What's Cooking?

An archaeological residue analysis of ceramics from Thailand

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ABSTRACT

Residue analysis is a relatively new method of investigating the past, and an analysis of ceramic residues has never been undertaken in Southeast Asia. The purpose of this study was to determine whether this type of analysis could successfully be carried out in the Southeast Asian context. Following this, the aim was to, as accurately as possible, identify the sources of the ceramic residues.

Sherds were collected from four sites in Thailand, Ban Non Wat, Ban Salao, Khok Phanom Di and Nong Nor. Residues were extracted from these sherds using a solvent in a Soxhlet apparatus. The extracted fatty acids were analysed using gas chromatography mass spectrometry in the Departments of Chemistry and Human Nutrition at the University of Otago. Carbon isotopic signatures were also obtained using gas chromatography isotope ratio mass spectrometry in the Department of Chemistry. The fatty acid results suggested an organic source for the residues from all the pots. The most likely food sources were plant, fish or mammal, or a combination of these. The ^{13}C isotopic results showed that the most likely source was a C_3 plant, or an animal feeding on these plants. The faunal data from the archaeological sites support these conclusions.

In conclusion this study showed that residue analysis is a viable avenue of archaeological enquiry in Southeast Asia.

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INTRODUCTION

Residue analysis is a relatively new avenue of enquiry in the field of archaeology. It can be used to identify the sources of organic residues found on stone tools, in soil sediments and also carbonised on or absorbed into ceramic vessels (Regert 2007, 61). It is important to know what the sources of these residues were, as it allows for more accurate interpretations of past cultural activities and uses carried out in an area or with particular implements. This, in turn, allows the painting of a more accurate picture of a past culture's day-to-day life.

Function and use studies have become an increasingly important and popular course for ceramic analyses, in order to illuminate the activities of past people (Rice 1996). Many methods have been used to interpret the past uses of ceramics, including analysing the technological and morphological features of vessels, ethnographic analogies and experimental archaeology (Charters et al. 1993). These traditional methods, however, can only provide indirect evidence of the past uses a vessel was put to. Residue analysis, on the other hand, provides a means of directly analysing a vessel's use.

Successful residue analyses have been carried out in many parts of the world: in China residues of a fermented beverage have been found in Shang vessels thought to have contained rice wine (McGovern et al. 2004); evidence for dairying in the Neolithic was discovered on the Hungarian Plains (Hoekman-Sites 2011), while evidence for dairying in the Near East was found as early as the seventh millennium BC (Evershed et al. 2008); and a variety of analyses have been undertaken in both South and North America, and in the Middle East (Evershed et al. 2008; Matheson et al. 2009; Rafferty 2007). Despite this success, however, when embarking on a residue analysis in new geographic regions, positive results cannot necessarily be anticipated. Organic materials are only preserved under certain conditions, and while the matrix of a ceramic vessel offers some protection, environmental factors such as aridity, humidity, water leaching, microbial activity and the age of a vessel will all affect the survival of any residues. Fatty acids, while relatively stable, break down over time, and this process can be accelerated by any of these environmental factors (Eerkens 2007).

An analysis of ceramic residues has never been carried out in Southeast Asia, which, with its monsoon climate, cannot be considered an ideal environment for the long-term survival of organic materials. Stable isotope analyses, which have been used to piece together the diet of past cultures through bone collagen, have never been used in Thailand to analyse

organic residues found in ceramic vessels. Similarly, fatty acids have not yet been used in Southeast Asia to determine the possible sources of organic residues.

Residue analyses cannot definitely identify the sources of vessel contents, but by comparing with local isotopic signatures, both modern and degraded fatty acid profiles, and with the archaeological record, a reasonably accurate interpretation down to the level of food classes can be reached.

Thesis Aims

The first aim of this study was to determine whether residue analyses are a viable line of enquiry in Southeast Asian archaeology.

Providing residue extraction and analysis was successful, the second aim of this study was to attempt to identify the residues contained in a number of vessels.

Study material

The original aim of this project was to look for the evidence of rice wine in a particular form of vessel found at Ban Non Wat in burials dating to the early Bronze Age. Fieldwork was undertaken over two months in Thailand at Ban Salao and Ban Non Wat in 2009-2010. Although the method of residue analysis was yet to be determined, it was clear that sherds, rather than whole pots, would be ideal. It was not feasible, however, to sample whole or reconstructed pots from prior excavations, the best way to ascertain the vessel form, especially as there was a chance the analytical method might have to be destructive. Eighteen sherds and nine soil samples from at least twelve whole pots from the Ban Non Wat and Ban Salao 2008-2010 seasons were made available on the stipulation that they would not be destroyed. Some of these pots were excavated previously and kept aside for future residue analyses. These samples were supplemented by a further fourteen sherds collected from whole pots at Ban Non Wat, which were allowed to be destroyed by grinding to extract absorbed residues. Unfortunately, during analysis, the residues extracted from all of these samples were accidentally destroyed in a laboratory accident. This proved a serious setback. Six Ban Non Wat samples consisted of more than one sherd, so these could be re-extracted and re-analysed. Reserve collections of sherds from previous excavations were made available, and twelve samples each, with a general archaeological context, from excavations at Khok Phanom Di (1985-6) and Nong Nor (1980-2) in Central Thailand were acquired for analysis. Thirty

samples were thus available, although only ten from Khok Phanom Di, and four each from Nong Nor and Ban Non Wat provided peaks high enough for interpretation.

The method of analysis in this study involved extraction using a Soxhlet apparatus. Subsequent analyses were carried out using gas chromatography mass spectrometry (GC-MS) and gas chromatography isotope ratio mass spectrometry (GC-IRMS). These processes are standard procedure in residue analyses (Lambert 1997, 130; Reber and Evershed 2004) and are described fully in the Chemical Analyses and Methodology sections of this thesis.

Thesis Organisation

The second chapter of this thesis, Background, provides background information, and a context to the research question. Basic methods of ceramic analysis are described, before residue analyses are introduced, as well as two ways in which they can be explored, either through fatty acid profiles or isotopic signatures.

The third chapter, Sites and Subsistence, provides a description of the subsistence of prehistoric Southeast Asia. The four sites from which samples were gathered are described, together with a brief description of the ceramic assemblages found in them. The chapter concludes by describing mortuary rituals generally practiced in prehistoric Southeast Asia.

Chapter four, Chemical Analyses, introduces the elemental principles of chemical analyses. The chemistry behind lipids and isotopes are explained, and the methods of analysis used in this thesis, including gas chromatography, mass spectrometry and isotope ratio mass spectrometry, are described.

Chapter five, Methodology, details the methodology employed in this thesis. The methods of collection, extraction and analysis, as well as the development of the extraction methodology, are described.

In chapter six, Results, a series of tables, graphs and chromatograms present the results obtained from the above analyses. The first half of the chapter focuses on the fatty acid and n-alkane results, while the second half deals with the isotopic signatures.

In chapter seven, Discussion, the results are discussed and compared with both modern and degraded fatty acid profiles, and with isotopic signatures from organic materials that were as local as possible. The residues of each sherd are interpreted based on these comparisons, and some limitations and difficulties of this project are discussed. Future avenues of research for residue analysis, particularly in Southeast Asia, are also suggested.

In the final chapter, Conclusion, the thesis, results, and interpretations of these, are summarised. How well the aims outlined in the introduction were met is addressed.

BACKGROUND

This literature review is organised into two parts. The first introduces ceramics and different methods for their analysis. These include traditional morphology and function and use analyses. The second part describes residue analysis, and methods of performing it. Fatty acid and isotope analysis are also introduced.

Ceramics

> "Pottery tends to arouse strong emotions in archaeologists: they either love it or hate it. For some it has an indefinable fascination, and is potentially full of information, which has to be teased out of it by careful and painstaking study. At the other end of the scale, it is seen as the most common of archaeological materials, whose main functions are to slow down the real business of digging, fill up stores, and behave as an archaeological 'black hole' for post-excavation resources" (Orton et al. 1993, 3).

> "It matters little if these pots sometimes are not much to look at; their durability transcends the superficiality of image" (Rice 1996, 139).

After stone, fired clay is the most robust and abundant material found in the archaeological record. It is incredibly durable, and ceramic sherds can sometimes dominate entire archaeological assemblages. Customarily, ceramic vessels have been associated with evidence for increasing sedentism, agricultural practices and population growth (Bellwood and Glover 2004). Since ceramic vessels are widely encountered in prehistory, even with mobile hunter-gatherers, they are ideal for archaeological study (Rice 1996, 139). Southeast Asia has a long ceramic tradition, and storage of surpluses of the main agricultural crop, rice, may well have allowed for population growth, increased sedentism and social complexity (Hayden 2009; Higham 1996).

Traditional Analysis

Conventionally, ceramic analyses have focused on aesthetics or type descriptions. These analyses employ vessel form and surface decoration to construct classifications, which archaeologists use for a variety of purposes. Temporal sequences can be created for a site, or a whole region, using relative dating techniques like typologies, stratigraphic context and seriation (Renfrew and Bahn 2000). When combined with an absolute dating method, such as radiocarbon dating, these can accurately date a sequence of events. For example, Ramenofsky and Feathers (2002) used a combination of historical documents, ceramic decoration sequences, tree-ring dates and thermoluminescence dating to estimate when cultures speaking the Tewa language abandoned the Lower Rio Chama in New Mexico in the mid- to late-seventeenth century.

Using morphological classifications and design features, archaeologists can infer much about the past cultures making and using pots (Rice 1996). Interaction with other cultures – the transfer of decorating or manufacturing ideas, or even the movement of new people into regions – can be explored through the exchange of pots and other goods. Some exchange systems can be tracked over considerable distances. For example, the Lapita culture, which has a distinctive dentate stamped decoration on pottery, is found to have ranged all the way from mainland New Guinea to Tonga. Lapita pottery has been found up to 400 kms from the source of the raw materials (Kirch 2002, 113).

The techniques of manufacture and decoration have also been used to indicate the size and level of complexity of a culture, by examining whether pots were made in small communities at a household level, or by a craft specialist sponsored by an elite class (Curewitz 2004; Hagstrum 1985). Aspects of religion can also be explored through ceramic vessels. For example Coe (1978), in his study of Classic Mayan ceramics from Central America, found that painted decoration often depicted scenes from a 2000 year old Mayan epic concerning the underworld, and argued that painted ceramics served a funerary function. Similarly, Hendon (1997), using images painted on ceramics, deduced that women's work in the Classic Maya period consisted mainly of food production and textile manufacture.

Traditional ceramic analyses have made a major contribution to archaeology and the understanding of various cultures throughout the world. However, there are several limitations to the inferences that can be made using ceramic vessels. Pots and people have often been equated in archaeology, the presence of a particular shaped vessel or decoration motif seen as an indication of belonging to a particular ethnic group. However, as found by Kalentizidou (2000), material culture, including ceramic vessels, can cross both geographical and strict

social boundaries. Similarly, Kletter (1999) warns that archaeology lacks sufficient evidence to define accurate border lines, or, for single sites, establish political affiliation.

Classification, while a helpful way to process and interpret, in some cases, thousands of vessels and sherds, is arbitrary. Depending on the questions being asked by the archaeologist, different features of the vessel will be selected on which to base a classificatory scheme (Adams and Adams 2007; Rouse 1960). Even when using the same features of the same vessels within the classification system, different archaeologists may assign vessels slightly differently. Pot forms evolved over time in response to many influences, and determining the point at which one form becomes another can be subjective (Beck and Jones 1989). People from the past were not making their pots with an archaeological classification system in mind. Such an archaeological classification system may have no bearing on what particular ceramic vessels were actually used for. Vessels that appear different may have had the same function. Comparison with modern vessel forms can lead to the risk of a 'folk taxonomy', whereby modern assumptions regarding vessel use are applied to the archaeological material (Smith 2003). It is this uncertainty about the validity of ceramic classifications that led to the shift in focus to function and use studies.

Function and Use Studies

In the past twenty years there has been a growing awareness of the importance of incorporating function and use studies into ceramic analysis (Rice 1996). "Archaeologists place a heavy inferential burden on ceramics (in terms of retrodicting household size, prehistoric diet, trade patterns, learning networks, change etc.), and it is difficult to investigate these issues until we better understand how pottery was employed in daily life" (Rice 1996, 138). Understanding the functions and uses of a vessel can lead to more accurate inferences about subsistence economy, consumption, and the trade and exchange practices of a past society.

The information used to examine this past use includes archaeological context, ethnographic observation of the present uses of similarly shaped vessels, use-wear patterns, pollen analysis, and residue analysis (Charters et al. 1993). Morphological classifications are also used to suggest past uses. For example:

> "...vessels with narrow openings may well have been containers for liquids; vessels with a round base and thin porous walls are more resistant to thermal stress and may have been used for

> cooking... [Although] ethnographic research shows that no one-to-one correlation exists between the use and the intrinsic properties of a vessel" (Regert 2007, 61).

Culinary vessels, or those inferred to have been used in food preparation or storage, have received much of the spotlight in function and use studies, in part due to their ubiquity in most eras and cultures (Rice 1996). These have been categorised into three different uses by Rice (1987, 207): dry substance storage, carrying of liquids and cooking or heating over fire.

The function and use of ceramic vessels are concepts that are quite distinct from each other. Function refers to the many possible activities or capabilities of ceramics, either as containers for various purposes, or as structural material such as building bricks. Use refers to the specific way or ways that a particular vessel was employed in the past (Rice 1996). Artefacts go through several steps in their life histories, being transformed from raw materials into useable artefacts, and then becoming waste, a mortuary gift or family heirloom (Read 2007, 189-191). Early studies of function have used indirect forms of evidence, such as mechanical, technological and morphological features, to infer the use a vessel was put to. "Early studies of ceramic function tended to dwell in this [uncertain] realm, and were based on fast and loose reasoning drawn from intuitive expectations, ethnographic analogies on the uses for which certain forms were deemed to be 'best suited' and ceramic engineering" (Rice 1996, 140). This is complicated by the fact that, throughout a vessel's life span, it may have been put to several different uses (Rice 1996. But see below). Understanding where in its life history an artefact was deposited into the archaeological record can give the archaeologist more insight into why it was found where it was, and provide a better foundation on which to base future inferences (Read 2007, 189).

Ethnoarchaeological and Experimental Studies

Ethnoarchaeology is a useful research strategy employed by archaeologists to provide data for their interpretations of archaeological material, that are, after all, based on inferential reasoning (Stark 2003). Topics that have been a focus for ethnoarchaeology investigations are ceramic technology and production, vessel function, recycling and disposal, vessel life-span and history, division of labour, transmission of learning and techniques, vessel style, ethnicity, distribution, and technological and stylistic change, among others (Stark 2003). The choices potters make during pottery manufacture are influenced by more than mere functional requirements (Arnold 2000). Stark et al. (2000) have shown that decisions regarding the

choice of clay may be influenced by workability of the raw clay, geographical proximity to the clay source, and local political and social boundaries. Ceramic production and manufacture techniques are used to infer specialisation. The division of labour has long been linked to increasing social and political complexity (Costin 2000). In terms of function, ethnographically ceramic vessels have been linked to food storage, processing, cooking and display, even among non-sedentary groups (Wendorf et al. 2002, 51). Aspects of a culture's religion can also be explored through their pottery. In India, potters make earthenware planters for basil, which represents the embodiment of the goddess *Tulasī* to Vaishnavite Hindus (Stark 2003). Decoration is another way in which ethnoarchaeologists explore social identities and boundaries. The decorations on Kalinga pottery in the Phillipines, for example, display political organisation, representing potential interaction between groups (Arnold 2000). The use-lives of ceramics reflect cultural behaviour regarding artefact consumption and discard, and have "direct archaeological implications for seriation and other site formation issues" (Arnold 2000, 115) Calder (1972) conducted an ethnographic study of the breakage and distribution patterns of pottery in a village in Northeast Thailand, Ban Koeng Nua. She found that there was a relationship between vessel function and sherds found within living areas, while there was no direct correlation to function with sherds found outside of living areas (Calder 1978, 74). She found that pottery distribution patterns could be used to identify specialised activity areas.

While experimental studies can provide an insight into the function of ceramic vessels, the conditions under which tests are carried out have to accurately replicate the archaeological reality to be of any use (Rice 1996). Even then, specific questions need to be asked. For example, while Barribeau (2007) has linked the size and shape of a vessel's mouth to the way in which it was utilised, he failed to provide a convincing link between rim size and the ability of a vessel to cool and retain water, which was his original hypothesis. To obtain the function of a vessel through experimental studies would require the testing of many hypotheses, which can be extremely time-consuming, and there is no guarantee of success: just because a vessel *could* be used for a particular function does not prove that it *was* used for that function in the past.

Manufacturing Methods

The 'paddle and anvil' technique is the main method of manufacture utilised in Thailand (Figure 1). Evidence for this technique in the past can be seen in the anvils, burnishing stones and clay cylinders found in prehistoric sites, sometimes as the mortuary

offerings of potters and their offspring (Chang 2004; Higham 2008; Higham and Thosarat 2006). The technique involves holding an anvil inside the vessel wall and beating it with a paddle into the desired shape (Lefferts and Cort 1997; Lefferts and Cort 1998; Stark 2000). The ceramics, which are porous, are likely to have been fired in open fires at temperatures of 800 to 1150°C (Sarjeant 2008, 24). These methods are more indicative of small-scale potters rather than large-scale standardised manufacture, which is reflected in the variations seen in the vessels from within and between sites. Only certain individuals were interred with potting implements, however, and this might suggest the existence of, possibly part-time, specialists (Chang 2004; Higham 2008; Higham et al. 2005; Higham and Thosarat 2006).



Figure 1 Woman manufacturing a ceramic vessel using the 'paddle and anvil' technique in Thailand (Shippen 2010, 89).

Ceramic Residues

While many inferences can be made about past cultures and the ways they used their pots using ethnographical and experimental studies, the direct study of carbonised or absorbed residues in the ceramic vessels is the best way to examine past vessel use. "These finest molecular traces are bringing new life to the study of the most familiar archaeological marker of the meal, the food vessels themselves" (Jones 2008, xii). Interpreting vessel use, particularly in residue analyses, is complicated by the fact that cooking vessels often had many contents, and would have been used multiple times (Rice 1996). However, the organic materials, particularly fats and oils, of foods cooked in the pot would clog any porous spaces in the ceramic fabric, sealing the ceramic matrix from intrusion by other organic materials. This limits the residues to the first several times a vessel was used for cooking or storage of

non-dry foods (Eerkens 2005). In addition "...general characterizations of residues from many vessels may be far more beneficial than proving that a specific food was prepared in a certain vessel" (Malainey 2007, 89). While other avenues of residue research include the analysis of visible or carbonised residues on the surface of vessels, this study is concerned with residues absorbed into the ceramic matrix.

Residue Analysis

Food is an important element of material culture, and is closely linked to economy, as well as to tradition. The use of different products and their combinations relies not only on the trade and seasonality of the region but also on the welfare, psychological and religious arrangements of the population consuming the food (Shishlina et al. 2007). One of the main places food and other organic residues are likely to survive in an archaeological context is within ceramic vessels (Heron et al. 1991).

As discussed above, until recently archaeologists conducting ceramic studies have focused on the morphology and physical characteristics of vessels to determine their past functions and uses. These methods can only provide hypotheses as to the possible function of artefacts, whereas residue analysis has the potential to be more precise about what was actually contained in a ceramic vessel (Eerkens 2007). It can allow researchers to determine more accurately an artefact's specific function or use, and the wider role it may have played in past cultural systems (Charters et al. 1993; Matheson 2009).

While food rarely remains intact within a ceramic vessel, the different types of molecules that do survive may signify what class of substance was once contained in it (Lambert 1997, 130). If a ceramic surface comes into constant or repeated contact with a particular substance it may eventually absorb and preserve that substance as a residue (Matheson et al. 2009). For example, when a ceramic vessel is continually used for cooking, or to store food, a residue (e.g. fats) might remain on the vessel surface or be absorbed into the ceramic matrix. These residues can survive in burial contexts, in some cases for thousands of years. By studying these residues archaeologists can more accurately infer what the vessel might once have contained, and, by extension, what it may have been used for (Charters et al. 1993; Eerkens and Barnard 2007; Matheson et al. 2009).

Residues were first noticed and described in ceramic vessels and on stone tools in the 19th century, but, without the chemical techniques and expertise available today, they remained unidentified until quite recently (Regert 2007). Over the last three decades a general

procedure for residue analyses has been developed. This analysis begins with the extraction of residues from a ceramic vessel by the use of a solvent, or using heating. The resulting mixture is then separated into identifiable components using chromatography, and the components are identified by carrying out spectroscopic tests (Lambert 1997, 130; Reber and Evershed 2004). These steps are discussed in more detail in subsequent sections. However, as Eerkens (2007, 90) has warned: "residue analysis is still in its infancy and there is much to be learned and fine-tuned, particularly on the methodology of the final interpretation of the biochemical findings". Furthermore, pottery residues are not a reflection of the overall diet of a population. Anything processed outside the pots will not be represented, and non-food resources are likely to have also been processed in the same or similarly shaped vessels (Reber 2007). Nevertheless, organic residues still provide a valuable insight into the diet of past societies and their use of ceramics and material culture.

Fatty Acids

Lipids are widely used in archaeological residue analysis, as they are relatively resistant to decomposition or degradation, and as such are relatively stable over long periods of time. They are also easy to extract from artefacts and to analyse, and have been extensively studied (Barnard et al. 2007; Eerkens 2007). "The prominence of... fats among the solvent-soluble components of various organic residues encountered at archaeological sites is consistent with their wide range of potential uses in antiquity, i.e., diet, art materials, lubricants, illuminants..." (Evershed et al. 2002, 660). Lipids are diverse and mostly hydrophobic (and so they will not dissolve in water), are present in almost all foods, and can easily become trapped in the matrices of ceramic vessels. Like all organic matter, once exposed to oxygen and water lipids begin to degrade. The long-chained compounds break down to form short-chained, often volatile, compounds. These are often noxious and associated with 'spoiled' foods. This process is accelerated by higher temperatures, and can hinder archaeological interpretations (Eerkens 2007).

Archaeological Identification of Lipids

Archaeologists use two main methods to link lipids in ceramic residues to particular food classes. The first is through the presence of distinct biomarkers. These are chemical compounds produced only by particular species, so that their presence indicates that the pot they are found in was likely used to store or cook that specific species. Examples include tartaric acid from fruit, which has been used to help identify wine (see McGovern et al. 2005,

below), and theobromine and caffeine, which can be used to help identify chocolate (Reber and Evershed 2004). However, they are rare in nature, and many organisms produce small amounts of the compounds used as a biomarker for another organism (Eerkens 2007). This method also relies very heavily on a presence/absence aspect. If, over time, the biomarker fatty acids for a particular organism decompose below the detectable threshold of the instruments used, the residue will not be able to be identified.

The second method presupposes that different species will produce different amounts of fatty acids, the relative ratios of which can be measured and compared across groups to determine what the origin of the residue might be. Archaeologists tend to assume that the different fatty acid ratios or profiles will remain reasonably unchanged over time, and so oversimplify this method to a few steps: extract the organic residues, determine the relative quantities of the fatty acids, and then compare these with profiles from different foods in a fatty acid database (Eerkens 2007).

It is much more likely, however, that the fatty acids will decompose at different rates, thus changing the relative percentages of compounds over time. Unsaturated fatty acids oxidise faster than saturated ones, and longer- and shorter-chained compounds (those with greater than 18 and less than 14 carbon atoms) oxidise faster than those of a medium-length chain (Malainey 2007). It has been estimated that the rate of oxidation of C18:0, C18:1, C18:2 and C18:3 at 100°c increases 1:100:1200:2500 (deMan 1992 in Eerkens 2005).Other factors, such as temperature and the presence/absence of oxygen and water also affect the rate at which fatty acids decompose, and each additional double bond in a chain increases the rate of decomposition about ten times (Eerkens 2007). Thermal decomposition during cooking also results in fewer fatty acids in the sample, the concentrations of saturated fatty acids increasing while that of unsaturated fatty acids decrease (Spangenberg et al. 2006).

The burial context also plays a vital role in decomposition. It has been noted that fatty acids extracted from sherds in waterlogged anaerobic environments undergo complex degradation processes, and it is possible that C18:1 might convert to C16:0 (Malainey et al. 1999). A possible solution is to use ratios of fatty acids that decompose at fairly similar rates, which would allow one to differentiate between very broad food classes (Eerkens 2007). Another approach is to try and simulate the decomposition of fatty acids over time, as it is preferable to not "compare modern uncooked plants and animals with highly degraded archaeological residues of prepared foodstuffs" (Malainey 2007, 77). For example, Malainey (2007) prepared 19 samples of meat, fish and plants, singly and combined, in replica ceramic vessels, and analysed the decomposition of fatty acids at room temperature for 80 days, and in

an oven at 75°C for 68 day periods over ten months, 68 days at 75°C being estimated to be the equivalent of around 36.3 years of oxidative decomposition.

So long as one understands how processing and decay are likely to affect residues, the arrangement of carbon atoms can allow for the identification of aspects of residues, even if they are considerably altered (Evershed 2008). "Many of the mechanisms and pathways of molecular structural change resulting from degradation and decay are predictable and thus can enhance the interpretative framework" (Evershed 2008, 902). Malainey (2007) recognised trends in fatty acid decomposition over time, and this allowed for a more accurate comparative sample to analyse archaeological residues within the area.

Regert (2007) recognised four categories of markers with which to interpret the molecular compositions of ancient residues. These are:

- biomarkers, which are molecules that have not transformed, and still contain their alcoholic or acidic functional groups.
- anthropogenic transformation markers, which are those that result from human agency, for example, through the mixing or heating of raw materials.
- natural degradation markers, which are caused by natural modification processes;
- and contaminants, usually soil, altering the molecular profile of what is in the vessel (Regert 2007).

For example, animal fats and plant oils, particularly unsaturated fatty acids, do not always survive, but their former presence can be determined from altered components, or natural degradation markers still present in the sample (Evershed 2008).

Most previous analytical studies of archaeological organic residues have focused on lipid components extractable by solvent, which have been proved to be directly linked to the original contents of a ceramic vessel. However, the oxidation products of unsaturated fatty acids, which should form during the use of unglazed ceramic vessels when processing plant and animal products, have never been observed during studies of absorbed lipids (Regert et al. 1998). Regert et. al. (1998) contributed this loss of lipid oxidation products to the leaching of percolating ground water in waterlogged sites. However, they found that following an alkaline treatment of the solution, insoluble residues suggested that these compounds survived in the pottery in a "covalently bound (esterified) form" (Regert et al. 1998, 2030). In more arid sites they could be found in the total lipid extracts (Regert et al. 1998).

As fatty acids are present in almost all organic matter, it is important to distinguish fatty acids sourced from residues from those that are native to the clay the vessel was made from, or derived from the matrix in which the pot was buried (Eerkens 2007; Heron et al. 1991). Fatty acids usually oxidise around 200-250°C, and poly- and mono-unsaturated fats at slightly lower temperatures. Ceramics are usually fired at 600-800°C, making it unlikely that any fatty acids native to the clay or from manufacture will have survived the firing process (Eerkens 2007; Heron et al. 1991; Rice 1996).

As well as food, other possible sources of organic residues in pottery include any refuse surrounding a vessel, human remains decaying near to a pot, and micro-organisms in the process of breaking down residues in the walls of a vessel (Barnard et al. 2007). It has been shown, however, that there is a marked difference in terms of lipid profiles between the residues extracted from ceramic sherds and the soil that they were found in (Eerkens 2007; Heron et al. 1991). It is therefore unlikely that organic residues derived from buried ceramics are a product of the matrix in which they were buried.

The presence of organic residues in the walls of ceramic vessels, after hundreds or even thousands of years, suggests that the movement of contaminants into the sherd matrix, or at least the destructive activity within, has been restricted in some way (Heron et al. 1991). It is possible the reason for this lies in the fact that lipids, being water insoluble, keep water out of the ceramic matrix – "after a pot has become infused with organic residues, water no longer leaks through and there is little room for the accumulation of additional residues" (Eerkens 2007, 91). In some cases, where there is little extracted residue, the distinction between the soil matrix and ceramic residue may not be as clear, as it is possible that soil lipids may have penetrated the very outer surface of the vessel. It is unlikely, however, that they will have been absorbed into the ceramic core and, when dealing with carbonised rather than absorbed residues, the effects of soil organic matter contamination is also negligible (Heron et al. 1991),.

Craig (2008), when analysing ceramic residues from the Neolithic Cave of Gerani in Crete, found that small amounts of phthalate esters, probably from post-excavation plastic contamination, were found on both the exterior and interior surfaces of vessels. Significantly, these were the only peaks obtained from the exterior of vessels, suggesting that the lipids found on the interior surfaces, even in low concentrations, are likely to have been related to the use of the vessel (Craig 2008).

It is difficult to definitely identify the source of the residues extracted from archaeological sherds. As found in Craig (2008), degraded fatty acid profiles cannot provide a

definite interpretation as to a particular organism of plant or animal product. Some general trends can be observed however. For example, Craig (2008) suggests that approximately equal amounts of C16:0 and C18:0 might indicate an animal origin, whereas large relative amounts of unsaturated fatty acids may be indicative of plant material (Craig 2008). While fatty acids cannot prove that a particular food was definitely cooked or stored in a vessel, they are useful to show which foods were not (Malainey 2007).

Malainey et al. (1999) investigated the possible effects that thermal and oxidative decomposition had on absorbed residues, by simulating long-term decomposition. They suggest that, as well as fatty acids usually detected, such as C18:0 and C16:0, the presence of some medium chain fatty acids (C13:0, C14:1 and C15:1) and long chain fatty acids (C18:3ω6, C18:3ω3 and C19:0), which were present in some of the archaeological samples in this study, indicate that the residues were not fully degraded (Malainey et al. 1999). In general, they found that saturated fatty acid levels increase over time, while unsaturated fatty acids decrease. They propose that a relative percentage of C18:0 of around 30% or higher is a likely indicator of a large herbivorous animal product, while lower C18:0 levels, ≤25%, are indicative of plants and fish. Medium chain fatty acids in levels of more than 10% were found to be indicative of plant greens, roots and berries (Malainey et al. 1991). High values of odd-chained fatty acids, particularly C15:0 and C17:0, might indicate the presence of ruminant animal meat in residues. Malainey (1997) posited that ratios of (C15:0 +C17:0) to (C12:0 + C14:0 +C16:0 + C18:0) greater than 0.04 are typical of ruminant animals (in Eerkens 2005).

Starchy grains, such as rice, are important staples to many societies. However, they are underrepresented in the archaeological residue literature. As starchy grains are dominated by a high ratio of starch to lipids, other residues absorbed into pottery matrices such as meat and fish with high lipid content will 'mask' the contributions of starchy grains, thus leading to their underestimation in residue analyses (Reber and Evershed 2004). In an experimental analysis investigating the degradation of cooked maize lipids, Reber and Evershed (2004) found that lipids from meat, dairy and other plants survived the six month decomposition after only one cooking episode, whereas it took long cooking periods for any maize lipids to survive. One can only assume that the same problems apply to rice, another starchy grain which is the staple food crop in Southeast Asia. Zhou et al. (2003) investigated the fatty acid composition of three rice varieties following simulated long-term storage. In all cases the major fatty acids extracted were palmitic, oleic and linoleic, (16:0, 18:1 and 18:2), together making up more than 90% of the total fatty acid content for each of the varieties (Zhoe et al. 2003).

It is essential for archaeologists to base their interpretations of any residue analysis results, as much as possible, on the animal and plant populations known to have existed in the geographic region and time period of the archaeological site, even if the palaeoecology may be understudied, and the archaeological evidence providing new information,. It is easy to brush-off interpretations if they do not make sense in the geographical, environmental or archaeological context (Evershed 2008). In an experimental analysis, Reber and Evershed (2004) found that different environments not only influenced the rate of decomposition in general, but also affected individual compounds very differently. Understanding the context samples are found in will aid in the development of accurate interpretations.

Case Studies

Charters et al. (1993) conducted a quantitative and qualitative study of hundreds of sherds from 62 reconstructed vessels from a multi-period site at Raunds, Northamptonshire in the United Kingdom. Their aim was to determine if different vessel forms resulted in a varying accumulation of lipids in different areas of the pots. Large vessels had a sample taken from the rim, the body and the base, while smaller vessels had a sample taken from the rim and the base. The results of this study showed that there was a dramatic difference in the areas of lipid accumulation according to vessel form, and, apparently, vessel use. Jars, for example, showed high concentrations of lipid accumulation in the rim and the body of the vessel and very little in the base sherd, and are suggested to have been used for 'open-top' cooking. 'Top-hat' vessels, however, had a higher concentration in the base, and are suggested to have been used for roasting food (Charters et al. 1993). "These variations in the extent of lipid accumulation in different parts of a vessel serve to highlight the potential interpretative difficulties and dangers of sampling single sherds of poorly defined origin", especially as it is base sherds that have traditionally been selected as samples for residue analysis (Charters et al. 1993, 216).

A laboratory involved in a blind 'Round Robin' test carried out by Barnard et al. (2007) also found that different portions of a sherd or vessel absorbed different amounts of fatty acids. In this case the upper portions of the sherd tested had absorbed more than the lower. Conversely, McGovern et al. (2005), in their analysis of ceramic sherds from Liangchengzhen in China, collected base sherds wherever possible, as this is where the most liquid is likely to have been absorbed. These sherds were from vessels thought to have been used for containing some form of fermented beverage. There were no visible residues, nor any of the pitting usually associated with acidic fermented beverages (McGovern et al. 2005).

Many of the vessels were 'cups' sourced from graves, and contained a mixed fermented beverage, providing the first direct chemical evidence for the production and use of a fermented drink during the Longshan period in northern China (McGovern et al. 2005).

Evershed et al. (2002) were able to establish the origin of, probably, animal fats from two types of medieval English vessels through their differing fatty acid compositions and compound-specific stable isotope analysis. The first type, lamps, was more abundant in $C_{18:0}$ than in $C_{16:0}$ fatty acids, whereas the 'dripping jars' showed the opposite trend. The lamps also contained more odd numbered carbon straight-chained components, particularly $C_{15:0}$, $C_{17:0}$ and $C_{19:0}$. The two types of vessel were further differentiated through their respective $\delta^{13}C$ values. The lamp $C_{16:0}$ was enriched in ^{13}C compared to $C_{18:0}$, while the dripping dishes showed the opposite result. These findings led the authors to suggest that the origin for fat in the 'dripping dishes' was monogastric animals, such as pigs, while the lamp fats were sourced from ruminant animals like cattle and sheep (Evershed et al. 2002).

Reber (2007), investigating the relationship of typology of archaeological pottery and their use, analysed 39 sherds from known vessel forms from sites in the Lower Mississippi Valley. The local flora, fauna and environmental conditions were considered during interpretation. One sherd was interpreted to have contained a wide variety of sources: fish, meat or animal products, and possibly C_3 plants. All samples had strong evidence of resource mixing. The author also found that variations in vessel form corresponded roughly with past vessel use (Reber 2007).

These studies show that fatty acids arrange themselves differently according to the shape and different uses of a vessel, and emphasise the importance of sourcing samples from several areas of a ceramic vessel, or designing the sampling strategy with a particular question in mind, such as searching for liquid contents. These studies also show how important it is to source samples from preferably whole pots with a secure archaeological context in order to secure accurate interpretations. They also suggest that there is in fact a relationship between vessel form and use. Most importantly, these studies reiterate that prehistoric people did not process only one resource in their pots. This corresponds with ethnographic studies in which foods from the same 'aspect of the world' are cooked together, for example, terrestrial plants and animals, whereas meat from birds is seen as coming from the sky and is processed separately. "We should remember that ancient pottery was not used in the way that would be easiest for us to interpret, but in the way that made the most sense to the ancient user" (Reber 2007, 158).

Not Just Food

In addition to the identification of food traces in ceramic vessels, residue analysis can be used to examine medicinal or psychoactive alkaloids, which "occur widely in wild plants as natural toxins" and "can act as narcotics, stimulants, or hallucinogens", although these have generally been underrepresented in the field (Rafferty 2007, 179). Examples of these alkaloids are caffeine (found in coffee and cacao) and nicotine (found in tobacco), both of which are widely used today. A study carried out by Rafferty (2007), which aimed to "draw scientific attention beyond subsistence", found residues of tobacco in North American pipes dated between 300 and 500 BC, which pushed back the known date for tobacco use by several centuries (Rafferty 2007). Ethnographic accounts note how communities exploit a wide variety of plants, only some of which are consumed for subsistence, and this should be kept in mind during residue analyses (Rafferty 2007).

> "Alcohol, perhaps the most ancient, the most widely used, and the most versatile drug in the world" (Jennings et al. 2005, 276).

Alcohol or fermented beverages are common to most cultures throughout history and around the world. Alcohol is often involved in feasting on auspicious occasions on a small scale and all the way up to large-scale ceremonial feasts for the entire society (McGovern et al. 2004). The importance of alcohol is well documented: in Peru the demand for alcohol may have contributed to the intensification of maize production; the demand of political elites for Italian wine drove the exchange systems in Iron Age Europe; in the ancient Near East barley and emmer wheat beer were widely consumed as a part of daily nutrition or for medicine and at feasts, as well as being offered to the gods; maize beer was a feature of large feasts held by the Inca; and the importance of fermented beverages to political, social and ritual activities during the early Bronze Age of Northern China are documented both archaeologically and textually (Jennings et al. 2005; McGovern et al. 2005).

For a long time the only way to research fermented beverages of the past was through traditional ceramic analyses and, where available, documentary evidence (McGovern 2003). The development of residue analyses, however, has allowed direct evidence of alcohol to be found. In Henan Province, China, for example, McGovern et al (2004) have found evidence of a mixed fermented beverage dated to 7000 BC at Jiahu, an early Neolithic village. Rice or millet 'wines' were also identified from tightly lidded bronze vessels (some still a quarter to half full of liquid) dated to the Shang and Western Zhou dynasties (1600-1046 BC and 1046-

722 BC respectively) (McGovern et al. 2004). Isaksson et.al. (2010) have also identified evidence of a biomarker for alcohol fermentation by yeast in Sweden.

Isotopes in Archaeology

Typically isotopic analysis is used in forensics and other fields to determine the geographical origin or source of a sample. It can, however, also be used to differentiate between samples with similar fatty acid profiles from the same region, but quite different sources, such as marine fish and rice, and also between plants with different biosynthetic pathways (Muccio and Jackson 2009).

Isotopes are expressed as ratios relative to a standard, and reported as δ values. The more negative the δ value, the less heavy isotopes are present in the sample. This is discussed in more detail in the Chemical Analyses chapter.

Terrestrial plants fall into two categories for $\delta^{13}C$: C_3 and C_4. C_3 plants have average $\delta^{13}C$ values of -27‰, with a range of about 15‰, whereas C_4 plants have an average of about -13‰, and a smaller range (Finlay and Kendall 2007). Terrestrial vegetation surrounding rivers and lakes are almost exclusively C_3, and will have $\delta^{13}C$ values near the average of -27‰ (Boutton 1991). Plants with restricted access to the atmosphere, such as under canopies, will have lighter $\delta^{13}C$ values, as will those grown in wetter rather than dry and saline soils (Cox 2009). Lipids also possess lighter $\delta^{13}C$ values than other biochemical fractions (Post et al. 2007; Stevenson and Cole 1999). While a thorough isotopic assessment of the local flora and fauna is necessary, there is a general understanding of Southeast Asian isotopic signatures. For example almost all edible plants have a C_3 synthetic pathway (King and Norr 2006).

In archaeology there are two main applications for stable isotopic analysis: the analysis of human remains in order to study past diet and migration, and the analysis of organic residues to determine possible diet. Below, several examples of isotopic studies of human remains and ceramic residues are discussed.

