant origin, while a ratio of ≥2 may reflect a meat origin for an archaeological lipid residue. These rules are based upon the ratios obtained for both freshly prepared and degraded comparative plant and meat standards (Appendix E), and considering the average ratio obtained for each category. The data indicate that there is some overlap of the ratios that can occur for meats and plants. In addition, we have no data for the ratios that might occur in residues left by freshwater fish or by dishes that included mixtures of meat and plant foods. Once again, therefore, there will be a degree of uncertainty associated with any identifications based solely on medium:long chain fatty acid criteria.

Applying the medium:long chain fatty acid criteria does allow us to suggest a greater number of identifications for the twelve archaeological residues in Cluster I (Table 8.4) than was possible using both the fatty acid criteria given in Table 8.2 and the proportion of long chain fatty acids. A plant origin can be suggested for five of the residues. The medium:long chain fatty acid ratios of four others, including the incensario from Aguateca (AG99.27), hint at a meat origin for the residues, although three of the

Table 8.4 Ratios of medium:long chain FAs in the archaeological residues.

Sample	Ratio of medium:long	Plant/meat identification
Cluster I(ai)		
CHAR4	0.250	plant
CHAR2	no long chain FAs	unidentified
CHAR3	10.438	meat
CU99.3	1.111	plant
AG99.27	3.560	meat
AG99.13	0.656	plant
AG99.4	1.087	plant
KX99.6	no long chain FAs	unidentified
KX99.39	2.908	meat
CU99.20	3.854	meat
CU99.12	1.691	plant
CU99.47	no long chain FAs	unidentified
Cluster II (ai)		
CU99.21	1.308	plant
CU99.30	0.867	plant
Cluster II aii)		
CU99.19	2.921	meat
CU99.26	4.704	meat
CU99.29	2.121	meat
Cluster II (b)		
CU99.6	7.433	meat
CU99.7	3.032	meat
CU99.25	1.906	plant
CU99.5	5.208	meat
Cluster II (ci)		
CU99.13	14.224	meat
CU99.41	18.414	meat
Cluster II (cii)		
CU99.9	7.218	meat
CU99.34	7.898	meat
CU99.37	3.649	meat
CU99.43	2.498	meat
CU99.1	9.891	meat
CU99.22	no long chain FAs	unidentified
KX99.8	4.366	meat

Table 8.4 (continued)

Sample	Ratio of medium:long	Plant/meat identification
Cluster III (a)		
CU99.42	0.959	plant
CU99.45	0.896	plant
Cluster III (bi)		
CU99.27	0.521	plant
CU99.39	0.370	plant
CU9932	0.236	plant
Cluster III (bii)		
CU99.31	1.693	plant
CU99.40	0.823	plant
KX99.17	1.047	plant
Cluster IV (a)		
AG99.17	1.240	plant
CU99.33	0.340	plant
KX99.49	no long chain FAs	unidentified
Cluster V (a)		
CU99.8	0.326	plant
CU99.23	0.502	plant
Cluster V (bi)		
CU99.14	14.749	meat
CU99.36	1.420	plant
CU99.44	no long chain FAs	unidentified
CU99.38	1.031	plant
CU99.25	0.020	plant
Cluster V (bii)		
CU99.10	0.990	plant
KX99.14	1.594	plant
CU99.2	5.800	meat
AG99.1	10.562	meat
CU99.35	0.536	plant
Outliers		
CU99.11	68.601	meat
CU99.15	4.081	meat
CU99.24	0.067	plant
AG99.3	0.0138	plant
KX99.11	no long chain FAs	unidentified

ratios are low enough that a plant origin cannot be ruled out. Ratios could not be calculated for the three remaining residues, as they contained no long chain fatty acids. The absence of long chain fatty acids does, however, imply a meat origin. On the basis of the medium:long chain fatty acid ratios, then, it seems that the archaeological residues grouped in Cluster I represent a mix of meat and plant residues. While more identifications of either meat or plant can be offered, it is important to acknowledge that these identifications are still tentative. It would be extremely useful to have another line of evidence to either support or question the identifications.

8.6.2 Fatty acid pattern of freshwater fish

All of the vessels in Cluster II(a) and Cluster II(b) are vessels from Cuello that had carbonised residues on their interior surfaces. Stable isotopic analyses of these residues showed that they contained significant amounts of freshwater fish (Chapter 6). I have great confidence in the identifications provided by the isotopic data. Therefore, it is interesting to see whether the lipid analyses are consistent with this indication that the vessels had been used for cooking fish. As noted, the vessels that belong to this cluster contained significant amounts of C13:0, C15:1, C15:0, as well as C11:0 and C17:1. A review of the fatty acid profiles indicated that these extracts, from vessels with charred surface residues as opposed to those without chars, appear to have different (greater) proportions of the odd numbered fatty acids (especially C13:0, C15:1, C15:0 but also C11:0, C17:1). A Mann-Whitney U-test was completed in order to verify this pattern. The test considered only those vessels that had been included in the cluster analysis. All residues extracted from vessels with chars, from Clusters II(a), II(b), V(b), and the

outliers were compared to all residues extracted from vessels that did not have chars. Residues extracted from the chars themselves (CHAR2, CHAR3 and CHAR4) and from the incensario from Aguateca, which had a surface char, were excluded from the analysis. The results indicate that there is a difference in the proportion of odd-numbered fatty acids identified in vessels with and without carbonised residues, which is strongly significant (U=56, *z*-value= -3.947, *p*-value <.0001, N_1=14, N_2=31). Judging by the means, the residues extracted from vessels that had surface chars tend to have greater proportions of the odd-numbered fatty acids ($\overline{X}$=28.0±19.1%, n=14) than do the vessels that lacked any surface residue ($\overline{X}$=5.4±7.0%, n=31). It is notable that residues from charred vessels that were excluded from the cluster analysis and from the Mann-Whitney U test just described also have fairly high relative percentages of the odd numbered fatty acids ($\overline{X}$=17.9 ± 16.3%, n = 10), while residues from vessels without surface residues once again have smaller proportions of these fatty acids ($\overline{X}$=7.2 ± 3.9%).

As previously noted, total lipid extracts from freshwater fish are characterized by precisely these odd-numbered fatty acids. It seems likely, therefore, that their abundance in the sherds of Cluster II (a and b) demonstrates that fatty acids derived from fish were absorbed into the vessel walls, and that a fatty acid signal of the fish remains preserved in the ancient lipid residues. In all nine of these residues, however, there are no detectable amounts of C16:0, C18:2, and C18:1, all of which are abundant in uncooked freshwater fish (Henderson and Tocher 1987:292, 293). This raises the question as to the real significance of the abundant odd-numbered fatty acids. Is it possible that these fatty acids are in fact merely the product of the degradation of other fatty acids, as a result of cooking or alteration during the burial history of the sherd?

This seems unlikely as the odd-numbered fatty acids are only found in such high abundance in sherds for which there is independent evidence for the cooking of fish. It seems more likely that if the sherds also once contained the other fatty acids, which are characteristic of freshwater fish, these lipids have been selectively lost from the sherds during cooking or subsequent to their burial.

The selective loss of one group of fatty acids is partially supported by another aspect of the complete data set, which is that one of these fatty acids, C16:0, is absent from a large number of the residues, although most plant or animal foods would be expected to include significant amounts of this fatty acid. Therefore, it seems that at least this one component had a tendency to be lost from the Maya sherds where it might have been expected to be present. Similarly, we see that sherds from other clusters that contain no trace of C16:0 also have lower proportions of the other fatty acids that are characteristic of fish (C18:2 and C18:1). Therefore, there is some suggestion that the absence of C16:0 and some other fatty acids may be a result of diagenesis (or perhaps cooking), and are likely to have introduced a general bias in the fatty acid record from all the sherds.

The ratios of medium:long chain fatty acids for the residues in Cluster II (a and b) (Table 8.4) suggest three identifications of plant and six identifications of meat. Three of the ratios that indicate a meat origin, however, are very close to the lower limit of 2 for this food category. As well, two of the three ratios suggesting a plant origin are near the upper end of the range for plants. Considering, too, what we have already learned from the stable carbon and nitrogen isotopic composition of the charred residues associated with these vessels, it is reasonable to argue that the medium:long chain fatty acid ratios indicate that a mixture of meat (or fish) and plants were cooked in the vessels. It would

be of interest at some point in the future to establish whether cooked, freshwater fish from the Maya area have ratios of the medium:long chain fatty acids that are more similar to plants or meats, or whether they lie somewhere in between.

Fatty acid extracts were also obtained from some of the charred residues found in these vessels (Appendix D, Cluster I; Table 7.1). Curiously, they gave very low proportions of the odd numbered fatty acids that are comparable to absorbed residues from vessels that had no chars, although they did contain significant amounts of C16:0. The isotopic analysis of these chars indicates that they were indeed derived from fish; apparently, the charring process is capable of destroying or altering these odd-numbered fatty acids. Thus, in the specific case of the vessels from Cuello containing charred residues, we can use the isotopic evidence for the presence of a distinctive food type (freshwater fish) to test the preservation of a fatty acid record in the absorbed residues of the sherd. These data suggest that while some characteristics of the expected deposit of fatty acids is preserved, the record appears to have been significantly altered through the loss of fatty acids that are also expected to have been present.

8.6.3 Identifying the remaining residues

Eight of nine archaeological residues in Cluster II (c) cannot be identified using the fatty acid criteria for identification given in Table 8.2. Relatively low proportions of the long chain fatty acids hint at a meat origin for the two residues in Cluster II (ci) as well as for two residues (CU99.22 and KX99.8) in Cluster II (cii). Meanwhile, the remaining five residues in Cluster II (cii) have greater proportions of the long chain fatty acids that would indicate a plant origin for these residues. The loss of C16:0 from all of these

residues and of various fatty acids with 18 carbons from some of the residues makes the plant/meat assignments unreliable. In contrast, high ratios of medium:long chain fatty acids for all of the residues in Cluster II (c) point to an identification of meat origin for all of these residues (Table 8.4).

The archaeological residues in Cluster III (subclusters a and b) also cannot be identified by their fatty acid distributions. Once again, high proportions of the long chain fatty acids are not necessarily indicative of a plant origin for the residues. As was true of the residues in Cluster II, these lipid extracts have no C16:0 even though virtually all possible food combinations would have resulted in the presence of this fatty acid. As a result of the absence of the C16:0 component, the relative percentages of the long chain and the medium chain fatty acids in the archaeological residues are shifted to higher values as compared to the same groups of fatty acids in the experimentally degraded plant extracts.

However, an identification of "plant" can be suggested for each of the eight residues in Cluster III using the ratio of medium:long chain fatty acids (Table 8.4).

The fatty acid distributions of three archaeological residues in Cluster IV also defy classification by comparison with the fatty acid profiles of modern, degraded cooking standards. No identification can be suggested for residue CU99.49, while reasonable arguments can be made for identifying residues AG99.17 and CU99.33 as either meat *or* leafy green/plant. The low proportions of the long chain fatty acids in the latter two residues are similar to those of degraded meat extracts. However, some degraded plant extracts also have low percentages of the long chain fatty acids. Moreover, the levels of the C18:2s are low enough to suggest a plant origin for the residues. All three residues in Cluster IV have far greater proportions of C18:0 than is seen in any of the degraded

standards, whether plant or meat. Therefore, there can be no certain identification offered for any of the residues in Cluster IV using the fatty acid criteria presented in Table 8.2.

Ratios of medium:long chain fatty acids that are <2 suggest that two of the residues in Cluster IV originate with plants. The third residue in the cluster cannot be identified as it lacks any long chain fatty acids which precludes a calculation of the ratio of medium:long chain fatty acids for this sample.

Two residues in Cluster V(a) (CU99.8 and especially CU99.23) match the criteria set out for degraded cooking extracts of leafy greens/plants. A plant identification is also suggested by the ratio of medium:long chain fatty acids for these two residues. Ten residues in Cluster V(b) also have fatty acid profiles that are similar in many respects to those of experimentally degraded cooking residues of leafy greens/plants. The proportions of C16:0 are somewhat higher, while those of the C18:2s and the long chain fatty acids are sometimes lower in the archaeological residues. Therefore, the identification of "leafy green/plant" for these archaeological residues can be viewed as tentative. A plant origin for six of these ten residues is implied by the ratios of the medium:long chain fatty acids of the residues. One residue cannot be identified by this approach. In contradiction to the fatty acid profiles, the medium:long chain fatty acid ratios of the remaining three residues suggest that they once contained meat rather than plant based food dishes.

Problems encountered in attempting to identify the five outliers using their fatty acid profiles were again similar to those met in trying to categorize the archaeological residues in Clusters I through IV. These residues also either have none of C16:0 and/or the C18:2s or they have very low percentages of these fatty acids compared to the

levels for the same fatty acids in the experimentally degraded residues. Therefore, the relative proportions of the medium and/or the long chain fatty acids in these archaeological residues are much greater, and are not comparable to the same groups of fatty acids in any of the experimentally degraded cooking extracts. The ratios of the medium:long chain fatty acids suggest two identifications of plant, two of meat, and one residue cannot be identified.

8.7 Problems with fatty acid profiles

Before the GC data for the degraded Maya foods was available, attempts were made to identify some of the lipid residues using the criteria established by Malainey and her co-workers (1999:100; Malainey 1997:184-185). Malainey's criteria for identifying ancient residues are based on the distributions of several selected fatty acids. These are the medium chain fatty acids (C12:0, C14:0, C15:0), C18:0 and the C18:1 isomers (Figure 8.4). Malainey's criteria were applied only to the lipid residues extracted from nineteen Cuello vessels, the original contents of which had already been partly characterized using carbon and nitrogen isotopic analysis of charred residues. Isotopic analysis is widely used and well established in studies of ancient foodways although few studies of charred residues have been published. My study indicates that the majority of these vessels had been used to cook freshwater fish along with some other meat and/or plant that lowered the $\delta^{15}N$ values slightly and shifted the carbon isotopic ratios in the C4 direction (Section 6.2).

This effort also had few successes and provided, at best, ambiguous identifications. Following Malainey's identification criteria, levels of the medium chain fatty acids (C12:0, C14:0, C15:0) that are ≥ 10% and proportions of C18:0 and C18:1

Figure 8.4 Criteria for Archaeological Residue Identification Based on Experimentally Degraded Cooking Residues of Foods from Western Canada (from Malainey et al. 1999:426).

Identification	Medium chain	C18:0	C18:1 isomers
Large herbivore	≤ 15%	≥ 27.5%	≤ 15%
Large herbivore with plant or bone marrow	Low	≥ 25%	15% ≤ X ≤25%
Plant with large herbivore	≥15%	≥ 25%	No data
Beaver	Low	Low	> 25%
Fish/corn	Low	≤ 25%	15% ≤ X ≤ 27.5%
Fish/corn with plant	> 15%	≤ 25%	15% ≤ X ≤ 27.5%
Plant (except corn)	> 10%	≤ 27.5%	≤ 15%

that are considerably lower than 27% and 15%, respectively, suggest a plant origin for the residues in ten of the vessels (CU99.4, 5, 6, 7, 14, 16, 20, 21, 25, and 30). No identifications can be suggested for the nine remaining residues. Of the ten residues identified as "plant" only one (CU99.14) was identified as such using the degraded cooked food standards from the Maya area. Although leafy green/plant would be the most reasonable identification, I have explained why I think such identifications are yet ambiguous with the available fatty acid data. It also was not possible to arrive at an identification of "fish" for any of the residues using Malainey's criteria for identification. In fact, the absence or very low levels of C18:0 and/or C18:1 in the lipid residues would indicate that the vessels did not contain fish (or corn). This is a predictable result, perhaps, as freshwater fish from tropical and temperate environments have very different fatty acid compositions (Henderson and Tocher 1997:292-294; also see section 8.3).

A problem with the use of Malainey's criteria for identifying residues in Maya vessels is that the small number of fatty acids used by her to identify food types occurs infrequently and/or in very small proportions in the latter samples. We may consider two possible explanations for the difference between the Canadian and Maya data sets. This may reflect that the different sets of foods from two very different geographic areas (Western Canada and the Maya Lowlands) have very different fatty acid compositions. Some evidence of this is that the fatty acid profiles of residues from Cuello vessels, which appear to have contained freshwater fish, do not match the fatty acid profile of temperate freshwater fish described in Malainey's criteria for identifying archaeological residues.

Second, Malainey's criteria make use of a very small number of fatty acids, while the proportions in which they are expected to occur for each different category of food are perhaps too broad (see Figure 8.3). The problem that this situation creates is that archaeological residues identified as having a "plant" origin, for example, can have quite different fatty acid distributions. Compare, for example, the fatty acid distributions of several samples that would all be identified as being plant residues following Malainey's guidelines, and which are illustrated in Table 8.5. An inherent limitation of archaeological lipid residues, however, is that there are few fatty acids that occur both commonly and in notable amounts. Therefore, Malainey's criteria necessarily include a small number of fatty acids with broad ranges for the proportions in which they are expected to occur.

CU99.7		CU99.20		CU99.30	
medium	44.7%	medium	52.2%	medium	11.4%
C18:0	24.3%	C18:0	3.8%	C18:0	10.5%
C18:1	0%	C18:1	6.0%	C18:1	0%

Table 8.5 Examples of the variety of fatty acid profiles identified as "plant" using Malainey's fatty acid criteria for identifying lipid residues.

I hoped that by considering a greater number of fatty acids I would have more success in identifying the Maya residues by comparison with degraded Maya food standards. The results described above indicate that, in general, this was not the outcome although some tentative identifications were possible. In addition, though efforts were made to be as specific as possible regarding the expected ranges for the

percentage of each fatty acid or group of fatty acids (medium and long chain), it was found that the same identification could be yet assigned to archaeological residues with quite variable fatty acid compositions. The possible origins of each of the residues shown in Table 8.6 have all been identified as "leafy green/plant".