Human Remains

In Liangchengzhen, a Longshan site in south-eastern Shandong province in China, an analysis was carried out on isotopes from human bone apatite and tooth enamel to explore the past diet. It was found that bone collagen only reflects the protein contribution of the diet where it relies solely on C_3 or C_4 pathway plants. Bone apatite and tooth enamel, on the other hand, reveal the contribution of the whole diet. Bone collagen and apatite, being continually

replaced, reflect the last several years of consumption, whereas tooth enamel apatite will only reflect diet during the years of crown formation (Lanehart et al. 2011). The carbon isotopic results averaged around -9.8‰, which suggested that the diet was probably based on foods with an average $\delta^{13}C$ value of -24 to -18‰. Rice and other C_3 plants have an average $\delta^{13}C$ value of -26‰, while the other staple of the region, millet, a C_4 plant, averages around -14‰. Using stable isotope analysis this study was able to show that by the Longshan period rice was increasingly becoming the staple diet (Lanehart et al. 2011).

The first isotopic analysis to be carried out in Mainland Southeast Asia involved an analysis of 33 skeletons from Ban Chiang in Thailand conducted by King and Norr (2006). The diet of individuals was determined through the isotopic analysis of their remains, which were compared against the local food web and its isotopic composition, as well as archaeological evidence such as faunal remains (King and Norr 2006). The authors found that, over time, increased consumption of aquatic animals, or carnivorous terrestrials, occurred at Ban Chiang. There was also a growing reliance on wet rice cultivation. The archaeological evidence suggests that wet rice agriculture and animal domesticate reliance was high by the Iron Age (King and Norr 2006).

Bentley et al. (2007) carried out an isotopic analysis of tooth enamel of individuals from Khok Phanom Di, also in Thailand. While Lanehart et al (2011) posited that tooth enamel is usually enriched in $\delta^{13}C$ by about +12‰, Bentley et al. (2007) suggest that it is by only about +9.4‰. If individuals existed on a solely C_3 (rice) diet the expected $\delta^{13}C$ value expected was about -15.4‰, and about -4.6‰ for a pure marine diet. This was based on the fact that C_3 plants such as rice have $\delta^{13}C$ values between -22 and -36‰, the average in Thailand being about -26‰ according to a study conducted by King (2006). An estimate for marine signatures at Khok Phanom Di of -14‰ was based on work in the Marianas carried out by Ambrose et al. (1997 in Bentley et al. 2007). Tooth enamel results fell around -12‰, and so a diet based on both rice or other C_3 plants and marine sources was most likely, as is suggested by the archaeological evidence (Bentley et al. 2007).

In investigating human migration in prehistoric Thailand, Cox (2009) used isotopic data from human tooth enamel from three sites in Northeast Thailand, Ban Non Wat, Ban Lum Khao and Noen U-Loke, to determine whether the onset of the Neolithic in Southeast Asia was due to intrusive farmers coming upon an established hunter-gatherer culture. The $\delta^{13}C$ values of samples from all three sites ranged from -15.08 to -12.91‰, the least negative or lightest values from Ban Non Wat, averaging at -13.9‰ (Cox 2009). As tooth enamel is enriched compared with the food source, according to Bentley et al. (2007) the average value

of the Ban Non Wat diet (all food sources combined) would be around -23.3‰, and according to Lanehart et al (2011) it would be around -25.9‰. This study found that, despite former theories of intrusive agriculturalists being the catalyst for the onset of the Neolithic in Northeast Thailand, the isotopic evidence did not support large-scale population movements into the Upper Mun River Valley at this time. The most likely scenario is one of "a long term intermingling and mixing of the inhabitants of the region" (Cox 2009, 298).

Ceramic Residues

Evershed et al. (1997) have shown that isotopic composition, particularly of carbon, seems to be unaffected by diagenetic processes during burial and so, together with modern comparisons, can be a good indication of the contents associated with the use of vessels in the past. An experimental analysis carried out by Hart et al. (2009) found that time is an important variable in the creation of residues and their bulk $\delta^{13}C$ values. They also found that long cooking times resulted in more depleted $\delta^{13}C$ values than did short cooking times. Spangenberg et al. (2006), however, suggest that cooking leads to a ±3‰ increase in $\delta^{13}C$. Conversely, heating experiments carried out by Beehr and Ambrose (2007) show that temperatures used in cooking do not significantly alter isotope ratios of foodstuffs. They also found that, when residue samples had been pre-treated to remove contaminants, there was only a very small average difference in the $\delta^{13}C$ values compared to untreated samples.

Solid ceramic residues from the study carried out at Liangchengzhen yielded $\delta^{13}C$ values of about -18‰, implying that the vessels may have contained fish (Lanehart et al. 2011). Rice from several contexts at Liangchengzhen has been identified by McGovern et al. (2005) as an ingredient in an alcoholic or fermented beverage. Further isotopic analyses of ceramic residues from this site are currently in progress (Lanehart et al. 2011). McGovern et al.(2004) also found evidence of a mixed fermented beverage from the Neolithic site of Jiahu in China, isotopic analysis being one of the five analytical techniques used.

Hoekman-Sites (2011), in her study of dairying practices on the Great Hungarian, Plain, suggests that when the $\delta^{13}C$ values of 16:0 and 18:0 are plotted against each other, the $\Delta^{13}C$ (defined as $\delta^{13}C18$- $\delta^{13}C16$) could indicate the source of animal fat in a sample. A difference of -3.3‰ or less was identified as dairy fat, one between -3.3 and 0.0‰ was identified as ruminant adipose fat, while a difference above 0.0‰ indicated porcine or non-ruminant adipose fat as the source (Hoekman-Sites 2011, 137-144).

In a study conducted by Barnard et al (2007), the interior of a vessel sherd in the blind 'Round Robin' experiment was found to consistently have more negative $\delta^{13}C$ values

(-22.3‰) than the exterior of the sherd (-19.2‰). The difference between the interior and exterior values was suggested to be a result of the value of the fuel used to fire the vessel, or heat it during cooking. The fuel may have had a higher $\delta^{13}C$ value than the food cooked inside. The most negative $\delta^{13}C$ values were found at 21-22mm below the rim, which was thought to indicate the 'boil line'. If the food was cooked in a liquid, fats, which are around 5‰ lighter than carbohydrates and protein, would float to the surface and be absorbed there at higher levels than the heavier components absorbed lower down in the vessel (Barnard et al. 2007).

Spangenberg et al. (2006), while searching for direct evidence of dairying at the prehistoric site of Arbon Bleiche 3 in Switzerland (c. 3384 and 3370 BC), also discovered a correlation between the geometry of a ceramic vessel and the fatty acids found within them. For example, on average the fatty acids from organic residues found in 'curved pots' were isotopically heaviest – which suggests they were most likely used for something with high protein and low fibre (Spangenberg et al. 2006).

Food for Thought: Potential Limitations of Residue Analysis in Archaeology

A dilemma faced by all archaeologists is that between the use, deposition, recovery and analysis of an artefact there are crucial time-lapses (Heron et al. 1991). During these time lapses the artefact might become altered in some way which could disturb any component being tested for. Fungi and bacteria in the soil feed on carbon-based materials, which severely affect their survival rate in the archaeological record (Eerkens 2007). If there are any remains left they are usually fragile, and only a few elements linger behind. The most common of these are carbon, hydrogen, oxygen and nitrogen (Heron et al. 1991; Lambert 1997).

Carbon isotopes allow an analysis of past diet, but many factors, not only decomposition, affect residual isotopes. There might be a difference in isotopic signatures from modern and archaeological sources. For example, in the preindustrial age the carbon dioxide in the atmosphere was isotopically heavier than it is now by around 1.6‰ (Spangenberg et al. 2006). As well as environmental and microbial degradation, modern contamination, human processing in antiquity, and the degree to which a region's natural resources have been surveyed will also affect interpretations of ancient residues (McGovern et al. 2005).

Another problem faced by archaeologists undertaking residue analyses is that, despite the increasing range of techniques being used to analyse organic residues, there has been little effort to standardise methods or to crosscheck laboratories and techniques. This complicates

the comparison of results, even within similar geographical areas (Eerkens and Barnard 2007). More quantitative analyses, which use internal standards, will allow for intra- and inter-site regional comparisons (Evershed 2008), for example that carried out by Charters et al. (1993).

Barnard et al. (2007) conducted a blind 'Round Robin' to test the accuracy of different methods of residue analysis. They cooked camel milk using a new vessel, and then simulated long-term degradation. They sent segments of the wall to eleven laboratories. The laboratories were not provided with any 'contextual' information for the pot or residue, adding a further impediment to accurate interpretation (Barnard et al. 2007). None of the laboratories were able to definitely identify the source of the residue, and two laboratories attained negative results: "the trend to only publish successful projects, though fully understandable, has contributed to a biased representation of the state of the field and unrealistic expectations" (Barnard et al. 2007, 211). Even without an archaeological context four out of seven laboratories were able to establish that the residue was of animal origin, and two were able to suggest the milk of a herbivore. When used in conjunction with all available archaeological information including context, faunal data and vessel shape, as well as other methods of diet reconstruction such as stable isotopic analysis of human bone, residue analysis can allow archaeologists to provide accurate interpretations of what was once contained in a pot. This study, however, shows the potential of residue analyses, even in isolation from other data.

It is also not guaranteed that archaeological residues will survive when embarking on organic residue analysis in a new geographical region (Evershed 2008). Residues are more likely to survive if they are protected from microbial degradation, for example in pottery matrices, or when found in waterlogged and anoxic conditions. However, "alternating wetting and drying in climate zones where season of high rainfall are followed by hot dry periods appears to be detrimental to residue survival" (Evershed 2008, 911). This shows that residue analyses should be conducted widely in many geographical areas, and that positive results should not be assumed in each new region.

Summary

This literature review introduced ceramic analyses with traditional methods, such as morphological classifications, the development of function and use studies and some ethnographic and experimental studies. How residue analysis will aid in determining past ceramic use was briefly explained. Different methods of undertaking residue analysis were

introduced and applied to archaeological examples, and some potential limitations faced by residue archaeologists were discussed. The next chapter will describe the subsistence practices of prehistoric Southeast Asians, and the sites from which residue samples were taken.

SITES AND SUBSISTENCE

> "One of the main points about Southeast Asia... is the relative ease of obtaining food, particularly in the rich coastal-estuarine areas, but also in the inland marshy river valleys... [And even with the hardships imposed by a long dry season,] rice is tailor-made for storage and fish, when salted, may be preserved for months on end" (Higham 1989, 29).

This section first outlines the archaeological evidence for subsistence strategies practiced in prehistoric Southeast Asia. The evidence is summarised for the Neolithic, Bronze Age and Iron Ages. This is followed by a description of the four sites from which sherds were analysed, and the regions they are located in. Lastly feasting, particularly mortuary feasting, a practice only possible with the provision of subsistence surpluses, will be discussed.

Subsistence

Subsistence in coastal prehistoric Southeast Asia was strongly affected by the fluctuating sea levels. Around 3000 to 2000 BC the sea level was between 2.5 and 5.8 m above the present coastline. Several areas were shallow extensions of the ocean, and, while the sea level began to lower around 2000 BC, there were some oscillations (Higham 2002, 8). Khok Phanom Di, for example, when first settled was situated in an estuarine-coastal and mangal environment. Later in the sequence, however, the saltwater dropped away and was replaced by freshwater, permitting rice cultivation. Shortly after, the sea level rose again and the environment returned to one of estuarine swamps, whereas the site is now situated 22km from the coast (Bentley et al. 2007).

Thailand (Figure 2), like most of Southeast Asia, experiences a sub-tropical monsoonal climate. Periods of heavy rainfall, resulting in seasonal flooding, are followed by a long dry season (Bellwood and Glover 2004). This would have dominated, as it still does, any decisions made regarding prehistoric settlement location and subsistence practices. In October to April the prevailing winds are from the northeast, but in May reverse direction. This brings the southwest monsoon. The Phetchabun, Cardamom and western ranges of Thailand receive heavy rainfall, while areas such as the Chao Phraya plains and the Khorat



Figure 2 Map of Southeast Asia showing the location of archaeological sites from Thailand mentioned in the text.

Plateau remain relatively dry. The latter areas rely on seasonal flooding of the rivers, which deposit silt over huge areas, allowing rice to grow (Higham 2002, 9-11).

Even within the parameters set by sea levels and seasonality, the people of each archaeological period exploited their environment for food in differing ways. Since the first anatomically modern humans set foot in Southeast Asia more than 50,000 years ago, hunting and gathering has played a major role in the subsistence of the region. Even today hunting and gathering is practiced "among the most specialised farming communities" (Higham 2002, 29). The forests would have teemed with game, easily collectable wild plants and vegetables, and rivers and lakes, as well as the sea, would have been abundant in shellfish and fish (Higham 2002). Hunting and gathering continued to supplement the diet after the innovation of rice cultivation.

Rice is typically grown in subtropical and tropical regions, can be harvested up to three times a year, and it wholly or partially supports the subsistence of about half the present world population (Williams 2006). Today in Southeast Asia it makes up more of the diet than staples anywhere else in the world. "To eat is to eat rice" (Freeman 2008 7-8).

The Neolithic

Domestic rice and millet were introduced into Southeast Asia after about 2,000 BC. At Khok Phanom Di rice chaff and spikelets have been identified in pottery and dated to between 2,000 and 1,700 BC, while coprolites also found at Khok Phanom Di contain common rice pests, indicating that large quantities of rice were being stored by around 1,500 BC (Weber et al. 2010). In the Neolithic phase at Ban Lum Khao faunal evidence includes wild mammals, such as water buffalo, deer, pig, and small civets, and large quantities of fish and marine animals, such as turtle and shark. This shows the important role that hunting still played in everyday life, despite the inception of plant cultivation and animal husbandry. Domesticated mammals, like the exotic dog, are first encountered in this phase at Khok Phanom Di, although they were rare. At the coastal sites of Khok Phanom Di and Nong Nor, fish, crabs and shellfish dominated, with very few terrestrial mammals (Higham 2002; Higham 2006b). The increase of freshwater fish may have been encouraged by the adoption of wet-rice agriculture, rice paddies hosting many fish species today (Figure 3). As well as providing flesh, fish also help to control weeds, mollusc and insect species harmful to rice plants, and, by stirring up soil nutrients for the rice plants, fish help production (Williams 2006). Freshwater fish and shellfish were abundantly found in the Neolithic layers at Ban Non Wat as well (Thosarat 2011), but a variety of terrestrial mammals were also exploited. Domesticated cattle, pig and dog remains, as well as wild bovid and deer species, were

uncovered, demonstrating that, even with the introduction of domestic species, hunting and trapping played an important role in the Neolithic at Ban Non Wat (Kijngam 2011).



Figure 3 Freshwater fishing in drained rice paddies. From Higham (2002, 161)

The Bronze Age

Subsistence practices in the Bronze Age, which started around 1500 BC, seem to have developed seamlessly from those of the Neolithic. General trends of subsistence can be recognised from a range of archaeological evidence. Settlements, for example, were usually located in close proximity to land suitable for rice or millet cultivation (Higham 2002, 160). Access to fresh water was important for the welfare of both people and their domestic animals, was a source of fish and shellfish, and rivers also facilitated trade. Faunal remains, while providing direct evidence of the species being exploited, may suffer from preservation bias, some elements being under- or over-represented in the archaeological record. Some of the faunal remains found at Bronze Age sites such as Ban Lum Khao and Ban Na Di include domestic pigs and cattle, dogs and chicken, wild mammals such as water buffalo and several deer species, as well as shellfish and abundant fish remains (Higham 2002, 135, 163). Many of the foods eaten today would not survive in the archaeological record, however, for example dung beetles, bamboo shoots, mushrooms, termites and ants (Higham 2002, 163). Artefacts associated with subsistence, such as sickles or knives for cutting grasses and harvesting rice provide indirect evidence of past diets, but again, preservation issues may bias the interpretation of these items. An example of this bias can be seen in material culture associated with fishing. Fish dominated the faunal record at most sites, and played an important part in the prehistoric diet, but at some sites, like Ban Na Di, any material culture

associated with fishing is absent. This might be explained by contemporary fishing practices which utilise nets and traps, neither of which is likely to survive in the archaeological record. Far-reaching exchange networks were also a feature of the Bronze Age, marine shell being found in settlements over 1,000 km from the coast (Higham 2002; Higham 2004).

Weber et al. (2010) have shown that millet was cultivated in Central Thailand during the Neolithic and Bronze Ages. Three sites, Nil Kham Haeng, Non Mak La and Non Pa Wai, were excavated, and extensive flotation and analysis of the soil samples was carried out. Millet was by far the most common taxa of seed present in the soil samples, the hundreds of carbonised millet seeds a sharp contrast to the less than fifty rice grains recovered (Weber et al. 2010) (see

Table 1Table 1). While millet has not been well studied in prehistoric Thailand, it may have played an important role in past subsistence.

Table 1 Seed recovery chart for sites used in the Thailand Archaeometallurgical Project, Nil Kham Haeng (NKH), Non Mak La (NML), and Non Pa Wai (NPW), from Weber et al. (2010, 84).

	NKH	NML	NPW	Total
Samples analysed	160	48	56	264
Carbonised seeds	1,542	441	1,311	3,294
Number of taxa	15	18	19	21
Rice percentage	10	6	3	8
Millet percentage	12	8	16	12

The Iron Age

The Iron Age, beginning around 500 BC, saw a proliferation of both sites and people, and subsistence revolved around the cultivation of rice. At some sites, such as Noen U-Loke in the Mun River Valley, the mortuary ritual included filling the grave with burnt rice (Higham 2002, 197-8). Hunting, gathering and animal husbandry were still important however. Faunal remains from Non Chai in the Chi Valley included abundant shellfish, fish and crabs, frogs, turtle and crocodile. Terrestrial animals included domestic water buffalo, cattle, dog and pig, while deer, rhino and small mammals were hunted (Higham 2002, 188). Salt is a vital resource in Thailand today, used to preserve fish collected and fermented during the wet season for consumption through the dry season. "The number of Iron Age salt-working mounds leaves little room for doubt that it could have been an important resource two millennia ago" (Higham 2010, 136). It has been proposed that control of the salt trade may have allowed the development of rich leaders of the moated Iron Age sites found in the

Mun Valley. The large moated site of Non Dua, for example, lies next to a large salt exposure called Bo Phan Khan, and is surrounded by mounds with evidence of salt extraction. The great number of these mounds suggest that salt production was happening on a scale far larger than necessary for local demand only (Higham 2002, 194). The moats surrounding Iron Age sites themselves may have been used for subsistence purposes, such as providing space for rice cultivation and as a source of fresh fish and shellfish, as well as predictable supplies of potable water (Higham 2002; Higham 2006b; Higham 2010).

Fish Species

Fish played an important role in past subsistence. This section briefly outlines evidence for the most common species found in pots from Ban Non Wat.

Animal remains found in ceramic vessels at Ban Non Wat were identified by Thosarat (2010), and more than 98% belonged to fish species. The majority of species belonged to the *Channa* genus or snakehead (43%, of which 90% was *Channa striata*, the common snakehead) and the *Clarius* genus or air breathing catfish (23%). These were followed in predominance by *Anabus testudineus* or climbing perch (12%), species belonging to the *Hemibagrus/Mystus* genus (large catfish, 11%), *Monopterus albus* or swamp/rice eel (5%), species belonging to the *Ompok/Wallago* genus (butter catfish, 4%). The remaining 2% were made up by the Asian knife fish, the leaf fish, pig, frog, rat and medium sized deer species (Thosarat 2010) (Table in Appendix 4).

The Sites

This section will briefly describe the four sites from which pot sherds were collected: Ban Non Wat, Ban Salao, Khok Phanom Di and Nong Nor, and the regions in which they are located: the Khorat Plateau in Northeast Thailand and the Chao Phraya Plains in Central Thailand.

The Khorat Plateau

The Mun River valley (Figure 4), located on the Khorat Plateau in Northeast Thailand, is the location of many prehistoric sites, including Ban Non Wat, Ban Salao, Noen U-Loke and Ban Lum Khao. The Mun sRiver drains the Khorat basin, joins the Chi River at Ubon, and then flows eastwards toward the Mekong River. The Mekong is important for both communication and trade within the region. A pass through the Petchabun Range in the west

links the Khorat Plateau with the Chao Phraya Valley, which, in turn, provides access to the sea and its marine resources. The lower terraces of the Khorat Plateau are alluvial floodplains suitable for the cultivation of rice. The middle and upper terraces, however, are not. The plateau also possesses rich deposits of salt, which were exploited and widely traded by the Iron Age, and possibly earlier. Copper sources are found to the west in the Khao Wong Prachan Valley, at Sepon in Laos to the east, and at Phu Lon in the north. Lead ore, other minerals and high quality stone sources are located in the highlands of the Mekong River. Settlements were clustered in the lowlands, where both Ban Non Wat and Ban Salao can be found (Higham 1996; Kijngam et al. 1980).

Because of its strategic location, the Mun River valley was chosen as the focus of the Origin of Angkor Archaeological Project's research. It is situated on both the communication route over the Petchabun Mountains to the copper mines of the Khao Wong Prachan Valley, and also along the Mun and Mekong River route to the copper mines in Sepon. Access to salt deposits makes the Mun River Valley ideal for prehistoric settlement, salt being essential for preserving fish for the dry season. Due to these favourable conditions, the Mun River Valley has dense concentrations of prehistoric settlements. The Iron Age moats ringing some are particularly obvious from aerial photographs, and ease the task of identifying some prehistoric sites. As such it is an ideal location for archaeological projects (Higham 1996; Higham 2008; Higham 2010; Higham et al. 2011; Higham and Thosarat 2006).

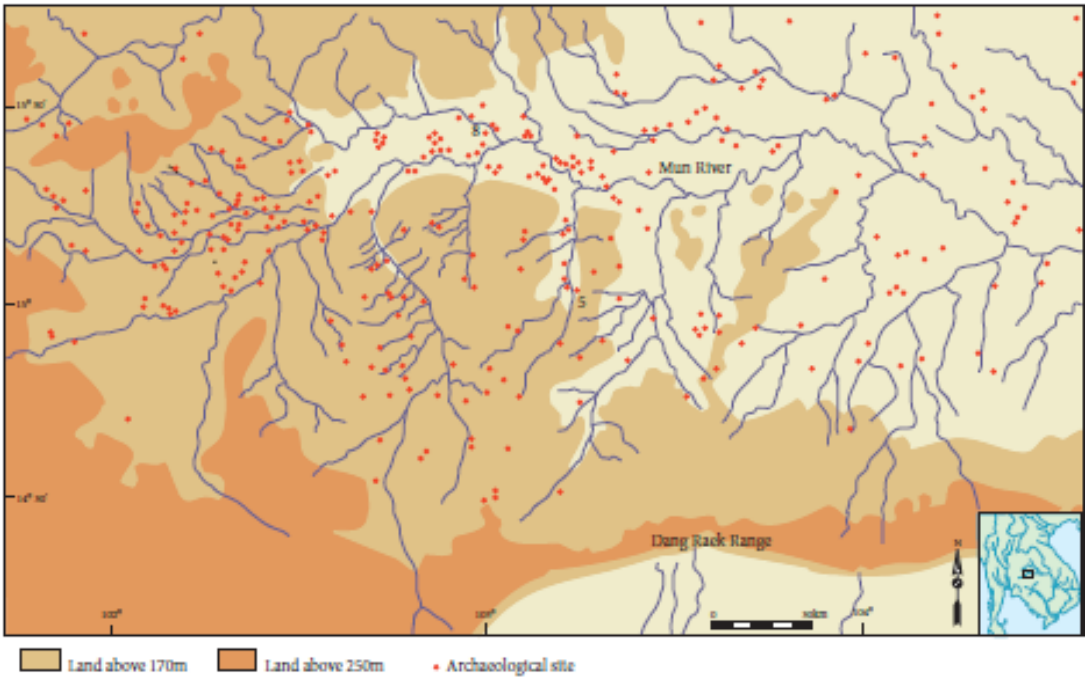


Figure 4 Map of the Mun River Valley, showing the location of all known archaeological sites (from Higham pers. comm.).

Ban Non Wat

Ban Non Wat, a large moated settlement site, is located in the upper Mun Valley. It was excavated as part of the Origins of Angkor Archaeological Project, a collaborative venture between the University of Otago and the Thai Fine Arts Department, from 2002 to 2008. An area of 892m^2, revealing an occupation spanning the Neolithic, the Bronze Age and the Iron Age, was uncovered. A total of 640 burials from all of the phases were excavated, and radiocarbon dates from *in situ* contexts provided the first reliable chronology for the Neolithic to Iron Age sequence in northeast Thailand (Higham 2008; Higham et al. 2011; Higham and Higham 2009; Higham and Thosarat 2006). Excavations continued during 2008 to 2010 as part of the Resilience and Opportunity in Ancient Southeast Asia (ROASEA) Project, which "aims to investigate environment change and society before Angkor: Ban Non Wat and the Upper Mun River Catchment in Prehistory" (Cawte 2010).



Figure 5 Aerial map of Ban Non Wat showing excavations undertaken by the Origins of Angkor project (from Higham pers. comm.).

The sensitive dating of Ban Non Wat allows almost twenty centuries of interments and occupation to be explored in a continuous fashion, starting with the initial settlement and interments in the 1600s BC. Higham and Kijngam (2009) believe that the burials began with a hunter-gatherer group. The earliest burials were flexed, characteristic of hunter-gatherers in the region, and distinct from the Neolithic supine and pot burials. The second Neolithic phase is dated to between 1300-1000 BC. The earliest Bronze Age burials, which began to be arranged in rows, are dated to around 1000 BC, followed by a further four Bronze Age and two Iron Age phases, ending around 500 AD (Higham et al. 2011; Higham and Higham 2009).

Food played an important role in the mortuary ritual at Ban Non Wat. Articulated pig and cow limb-bones, chicken, shellfish, fish skeletons and a bird's egg have all been found placed with the dead. While it is not possible to assign a definite use to the ceramic vessels, pottery forms throughout the phases suggest use as food storage, for food display and for drinking, and several vessels contained fish remains. Burial 90 from Bronze Age 2 (Figure 6),

for example, was interred with numerous vessels thought to have contained food or drink. The suggested drinking vessels, however, waned in popularity in the later Bronze Age phases, and are absent by the Iron Age (Higham, in Hauman 2009). Infants were treated to the same, sometimes sumptuous, mortuary ritual shown to adults, placed in overlarge graves with miniature versions of the vessel forms used for the adults. The sheer quantity of pots, marine shell and marble jewellery found interred, particularly in the Bronze Age 2 and Bronze Age 3 phases, is unrivalled in Thailand (Higham 2011; Higham and Higham 2009).



Figure 6 Burial 90 from the early Bronze Age at Ban Non Wat displaying the mortuary wealth typical of this phase (from Higham pers. comm.).

Ban Salao

Ban Salao (Figure 7) is an Iron Age site located in the Nong Sung area of Northeast Thailand. IT is unlike other Iron Age sites in the region in that it is not surrounded by moats (Cawte 2010). During one season of excavations undertaken in 2009-2010 as part of the ROASEA project, a 4x4 m square was excavated as close to the centre of the mound as

possible. Nine stratigraphic layers, roughly three metres deep, were encountered, natural being reached about three metres below the surface. Excavations produced an assortment of, possibly structural, features, ceramics and a layer of animal bones, the majority of which showed evidence for butchery or modification into tools. These, along with the adjacent salt deposits, have led to the interpretation of Ban Salao as possibly being a site of prehistoric animal processing. An alternative theory posited is that it might have been used as a site of salt production (Cawte 2010).

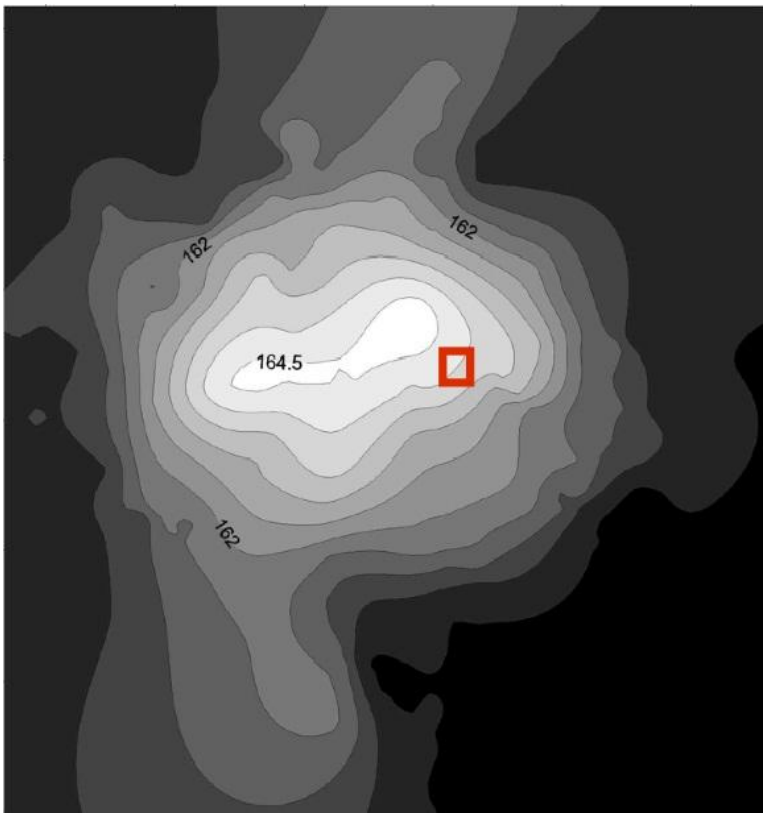


Figure 7 Archaeological site of Ban Salao showing approximate location of the 2009-2010 excavations (from Cawte 2010)

The first cultural layers, layers 7 and 8, showed that the earliest ceramics at this site were typical of the Iron Age in this region. A clay-lined dish or basin with adjacent hole, similar to contemporary salt production equipment, and an infant burial (Figure 8) similar to other Iron Age burials in the region, were also uncovered in these layers. The mortuary offerings interred with the infant are similar to those of Iron Age burials at Noen U-Loke, suggesting that the date of the burial may correspond to the fourth mortuary phase at that site. The ceramics are consistent in form throughout the various layers, but it is the faunal material that is of most interest (Cawte 2010).



Figure 8 Burial 1 from Ban Salao. An infant interred with several ceramic vessels and some beads (Hauman unpublished).

The evidence suggests that this site, initially occupied in the Iron Age as a permanent settlement, may have practiced salt working, but that this was not the sole activity. Although it has been suggested that some small Iron Age sites might primarily have been used for salt working, salt production may have supplemented other activities such as processing of animal carcasses, rather than forming the main reason for site occupation at Ban Salao. The ceramic vessels interred with the infant, like other Iron Age mortuary vessels, are of a form likely to have been used for food storage. Some of the vessels also contained the remains of fish or small mammals (Cawte 2010).

Central Thailand/Chao Phraya Plains

Central Thailand is separated from the Khorat Plateau by the Phetchabun Range, and is enclosed by the Gulf of Siam in the South. A swift rise in sea levels around 8000 to 6000 BC enveloped a large expanse of land, including much of what once was part of Central Thailand, before again retreating (Maloney et al. 1989). It was described by Henri Mouhot, a French scholar travelling in Southeast Asia from 1858-1861:

> "At the first glance, one distinguishes what was formerly the bed of the sea, this great plain having taken the place of an ancient gulf; proof of which is afforded by numerous marine shells" (in Higham 1989, 19).

The area is influenced by the southwest monsoon, which brings heavy rainfall from May to November, while the rest of the year it experiences arid conditions. Being near the sea helps to offset the effects of the monsoon, but the storage of food supplies during the dry season is of utmost importance. In the present day rice is stored in granaries, while fish can be salted and fermented then stored in ceramic vessels (Higham 1989, 67-9).

The Bang Pakong is the most eastern of five major rivers flowing into the Gulf of Thailand, and is the location for the Bang Pakong Valley Research Project (Figure 9), a multidisciplinary investigation into human adaptation to tropical marine and riverine environments (Higham 1990). The Bang Pakong Valley is an area with access to diverse subsistence resources including mangrove, riverine, fresh-water swamps, alluvial plains and grasslands, as well as access to marine resources in the Gulf of Thailand (Kealhofer and Piperno 1994).

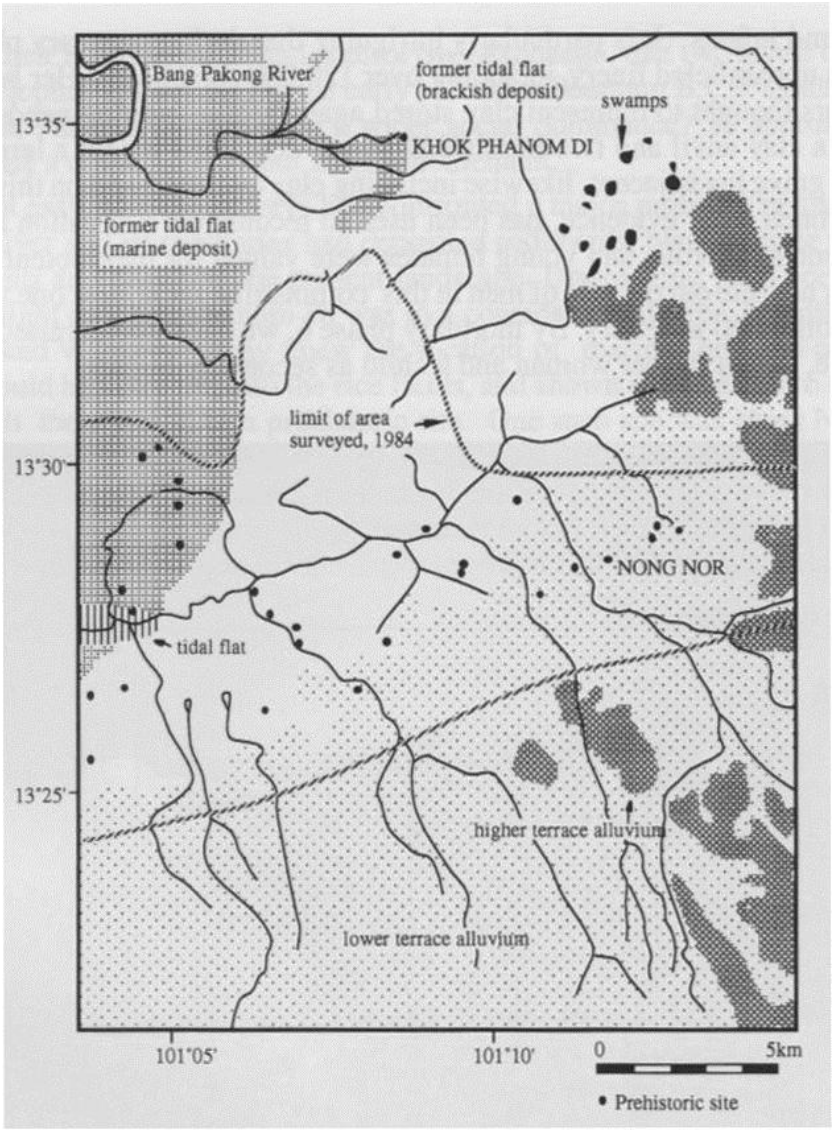


Figure 9 The Bang Pakong Valley survey area from Higham et al. (1998, 3)

Khok Phanom Di

In 1984-1985 a 10 by 10 metre area was opened up at a prominent mound, called Khok Phanom Di, up to a depth of seven metres. Although faunal and palynological remains indicate that it was once a mangrove or estuarine habitat with access to marine resources, Khok Phanom Di is now located around 20km from the Gulf of Thailand (Higham and Bannanurag 1990).

Excavations revealed eleven layers, the radiocarbon dates indicating occupation from c. 2000-1500 BC. Seven mortuary phases, representing about twenty generations, were uncovered. The burials were clustered in a highly structured manner that suggested the presence of kinship groups. Genetic analysis of the skeletons later provided evidence supporting this hypothesis (Higham 1996; Higham 2002; Higham and Bannanurag 1990; Higham and Thosarat 2004; Vincent 2004).

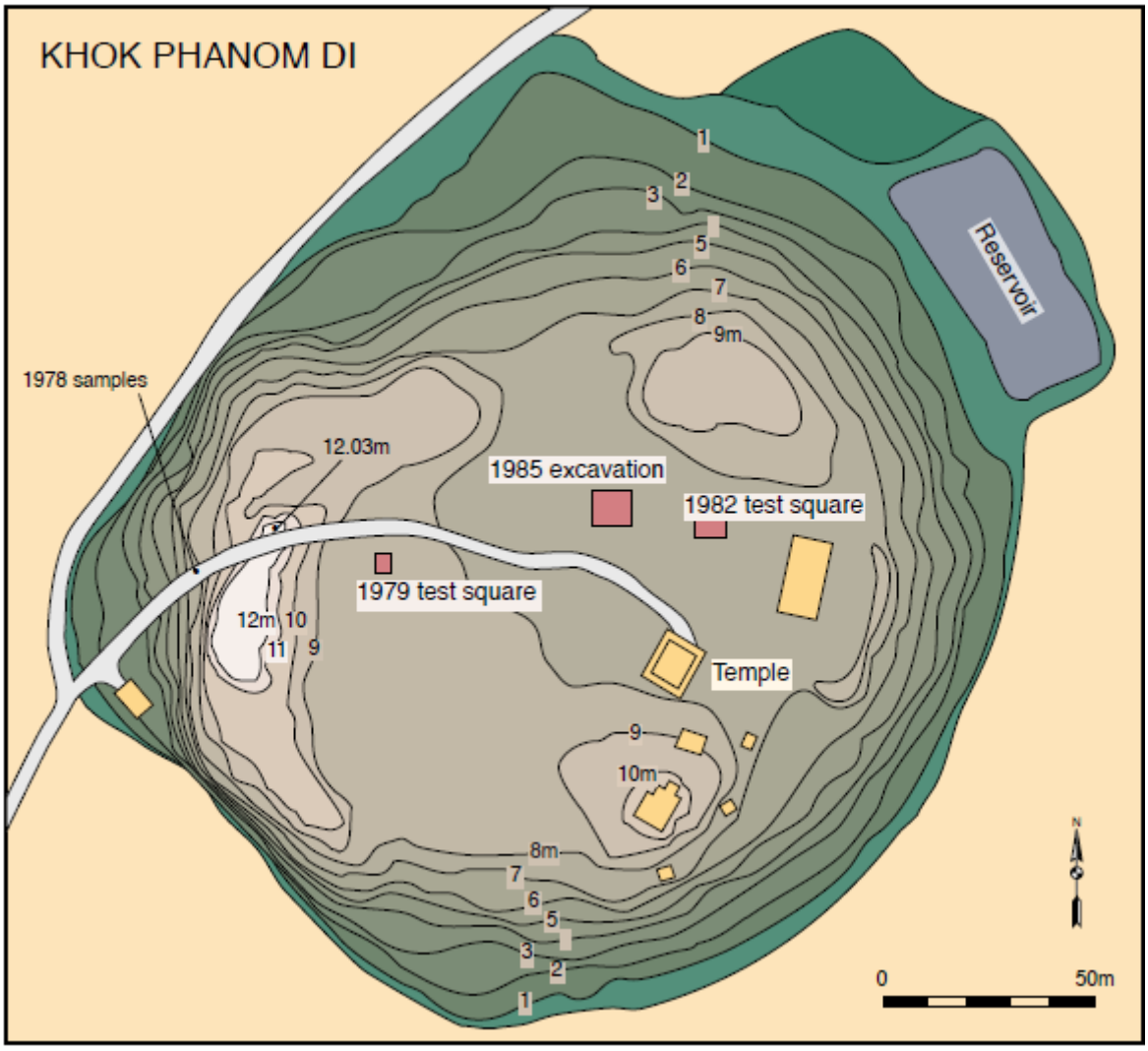


Figure 10 Map of Khok Phanom Di showing the location of excavations undertaken by the Origins of Angkor Project (Higham 2002, 57)

Faunal remains suggest that the inhabitants of Khok Phanom Di exploited a wide range of resources. From marine environments they obtained turtle and sharks, from mangal environments crabs and shellfish, and from terrestrial environments a range of birds and mammals like macaque, pigs and rodents. Halfway through the mortuary sequence the domestic dog was introduced. From initial settlement, situated in an estuarine and coastal environment, it is suggested that subsistence oscillated from marine to freshwater, back to marine, and finally to dry-land conditions (see Table 2). The saline conditions at Khok Phanom Di prevented rice cultivation until the fourth of the seven mortuary phases, but interestingly, rice was retrieved from all the layers and may have been an established resource by c. 2000 BC. For example, rice chaff, as well as the remains of freshwater fish, were found in the pelvic region of a small woman (burial 56, see Figure 11). “At Khok Phanom Di we

find that rice was consumed virtually from initial settlement despite the most unresponsive environment for its local cultivation" (Higham 2002, 111). The most likely scenario is that there was trade or exchange with inland farming communities for marine resources or possibly ceramics. It has been suggested that Khok Phanom Di may have been one of the largest centres of ceramic production in Central Thailand (Higham 2002; Higham 2008; Higham and Bannanurag 1990; Higham and Bannanurag 1991; Higham and Thosarat 2004; Vincent 2004). Salt was yet another potential trading commodity. Along with salted fish it would have been a valuable resource for exchange with inland communities, and also fits the ceramic vessel evidence (Vincent 2004). Wood is also found preserved in some post holes at Khok Phanom Di, which increases the likelihood of the survival of other organic material, such as residues, at this site (Higham 2002).