CU99.8	
medium	16.9%
C16:1	0.0%
C16:0	24.0%
C18:2n6c	0.0%
C18:2n6t	7.3%
C18:1	0.0%
C18:0	0.0%
long	51.8%

CU99.23	
medium	12.7%
C16:1	1.4%
C16:0	38.2%
C18:2n6c	4.1%
C18:2n6t	0.0%
C18:1	0.0%
C18:0	17.4%
long	25.2%

KX99.14	
medium	3.5%
C16:1	0.5%
C16:0	67.2%
C18:2n6c	0.0%
C18:2n6t	2.5%
C18:1	1.8%
C18:0	21.9%
long	2.2%

Table 8.6 Examples of the variety of fatty acid profiles identified as "leafy green/ plant" using experimentally degraded, comparative foods from the Maya area.

In this case the problem is neither that there are too few fatty acids used to identify the residues, nor is it that the proportions expected for each fatty acid are not specific enough. The greatest problem is simply that the fatty acid compositions of the ancient residues and the degraded cooking waters that were used as comparative standards do not match. They differ in two major ways. First, the proportions of both the medium and long chain fatty acids tend to be far greater in the archaeological residues than they are in the degraded cooking waters. The second way in which they differ is that the percentages of the fatty acids with 16 and 18 carbons are generally much larger in the experimentally degraded, comparative food standards. Trying to classify the residues

using the fatty acid profiles of the degraded cooking waters was very much like trying to put that round peg into the square hole.

The root of the problem, I believe, is that in producing experimentally degraded lipid residues, it is not possible to replicate the complex of factors and conditions that affect the formation, degradation, and preservation of organic residues that exist in buried archaeological contexts. Some potential problems with the method that was used to degrade the Maya food standards have already been acknowledged (section 5.2.2). Preparing all of the standards again would not necessarily result in degraded food standards that are more like the archaeological lipid residues, however, because there are so many different factors that can affect the degradation/preservation of an archaeological residue. At this point, very little is known about how absorbed lipid residues are preserved and how they degrade. It is unlikely, therefore, that we can even identify all of the factors that have a part in the degradation of the lipid residues in archaeological contexts. In addition to the more obvious factors such as temperature, light, moisture, and time, I expect that we must consider the unique micro-environment created in the pores of the ceramics, including the amount of moisture and oxygen, and the types of bacteria and other microorganisms (which can catalyze reactions and contribute lipids) that are present. The length of time that a sherd or vessel remains on the ground surface before it is buried and how deeply it is buried (as it affects the amount of oxygen present and temperature) likely have an affect on the processes of preservation and degradation as well. Metals present in the burial environment and, more importantly, in the clays used to manufacture the vessels and in the slips used to colour the vessels may also catalyze some degradation reactions. Small pieces of iron

oxide are visible in some of the sherds from Aguateca and the Maya often added hematite to slips as a pigment.

8.8 Chapter discussion and summary

Evidence to establish the archaeological origin of the lipid residues extracted from many ancient Maya vessels included in this study has been given in Chapter 7. In this chapter it has been possible to show that the patterning of the fatty acids that remain in the ceramics still contains a record, albeit greatly altered, of the former contents of the vessels. Indeed, at least some of the vessels still offer some clues as to what those contents may have been. The first and perhaps most straightforward indication of this are the results of a hierarchical cluster analysis of the fatty acid profiles of the archaeological residues. The small number of clusters that have been identified from the diversity of fatty acid profiles that exist for the archaeological residues suggests that each cluster of residues may represent distinct food types or dishes. As well, the presence of a variety of long chain and unsaturated fatty acids that occur in the cooking waters, the degraded cooking residues, and the archaeological residues, which are part of a geographic fatty acid signature for foods from the Maya Lowlands, suggest that the residues originate with a similar suite of foods that are represented in the modern comparative food standards.

Attempts were made to identify the archaeological residues by drawing comparisons between their fatty acid profiles and those of freshly cooked and experimentally degraded lipid extracts obtained from modern foods. Using the fatty acid compositions of the experimentally degraded lipid extracts from twelve cooked foods, in particular, a set of criteria for identifying food residues in archaeological Maya vessels

was developed. In developing the criteria for identification, consideration was given to the suite of fatty acids that appear to be characteristic of the assemblage of Maya foods that were analysed. Efforts were also made to include as many different fatty acids as possible in the criteria in order to maximize their utility and effectiveness. Patterns present in the fatty acid compositions of the degraded residues suggest that it might be possible to distinguish between four general categories of foods: maize, squash seeds, meats, and leafy greens/plants.

Ultimately, though, it became apparent that there are poorly understood differences between the fatty acid compositions of the archaeological residues and the comparative food standards (fresh and degraded) that make comparisons among the different types of samples extremely difficult, and which frustrate attempts to identify the archaeological residues. The source of the disparities are the various and complex processes of degradation, which are also poorly understood, and which leave the fatty acid profiles of the archaeological food residues much altered from their original composition. Unfortunately, the experimentally cooked and degraded food standards do not mimic the complex histories of degradation of the archaeological vessels.

This frustrating outcome did, however, require that I look at the data in some new and unique ways that may ultimately provide archaeologists with two methods by which to use fatty acid profiles to assign either a plant or meat origin to ancient lipid residues from Maya vessels. It seems that a meat or plant origin can at least be proposed based on the relative proportions of long chain fatty acids. The fatty acid profiles of meats comprise $< 4\%$ long chain fatty acids, while those of plants exhibit a wide range of values but all have $\geq 4\%$ of the fatty acids with 20 or more carbons. This distinction was first noted for lipid extractions from cooking waters and it remained true even after these

extracts had been degraded for lengthy periods of time. One qualification may be that an identification of meat or plant should only be offered when a residue is preserved well enough to have fatty acids with 16 and 18 carbons present, as the relative percentages of the long chain or other fatty acids will be elevated as a result of their absence.

Use of the ratio of medium:long chain fatty acids may hold more promise for assigning identifications of either plant or meat to archaeological residues. Plants and meats were found to have different ratios of medium:long chain fatty acids. This ratio in plants tends to be lower (< 2), whereas meats have ratios that are ≥ 2. The difference in the ratios was found to be statistically significant for the fatty acid profiles of freshly cooked foods and for a combined sample of both the fresh and degraded extracts. At the least, this second approach allowed us to suggest identifications for a greater number of the archaeological residues that were analysed, as compared to using just the proportion of long chain fatty acids in a residue.

More significantly, the identifications determined for residues within the same cluster tend to be either plant or meat, with few exceptions. For example, the identifications suggested for residues in Cluster II (a, b, and c) are predominantly meat (n=18, meat =14, plant = 3, unidentified =1). Recall that the residues in sub-Clusters II (a and b) certainly have a fish component and also a starchy plant ingredient. The lower medium:long chain fatty acid ratios of residues in these two sub-clusters, compared to those for samples in sub-Cluster II (c), may reflect that a mixture of foods (plant and fish) were cooked in the vessels, whereas a greater proportion of meat may be have been prepared in the vessels in sub-Cluster II (c). In fact, the ratios for residues in sub-Clusters II (a and b) were found to be significantly different than those of the residues in sub-Cluster II (c) ($U=12$, z-value= -2.309, p-value=.0209, $N_1=9$, $N_2=8$). Plant origins

have been suggested for all of the archaeological residues in Cluster III and Cluster IV. Most of the twelve residues in Cluster V are identified as plant (n=8) with just three identifications of meat. Although the residues in Cluster I exhibit a greater mix of plant and meat identifications, it is apparent from the dendrogram generated by the cluster analysis that the fatty acid composition of the residues in this cluster are not as closely linked as the residues in other clusters are. The fact that an identification of either meat or plant can be associated with the majority of residues in each cluster is of some importance. First, it reinforces that the small number of clusters that were identified by cluster analysis do very likely represent different groupings of vessels, each of which once contained a particular type of food or dish. In addition, it does lend some credibility to the use of the ratio of medium:long chain fatty acids to separate archaeological lipid residues of different origins.

This result does not indicate the accuracy of the specific assignments of "meat" or "plant", however. Unfortunately, other lines of evidence, which might support or refute the identifications that were made using two of the proposed criteria for identification (ratio of medium:long chain fatty acids and % long chain fatty acids), are not available at this time. It will also be necessary in the future to establish the range of values that might be expected for samples of freshwater fish and mixtures of meats and plants for both of these methods of residue identification. When these steps are completed it will be possible to verify the identifications and to establish whether it will be possible to identify more than the two categories of food – meat and plant – using these two methods.

The value of having other lines of evidence is clearly shown in the case of the residues in Cluster II (a and b), where a suggested identification of fish is based on a

relative abundance of odd-numbered fatty acids in these residues. The identification is supported by carbon and nitrogen isotopic analyses of charred residues from the same vessels, which also indicate that freshwater fish were a component of the dishes cooked in the pots. Furthermore, it is significant that at least in this one special case it was possible to offer an identification of the original contents of the vessels based on the types and proportions of particular fatty acids that are present in the residues. In principle, then, other residues could also be identified despite the inevitable distortions of the fatty acid profiles through the period of burial.

To close this chapter, it should be emphasized that the methods of residue identification (% long chain fatty acids; ratio of medium:long chain fatty acids; association of odd-numbered fatty acids and freshwater fish), which have shown some potential for identifying ancient Maya food residues, will not necessarily find utility when applied to archaeological lipid residues from other geographical areas. Given the many and varied pathways of diagenesis, and because foods from different geographic areas appear to have different fatty acid "signatures", the potential utility of these methods to residue analysis, generally, will need to be tested using food assemblages from different regions. Should an archaeologist choose to use fatty acid analysis of residues, they would first have to establish specific criteria using cooked and degraded foods that have been collected from their geographic area of interest. The conditions for degradation that would be found in the field should also be replicated to the extent that this is possible when producing the degraded food standards.

Chapter 9.

Summary and Conclusions

9.1 Introduction

The main objective of this final chapter is to evaluate the contributions and utility of each of the two approaches to residue analysis (stable isotopic analysis of charred food residues and fatty acid analysis of absorbed lipid residues) that were used in this project. The evaluation is made from the perspective of an archaeologist who is interested in using residue analyses to investigate various facets of an ancient foodway. Therefore, the usefulness of each method is measured by considering the extent to which the results of the residue analyses make this possible. The utility of each analytical technique is also assessed by comparing various aspects of the methods, from sample preparation to interpretation and reliability of the results, with similar elements of another archaeometric technique. The technique that was selected for this comparison is stable carbon and isotopic analysis of human bone. This is a better-established archaeometric technique that has become widely used and which has contributed a great deal to studies of ancient foodways. As well, I have applied this technique in an earlier investigation of ancient Maya foodways and so am familiar with the different aspects of its theory, application, and interpretations (Coyston 1995; Coyston *et al.* 1999). The chapter closes with a discussion of what are seen to be the potential roles of each of several different approaches to the analysis of food residues in archaeological investigations of ancient foodways.

9.2 Objectives *versus* realizations: residues of ancient Maya foodways

The argument was made in an earlier chapter that if residue studies are to become more commonly used in archaeology, the results of the analyses must be both reliable and useful for meeting the objectives of the discipline. As residue analyses are very costly in terms of the time and funds invested in them, it is also reasonable for archaeologists to expect that these analyses will provide different information or perspectives on past foodways than can be obtained by using more traditional lines of evidence, including material remains and ethnohistoric and ethnographic analogy. The two anthropological objectives that were established at the outset of this residue project were: 1) to explore the dynamic relationship between food preparation, food distribution, food consumption, and other aspects of domestic economies in order to understand how broader societal changes during the Late Preclassic and Early Classic periods affected Maya households; and 2) to establish whether and how food might have played a role in the creation and maintenance of socio-economic and political hierarchies in Maya society. The final concern for this project was to evaluate the usefulness of techniques of residue analysis to investigations of ancient foodways and to the discipline of archaeology. The evaluation of each residue technique will begin with a summary of what was learned about the ancient Maya through the residues left on some of their cooking pots. The review will then turn to a more general discussion of some of the strengths and limitations of each approach to residue analysis.

9.2.1 Evaluation: isotopic analysis of chars

Twenty-three carbonised food residues taken from vessels from Cuello were analysed using stable carbon and nitrogen isotopic analysis. The isotopic composition

of all of the residues that yield both carbon and nitrogen results (n=13) indicate that these vessels had been used to prepare freshwater fish. Other foods were also cooked in these vessels either in combination with the fish or in separate cooking events. It seems that a starchy plant, perhaps a root, was also cooked in these vessels because the chars formed as thick encrustations that cover large patches on the interior bodies of the vessels. The $\delta^{13}C$ values of these thirteen residues suggest that the starchy plant was not maize or at least not primarily maize. Ten other chars did not contain sufficient amounts of nitrogen to obtain $\delta^{15}N$ values. Therefore, we cannot know if these vessels were also used to cook freshwater fish. However, the physical properties and placement of these chars suggest that these vessels, too, were used to prepare a starchy food plant. The carbon isotopic ratios of the residues indicate that eight of the chars resulted from cooking a C3 plant. Two more appear to have also contained some maize.

The identifications of freshwater fish and root crops are interesting and important for several reasons. Certainly, the identifications of freshwater fish were very much unexpected, as was the very minimal evidence for the preparation of maize and beans. Due to poor conditions for the preservation and recovery of fish remains at the site, there is only scant evidence for the use of fish in the faunal assemblage excavated from Cuello. Evidence for the consumption of freshwater fish by Cuello residents also cannot be distinguished in the nitrogen isotopic composition of their bone collagen because of the mixture of protein sources that were included in their diets. The results obtained by stable isotopic analysis of carbonised food residues, therefore, are important because they provide clear evidence for the preparation and use of freshwater fish by the Preclassic Maya at Cuello. Moreover, the fact that 100% (n=13) of the vessels for which there are nitrogen data record a signal for freshwater fish suggests that these people

made regular use of this food resource. The physical characteristics of the residues and the isotopic results also provide evidence of one way in which fish was prepared, along with manioc perhaps, during the Preclassic period at Cuello.

It is also interesting that the formation of carbonised food residues is largely restricted to the earliest times of settlement at the site, during the Swasey Phase of the Middle Preclassic period. At this point, it has not been possible to determine whether this pattern reflects a change in the amount of fish and/or manioc that was used, in the ways in which these foods were prepared, or in the location at which foods were cooked so that food preparation areas were no longer sampled in the excavation trench at the Platform 34 locus.

Although isotopic analysis of the carbonised residues does not give us a complete picture of the foodways at Cuello, and although we cannot fully explain all of the temporal patterning in the data, it has arguably added another dimension to our understanding of how the earliest Maya subsisted in the lowland forests of Mesoamerica. Certainly it adds to our knowledge of how these Maya made use of the wetlands surrounding the site, which is one research focus for the archaeologists who are investigating Cuello.

With a larger number of samples obtained from greater temporal and areal distributions within an archaeological site than was the case at Cuello, stable carbon and nitrogen isotopic analysis of carbonised residues has the potential to provide additional interesting and useful insights into resource use as well as patterns of cooking and cuisine. This potential exists because several foods that the Maya are known to have used will produce carbonised residues if they are left to burn in a ceramic vessel. These include fatty meats that might have been included in soups or stews as well as several

starchy plant foods. In addition to the root crops identified in the vessels from Cuello, these include maize and beans. These foods are from several of the different, isotopically distinct categories (terrestrial animals, non-leguminous C4 plants, non-leguminous C3 plants, and C3 legumes) that have been described in Chapter 4 (sections 4.5.2, 4.5.3, and 4.5.5), and so can be distinguished on the basis of their distinct carbon and nitrogen isotopic compositions.

What is more, it is a rich coincidence that a number of these isotopically distinct foods that have the potential to leave a carbonised residue on cooking vessels were either nutritionally, economically, and/or culturally important to the ancient Maya. For example, maize (a C4 plant) was very important economically. However, maize and some types of meat may also have been ritually important and/or used to mark socio-political status distinctions (Chapter 3, section 3.5.3). Beans, a C3 legume, were nutritionally important in some Maya diets that may otherwise have had little protein and also as part of the maize-beans-squash triad. Therefore, given a sufficient sample size, charred food residues could be helpful to answering archaeological questions regarding how the Maya used food, not just as part of their subsistence but to mark and organize their social and political relationships, as well.

Finally, isotopic analysis of carbonised residues has the advantage of having a strong theoretical basis, which allows for reliable interpretations of the stable carbon and nitrogen ratios that are preserved in organic materials from archaeological contexts. The dependability and consistency of the results have been demonstrated through numerous applications of the analytical method to the analysis of ancient human bone tissues. As well, both the theory and results can be readily understood and interpreted by

archaeologists who may not have a background in the sciences or chemistry. These are issues that will be discussed to a greater extent in the following section (section 9.4).

Unfortunately, despite its strengths and latent value, the contributions that isotopic analysis of charred residues can make to understandings of how the ancient Maya used food are limited by the reality that carbonised food residues are very rare at sites in the Maya Lowlands. Just twenty-three carbonised residues were found among the many thousands of ceramic sherds excavated from Cuello. Yet, this may be considered a very large sample of chars from a single Maya site. The ceramic vessels excavated from Aguateca include a single carbonised residue, from an *incensario*, rather than a cooking vessel. The collections from K'axob and Cerén had no charred food residues. In addition to being rare, a large proportion of the chars do not preserve enough nitrogen to permit a measurement of the $^{15}N/^{14}N$ ratio by a mass spectrometer. Therefore, any small number of charred residues is likely to be reduced further and to be rendered less informative as a result of this expected limitation of the data source.

We can only speculate as to why the residues are so rare. Not every food produces a thick, carbonised residue when it is burnt and certainly this is part of the explanation. However, other foods that the Maya are assumed or known to have cooked in ceramic vessels, such as fatty meats and starchy maize, can/do produce charred residues. Therefore, other factors may also contribute to their paucity at Lowland sites. For example, Maya cooks may simply have been careful about not allowing the dishes to burn or perhaps they scrubbed their pots very well. Perhaps cooking vessels were discarded after minor burning episodes because it was known that chars would build up at these "hot spots" in subsequent cooking events. Another possibility is that, subsequent to their discard and burial, the charred cooking residues are removed from

ceramic sherds or are broken down by the same destructive processes that remove carbonised seeds and wood from archaeological deposits at most Maya sites.

9.2.2 Evaluation: GC analysis of fatty acids

It was possible, using GC analysis of fatty acids, to provide further evidence of the former presence of fish in a number of ceramic jars from the site of Cuello that had carbonized surface residues. Nine absorbed lipid residues from some of the same jars exhibit unusually high proportions of the odd-numbered fatty acids (C11:0, C13:0, C15:1, C15:0, C17:1) that are also present in the total lipid extracts of some freshwater fish. The shared fatty acid composition of this group of residues was also recognized by a cluster analysis, which included them together in Cluster II (a and b). Moreover, the ratios of medium:long chain fatty acids for the majority of these residues (6/9) suggest either a meat origin or perhaps a mixture of foods that included both meat (fish?) and plants. The latter identification would fit nicely with isotopic results that suggest that a mixture of fish and a starchy plant food was prepared in these vessels.

Assuming that the ratios of the medium:long chain fatty acids do accurately distinguish between plant and meat origins for the residues, it is possible to conclude that a greater number of the vessels that were included in the cluster analysis (N=51) were used to prepare food plants (n=28) than were used to prepare meats (n=23). Seven of the residues could not be identified by this method. This result should not be surprising as we know from ethnohistoric and ethnographic analogy that plant foods and cultigens, in particular, likely were a very important part of ancient Maya economies and diets. Often, though, evidence of their importance in the various aspects of ancient

Maya foodways cannot be directly measured because of the very poorly preserved archaeobotanical record at Lowland Maya sites.

Should the medium:long chain fatty acid approach prove to offer reliable identifications, even though they are not more specific than meat versus plant, GC analysis of the fatty acid composition of archaeological lipid residues could potentially be a useful analytical tool for gathering evidence about ancient Maya foodways. Although faunal and botanical remains are preserved at some sites in the Maya Lowlands, these types of remains are poorly preserved. As such, they are not only scarce but are unevenly distributed across a site and over different occupation levels. Ceramic sherds, though, are abundant and are associated with every occupation level and with virtually every household at each Maya site. Therefore, fatty acid analysis may potentially offer a way by which to investigate differences in the preparation and use of these two categories of food (meat and plants) across space and time by filling in the gaps in the data.

There are, however, a number of caveats that Maya archaeologists will have to weigh before starting a residue project. Several cautions that archaeologists should take heed of before deciding to do a residue study are discussed in a later section of this chapter. Here, the focus is upon the limitations that arise as a result of the non-specific nature of the residue identifications provided by the use of the ratio of medium:long chain fatty acids. Certainly, the possibility of identifying residues only to the level of meat or plant will limit the questions that can be addressed regarding how the ancient Maya used food in economic, social, or political contexts, as the information that such identifications can provide is inherently limited. For example, if an analysis of vessels from elite and non-elite residences showed that similar proportions of vessels were used

to prepare meat in the households of both status groups, it would be possible to suggest that people from the two different status groups may have used the same proportions of meat. However, the residues could not tell us if the Maya elites did or did not have access to favoured types of meat, such as deer, as some have suggested.

The identifications that fatty acid analysis can provide are very basic. In contrast, ancient Maya society and the records of its settlements from which archaeologists must collect a suitable assemblage of vessels (residues) to analyse are both very complex. Consider the large variety of vessel forms and types that were made and used by the Maya in each period of their history. Clearly, it will be necessary to analyse a very large number of residues from a variety of cultural and temporal contexts in order to begin to understand the significance of any spatial or temporal patterns that might be observed in the basic distinctions made between meat and plant. Ultimately having too few residues with identifications hindered our ability to search for and understand any patterning in the data that were obtained in this project. For example, residues from 10% of the bowls from Cuello were identified as meat compared to 17% of the residues from jars. However, because the samples of jars (n=6) and bowls (n=10) are so small, we cannot know if this pattern reflects a difference in vessel function related to form. In fact, it would be difficult to know whether the difference was even a significant one.

Overall, the number of residues that could be identified during this project (n=43) was not sufficient to begin addressing some of the more interesting aspects of ancient Maya foodways. Although this project began with a fairly large number of vessels from a variety of household contexts and different cultural periods in Maya history, a number of decisions had to be made to eliminate samples from the analysis due to time limitations, inadequate preservation of the lipids in some sherds, and also because some sherds

had been contaminated following excavation. All of these factors, and particularly problems with obtaining sufficient amounts of residue will be potential problems for any study of lipid residues from Maya vessels.

Additional lines of evidence would also be essential because only general identifications can be suggested for the residues. These other types of information would be useful either for clarifying the significance of patterning in the data or for verifying identifications that are offered. It is unlikely that the links among identifications of "meat", unusual patterns of odd-numbered fatty acids, and the cooking of fish, for a group of absorbed residues from Cuello would have been recognized if isotopic evidence that also suggested the former presence of fish was not also available.

9.3 Residue analyses *versus* isotopic analysis of bone

In Chapter 4, I suggested that chemical analysis of food residues had not found wide application in the thirty years that archaeologists and chemists have been testing its possibilities because the utility of residue analysis for investigating foodways of ancient societies has not yet been adequately demonstrated despite the availability of sound analytical methods. At that point, I remarked on the relatively more rapid and general acceptance of another archaeometric technique, isotopic analysis of human bone, which was introduced to archaeologists some twenty-five years ago (Vogel and Van der Merwe 1977) and has proven to be a very useful method for investigating ancient foodways by giving direct evidence of people's food consumption patterns in the past[1]. At other points, the reader has been asked to consider the reliability and

[1] To gain a sense of the scope of the problems that have been addressed with this method, as well as the application to problems in many different culture and geographic areas, see the following references: Tauber 1981; Chisholm *et al.* 1982; Schwarcz *et al.* 1985; Walker and

directness of the results obtained from the isotopic analysis of charred residues, which is based upon the same theoretical principles as the analysis of bone, and to contrast these to the data generated by the analysis of fatty acids using gas chromatography. Here I want to elaborate on some of the myriad reasons as to why the two archaeometric techniques, isotopic analysis and lipid analysis, have had such very different histories with regard to their acceptance and application within the discipline of archaeology. Some of these reasons have already been discussed in this chapter and in earlier chapters.

One of the primary reasons why stable carbon and nitrogen isotopic analysis of bone collagen and other tissues has proven to be so useful is that it has a strong theoretical foundation. Isotopic analysis is based on the knowledge that several categories of plants and animals (e.g. C4 plants, non-leguminous C3 plants, C3 legumes, terrestrial animals, marine animals) can be distinguished by differences in their stable carbon and nitrogen isotopic ratios. The isotopic separation of the different categories and the origins of the isotopic variability have been clearly explained and illustrated in a number of studies (Bender 1968, 1971; Chisholm *et al.*1982; DeNiro and Epstein 1978a, 1978b, 1981; Schoeninger 1985; Schoeninger *et al.* 1983; Smith and Epstein 1971; Tauber 1981; Van der Merwe and Vogel 1978; Vogel 1978). Moreover, although the average carbon and nitrogen isotopic ratios vary slightly between different geographic locations, the ranges within which they fall are universal. Thus, the isotopic criteria used to separate the different plant and animal categories have utility worldwide. It is also clear that the isotopic compositions of people's body tissues, including their bones, are determined by the foods that they consume. As the ratios of $^{12}C/^{13}C$ and

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DeNiro 1986; Roksandic *et al.* 1988; White and Schwarcz 1989; Burger *et al.* 1990; Buikstra and Milner 1991; White *et al.* 1993; Wright 1994; Dupras 1999; Prowse 2001.

$^{15}N/^{14}N$ in bone collagen remain unaltered over archaeological time, it is possible to establish the relative contributions that particular, isotopically distinct foods made to people's diets in the past by measuring the carbon and nitrogen isotopic compositions of their bones.

Because the theoretical foundation of isotopic analysis is very sound it can be explained in a straightforward and succinct manner, although the theory is truly quite complex and there are aspects of it that are not yet fully understood and explained (e.g. Ambrose and Norr 1993; Sillen *et al.* 1989). One consequence of this is that the basic knowledge that is required not only to interpret the isotopic results but to critically evaluate those results and any interpretations based on them has been made accessible to archaeologists, whether or not they have an extensive background in chemistry. Having the ability to participate in these stages of the analysis has been important to the development and application of isotopic analysis as an archaeometric technique. Knowledge and understanding of the method and its potential outcomes surely have given archaeologists the confidence needed to devote time and funds to its application to studies of palaeodiets and ancient foodways. For the reason that isotopic theory is well grounded, such applications have repeatedly allowed for reconstructions of patterns of food consumption that are credible. For example, at times and places where populations are known to have eaten maize, the C4 signal has indeed been shown to be recorded in their bones (Buikstra and Milner 1991; Van der Merwe and Vogel 1978; White and Schwarcz 1989), and where ancient peoples ate marine foods, that isotopic signal has also been detected (Chisholm *et al.* 1982; Tauber 1981; Walker and DeNiro 1986). The dependability and consistency of the results have been demonstrated

through numerous applications of the analytical method to the analysis of ancient human bone tissues such as these.

Fortuitously, a number of the isotopically distinct categories of plants and animals also correspond to foods that were either nutritionally, economically, and/or culturally important to many ancient societies. For example, the major cultigens of the world are C3 plants (e.g. wheat, barley, rice) or C4 plants (maize and millet) and many societies tend to rely more heavily on either marine or terrestrial animals. Therefore, isotopic analysis of bone makes it possible to observe changes or variations in the consumption of specific and important types of food over time, or between places and populations. In establishing the possible economic, cultural, or nutritional/environmental reasons for the patterns that are observed, archaeologists can ultimately contribute to a greater understanding of many different dimensions of the ancient foodways and societies that they are investigating.

A final point to be made regarding the reasons why archaeologists have readily accepted isotopic analysis of bone collagen is the relative ease with which the technique, including the theory and sample preparation, can be learned and applied even in cases where individuals have little or no prior laboratory experience. It has been possible for graduate students to learn the methods and to complete isotopic projects within the period of their degrees. The result is that there is now a "second generation"[2] of physical anthropologists and archaeologists who have established, or who are in the process of setting up stable isotope laboratories at a greater number of institutions.

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[2]This second generation includes researchers such as Christine White (University of Western Ontario), Anne Katzenberg (University of Calgary), Lori Wright (Texas A&M), Tosha Dupras (University of Central Florida).

Therefore, it is likely that isotopic analysis of bone will become more routinely incorporated into large archaeological projects in the next decades.

Comparatively, the theoretical principles that govern the analysis of ancient lipid residues by gas chromatography are not as well established as those of isotopic analysis. This is not to say that they have no basis. Certainly, plants and animals have distinct fatty acid distributions and unique biomarkers in life. However, the ancient signals that must be detected and interpreted are more complex than just the two signals (the ratios of $^{13}C/^{12}C$ and $^{15}N/^{14}N$) that are of concern in isotopic analyses, and which remain unaltered over time. In contrast, there are a large number of different types of lipids that are preserved in archaeological residues, and analyses of the residues have not focused on just one or two types of lipids. Archaeologists who have explored the possibilities of residue analysis have tended to use fatty acid analysis to identify the residues (e.g. Deal *et al.* 1991; Fankhauser 1994; Malainey 1997; Malainey *et al.* 1999; Marchbanks 1989; Skibo 1992). Chemists, however, are currently utilizing a myriad of different lipids including waxes, sterols, triacylglycerols, lactones, and ketones and other products of pyrolysis (heating/cooking) (Chapter 4). What is more, highly variable processes of residue formation, preservation, and diagenesis, none of which are fully comprehended at this time, alter and further complicate these signals, particularly the fatty acids and secondary lipids produced during cooking.

Due to the fact that residue analysts have been utilizing a diversity of signals in the lipid residues, there are, of course, no universal criteria for identifying the foods that people were utilizing in the past. Here, again, residue analysis differs from isotopic analysis of bone. To date, unique lipid biomarkers have only been used to identify foods that were used in fairly restricted ritual and/or geographic contexts in the past (e.g.

cacao, kava, and cabbage). Unique biomarkers have not been identified for most foods of interest in studies of ancient foodways. If lipid residue analysis is to find wider application using this approach, it would be necessary to look for biomarkers in a large number of ancient foods not only to identify the biomarkers but to establish that they are, in fact, unique to only one or a small number of foods.

Although a number of studies have concentrated upon the use of fatty acids, the laboratory methods used to identify the fatty acids have not been standardized. For example, residue analysts have each used different columns, temperature programs, and run times. Of course, we can expect that each researcher combined these varied elements in such a way as to obtain a maximum separation and resolution of the fatty acids when the lipid extracts were run on the GC. Yet, it is possible that each analyst had greater or lesser chances or ability to identify some fatty acids. For instance, Malainey (1997) does not distinguish between the C18:2 isomers. She also found that the C18:1 isomers did not always separate (Malainey 1997:158). In this study it was not possible to distinguish between different isomers of C18:1 but the isomers of C18:2 (C18:2n6c and C18:2n6t) did separate on the column. Given that the various researchers also purchase and/or have available to them different fatty acid standards adds to the likelihood that they do not have exactly the same capabilities for identifying all of the same fatty acids between residue studies.

The methods used to identify the origins of the residues using fatty acids have also not been standardized between investigations. Some investigators have used the proportions of certain fatty acids, while others have elected to use ratios of different fatty acids in order to identify the residues (see Chapter 4, section 4.4.4). Indeed, there may be no way to avoid this situation if the fatty acids identified in the samples vary

appreciably between different assemblages of residues. It is unlikely that standardizing laboratory procedures will eliminate many of the differences that exist among residues from different sites. In this study of Maya residues, it became apparent that food assemblages from different geographic areas may simply have fatty acid "baselines" that are not comparable. Diverse processes and rates of diagenesis will result in different fatty acid profiles for lipid residues that have been preserved in vessels from different sites and regions. Together, these circumstances may preclude the development of a universal set of fatty acid criteria that can be used for the identification of ancient food residues.

The lack of standardized approaches for the analysis and identification of lipid residues certainly has been a factor in the slower development and smaller number of applications of residue analysis to investigations of ancient foodways compared to isotopic analyses of human bone. If new methods or strategies for identifying the residues must be developed for each project it certainly increases the amount of work that must be done relative to isotopic analysis. Perhaps, too, the lack of consistency between studies does not inspire the same level of confidence in the analytical technique as exists for isotopic analysis of bone.

Lipid residue analysis has also not benefited from the same good fortune of being able to identify food types or categories that nicely correspond to foods that were either nutritionally, economically, and/or culturally important to many ancient societies. To date, unique biomarkers have been used to identify cabbage, *cacao*, and *kava*. While the latter two plants were culturally or ritually important, they were each important within a single society, unlike maize, for example, which was culturally and economically important in many American societies. Fatty acids have essentially been used to identify

residues simply as meat, plant, or fish (Malainey 1997; Marchbanks 1989; and this study), and sometimes they do not allow for identifications at all (e.g. Skibo 1992:97).

The current trend toward using ever different and diverse lipids, and particularly the search for unique biomarkers, is perhaps also somewhat intimidating to some archaeologists, as most have no background in organic chemistry. Unfortunately, because such specialized knowledge is required to analyse and determine the origins of the lipid residues, the information obtained at some levels perhaps remains inaccessible to archaeologists. At the least, and different again from isotopic analysis, it is more difficult to evaluate the reliability of the results and interpretations that are offered. Certainly, this is one reason why the archaeologists who have undertaken residue projects have elected to use fatty acids rather than to search for biomarkers of individual foods.

The laboratory techniques used to extract and prepare lipid residues for analysis also require relatively more time to learn (although this will vary according to how much prior laboratory experience an individual has had) and they are more time consuming and cumbersome. Moreover, while isotopic samples may be prepared in large batches (*i.e.* tens of samples), batches of five to ten samples were found to be more feasible for lipid analysis. The additional time and labour required for sample preparation may limit the number of samples archaeologists can examine, as it will add significantly to the costs of the analyses.

The discussion above is intended to explain some of the reasons why stable carbon and nitrogen isotopic analysis of bone has found greater application to investigations of palaeodiets and past foodways than has the analysis of food residues. The purpose of this comparison is not to conclude that residue analysis has no utility.

What the discussion should make clear is that it is unlikely that residue analysis will soon, if ever, play as significant a role in studies of foodways. Residue analysis will likely be used to investigate very different, and perhaps much smaller questions than is true for isotopic studies. The potential contributions of residue analysis are described in the following section.

9.4 Residue analyses: potential contributions to the archaeometric toolbox

In this section, the potential roles that each different approach to residue analysis – isotopic, fatty acid, and total lipid analysis - might have in archaeological investigations of ancient foodways are discussed.

isotopic analysis of charred residues

Stable carbon and nitrogen isotopic analysis of carbonized residues has a latent potential that would be very useful in the study of ancient foodways. Having a strong theoretical basis that is readily understandable by researchers with little background in chemistry, the method provides a reliable way in which to identify a number of different categories of food that are both capable of producing residues and were of economic and/or cultural importance to the ancient Maya, as well as other ancient societies around the world. Given a large enough number of samples, an isotopic study of carbonised residues could be used to investigate both economic and cultural (social and political) aspects of ancient foodways.

Unfortunately, the greatest limitation to the application of this method is the rare occurrence of charred residues in the archaeological record of the Maya Lowlands and indeed many other parts of the world, as well. Therefore, stable isotopic analysis of carbonised residues will continue to be used only intermittently for the analysis of small

numbers of samples. As such, it should not be looked to as a primary line of evidence in the study of foodways. However, given the value of the information that it can provide, even where there is a relatively small number of samples, it may at times be a useful secondary line of evidence, which can be used to flesh out our understandings of ancient foodways, or that will be an aid to understanding the significance of patterns that emerge from the analysis of other types of archaeological remains.

A good example of the contribution that isotopic analysis of carbonised residues can make can be found in Hastorf's application of the method to a collection of residues from archaeological sites in Peru. Her work (Hastorf 1985, 1988; Hastorf and DeNiro 1985) initially describes the results and provides some limited interpretations, which ultimately reveal their full potential once she weaves them into a larger body of archaeological, ethnohistoric, and ethnographic data, and a more complete understanding of the importance of maize in Pre-Hispanic Peru (Hastorf and Johannessen 1993).