Table 2 Mortuary Sequence at Khok Phanom Di, showing the environmental conditions and diet of different phases. From Bentley et al. (2007, 303). All sherds analysed are from mortuary phase 2-4, c. 1800-1600 BC

Mortuary Phase	Date (cal BC)	Number of Burials	Diet	Environmental Conditions
1	1900-1850	6	Marine fish, shellfish, crabs	Estuarine-coastal mangrove
2	1850-1800	55	Marine fish, shellfish, crabs	Estuarine-coastal mangrove
3A	1800-1750	23	Marine fish, shellfish, crabs	Estuarine-coastal mangrove
3B	1750-1700	20	Increasing freshwater fish, rice	Freshwater ponds, lakes
4	1700-1650	29	Increasing freshwater fish, rice	Freshwater ponds, lakes
5	1650-1600	4	Marine	Estuarine-coastal mangrove
6	1600-1500	12	Marine	Estuarine-coastal mangrove
7	ca.1500	5	Marine	Estuarine-coastal mangrove



Figure 11 Food remains, including rice chaff and freshwater fish remains, found in the abdominal region of burial 56 at Khok Phanom Di, from Higham (2002, 80)

Nong Nor

Nong Nor (Figure 12) is a shallow midden and cemetery site situated 14 km southeast of Khok Phanom Di and about 25 km from the Gulf of Siam. It was excavated during the Bang Pakong Valley Research Project over three seasons, from 1991-1993.

The deepest and most complex layer is only 1.6m below the surface, and the site is estimated to be about 700-100 m^2, about half of which has been opened (Higham 2002; Higham 2004; Higham et al. 1998; Vincent 2004).

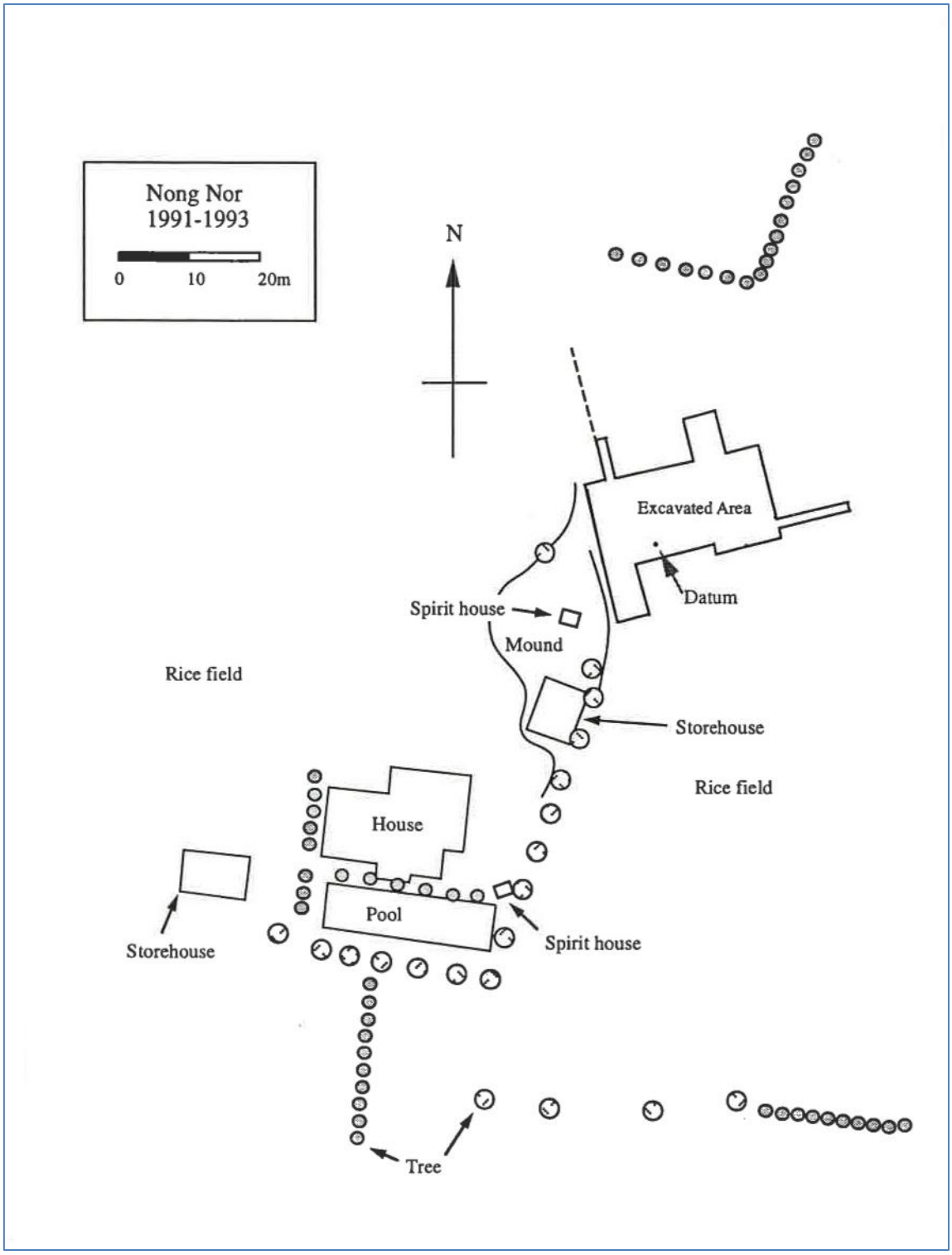


Figure 12 Map showing the excavated area and surroundings of Nong Nor, from Higham et al. (1998, 5)

Initial occupation was represented by a shell midden (Figure 13) dated to around 2450 BC, preceding the occupations at Khok Phanom Di. The site is thought to have been inhabited for only a matter of months. The later Bronze Age cemetery cut into the midden, and is dated to around 600-500 BC, the two occupations bracketing the occupation of Khok Phanom Di.

One hunter gatherer burial from the initial phase and 155 Bronze Age graves were uncovered. No evidence of Bronze Age habitation was discovered, leading to the suggestion that Nong Nor was a separate cemetery site. Copper-based artefacts showed that exchange with the nearby Khao Wong Prachan Valley was being undertaken (Higham 2002; Higham 2004; Higham et al. 1998).

Similar to Khok Phanom Di, Nong Nor during the third millennium BC was a coastal site, with access to estuarine resources and the open sea. In the initial phase, small fish remains and microgastropods formed a large part of the faunal remains, although large marine species such as bull and tiger sharks, eagle rays, turtles and dolphins are also present. The mammalian bones in the Bronze Age phase were dominated by bovid species. Other domesticates, including pig and dog, are present, and rice cultivation was carried out (Higham 2004; Higham 2006b; Higham et al. 1998).



Figure 13 Section Q/R 1-26 from Nong Nor showing dense concentration of shell midden found in the initial occupation phase, from Higham et al. (1998, 8)

Sites Summary

Despite their diverse locations, environments and periods of occupation, the four sites have many archaeological features in common. All were involved in some form of long-distance exchange. As well as rice, exotic tridacna shell jewellery and ivory were interred

during the fifth mortuary phase of Khok Phanom Di, exotic stones such as serpentine, jade and carnelian were found at Nong Nor, while exotic shell and marble ornaments were found at Ban Non Wat (Higham 2002, 74).

These items, as well as ceramics and a variety of faunal remains, are all common mortuary offerings found throughout the archaeological phases (Higham 2006; Higham and O'Reilly 2004; Higham and Thosarat 2006). One interpretation of these remains, as well as the many vessels which accompany them, particularly at early Bronze Age Ban Non Wat in large numbers, and the associated faunal material, is that they were used in elaborate mortuary feasting.

In addition to these similarities, all four sites are located in monsoonal sub-tropical climates, which are not ideal for the preservation of organics (Evershed 2008). As well as great time-depth, any possible food residues will all have been exposed to extreme humidity, seasonal flooding and fluctuating sea levels. The most likely place that organic matter may have survived is absorbed into the matrices of porous ceramic vessels.

The Ceramics

The sherds used in this thesis were sourced from ceramic vessels excavated at the four sites just described. Unintentionally, each site, to a degree, also represents an archaeological phase. Samples from Khok Phanom Di correspond to the marine hunter gatherers, those from Nong Nor to the Bronze Age, and samples from both Ban Non Wat and Ban Salao are from the Iron Age. In Figures 14 to 16 the ceramic forms encountered at Khok Phanom Di, Nong Nor and Ban Non Wat are displayed. Very few complete vessels were encountered at the single season of excavation at Ban Salao, but these are typical of the globular forms encountered in the Iron Age at Ban Non Wat and are exemplified by the vessel in Figure 17.

The vessels are classed according to their morphological features. These may reflect their past use. For example, large vessels with wide openings are suggested to have been used for cooking, those with narrow openings for storage of liquids, and some flatter 'plate'-like vessels are suggested to have been used for display purposes (Regert 2007). Technological features are also taken into consideration. For example, non-mortuary ceramics at Khok Phanom Di are generally more crudely made, and their walls and bases are often thicker than normal wares. It has been suggested that this may have been an attempt to reduce the effects of thermal stress, and that these vessels may have been used in cooking (Vincent 2004).

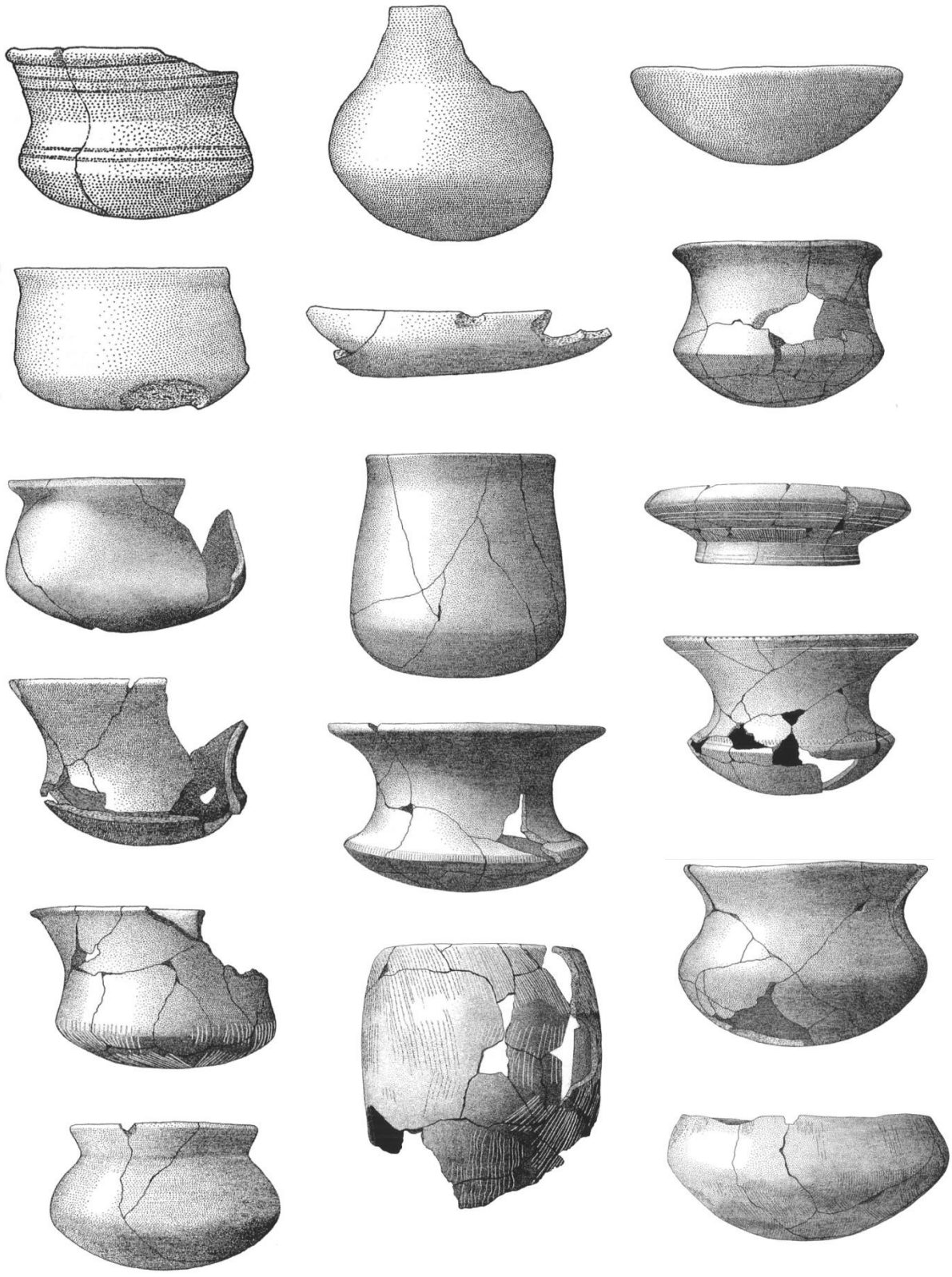


Figure 14 A sample of ceramic forms excavated from Khok Phanom Di, from Vincent (2003)



Figure 15 A sample of ceramic forms excavated at Nong Nor, from Higham et al. (1998).

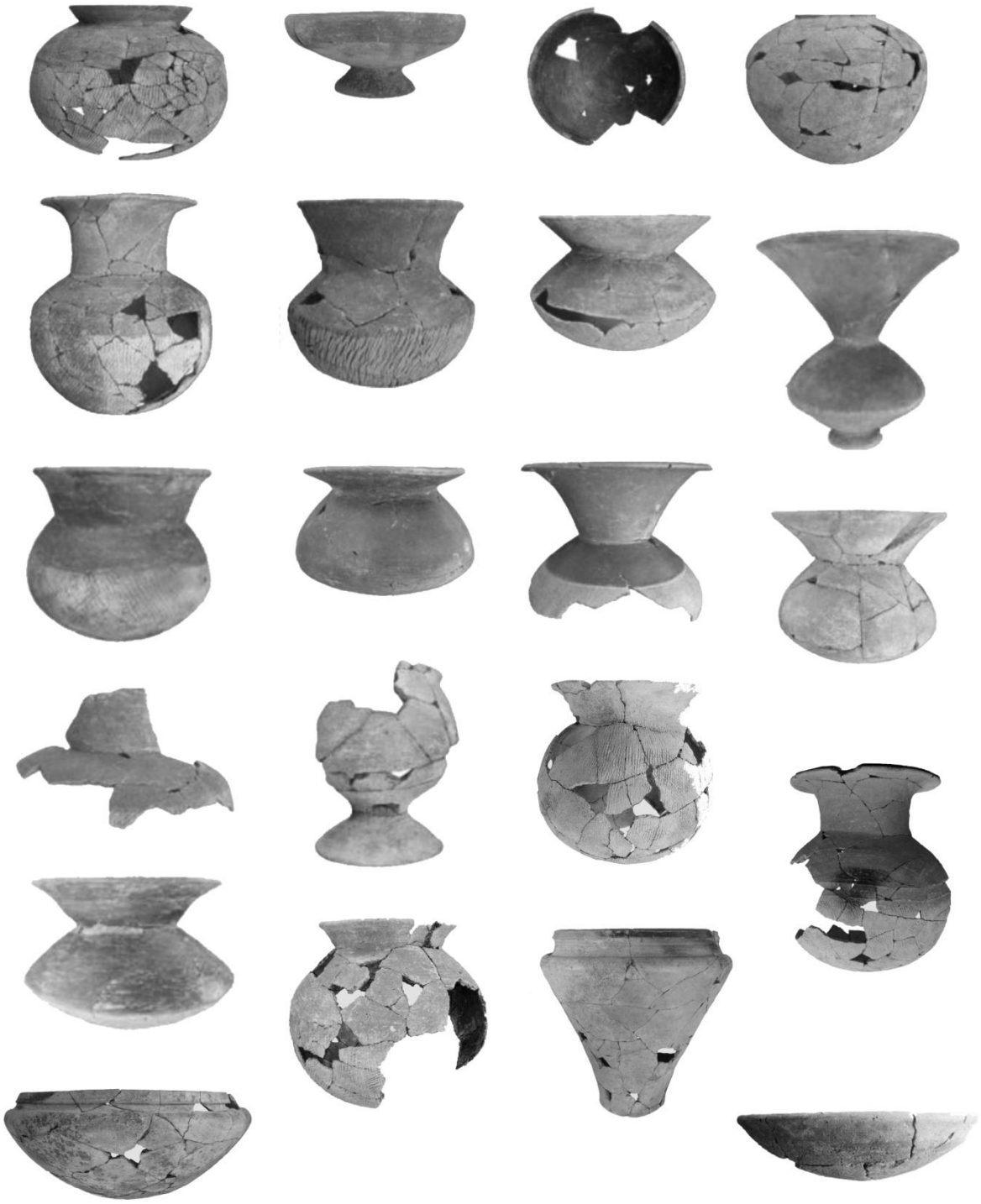


Figure 16 A sample of ceramic forms excavated from Ban Non Wat, from (Higham pers. comm. and Sarjeant 2008).



Figure 17 Typical rim and vessel form for ceramics encountered at Ban Salao during excavation (from Cawte 2010)

Mortuary Feasting

> "All around the castle was a scene of busy commotion; for such funeral banquets were a time of general and profuse hospitality, which not only everyone who could claim the most distant connection with the deceased, but all passengers whatsoever were invited to partake." *Ivanhoe* (Scott 1821, 212)

Feasting is a subject which has become increasingly important to studies of past and present societies. It has been recognised that feasts play an important role in establishing, or manoeuvring, economic, political and trade relationships, and maintaining social interactions between different kinship groups and villages. They are common among all strata of society, and are used to mark major life events and auspicious occasions (Jennings et al. 2005; McGovern et al. 2004; Renfrew and Bahn 2000). "Feasts are sensuous events that put people in favourable moods and dispositions (often with the aid of intoxicants)... [They] are pregnant with symbolism... [and] to reaffirm or alter others' attitudes and relationships towards specific people... then one must appeal to their emotions and attempt to influence the guests' and supporters' emotions" (Hayden 2009, 37). Death and grief are aspects of life that profoundly affect people's emotions, and are, for this reason, ideal for manipulating social positions (Hayden 2009).

Despite their economical irrationality, lavish funeral feasts are a common occurrence in contemporary Southeast Asia (Hayden 2009). Families willingly put themselves into, sometimes crippling, debt to put on a suitably impressive feast. Feasts are a means for families or communities to display their wealth, success and power to other groups. In parts of Thailand Hayden (2001) found that domestic stock ownership was more likely to be linked to a display of wealth or status, than to other reasons such as farming, forest clearing, or being a regular feature of the diet. In some modern examples of funerary feasts, the deceased remained unburied until a suitable food and alcohol surplus had been amassed. Alternatively, the deceased was exhumed and reinterred when the feast was ready to be given (Hayden 2009). Elaborate ceremonies are a reflection of the wealth and success of a family group or community, and there are ethnographic examples of funeral ceremonies wildly beyond the social status of the deceased (Hayden 2009; Pearson 1999).

Archaeological evidence of feasting can include the faunal remains from the food consumed, or the vessels used to store, prepare and present the food and drink, especially if highly decorated (Hayden in Siferd 2009). The Thai mortuary ritual includes sometimes large numbers of vessels suggested to have been used for food or intoxicants in association with faunal remains, and may be indicative of funeral feasting in the past. Higham (in Hauman 2009) has suggested that vessels of a particular form with a broad-trumpet rim, common to burials of the early Bronze Age in Thailand, may have been used as wine containers at funerary feasts. Serving vessels, often elaborately decorated, are also very common to mortuary contexts. For example, open pedestaled-bowls, which may have been used to serve food, are found at Nong Nor (Higham et al. 1998).

At Liangchengzhen in China, McGovern et al. (2005) identified residues of a fermented beverage of mixed origin, including rice, from vessels thought to have been used in rituals. McGovern et al. (2005), as well as Lanehart et al. (2011), have suggested that this find, as well as the presence of some very large vessels, is indicative of social and ritual feasting. Increased mortuary feasting activities in residential periods during the Dawenkou and early-middle Longshan periods increased demand for prestigious foods, beverages and vessels. In turn, this may have played a role in the increasing stratification seen at this time (Underhill 2002 in McGovern et al. 2005).

Food and beverages would have been liberally consumed at many feasts, and the sponsor would have had to face the problem of amassing huge amounts of both in the days preceding the occasion (Jennings et al. 2005). For example, modern rice beer needs 10 kg of rice to make 13 to 15 average sized bottles. At large feasts guests can consume up to 3,000

litres of beer, and to supply this 1-1.5 metric tons of surplus rice would have to be assembled (Hayden in Jennings et al. 2005, 291). This shows that feasts are "above all, concerned with surpluses, their production, use, transformation, control and distribution" (Hayden 2001, 39).

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Summary

In the first part of this chapter the environmental and climatic factors affecting subsistence in prehistoric Southeast Asia were described. A general subsistence strategy was outlined for the Neolithic, Bronze Age and Iron Age in Thailand, supported by a variety of archaeological evidence. A summary of the main fish species found in ceramic vessels was also given.

In the second section the two regions, the Khorat Plateau and the Chao Phraya Plains, and four sites, Ban Non Wat, Ban Salao, Khok Phanom Di and Nong Nor, were described. Some similarities between the sites were summarised, the ceramic assemblages presented, and then theories of mortuary feasting were introduced.

In the next chapter the chemistry behind residue analysis is explained.

CHEMICAL ANALYSES

> "Chemistry is a subject of immense potential value to archaeologists... The reader who has long been a stranger to the principles of chemistry may be – understandably – a little afraid of this section at first. However, he will find little in it to daunt him" (Goffer 1980, 2)

There are many archaeological applications for chemistry. These range from radio-carbon dating through to techniques used to conserve and repair artefacts, and also to the analysis of residues found on ceramics and stone tools. This section of the literature review begins with a brief introduction to the chemistry relevant to the study, and then introduces lipids and fatty acids, and isotope studies. The methods involved in gas chromatography, mass spectrometry and isotope ratio mass spectrometry are also described.

Introduction to Chemistry

Chemistry is the study of matter, both that which occurs naturally and is used by humans in its original state, and that which is altered in some way before its use (Goffer 1980). All matter is made up of elements, which are in turn made up of nearly identical atoms. Atoms have, within their nucleus, protons which are positively charged and neutrons with no charge. Outside the nucleus are negatively charged electrons, arranged in concentric rings, in numbers equal to the protons (Goffer 1980, 9-12).

The physical properties of an atom are determined by the number of protons, which is also its atomic number, while the chemical properties are determined by the behaviour of the electrons in the outermost ring (Goffer 1980, 14-15). One can use this information to identify the chemical composition of a mix of compounds using gas chromatography (GC) and mass spectrometry (MS). GC separates the various compounds into identifiable components, while MS can identify the resulting elements and discern their relative abundances, as well as their various isotopes (Eerkens and Barnard 2007; Goffer 1980; Lambert 1997). Isotopes are atoms which have the same atomic number (the same number of protons and electrons) but different numbers of neutrons. This means that the chemical properties of isotopes are the same because the charge of the atom is not affected by the addition or subtraction of neutrons, but extra neutrons make the atom 'heavier' which means some isotopes will react more slowly

than others (Goffer 1980, 55). All elements have at least one isotope, and often more. Out of the 3100 discovered nuclides, however, there are only 283 isotopes which do not undergo radioactive decay and are therefore considered 'stable' (Fry 2006, 7). It is this stability over time that makes these isotopes suitable for ecological and ancient isotope analysis (Fry 2006, 8). Isotopic studies are examined in more detail below, but first a more general introduction to the field of residue analysis is provided.

Lipids

The most commonly studied lipids are fatty acids, which are made up of strings of carbon with an acidic carboxyl (-COOH) group at one end of the molecule (Barnard et al. 2007). The most common fatty acids in plant and animal lipids are straight chain carboxylic acids, C x:y where x is the number of carbons and $_y$ is the number of double carbon-carbon bonds (Spangenberg et al. 2006). Short and medium length chain fatty acids ($C_{4:0}$- $C_{14:0}$) are more water soluble and volatile, so in waterlogged contexts degraded fat is likely to be identified by high concentrations of longer chained fatty acids, for example palmitic ($C_{16:0}$) and stearic ($C_{18:0}$) acids (Spangenberg et al. 2006). Unsaturated and poly-unsaturated fatty acids (those with more than one double bond between carbons) are present in higher quantities in food and material of a vegetable origin than those of animal origin. Dicarboxylic (mono-unsaturated) fatty acids are also found more abundantly in oils and fats of vegetable origin (Barnard et al. 2007). To enable lipids to pass through a gas chromatograph (GC) one has to make them less polar, and more thermally stable. This is accomplished through a process called derivatisation which replaces the hydrogen in the COOH-group with a non-polar group (Barnard et al. 2007).

Isotopic Analysis

> "Reading isotope studies about ancient humans will convince you rapidly that food has always been a centrepiece of human ecology and culture" (Fry 2006, 57).

Isotope analysis is not only important to residue analysis, but is integral to many other studies such as radiocarbon dating, which deals with the heavier radioactive isotope of carbon, ^{14}C (Fry 2006, 10). Isotopes have already been described above as forms of an element with

the same atomic number (number of protons and electrons) but different numbers of neutrons. The main isotopes used to trace elements cycling in the environment are hydrogen, carbon, nitrogen, oxygen and sulphur. Each of these elements has two or more isotopes, and together they make up the majority of the organic mass on Earth (Fry 2006, 9).

There are large source pools for isotopes in the biosphere. For instance, the ocean is an important source for hydrogen, oxygen, carbon and sulphur, while nitrogen has an atmospheric reservoir. All of these pools are part of much larger geochemical reservoirs, which circulate on a geological time scale (Fry 2006, 41). While there could be an infinite number of ways that isotopes can react with each other, there are characteristic isotope value patterns. For carbon, nitrogen and sulphur the reasons for this include the large isotope reservoirs in the ocean and atmosphere, as well as a "few key enzymes involved in resource uptake, and common ecological stoichiometries that link together organic matter cycles" (Fry 2006, 42). Pulsed events, such as storms, seasons and increased pollution can affect the cycling isotope patterns.

The isotopes of carbon and nitrogen are those most often used in trying to understand food-webs. Carbon is useful in isotopic analyses as it shows whether an organism gets its main dietary protein from a marine or a terrestrial source. Carbon can also differentiate between the consumption of C_3 and C_4 photosynthetic pathway plants, as C_3 plants, such as trees, shrubs and many grasses, absorb less ^{13}C than those which use C_4 pathways, such as corn, sugarcane and dry-land grasses (Hu et al. 2009). Nitrogen can be used to distinguish where on the food chain a particular organism sits (its trophic level), and, together with carbon, can reveal the intricacies of food-webs. Essentially, isotopic analysis proves that you are, in fact, what you eat (Beehr and Ambrose 2007).

Two concepts important to understanding the actions of cycling isotopes in nature are mixing and fractionation. Mixing is simply the combining of different isotopes into a homogeneous whole, while fractionation, in essence, separates the isotopes for the mixing process (Fry 2006, 12-13).

> "Isotopes function as natural dyes or colors, generally tracking the circulation of elements. Isotopes trace ecological connections at many levels, from individual microbes to whole landscapes. Isotope colors mix when source materials combine, and in a cyclic process that ecologists can appreciate, the process of isotope fractionation takes the mixed material and

> regenerates the sources by splitting or fractionating the mixtures." (Fry 2006, 40).

The extra neutron(s) in the nucleus of heavier isotopes generally slows down their reaction, so that in forward-moving reactions the end product is higher in lighter isotopes, with fewer neutrons. In exchange reactions, however, where reactions occur in both forward and backwards-directions, heavy isotopes will concentrate where the bonds are strongest, and an equilibrium will eventually be reached (Fry 2006, 12).

These effects are very subtle, and the differences between samples are very small, hence stable isotope measurements are most commonly expressed in δ values. The δ notation uses ratios to express parts per thousand difference from a standard (Beehr and Ambrose 2007). The higher the δ value the greater the amount of heavy isotope. The lower the δ value the lower the amount of heavy isotope (Fry 2006, 22). The equation used to express a sample's δ value is:

$$\delta^{H}\chi=[(R_{SAMPLE}/R_{STANDARD}-1)*1000$$

where χ is the element, H is the heavy isotope mass of the element, and R is the ratio of heavy to light isotopes for the element (e.g. for hydrogen 2H:1H). Multiplying by 1000 converts the result into parts per thousand, or per mil (‰) (Fry 2006, 22-3). Most δ values fall between -100 and +50‰ in the natural world, the majority of which are negative δ values (Fry 2006, 23). This does not mean that there are few or negative isotopes in the sample but rather that there are relatively less heavy isotopes in relation to the standard, the δ value of which is 0‰. Higher δ values indicate that the sample has more heavy isotopes in relation to the standard (Fry 2006, 24).

The δ notation is useful in isotope studies because it uses simple algebra to calculate mixing and fractionation, and the results obtained are accurate to the level of most experimental data (Fry 2006, 26). Fractionation occurs during reactions, and is denoted in equations by the Greek symbol 'Δ'. Δ values reflect the net balance of fractionating, or losses, and source mixing, or gains, not mixing alone (Fry 2006, 77, 115). It is generally accurate and simple enough to apply to all situations, and is widely used by isotope scientists. For example C_3 plants, including rice, have a lower $\delta^{13}C$ value ranging between -34‰ and -22‰, and an average of -28‰, than C_4 plants, like millet, which have higher values ranging between -16‰ and -9‰, and an average of -13‰. These distinctions occur during

photosynthesis, when carbon atoms form either 3-carbon or 4-carbon pathway sugars when forming new chemical bonds. When a C_3 plant fixes CO_2 during photosynthesis, a difference, or fractionation, of 20‰ occurs between the source atmospheric CO_2 (-8‰) $\delta^{13}C$ and the -28‰ of the plant sugar fixed in tree leaves formed from the CO_2 and therefore, in this case, Δ=20‰ (Fry 2006, 27, 63). There is an increase of 1 to 2‰ from a consumer and its food source, so that if an animal's ^{13}C signature is close to -12‰ it is likely subsisting on C_4 plants, whereas if it is lower than -22‰ it will probably subsist on C_3 plants (Spangenberg et al. 2006).

It is important to remember that isotopes will never be a perfect form of scientific evidence, and it is better to use multiple lines of enquiry and see how the isotope results fit into this broader approach (Fry 2006, 159). Isotope analysis is very useful in determining what a residue might be made of through establishing the geographical origin, trophic level and main subsistence of the organisms making it up.

Methods

Gas Chromatography (GC)

GC is an important method in residue studies because it easily separates molecules in a complex biological or environmental sample so that they can be analysed and then identified (Barclay 2001; Eerkens and Barnard 2007; Evershed 2008). It works on the basis that different molecules in a mixture will travel at a different rate to others through an absorbent surface where, eventually, they settle (Barclay 2001). GC has two phases: first a mobile phase that transports the sample components to where they are detected, and a stationary phase where the various components are retained at differing rates, depending on their individual boiling points and strength of their interaction with the stationary phase (Barnard et al. 2007). The GC machine (see Figure 18) consists of a coiled glass column which is usually 15-60 metres long, 0.1-0.5 mm thick and has a steady flow of inert gas (typically helium or nitrogen) maintained throughout. This is the mobile phase. On the inside, the column is coated with a thin layer of liquid or polymer on a solid support to which some molecules will be attracted. This is the stationary phase. The beginning of the glass column is attached to an evaporation chamber and the sample inlet. The temperature is carefully controlled by keeping the column and sample inlet in an oven. The end of the column is connected to a detector where the abundance of emerging molecules are recorded, or to the inlet of the mass spectrometer (MS),

where what is present in the sample and in what quantities or proportions can be determined (Barclay 2001; Barnard et al. 2007).

Mass spectrometry (MS)

MS describes a variety of techniques that are used to measure the mass of molecules or, rather, the mass to charge ratio (m/z – the mass of a particle divided by its charge) of their ions (Barnard et al. 2007). The main principle of mass spectrometry separation is inertia. In other words, gas molecules with extra neutrons, which have heavier molecules, will need more force to displace them from their path of flight. Therefore, their flight paths are straighter than lighter isotopes, which need less force to change their direction (Fry 2006 29). Mass spectrometers (see Figure 18) all consist of three components: a sample inlet, where the molecules are ionised; a mass analyser, where the ions are separated according to their m/z; and a detector. Molecules that do not decompose completely when ionised are not analysed (Barnard et al. 2007). Ions of different masses separate after ionisation due to the difference in the behaviour of their electro-magnetic fields inside the mass analyser. These are kept at a high vacuum to avoid the collision of ions in the sample with other molecules (Barnard et al. 2007). The current, which is created through the amplification of the impact of single ions, is measured and the relative frequency of each m/z during a pre-determined time is plotted on a mass spectrum (Barnard et al. 2007). As the mass of a molecule is the sum of the mass of all atoms within it, it is the m/z and not the mass of a molecule which determines whether or not an ion is recorded. Each peak in a chromatogram is at least one molecule in a sample and the mass spectrum can be created from each peak. Mass spectra of unknown compounds can be electronically compared with spectra of known compounds in a digital library (Barnard et al. 2007). By this means, the compounds within a sample can be identified.

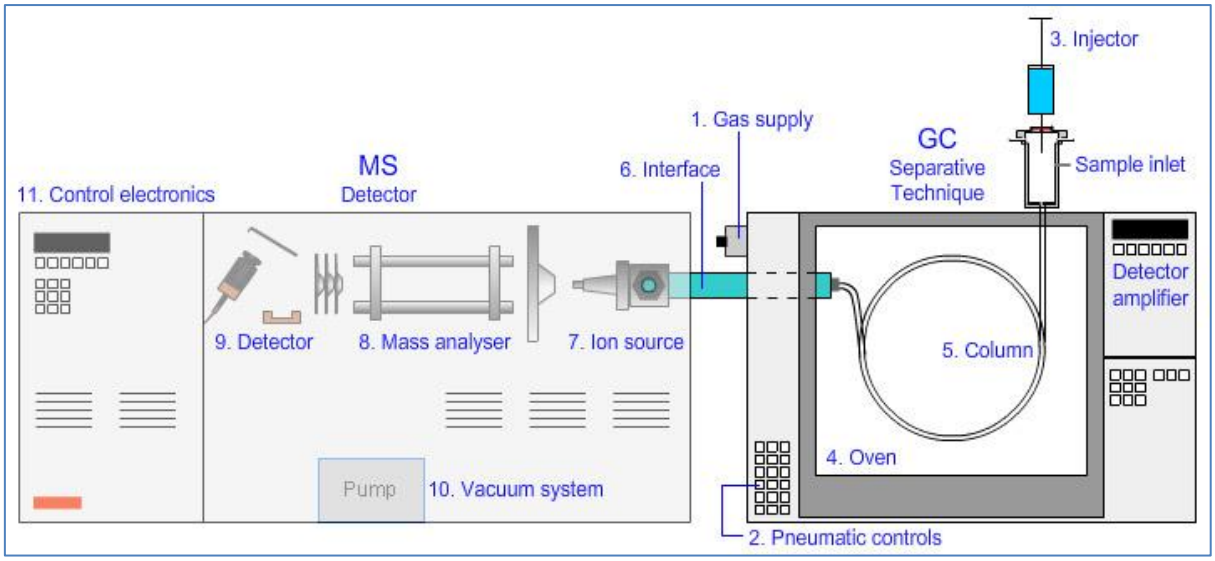


Figure 18 Schematic drawing of a typical GC-MS. From http://www.chromacademy.com

Isotope Ratio Mass Spectrometry

A slightly different mass spectrometer is used to determine the isotope ratios of a sample (Figure 19). Measuring the isotope ratio of individual residue components is achieved by first separating the components using a GC as described above. The sample must then be converted into a gas. For example, to determine the ratio of carbon $^{13}C/^{12}C$ isotopes in a sample, the sample would be oxidised to carbon dioxide (CO_2). The effluent from the GC is passed through a micro combustion column that converts the compound to CO_2, which is then passed directly to the sample inlet of the mass spectrometer for measurement. The carrier gas stream containing the CO_2 is admitted to the sample inlet of the mass spectrometer where some molecules (about one in a thousand) are ionised and accelerated through a magnetic field. The magnetic field deflects the path of the ion and the extent of deflection depends on its momentum, i.e. its mass. An isotope ratio mass spectrometer (IR-MS) has several collectors that are arranged to measure the amounts of several masses simultaneously. For CO_2 you would monitor masses 44 ($^{12}C^{16}O^{16}O$), 45 (mainly $^{13}C^{16}O^{16}O$) and 46 (mainly $^{12}C^{18}O^{16}O$). These measurements allow the ratio of $^{13}C/^{12}C$ in the original sample to be determined. By this means very small quantities of a compound can be analysed. Typically it requires 50 ng of carbon on the column for a measurement (Evershed et al. 1994).

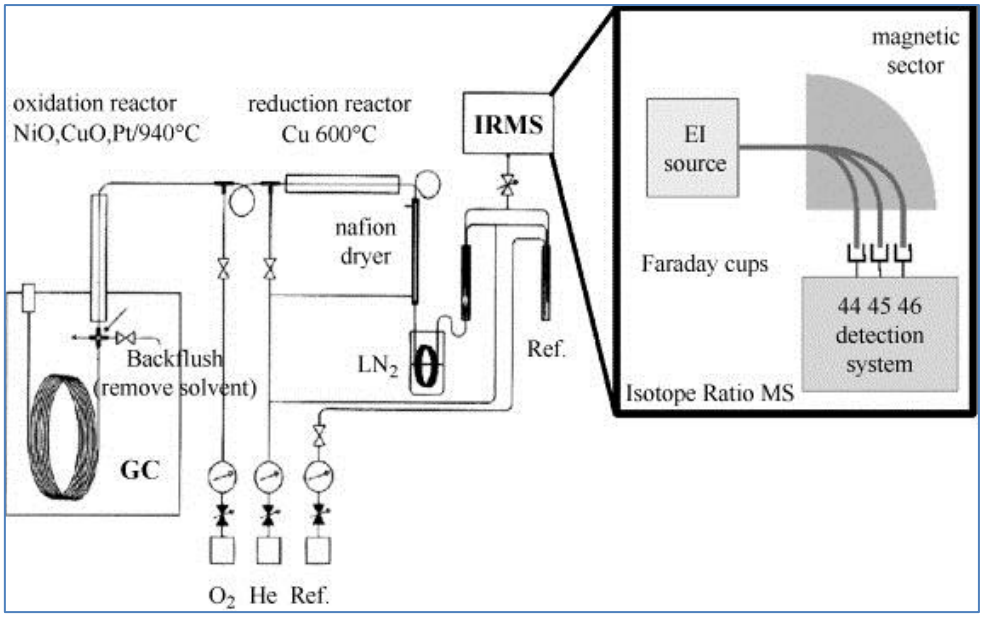


Figure 19 Diagram of an isotope ratio mass spectrometer coupled to a gas chromatograph (GC-IRMS). The IRMS schematic shows the cups configured to measure $^{13}C/^{12}C$ isotope ratios, from Meier-Augenstein (2002).

Summary

This chapter briefly introduced some basic chemistry necessary to understand this study, before describing lipids. Isotopes, their place in the environment and how stable isotopes are used to understand food-webs were introduced. The methods involved in gas chromatography, mass spectrometry and isotope ratio mass spectrometry were explained. The next chapter describes the methodology utilised in this study.

METHODOLOGY

To achieve the objectives outlined in the introduction, suitable methods for the collection of appropriate samples and the subsequent analyses were required. The data to be collected was the ratios of the different fatty acids extracted from the samples, together with the stable carbon isotope compositions of these fatty acids. The following were the methods employed.

Samples

Sample Selection

The sampling strategy employed in this analysis was based upon availability. Sherds selected for analysis were from pots excavated at Ban Salao, Ban Non Wat, Khok Phanom Di and Nong Nor in Thailand. The sherds from Ban Salao were excavated during the 2009-2010 season, and those from Ban Non Wat during the 2008-2010 seasons. The sherds from Khok Phanom Di and Nong Nor were excavated in 1984-1985 and 1991-1993, respectively, and have since been kept in storage in the Department of Anthropology and Archaeology at the University of Otago. Sherds from Khok Phanom Di and Nong Nor were selected for analysis only if context information was available. It is unclear from where in the pot these sherds were collected. Where possible, following the method of McGovern at al. (2005), Ban Non Wat and Ban Salao sherds were collected from the base of the ceramic vessel. In some cases, however, it is also uncertain from which part of the pot the sherds were from. Most sherds analysed were from the body, the rims being too large to fit into the extraction glassware.

Sample Preparation

In New Zealand the sherds selected for analysis were at all times handled wearing disposable gloves to prevent, or at least minimise, contamination. In the Department of Chemistry at the University of Otago all sherds were gently brushed to remove any adhering dirt and then, in the case of the sherds which were being extracted whole, were placed into Soxhlet thimbles. In the case of sherds which were allowed to be broken, the sherds were ground to a fine powder using a mortar and pestle obtained from the Department of Anthropology and Archaeology. In between uses the mortar and pestle were soaked in Pyroneg (Diversey New Zealand Ltd), a mildly alkaline detergent, scrubbed and thoroughly dried in an oven. The resulting particles were put into Soxhlet thimbles with glass wool

placed on top, both to prevent fragments getting caught in the glassware and to prevent the solvent from dripping through the same avenue of the powdered sample. The soil samples were placed in Soxhlet thimbles with glass wool placed over the top for the same reason.

Extraction and Processing

Soxhlet Extraction Method

All successfully analysed residues were extracted using the Soxhlet method. The thimbles containing a whole sherd, ground sherd fragments or soil, were placed into a Soxhlet (Figure 20). This is a glass apparatus that allows solvent to rinse through the sample continuously, extracting any absorbed residues that may be present in the sample. Enough dichloromethane (DCM) was poured into the Soxhlet to empty through into the round-bottomed flask attached to the bottom, plus a little extra in case some solvent evaporated. This was approximately 150 mls. The Soxhlet and flask were then gently heated to around 40 °C, the boiling point of DCM, and left for 24 hours. The solvent cycled through the sample approximately every 15 minutes.

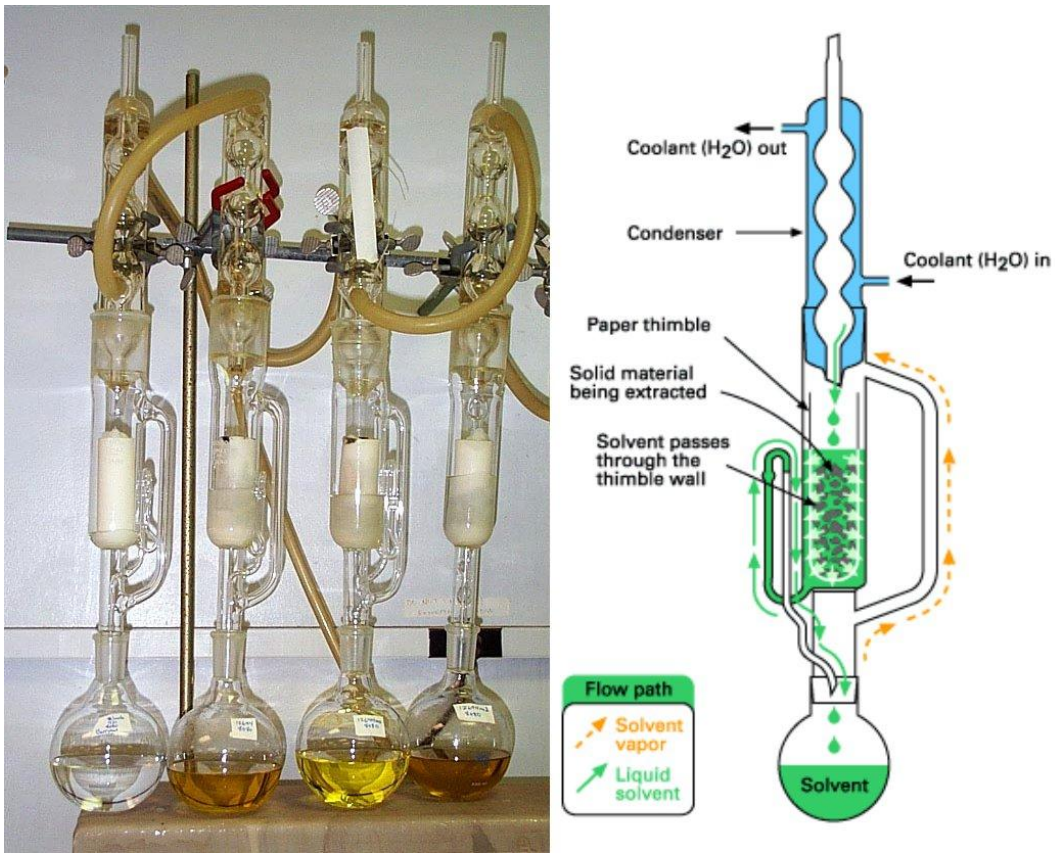


Figure 20 Image and diagram of a Soxhlet apparatus. From http://www.aquaculture.ugent.be

Clean up step (following Spangenberg et al. 2006)

After 24 hours the Soxhlet and flask were removed from the heat and the solution in the round-bottomed flask was evaporated down to a few ml using a rotary evaporator and water bath heated to 40 °C. The sample and remaining solvent were then transferred to a test tube. The solvent was evaporated under a stream of nitrogen (N_2) gas at 40 °C and 2000 µl of 1 M aqueous ethanolic potassium hydroxide was added to the dried samples. The samples were baked at 60 °C for three hours, the caps being tightened after twenty minutes to prevent the sample evaporating, and then cooled. The samples were then washed with hexane aliquots. 2000 µl of hexane was added to the samples which were vortexed for one minute, and the resulting layers allowed to separate. The hexane (top layer) was removed and dried down under a stream of N_2 gas at 40 °C and reconstituted with 1000 µl chloroform for n-alkane analysis. The fatty acid samples were again washed with 2000 µls of hexane, which was discarded this time; the bottom layer was transferred to another tube and then evaporated under a stream of N_2 gas at 40 °C.

Fatty Acid Methyl Ester (FAME) Preparation

500 µl of boron trifluoride methanol solution (BF_3/MeOH) was mixed thoroughly with the dried sample and the mixture was baked in the oven for twenty minutes at 70 °C to perform esterification of the sample. Alternatively, 3000 µl of 6% sulphuric acid in methanol was added and the samples were methylated by acid-catalysed transesterification at 80 °C for three hours. This process exchanges the organic group of an ester with the organic group of an alcohol. The former method, due to its shorter laboratory preparation time, was preferred. After cooling the samples to room temperature, 2000 µl of hexane was added to the sample and it was vortexed for two minutes. 1000 µl of distilled water was added to the sample before vortexing for a further minute. The layers in the sample were then allowed to separate. Using a pipette the top layer was transferred to another test tube and dried under a stream of N_2 gas at 40 °C. The bottom layer was discarded. Using a pipette, 700 µl of hexane was thoroughly mixed with the dried sample. The solution was then transferred to a small sealable jar and stored under refrigeration until gas chromatographic (GC) analysis took place.

Concentration

To improve peak detection, several of the extracted residue samples were concentrated in the Department of Human Nutrition, some after first analysis on the GC and some prior to this. The samples were evaporated under N_2 and reconstituted in 100 µl of hexane. The

samples were then put into v-bottomed inserts inside small sealable jars for GC analysis. In the case of n-alkane samples they were reconstituted in 100 µl of chloroform.

Analysis

Gas Chromatography Analysis

GC analysis was performed at the Department of Chemistry at the University of Otago on an Agilent Technologies 6850N Network GC System (Agilent Technologies, Santa Clara, CA, USA) equipped with a flame ionization detector. FAMEs were separated on an Equity-1 capillary column. The column used was a 30 m x 0.24mm fused silica capillary DB wax column with 0.25 µm film thickness. The carrier gas was hydrogen and the inlet temperature was 290 °C. The temperature programme consisted of a 3 minute isothermal at 30 °C and then ramped to 270 °C at 15 °C min^{-1} and after that at 5 °C min^{-1} to 290 °C. The FA peaks were captured using Dionex's Chromeleon software and were identified by retention time matching with commercially available FAME standards (NuCheck Prep, Elysian, Minnesota and Sigma, St. Louis, Missouri) provided by the Department of Chemistry. Peak identities were then confirmed by mass spectrometry. Peak areas were calculated and reported as percentage of total fatty acid (FA). FA notation describes the carbon chain length, followed by a colon and the number of double bonds. The position of the first double bond is specified from the methyl end (ω), with all subsequent bonds methylene-interrupted. Results of the GC analysis were transformed into a spreadsheet using a Microsoft Excel macro program.

Some of the samples were analysed at the Department of Human Nutrition, University of Otago. The hexane in which the FAMES were dissolved was evaporated under N_2 at 40 °C, and the FAMEs reconstituted in 45 µl of hexane. The FAMES were separated using a DB225 capillary column which was 30 m x 0.53mm long with a 0.25 µm film (Agilent Technologies U.S.A.). The analysis was performed on an Agilent Technologies 5890 GC equipped with an autosampler (HP7673) and Chem Station integration (all Hewlett Packard, Avondale, PA). The column oven was held at an isothermal temperature of 190 °C for 30 minutes. The chromatograms were captured using Hewlett Packard's Chem Station integration. FA peaks were identified by retention time matching with authentic standards – a composite standard made from commercially available methyl esters (NuCheck Prep, Elysian, Minnesota and Sigma, St.Louis, Missouri). Results of the GC analysis were transformed into a spreadsheet using a Microsoft Excel macro program.

N-alkanes were analysed using the same method as that outlined for the FAs, although appropriate reference standards were not available at the time of analysis.

Gas Chromatography-Isotope Ratio Mass spectrometry (GC-IRMS)

Compound specific $\delta^{13}C$ signatures were measured using a Trace Ultra gas chromatograph (Thermo, Milan, Italy) coupled to a Delta^{plus}XP isotope ratio mass spectrometer (Thermo, Bremen, Germany). The sample was introduced to the GC through a split/splitless injector (300 ºC, splitless) via a CombiPAL auto sampler (CTC, Zwingen, Switzerland). Compounds were separated using a BP-225 GC column (60 m, 0.22 mm i.d., 0.50 µm film; SGE, Melbourne, Australia). The initial temperature of the GC oven was 30 ºC, which was held for 3 min, before being raised to 270 ºC at a rate of 15 ºC/min then ramped to 290 °C at 5 °C/min^{-1}. The carrier gas was helium with a constant flow of 2 ml/min. To correct for instrumental drift, and to ensure that measured and true isotopic values agreed, a blend of three commercially available esters of isopropyl pentanoate C5:0, isopropyl nonanoate (C9:0) and methyl heneicosanoate (C21:0) (Penta manufacturing, Livingston, NJ, USA) were co-injected with each sample as an internal standard. Results for the carbon isotopes were calibrated against international standards, usually with a precision of ±0.1‰.

The raw result obtained from the GC-IRMS is the $\delta^{13}C$ of the methyl ester. The methyl ester is derived from the FA by addition of one carbon from methanol. To get the 'true' $\delta^{13}C$ of the FA, a correction needs to be applied based on a mass balance

$$\delta^{13}C_{methylester} = (\delta^{13}C_{fatty\ acid} * \frac{n-1}{n}) + (\delta^{13}C_{\ methanol} * \frac{1}{n})$$

Where n= the number of carbons in the methyl ester. To get the $\delta^{13}C$ of the FA, the equation is rearranged thus:

$$\delta^{13}C_{methylester} - (\delta^{13}C_{\ methanol} * \frac{1}{n}) / (\frac{n-1}{n}) = \delta^{13}C_{fatty\ acid}$$

In this study the methanol had a $\delta^{13}C$ value of -35‰.

Graphical Analysis

A bar graph comparing the relative amounts of eleven FAs across the three sites, a scatter-plot showing the results of the isotopic analysis, and all tables, were created using Microsoft Excel 2010.

Development of the method

Before any of the sherds were submitted to the extraction method detailed above some 'experimental sherds' were analysed to test that the method worked. A terracotta pot was purchased from Mitre 10 Mega in Dunedin and broken into several sherds. These were cleansed by boiling in water for ten minutes to minimise the effects of contamination through any handling they might have received. Four sherds were chosen for testing. One was covered in salmon basted in pesto. A second had freshly cooked rice placed on it. The sherds were separately covered in plastic wrap and then tinfoil, and then kept in a plastic bag to decompose at room temperature for two months (63 days). A third sherd was also put into the plastic bag, and over time absorbed liquid from one of the other sherds and was named the 'mystery' sherd. A fourth sherd was handled repeatedly by a number of people to determine if it was possible to detect traces of human contamination in any of the other sherds.

The food was left to decompose for 63 days, after which the sherds were washed with water to remove remaining traces of salmon or rice. The sherds were placed in a Soxhlet thimble and extracted using the Soxhlet method outlined above for 24 hours. The resulting solution was evaporated using a rotary evaporator and water bath at 40 °C and then split into two test tubes. The solution set aside for n-alkanes was dried under N_2 at 40 °C before adding 1000 µl of hexane and being stored in a small sealable jar. The solution intended for fatty acid analysis underwent the standard fatty acid methylation method carried out by the Department of Chemistry, University of Otago.

During analysis, the inlet of the GC column was contaminated by the salmon sample, which may have contained non-organic compounds. The column inlet was decontaminated and the practice samples were run again. This incident led, first, to the salmon and mystery samples being diluted 1000 fold, and then, to the development of a 'clean up step' based on Spangenberg et al.'s (2006) method, as outlined above.

Although the Soxhlet extraction method was successful, the size of the glassware restricted the number of sherds from Ban Salao and the later Ban Non Wat excavation seasons that could be analysed, as they did not fit in the extraction apparatus. Different methods of extraction were trialled with larger sherds to see if it would be viable to include them in the analysis, and these are set out below.

The first alternative method involved putting a sherd into a beaker and covering it with DCM. Tinfoil was wrapped around the lip of the beaker to create a seal, with a concave glass lid placed on top. The beaker and solvent were gently heated for 24 hours at 40 °C. The

condensate from the heated solvent was expected to extract residues from the sherd. After 24 hours the sherd was removed and the solution was evaporated using a rotary evaporator and water bath heated to 40 °C. The remaining solution was split into two test tubes, one for n-alkane analysis and the other to undergo FAME analysis.

In the second alternative method a sherd was put into a beaker and covered with DCM. The beaker was covered with tinfoil to avoid the solution evaporating. The beaker was then placed into a sonicated bath heated to 40 °C. The sherd was sonicated for five minutes. The sherd was removed and the solution transferred into a flask. The solution was then evaporated using the rotary evaporator and water bath heated to 40°C. The remaining solution was split into two test tubes, one for n-alkane analysis and one for FAME.

The third alternative method is exactly the same as the second but the sherd was sonicated in five minute cycles with a twenty minute break between each sonication. This cycle was repeated four times and the sherd was thus sonicated for twenty minutes in total. The sherd was removed from the beaker and the resulting solution was transferred to a flask and evaporated using a rotary evaporator and 40 °C water bath, and split into two test tubes for n-alkane and FAME analysis.

None of these methods proved as successful for the extraction of the archaeological residues as the Soxhlet method, so samples were restricted to those that could be ground, or were small enough to fit in the glassware. After it became clear that grinding the samples led to higher concentrations of extracted residues, all sherds that could be were ground into a fine powder.

The following chapter sets out the results of the chemical analysis, as outlined in the methodology above.

RESULTS

This chapter sets out the results of the chemical analyses carried out on archaeological sherds from Khok Phanom Di, Nong Nor and Ban Non Wat. First the fatty acids (FAs) and n-alkane results are described, followed by the results of the isotopic analysis.

Fatty Acids and N-Alkanes

After analysis by gas chromatography mass spectrometry (GC-MS), chromatograms were plotted from the results. FAs with peaks above one pico amp (pA) were at least double the height of the majority of background noise on the column, and so were considered most reliable for interpretation. A signal of this magnitude would not be suitable for analytical work, as it is below the limit of quantification, but was considered suitable for the qualitative requirements of the present work. Samples with all FA peaks below 1 pA, while still included in the analysis, were interpreted with caution.

The results for sample 2325 from Khok Phanom Di, which is representative of all of the FA peaks and chromatograms, are shown in Figure 21. The most prominent FAs are 16:0 and 18:0, with 16:0 relatively more abundant. 18:1n-9, 20:0, 20:1n9 and 20:4n6, as well as 14:0, are also found in this sample in quantities greater than 1 pA. There are several other FAs present in much smaller quantities, including the longer-chained fatty acids 22:0 and 24:0.

N-alkane samples were similarly analysed using GC-MS. It was not possible to identify the peaks, as a suitable n-alkane standard was not available at the time of analysis. The retention times were, however, recorded and are comparable among samples.

Figure 22 displays the results obtained for sample 1000 from Nong Nor, which is representative of all n-alkane chromatographic results. The peaks are temporally regular in their occurrence, and are similar in size.

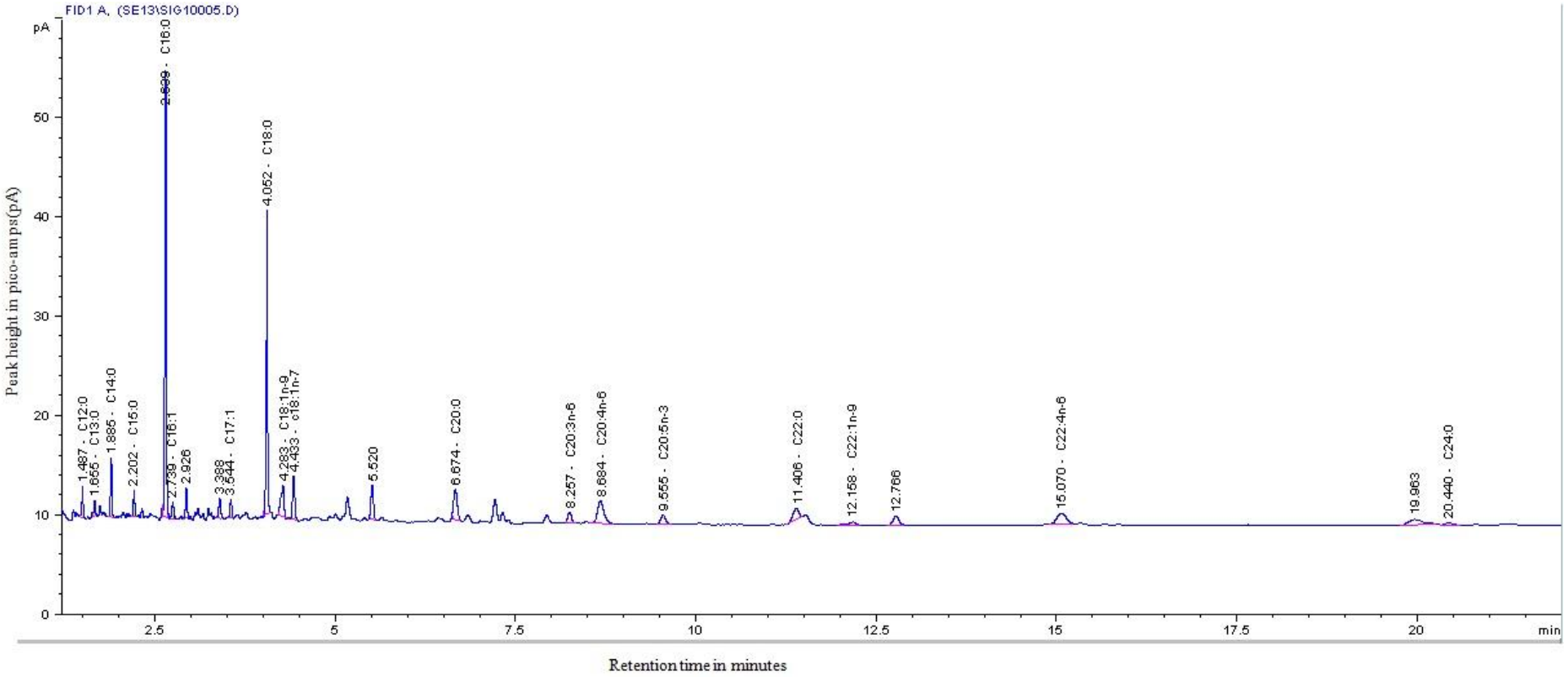


Figure 21 Chromatogram of fatty acids extracted from sample 2325 from Khok Phanom Di. Only peaks above one pico-amp (pA) are displayed

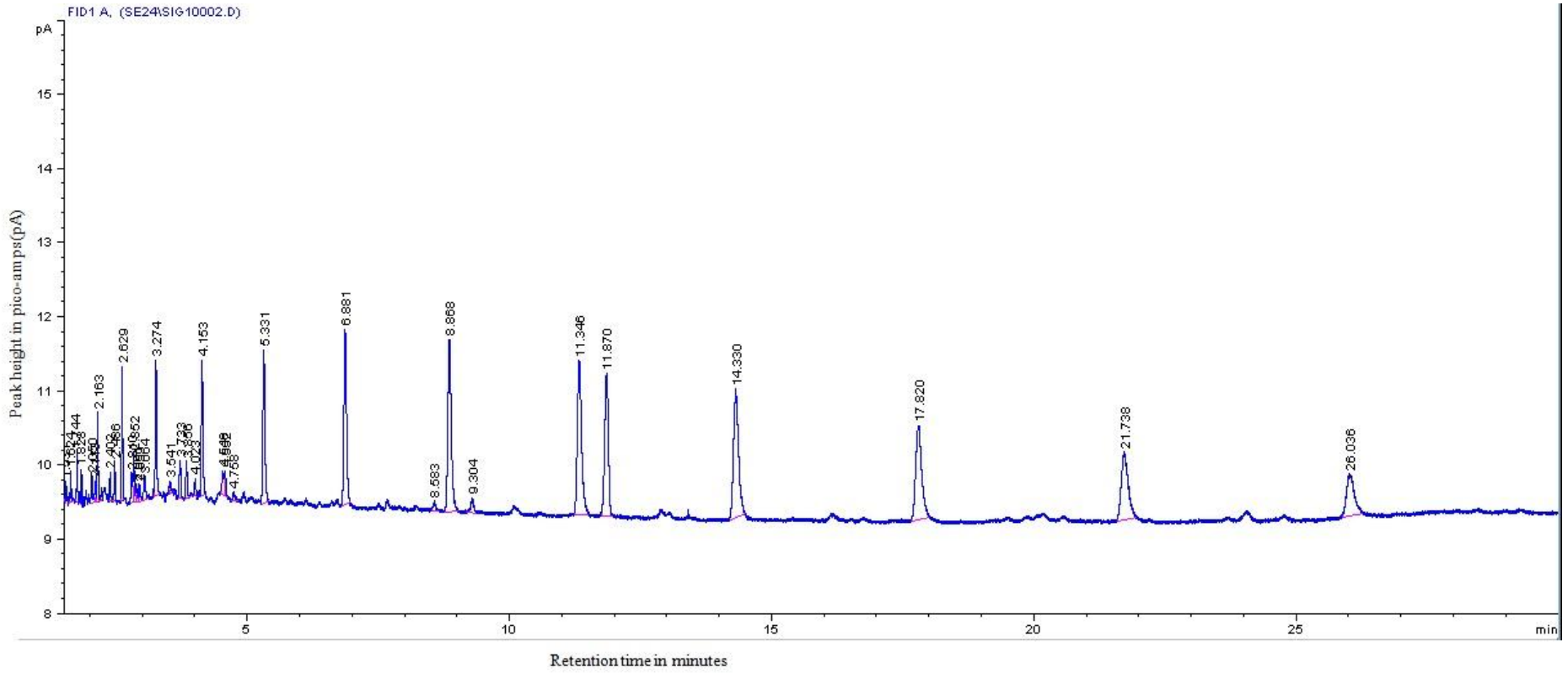


Figure 22 Chromatogram of unidentified n-alkanes extracted from sample 1000 from Nong Nor. Only peaks above one pA are displayed.

The relative amounts (% total FA) of the main FAs extracted from each sample from Khok Phanom Di, Nong Nor and Ban Non Wat are shown in Tables 3,4 and 5, respectively. Samples shaded in grey indicate those that had very little FA residue (all peaks were below 1 pA). These samples were considered not to be as reliable as those with higher peaks, but the FA composition of their residues is still important to note, and supports interpretations made for samples with higher peaks.

Table 3 presents the results of samples from Khok Phanom Di. In most samples, eleven fatty acid isomers were detected and measured. The exceptions are the two samples with all peaks below 1pA, 1884 and 2286, which contain very few FAs. The most prominent FAs are 18:0 and 16:0, and, in some cases, 12:0 and 14:0 are also present in relatively large quantities. Samples B63 and 2199 contain significantly less 16:0 than 18:0, while the other samples contain roughly equal amounts of the FAs, or more 16:0.

Table 3 Relative amounts (% total FA) of the main FAs identified for samples from Khok Phanom Di. Samples with no peaks above 1 pA are shaded grey.

	Lauric	Myristic	Palmitic	Palmitoleic		Stearic	Oleic	Linoleic	Arachidonic		
Sample	C12:0	C14:0	C16:0	C16:1	C17:0	C18:0	C18:1n-9	C18:2n-6	C20:0	C22:0	C24:0
B63	2.5	3.1	3.3	0.6	6.6	56	7.1	2.7	12.2	4.7	1.3
2311	0.6	0.6	35.4	0.8	1.4	35.8	14.2	4.3	5.5	1.5	0
2325	2.6	4.2	35.3	2.1	0.8	36.7	7.5	0	6.7	3.1	1
2199	8.5	1.9	2.3	1.9	2.7	57.7	7	0.6	5.1	5.6	6.9
2280	23.7	9.4	31.2	1.6	0	21.5	7.7	1.6	0	3.4	0
2567	3	16.8	32.3	2.8	2.3	17.7	2.7	12.1	0	10.2	0
164	13.4	8.4	42.8	0	0	25.5	3.8	0.9	1.8	3.5	0
2271	27.8	8	32.1	0	0	22.2	6.8	1.5	0	1.7	0
1694	2.1	23.5	34.3	3.4	1.6	14.6	2.8	10.8	0	6.5	0
2563	3.0	1.2	66.7	1	0	17.8	2.2	0	3.4	4.7	0
1884	0	0	24.7	0	0	38.8	16.1	0	0	0	20.5
2286	0	0	48.8	0	0	51.2	0	0	0	0	0

Table 4 presents the results from samples from Nong Nor. The majority had no peaks above 1 pA, and contained very few of the eleven FAs detected in samples from the other sites. The most prominent FAs were once again 16:0 and 18:0, followed by the unsaturated FA 18:1n9. All samples possessed greater quantities of 16:0 than 18:0. No samples contained the FAs 16:1, 17:0 or 24:0.

Table 4 Relative amounts (% total FA) of the main FAs identified for samples from Nong Nor. Samples with no peaks above 1 pA are shaded grey.

Sample	Lauric C12:0	Myristic C14:0	Palmitic C16:0	Palmitoleic C16:1	C17:0	Stearic C18:0	Oleic C18:1n-9	Linoleic C18:2n-6	Arachidonic C20:0	C22:0	C24:0
1013	10.3	10.0	35.8		0.0	19.1	16.4	4.5	0.9	2.9	0
A4u23	9.7	4.2	35.1	0.0	0.0	30.3	11.5	3.9	0.7	4.6	0
1000	7.1	7.4	34.4	0.0	0.0	22.2	18.8	4.7	0.0	5.3	0
551	6.3	7.6	42.9	0.0	0.0	32.1	4.3	1.0	3.8	2.0	0
U40-1	0	0	49	0	0	51	0	0	0	0	0
998	0	0	39.4	0	0	60.6	0	0	0	0	0
1004	0	0	50.4	0	0	49.6	0	0	0	0	0
997	0	0	54.7	0	0	45.3	0	0	0	0	0
887	0	0	34.8	0	0	65.2	0	0	0	0	0
967	0	0	35.2	0	0	41.4	0	0	23.4	0	0
977	0	0	49	0	0	51	13.3	0	0	0	0
917	0	0	39.4	0	0	60.6	8.6	0	0	12.4	0

Table 5 presents the results from samples from Ban Non Wat. The most prominent FAs were 16:0 and 18:0. Sample 23109 also had relatively high amounts of 18:1n9, 20:0 and 22:0, as well as considerably less 16:0 than 18:0. No samples contained 16:1 or 24:0. The samples with peaks below 1 pA, 23663 and 26152, only possessed 16:0 and 18:0.

Table 5 Relative amounts (% total FA) of the main FAs identified for samples from Ban Non Wat. Samples with no peaks above 1 pA are shaded grey.

Sample	Lauric C12:0	Myristic C14:0	Palmitic C16:0	C16:1	C17:0	Stearic C18:0	Oleic C18:1n-9	Linoleic C18:2n-6	Arachidonic C20:0	C22:0	C24:0
21285	0	3.4	46.2	0	0	50.37	0	0	0	0	0
23109	3	3.1	3.6	0	4.6	46.8	10.3	1.7	12.9	14	0
19630	0.5	0.5	41.4	0	1.2	45.6	5.5	0.	3.6	0.9	0
12127	0	1.6	45.2	0	0	45.1	4.8	0	0	3.3	0
23663	0	0	50.4	0	0	49.6	0	0	0	0	0
26152	0	0	49.5	0	0	50.5	0	0	0	0	0

Table 6 presents the approximate retention times of n-alkanes extracted from sample 1000 from Nong Nor.

Table 6 Approximate retention times and peak heights for n-alkanes extracted from sample 1000 from Nong Nor. The times in minutes are displayed in the second row, while the relative amount (% total NA) of that particular n-alkane is presented in the bottom row.

Sample 1000N															
Peak Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Retention Time	1.75	2.48	4.02	4.35	4.95	6.88	7.08	7.68	8.87	10.5	11.3	14.33	17.8	21.74	26.06
% total NA	1	10.2	0	0	0	10.5	0	2.1	14.4	0	15.3	15.6	13	10.8	7.3

Figure 23 displays the relative amounts (% total FA) of individual FAs present in sherds from each of the sites. Across the three sites the most abundant FAs were 16:0 and 18:0. Several other FAs were present across the three sites, but for the most part were more abundant in samples from Khok Phanom Di. FA 12:0 is an example of this. 16:1 and 24:0 were only found at Khok Phanom Di, while 17:0 was not found at Nong Nor. 18:1n9 was more abundant at Nong Nor than at Khok Phanom Di and Ban Non Wat, whereas 22:0 was present in the greatest quantities at Ban Non Wat.

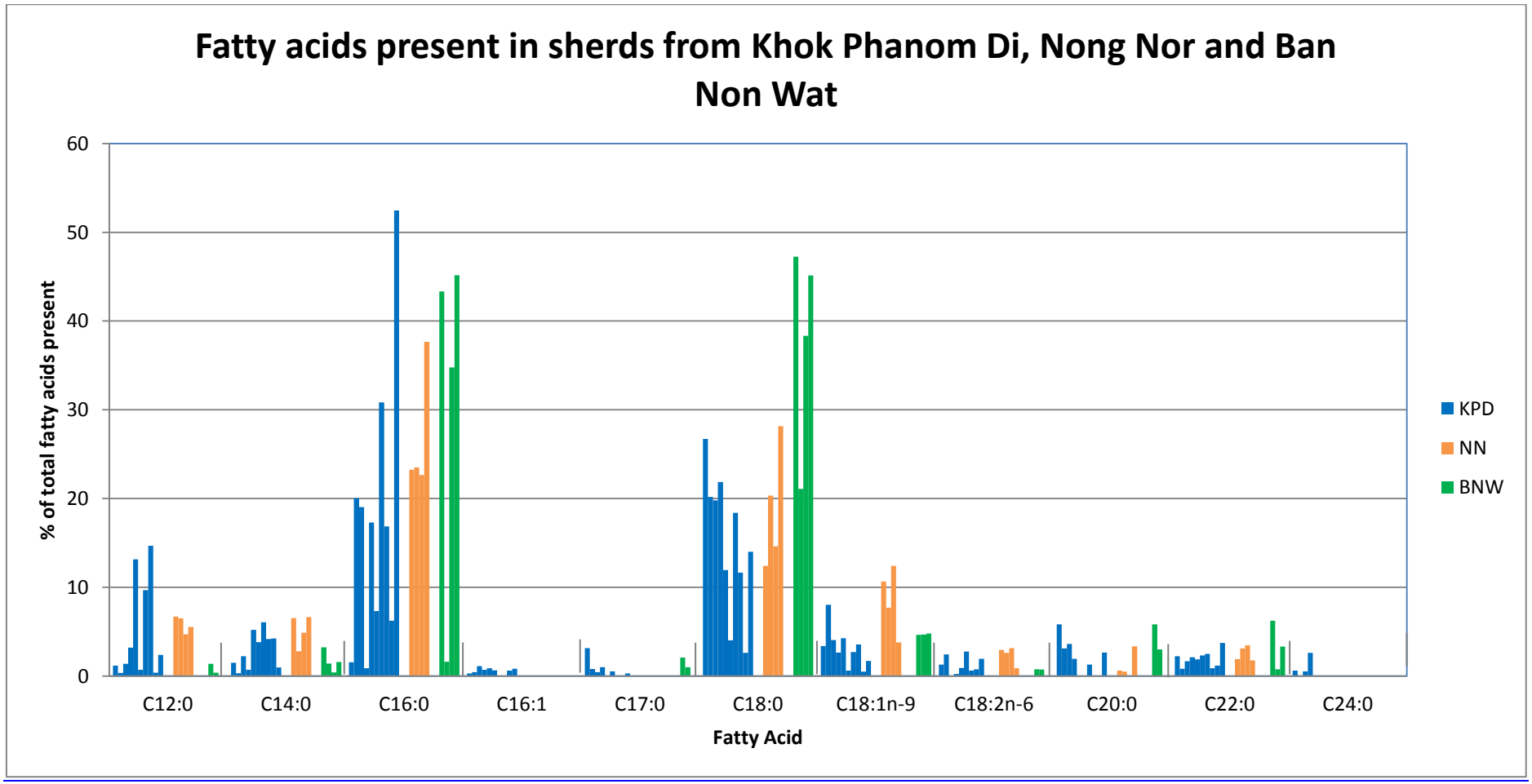


Figure 23 Relative amounts (% total FA) of fatty acids present in individual samples from Khok Phanom Di (KPD), Nong Nor (NN) and Ban Non Wat (BNW). Fatty acid amounts were calculated by measuring peak areas produced by gas chromatography. Samples with no peaks above 1 pA are excluded.

Stable Isotopes of Carbon (^{13}C) of Individual Compounds

Table 7 displays the results of gas chromatography isotope ratio mass spectrometry (GC-IRMS) of FAs obtained from six samples, three from Nong Nor and three from Khok Phanom Di. These were the only samples with peaks above 500 millivolts (mv), a recognised threshold for reliable GC-IRMS analysis (Jochmann et al. 2006). In most samples, values of $\delta^{13}C$ were obtained for five FA isomers. All values of $\delta^{13}C$ fell between -30.4 and -26.8‰.

Table 7 Values of $\delta^{13}C$ (‰) of individual FA isomers for six samples from Khok Phanom Di (KPD) and Nong Nor (NN).

	C12 Lauric	C14 Myristic	C16 Palmitic	C18 Stearic	C18:1 Oleic
CH2563 (KPD)	-30.4	-29.6	-28.9	-28.4	n/a
CH2280 (KPD)	-29.1	-28.3	-28.5	-28.9	-29.0
CH2567 (KPD)	-30.0	n/a	-27.4	-26.8	n/a
CH1000 (NN)	-28.8	-28.3	-28.5	-28.4	-30.3
CHA4U23 (NN)	-29.2	n/a	-28.6	-28.3	-27.3
CHNN1013 (NN)	-28.5	-28.1	-28.1	-28.2	-28.3

In Figure 24 the FA specific ^{13}C values for each of the sites are displayed. For all but C18:1 the values from Nong Nor had a small range, from -29.2 to -27.3‰. Values from Khok Phanom Di were more variable, ranging from -30.4 to -26.8‰. There are not enough data points to test for a correlation, but there appears to be a trend of increasing $\delta^{13}C$ with carbon chain length, with the exception of C18:1.

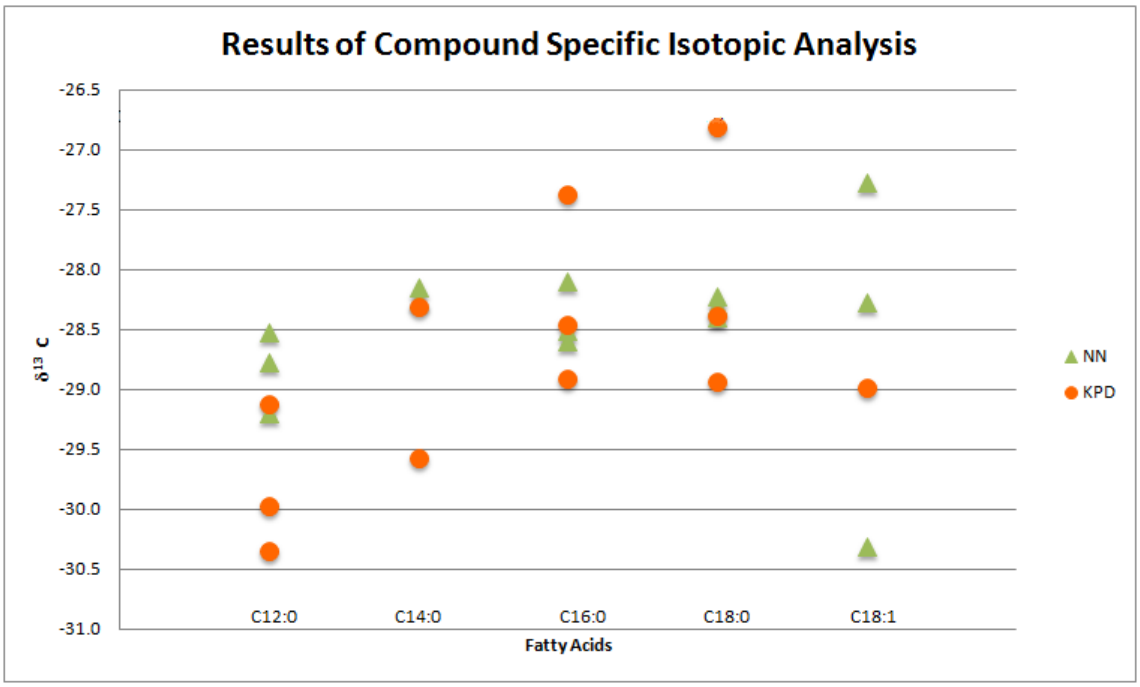


Figure 24 Scatter plot displaying the results of FA specific analysis of isotope ratios of carbon according to site, Khok Phanom Di (KPD) and Nong Nor (NN).