Where other lines of evidence are available, the application of isotopic analysis to even a relatively small number of samples (e.g. 25-30) may often still prove to be worthwhile. The reliable results and identifications of the residues are a good return for the time or funds spent doing the analyses. As the theoretical basis for isotopic analysis, sample preparation, and interpretation of the results can all be learned relatively quickly and easily, archaeologists may also choose to do this work themselves, which will potentially widen its application.

fatty acid analysis of absorbed residues

It is clear from this study and others that the fatty acid compositions of archaeological food residues can and do sometimes hold evidence of the original contents of ancient vessels. To date, the most successful applications have been able to suggest very general identifications for archaeological residues of meat, plant, or freshwater fish using their fatty acid compositions. However, there are several concerns that archaeologists will have to weigh before applying fatty acid analysis of lipid residues to investigate past foodways.

The first consideration is the non-specific nature of even the most reliable identifications. This, coupled with the fact that just two or three food categories have been found to be distinguishable using fatty acids will certainly restrict the types of questions and problems regarding past economic, social, and political uses of foods in any society that we can hope to address with the residue data. Perhaps the most that we can expect is to look for broad changes or differences over time or between groups of people (status groups, sites, regions) in the amount of meat *versus* plants being prepared in the vessels. Such information might be of interest to archaeologists who are interested in looking at changes or differences in resource use. It might also be useful for answering questions of whether the elites of a particular stratified society did or did not prepare meat in a greater proportion of their vessels than did non-elites or whether consumption of meat was affected by human induced environmental changes such as deforestation resulting from population growth. As well, in order to address even such basic questions it will be necessary to analyse a very large number of residues, which would be a very costly commitment.

Another point to consider is that there is no readily available set of rules or guidelines for using fatty acids to identify the residues. In each study that has had some success in identifying the residues (including this report as well as Malainey 1997; Marchbanks 1989) it was necessary for the investigators to establish unique strategies and criteria for use with the different sets of fatty acid data. At best, each investigator who completes a residue study will have the added work of creating and demonstrating the utility of their own criteria for their own data. However, it is also possible that it will not always be possible to identify the residues using their fatty acids (e.g. Skibo 1982).

As it has now been demonstrated several times, including in this study, that fatty acid analysis can provide us with some information regarding the origins of ancient lipid residues, the method may be applied with some more regularity in the future. It is unlikely that it will be widely used, however, given the limited amount of information that it does provide relative to the costs and risks involved in the analysis. I expect that archaeologists who are investigating foodways of periods and places for which other types of food remains (faunal and botanical) are poorly preserved or otherwise scarce will most often consider its utility. In such cases, any additional information on patterns in food use might be of value. However, the returns may be deemed too small where ample information about various aspects of a people's foodways already exists in other forms of evidence.

Future research might work to establish whether ratios of medium:long chain fatty acids used in this study to distinguish between residues of plant and meat origins might not have broader application to sets of foods and residues from geographical and cultural areas outside of the Maya Lowlands. Any criteria for identification that did have

some broader utility would not only facilitate data analysis and interpretation but would also lend greater credibility to identifications that were suggested.

total lipid analysis of absorbed residues

Total lipid analysis of various classes of lipids and unique biomarkers was not attempted as part of this residue study. The laboratory experience that I have gained, however, has given me a different perspective from which to comment on how this analytical method might best contribute to understandings of how people used food in the past. I see that total lipid analysis, like other residue methods, will probably not have more than its current, limited role in archaeological investigations of foodways. It will continue to serve as a secondary line of evidence when it is used.

Using gas chromatography/mass spectrometry to detect the presence or absence of cholesterol, campesterol, and sitosterol, it would be possible to identify the contents of vessels as meat, plant, or mixtures of these two food categories. The advantage of this strategy over fatty acid analysis is that the different sterols will give unambiguous identifications of these categories of foods. A disadvantage would be the cost and time involved in running each lipid extract several times, on the GC/MS in order to collect mass spectral data on each of the potential sterol peaks, and so to determine the presence/absence of each of a number of different sterols.

The implied revolutionary impact that total lipid analysis would have on studies of palaeodiets and foodways, because of its potential to provide species or genus level identifications of food plants, in particular, which are otherwise rarely preserved, (Evershed *et al.* 1991) is unlikely to transpire. In the ten years since Evershed and his colleagues published their identification of cabbage in several vessels from Britain, no

other specific plant identifications have been reported for other residues. Further application of this technique has been hindered because we simply have not identified biomarkers of other foods that were important in the past. Faced with the task of identifying the lipid residues from a large collection of vessels for which the original contents are entirely unknown, the possibility of using unique biomarkers to identify the residues is daunting. It would first be necessary to search for the existence of any relatively unique biomarkers for the foods that are believed to comprise the assemblage of foods that were used in a particular culture area and period. This step alone would require years of work. Imagine that we were already aware of the unique lipid biomarkers for a number of plants. It would still be a huge job to identify a large number of residues unless we already had some clues as to what contents each of the vessels may have once held (e.g. hieroglyphs, ethnographic analogy of function based on form). Otherwise, multiple runs on the GC/MS would have to be completed in order to look for each of the biomarkers. This would be a cumbersome and a costly strategy for a large number of residues.

Therefore, I expect that the analysis of total lipid residues by GC/MS will be used to identify the origins of small numbers of residues only where there is already some indication of what the contents of the vessels might have been. In these cases, it will be more practical to search for potential biomarkers. The direct evidence obtained of the contents and function of a single vessel or of a small number of vessels may perhaps be extrapolated to vessels of similar form in order to look for changing or different patterns in food preparation over time and between locations or groups of people within the same society.

9.5 The noble chemist and the archaeologist: the moral of the story

Archaeologists often look to the physical sciences and the analytical techniques that the sciences offer in order to obtain more information or different types of information than can be gathered by more traditional means of artifact analysis. The revolutionary successes of some archaeometric techniques, including isotopic analysis of bone collagen, and before that a variety of absolute dating techniques set high standards and almost certainly are the source of regard which archaeologists give to archaeometric techniques. Certainly archaeologists do not expect that every archaeometric technique will revolutionize the way in which we approach archaeological data and questions. Still, there is sometimes an inclination to give priority to archaeometric data owing to the numeric nature of the data and the very objective manner in which it was generated and collected. It is important for archaeometrists and archaeologists alike to be aware of, and to clearly acknowledge that each archaeometric technique involves its own set of limitations. It is also important to recognize the subjectivity involved in interpreting the meaning of patterns that are made apparent in the quantitative data generated by archaeometric methods. Moreover, because any form of archaeometric data ultimately comes from the material archaeological record, like all other lines of archaeological evidence the information that we can derive from it is also limited by the inherently fragmentary nature of that record. In addition to providing some different insights into ancient Maya food use, my own experience of the application of two residue methods has left me with a renewed sense of the equivalent value of information gained through archaeometric and more traditional archaeological approaches to the analysis of past foodways.

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Appendix A

Results of Mann-Whitney U Tests Comparing the Concentration of Lipid Residues from Cuello Vessels to Residues from Aguateca, K'axob, and Cerén Vessels

Mann-Whitney U for Concentration (µg/g)
Grouping Variable: Site

U	242.000
U Prime	604.000
Z-Value	-2.653
P-Value	.0080
Tied Z-Value	-2.653
Tied P-Value	.0080
# Ties	0

One case was omitted due to missing values.

Mann-Whitney Rank Info for Concentration (µg/g)
Grouping Variable: Site

	Count	Sum Ra..	Mean R..
Cuello	47	1732.000	36.851
Aguateca	18	413.000	22.944

One case was omitted due to missing values.

A Mann-Whitney U Test Shows that the Concentrations of Fatty Acids in Vessels from Cuello are Different than the Concentrations of Residues in the Vessels from Aguateca.

Mann-Whitney U for Concentration (µg/g)
Grouping Variable: Site

U	44.000
U Prime	473.000
Z-Value	-4.254
P-Value	<.0001
Tied Z-Value	-4.254
Tied P-Value	<.0001
# Ties	0

One case was omitted due to missing values.

Mann-Whitney Rank Info for Concentration (µg/g)
Grouping Variable: Site

	Count	Sum Ra..	Mean R..
Cuello	47	1601.000	34.064
K'axob	11	110.000	10.000

One case was omitted due to missing values.

A Mann-Whitney U Test Shows that the Concentrations of Fatty Acids in All Vessels from Cuello are Different than the Concentrations of Residues in Vessels from K'axob.

Mann-Whitney U for Concentration (µg/g)
Grouping Variable: Site

U	0.000
U Prime	235.000
Z-Value	-3.647
P-Value	.0003
Tied Z-Value	-3.647
Tied P-Value	.0003
# Ties	0

2 cases were omitted due to missing values.

Mann-Whitney Rank Info for Concentration (µg/g)
Grouping Variable: Site

	Count	Sum Ra..	Mean R..
Cuello	47	1363.000	29.000
Ceren	5	15.000	3.000

2 cases were omitted due to missing values.

A Mann-Whitney U Test Shows that the Concentration of Fatty Acids in All Vessels from Cuello are Different than the Concentrations of Fatty Acids in All Vessels from Cerén.

Mann-Whitney U for Concentration (µg/g)
Grouping Variable: Site

U	53.500
U Prime	144.500
Z-Value	-2.045
P-Value	.0408
Tied Z-Value	-2.045
Tied P-Value	.0408
# Ties	1

2 cases were omitted due to missing values.

Mann-Whitney Rank Info for Concentration (µg/g)
Grouping Variable: Site

	Count	Sum Ra..	Mean R..
Aguateca	18	315.500	17.528
K'axob	11	119.500	10.864

2 cases were omitted due to missing values.

A Mann-Whitney U Test Shows that the Concentrations of Fatty Acids in Vessels from Aguateca are Different than the Concentrations of Residues in Vessels from K'axob.

Appendix B

Results of Cluster Analysis: Modern Cooked Food Standards

Results of Cluster Analysis of the Modern Cooked Food Standards:
Relative Percentages of the Identified Fatty Acids
Cluster I: maize and other starchy plants
Subcluster a(i): maize and other starchy plants Subcluster a(ii)†:starchy plants

FA/Sample:	CKG35 maize	CKG36 maize	CKG30 flor*	CKG11 pacaya	CKG12 guisqil	CKG14 chaya	CKG20 camote
C8:0	0.000	0.000	0.000	0.000	7.075	0.000	0.000
C10:0	0.000	0.000	0.000	0.000	3.145	0.000	0.000
C11:0	0.000	0.000	0.000	0.181	0.000	0.000	0.000
C12:0	0.000	0.000	0.000	0.211	0.000	1.249	0.000
C13:0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C14:1	0.000	0.000	0.000	0.241	2.201	1.707	0.000
C14:0	0.000	0.000	0.000	0.000	0.000	0.670	0.000
C15:1	0.000	0.000	0.048	0.271	0.000	0.000	0.000
C15:0	0.000	0.000	0.000	1.386	0.943	0.000	0.000
C16:1	0.216	0.000	1.137	0.542	0.000	0.000	0.000
C16:0	13.203	13.713	15.814	11.329	19.654	21.379	33.161
C17:1	0.000	0.000	0.359	0.000	0.000	0.000	0.000
C18:2n6c	65.584	63.924	58.332	75.384	58.333	59.862	57.709
C18:2n6t	18.615	18.656	21.897	4.791	0.314	4.612	0.603
C18:1	0.433	0.000	0.000	0.723	0.000	0.000	0.000
C18:0	0.000	0.000	1.256	3.706	0.000	5.048	0.000
C20:1	0.000	0.000	0.000	0.512	0.000	0.000	0.000
C20:0	0.000	3.165	0.000	0.241	0.000	0.554	0.000
C21:0	0.000	0.000	0.000	0.000	1.258	1.474	0.000
C22:2	0.000	0.000	0.000	0.000	0.000	1.245	3.359
C22:1	0.433	0.000	0.000	0.000	0.000	0.000	0.000
C22:0	0.649	0.000	0.459	0.000	0.000	0.620	0.000
C23:0	0.000	0.000	0.000	0.000	0.000	0.000	1.550
C24:1	0.433	0.000	0.000	0.000	0.000	0.000	0.000
C24:0	0.433	0.633	0.698	0.482	7.075	1.580	3.618

†closely linked to subcluster Ia(i)
**flor de epazote*

Results of Cluster Analysis of the Modern Cooked Food Standards:
Relative Percentages of the Identified Fatty Acids
Cluster II: meats and oily vegetables
Subcluster (a)i: meats and squash seeds

FA/Sample:	CKG34 squash*	CKG38 deer	CKG39 turkey	CKG40 armadillo	CKG28 squash*
C8:0	0.000	0.000	0.000	0.000	0.000
C10:0	0.000	0.000	0.000	0.000	0.000
C11:0	0.000	0.000	0.000	0.000	0.000
C12:0	0.000	0.000	0.047	0.266	0.000
C13:0	0.000	5.763	0.249	0.082	0.000
C14:1	0.000	0.000	0.047	0.123	0.000
C14:0	0.000	0.678	0.405	1.045	0.000
C15:1	0.000	0.339	0.000	0.000	0.000
C15:0	0.000	5.424	0.093	0.451	0.000
C16:1	0.000	1.695	2.506	3.503	0.000
C16:0	18.613	23.390	25.249	25.200	21.474
C17:1	0.000	1.017	0.000	0.000	0.000
C18:2n6c	34.913	25.763	30.230	27.453	43.984
C18:2n6t	14.451	14.576	24.191	32.821	24.443
C18:1	0.116	0.678	2.973	0.000	0.000
C18:0	27.514	20.000	12.920	8.072	10.099
C20:1	0.000	0.000	0.311	0.389	0.000
C20:0	0.000	0.000	0.016	0.287	0.000
C21:0	0.000	0.000	0.000	0.000	0.000
C22:2	0.347	0.000	0.000	0.000	0.000
C22:1	0.000	0.000	0.592	0.184	0.000
C22:0	0.694	0.678	0.093	0.000	0.000
C23:0	0.462	0.000	0.000	0.000	0.000
C24:1	0.000	0.000	0.047	0.000	0.000
C24:0	2.890	0.000	0.031	0.123	0.000

*squash seeds

Results of Cluster Analysis of the Modern Cooked Food Standards:
Relative Percentages of the Identified Fatty Acids
Cluster II: meats and oily vegetables
Subcluster(b)i: oily/waxy plant products

FA/Sample:	CKG8 chile	CKG37 tepescuintle	CKG29 loroco	CKG25 achiote	CKG33 tomato	CKG13 macal	CKG17 pimienta
C8:0	0.000	0.000	0.000	0.000	0.000	2.192	0.000
C10:0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C11:0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C12:0	0.189	0.538	0.000	0.000	0.000	2.970	0.000
C13:0	0.000	0.497	0.000	0.000	0.000	0.000	0.000
C14:1	0.000	0.041	0.000	0.000	0.000	2.192	6.443
C14:0	1.344	1.843	0.000	0.000	2.804	2.475	0.000
C15:1	0.151	0.104	0.000	0.000	0.000	0.000	0.000
C15:0	0.682	0.145	0.000	0.000	0.000	0.000	4.698
C16:1	0.000	2.340	1.914	0.730	0.000	0.000	0.000
C16:0	29.521	24.244	27.585	35.142	26.168	16.973	18.926
C17:1	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C18:2n6c	47.283	38.137	35.963	32.878	24.299	40.736	26.309
C18:2n6t	9.563	18.447	12.975	11.115	14.019	3.182	4.295
C18:1	0.000	0.166	6.674	1.085	0.000	0.000	0.000
C18:0	9.089	13.251	5.648	13.641	22.430	6.365	5.638
C20:1	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C20:0	0.625	0.000	1.820	1.722	0.000	0.000	7.383
C21:0	0.208	0.000	0.490	0.000	0.000	6.506	0.000
C22:2	0.000	0.000	0.000	0.000	0.000	6.365	4.698
C22:1	0.000	0.104	0.000	0.000	0.000	0.000	0.000
C22:0	0.303	0.083	1.750	0.655	2.804	1.909	2.685
C23:0	0.000	0.000	0.000	0.000	2.804	0.000	0.000
C24:1	0.000	0.041	2.170	0.730	0.000	0.000	0.000
C24:0	1.041	0.021	3.011	2.302	4.673	8.133	18.926

Results of Cluster Analysis of the Modern Cooked Food Standards:
Relative Percentages of the Identified Fatty Acids
Cluster II: meats and oily vegetables
Subcluster b(ii): oily vegetables

FA/Sample:	CKG41 avocado	CKG21 cacao	CKG9 bledo	CKG15 h. mora	CKG7 corozo
C8:0	0.114	0.000	0.000	0.000	8.260
C10:0	0.000	0.000	0.000	0.000	28.183
C11:0	0.000	0.000	0.000	0.000	0.000
C12:0	0.114	0.000	0.000	0.000	0.000
C13:0	0.000	0.000	0.000	0.000	0.000
C14:1	0.000	0.000	0.000	0.000	0.000
C14:0	0.114	0.000	0.000	3.810	0.000
C15:1	0.571	0.000	0.000	0.000	0.000
C15:0	0.114	0.000	0.000	0.000	0.000
C16:1	6.453	0.000	0.000	0.000	0.000
C16:0	18.161	25.279	12.093	0.000	8.844
C17:1	0.000	0.000	0.000	0.000	0.000
C18:2n6c	12.564	5.162	37.209	0.000	2.041
C18:2n6t	34.095	31.413	0.000	22.857	32.653
C18:1	2.856	0.000	0.000	0.000	0.000
C18:0	3.370	36.402	46.512	39.048	0.000
C20:1	0.114	0.000	0.000	0.000	0.000
C20:0	0.286	1.082	0.000	0.000	0.000
C21:0	15.705	0.000	0.000	0.000	0.000
C22:2	2.456	0.000	0.000	17.143	0.000
C22:1	0.000	0.000	0.000	0.000	0.000
C22:0	1.999	0.331	0.000	0.000	0.000
C23:0	0.857	0.000	0.000	0.000	0.000
C24:1	0.000	0.000	0.000	0.000	0.000
C24:0	0.057	0.331	4.186	17.143	20.019