Summary of Results

The results show that several fatty acids (FAs) have survived trapped in the matrix of ceramic vessels at Khok Phanom Di, Nong Nor and Ban Non Wat. The most prominent FAs were 16:0 and 18:0. Other FAs present in the majority of the samples with peaks above 1 pA included 18:1n-9, 18:2n-6, 22:0 and, in some cases, 12:0 and 14:0. Samples from Khok Phanom Di appear to be the best preserved, possessing the greatest quantities and range of FAs. Only Khok Phanom Di samples contained the FAs 16:1 and 24:0. Most of the samples across the sites possessed more 16:0 than 18:0, or have both FAs in roughly equal amounts. Three samples however, B63 and 2199 from Khok Phanom Di and 23109 from Ban Non Wat, had less 16:0 than 18:0. All six samples that provided ^{13}C signatures fell within a fairly small range of -30.4 to -26.8‰. The significance of all this is discussed below.

DISCUSSION

In this chapter, the results described in the previous section are elaborated on in the context of the thesis aims. First the fatty acid (FA) results are interpreted, and then compared with fatty acid compositions of modern foodstuffs which may have been contained in the vessels according to the archaeological data. The isotopic analyses are more fully explained before they are compared with modern isotopic signatures obtained from possible food sources. The data for each sherd is interpreted based on comparison with modern samples and using models developed for archaeologists for degraded samples, before the limitations of this study and future considerations are discussed.

Fatty Acid Compositions

The majority of samples from Ban Non Wat and Ban Salao, extracted and put through the fatty acid methyl ester (FAME) preparation at the same time, appeared to have little to nothing in them after gas chromatography (GC) analysis (see Appendix 3). It was subsequently found that solvent contamination during analysis had resulted in the loss of these samples. Fortunately, some of the Ban Non Wat samples consisted of more than one sherd, so a few of these samples could be re-extracted and included in the analysis. More potsherd samples were located in the University of Otago Anthropology Department archives from prior excavations at Khok Phanom Di and Nong Nor. It is these samples that have provided the majority of the results set out in the previous chapter.

Table 3, which displays the FAs present in samples from Khok Phanom Di, indicates that the residues were, on the whole, very well preserved. There is a wide range of FAs of differing lengths, and even monounsaturated and polyunsaturated FAs (such as 16:1, 18:1n-9 and 18:2n6), which are expected to degrade very quickly (Eerkens 2007), were present. All but two samples, B63 and 2199, had roughly equal amounts of, or more, 18:0 than 16:0. Most other FAs in these two samples were present in greater amounts than 16:0. These samples also had long-chained FAs, including 24:0. The only other sample to possess 24:0 was sample 2325, which had 16:0 and 18:0 in roughly the same amount. The majority of samples had the long-chained FAs 20:0 and 22:0, which, in conjunction with the unsaturated FAs, particularly 18:2n6, may suggest residues of a plant origin (Craig 2008). Those samples with roughly equal amounts of 18:0 and 16:0, or more 18:0, however, might indicate residues of an animal origin (Craig 2008). A few samples had the odd numbered FA 17:0, and a small amount of 15:0 and 19:0. Odd-chained FAs may be indicative of contamination, or, in the case of 15:0

and 17:0 which are produced by rumen bacteria, indicate the presence of ruminant animal products in the residue (Malainey 1997 in Eerkens 2005). 15:0 and 17:0 are similarly used as biomarkers for bacteria in ecological studies (e.g. McLeod and Wing 2009).

The samples from Nong Nor (Table 4) do not appear to be as well preserved as those from Khok Phanom Di. The majority had no peaks above the requisite 1 pA height, meaning that the FAs were present in such small amounts they could not be relied on for an accurate interpretation. All four samples with peaks above 1 pA had more 16:0 than 18:0. The monounsaturated and polyunsaturated isomers of 18:0, 18:1n9 and 18:2n6, were present, as was 22:0. The monounsaturated 16:1, the odd-chained 17:0, and the long-chained 24:0 FAs were, however, absent. Residues from these samples are most likely to have been of plant origin due to their 16:0 and 18:0 ratios, plants containing significantly more 16:0 than 18:0 (Beck and Stout 2008). Plant residues are also likely due to the presence of monounsaturated and polyunsaturated 18:0 isomers.

Table 5 displays the results of samples from Ban Non Wat, which also do not appear to be as well preserved as those from Khok Phanom Di sherds. No sample had monounsaturated 16:1 or long-chained 24:0, and only two samples have the polyunsaturated 18:2n6, in small quantities. One of the samples containing 18:2n6, sample 23109, also contained more 18:0 relative to 16:0. As seen in the Khok Phanom Di examples, in this sample most of the other FAs were present in greater quantities than 16:0. Sample 23109 also had the highest amounts of both 20:0 and 22:0. Sample 19630, similarly, had less 16:0 than 18:0, and is the only other sample that contained 20:0. Samples with more 18:0 than 16:0 are likely to have contained residues of an animal origin, and those with longer-chained and unsaturated FAs may include fish residues. The samples with more 16:0 than 18:0 are most likely to contain plant residues (Craig 2008; Craig et al. 2003).

While little can be said of the n-alkanes encountered in this study, they are serve as further proof of the preservation of organic residues from Thai sites. Table 6 shows the approximate retention times of n-alkanes from sample 1000 from Nong Nor. These may, in future analyses, help to identify the n-alkanes present.

Figure 23 displays the relative amounts (% total FA) of fatty acids in samples from each of the three sites tested. The better preservation of the Khok Phanom Di residues is indicated by the range and quantities of fatty acids in these samples. The most obvious difference between the three sites is that Khok Phanom Di was the only one with 16:1 and 24:0. It also had the largest proportion of 12:0 and 17:0 FAs. 17:0 is a potential indicator of

microbial action, while 24:0 can be found in plants or beeswax, and, in trace amounts, in fish (Chedoloh et al. 2011; Jin et al. 2010; Regert et al. 2001). Whether this is merely a symptom of better preservation, or indicative of different residue origins is uncertain, but will be addressed below. Nong Nor, on the other hand, had the largest overall proportion of 18:1n9, which is present in marine organisms and plants, as well as 18:2n6, which may also indicate either fish or plant sources (Beck and Stout 2008; Chedoloh et al. 2011). This, together with the 16:0 to 18:0 ratios, and the presence of longer chained fatty acids, suggests that these samples were most likely to be of plant or fish origin rather than from terrestrial mammals (Beck and Stout 2008). Ban Non Wat has a similar, albeit smaller, range and quantity of fatty acids to Khok Phanom Di. Samples at both of these sites might include residues of fish, mammal or plant origin. As suggested by Eerkens (2005), the fact that some sherds have very little or no FAs, while others have a large amount and diverse range, makes it unlikely that the residues are a product of processing contamination during excavation, extraction or analysis.

Comparison with modern fatty acids

Eerkens (2005) found that by plotting the ratios between saturated fatty acids, (15:0+17:0)/18:0, and unsaturated fatty acids, 16:1/18:1, modern samples could be separated into food classes. Preferential degradation of the longer-chained 18:1 suggests that, over time, there will be an increase in the ratio of 16:1 to 18:1, and so degraded samples should shift slightly to the right of the modern samples to reflect this (Eerkens 2005). In Figure 25 the samples from all three sites were plotted onto Eerkens' original graph. Unfortunately, many of the samples did not contain 16:1 which resulted in a zero on the x-axis, and some samples did not contain 15:0 or 17:0 either, resulting in a zero on the y-axis as well. The samples which are plotted on both the x- and y-axes, all from Khok Phanom Di, are quite spread out, but, taking into consideration the slight shift to the right, fall roughly within the ranges of modern roots, greens, fish and terrestrial mammals.

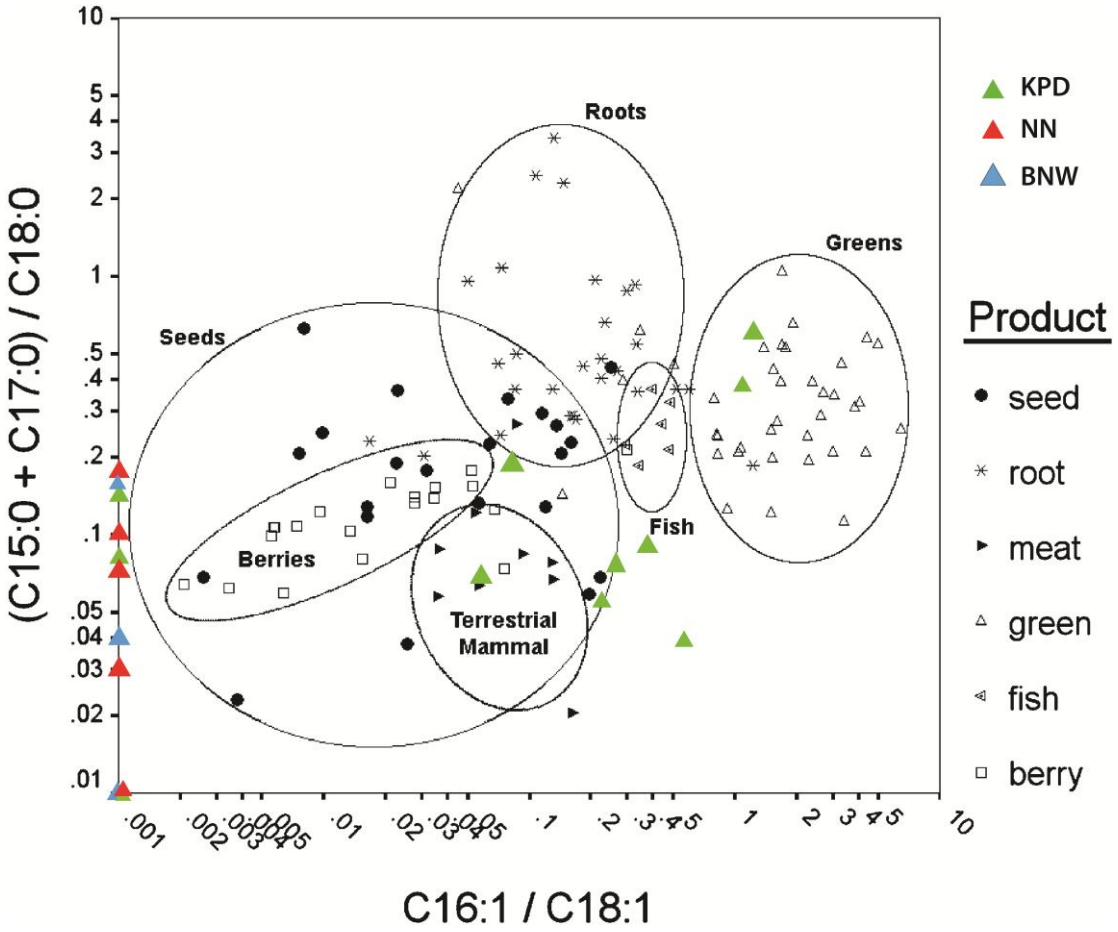


Figure 25 A bi plot showing two fatty acid ratios of modern food sources after Eerkens (2005, 90). The values for the archaeological samples are identified by site, Khok Phanom Di (KPD), Nong Nor (NN) and Ban Non Wat (BNW).

Eerkens (2005) also found that by plotting the ratio of 16:0 to 18:0 against 12:0 to 14:0, the different food types could be further isolated, particularly separating fish and terrestrial meats for modern samples. The samples from all three sites are plotted on Eerkens' original graph in Figure 26. Some of the samples did not contain 12:0 or 14:0 resulting in a zero on the y-axis. Again, the ratio of 16:0 to 18:0 is expected to increase over time, and so archaeological samples should shift slightly to the right. Keeping this in mind, in this plot the samples are split into two groups which fall roughly within the ranges of modern terrestrial mammals or fish, or in seeds or berries.

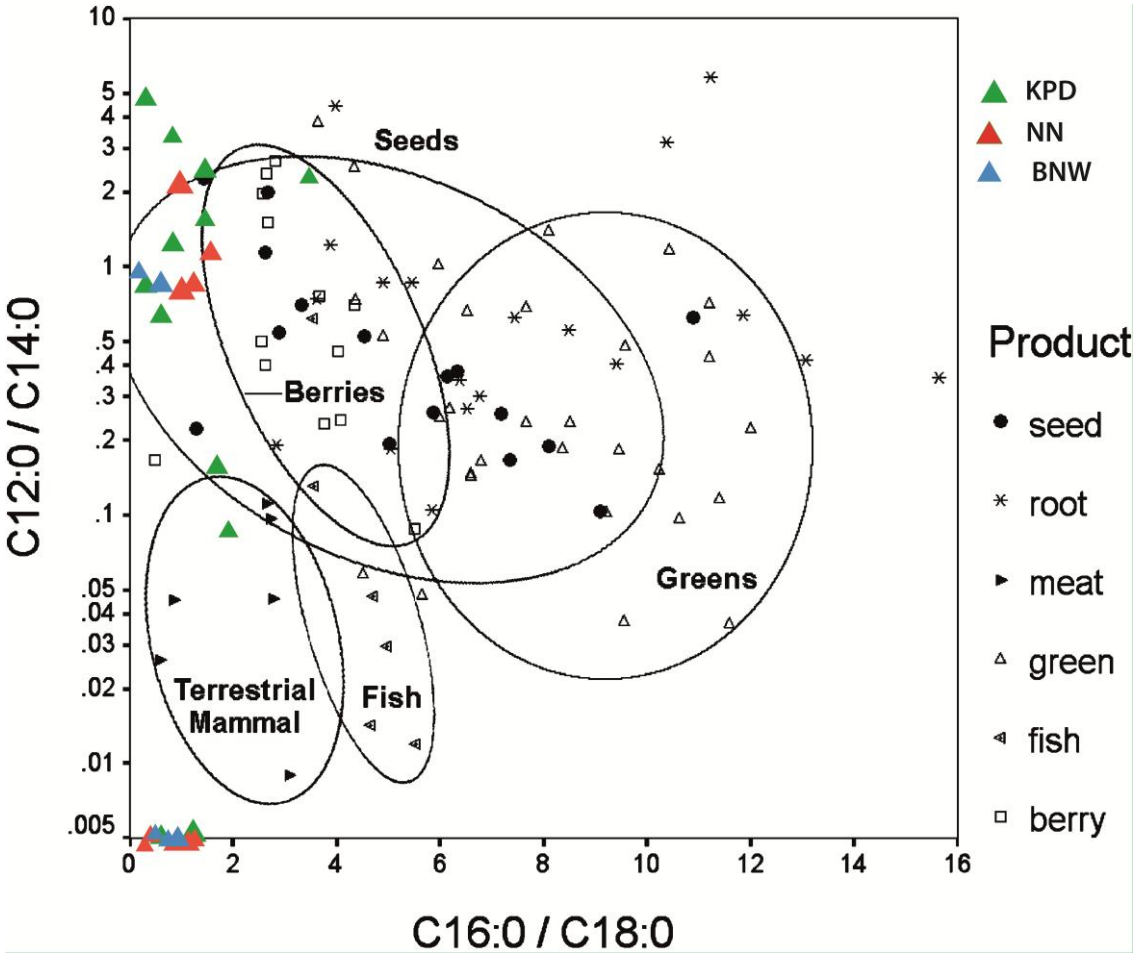


Figure 26 A bi plot showing two fatty acid ratios of modern food sources after Eerkens (2005, 90). The values for the archaeological samples are are identified by site, Khok Phanom Di (KPD), Nong Nor (NN) and Ban Non Wat (BNW).

There is obviously an overlap in the ratios of fatty acids in both of these graphs, and it is difficult to draw a definite conclusion as to what might have been in the residues. However, at a general level, these ratios are helpful in exploring the potential food classes in the vessel residues. They are also useful to eliminate things that are unlikely to have been contained in the pots, e.g. greens. Studies in which experimental degradation of the different foodstuffs is carried out, and the ratios re-measured, will increase the accuracy of determining the origin of archaeological residues using modern FA compositions.

Table 8 shows the relative amounts (% total FA) of FAs extracted from modern rice samples. The most prominent FAs are 16:0, 18:1 and 18:2, while 18:0, which is prominent in the archaeological samples, is present in relatively small amounts. Unsaturated FAs are expected to degrade very quickly, the addition of each double bond increasing the rate of decomposition (Eerkens 2007). It would therefore not be surprising, if the archaeological

samples collected from Thailand had contained rice, that the relative amounts of 18:1 and 18:2 would be much lower than those found in modern rice samples. The fact that there is any left at all after such a great time span suggests that originally there must have been quite a large amount of these FAs. As the unsaturated isomers decomposed in the archaeological samples, it is logical for the amount of saturated 18:0 to have increased relatively. Most of the archaeological samples fall within the vicinity of, or above, the modern 16:0 ranges. The only exceptions being those with more 18:0 than 16:0, and so more likely to be of animal than plant origin, and sample 977 from Nong Nor. Sample 977 has no peaks above 1 pA and cannot be reliably interpreted, and so will be excluded from analysis here.

Although these results suggest that rice was not present in the residue samples, it is commonly found in the archaeological record, and is a staple throughout the region today. Issues with the preservation of starchy staples, such as rice, in residues make it important to keep rice in mind as a potential interpretation (see Reber and Evershed 2004).

Modern rice also possesses small amounts of 14:0, 16:1 and 20:0. In the case of 14:0 and 20:0, which, when present in the archaeological samples, are often so in higher quantities, their relative percentage should increase over time as unsaturated FAs degrade (Malainey et al. 1999). The very small amounts of 16:1 in modern rice, however, are very interesting, considering the relatively large amounts in the few archaeological samples in which this fatty acid is present. The samples originating from Japan and the Philippines, moreover, possess no 16:1 at all. If the archaeological samples only contained a very small amount originally it is not surprising that there is no trace of it left. However, Malainey et al. (1999) found that FAs extracted from sherds in waterlogged and anaerobic environments undergo very complex degradation processes. They found that it was possible that 18:1 might convert to 16:1 over time, and this might explain the quantities present in some Khok Phanom Di samples.

Table 8 Relative amounts (% total FA) of fatty acids extracted from rice according to species and location. From Lugay and Juliano (1964, 274-5).

Rice Bran Lipids	C14:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	C20:0
Peta	0.3	20.5	0.2	1.1	41.9	34.1	1.1	0.7
Malagkit Sungsong Puti	0.4	17.8	0.2	1.4	44.2	34.5	0.9	0.7
Taichung 65	0.2	16.9	0.1	1.8	40.8	38.9	0.9	0.3
Taichung glutinous 46	0.5	18.0	0.2	1.4	37.1	40.7	1.4	0.7
Mean	0.3	18.3	0.2	1.4	41.0	37.1	1.1	0.6
Milled Rice Lipids	C14:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	C20:0
Peta	0.6	25.1	0.5	1.4	42.6	28.3	0.9	0.6
Malagkit Sungsong Puti	0.5	28.7	0.4	2.4	46.1	21.3	0.4	0.4
Taichung 65	0.6	37.4	0.4	3.8	45.2	12.0	0.3	0.3
Taichung glutinous 46	0.8	44.1	0.4	3.3	39.4	10.6	0.8	0.5
Mean	0.6	33.8	0.4	2.7	43.3	18.0	0.6	0.4
Sample Origin	C14:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	C20:0
Phillipines	0.4	18.3	0.2	1.4	41.0	37.0	1.1	0.6
United States (crude oil)	0.4	17.9	0.2	1.3	41.2	37.7	1.1	0.1
United States (edible oil)	0.5	18.3	0.4	1.5	45.0	33.5	0.5	0.3
Japan	0.6	21.0	0.0	1.6	38.1	37.8	0.9	0.0
Philippine (5)	0.2	18.7	0.0	1.9	49.3	29.9	0.0	0.7
Philippines (6)	0.1	18.3	0.0	2.8	49.0	29.8	0.0	0.5

In Table 9 the ratio of 16:0 to 18:0 is calculated for each of the modern rice samples, and compared with the same ratios for the archaeological samples. As the chemical structures of the FAs 16:0 and 18:0 are similar, the relative amounts of these FAs should stay relatively constant over time (Evershed 2008). None of the archaeological samples fall within the range of 16:0 to 18:0 ratios of modern rice samples. The large amount of unsaturated FAs in modern rice, and the amount surviving in the archaeological samples despite their expected rapid degradation, supports the conjecture that some of the residues are, at least, of plant origin, and possibly rice. Looking at other sources of information, such as the results of isotopic analyses and archaeological data will help to clarify this.

Table 9 Ratios of C16:0 to C18:0 in modern rice samples (Lugay and Juliano 1964, 274-5) and comparisons of these ratios to those for samples from Khok Phanom Di (KPD), Nong Nor (NN) and Ban Non Wat (BNW). Samples in grey are those below 1 pA.

Rice Bran	C16:0/ C18:0	KPD	C16:0/ C18:0	NN	C16:0/ C18:0	BNW	C16:0/ C18:0
Peta	18.64	B63	0.06	1013	1.87	21285	0.92
Malagkit Sungsong Puti	12.71	2311	0.99	A4u23	1.16	23109	0.08
Taichung 65	9.39	2325	0.96	1000	1.55	19630	0.91
Taichung glutinous 46	12.86	2199	0.04	551	1.34	12127	1
Milled Rice Lipids		2280	1.45	U40-1	0.96	23663	1.02
Peta	17.93	2567	1.82	998	0.65	ch26152	0.98
Malagkit Sungsong Puti	11.96	164	1.68	1004	1.02		
Taichung 65	9.84	2271	1.45	997	1.21		
Taichung glutinous 46	13.36	1694	2.37	887	0.53		
Sample Origin		2563	3.75	967	0.85		
Philippines	13.07	1884	0.64	977	0.94		
United States (crude oil)	13.77	2286	0.95	917	1.13		
United States (edible oil)	12.2						
Japan	12.88						
Phillipine (5)	9.84						
Philippines (6)	6.54						

The relative amounts (% total FA) of five of the main FAs found in modern freshwater fish from Thailand are displayed in Table 10. 16:0, 18:1n9 and, to a lesser extent, 22:6n3 are the most prominent FAs. 16:0 and 18:1n9 are generally present in much lower quantities than in the rice samples above. 18:0, however, is much more abundant than in rice. While, for the most part, the modern range of 18:0 is still lower than that found in the archaeological samples, the amount of long-lived 18:0 in samples will increase as other shorter-lived FAs decompose (Malainey et al. 1999). The much greater quantities of 18:1n9 and 18:2n6 in rice as compared to fish might help in interpretation of the archaeological residues. In a context that is less than ideal for preservation, any traces of these FAs will be less likely to survive after a great time span, and yet they are found in many of the archaeological samples.

Table 10 Relative amounts (% total FA) of fatty acids extracted from freshwater commercial fish species in Thailand according to Chedoloh et al. (2011, 787).

Freshwater Species	C16:0	C18:0	C18:1n9	C18:2n6	C22:6n3
Hoplolatilus sp.	24.2	13.4	23.3	9.1	2.9
A. truncatus	26.9	8.6	9.2	12.1	3.9
C. batrachus	23.1	3.7	20.2	1.5	23.3
H. temmincki	29.1	4.9	6	1.2	12.6
N. notopterus	30.4	11.1	20.9	0.8	13
C. striata	22.1	11.2	13.3	1.6	13
P. gonionotus	14.6	0.4	29.8	2.3	16

Not all samples were tested for the last FA, 22:6n3. Of those that were tested, however, three samples, 2311 and 2199 from Khok Phanom Di and 19630B from Ban Non Wat, did contain small amounts. This is important, as 22:6n3, being the polyunsaturated isomer of a long-chained fatty acid, should decompose very rapidly (Malainey et al. 1999). Any trace of this FA in the residues might indicate that there was originally a significant amount in the samples. Unfortunately, the quantities of 14:0, 16:1, 18:3 and 20:0 are not given for Thai freshwater fish, and so these cannot be used to compare the likelihood of the samples being of a fish or rice origin. FA 22:6n3, however, is unlikely to be found in a terrestrial plant source, found in the highest quantities in fatty fish and at low levels in meat and eggs (Horrocks and Yeo 1999).

Table 11 compares the 16:0 to 18:0 ratios of modern freshwater fish species with the ratios from the archaeological samples. In the case of the modern fish samples, C16:0 is always present in greater quantities than C18:0. Four samples fall within the modern range of freshwater fish, samples 2567, 1694 and 2563 from Khok Phanom Di, and sample 1013 from Nong Nor. Some other samples, such as 164 from Khok Phanom Di and 1000 from Nong Nor, are close to the modern range. As discussed elsewhere, 16:0 and 18:0, being saturated fatty acids, are expected to degrade at roughly the same rate, keeping the ratio between them fairly constant (Malainey et al. 1999). Interestingly, the four samples which fall within the same range as the modern ratios are not the same as those which have 22:6n3. The samples which do have 22:6n3, 2311 and 2199 from Khok Phanom Di and 19630 from Ban Non Wat, have slightly more 18:0 than 16:0. In the case of sample 2199 there is significantly more 18:0 than 16:0. This increases the chance of these samples being of animal rather than plant origin (Craig 2008).

Table 11 Ratios of C16:0 to C18:0 in modern fish samples (Chedoloh et al. 2011, 787) compared to those for samples from Khok Phanom Di (KPD), Nong Nor (NN) and Ban Non Wat (BNW). Samples in grey are those below 1pA and values in purple fall within the range of modern ratios.

Freshwater Species	C16:0/C18:0	KPD	C16:0/C18:0	NN	C16:0/C18:0	BNW	C16:0/C18:0
Hoplolatilus sp.	1.81	B63	0.06	nn1013	1.87	21285	0.92
A. truncates	3.13	2311	0.99	A4u23	1.16	23109B	0.08
C. batrachus	6.24	2325	0.96	1000	1.55	19630B	0.91
H. temmincki	5.94	2199	0.04	nn551	1.34	12127	1.00
N. notopterus	2.74	2280	1.45	U40-1	0.96	23663	1.02
C. striata	1.97	2567	1.82	998	0.65	ch26152	0.98
P. gonionotus	36.50	164	1.68	1004	1.02		
		2271	1.45	997	1.21		
		1694	2.37	887	0.53		
		2563	3.75	967	0.85		
		1884	0.64	nn977	0.94		
		2286	0.95	nn917	1.13		

Table 12 Fish identified (to genus or species) by Thosarat (2010) present in mortuary vessels from Ban Non Wat in the greatest numbers. The number of individuals for all identified species can be found in Appendix 4.

Species	Individuals
Channa striata	253
Clarius sp.	143
Anabus testudineus	80
Hemibagrus/Mystus	66
Monopterus albus	34

As can be seen in Table 12, the most commonly found species in pots from Ban Non Wat are *C. striata*, the common snakehead, followed by catfish species belonging to the *Clarius* genus (Thosarat 2010). Two of the four samples which fall in the modern range above, 2567 from Khok Phanom Di and 1013 from Nong Nor, are very close to the ratio of 16:0 to 18:0 of modern *C. striata*. The other two are also reasonably close to the modern ratios of *C. striata*. All four samples fall very comfortably in the modern range of 16:0 to 18:0 for freshwater fish, and several others are not far off. Therefore, if direct comparison with modern FA ratios is accurate, freshwater fish is another viable source for the residues extracted from the archaeological samples.

Millet is another possible food source exploited in prehistoric Thailand according to Weber et al. (2010). Table 13 displays the fatty acid composition of foxtail millet, the most commonly found variety. The final column shows the ratio of C16:0 to C18:0. When compared with the archaeological residues in Table 9 and 11, eight samples (2280, 2567, 164, 2271, 1694 and 2563 from Khok Phanom Di, and 1013 and 1000 from Nong Nor) fall comfortably within the range of modern millet ratios, and so this is another possible source for the archaeological residues absorbed into sherds from Khok Phanom Di, Nong Nor and Ban Non Wat.

Table 13 Fatty acid composition of non-glutinous and glutinous foxtail millet, from Taira, H. (1984, 370). Ratios of 16:0 to 18:0 are shown in the last column.

	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	C20:0	C20:1	C16:0/C18:0
Non-glut meanA	7.8	0.2	5.6	13.3	68.0	2.8	1.7	0.6	1.38
Non-glut meanB	8.9	0.2	1.6	15.6	70.7	2.4	0.9	0.5	5.14
Glut A	9.0	0.2	4.8	12.4	68.3	3.0	1.7	0.1	1.87
Glut B	9.4	0.2	1.1	16.2	69.4	2.6	0.7	0.6	8.90
Average	8.6	0.2	3.3	14.4	69.1	2.7	1.2	0.4	2.62

Isotope Results

Carbon isotopic signatures were obtained for five FAs extracted from six samples, three from Khok Phanom Di and three from Nong Nor. The isotopic values of the FAs in samples from Khok Phanom Di ranged from -30.4 to -26.8‰, while those from Nong Nor had a smaller range, from -29.2 to -27.3‰. The ratios fall comfortably within the range for terrestrial C_3 plants, -36 to -22‰, which make up the majority of plants in Southeast Asia (King and Norr 2006; King 2006, 81). C_4 plants are more positive, and average around -13‰ (Finlay and Kendall 2007), while marine sources can be expected to have a $\delta^{13}C$ value of around -14‰ (Ambrose et al. 1997 in Bentley et al. 2007).

The average carbon isotopic values sourced from tooth enamel at Khok Phanom Di and Ban Non Wat are between -14 and -12‰, which suggests that the average ^{13}C value of the diet at these sites fell between -25.9 and -21.4‰ once isotopic fractionation has been accounted for (Bentley et al. 2007; Lanehart et al. 2011). The diet at Khok Phanom Di, with its slightly more positive values, was suggested to have been based on rice or C_3 plants and food from a marine source (Bentley et al. 2007). The diet at Ban Non Wat was probably more reliant on C_3 terrestrial sources, based on the more negative $\delta^{13}C$ values and its relative isolation from the ocean. These results, however, reflect the contribution of the whole diet

rather than a single, or a few food sources. Ceramic residue signatures are more likely to be from only a handful of sources, and so diet reconstructions are only useful as a guide. Furthermore, lipids have more negative $\delta^{13}C$ values than bulk tissue samples, and are around 5‰ lighter than carbohydrates and proteins (Barnard et al. 2007; Post et al. 2007; Stevenson and Cole 1999). This may influence the $\delta^{13}C$ values of the surviving isotopic signatures, which were all extracted from lipids.

Another consideration is that, while carbon isotopes are seemingly unaffected by diagenetic processes (Evershed et al. 1997 in Spangenberg et al. 2006), lipids are not immune to degradation. Until the effects of degradation on isotopic signatures derived from FAs have been better studied and understood, the ^{13}C values obtained from them should be treated with caution. It is best to use them to complement the archaeological and environmental data, as well as any lipid results. In fact, isotopic data are more useful to determine what was not present in the residues. For example, the $\delta^{13}C$ values from Khok Phanom Di and Nong Nor are almost certainly not from a C_4 source, such as millet, nor of marine origin. The results suggest that the food cooked or stored in the ceramic vessels are more likely to have been from a C_3 plant source, such as rice, or else an animal feeding solely on C_3 sources, such as freshwater fish or terrestrial mammals.

Comparison with modern isotopes

The faunal evidence from Ban Non Wat, Khok Phanom Di and Nong Nor shows that fish were a prominently exploited resource. The remains of freshwater species are found in many ceramic vessels at Ban Non Wat. Figure 27 displays the $\delta^{13}C$ and $\delta^{15}N$ values of a number of different contemporary freshwater fish species, and their food sources, in the Mekong River. Unfortunately FAs contain no N and so do not provide $\delta^{15}N$ signatures (Meier-Augenstein 2002). Fish do, however, contain high levels of amino acids and a complimentary study of the isotopic composition of amino acids would be useful, though outside the scope of the present study (see Simpson et al. 1998). The $\delta^{13}C$ values, at least, of modern and ancient freshwater fish in Thailand are expected to be similar. The terrestrial plants (PLA) and *Henicorynchus* spp. (Ps) in Figure 27 are of the most interest to this study. Based on the archaeological evidence, terrestrial plants and freshwater fish, and so values between -31 and -27‰ and -29 and -23‰, respectively, are expected from the residue samples. The large number of ceramic vessels in which fish remains were identified suggests that one of the most likely sources of food contained within them is fish. These fish would

potentially have fed on terrestrial plants, such as rice when kept in rice paddies, or else on the periphyton and other organisms themselves feeding off the terrestrial plants. The only species in this chart that does not follow this pattern is *Pangasius krempfi* (Pk). This species only travels into the freshwaters of the Mekong to spawn, and so has isotopic values typical of marine fish (Hogan et al. 2007).

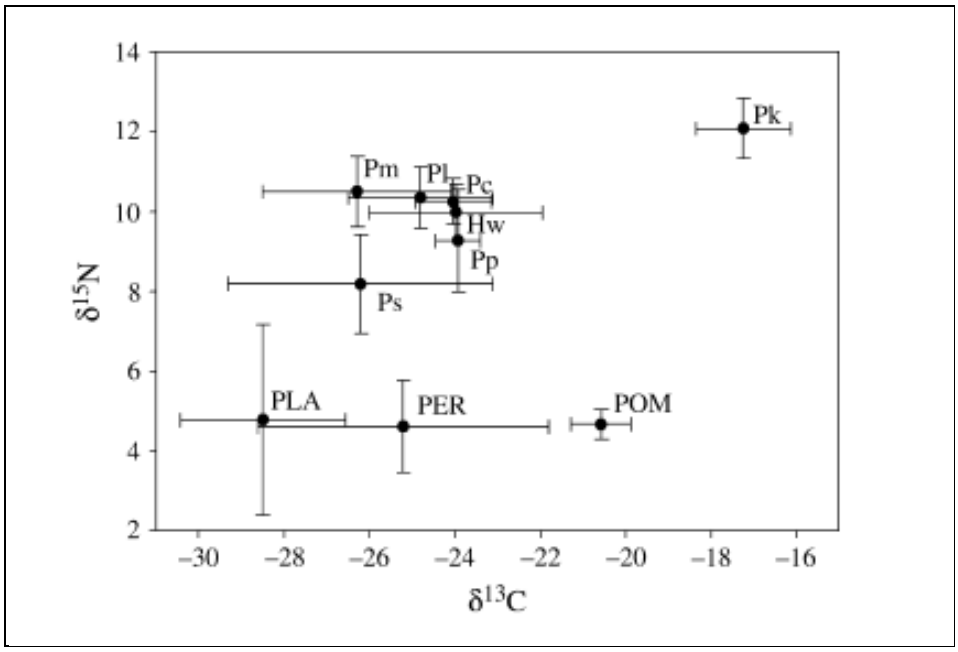


Figure 27 Food web of Mekong River based on stable carbon and nitrogen isotopes, after Hogan et al. (2007, 825) Fishes: Pk, *Pangasius krempfi*; Pl, *Pangasius larnaudii*; Pc, *Pangasius conchophilus*; Pm, *Pangasius macronema*; Pp, *Pangasius pleurotaenia*; Hw, *Helicophagus waandersii*; Ps, *Henicorynchus* spp. Sources: PLA, terrestrial plants; PER, periphyton; POM, particulate organic matter. *P. krempfi* has carbon and nitrogen isotopic signatures typical of marine fishes.

Faunal evidence from all three sites includes large numbers of terrestrial mammal species such as deer, cattle and pig. No bones of these large species have been found in ceramic vessels, but they are often included as part of the mortuary ritual, and were likely cooked, along with other resources, in some ceramic vessels (Higham 2002; 2004; Higham et al. 1998; Higham and Bannanurag 1991). Hoekman-Sites (2011) suggested that the difference in $\delta^{13}C$ of C18:0 and C16:0, when plotted against each other, indicate whether the source of fat in modern animal sources was ruminant or porcine.

Table 14 displays the results of this comparison, and the suggested sources of animal fat in each of the six archaeological samples tested. Two samples, 2280 from Khok Phanom Di and 1013 from Nong Nor, are more likely to have contained ruminant adipose fat, while

the other four samples more likely to have contained porcine, or non-ruminant, adipose fat. Unfortunately, according to interpretations of the FA results (see Table 34), none of these six samples contain terrestrial mammal sources. FA analyses, being better understood at this stage of archaeological residue research, take precedence over the isotopic results in the interpretations of this thesis. However, in conjunction with the FA results, the isotopic values help to 'flesh out' interpretations of what may have been absorbed into ceramic vessels.

Table 14 The $\Delta^{13}C$ ($\delta^{13}C18‰-\delta^{13}C16‰$) of the samples from Khok Phanom Di (KPD) and Nong Nor (NN), identifying from what type of animal the lipids were likely to have been extracted from according to Hoekman-Sites (2011, 137-44)

	$\Delta^{13}C$	Animal Source
CH2563 (KPD)	0.5	Porcine Adipose Fat
CH2280 (KPD)	-0.5	Ruminant Adipose Fat
CH2567(KPD)	0.6	Porcine Adipose Fat
CH1000 (NN)	0.1	Porcine Adipose Fat
CHA4U23 (NN)	0.3	Porcine Adipose Fat
CHNN1013 (NN)	-0.1	Ruminant Adipose Fat

What *was* cooking?

In this section each sherd will be interpreted based on the results of the residue analysis, and also on the archaeological evidence. Table 15Table 15 displays a summary of flora and fauna found at sites in Thailand according to archaeological phase. This provides a series of possibilities, according to the archaeological record, of sources for the residues found in the vessels excavated from Ban Non Wat, Khok Phanom Di and Nong Nor.

Table 15 Summary of classes of edible flora and fauna for which archaeological evidence was found at sites in Thailand in the Hunter Gatherer, Bronze Age and Iron Age periods (from Higham 2002; Higham and Bannanurag 1991; Higham et al. 1998).

Hunter gatherer, KPD	Bronze Age	Iron Age
Wild mammals e.g. water buffalo, deer, pig	Domestic mammals e.g. cattle, pig, dog, chicken	Domestic mammals e.g. water buffalo, cattle, dog and pig
Marine fish and animals e.g. turtle and shark	Wild mammals e.g. water buffalo and deer species	Wild mammals e.g. deer and rhino
Domestic dog	Freshwater and marine shellfish and fish	Freshwater fish and shellfish
Freshwater fish	Rice	Marine animals e.g. turtle
Rice	Millet	Rice
		Millet

Table 34, at the end of this section, summarises the results of the various approaches to identifying absorbed residues for each sample, as described in the literature review. Overall, the classes suggested by testing modern samples (e.g. Eerkens 2005; and Zhou et al.

2003) roughly match up with what is suggested by the food classes suggested by authors working with ancient or degraded residues (e.g. Malainey et al. 1999; Craig 2008). In some cases, however, there is no real overlap between the modern sources and the expected FA ratios of the degraded residues. The possible source(s) of the ancient residues from each of the samples will be discussed below.

Sample B63 from Khok Phanom Di (Table 16), according to the food classes suggested by Eerkens' (2005), may have contained plant sources such as seeds, roots and berries. The ratio of C16:0 to C18:0, the relative amount of C18:0 and the odd numbered FA ratios divided by the ratios of the even numbered FAs (as set out by Malainey 1997 in Eerkens 2005) (hereafter "odd/even ratios") in the sample, however, suggest that this sample may have contained an animal source, perhaps a large ruminant mammal (Malainey 1997 in Eerkens 2005; Malainey 1999; Craig 2008). The presence of C24:0 may also indicate a plant source, however, and it is also found in honey (Regert et al. 2001).

Table 16 Possible interpretation of the source of FAs of sample B63 from Khok Phanom Di, using algorithms based on both modern and degraded samples

Sample	C16:C18	Eerkens1	Eerkens2	C18:0 >30% or <25%	Odd/even >0.04
B63	Animal	Seeds/roots/berries	Seeds/berries	Large herbivorous animal	Ruminant

Sample 2311 from Khok Phanom Di (Table 17), may have contained a terrestrial mammal or plant source, according to Eerkens' (2005) food classes. The C16:0 to C18:0 ratio, relative amount of C18:0, and the odd/even ratios agree with this to a degree, suggesting that the pot may have once contained the remains of a large ruminant animal (Malainey et al. 1999; Craig 2008). The only confounding factor is the presence of C22:6n3. This is one of the FAs tested for in the analysis of modern Thai freshwater fish, and is a prominent FA found in fish (Horrocks and Yeo 1999). Perhaps this sample contained both plant sources and animal, most likely of fish but possibly also mammal origin.

Table 17 Possible interpretation of the source of FAs of sample 2311 from Khok Phanom Di, using algorithms based on both modern and degraded samples

Sample	C16:C18	Eerkens1	Eerkens2	C18:0 >30% or <25%	C22:6n3	Odd/even >0.04
2311	Animal	Terrestrial mammal/seeds	Seeds/berries	Large herbivorous animal	Fish	Non ruminant

Sample 2325 from Khok Phanom Di (Table 18), following the modern food classes, may have contained fish, seeds or greens (Eerkens 2005). The ratio of C16:0 to C18:0 suggests that it is more likely to have been an animal, and the relative amount of C18:0 and odd/even FAs suggests that it was a large, herbivorous, non-ruminant animal (Malainey 1997 in Eerkens 2005; Malainey 1999; Craig 2008). Here it is possible that the sample contained an animal source such as fish or a terrestrial mammal, or a combination of both, whereas a plant source seems less likely according to the degraded sample models.

Table 18 Possible interpretation of the source of FAs of sample 2325 from Khok Phanom Di, using algorithms based on both modern and degraded samples

Sample	C16:C18	Eerkens1	Eerkens2	C18:0 >30% or <25%	Odd/even >0.04
2325	Animal	Fish/greens/seeds	Seeds/berries	Large herbivorous animal	Non ruminant

Sample 2199 from Khok Phanom Di (Table 19), according to Eerkens' (2005) designations, may have contained fish, terrestrial mammals or seeds. The C16:0 to C18:0 ratio, relative C18:0 and odd/even FAs, however, suggest that this sample was more likely to have contained a large, herbivorous, ruminant animal source (Malainey 1997 in Eerkens 2005; Malainey 1999; Craig 2008). This sample also contains C24:0, which might support the plant interpretation, or may even suggest the presence of honey (Regert et al. 2001).

Table 19 Possible interpretation of the source of FAs of sample 2199 from Khok Phanom Di, using algorithms based on both modern and degraded samples

Sample	C16:C18	Eerkens1	Eerkens2	C18:0 >30% or <25%	Odd/even >0.04
2199	Animal	Fish/seeds/terrestrial mammals	Poss. seeds?	Large herbivorous animal	Ruminant

Sample 2280 from Khok Phanom Di (Table 20) seems to contain all possible modern food classes – seeds, berries, terrestrial mammals and fish (Eerkens 2005). The C16:0 to C18:0 ratio and relative C18:0 suggest that this sample may be of plant origin, or perhaps fish. The presence of medium chained FAs in excess of 10% of the total suggests that the plant source may be greens, roots or berries, while the C16:0 to C18:0 ratio falls within the range of modern millet. This possibility is negated by the ^{13}C signature, which identifies the source of this sample as belonging to either a C_3 plant, or something that fed on it. There is an increase of +1 to 2‰ from a consumer to its food source, so animals with $\delta^{13}C$ values lower than -

22‰ are likely to have subsisted on C_3 plants (Spangenberg et al. 2006). The odd/even FAs indicate that, if of an animal source, this sample may have contained a non-ruminant animal. The $\Delta^{13}C$ value suggests that it might be ruminant instead (Hoekman-Sites 2011; Malainey 1997 in Eerkens 2005; Malainey 1999; Craig 2008). However, a plant or fish source seems more likely.

Table 20 Possible interpretation of the source of FAs of sample 2280 from Khok Phanom Di, using algorithms based on both modern and degraded samples

Sample	C16:C18	Eerkens1	Eerkens2	Medium FAs >10%	C18:0 >30%or <25%	Modern C16:C18	Odd/even >0.04	Average $\delta^{13}C$	$\Delta^{13}C$
2280	Plant	Fish/seeds/ terrestrial mammals	Seeds/ berries	Greens, root/ berries	Fish or plant	Millet	Non Ruminant	C3 plant/ fed	Ruminant

Sample 2567 (Table 21) from Khok Phanom Di may have contained plant greens, terrestrial mammals, seeds or berries (Eerkens 2005). The C16:0 to C18:0 ratio suggests that this sample may have been of a plant origin, and falls within the modern range of fish and millet. The overall C18:0 content also suggests a plant source, or perhaps fish. The presence of millet is negated by the $\delta^{13}C$ results, which confirm this sample to have either a C_3 plant source or an animal feeding on one. The $\Delta^{13}C$ value and odd/even FAs again suggest opposite results, the FAs suggesting a ruminant animal while the isotopes suggest non-ruminant (Hoekman-Sites 2011; Malainey 1997 in Eerkens 2005; Malainey 1999; Craig 2008). Overall, however, the other data seems to point more towards a plant or fish source.

Table 21 Possible interpretation of the source of FAs of sample 2567 from Khok Phanom Di, using algorithms based on both modern and degraded samples

Sample	C16:C18	Eerkens1	Eerkens2	C18:0 >30% or <25%	Modern C16:C18	Odd/even >0.04	Average $\delta^{13}C$	$\Delta^{13}C$
2567	Plant	Plant greens	mammals/ seeds/berries	Fish or plant	Fish and Millet	Ruminant	C3 plant/fed	Non Ruminant

Sample 164 from Khok Phanom Di (Table 22) may have contained seeds or berries according to the modern FA designations (Eerkens 2005). The C16:0 to C18:0 ratio, relative C18:0 content, and the presence of medium-chained FAs in excess of 10% suggest that this sample may have contained a plant source, or perhaps fish. The C16:0 to C18:0 ratio also falls within the modern range of millet, and the odd/even FAs suggest that, if of an animal origin, it may be a ruminant animal (Malainey 1997 in Eerkens 2005; Malainey 1999; Craig 2008). The

fact that almost all edible plants in Thailand have C_3 synthetic pathways, and the results of isotopic analyses, however, suggests that millet is not a very likely source. A different plant source, or perhaps fish, is a more likely interpretation of the data.

Table 22 Possible interpretation of the source of FAs of sample 164 from Khok Phanom Di, using algorithms based on both modern and degraded samples

Sample	C16:C18	Eerkens1	Eerkens2	Medium FAs >10%	C18:0 >30% or <25%	Modern C16:C18	Odd/even >0.04
164	Plant	Possibly seeds/ berries/fish/greens	Seeds/berries	Greens, roots/ berries	Fish or plant	Millet	Ruminant

Sample 2271 from Khok Phanom Di (Table 23) did not possess all of the FAs necessary to compare it against the modern food classes proposed by Eerkens (2005). It does fall within the modern range of millet C16:0 to C18:0 ratio. However, as mentioned previously, millet is not a very likely source. The C16:0 to C18:0 ratios suggest this sample has a plant origin, as does the relative amount of C18:0 and the presence of medium-chain FAs in excess of 10%. The odd/even FAs suggest that, if there are any animal sources present, they are non-ruminant (Malainey 1997 in Eerkens 2005; Malainey 1999; Craig 2008). The most likely interpretation of this sample is that the vessel once contained food of a plant source.

Table 23 Possible interpretation of the source of FAs of sample 2271 from Khok Phanom Di, using algorithms based on both modern and degraded samples

Sample	C16:C18	Eerkens1	Eerkens2	Medium FAs >10%	C18:0 >30% or <25%	Modern C16:C18	Odd/even >0.04
2271	Plant	Possibly seeds/berries/ terrestrial mammals/ greens	Possibly seeds	Greens, roots/ berries	Fish or plant	Millet	Non ruminant

Sample 1694 from Khok Phanom Di (Table 24) falls within the modern ranges of plant greens, terrestrial mammals and possibly fish (Eerkens 2005). The C16:0 to C18:0 ratio suggests it is of plant origin, and the relative amount of C18:0 suggests plant or fish sources. It falls within the modern ratios of C16:0 to C18:0 for both millet and fish, and the odd/even FAs suggest that, if there are animal sources present in this sample, they are from ruminant animals (Malainey 1997 in Eerkens 2005; Malainey 1999; Craig 2008). The most likely interpretation of this sample appears to be a combination of plant and animal, perhaps fish or ruminant mammal, sources.

Table 24 Possible interpretation of the source of FAs of sample 1694 from Khok Phanom Di, using algorithms based on both modern and degraded samples

Sample	C16:C18	Eerkens1	Eerkens2	C18:0 >30% or <25%	Modern C16:C18	Odd/even >0.04
1694	Plant	Plant greens	Terrestrial mammals/ Possibly fish	Fish or plant	Fish and Millet	Ruminant

Sample 2563 from Khok Phanom Di (Table 25) does not fall within the modern ranges of any food class, but is instead equidistant between greens, fish, seeds and terrestrial mammals (Eerkens 2005). The C16:0 to C18:0 ratio suggests that this sample is of plant origin, as does the presence of medium-chained FAs in excess of 10%. The relative C18:0 content suggests a plant or fish source. This sample falls within the modern ranges of millet and fish for C16:0 to C18:0 ratios and the odd/even FAs suggest that any animal sources present are non-ruminant in nature. The average $\delta^{13}C$ values suggest that this sample is either of a C_3 plant source, ruling out millet, or of something subsisting on these sources. The $\Delta^{13}C$ value also suggests that any animal sources present are non-ruminant (Hoekman-Sites 2011; Malainey 1997 in Eerkens 2005; Malainey 1999; Craig 2008). This sample most likely contained C_3 plant sources, perhaps plant greens, and may have also contained some residues of fish origin.

Table 25 Possible interpretation of the source of FAs of sample 2563 from Khok Phanom Di, using algorithms based on both modern and degraded samples

Sample	C16:C18	Eerkens1	Medium FAs >10%	C18:0 >30% or <25%	Modern C16:C18	Odd/even >0.04	Average $\delta^{13}C$	$\Delta^{13}C$
2563	Plant	Equidistant between greens, fish, seeds & terrestrial mammals	Greens, roots/ berries	Fish or plant	Fish and Millet	Non ruminant	C3 plant/fed	Porcine

Sample 1013 from Nong Nor (Table 26), falls within the modern range of seeds and berries, and possibly also fish or greens (Eerkens 2005). The ratio of C16:0 to C18:0 suggests that this sample has a plant source, as does the presence of medium-chained FAs in excess of 10%, while the relative C18:0 suggests that it is of fish or plant origin. The sample falls within the modern ratios of C16:0 to C18:0 for both fish and millet, although the $\delta^{13}C$ values negate millet as a possible source, and instead suggest a C_3 plant or animal fed on C_3 sources. The odd/even FAs suggest that any animal residues present would be from a ruminant animal while the $\Delta^{13}C$ instead suggests that it would be non-ruminant (Hoekman-Sites 2011;

Malainey 1997 in Eerkens 2005; Malainey 1999; Craig 2008). The most likely interpretation is that this sample contained a C_3 plant source, and may have contained fish feeding on these C_3 sources.

Table 26 Possible interpretation of the source of FAs of sample 1013 from Nong Nor, using algorithms based on both modern and degraded samples

Sample	C16:C18	Eerkens1	Eerkens2	Medium FAs >10%	C18:0 >30%or <25%	Modern C16:C18	Odd/even >0.04	Average $\delta^{13}C$	$\Delta^{13}C$
1013	Plant	Possibly seeds/ berries/fish/greens	Seeds/ berries	Greens, roots/ berries	Fish or plant	Fish and Millet	Ruminant	C3 plant/fed	Porcine

Sample A4U23 from Nong Nor (Table 27) falls within the modern ranges of seeds and berries, and potentially could also fall within the range of terrestrial mammals (Eerkens 2005). The C16:0 to C18:0 ratio suggests that this sample could be of a plant or an animal source. The relative amount of C18:0 suggests that a large herbivorous mammal is a likely source, and odd/even FAs suggest that it would be non-ruminant. The $\Delta^{13}C$ value again opposes this, and suggests that the animal source may instead be a ruminant one, while the $\delta^{13}C$ values suggest that this sample contains either a C_3 plant source or animal fed on this (Hoekman-Sites 2011; Malainey 1997 in Eerkens 2005; Malainey 1999; Craig 2008). The evidence suggests that this sample most likely contained a terrestrial mammal source fed on C_3 plants, and perhaps the plant sources themselves.

Table 27 Possible interpretation of the source of FAs of sample A4u23 from Nong Nor, using algorithms based on both modern and degraded samples

Sample	C16:C18	Eerkens1	Eerkens2	C18:0 >30% or <25%	Odd/even >0.04	Average $\delta^{13}C$	$\Delta^{13}C$
A4u23	Plant/Animal	Possibly seeds/ terrestrial mammals	Seeds/berries	Large herbivorous animal	Non ruminant.	C3 plant/fed	Ruminant

Sample 1000 from Nong Nor (Table 28) falls within the modern range of seeds or berries, and possibly terrestrial mammals or greens (Eerkens 2005). The ratio of C16:0 to C18:0 suggests a plant source, the relative C18:0 content suggests a fish or plant origin, while the odd/even FAs suggest that any animal sources are non-ruminant. The sample falls within the modern range of millet for C16:0 to C18:0 ratios but the $\delta^{13}C$ values, again, negate the presence of any C_4 plant sources in this sample. The $\Delta^{13}C$ value agrees with the interpretation that any animal sources would be non-ruminant (Hoekman-Sites 2011; Malainey 1997 in

Eerkens 2005; Malainey 1999; Craig 2008). This sample most likely contained a C_3 plant source, and perhaps fish feeding on these.

Table 28 Possible interpretation of the source of FAs of sample 1000 from Nong Nor, using algorithms based on both modern and degraded samples

Sample	C16:C18	Eerkens1	Eerkens2	C18:0 >30% or <25%	Modern C16:C18	Odd/even >0.04	Average $\delta^{13}C$	$\Delta^{13}C$
1000	Plant	Possibly seeds/berries/ terrestrial mammals/ greens	Seeds/berries	Fish or plant	Millet	Non ruminant	C3 plant/fed	Porcine

Sample 551 from Nong Nor (Table 29) falls within the modern range of seeds or berries, and possibly terrestrial mammals or greens (Eerkens 2005). The C16:0 to C18:0 ratio suggests that this sample contained a plant source, while the relative C18:0 content suggests a large herbivorous mammal, that, according to the odd/even FAs, is a non-ruminant animal (Hoekman-Sites 2011; Malainey 1997 in Eerkens 2005; Malainey 1999; Craig 2008). This sample may have contained a mixture of plant and mammal resources.

Table 29 Possible interpretation of the source of FAs of sample 551 from Nong Nor, using algorithms based on both modern and degraded samples

Sample	C16:C18	Eerkens1	Eerkens2	C18:0 >30% or <25%	Odd/even >0.04
551	Plant	Possibly seeds/berries/terrestrial mammals/greens	Seeds/berries	Large herbivorous animal	Non ruminant

Sample 21285 from Ban Non Wat (Table 30) does not contain all of the FAs necessary to place it in any of the modern food classes proposed by Eerkens (2005). It does, however, contain C16:0, C18:1 and C18:2 in excess of 90%, which Zhou et al. (2003) found to be the case in all modern examples of rice. The C16:0 to C18:0 ratio, however, suggest that this sample contained an animal source, the relative amount of C18:0 and the odd/even FAs suggesting a large herbivorous and non-ruminant mammal (Malainey 1997 in Eerkens 2005; Malainey 1999; Craig 2008). This sample may have contained a large mammal source, and perhaps some rice or a similar plant source, but, until comparing modern to ancient FA ratios is better understood, the evidence suggests an animal source.

Table 30 Possible interpretation of the source of FAs of sample 21285 from Ban Non Wat, using algorithms based on both modern and degraded samples

Sample	C16:C18	Zhou	C18:0 >30% or <25%	Odd/even >0.04
21285	Animal	Rice	Large herbivorous animal	Non ruminant

Sample 23109 from Ban Non Wat (Table 31) falls within the modern range of seeds or berries, and possibly in the range of terrestrial mammals as well (Eerkens 2005). FAs C16:0, C18:1 and C18:2 are present in excess of 90%, which might indicate the presence of rice (Zhou et al. 2003). The C16:0 to C18:0 ratio suggests that this sample contained an animal source, the odd/even FAs and relative C18:0 suggesting a large ruminant mammal (Malainey 1997 in Eerkens 2005; Malainey 1999; Craig 2008). The evidence suggests that this sample contained an animal source, possibly a ruminant mammal.

Table 31 Possible interpretation of the source of FAs of sample 23109 from Ban Non Wat, using algorithms based on both modern and degraded samples

Sample	C16:C18	Eerkens1	Eerkens2	C18:0 >30% or <25%	Odd/even >0.04
23109	Animal	Possibly seeds/terrestrial mammals	Seeds/berries	Large herbivorous animal	Ruminant

Sample 19630 from Ban Non Wat (Table 32) falls within the modern range of seeds or berries, and possibly in the range of fish or greens (Eerkens 2005). C16:0, C18:1 and C18:2 are present in excess of 90% which might indicate rice (Zhou et al. 2003). The C16:0 to C18:0 ratio suggests that this sample contained an animal source, the relative C18:0 and odd/even FAs suggesting a large non-ruminant animal (Malainey 1997 in Eerkens 2005; Malainey 1999; Craig 2008). This sample does, however, also contain C22:6n3 which probably indicates the presence of fish (Horrocks and Yeo 1999). The evidence suggests that this sample may have contained a plant and animal, most likely fish, source.

Table 32 Possible interpretation of the source of FAs of sample 19630 from Ban Non Wat, using algorithms based on both modern and degraded samples

Sample	C16:C18	Eerkens1	Eerkens2	Zhou	C18:0 <25%	>30% or	C22:6n3	Odd/even >0.04
19630	Animal	Possibly seeds/berries/ fish/ greens	Seeds/berries	Rice	Large animal	herbivorous	Fish	Non ruminant

Sample 12127 from Ban Non Wat (Table 33) did not contain all of the FAs necessary to designate it a modern food class according to the criteria proposed by Eekens (2005). According to Zhou et al. (2003), rice may have been contained in this sampl,e as C16:0, C18:1 and C18:2 are present together in excess of 90%. The C16:0 to C18:0 ratio, however, suggests an animal source, the relative C18:0 and odd/even FAs suggesting it was a large herbivorous and non-ruminant animal (Malainey 1997 in Eerkens 2005; Malainey 1999; Craig 2008). With no other evidence it seems most likely that this sample contained an animal source, potentially a herbivorous and non-ruminant one.

Table 33 Possible interpretation of the source of FAs of sample 12127 from Ban Non Wat, using algorithms based on both modern and degraded samples

Sample	C16:C18	Zhou	C18:0 >30% or <25%	Odd/even >0.04
12127	Animal	Rice	Large herbivorous animal	Non ruminant

Summary

The samples from Khok Phanom Di have the widest range of possible interpretations. These range from solely a plant or animal source, to a combination of plant and animal sources, which may include both fish and terrestrial mammals. The isotopic results from Khok Phanom Di indicate that all samples tested were either from a C_3 plant source, or an animal feeding on these.

The samples from Nong Nor also have varying interpretations, but seem most likely to be a combination of C_3 plants and animals, whether fish or mammal, feeding on these plants.

The samples from Ban Non Wat have the narrowest range of interpretations. All appear to have contained an animal source, half of mammal and half of fish. All four samples, however, are the only ones to meet Zhou et al.'s (2003) criteria for identifying modern rice. Until it is better understood how one should go about comparing modern FA compositions with degraded samples, it seems more likely that these samples contained an animal source.

Only six samples provided $\delta^{13}C$ values, and these all indicated that the residue was composed of C_3 plants, or of animals feeding on these, or both. Unfortunately isotopic values could not be obtained for other samples, but, due to the fact that almost all edible plants in Thailand have a C_3 synthetic pathway, it is feasible that C_3 plants are a more likely source than C_4 plants (King and Norr 2006). This suggests that, despite some samples falling in the

modern ranges of the C16:0 to C18:0 ratio of millet, it is an unlikely origin for the plant source found in the residues.

However, it is important to remember that prehistoric people did not process only one resource in their pots (Reber 2007), and so it is difficult to define a single source of residues. In some of the cases where there is evidence for many different, and sometimes conflicting, resources, this may indicate a scenario in which multiple sources were prepared, cooked or stored in the vessel, either in one cooking or serving event, or over a series of these.

Table 34 Interpretation of individual sample residues according to all suggested classification schemes of both modern and degraded fatty acids and isotopic values according to those set out in the literature review (Craig 2008; Eerkens 2005; Hoekman-Sites 2011; Horrocks and Yeo 1999; Malainey 1997 in Eerkens 2005; Malainey 1999; Spangenberg 2006). (T. Mammals=terrestrial mammals; Poss.=possibly; N. Ruminant=non ruminant)

Sample	C16:C18	Eerkens1	Eerkens2	Zhou	Medium FAs >10%	C18:0 >30% or <25%	Modern C16:C18	C22:6 n3	Odd/even >0.04	Average $\delta^{13}C$	$\Delta^{13}C$
B63	Animal	Seeds/roots/berries	Seeds/berries	< 90%	< 10%	Large herbivorous animal			Ruminant		
2311	Animal	T. mammal/seeds	Seeds/berries	< 90%	< 10%	Large herbivorous animal		Fish	N.ruminant		
2325	Animal	Fish/greens/seeds	Seeds/berries	< 90%	< 10%	Large herbivorous animal			N.ruminant		
2199	Animal	Fish/seeds/T. Mammals	Poss. seeds?	< 90%	< 10%	Large herbivorous animal			Ruminant		
2280	Plant	Fish/seeds/T. mammals	Seeds/berries	< 90%	Greens, root / berries	Fish or plant	Millet		N.ruminant	C_3 plant/fed	Ruminant
2567	Plant	Plant greens	T. mammals/seeds/ berries	< 90%	< 10%	Fish or plant	Fish and Millet		Ruminant	C_3 plant/fed	Porcine
164	Plant	Poss. seeds/ berries/fish/greens	Seeds/berries	< 90%	Greens, roots/ berries	Fish or plant	Millet		Ruminant		
2271	Plant	Poss. seeds/berries/T. mammals/greens	Poss. seeds	< 90%	Greens, roots/ berries	Fish or plant	Millet		N.ruminant		
1694	Plant	Plant greens	T. mammals/ Poss. fish	< 90%	< 10%	Fish or plant	Fish and Millet		Ruminant		
2563	Plant	= between greens, fish, seeds & T. mammals		< 90%	Greens, roots/ berries	Fish or plant	Fish and Millet		N.ruminant	C_3 plant/fed	Porcine
1013	Plant	Poss. seeds/ berries/fish/greens	Seeds/berries	< 90%	Greens, roots/ berries	Fish or plant	Fish and Millet		Ruminant	C_3 plant/fed	Porcine
A4u23	Plant/Animal	Poss. seeds/T. mammals	Seeds/berries	< 90%	< 10%	Large herbivorous animal			N.ruminant	C_3 plant/fed	Ruminant
1000	Plant	Poss. seeds/berries/T. mammals/greens	Seeds/berries	< 90%	< 10%	Fish or plant	Millet		N.ruminant	C_3 plant/fed	Porcine
551	Plant	Poss. seeds/berries/T. mammals/greens	Seeds/berries	< 90%	< 10%	Large herbivorous animal			N.ruminant		
21285	Animal	N/A	N/A	Rice	< 10%	Large herbivorous animal			N.ruminant		
23109	Animal	Poss. seeds/T. mammals	Seeds/berries	< 90%	< 10%	Large herbivorous animal			Ruminant		
19630	Animal	Poss. seeds /berries/fish/ greens	Seeds/berries	Rice	< 10%	Large herbivorous animal		Fish	N.ruminant		
12127	Animal	N/A	N/A	Rice	< 10%	Large herbivorous animal			N.ruminant		

Limitations

The original aim of this research project was to look for the presence of a 'rice wine' or other fermented beverage in vessels of a particular shape and form from Ban Non Wat. This form, with a broad-trumpet rim, and common to particularly wealthy burials in the Bronze Age, was suggested to have been used in mortuary feasting as containers of an alcoholic beverage (Higham in Hauman 2009). All literature read prior to sampling was carried out with this vessel form and the intention to find evidence of a 'rice wine' in mind. All sherds collected from Ban Non Wat and Ban Salao were sourced from the base of vessels, this being the most likely place for a liquid to be absorbed (McGovern 2005). No vessels, however, were of the particular form sought, and being generally of a 'squatter' shape, were unlikely to have been used for the consumption or storage of beverages. In many of the pots small bones belonging to fish and other vertebrates were also uncovered, making the presence of an alcoholic beverage even less likely. The project was therefore modified to study whether or not residues could be extracted from those sherds, and, if so, whether anything could be said about the possible contents of the vessel from which the sherd originated.

It is essential, however, for different areas of the same vessel to be tested. Barnard et al. (2007) found that fats were more likely to be absorbed higher up in vessels, at the 'boil line', and so would result in lighter $\delta^{13}C$ values in a sample than those collected lower in the vessel, where the heavier carbohydrates and proteins were more likely to be absorbed. Similarly, Charters et al. (1993) found that differently shaped vessels accumulated lipids in different areas, and might reflect different uses or ways of cooking.

This possible bias in sampling was removed by the loss of all of the original samples during the methylation process. All samples that were successfully analysed were collected from whole vessels (for the surviving Ban Non Wat samples) from an unspecified location on the body, while the sherds from Nong Nor and Khok Phanom Di, apart from a general archaeological context, were completely unknown in terms of either vessel form or sherd location. This, while alleviating one limitation, led to another.

The samples from Khok Phanom Di and Nong Nor, collected from the Department of Anthropology and Archaeology's off-site storage at the University of Otago, did not all have a secure archaeological context. It was possible to assign the majority of sherds to either a mortuary phase or general time period, but, for the most part, not much more can be said of them. A few, fortunately, were catalogued vessels from burial contexts, and so a description or image of these could be located. The vast majority, however, were without this

information. This, in a way, recreates the 'blind round-robin' test carried out by Barnard et al. (2007), and was a way of testing the methods of analysis themselves. However, without knowing the exact context of the samples, nor even the vessel form from which they were collected, accurate interpretations are both more difficult to make, and also less meaningful. It is not possible to assign certain food classes to particular vessel forms, as one might do if certain pots were consistently showing up with a particular pattern of FAs.

Without a secure context or knowledge of vessel shape, interpretations may also have to be more general than if a precise archaeological context were known. The current uncertainties associated with ancient residues, however, mean that a general interpretation is better than a definite identification, which may not be accurate and end up being misleading. Residue analysis is not an exact science yet, but with further work it can become more accurate, and increasingly valuable to archaeological research. This thesis, while not able to make deductions about the past uses of particular vessel forms, was able to provide a general picture of what may have been contained in ceramics in ancient Thailand. It highlights the feasibility and potentials of carrying out residue analysis in Southeast Asian archaeology

Thailand, located in the sub-tropics and therefore subject to monsoons and long dry seasons, is not an ideal place for the survival of organic material (Evershed 2008). Compounding this, prehistoric sites are often just on, or below, the local water-table and would be inundated during the wet season. While some individuals were buried in coffins, the majority were interred in the ground, giving microorganisms and invertebrates free rein to feast on any organics contained in ceramic vessels. Sea level fluctuations will have affected the previously coastal sites of Nong Nor and Khok Phanom Di, while occasional flooding, either seasonal during the monsoon, or through severe weather events, will have affected all of the sites (Bellwood and Glover 2004; Higham 2002). However, wood was discovered in post holes at Khok Phanom Di, suggesting that conditions at this site, at least, may have been conducive to the survival of organic materials (Higham 2002, 61). As mentioned previously, FAs preserved in residues from Khok Phanom Di are the most varied in terms of saturated, unsaturated and polyunsaturated, as well as in terms of the presence of odd numbered chains of FAs. This might reflect the favourable conditions for organics survival at this site.

Another issue with the sherds collected from Khok Phanom Di and Nong Nor, as well as those from reconstructed vessels from Ban Non Wat, is that it is uncertain how they may have been handled during excavation, washing, reconstruction, and even storage. It was unclear how washing would affect the absorbed residues, or if there would be any left to

extract. Fortunately, there seemed to have been little effect on the residues. Perhaps, protected in the ceramic matrix, FAs were prevented from untoward damage. Water used for washing the sherds prior to sorting would have been free of detergents, and so similar to the percolating ground water in which the sherds would have been buried. Modern contamination by human handling seems negligible, although this is something that will need to be addressed in future research projects. Without samples being specifically collected and treated for residue analysis, it is not clear how post-excavation treatment may have affected the absorbed residues. All precautions were taken in the laboratory, however, to prevent further contamination. A way around possible sample contamination in the future is to grind off the outer surfaces of the sherd, leaving only the interior matrix, in which the residues should have been absorbed.

The long storage times of sherds from Khok Phanom Di and Nong Nor, compared with the shorter storage period of Ban Non Wat samples, did not seem to affect the residues very much either, as sherds from Khok Phanom Di had the most varied and well preserved FAs extracted.

One other issue, or question, that was dealt with in this thesis, is what the best method of extracting residues from ceramic sherds was. The original samples collected from Ban Non Wat and Ban Salao were not allowed to be extracted in any way which would be destructive, and so samples tested were restricted by the size of the glassware available in the Department of Chemistry at the University of Otago. Even sherds which could fit into the Soxhlet provided negligible extraction results, and a noticeable difference was found between the residues extracted from whole sherds and those extracted from ground sherds. When sherds from reconstructed Ban Non Wat vessels and sherds from Khok Phanom Di and Nong Nor were added to the experiment, this allowed the extraction of whole sherds to be compared with extracting sherds ground to a fine powder. While the disappointing loss of the original samples did not enable an accurate quantitative approach to this question, it was observed that samples which had been ground resulted in a larger range of fatty acids in identifiable quantities. This shows that, in future projects, grinding samples prior to extraction using a Soxhlet apparatus is the preferred method, and that residue analysis, by its nature, has to be destructive to furnish us with accurate data.

Future Avenues of Research

It has been well documented that environmental factors affect the survival of organic matter in the archaeological record (Evershed 2008). It is known that preferential preservation occurs in certain circumstances: in very dry areas, such as those found in Egypt (McGovern et al. 2009); in boggy areas found, for example, at Monte Verde in Chile (McGovern et al. 2009); or in cases where the residues are safely sealed from outside influences, such as in stoppered vessels or sealed tombs (for example, the large amount of yeast DNA found in closed pottery containers in a tomb at Abydos, (Cavalieri et al. 2003); and liquid beverage samples found in tightly lidded bronze vessels from the Shang and Western Zhou Dynasties, (McGovern et al. 2004)). It is also known that constant changes in temperature and humidity, as well as exposure to oxygen and consumption by microorganisms and invertebrates, are detrimental to the survival of organics. What is not well understood, however, is to what extent absorbed residues are affected by these factors. How do the different FAs degrade in different environments? How does this affect the surviving ratios? Do the longer chained FAs degrade to form shorter chained FAs (Malainey et al. 1999), or do they form two separate short chain FAs? Or, do they even form different organic compounds? Isotopic signatures remain constant and unchanging over the course of time, but, in the case of residue analyses, they are often extracted from decaying FAs. How does this affect any isotopic signatures obtained? Will compound-specific isotopic analysis take precedence over FA profiles, eventually being a more consistent way to predict vessel contents? These are all issues that need to be addressed in future residue analyses to increase the accuracy and relevance of the field.

The best way to understand the degradation processes affecting organics in different regions is through experimentation. Replicating long-term decomposition and recreating different conditions, such as the experiments carried out by Malainey (2007), are one approach. Another possibility involves the experimental degradation of different foodstuffs by interring them in the same environment that the archaeological samples are sourced from. Ideally the foodstuffs would be similar to those expected in the archaeological record, and cooked in a roughly similar fashion, in a series of vessels of the same shape and fabric as those excavated. Before burial, isotopic signatures and FA ratios of different food classes would be measured, and, after a predetermined time period, and after several more such time periods, a vessel would be excavated and the data re-measured. Different areas of the vessel could be subjected to analysis at the same time, to avoid any bias in this respect. This data can

then be used to develop an algorithm of the expected decomposition rates of varying FAs, and how this affects the isotopic signatures obtained from them. This would help archaeologists understand the degradation rates of organics under similar conditions to those that their archaeological samples are exposed to, and provide a better understanding of the applicability of using modern foods to determine the origin of archaeological residues.

Once residue analyses become more commonly used in research projects, and the effects of degradation on the FAs and isotopes are better understood, it will be easier to analyse and classify ceramic vessels using traditional methods of ceramic analyses. Traditional analyses can be carried out at far less cost, and most likely in less time. For example, McGovern et al. (2005), found that some forms of Neolithic pottery in China were very similar in form to bronze vessels found in the Bronze Age that were known to have been used for drinking and preparing fermented beverages. The residues from these ceramic vessel forms were analysed, and evidence for the presence of some form of fermented beverage was found in all of them. Reber (2007) also found that variations in vessel form roughly corresponded with past vessel use. If, similarly, at other sites, a particular form could consistently be shown to contain residues of a particular foodstuff, a similar use for all vessels of that form at the site could be conjectured. Further analyses of these vessels would be much easier, as the vessel use would already have been interpreted, and this would, in turn, make any classifications more accurate, based on use as well as form.

Ancient residue analysis, being in its infancy, has a long way to go before it reaches its full potential. Fortunately, it is becoming a more popular method of investigating the past. As well as being carried out in various parts of Europe, East Asia and North America, research projects have started in many other parts of the world. As well as this thesis, in Southeast Asia, for example, Kanthilatha (pers. comm.) is examining sediment samples from ‘floors’ at Non Hua Ret, located seven kilometres away from Ban Non Wat. She is using inductively coupled plasma mass spectrometry (ICP/MS) to analyse trace elements, GC/MS for FAs, and is also looking at any phytolith evidence. Initial results suggest the presence of a series of FAs.

As more work is carried out on analysing ancient residues, a better understanding of its use in the archaeological context will be reached. Publishing of results, even negative ones, and communication and collaboration between researchers in different laboratories and parts of the world will only increase the relevance of this study to the field of archaeology. A reliable database of FAs, isotopes, and other components should be created for different

regions and different environments. As suggested by Evershed (2008), more quantitative analyses using internal standards are necessary, to allow archaeologists to make both intra and inter-site/region comparisons. Overall this will contribute to our understanding of past societies, their rituals and practices, and the way in which they used their material culture.

Summary

In this chapter the results in the previous section were described and discussed more fully. First the FA results and then the isotopic results were compared with values obtained from modern samples of foodstuffs possibly contained in the vessels. An interpretation was made based on this evidence, and on models suggested in the literature for degraded samples, for each sherd. Limitations encountered in this particular project were detailed, and ways in which they were dealt with and could be avoided in future studies were given. Finally, questions which need to be answered in residue analysis, as well as some ways in which this could be achieved, and the future potential of archaeological residue analyses were presented.

CONCLUSION

Understanding the past uses a ceramic vessel may have been put to contributes to the understanding of the activities and lives of former peoples.

Residue analysis, a relatively new avenue of archaeological enquiry, is a way to directly analyse the former contents of pots, which allows a more accurate interpretation to be made of vessel use. This, in turn, permits archaeologists to paint a more full, colourful and accurate picture of the past.

This thesis explored whether it was possible to undertake successful analyses of residues absorbed into ceramic vessels from Southeast Asia. Sherds from four sites in Thailand, Ban Non Wat, Ban Salao, Khok Phanom Di and Nong Nor were selected, either during excavation or from storage, for analysis. The sites ranged in terms of time from the pre-metal and Neolithic ages through to the late Iron Age.

Despite difficulties in sampling bias, loss of samples, and then years of storage and an uncertainty of both context and past handling, the majority of the sherds analysed yielded appreciable amounts of fatty acids (FAs), which allowed some interpretation. Six of the samples also provided carbon isotopic signatures for five FAs. This demonstrates that it is possible to conduct a successful residue analysis in Southeast Asia, even with factors which made the survival of organic residues unlikely, such as the monsoon climate (constant wetting and drying) and considerable time depth of all of the sites.

While not all samples were interpretable, ten sherds from Khok Phanom Di and four each from Nong Nor and Ban Non Wat yielded enough data to allow likely food classes to be assigned to each sherd. The isotopic analyses were able to show that the most likely source contained in the pots is of a C_3 plant source, like rice, or animals, such as terrestrial mammals and freshwater fish, feeding on these sources. Despite some archaeological evidence for the presence of millet, the isotopic signatures did not support the possibility of C_4 plants sources being present in the vessels studied. The archaeological evidence, however, does support both fish and terrestrial mammals, and possibly rice, as likely candidates for residue sources in the pot samples.

Further work is necessary to fully understand the complex degradation likely to occur in samples from sites in Southeast Asia, and to allow more accurate comparisons between modern and degraded FA or isotopic samples.

This study, which has shown that residue analysis is not only possible, but a viable means of researching the use of ancient ceramics in Southeast Asia, is a useful springboard for future analyses in the field.

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APPENDICES

Appendix 1: Fatty Acid Chromatograms and Unprocessed Fatty Acid Results

Samples from Khok Phanom Di

Figure 28 shows the results of analysis carried out on B.63 from mortuary phase 3 at Khok Phanom Di. The most prominent fatty acids are C18:0 and C16:0, in that order, followed by C18:1n-9, although there are many other fatty acids present in smaller quantities. Interestingly, longer-chained fatty acids, such as C20:0 and C22:0 and their isomers are also present, albeit in much smaller amounts. There is also some C19:0 present in the sample. Odd-numbered chains of fatty acids are potentially indicative of microbial activity.