Results of Cluster Analysis of the Modern Cooked Food Standards:
Relative Percentages of the Identified Fatty Acids
Cluster III: greens and vegetables
Subcluster a(I): greens and vegetables Subcluster a(ii): greens

FA/Sample:	CKG19 mint*	CKG27 mint*	CKG22 guisqil	CKG32 tomatillo	CKG16 Sta. Maria	CKG31 pimienta
C8:0	0.000	0.000	0.000	0.000	0.000	0.000
C10:0	0.000	0.000	0.000	0.000	0.289	0.000
C11:0	0.000	0.000	1.068	0.000	0.000	0.000
C12:0	0.139	0.647	0.000	0.044	0.454	0.000
C13:0	0.000	0.000	0.000	0.000	0.000	0.000
C14:1	0.301	0.000	0.000	0.000	0.289	0.000
C14:0	1.110	0.000	0.000	2.036	0.907	0.000
C15:1	0.301	0.576	0.000	0.354	0.866	0.000
C15:0	1.064	1.153	0.000	0.487	0.948	0.000
C16:1	0.416	0.495	0.000	0.575	0.000	0.000
C16:0	79.482	69.707	62.777	59.761	50.515	51.724
C17:1	0.416	0.000	0.000	0.000	0.000	0.000
C18:2n6c	0.000	0.000	6.163	14.210	0.000	0.000
C18:2n6t	2.244	4.621	8.792	0.885	23.052	15.517
C18:1	1.087	0.789	0.000	0.000	0.000	0.000
C18:0	8.952	13.266	3.615	10.137	11.588	7.759
C20:1	0.000	0.000	0.000	0.310	0.371	0.000
C20:0	1.642	0.789	1.397	3.586	0.907	0.000
C21:0	0.000	0.000	0.000	0.531	1.361	0.000
C22:2	0.370	0.000	0.000	0.089	0.000	0.000
C22:1	0.000	0.000	0.000	0.000	0.000	0.000
C22:0	0.671	5.248	4.848	3.276	1.237	0.000
C23:0	0.370	0.000	0.000	0.664	0.412	0.000
C24:1	0.000	0.000	0.000	0.000	0.000	0.000
C24:0	1.434	2.710	11.339	3.054	6.804	25.000

Results of Cluster Analysis of the Modern Cooked Food Standards:
Relative Percentages of the Identified Fatty Acids
Outliers:

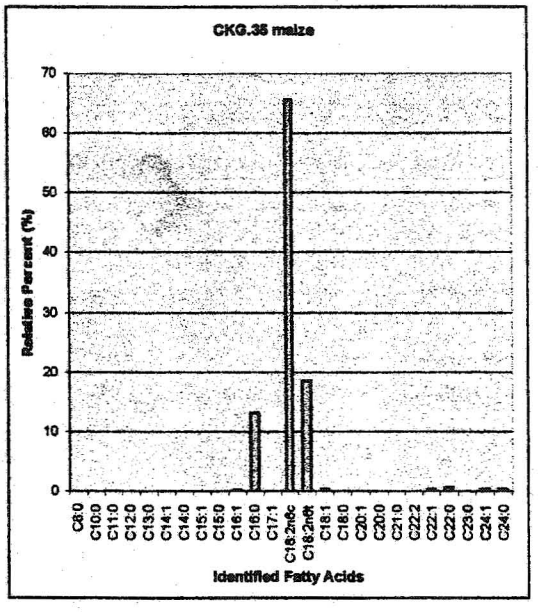
FA/Sample:	CKG6 bean	CKG18 rosa†	CKG10 chipilín	CKG24 bean	CKG 26 red bean
C8:0	15.056	0.000	0.912	0.000	20.628
C10:0	0.000	0.000	0.456	0.000	0.000
C11:0	0.000	0.000	1.672	0.000	0.000
C12:0	1.272	1.352	1.216	0.000	0.600
C13:0	0.000	0.000	0.000	0.000	0.000
C14:1	2.747	0.000	0.000	0.000	0.000
C14:0	3.510	4.816	0.000	0.000	0.000
C15:1	1.272	0.000	0.000	0.000	0.000
C15:0	0.458	0.000	0.000	0.000	0.000
C16:1	3.306	0.000	0.000	0.000	0.000
C16:0	0.000	0.000	7.903	37.452	6.330
C17:1	0.000	0.000	0.000	0.000	0.000
C18:2n6c	64.598	44.233	29.179	0.000	0.000
C18:2n6t	0.000	4.689	0.912	2.852	0.791
C18:1	0.000	0.000	0.000	0.000	0.000
C18:0	0.000	7.140	2.432	0.000	0.000
C20:1	0.000	0.000	0.000	0.000	0.000
C20:0	1.017	29.531	0.000	0.000	0.000
C21:0	0.000	0.000	39.970	0.000	0.000
C22:2	0.000	0.000	0.000	0.000	0.955
C22:1	0.000	0.000	0.000	0.000	0.000
C22:0	0.000	3.295	0.000	5.703	0.000
C23:0	0.000	0.887	0.000	0.000	0.000
C24:1	0.000	0.000	0.000	0.000	8.813
C24:0	6.765	4.056	15.350	53.992	61.883

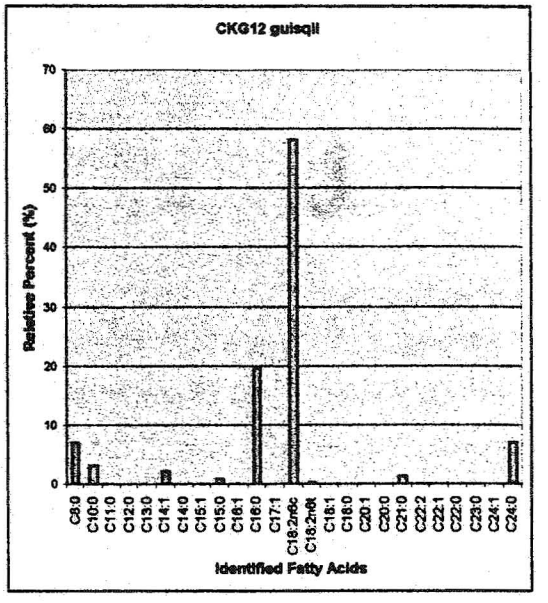
Appendix C

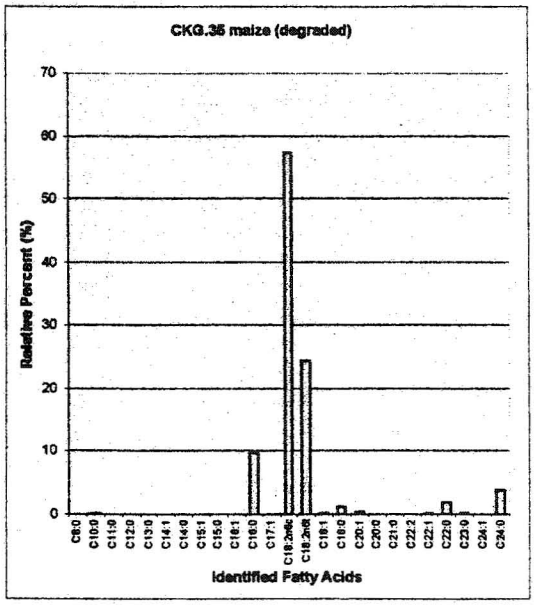
Fatty Acid Distributions of Experimentally Degraded, Cooked Food Standards

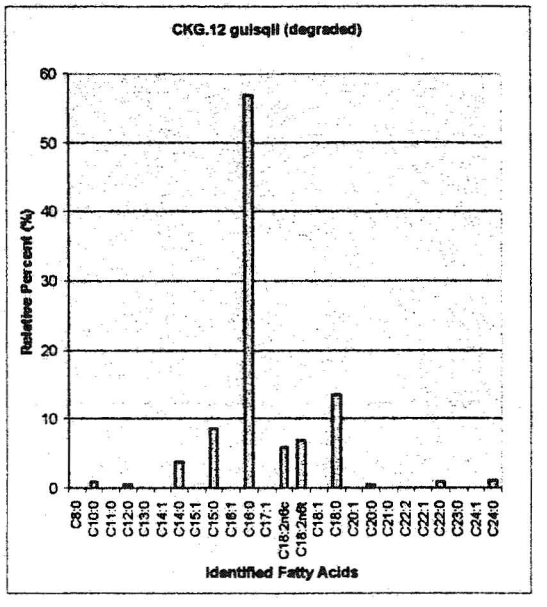
Relative Percentages of the Identified Fatty Acids in Experimentally Degraded, Cooked Foods From Cluster I: maize/starchy plants

FA/Sample:	CKG35 maize	CKG12 guisqil
C8:0	0.000	0.000
C10:0	0.116	0.985
C11:0	0.000	0.000
C12:0	0.000	0.493
C13:0	0.000	0.000
C14:1	0.000	0.000
C14:0	0.077	3.941
C15:1	0.000	0.000
C15:0	0.000	8.621
C16:1	0.000	0.000
C16:0	9.896	56.897
C17:1	0.000	0.000
C18:2n6c	57.286	5.911
C18:2n6t	24.584	6.897
C18:1	0.271	0.000
C18:0	1.237	13.547
C20:1	0.348	0.000
C20:0	0.000	0.493
C21:0	0.000	0.000
C22:2	0.000	0.000
C22:1	0.271	0.000
C22:0	1.894	0.985
C23:0	0.232	0.000
C24:1	0.000	0.000
C24:0	3.788	1.232


CKG.35 maize
Relative Percent (%)
Identified Fatty Acids

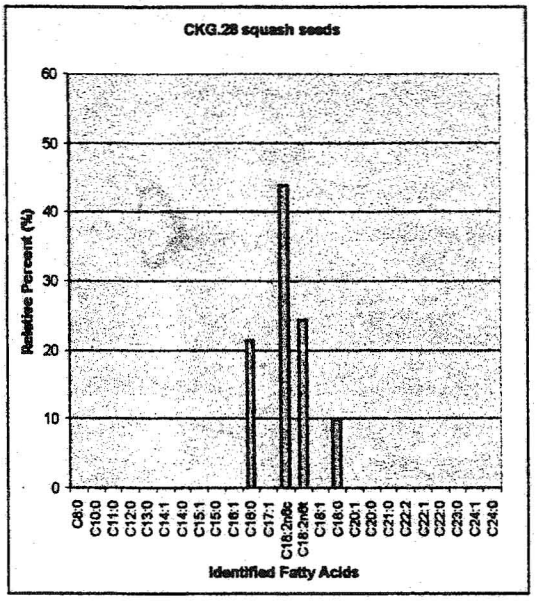

CKG12 guisqil
Relative Percent (%)
Identified Fatty Acids

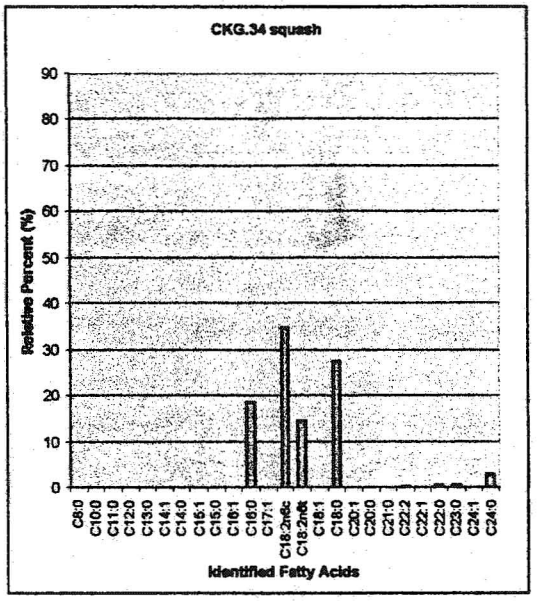

CKG.35 maize (degraded)
Relative Percent (%)
Identified Fatty Acids

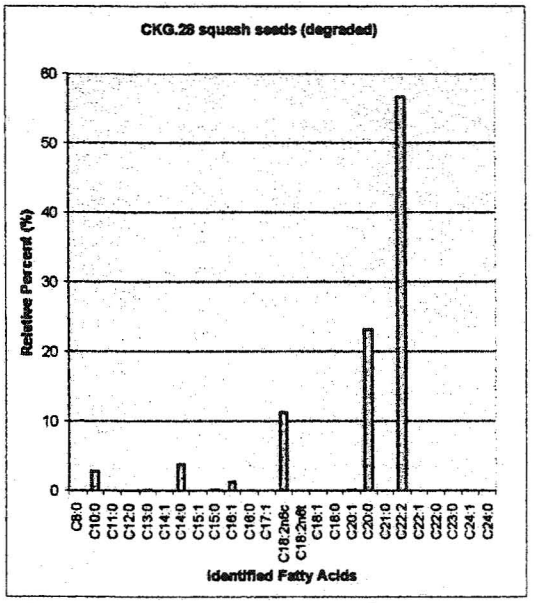

CKG.12 guisqil (degraded)
Relative Percent (%)
Identified Fatty Acids

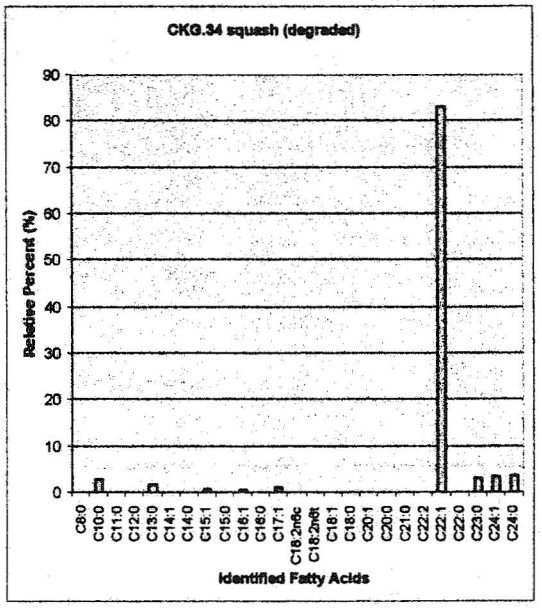
Relative Percentages of Identified Fatty Acids in Experimentally Degraded, Cooked Foods
From Cluster II(a): meats and squash

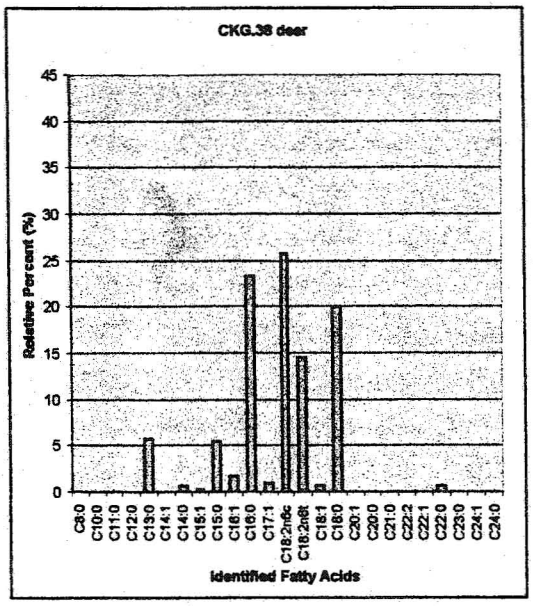
FA/Sample:	CKG.28 squash	CKG.34 squash	[CKG.38	CKG.38 deer	CKG.38]	[CKG.40 armadillo	CKG.40]
C8:0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C10:0	2.962	2.793	0.000	0.000	0.000	0.319	0.865
C11:0	0.000	0.000	0.000	0.000	0.000	0.433	1.260
C12:0	0.064	0.000	0.000	0.000	0.000	0.228	1.769
C13:0	0.116	1.622	0.000	0.000	0.000	0.182	2.430
C14:1	0.000	0.000	0.000	0.000	0.000	0.228	3.046
C14:0	3.832	0.000	0.000	0.000	0.000	0.394	3.181
C15:1	0.000	0.901	0.000	0.000	0.000	0.387	0.000
C15:0	0.105	0.000	7.035	0.000	0.000	2.277	3.989
C16:1	1.293	0.451	2.010	2.294	2.500	0.137	4.594
C16:0	0.000	0.000	17.588	21.789	20.838	0.000	4.842
C17:1	0.000	1.126	0.000	0.000	0.000	2.527	0.000
C18:2n6c	11.389	0.000	23.618	0.229	24.167	39.549	6.114
C18:2n6t	0.000	0.000	15.578	22.362	18.333	0.000	6.210
C18:1	0.000	0.000	1.005	1.720	0.833	7.309	6.249
C18:0	0.000	0.000	30.151	41.858	32.500	41.781	6.464
C20:1	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C20:0	0.000	0.000	0.000	0.000	0.000	0.000	8.001
C21:0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C22:2	56.700	0.000	0.503	8.601	0.000	0.250	9.453
C22:1	0.000	82.902	0.000	0.000	0.000	0.000	0.000
C22:0	0.000	0.000	1.508	1.147	0.833	0.000	10.137
C23:0	0.000	3.109	0.503	0.000	0.000	0.000	0.000
C24:1	0.000	3.424	0.000	0.000	0.000	0.000	10.594
C24:0	0.000	3.672	0.503	0.000	0.000	0.000	10.803

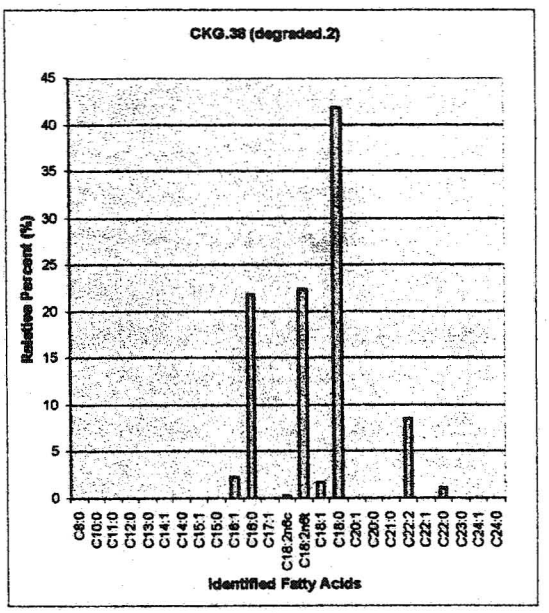

CKG.28 squash seeds
Relative Percent (%)
0
10
20
30
40
50
60
C8:0
C10:0
C11:0
C12:0
C13:0
C14:1
C14:0
C15:1
C15:0
C16:1
C16:0
C17:1
C18:2n6c
C18:2n6t
C18:1
C18:0
C20:1
C20:0
C21:0
C22:2
C22:1
C22:0
C23:0
C24:1
C24:0
Identified Fatty Acids