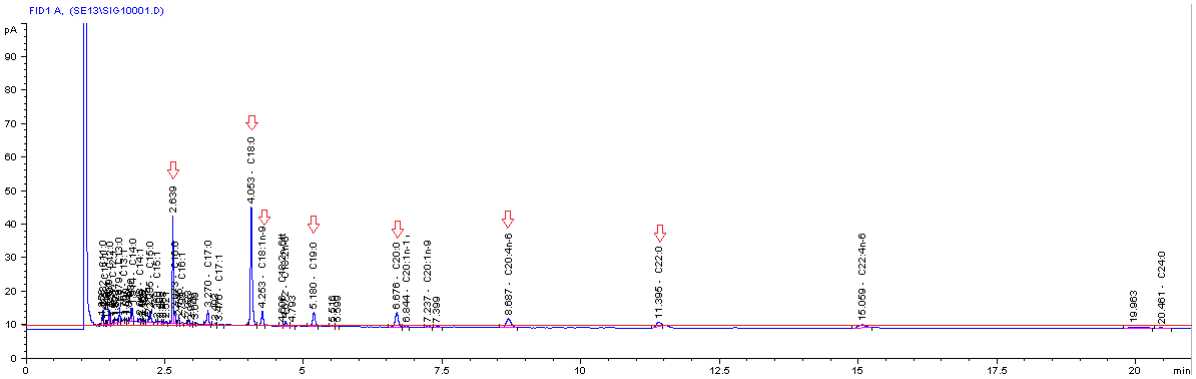


Figure 28 Chromatogram for fatty acids extracted from sample B63 from Khok Phanom Di

Figure 29 shows the results from GC-MS analysis of sample 2311. Again C16:0 and C18:0, and two of its isomers C18:1n-9 and C18:1n-7, are the fatty acids present in the greatest amounts. In this case there is more C16:0 than C18:0 present. Some longer-chained fatty acids are also present but they are in much smaller amounts.

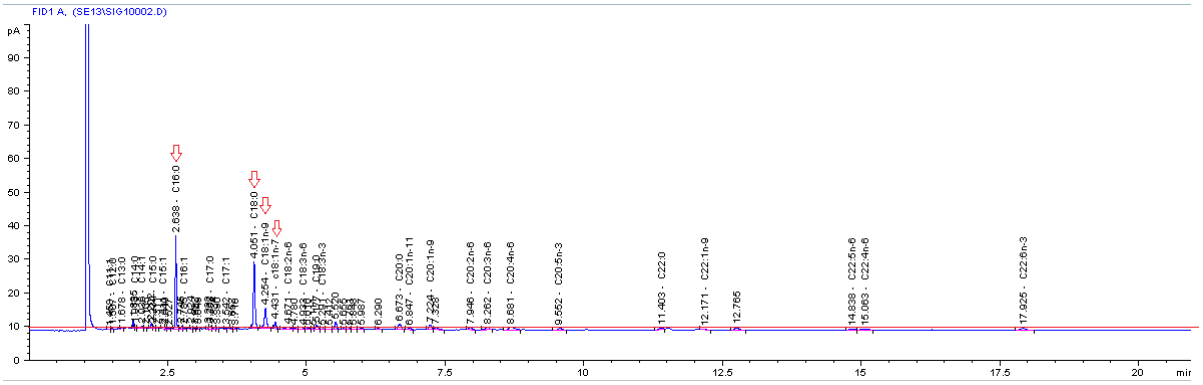


Figure 29 Chromatogram for fatty acids extracted from sample 2311 from Khok Phanom Di

Figure 30 displays results from sample 2325. As with other samples, the fatty acids present in the greatest quantities are C16:0 and C18:0, with C16:0 relatively more abundant. C18:1n-9, C20:0 and two of its isomers, as well as some C14:0 are also found in this sample.

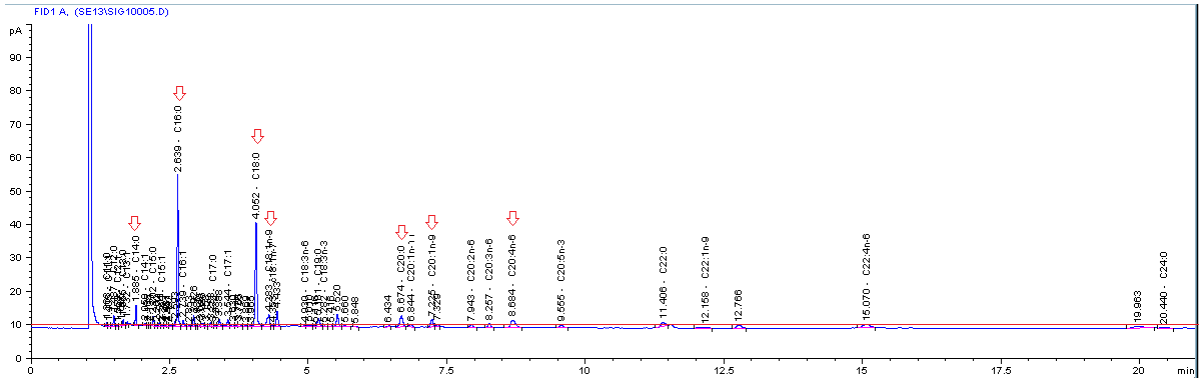


Figure 30 Chromatogram for fatty acids extracted from sample 2325 Khok Phanom Di

Figure 31 shows results from sample 2199. There are large quantities of both C16:0 and C18:0, with relatively more of C16:0. C18:1n-9, C20:0 and C22:0 are present, as well as quite high peaks of C12:0 and C14:0.

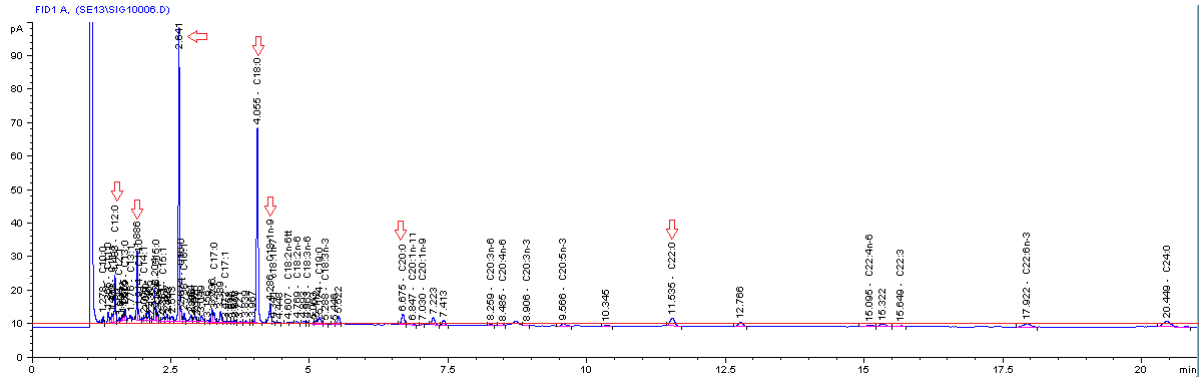


Figure 31 Chromatogram for fatty acids extracted from sample 2199 from Khok Phanom Di

Figure 32 shows the results from analysis of sample 2280. This sample has comparatively little in both variety and quantities of fatty acids. There is still some C16:0 and, slightly less, C18:0, but there is more C12:0 than either of them. C14:0 is also present in appreciable quantities.

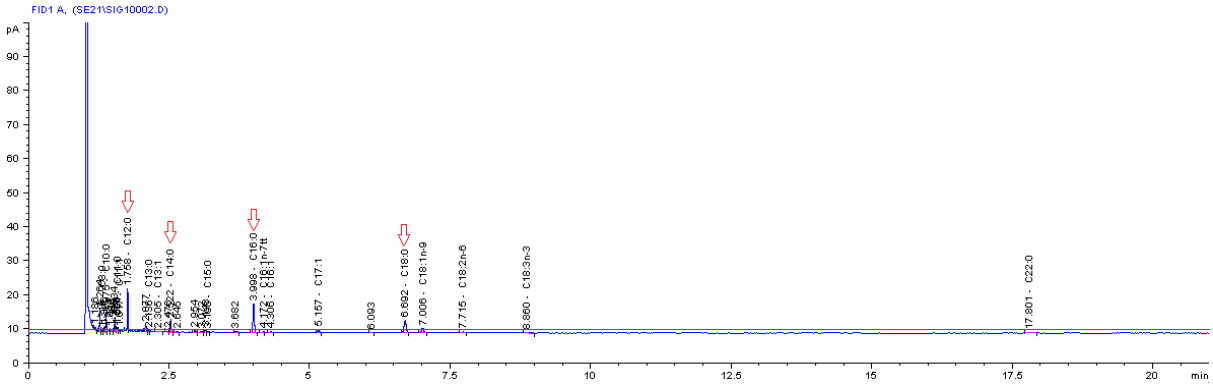


Figure 32 Chromatogram for fatty acids extracted from sample 2280 from Khok Phanom Di

Figure 33 shows the results from analysis of sample 2567. This sample is depleted in fatty acids compared to other samples. While C16:0 and C18:0 are present it is in small quantities, with slightly more C16:0 than C18:0.

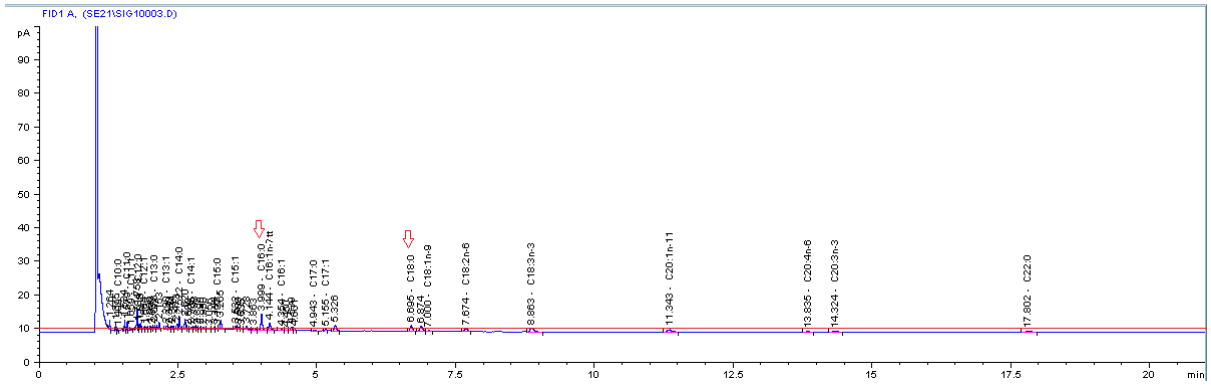


Figure 33 Chromatogram for fatty acids extracted from sample 2567 from Khok Phanom Di

Figure 34 shows the results from analysis of sample 164. The most prominent fatty acids in this sample are C16:0 followed by C12:0 and C18:0. C18:1n-9 and C14:0 are also present in reasonable quantities, with many other fatty acids present in much smaller quantities. C12:0 is, however, present in greater quantities than both C16:0 and C18:0. The odd-chained C15:0 is also present in appreciable quantities in this sample.

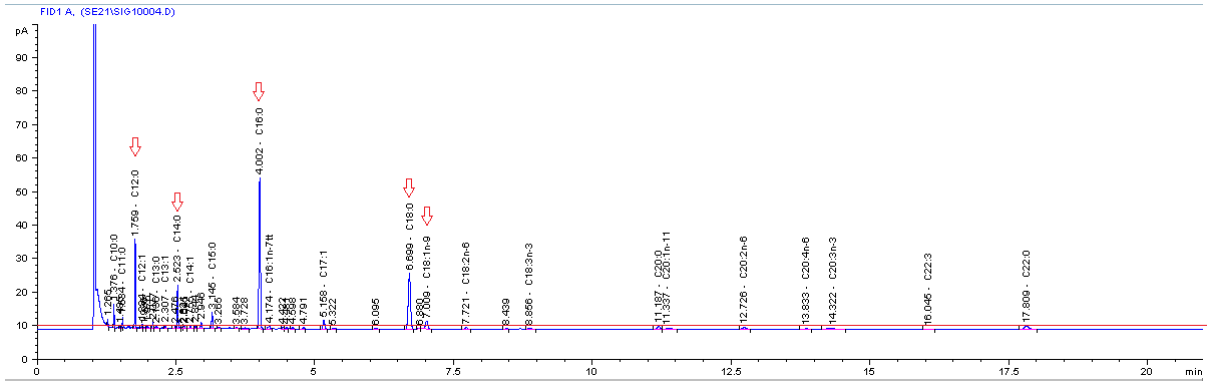


Figure 34 Chromatogram for fatty acids extracted from sample 164 from Khok Phanom Di

Figure 35 shows the results from analysis of sample 2271. This sample is unusual in that the shorter-chained fatty acids, C10:0 and C12:0, are more prominent than C16:0 and C18:0. There is more C16:0 than C18:0 present in this sample and there is a small amount of both C18:1n-9 and C14:0.

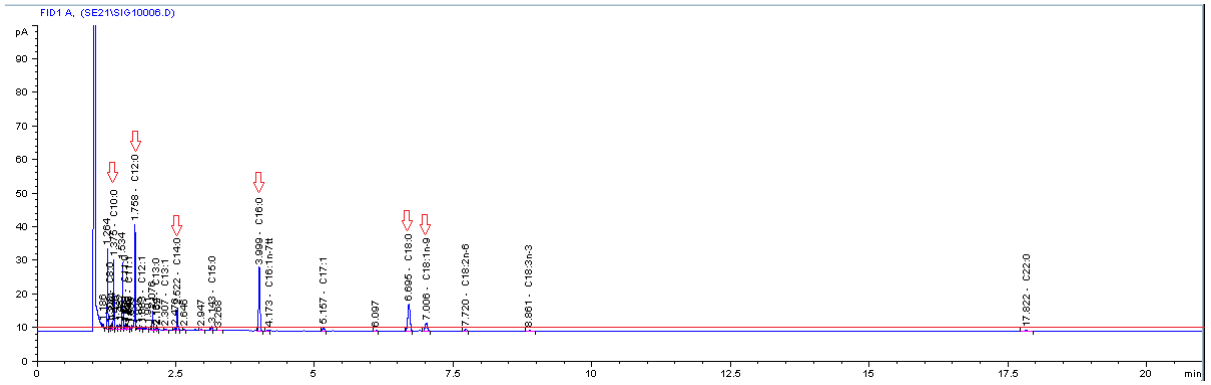


Figure 35 Chromatogram for fatty acids extracted from sample 2271 from Khok Phanom Di

Figure 36 shows results from analysis of sample 1694. Fatty acids present in this sample are mainly in very small quantities, C16:0 being slightly more prominent. Small amounts of C18:0, C18:1n-9 and C14:0 are also present.

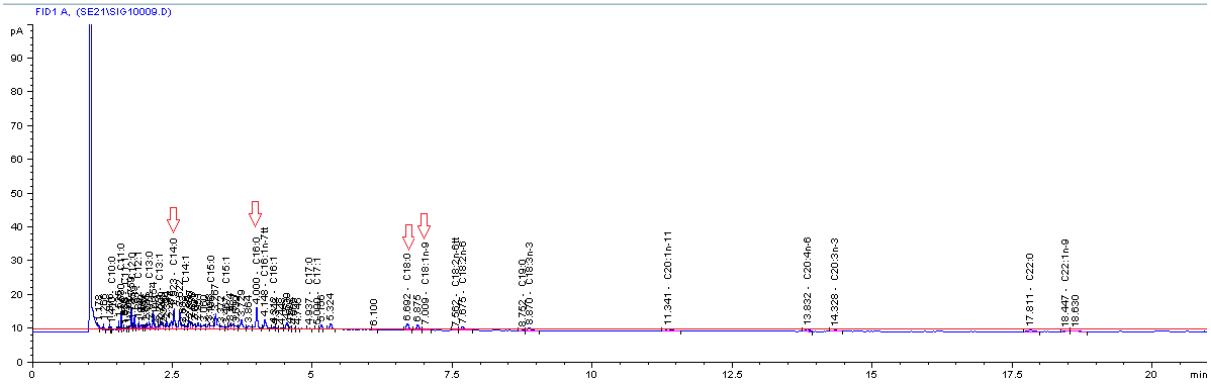


Figure 36 Chromatogram for fatty acids extracted from sample 1694 from Khok Phanom Di

Figure 37 shows results from the analysis of sample 2563. In this sample C16:0 is the most abundant fatty acid. C18:0 is next in abundance but is present in much smaller quantities. C18:1n-9 is also present but only in very small quantities. C12:0 and C14:0 are also present in reasonable quantities, but they appear before the baseline flattens and may be in part due to noise on the instrument.

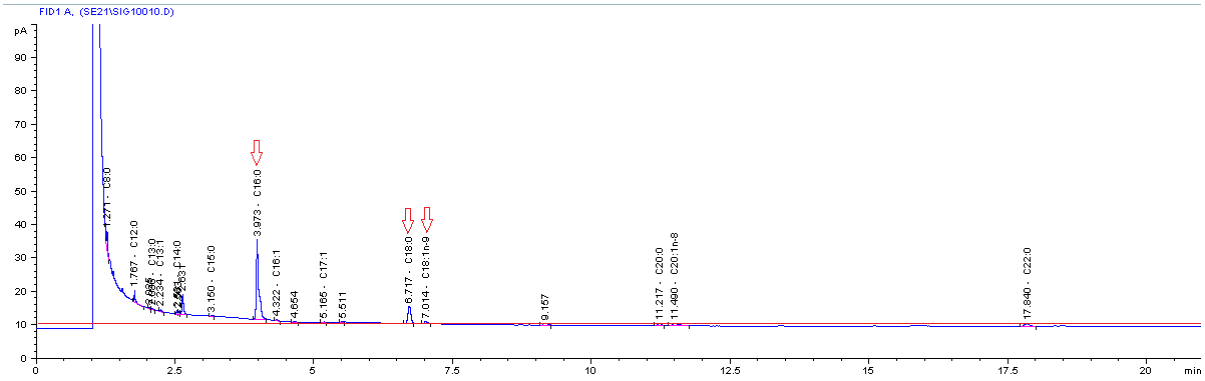


Figure 37 Chromatogram for fatty acids extracted from sample 2563 from Khok Phanom Di

Figure 38 shows results from analysis of sample 1884. Small amounts of C16:0, C18:0 and its isomer C18:1n-9, are present in this sample but in quantities below 1 pA.

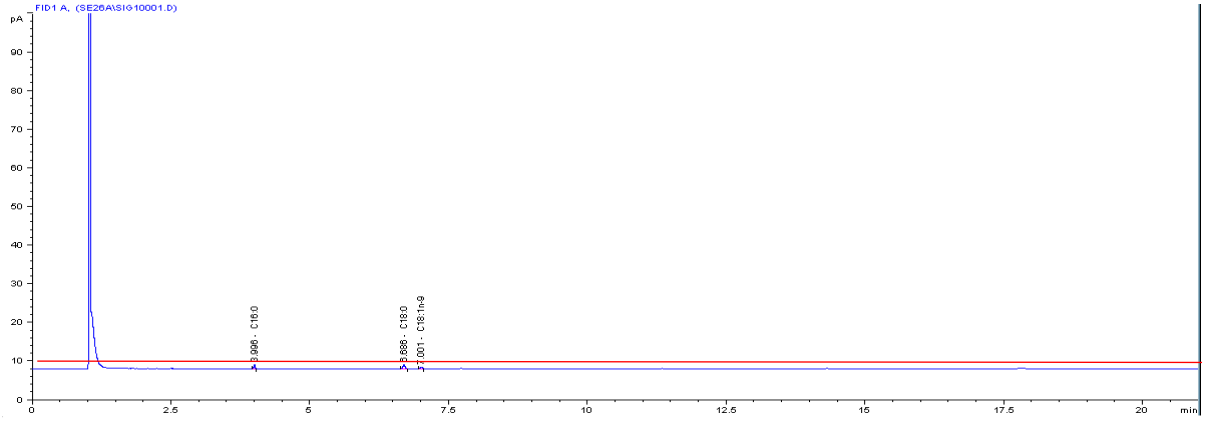


Figure 38 Chromatogram for fatty acids extracted from sample 1884 from Khok Phanom Di

Figure 39 shows results from analysis of sample 2286. Very small quantities of C16:0 and C18:0 are present in this sample, but with peaks below 1 pA.

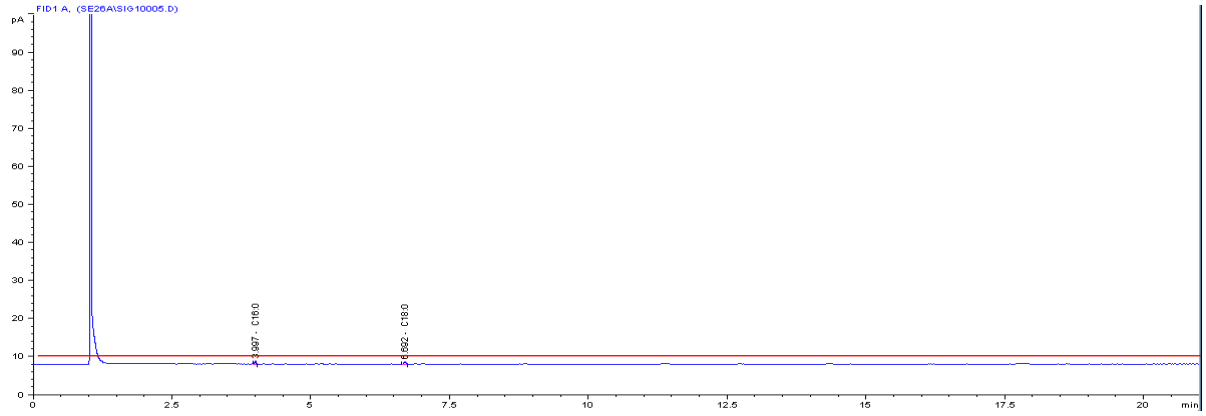


Figure 39 Chromatogram for fatty acids extracted from sample 2286 from Khok Phanom Di

Samples from Nong Nor

Figure 40 shows the results from analysis of sample 1013. C16:0 is present in the largest quantities in this sample. C18:0 and its isomer C18:1n-9 are present, albeit in smaller quantities than both the C12:0 and C14:0, which are also present.

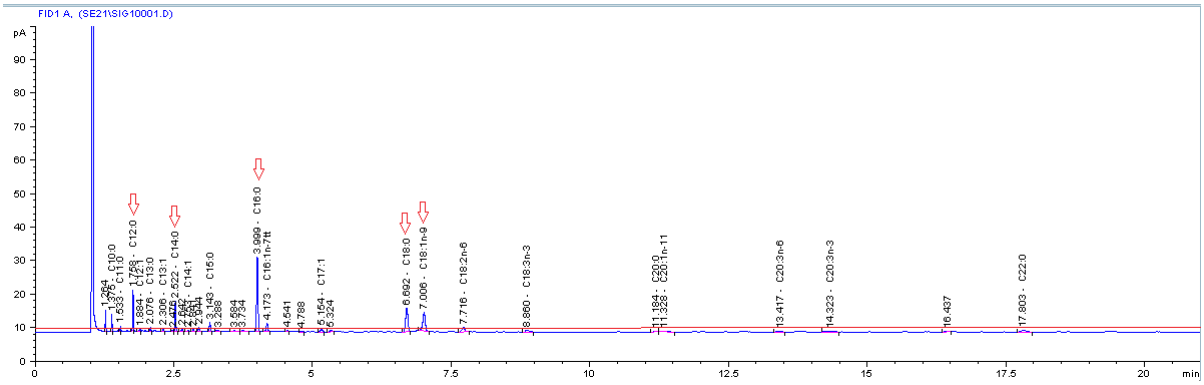


Figure 40 Chromatogram for fatty acids extracted from sample 1013 from Nong Nor

Figure 41shows the results from analysis of sample A4u23. The most abundant fatty acids in this sample are C16:0 followed by C18:0 and then C12:0. C18:1n-9 and C14:0 are also present.

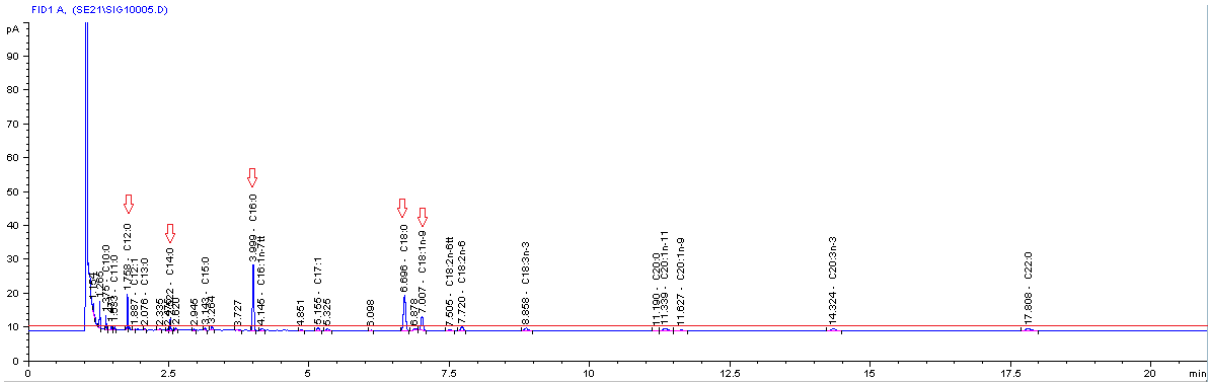


Figure 41 Chromatogram for fatty acids extracted from sample A4u23 from Nong Nor

Figure 42 shows the results from analysis of sample 1000. C16:0, C18:0, and its isomer c18:1n-9, are the most prominent fatty acids in this sample. C12:0 is also present in relatively large quantities, with C14:0 present in smaller amounts.

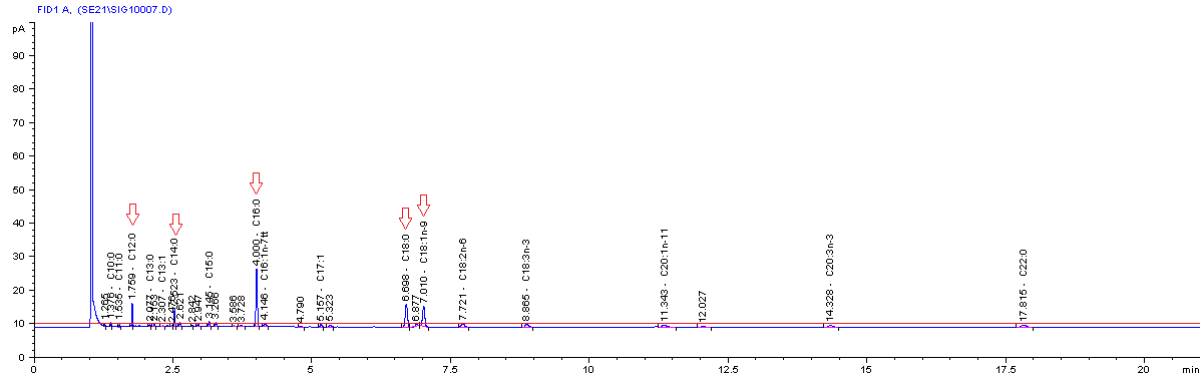


Figure 42 Chromatogram for fatty acids extracted from sample 1000 from Nong Nor

Figure 43 shows the results from analysis of sample 551. The most prominent fatty acids in this sample are C16:0 followed by C18:0. C12:0 and C14:0 are also present in smaller quantities, as is C18:1n-9.

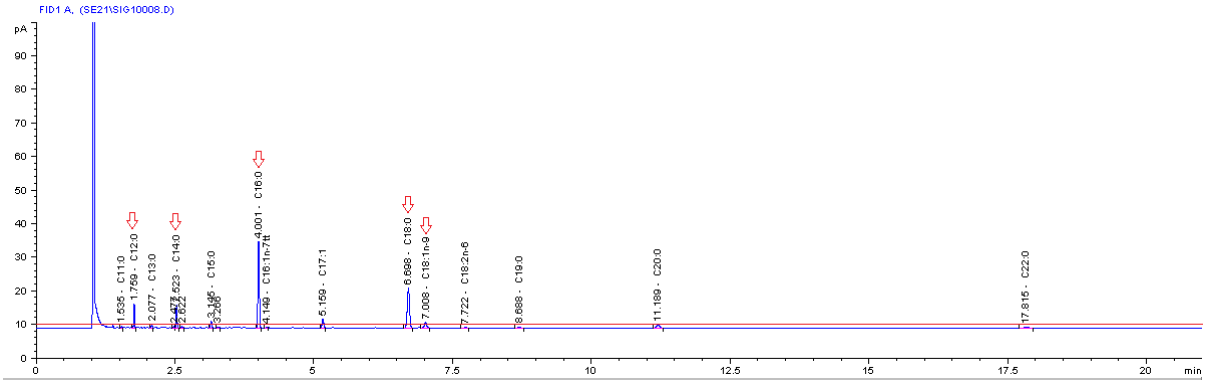


Figure 43 Chromatogram for fatty acids extracted from sample 551 from Nong Nor

Figure 44 shows the results from analysis of sample U40-1. There is very little in this sample, C16:0 being the only identified fatty acid, at very low levels.

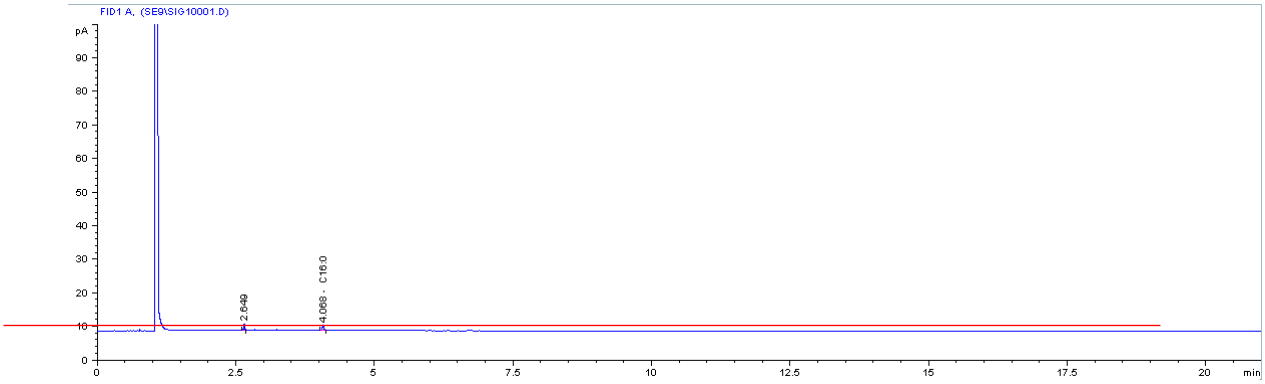


Figure 44 Chromatogram for fatty acids extracted from sample U40-1 from Nong Nor

Figure 45 shows the results from analysis of sample 998. There is very little identified in this sample besides miniscule amounts of C16:0, the peak height being less than 1 pA.

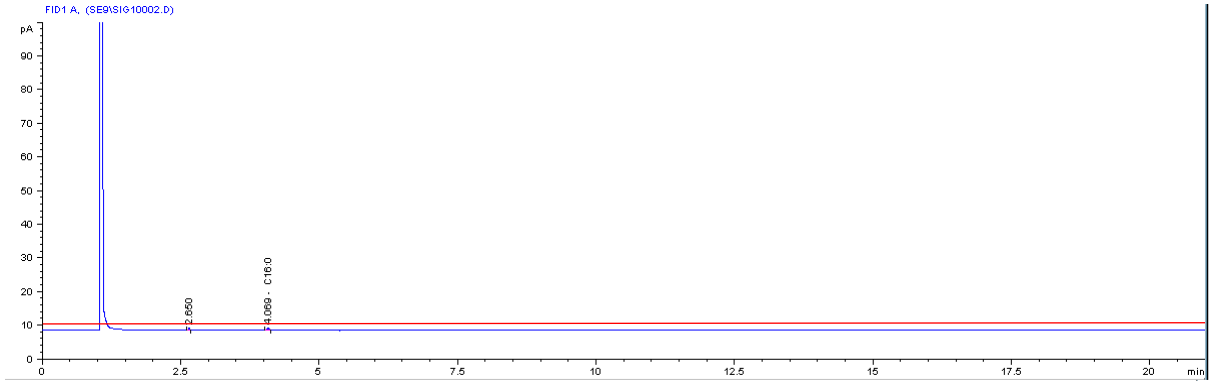


Figure 45 Chromatogram for fatty acids extracted from sample 998 from Nong Nor

Figure 46 showing the results from analysis of sample 1004. This sample has very little identified apart from a small amount of C16:0.

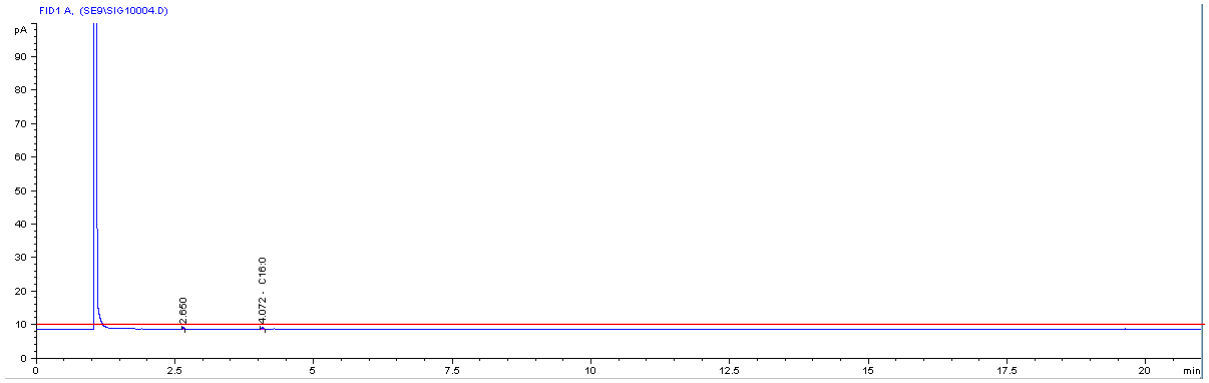


Figure 46 Chromatogram for fatty acids extracted from sample 1004 from Nong Nor

Figure 47 shows the results from analysis of sample 997. This sample has a small amount of C16:0, but no other identified fatty acids.

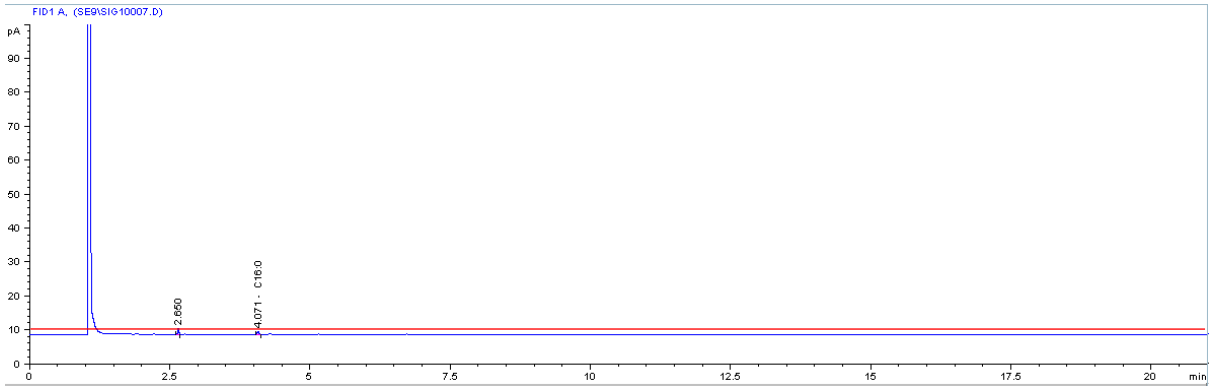


Figure 47 Chromatogram for fatty acids extracted from sample 997 from Nong Nor

Figure 48 shows the results from analysis of sample 887. This sample has C16:0 in small quantities and no other identified fatty acids.

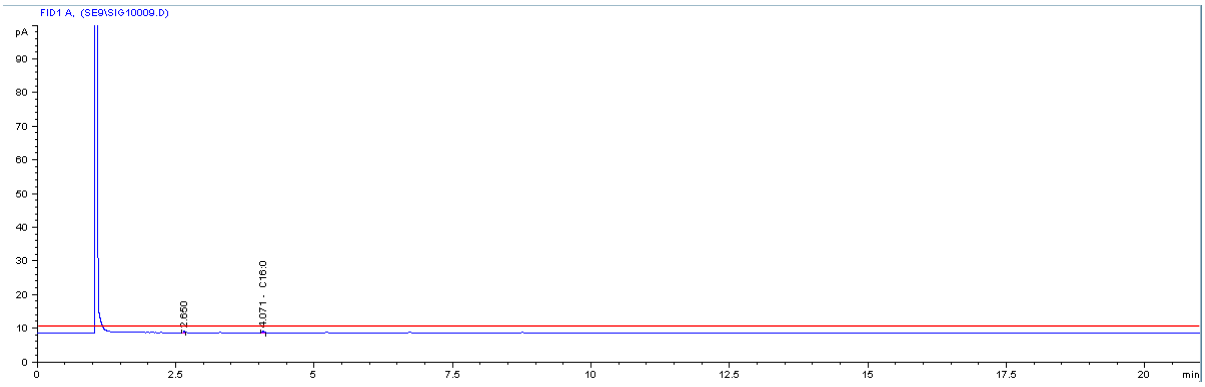


Figure 48 Chromatogram for fatty acids extracted from sample 887 from Nong Nor

Figure 49 shows results from analysis of sample 967. This sample has very small amounts of both C16:0 and C18:0.

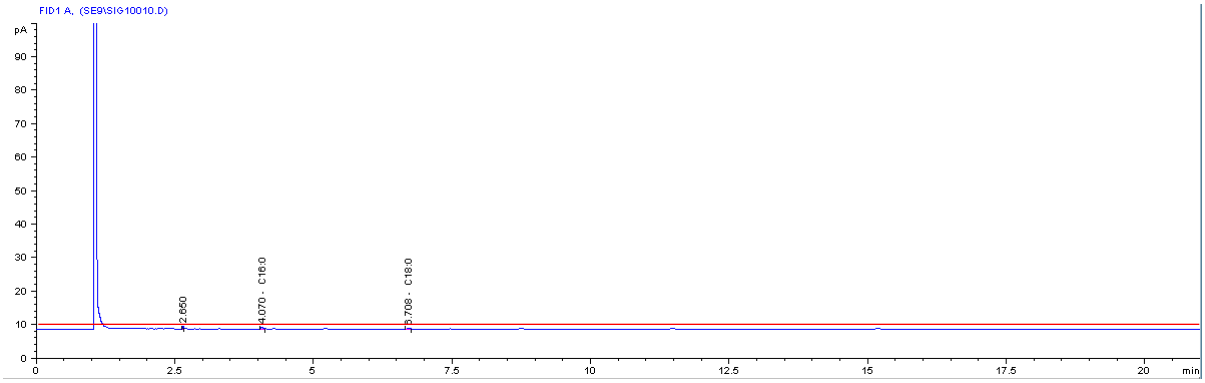


Figure 49 Chromatogram for fatty acids extracted from sample 967 from Nong Nor

Figure 50 shows results from analysis of sample 977. This sample has very small quantities of C16:0, C18:0 and C20:0 as well as some of their isomers, but are all below the 1 pA cut-off.