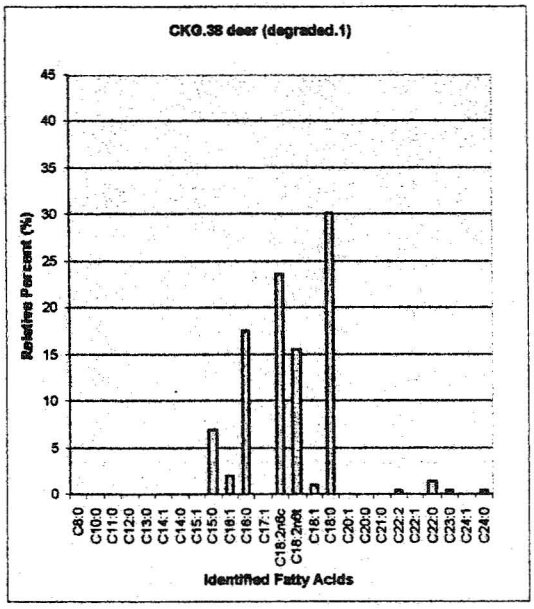

CKG.34 squash
Relative Percent (%)
0
10
20
30
40
50
60
70
80
90
C8:0
C10:0
C11:0
C12:0
C13:0
C14:1
C14:0
C15:1
C15:0
C16:1
C16:0
C17:1
C18:2n6c
C18:2n6t
C18:1
C18:0
C20:1
C20:0
C21:0
C22:2
C22:1
C22:0
C23:0
C24:1
C24:0
Identified Fatty Acids

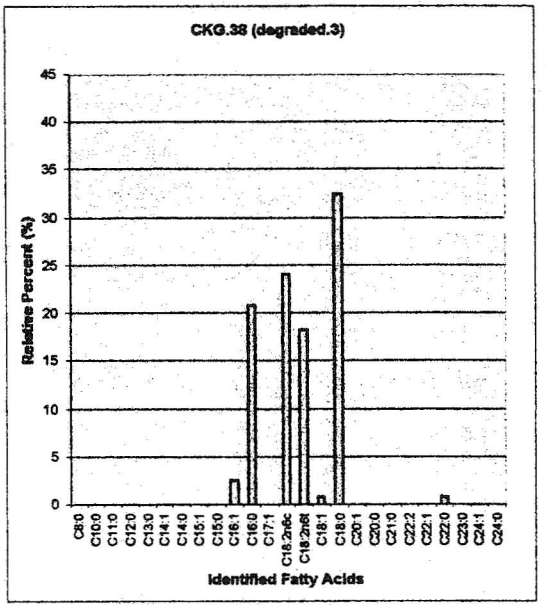

CKG.28 squash seeds (degraded)
Relative Percent (%)
0
10
20
30
40
50
60
C8:0
C10:0
C11:0
C12:0
C13:0
C14:1
C14:0
C15:1
C15:0
C16:1
C16:0
C17:1
C18:2n6c
C18:2n6t
C18:1
C18:0
C20:1
C20:0
C21:0
C22:2
C22:1
C22:0
C23:0
C24:1
C24:0
Identified Fatty Acids

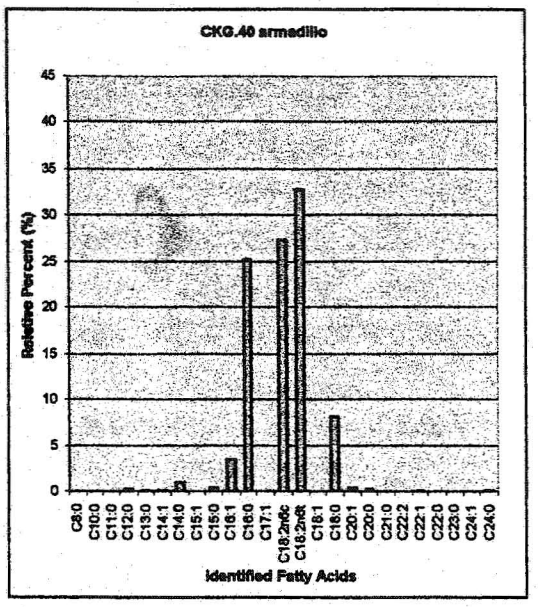

CKG.34 squash (degraded)
Relative Percent (%)
0
10
20
30
40
50
60
70
80
90
C8:0
C10:0
C11:0
C12:0
C13:0
C14:1
C14:0
C15:1
C15:0
C16:1
C16:0
C17:1
C18:2n6c
C18:2n6t
C18:1
C18:0
C20:1
C20:0
C21:0
C22:2
C22:1
C22:0
C23:0
C24:1
C24:0
Identified Fatty Acids

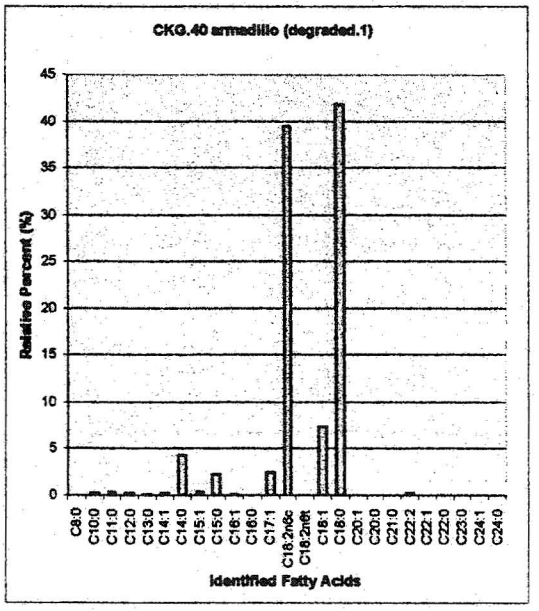

CKG.38 deer
Relative Percent (%)
Identified Fatty Acids

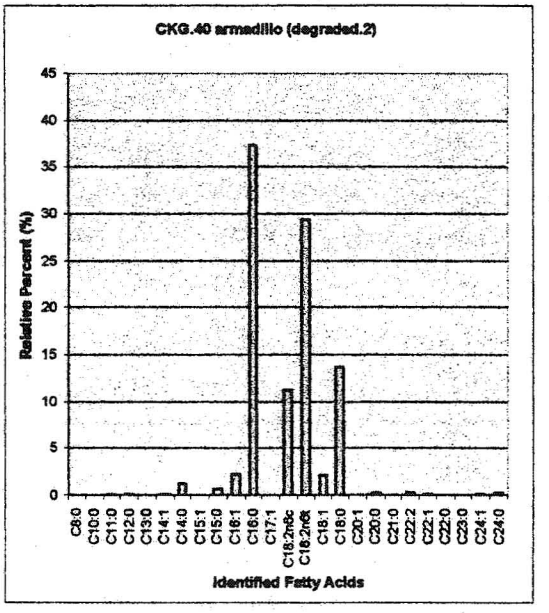

CKG.38 (degraded.2)
Relative Percent (%)
Identified Fatty Acids


CKG.38 deer (degraded.1)
Relative Percent (%)
Identified Fatty Acids


CKG.38 (degraded.3)
Relative Percent (%)
Identified Fatty Acids

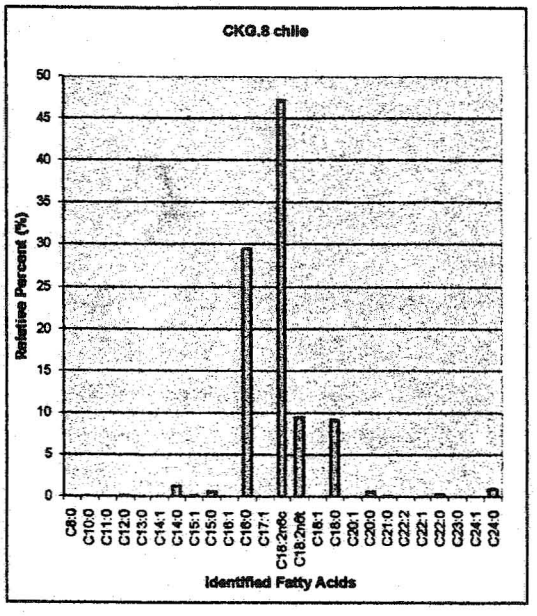

CKG.40 armadillo
Relative Percent (%)
0
5
10
15
20
25
30
35
40
45
C8:0
C10:0
C11:0
C12:0
C13:0
C14:1
C14:0
C15:1
C15:0
C16:1
C16:0
C17:1
C18:2n6c
C18:2n6t
C18:1
C18:0
C20:1
C20:0
C21:0
C22:2
C22:1
C22:0
C23:0
C24:1
C24:0
Identified Fatty Acids

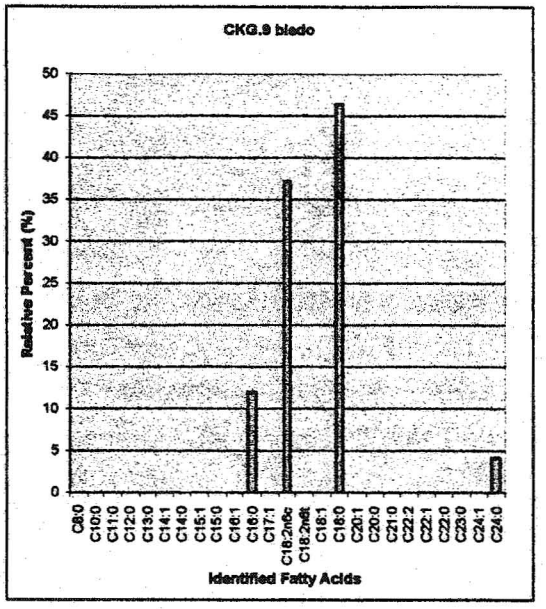

CKG.40 armadillo (degraded.1)
Relative Percent (%)
0
5
10
15
20
25
30
35
40
45
C8:0
C10:0
C11:0
C12:0
C13:0
C14:1
C14:0
C15:1
C15:0
C16:1
C16:0
C17:1
C18:2n6c
C18:2n6t
C18:1
C18:0
C20:1
C20:0
C21:0
C22:2
C22:1
C22:0
C23:0
C24:1
C24:0
Identified Fatty Acids

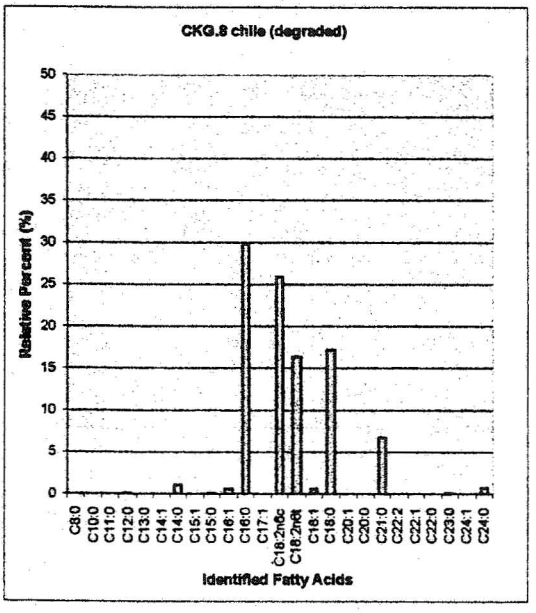

CKG.40 armadillo (degraded.2)
Relative Percent (%)
0
5
10
15
20
25
30
35
40
45
C8:0
C10:0
C11:0
C12:0
C13:0
C14:1
C14:0
C15:1
C15:0
C16:1
C16:0
C17:1
C18:2n6c
C18:2n6t
C18:1
C18:0
C20:1
C20:0
C21:0
C22:2
C22:1
C22:0
C23:0
C24:1
C24:0
Identified Fatty Acids

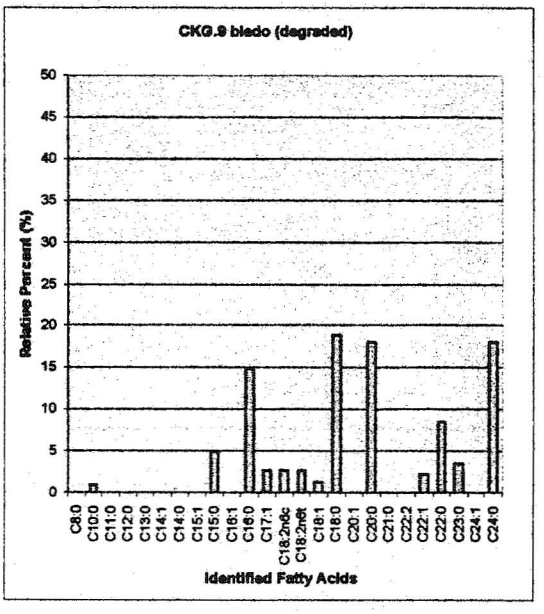
Relative Percentages of the Identified Fatty Acids in Experimentally Degraded, Cooked Foods From Cluster II(b): oily/waxy plant products

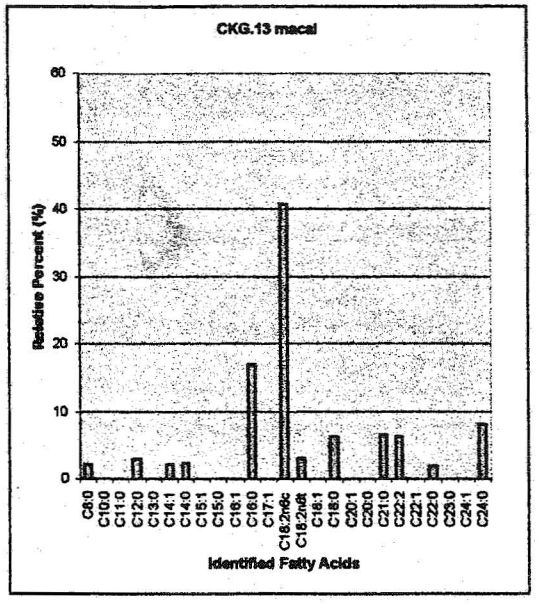
FA/Sample:	CKG.8 chile	CKG.9 bledo	CKG.13 macal	[CKG.40 tepescuintle	CKG.40]
C8:0	0.000	0.000	0.000	0.000	0.000
C10:0	0.039	0.905	0.215	0.000	0.000
C11:0	0.000	0.000	0.000	0.000	0.000
C12:0	0.154	0.000	0.430	1.272	1.102
C13:0	0.000	0.000	0.000	0.032	0.000
C14:1	0.000	0.000	0.000	0.040	0.042
C14:0	1.108	0.000	1.074	6.406	5.911
C15:1	0.000	0.000	0.000	0.000	0.000
C15:0	0.222	4.977	3.221	0.729	7.413
C16:1	0.684	0.000	1.718	2.098	2.005
C16:0	29.761	14.932	53.259	48.732	45.853
C17:1	0.000	2.715	0.000	0.000	0.000
C18:2n6c	25.944	2.715	1.074	2.486	2.488
C18:2n6t	16.471	2.715	0.000	21.552	21.189
C18:1	0.694	1.357	0.000	0.859	0.850
C18:0	17.222	19.005	1.321	12.133	11.928
C20:1	0.048	0.000	0.000	0.283	0.315
C20:0	0.000	18.100	5.476	0.219	0.430
C21:0	6.756	0.000	0.000	0.000	0.000
C22:2	0.000	0.000	5.369	2.981	0.021
C22:1	0.000	2.262	0.000	0.024	0.042
C22:0	0.000	8.597	8.698	0.113	0.178
C23:0	0.145	3.620	1.933	0.000	0.000
C24:1	0.000	0.000	0.000	0.049	0.115
C24:0	0.752	18.100	16.214	0.081	0.115

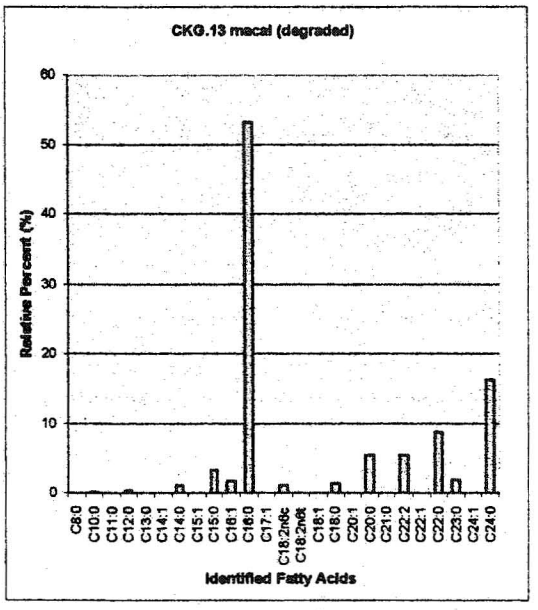

CKG.8 chile
Relative Percent (%)
Identified Fatty Acids
C8:0
C10:0
C11:0
C12:0
C13:0
C14:1
C14:0
C15:1
C15:0
C16:1
C16:0
C17:1
C18:2n6c
C18:2n6t
C18:1
C18:0
C20:1
C20:0
C21:0
C22:2
C22:1
C22:0
C23:0
C24:1
C24:0

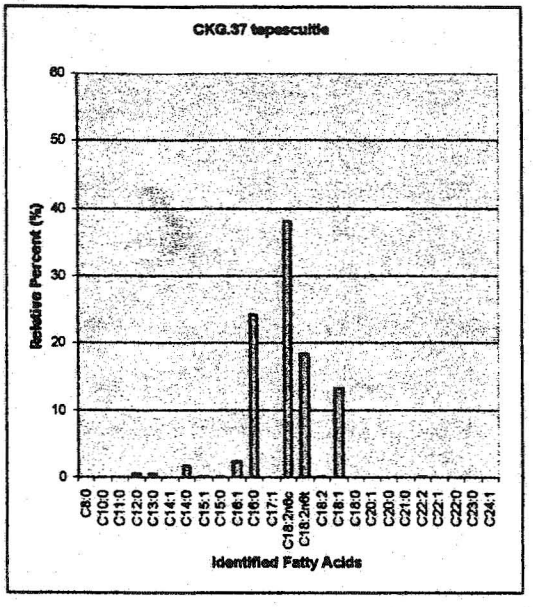

CKG.9 biedo
Relative Percent (%)
Identified Fatty Acids
C8:0
C10:0
C11:0
C12:0
C13:0
C14:1
C14:0
C15:1
C15:0
C16:1
C16:0
C17:1
C18:2n6c
C18:2n6t
C18:1
C18:0
C20:1
C20:0
C21:0
C22:2
C22:1
C23:0
C24:1
C24:0

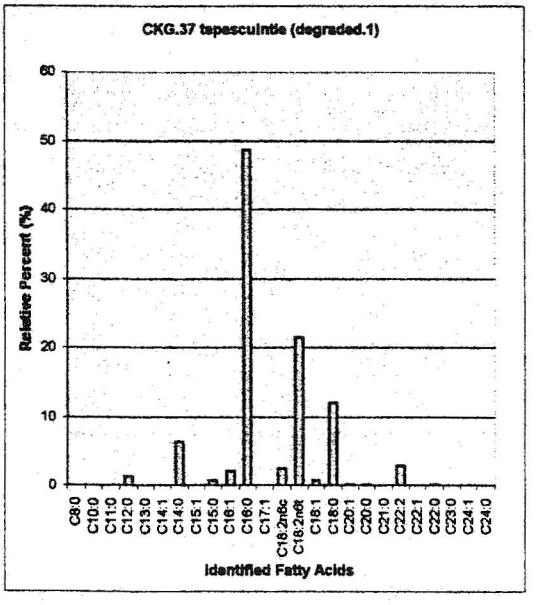

CKG.8 chile (degraded)
Relative Percent (%)
Identified Fatty Acids
C8:0
C10:0
C11:0
C12:0
C13:0
C14:1
C14:0
C15:1
C15:0
C16:1
C16:0
C17:1
C18:2n6c
C18:2n6t
C18:1
C18:0
C20:1
C20:0
C21:0
C22:2
C22:1
C22:0
C23:0
C24:1
C24:0

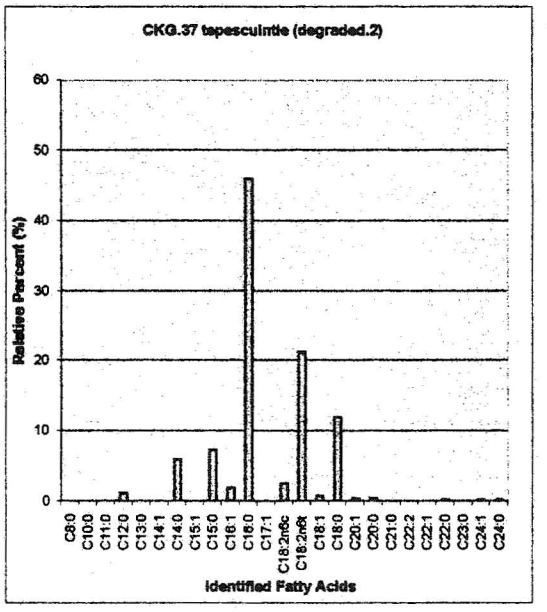

CKG.9 biedo (degraded)
Relative Percent (%)
Identified Fatty Acids
C8:0
C10:0
C11:0
C12:0
C13:0
C14:1
C14:0
C15:1
C15:0
C16:1
C16:0
C17:1
C18:2n6c
C18:2n6t
C18:1
C18:0
C20:1
C20:0
C21:0
C22:2
C22:1
C22:0
C23:0
C24:1
C24:0


CKG.13 macal
Relative Percent (%)
60
50
40
30
20
10
0
C8:0
C10:0
C11:0
C12:0
C13:0
C14:1
C14:0
C15:1
C15:0
C16:1
C16:0
C17:1
C18:2n6c
C18:2n6t
C18:1
C18:0
C20:1
C20:0
C21:0
C22:2
C22:1
C22:0
C23:0
C24:1
C24:0
Identified Fatty Acids


CKG.13 macal (degraded)
Relative Percent (%)
60
50
40
30
20
10
0
C8:0
C10:0
C11:0
C12:0
C13:0
C14:1
C14:0
C15:1
C15:0
C16:1
C16:0
C17:1
C18:2n6c
C18:2n6t
C18:1
C18:0
C20:1
C20:0
C21:0
C22:2
C22:1
C22:0
C23:0
C24:1
C24:0
Identified Fatty Acids

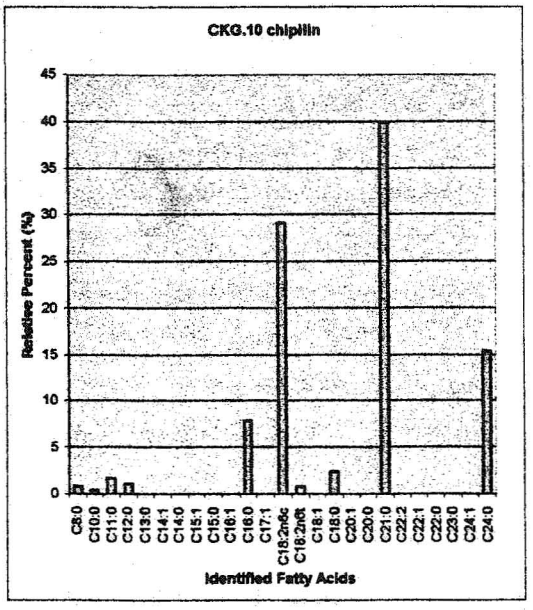

CKG.37 tapesculitie
Relative Percent (%)
0
10
20
30
40
50
60
C8:0
C10:0
C11:0
C12:0
C13:0
C14:1
C14:0
C15:1
C15:0
C16:1
C16:0
C17:1
C18:2n6c
C18:2n6t
C18:2
C18:1
C18:0
C20:1
C20:0
C21:0
C22:2
C22:1
C22:0
C23:0
C24:1
Identified Fatty Acids

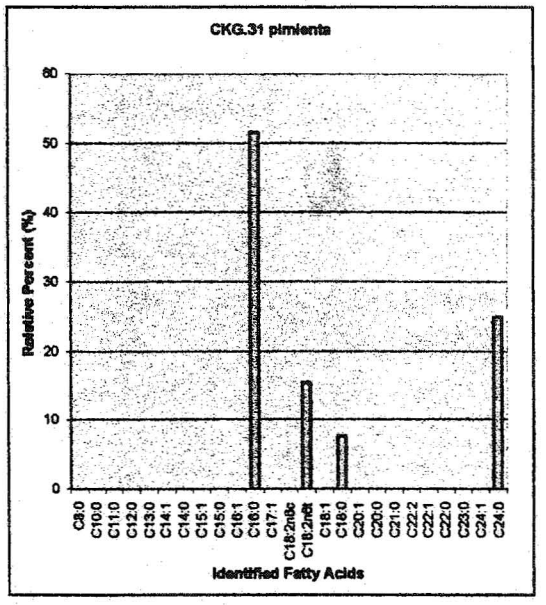

CKG.37 tapesculintie (degraded.1)
Relative Percent (%)
0
10
20
30
40
50
60
C8:0
C10:0
C11:0
C12:0
C13:0
C14:1
C14:0
C15:1
C15:0
C16:1
C16:0
C17:1
C18:2n6c
C18:2n6t
C18:1
C18:0
C20:1
C20:0
C21:0
C22:2
C22:1
C22:0
C23:0
C24:1
C24:0
Identified Fatty Acids

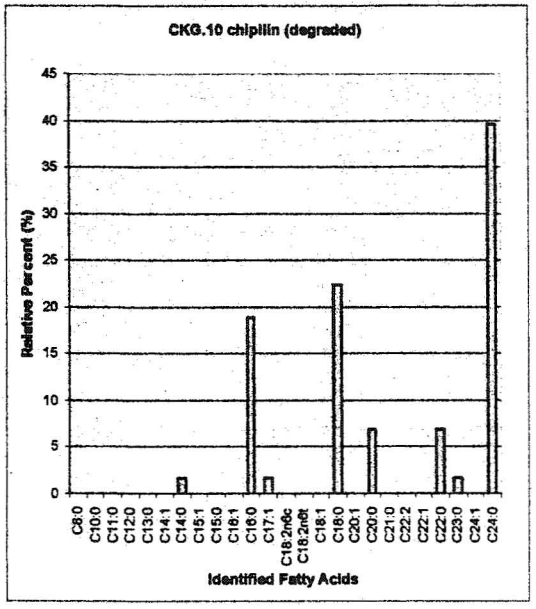

CKG.37 tapesculintie (degraded.2)
Relative Percent (%)
0
10
20
30
40
50
60
C8:0
C10:0
C11:0
C12:0
C13:0
C14:1
C14:0
C15:1
C15:0
C16:1
C16:0
C17:1
C18:2n6c
C18:2n6t
C18:1
C18:0
C20:1
C20:0
C21:0
C22:2
C22:1
C22:0
C23:0
C24:1
C24:0
Identified Fatty Acids

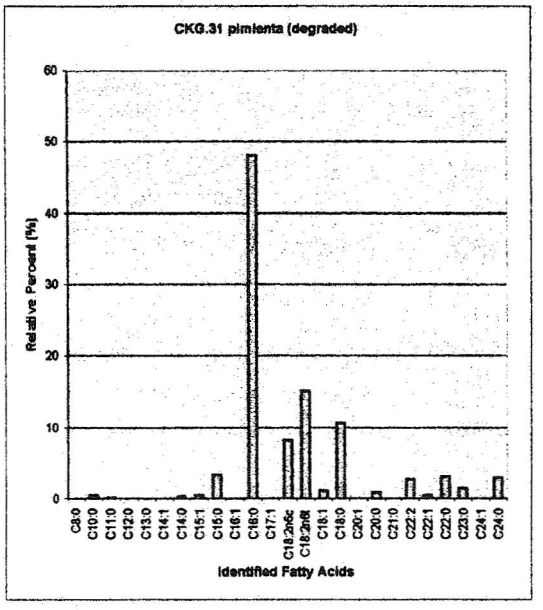
Relative Percentages of the Identified Fatty Acids in Experimentally Degraded, Cooked Foods From Cluster III(a): leafy plant greens

FA/Sample:	CKG.10 chipilín	CKG.31 pimienta
C8:0	0.000	0.000
C10:0	0.000	0.484
C11:0	0.000	0.127
C12:0	0.000	0.000
C13:0	0.000	0.000
C14:1	0.000	0.000
C14:0	1.724	0.408
C15:1	0.000	0.535
C15:0	0.000	3.366
C16:1	0.000	0.000
C16:0	18.966	48.139
C17:1	1.742	2.715
C18:2n6c	0.000	8.236
C18:2n6t	0.000	15.120
C18:1	0.000	1.045
C18:0	22.414	10.632
C20:1	0.000	0.000
C20:0	6.897	0.867
C21:0	0.000	0.000
C22:2	0.000	2.278
C22:1	0.000	0.586
C22:0	6.897	3.213
C23:0	1.724	1.428
C24:1	0.000	0.000
C24:0	39.655	3.085


CKG.10 chipilin
Relative Percent (%)
Identified Fatty Acids
C8:0
C10:0
C11:0
C12:0
C13:0
C14:1
C14:0
C15:1
C15:0
C16:1
C16:0
C17:1
C18:2n6c
C18:2n6t
C18:1
C18:0
C20:1
C20:0
C21:0
C22:2
C22:1
C22:0
C23:0
C24:1
C24:0


CKG.31 pimienta
Relative Percent (%)
Identified Fatty Acids


CKG.10 chipilin (degraded)
Relative Percent (%)
Identified Fatty Acids


CKG.31 pimienta (degraded)
Relative Percent (%)
Identified Fatty Acids

Appendix D

Results of Cluster Analysis: Archaeological Vessels

Results of Cluster Analysis for the Archaeological Vessels:
Relative Percentages of the Identified Fatty Acids
Cluster I

FA/Sample:	CHAR4 jar	CHAR2 jar	CHAR3 jar	CU99.3 jar	AG99.27 incensario	AG99.13 jar	AG99.4 jar	KX99.6 jar
C8:0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.951
C10:0	0.000	0.000	0.000	0.378	0.000	0.000	0.000	0.000
C11:0	0.000	0.000	0.027	1.209	0.000	0.000	0.000	0.000
C12:0	0.878	3.427	16.613	8.390	4.513	2.368	0.000	7.407
C13:0	0.000	0.000	0.000	1.209	2.821	0.000	0.000	0.000
C14:1	0.000	0.000	0.772	2.494	0.000	5.100	0.000	0.000
C14:0	4.588	15.965	23.775	14.739	16.008	4.007	17.088	5.185
C15:1	0.000	0.000	0.000	0.000	4.020	0.000	0.000	16.790
C15:0	2.099	0.000	0.772	6.425	0.000	0.000	3.418	4.444
C16:1	0.878	44.859	0.000	0.000	3.456	0.000	0.000	3.210
C16:0	46.120	35.748	54.020	0.000	9.097	4.736	0.000	0.000
C17:1	0.000	0.000	0.000	0.000	0.000	0.000	5.646	8.642
C18:2n6c	0.000	0.000	0.000	8.466	20.733	19.126	7.281	8.148
C18:2n6t	4.392	0.000	0.000	17.914	18.406	27.322	21.694	13.086
C18:1	0.000	0.000	0.000	4.913	0.000	2.914	0.000	0.000
C18:0	10.737	0.000	0.000	2.494	13.258	16.940	26.003	29.136
C20:1	0.000	0.000	0.000	15.193	0.000	1.639	0.000	0.000
C20:0	0.439	0.000	0.000	0.000	0.000	4.736	0.000	0.000
C21:0	0.000	0.000	2.476	0.000	0.000	2.004	0.000	0.000
C22:2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C22:1	0.878	0.000	0.000	4.308	0.000	2.914	0.000	0.000
C22:0	0.000	0.000	0.000	0.000	0.000	6.193	0.000	0.000
C23:0	0.000	0.000	0.000	0.000	0.000	0.000	2.675	0.000
C24:1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C24:0	28.990	0.000	1.544	11.867	7.687	0.000	16.196	0.000

Results of Cluster Analysis for the Archaeological Vessels:
Relative Percentages of the Identified Fatty Acids
Cluster I (continued)

FA/Sample:	KX99.39 jar	CU99.20 unid.	CU99.12 open	CU99.47 jar
C8:0	0.642	0.000	0.000	0.000
C10:0	0.000	0.000	1.105	0.169
C11:0	0.000	0.000	0.000	2.672
C12:0	1.376	1.891	0.000	6.637
C13:0	0.000	13.366	0.000	0.000
C14:1	0.000	0.000	5.341	67.773
C14:0	25.963	17.743	0.000	10.349
C15:1	0.000	0.489	44.015	5.652
C15:0	0.000	32.597	0.000	0.000
C16:1	0.000	0.000	0.000	0.000
C16:0	0.000	0.000	0.000	1.406
C17:1	0.000	1.530	0.000	0.000
C18:2n6c	0.000	4.654	19.705	0.000
C18:2n6t	29.817	0.807	0.000	0.000
C18:1	0.000	5.992	0.000	0.000
C18:0	32.569	3.782	0.000	5.343
C20:1	9.633	0.000	22.099	0.000
C20:0	0.000	0.000	0.000	0.000
C21:0	0.000	0.000	0.000	0.000
C22:2	0.000	0.000	4.420	0.000
C22:1	0.000	1.657	0.000	0.000
C22:0	0.000	12.240	0.000	0.000
C23:0	0.000	0.000	3.315	0.000
C24:1	0.000	0.000	0.000	0.000
C24:0	0.000	3.251	0.000	0.000

Results of Cluster Analysis for the Archaeological Vessels:
Relative Percentages of the Identified Fatty Acids

	Cluster II Subcluster (ai)		Cluster II Subcluster (aii)		
FA/Sample:	CU99.21 unid.	CU99.30 unid.	CU99.19 open	CU99.26 open	CU99.29 unid.
C8:0	0.000	0.000	0.000	0.000	0.000
C10:0	0.000	0.000	0.000	0.000	0.000
C11:0	0.000	0.000	0.000	0.000	0.000
C12:0	1.503	0.983	3.316	3.531	3.023
C13:0	34.523	24.980	30.624	39.326	30.310
C14:1	0.000	0.614	0.000	1.525	1.716
C14:0	12.212	10.360	0.000	0.000	0.000
C15:1	0.000	0.000	16.190	13.002	13.807
C15:0	0.000	0.000	0.000	0.000	0.000
C16:1	0.000	2.498	0.000	0.000	11.111
C16:0	0.000	0.000	0.000	0.000	0.000
C17:1	5.026	2.416	4.356	0.000	1.552
C18:2n6c	6.153	5.037	12.354	11.798	0.000
C18:2n6t	0.000	0.000	0.000	0.000	0.000
C18:1	0.000	0.000	0.000	0.000	0.000
C18:0	3.711	10.483	15.995	18.620	15.441
C20:1	0.000	0.000	0.000	0.000	0.000
C20:0	0.000	0.000	0.000	0.000	2.042
C21:0	0.000	0.000	0.000	0.000	0.000
C22:2	0.000	0.000	0.000	0.000	0.000
C22:1	5.918	3.972	3.966	3.291	10.458
C22:0	0.000	0.000	0.000	0.000	0.000
C23:0	0.000	0.000	0.000	0.000	0.000
C24:1	0.000	0.000	0.000	0.000	0.000
C24:0	30.953	38.657	13.199	8.909	10.539

Results of Cluster Analysis for the Archaeological Vessels:
Relative Percentages of the Identified Fatty Acids
Cluster II
Subcluster b

FA/Sample:	CU99.6 unid.	CU99.7 open	CU99.25 open	CU99.5 unid.
C8:0	0.000	0.000	0.000	0.000
C10:0	0.000	0.000	0.000	2.128
C11:0	1.654	1.704	0.000	2.128
C12:0	3.526	4.194	1.587	4.639
C13:0	6.455	3.277	13.095	3.035
C14:1	2.116	0.000	0.000	0.000
C14:0	51.288	40.498	31.878	41.123
C15:1	7.540	0.000	1.587	2.895
C15:0	0.000	0.000	0.000	0.000
C16:1	9.330	9.699	6.746	11.057
C16:0	0.000	0.000	0.000	0.000
C17:1	0.000	0.000	2.910	0.000
C18:2n6c	0.000	0.000	8.598	16.707
C18:2n6t	0.000	0.000	0.000	0.000
C18:1	0.000	0.000	0.000	0.000
C18:0	8.327	24.246	8.333	5.546
C20:1	0.000	0.000	0.000	0.000
C20:0	0.000	0.000	0.000	0.000
C21:0	0.000	0.000	0.000	0.000
C22:2	0.000	0.000	0.000	0.000
C22:1	0.000	2.621	3.968	2.163
C22:0	0.000	0.000	3.836	0.000
C23:0	0.000	0.000	2.646	0.000
C24:1	0.000	0.000	0.000	0.000
C24:0	9.764	13.761	14.815	8.580

Results of Cluster Analysis for the Archaeological Vessels:
Relative Percentages of the Identified Fatty Acids
Cluster II
Subcluster (ci)

FA/Sample:	CU99.13 jar	CU99.41 jar
C8:0	1.487	0.000
C10:0	3.222	0.332
C11:0	5.328	1.281
C12:0	12.268	12.524
C13:0	0.000	1.850
C14:1	9.046	14.326
C14:0	36.307	28.937
C15:1	1.735	10.199
C15:0	1.115	2.182
C16:1	0.000	0.000
C16:0	0.000	0.000
C17:1	10.409	2.182
C18:2n6c	3.965	7.970
C18:2n6t	0.000	1.044
C18:1	0.000	10.484
C18:0	10.161	12.287
C20:1	4.957	0.000
C20:0	0.000	1.091
C21:0	0.000	0.000
C22:2	0.000	0.000
C22:1	0.000	2.799
C22:0	0.000	0.000
C23:0	0.000	0.000
C24:1	0.000	0.000
C24:0	0.000	0.000

Results of Cluster Analysis for the Archaeological Vessels:
Relative Percentages of the Identified Fatty Acids
Cluster II
Subcluster (cii)

FA/Sample:	CU99.9 bowl	CU99.34 jar	CU99.37 jar	CU9943 bowl	CU99.1 jar	CU99.22 bowl	KX99.8 jar
C8:0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C10:0	9.388	1.847	0.756	0.000	0.000	3.525	0.000
C11:0	4.430	0.095	1.986	0.000	0.000	3.277	0.000
C12:0	20.200	29.986	15.584	22.091	22.021	16.118	3.351
C13:0	1.951	2.653	3.087	0.000	3.109	0.901	0.000
C14:1	4.008	0.000	3.212	0.000	14.508	7.392	0.000
C14:0	34.652	35.812	28.478	29.073	36.399	29.145	25.453
C15:1	0.000	0.000	0.000	0.000	5.959	5.478	18.659
C15:0	2.268	2.937	3.245	2.899	0.000	1.721	0.000
C16:1	0.000	0.000	1.249	0.000	5.440	0.000	0.000
C16:0	0.000	0.000	0.938	0.000	0.000	0.000	0.000
C17:1	0.000	1.232	0.689	0.000	0.000	0.694	8.967
C18:2n6c	7.068	6.537	4.303	0.000	0.000	1.579	5.344
C18:2n6t	0.000	0.947	2.340	7.146	0.000	0.022	3.533
C18:1	0.000	0.000	2.666	0.000	0.000	1.038	0.000
C18:0	5.380	8.669	16.025	17.150	4.275	29.110	23.822
C20:1	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C20:0	0.000	0.000	1.063	0.000	0.000	0.000	1.359
C21:0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C22:2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C22:1	0.000	0.000	3.982	0.000	0.000	0.000	0.000
C22:0	0.000	0.000	0.857	0.000	0.000	0.000	0.000
C23:0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C24:1	0.000	0.000	0.464	0.000	0.000	0.000	9.511
C24:0	10.654	9.285	9.075	21.641	8.290	0.000	0.000

Results of Cluster Analysis for the Archaeological Vessels:
Relative Percentages of the Identified Fatty Acids
Cluster III
Subcluster (ai)

FA/Sample:	CU99.42 bowl	CU99.45 bowl
C8:0	0.000	0.000
C10:0	0.000	0.000
C11:0	0.000	0.000
C12:0	1.851	1.997
C13:0	0.000	0.000
C14:1	42.551	38.386
C14:0	3.321	4.614
C15:1	0.000	1.198
C15:0	0.000	0.000
C16:1	0.000	0.000
C16:0	0.000	0.000
C17:1	0.000	0.000
C18:2n6c	0.000	0.000
C18:2n6t	0.000	0.000
C18:1	0.000	0.000
C18:0	2.498	2.237
C20:1	0.000	0.000
C20:0	0.000	0.000
C21:0	0.000	0.000
C22:2	0.000	0.000
C22:1	0.000	0.000
C22:0	0.000	0.000
C23:0	0.000	0.000
C24:1	0.000	0.000
C24:0	49.780	51.568

Results of Cluster Analysis for the Archaeological Vessels:
Relative Percentages of the Identified Fatty Acids

	Cluster III Subcluster (bi)			Cluster III Subcluster (bii)		
FA/Sample:	CU99.27 bowl	CU99.39 bowl	CU99.32 plate	CU99.31 plate	CU99.40 bowl	KX99.17 jar
C8:0	0.000	0.000	0.000	0.000	0.000	0.000
C10:0	0.000	0.000	0.000	0.000	0.000	0.000
C11:0	0.000	1.069	0.000	0.000	0.977	0.000
C12:0	7.591	4.704	3.892	5.279	8.466	0.000
C13:0	0.000	0.000	0.682	2.791	1.547	0.000
C14:1	7.243	1.639	3.430	3.944	0.000	0.000
C14:0	10.288	16.607	5.563	34.951	19.170	19.130
C15:1	0.000	0.000	0.000	0.000	2.523	14.783
C15:0	2.338	0.927	0.594	1.517	1.302	5.217
C16:1	0.000	0.000	0.000	0.000	0.000	0.000
C16:0	0.000	0.000	0.000	0.000	0.000	0.000
C17:1	0.000	1.069	0.836	1.274	0.529	0.000
C18:2n6c	0.000	0.000	2.924	5.340	10.745	14.783
C18:2n6t	2.023	0.000	7.740	4.551	5.983	8.696
C18:1	0.000	0.000	14.424	0.000	0.000	0.000
C18:0	17.847	6.557	0.000	11.711	7.448	0.000
C20:1	0.000	1.639	0.000	0.000	0.000	0.000
C20:0	0.000	0.000	0.967	0.000	0.692	0.000
C21:0	0.000	0.000	0.000	0.000	0.000	0.000
C22:2	0.000	0.000	0.000	0.000	0.000	0.000
C22:1	3.774	2.566	0.000	0.000	1.018	0.000
C22:0	0.000	0.000	0.000	0.000	0.000	0.000
C23:0	0.000	0.000	0.000	0.000	0.000	0.000
C24:1	0.000	0.000	0.000	0.000	0.000	8.696
C24:0	48.896	63.222	58.949	28.641	39.601	28.696

Results of Cluster Analysis for the Archaeological Vessels:
Relative Percentages of the Identified Fatty Acids

	Cluster IV			Cluster V Subcluster (a)	
FA/Sample:	AG99.17 unid.	CU99.33 plate	CU99.49 jar	CU99.8 plate	CU99.23 bowl
C8:0	0.000	0.000	1.663	0.000	0.000
C10:0	0.000	0.044	0.000	0.841	0.584
C11:0	0.000	0.000	0.000	0.000	0.452
C12:0	0.264	0.639	4.276	4.599	2.190
C13:0	0.000	0.341	0.000	0.000	0.813
C14:1	0.000	0.000	0.000	0.000	0.000
C14:0	0.681	0.000	19.240	11.441	7.023
C15:1	0.000	0.079	0.000	0.000	0.000
C15:0	0.348	0.271	0.000	0.000	1.613
C16:1	0.000	0.000	0.000	0.000	1.364
C16:0	17.017	6.414	0.000	24.004	38.243
C17:1	0.000	0.805	0.000	0.000	0.000
C18:2n6c	0.667	0.210	0.000	0.000	4.131
C18:2n6t	10.149	1.873	6.176	7.291	0.964
C18:1	0.584	0.000	0.000	0.000	0.000
C18:0	69.248	85.282	68.646	0.000	17.397
C20:1	0.000	0.000	0.000	26.248	0.000
C20:0	0.000	1.479	0.000	0.000	0.643
C21:0	0.000	0.324	0.000	6.450	0.000
C22:2	0.000	0.000	0.000	0.000	0.000
C22:1	0.000	0.123	0.000	17.443	22.433
C22:0	0.570	0.271	0.000	0.000	0.000
C23:0	0.000	0.131	0.000	0.000	0.000
C24:1	0.000	0.000	0.000	1.683	2.151
C24:0	0.473	1.715	0.000	0.000	0.000

Results of Cluster Analysis for the Archaeological Vessels:
Relative Percentages of the Identified Fatty Acids
Cluster V
Subcluster (bi)

FA/Sample:	CU99.14 open	CU99.36 jar	CU99.44 bowl	CU99.38 bowl	AG99.25 bowl
C8:0	0.000	0.000	0.000	0.000	0.066
C10:0	0.390	0.000	0.337	0.045	0.000
C11:0	0.657	0.000	0.000	0.249	0.000
C12:0	1.438	2.812	1.645	0.741	0.095
C13:0	1.253	0.000	0.000	0.302	0.000
C14:1	0.000	1.533	0.000	0.340	0.107
C14:0	8.835	5.151	4.887	4.686	0.150
C15:1	0.760	1.394	1.048	0.219	0.000
C15:0	0.000	0.415	0.000	0.937	0.153
C16:1	1.459	0.000	0.000	0.000	0.367
C16:0	77.337	77.115	84.649	69.256	68.540
C17:1	0.000	0.127	0.000	0.136	0.128
C18:2n6c	1.890	1.026	0.000	0.582	2.034
C18:2n6t	0.000	0.000	0.737	11.918	0.000
C18:1	0.000	0.000	0.000	3.295	0.000
C18:0	5.075	2.466	2.651	0.000	0.000
C20:1	0.000	0.000	0.000	0.000	0.883
C20:0	0.000	0.000	0.000	3.272	17.108
C21:0	0.000	0.000	0.000	0.000	0.553
C22:2	0.000	0.000	0.000	0.000	0.000
C22:1	0.000	0.542	0.000	0.000	0.000
C22:0	0.000	0.000	0.000	0.778	7.863
C23:0	0.000	0.000	0.000	0.083	1.947
C24:1	0.000	0.000	0.000	0.000	0.000
C24:0	0.904	7.421	0.000	3.159	0.000

Results of Cluster Analysis for the Archaeological Vessels:
Relative Percentages of the Identified Fatty Acids
Cluster V
Subcluster (bii)

FA/Sample:	CU99.10 jar	KX99.14 jar	CU99.2 tecomate	AG99.1 bowl	CU99.35 bowl
C8:0	0.000	0.000	0.000	0.000	0.000
C10:0	0.245	0.000	1.445	0.000	0.000
C11:0	0.135	0.000	0.637	0.000	0.185
C12:0	0.508	0.081	3.431	5.004	2.263
C13:0	0.214	0.000	0.760	0.000	0.566
C14:1	0.098	0.000	0.637	1.311	2.002
C14:0	3.248	1.953	9.846	9.490	4.700
C15:1	0.000	0.076	0.000	0.000	1.665
C15:0	1.125	1.383	1.711	1.939	0.457
C16:1	0.312	0.542	0.000	3.545	0.598
C16:0	58.098	67.186	56.776	42.873	44.729
C17:1	0.477	0.046	0.000	4.413	0.250
C18:2n6c	0.000	0.000	0.000	6.278	2.285
C18:2n6t	7.064	2.468	0.000	12.888	2.143
C18:1	0.000	1.796	0.000	1.625	0.000
C18:0	22.850	21.862	21.574	8.955	16.070
C20:1	1.315	0.000	0.000	0.000	0.000
C20:0	1.731	1.318	1.178	0.000	1.023
C21:0	0.294	0.244	0.000	0.000	0.000
C22:2	0.000	0.000	0.000	0.000	0.000
C22:1	0.061	0.000	0.000	0.000	0.413
C22:0	1.284	0.570	0.000	0.000	0.294
C23:0	0.336	0.000	0.000	0.000	0.000
C24:1	0.000	0.000	0.000	0.000	0.000
C24:0	0.606	0.060	2.005	1.680	20.357

Results of Cluster Analysis for the Archaeological Vessels:
Relative Percentages of the Identified Fatty Acids
Outliers

FA/Sample:	KX99.31 jar	AG99.19 bowl	CU99.11 jar	CU99.15 jar	CU99.24 open	AG99.3 unid.	KX99.11 jar
C8:0	0.000	0.000	8.029	0.000	0.000	0.000	0.000
C10:0	0.000	0.000	6.887	0.000	0.000	0.000	0.169
C11:0	0.000	0.000	2.397	1.840	0.000	0.000	2.762
C12:0	0.000	0.000	11.492	3.681	0.695	0.048	6.637
C13:0	0.000	0.000	1.522	2.699	2.276	0.017	0.000
C14:1	0.000	0.000	28.349	6.748	0.000	0.031	67.773
C14:0	0.000	0.000	19.216	0.000	1.188	0.031	10.349
C15:1	0.000	0.000	12.976	28.098	0.291	0.024	5.652
C15:0	0.000	0.000	0.495	0.000	0.000	0.128	0.000
C16:1	0.000	0.000	0.000	20.123	0.000	0.116	0.000
C16:0	0.000	0.000	0.000	0.000	0.000	0.000	1.406
C17:1	0.000	0.000	0.571	0.000	0.000	0.000	0.000
C18:2n6c	0.000	0.000	0.000	0.000	4.197	1.315	0.000
C18:2n6t	0.000	0.000	0.000	0.000	19.697	0.000	0.000
C18:1	0.000	0.000	0.000	0.000	0.000	78.077	0.000
C18:0	0.000	0.000	6.735	26.258	5.272	0.000	5.343
C20:1	0.000	0.000	0.000	0.000	3.312	0.849	0.000
C20:0	0.000	0.000	0.000	0.000	52.554	14.196	0.000
C21:0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C22:2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C22:1	0.000	0.000	0.000	0.000	2.238	0.026	0.000
C22:0	0.000	0.000	0.000	0.000	0.303	3.929	0.000
C23:0	0.000	0.000	0.000	0.000	0.000	1.216	0.000
C24:1	0.000	0.000	0.000	0.000	0.379	0.000	0.000
C24:0	0.000	0.000	1.332	10.552	7.598	0.000	0.000

Appendix E

Ratios of Medium:Long Chain Fatty Acids in Comparative Food Standards

Ratios of medium chain FAs:long chain FAs in freshly prepared cooking water extracts.

Sample name	Food	Ratio of medium:long
Food plants:		
Cluster I(i)		
CKG.35	maize	0.000
CKG.36	maize	0.000
CKG.30	*flor de epazote*	0.041
CKG.11	*pacaya*	1.854
Cluster I(ii)		
CKG.12	*guisqil*	1.604
CKG.14	*chaya*	0.663
CKG.20	*camote*	0.000
Cluster II(ai)		
CKG.34	squash seeds	0.000
CKG.28	squash seeds	0.000
Cluster II(bi)		
CKG.8	*chile*	1.087
CKG.29	*loroco*	0.000
CKG.25	*achiote*	0.000
CKG.33	tomato	0.273
CKG.13	*macal*	0.429
CKG.17	*pimienta*	0.331
Cluster II(bii)		
CKG.41	avocado	N/A
CKG.21	*cacao*	0.000
CKG.9	*bledo*	0.000
CKG.15	*hierba mora*	0.111
CKG.7	*corozo*	1.870
CKG.26	bean	0.296
Cluster III(ai)		
CKG.19	*hierba buena*	0.650
CKG.27	*hierba buena*	0.272
CKG.22	*guisqil*	0.061
CKG.32	*tomatillo*	0.254
Cluster III(aii)		
CKG.16	*Sta. Maria*	0.338
CKG.31	*pimienta*	0.000
Outliers		
CKG.6	bean	3.125
CKG.18	*rosa de jamaica*	0.163
CKG.10	*chipilín*	0.077

Ratios of medium chain FAs:long chain FAs in freshly prepared cooking water extracts (continued).

Sample name	Food	Ratio of medium:long
Meats:		
Cluster II(ai)		
CKG.38	deer	18.000
CKG.39	turkey	0.772
CKG.40	armadillo	2.001
Cluster II(bi)		
CKG.37	tepesuintle	12.723

Ratios of medium chain FAs:long chain FAs in degraded cooking water extracts.

Sample name	Food	Ratio of medium:long
Plants:		
CKG.35	maize	0.030
CKG.12	*guisqil*	5.181
CKG.28	squash seeds	0.088
CKG34	squash seeds	0.057
CKG.8	*chile*	0.198
CKG.13	*macal*	0.131
CKG.31	*pimienta*	0.413
CKG.10	*chipilín*	0.031
CKG.9	*bledo*	0.116
Meats:		
CKG.38	deer	2.332
CKG.38	deer	0.000
CKG.30	armadillo	33.792
CKG.30	armadillo	1.876
CKG.37	tepesuintle	2.261
CKG.37	tepescuintle	11.898