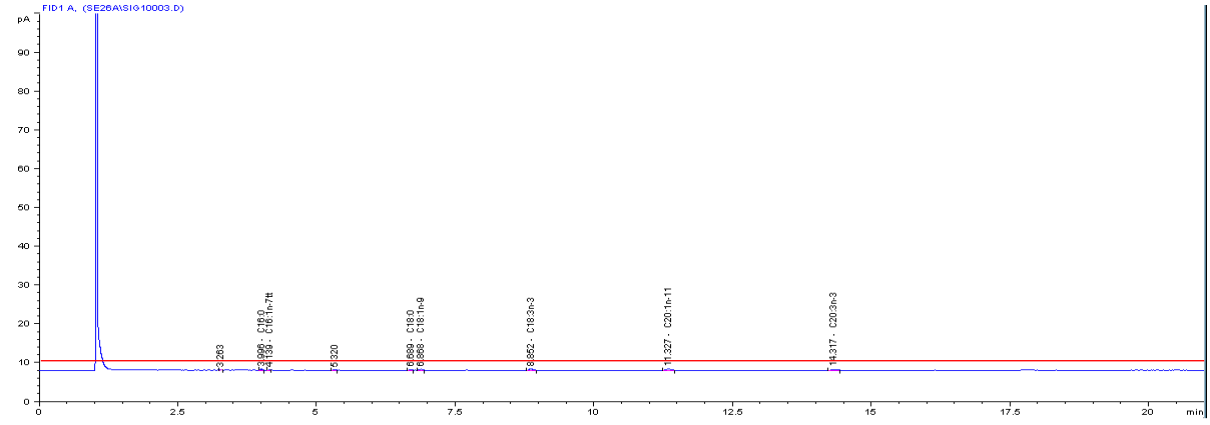


Figure 50 Chromatogram for fatty acids extracted from sample 977 from Nong Nor

Figure 51 shows results from analysis of sample 917. Very small amounts of fatty acids are present in this sample, including C16:0, C18:0 and C20:0 as well as some of their isomers. A miniscule amount of C22:0 is also present. All of the fatty acid peaks, however, are below the 1 pA cut-off.

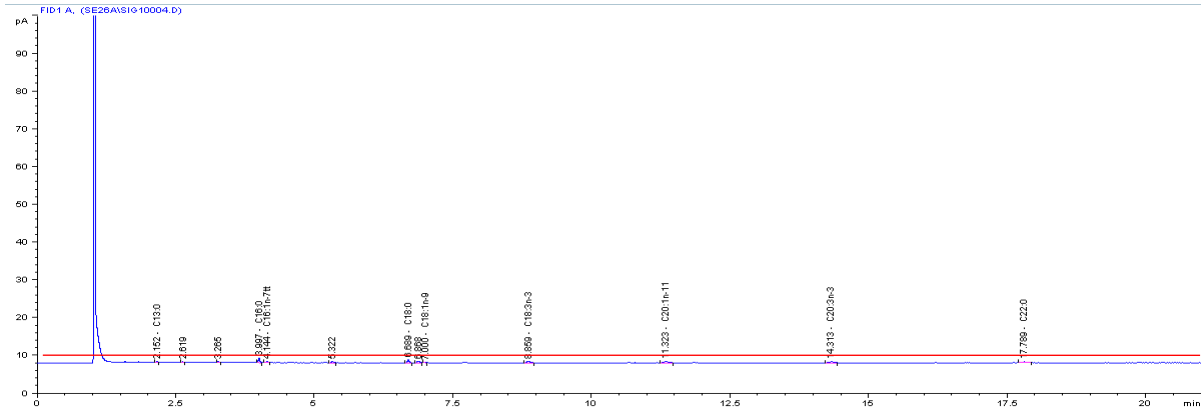


Figure 51 Chromatogram for fatty acids extracted from sample 917 from Nong Nor

Samples from Ban Non Wat

Figure 52 shows results from analysis of sample 21285. This sample has slightly more C16:0 than C18:0. Miniscule amounts of other fatty acids, including two isomers of C18:0 and one of C20:0, are present.

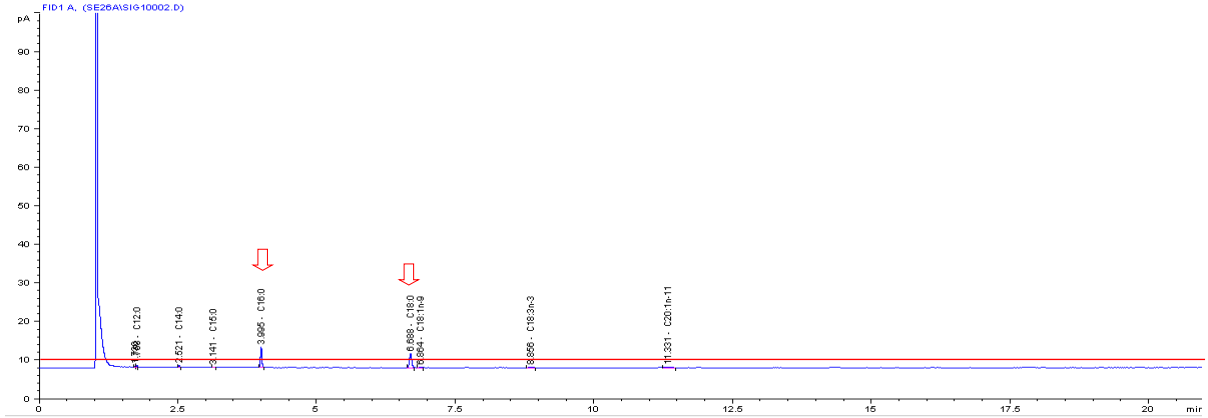


Figure 52 Chromatogram for fatty acids extracted from sample 21285 from Ban Non Wat

Figure 53 shows the results of analysis carried out on sample 23109. C16:0 and C18:0 are the most prominent, with C16:0 present in slightly larger quantities. C18:1n-9 and the longer-chained fatty acid C20:0 are both represented, as well as a small amount of the odd-numbered C19:0. Small amounts of C20:0 isomers are also present in this sample.

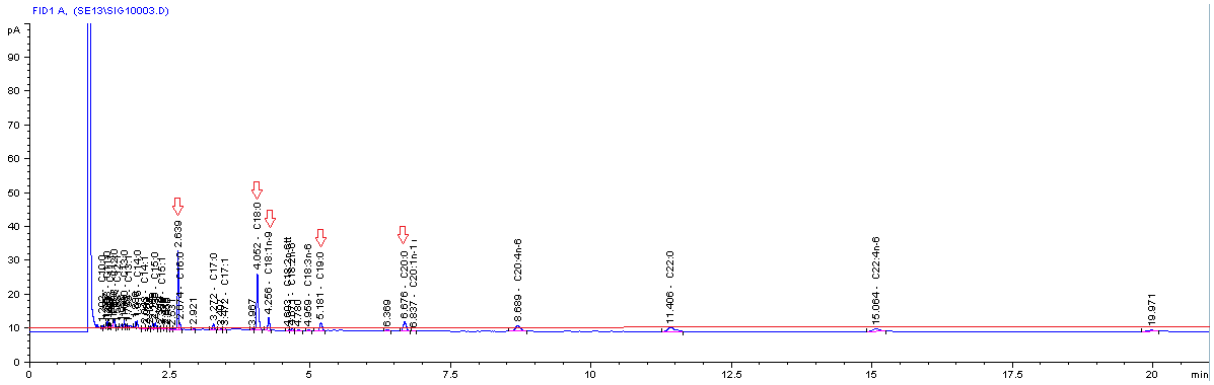


Figure 53 Chromatogram for fatty acids extracted from sample 23109 from Ban Non Wat

Figure 54 displays the results obtained from analysis of sample 19630. While a variety of fatty acids are present, C16:0 and C18:0 are by far the most abundant, the proportion of C16:0 being greater than that of C18:0. C18:1n-9 is next in prominence, followed by C14:0, C20:0 and its isomers. There is also some C19:0 present.

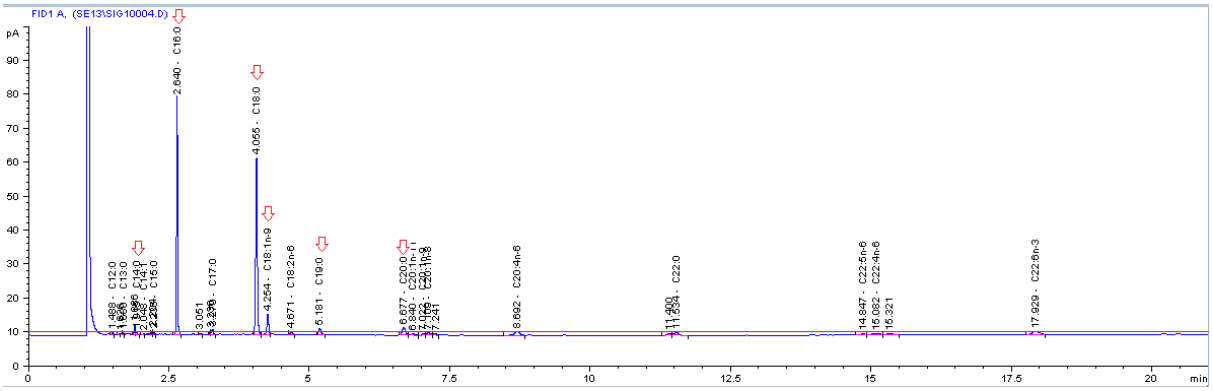


Figure 54 Chromatogram for fatty acids extracted from sample 19630 from Ban Non Wat

Figure 55 shows results from analysis of sample 12127. In this sample C16:0 and C18:0 are both present in significant quantities, with more C16:0 than C18:0. A small amount of C18:1n-9 is also present.

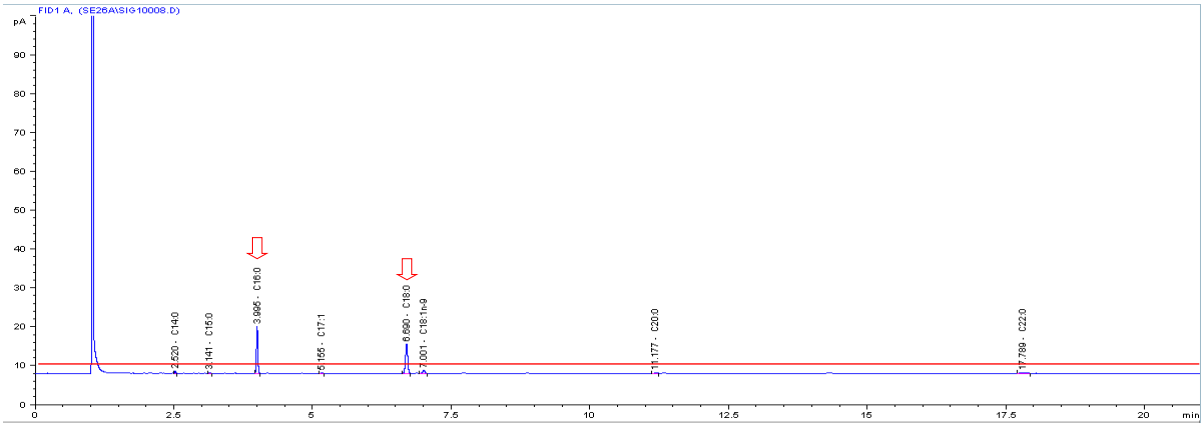


Figure 55 Chromatogram for fatty acids extracted from sample 12127 from Ban Non Wat

Figure 56 shows the results from analysis of sample 23663. This sample has very small quantities of C16:0 and C18:0, both below the 1 pA cut-off. There is more C16:0 than C18:0.

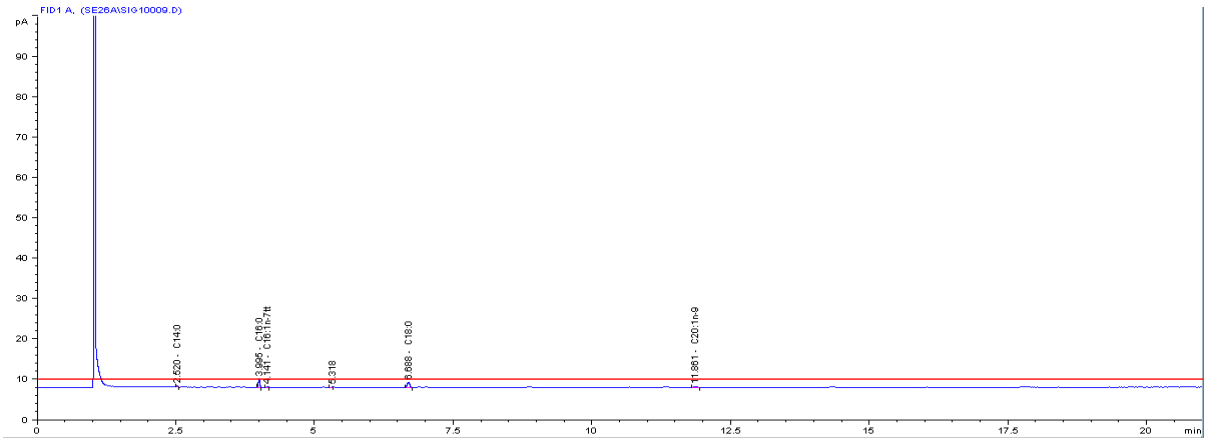


Figure 56 Chromatogram for fatty acids extracted from sample 23663 from Ban Non Wat

Figure 57 shows the results from analysis of sample 26152. There are small amounts of C16:0 and C18:0, with more C16:0 present in this sample.

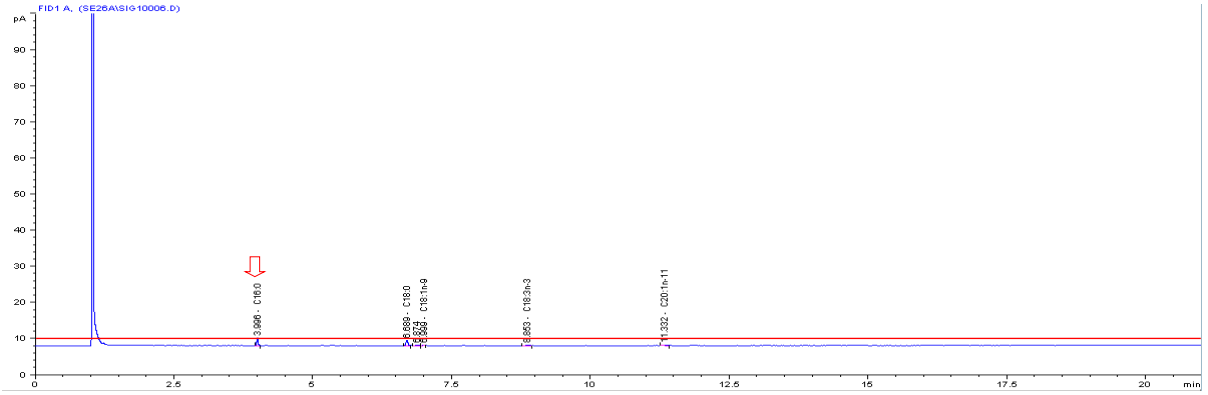


Figure 57 Chromatogram for fatty acids extracted from sample 26152 from Ban Non Wat

Figure 58 shows the chromatogram of the external standard GLC462 supplied by the Department of Human Nutrition at the University of Otago. The fatty acids present in the samples can be identified by comparing their retention times with those of the standards.

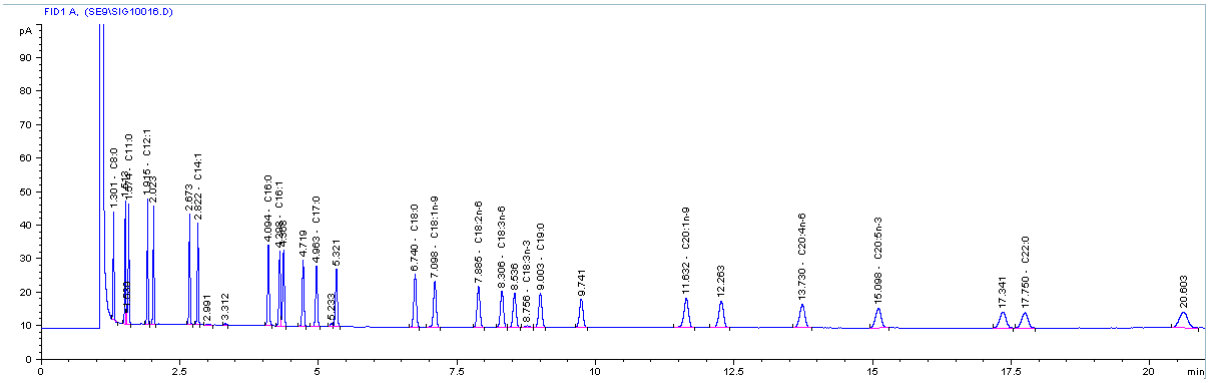


Figure 58 Chromatogram for fatty acids from external standard GLC462 supplied by the Human Nutrition Department at the University of Otago.

Unprocessed Fatty Acid Results

Table 35 Unprocessed fatty acid results of GC-MS analysis

Sample Name	Compound Name C10:0	C11:0	C11:1	C12:0	C12:1	C13:0	C13:1	C14:0	C14:1	C15:0	C15:1	C16:0	C16:1	C17:0	C17:1	C18:0
#2199	0.414	1.138	0.815	3.209	0.358	0.558	0.131	0.701	0.354	0.831	0.502	0.883	0.701	1.008	0.196	21.873
#2311	0	0	0.265	0.351	0	0.306	0	0.315	0.846	0.573	0.665	20.039	0.443	0.777	0.413	20.195
#2325	0	0.548	0.447	1.392	0.17	0.7	0.412	2.24	0.369	1.251	0.199	19.037	1.116	0.425	1.497	19.802
19630B	0	0	0	0.379	0	0.25	0	0.413	0.265	0.366	0	34.771	0	0.991	0	38.348
23109B	0.381	1.097	0.574	1.371	0.386	1.245	0.408	1.411	0.643	1.584	0.752	1.605	0	2.075	0.301	21.106
B63	0	1.66	0.478	1.171	0.525	1.799	0.313	1.488	0.686	1.806	0.24	1.558	0.304	3.15	0.327	26.708

Sample Name	C18:1	c18:1n-7	C18:1 n-9	C18:1t	C18:2n-6	C18:2n-6tt	C18:3n-3	C18:3n-6	C19:0	C20:0	C20:1n-11	C20:1n-8	C20:1n-9	C20:2 n-6	C20:3n -3	C20:3n-6
#2199	0	0.181	2.653	0	0.233	0.13	0.194	0.27	1.226	1.929	0.468	0	0.258	0	0.136	0.395
#2311	0	2.116	8.026	0	2.452	0	0.331	0.474	2.309	3.113	0.917	0	2.055	1.462	0	1.851
#2325	0	0.23	4.062	0	0	0	0.2	0.362	2.249	3.609	0.793	0	2.005	0.892	0	1.178
19630B	0	0	4.661	0	0.735	0	0	0	2.142	2.999	0.609	0.579	0.35	0	0	0
23109B	0	0	4.65	0	0.769	0.356	0	0.435	4.245	5.826	0.365	0	0	0	0	0
B63	0	0	3.369	0	1.29	0.282	0	0	4.698	5.829	0.521	0	0.635	0	0	0

Sample Name	C20:4n-6	C20:5n-3	C22:0	C22:1n-9	C22:2n-6	C22:3	C22:4n-6	C22:5n-3	C22:5n-6	C22:6n-3	C24:0	C24:1	C8:0	?
#2199	0.132	0.748	2.123	0	0	0.256	0.506	0	0	1.556	2.622	0	0	50.309
#2311	2.766	1.336	0.827	0.74	0	0	1.424	0	0.892	2.307	0	0	0	19.416
#2325	3.83	1.226	1.666	0.818	0	0	2.875	0	0	0	0.534	0	0	23.865
19630B	3.011	0	0.77	0	0	0	0.874	0	0.459	2.635	0	0	0	4.393
23109B	5.93	0	6.245	0	0	0	3.599	0	0	0	0	0	0	32.641
B63	5.236	0	2.236	0	0	0	3.116	0	0	0	0.605	0	0	29.972

Table 36 Unprocessed fatty acid results of GC-MS analysis, concentrations in pico amps (pA)

Sample Name	C10:0	C11:0	C11:1	C12:0	C12:1	C13:0	C13:1	C14:0	C14:1	C15:0	C15:1	C16:0	C16:1	C16:1n-7tt	C17:0	C17:1
#1000	0.91	0.69	0	4.7	0	0.55	0.52	4.87	0	1.57	0	22.66	0	1.74	0	1.42
#164	2.33	1.17	0	9.68	0.61	0.6	0.46	6.05	0.8	2.72	0	30.82	0	0.92	0	2.3
#1694	0.35	1.87	0.37	0.38	0.91	1.4	0.8	4.23	0.86	1.41	0.64	6.22	0.61	3.4	0.29	0.27
#2271	9.11	0.57	0.56	14.67	0.64	0.46	0.34	4.18	0	1.06	0	16.87	0	0.47	0	1.32
#2280	5.4	1.49	1.08	13.15	0	0.67	0.66	5.21	0	0.74	0	17.31	0.88	0.78	0	2.09
#2563	0	0	0	2.38	0	0.42	0.57	0.97	0	0.62	0	52.47	0.82	0	0	0.52
#2567	0.46	1.93	0.82	0.69	0.67	0.92	1.63	3.81	0.81	0.79	1.75	7.32	0.63	3.95	0.53	0.73
A4u23	2.35	0.95	0	6.49	0.47	0.43	0	2.79	0	0.64	0	23.51	0	1.19	0	1.49
nn1013	2.71	0.98	0	6.72	0.64	0.69	0.71	6.53	0.52	2.36	0	23.23	0	3.19	0	1.68
nn551	0	0.5	0	5.54	0	1.04	0	6.65	0	2.35	0	37.66	0	0.51	0	4.79

Sample Name	C18:0	C18:1n-9	C18:2n-6	C18:2n-6tt	C18:3n-3	C19:0	C20:0	C20:1n-11	C20:1n-8	C20:3n-3	C20:4n-6	C22:0
#1000	14.63	12.42	3.13	0	2.65	0	0	3.04	0	2.89	0	3.46
#164	18.38	2.71	0.62	0	0.73	0	1.29	0.94	0	1.43	0.47	2.51
#1694	2.63	0.51	1.95	0.41	1.83	0.25	0	1.85	0	1.02	1.57	1.17
#2271	11.64	3.56	0.76	0	0.47	0	0	0	0	0	0	0.89
#2280	11.94	4.27	0.91	0	1.02	0	0	0	0	0	0	1.89
#2563	14	1.71	0	0	0	0	2.65	0	3.88	0	0	3.72
#2567	4.02	0.62	2.75	0	4.17	0	0	3.6	0	2.34	1.39	2.31
A4u23	20.32	7.72	2.61	0.96	2.29	0	0.48	2.68	0	2.69	0	3.11
nn1013	12.42	10.64	2.94	0	1.3	0	0.62	1.02	0	1.4	0	1.91
nn551	28.16	3.78	0.89	0	0	1.43	3.34	0	0	0	0	1.76

Table 37 Unprocessed fatty acid results of GC-MS analysis. Concentrations in pico amps (pA)

Compound Name / Sample Name	C10:0	C11:0	C11:1	C12:0	C12:1	C13:0	C13:1	C14:0	C14:1	C15:0	C15:1	C16:0	C16:1	C17:0	C17:1	C18:0
1004	0	0	0	0	0	0	0	0	0	0	0	50.43405	0	0	0	49.56595
887	0	0	0	0	0	0	0	0	0	0	0	34.79599	0	0	0	65.20401
967	0	0	0	0	0	0	0	0	0	0	0	35.2249	0	0	0	41.3539
997	0	0	0	0	0	0	0	0	0	0	0	54.73511	0	0	0	45.26489
998	0	0	0	0	0	0	0	0	0	0	0	39.41338	0	0	0	60.58662
U40-1	0	0	0	0	0	0	0	0	0	0	0	48.96821	0	0	0	51.03179

Sample Name	C18:1	c18:1n-7	C18:1n-9	C18:1t	C18:2n-6	C18:2n-6tt	C18:3n-3	C18:3n-6	C19:0	C20:0	C20:1n-11	C20:1n-8	C20:1n-9	C20:2n-6	C20:3n-3	C20:3n-6
1004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
887	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
967	0	0	0	0	0	0	0	0	0	23.42121	0	0	0	0	0	0
997	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U40-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Sample Name	C20:4n-6	C20:5n-3	C22:0	C22:1n-9	C22:2n-6	C22:3	C22:4n-6	C22:5n-3	C22:5n-6	C22:6n-3	C24:0	C24:1	C8:0
1004	0	0	0	0	0	0	0	0	0	0	0	0	0
887	0	0	0	0	0	0	0	0	0	0	0	0	0
967	0	0	0	0	0	0	0	0	0	0	0	0	0
997	0	0	0	0	0	0	0	0	0	0	0	0	0
998	0	0	0	0	0	0	0	0	0	0	0	0	0
U40-1	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 2: N-Alkanes

Table 38Approximate retention times and concentrations (pA) of n-alkanes extracted from Khok Phanom Di sherds

	Retention time (minutes)														
Sample	1.75	2.48	4.02	4.35	4.95	6.88	7.08	7.68	8.87	10.45	11.34	14.33	17.8	21.74	26.055
2199N	0.23	0.26	0.50	0.16	0.23	0.17	3.35	0.53	4.67	0.13	4.26	4.61	3.20	3.00	1.79
2280N	1.35	0.42	0.45	0.33	0.23	0.20	3.39	0.73	4.55	0.00	4.32	4.29	3.14	2.52	1.73
2567N	4.22	3.46	0.00	0.00	0.00	9.06	0.00	0.00	9.57	0.00	8.35	0.00	0.00	0.00	0.00
164N	0.33	1.08	0.17	0.24	0.32	4.32	0.00	0.67	7.22	0.00	9.31	10.02	8.88	7.46	5.12
2271N	0.63	0.71	0.78	0.21	0.27	4.82	0.16	0.31	6.59	0.00	7.02	6.66	5.30	4.28	2.90
1694N	2.84	3.45	0.00	0.00	0.00	5.46	0.00	0.00	3.90	0.00	0.00	0.00	0.00	0.00	0.00
2563N	0.23	0.27	0.32	0.23	0.22	5.63	0.00	0.65	8.67	0.00	9.77	10.46	8.56	7.26	4.61
1884N	0.56	0.98	0.82	0.00	0.22	4.76	0.00	0.98	6.38	0.00	6.20	5.87	4.63	3.96	2.70
2286N	0.97	0.49	0.71	0.29	0.23	4.51	0.00	1.50	5.91	0.00	5.24	4.88	3.67	3.00	2.12

Table 39 Approximate retention times and concentrations (pA) of N alkanes extracted from Nong Nor sherds

	Retention time (minutes)														
Sample	1.75	2.48	4.02	4.35	4.95	6.88	7.08	7.68	8.87	10.45	11.34	14.33	17.8	21.74	26.055
1013N	0.53	2.74	0.00	0.30	0.20	3.92	0.84	1.30	6.66	0.00	4.76	6.97	4.50	4.07	2.50
A4U23N	0.28	2.69	0.37	0.23	0.17	4.98	0.00	0.45	7.64	0.00	8.96	9.31	8.10	6.47	4.49
1000N	0.36	3.85	0.00	0.00	0.00	3.98	0.00	0.79	5.46	0.00	5.81	5.90	4.91	4.09	2.77
551N	1.11	2.23	0.00	0.00	0.00	4.68	0.00	0.00	3.80	0.00	2.89	2.29	0.00	0.00	0.00
977N	0.41	2.51	0.00	0.00	0.00	6.53	0.00	0.74	9.39	0.00	10.24	10.20	8.26	6.96	4.72
917N	1.17	1.53	0.00	0.00	0.00	7.93	0.00	0.00	10.48	0.00	11.09	10.47	8.27	6.52	4.01

Table 40 Approximate retention times and concentrations (pA) of N-alkanes extracted from Ban Non Wat sherds

	Retention times (minutes)														
Sample	1.75	2.48	4.02	4.35	4.95	6.88	7.08	7.68	8.87	10.45	11.34	14.33	17.8	21.74	26.055
21285N	1.56	0.00	0.00	0.00	0.00	6.69	0.00	0.00	9.96	0.00	11.53	12.10	10.54	8.64	6.04
12127N	0.19	0.67	0.00	0.00	0.00	6.16	0.00	0.23	9.19	0.00	10.61	11.16	9.50	7.79	5.34
23663N	0.10	0.14	0.25	0.00	0.09	2.62	0.00	0.00	3.47	0.00	3.85	3.83	3.19	2.59	1.85
26152N	0.61	0.73	0.00	0.00	0.00	6.55	0.00	0.00	8.67	0.00	9.48	9.29	8.25	6.70	4.63

Appendix 3: Unprocessed results of initial analysis

Table 41 Unprocessed results for analysis of practice sherds. Concentrations are measured in pA. The relative amounts of each of the four fatty acids tested are shown and were used to make comparison with other samples easier.

	Fatty Acids				Relative Concentration			
Sample	22:0	20:0	18:0	16:0	%22:0	%20:0	%18:0	%16:0
Rice Alkane undil	0.00	0.43	0.13	0.26		0.53	0.16	0.31
Handled Alkane undil	0.00	0.00	0.15	0.34			0.31	0.69
Mystery Alkane 1/100 dil	0.00	0.00	0.00	0.00				
Salmon Alkane 1/100 dil	0.00	0.00	0.67	0.18			0.79	0.21
Mystery Alkane undil	0.00	0.22	4.16	1.81		0.03	0.67	0.30
Salmon Alkane undil	0.00	1.93	1.16	16.80		0.10	0.06	0.84
Rice FAME clean	0.00	0.12	0.14	0.00		0.45	0.55	
Handled FAME clean	0.00	0.12	1.19	0.00		0.09	0.91	
Salmon FAME clean	0.00	0.27	2.05	0.00		0.12	0.88	

Table 41 displays the unprocessed results of analysis carried out on the 'practice' sherds. The undiluted salmon sample possessed appreciable quantities of C16:0, C18:0 and C20:0, the quantity of C16:0 (in grey) by far the greatest. The undiluted mystery sample had C16:0 and C18:0 peaks above 1 pA. Both the handled and the salmon sherd which underwent the clean up step (following Spangenberg et al. 2006), had C18:0 present in quantitiesg greater than 1 pA.

Table 42 The date and extraction method for samples from Ban Non Wat and Ban Salao. Purple indicates sherds that were ground prior to extraction and orange indicates soil samples.

Date	Site	Provenance	Bag Number	Burial Number	Catalogue Number	Extraction Method
23/09/2010	BNW 08/09	P300 3:^5F4 A	15600			Soxhlet
23/09/2010	BNW 08/09	P300 3:^5F4 B	15600			Beaker
23/09/2010	BNW 08/09	G104 6:^2 F16 A	13878		31535	Beaker
23/09/2010	BNW 08/09	S400 6:^1 F24 A	15405		34413	Beaker
9/09/2010	BNW 08/09	S400 6:^1 F24 A	15405		34413	Sonic Bath 5mins
9/09/2010	BNW 08/09	P300 3:^5F4 C	15600			Sonic Bath 5mins
17/09/2010	BNW 08/09	G104 6:^2 F16 A	13878		31535	Sonic Bath 20mins
17/09/2010	BNW 08/09	S400 6:^1 F24 B	15405		34413	Sonic Bath 20mins
20/10/2010	BNW			Burial 13341	19630	Soxhlet
20/10/2010	BNW			Burial 494	23109	Soxhlet
27/10/2010	BNW			Burial 13341	19630	Soxhlet
27/10/2010	BNW			Burial 225	12127	Soxhlet
1/11/2010	BNW			Burial 939	21285	Soxhlet
1/11/2010	BNW			Burial 497	26152	Soxhlet
17/11/2010	BNW			Burial 375	17719	Soxhlet
17/11/2010	BNW			Burial 494	23109	Soxhlet
22/11/2010	BNW			Burial 46	19904	Soxhlet
22/11/2010	BNW			Burial 513	23663	Soxhlet
23/11/2010	BNW			Burial 245	13627	Soxhlet
23/11/2010	BNW			Burial 245	13245	Soxhlet
25/11/2010	BNW			Burial 568	26379	Soxhlet
25/11/2010	BNW			Burial 534	25813	Soxhlet
29/11/2010	BNW			Burial 238	14103	Soxhlet
29/11/2010	BNW			Burial 456	18338	Soxhlet
13/12/2010	BNW 07/08	N100 7^1	12533	Burial 661	27570	Soxhlet
13/12/2010	BSL 09/10	M1007^2	304	Burial 1	391	Soxhlet
14/12/2010	BSL 09/10	M1007^2	304	Burial 1	390	Soxhlet
14/12/2010	BSL 09/10	M1007^2	304	Burial 1	389	Soxhlet
20/01/2011	BSL 09/10	M1007^2	304	Burial 1	393	Soxhlet
20/01/2011	BNW 09/10	N96 6^7 F15	15286	Burial 689	39354	Soxhlet
20/01/2011	BSL 09/10	M1007^2	304	Burial 1	388	Soxhlet
20/01/2011	BSL 09/10	M1007^2	304	Burial 1	392	Soxhlet
24/01/2011	BSL 09/10	M1007^2	304	Burial 1	393	Soxhlet
24/01/2011	BSL 09/10	M1007^2	304	Burial 1	390	Soxhlet
25/01/2011	BSL 09/10	M1007^2	304	Burial 1	388	Soxhlet
25/01/2011	BNW	W2007^3 F20	16686		37209	Soxhlet
25/01/2011	BNW				27570	Soxhlet
25/01/2011	BSL 09/10	M1007^2	304	Burial 1	389	Soxhlet

Table 43 Unprocessed results for the fatty acid analysis of sherds from Ban Non Wat and Ban Salao. Concentrations are measured in pA. None of the fatty acids gave peaks above 1 pA. The relative amounts of each of the four fatty acids tested for are given to make comparison with other samples easier.

	Fatty Acids				Relative Concentration			
Sample	22:00	20:00	18:00	16:00	%22:0	%20:0	%18:0	%16:0
12127	0.00	0.00	0.00	0.20				100
19630	0.00	0.00	0.00	0.13				100
19630 ground	0.00	0.00	0.51	0.52			49.5	50.5
21285	0.00	0.00	0.00	0.21				100
23109	0.00	0.00	0.00	0.12				100
26152	0.00	0.75	0.11	0.15		74	11	15
S400a	0.01	0.01	0.06	0.08	8	8	35	49
S400b	0.08	0.00	0.04	0.00	65	3	30	2
G104	0.18	0.03	0.07	0.00	65	10	24	1
18338	0.11	0.00	0.01	0.01	83	3	5	9
26739	0.01	0.04	0.24	0.46	1	6	32	61
25813	0.01	0.01	0.01	0.01	42	18	23	17
14130	0.04	0.00	0.01	0.01	64	7	10	19
P300	0.00	0.01	0.01	0.01	6	30	30	34
13627	0.48	0.00	0.02	0.03	90	0.3	4	6
19904	0.02	0.00	0.00	0.01	65	4	11	20
13624	0.05	0.00	0.01	0.02	64	3	9	24
23663	0.01	0.00	0.00	0.01	34	12	18	36
13627	0.49	0.00	0.04	0.00	92	0.2	7	0.4
19904	0.02	0.01	0.01	0.01	50	17	15	18
13624	0.01	0.00	0.01	0.02	22	10	21	47
23109	0.00	0.01	0.00	0.00		97	3	
17719	0.00	0.00	0.00	0.05		7		93
389 soil	0.00	0.00	0.00	0.02		15	2	83
390 soil	0.00	0.00	0.00	0.01		1		99
27570 soil	0.00	0.02	0.00	0.00		98	1	1
391 soil	0.00	0.00	0.00	0.00			100	
388	0.00	0.00	0.00	0.00		67	33	
393 soil	0.00	0.00	0.00	0.00		100		
393	0.00	0.00	0.00	0.00				100
37209	0.00	0.00	0.00	0.00				
39354	0.00	0.00	0.00	0.00				
392 soil	0.00	0.00	0.00	0.00				
388 soil	0.00	0.00	0.00	0.00		25	50	25
390	0.00	0.00	0.00	0.00				100

Table 44 Unprocessed results for fatty acids after attempt at re-methylating. Concentrations given as pA. The relative amounts of each of the four fatty acids tested for are also shown to make comparison with other samples easier.

	Fatty Acids				Relative Concentration			
Sample	22:00	20:00	18:00	16:00	%22:0	%20:0	%18:0	%16:0
388 soil	0.00	0.00	0.00	0.00				100
393	0.00	0.00	0.00	0.00				
389 soil	0.00	0.06	0.08	0.06		32	39	29
12127	0.00	0.00	0.00	0.20				100
19630	0.00	0.00	0.00	0.13				100
19630 ground	0.00	0.00	0.99	0.51			66	34
21285	0.00	0.00	0.00	0.12				100
23109	0.00	0.01	0.00	0.12		5		95
26152	0.48	0.75	0.00	0.20	34	52		14
S400a	0.00	0.00	0.00	0.01				100
S400b	0.00	0.00	0.00	0.00				100
G104	0.00	0.00	0.00	0.01				100
18338	0.00	0.00	0.04	0.03			60	40
26379	0.00	0.00	0.00	0.01				100
25813	0.00	0.00	0.00	0.01				100
14130	0.00	0.00	0.00	0.00				100
P300	0.00	0.00	0.00	0.01				100
13627	0.11	0.15	0.23	0.01	22	31	46	1
19904	0.00	0.00	0.00	0.28				100
13624	0.00	0.00	0.07	0.01			93	7
23663	0.00	0.00	0.00	0.01				100
17719	0.00	0.00	0.00	0.00				100
390 soil	0.00	0.00	0.00	0.00				100
27570 soil	0.00	0.10	0.00	0.01		90		10
391 soil	0.00	0.00	0.00	0.00				100
388	0.00	0.00	0.00	0.00				100
393 soil	0.00	0.00	0.00	0.00				100
37209	0.00	0.00	0.00	0.00				100
39354	0.00	0.00	0.00	0.00				100
392 soil	0.00	0.00	0.00	0.00				100
390	0.00	0.00	0.00	0.00				

Table 45 Approximate retention times and peak heights (pico amps (pA) of the n-alkanes extracted.

Sample	Retention time	pA
389 soil	13.82	0.82
23663	13.79	0.60
13627	16.50	0.32

Appendix 4: Faunal Data

Table 46 MNI (minimum number of individuals) of fish and other species identified contained in mortuary ceramics from Ban Non Wat by Thosarat (2010)

Clarius spp.	143
Clarias macrocephalus	7
Clarias batrachus	2
Channa spp.	19
Channa striata	253
Channa micropeltes	4
Channa lucius	6
Hemibagrus/Mystus	66
Hemibagrus nemurus	8
Monopterus albus	34
Anabus testudineus	80
Ompok bimaculatus	2
Ompok/Wallago	23
Pristolepis fasciatus	1
Notopterus notopterus	1
Medium-sized deer	1
Pig	1
Frog	1
Rat	1

Table 47 Faunal data from the Neolithic phase at Ban Non Wat (from Thosarat 2011, 179-80, and Kijngam 2011, 199). MNI = minimum number of individuals.

Ban Non Wat Neolithic Animal	MNI
Bovidae	199
Bubulus bubulis	27
Bibos sp.	165
Sus scrofa	353
Canis familiaris	102
Cervis unicolor	75
Cervus schombergki/Cervus eldi	449
Axi porcinus/ Muntiacus muntjac	33
Muntiacus muntjac	108
Rattus sp.	33
Gallus sp.	24
Small mammal	44
Lepus peguensis	2
Tetudo elongata/ Malayemys subtrijuga	1288
Rinoceros sondaicus	2
Amyda cartillaginea	19
Bird	8
Hoplobatrachus tigerius	5
Varanus nebulosus	1
Panthera tigris	9
Hemibagrus	68
Hembagrus/Mystus	435
Channa lucius	5
Channa micropeltes	9
Channa striata	239
Channa sp.	56
Clarias sp.	272
Clarias macrocephalus	4
Anabas testudineus	226
Ompok bimaculatus	9
Wallago	4
Ompok/Wallago	168
Monopterus albus	60
Notopteridae	5
Cyprinidae	2
Mystus	3
Ompok	10
Mastacembelus sp.	1
Pristolepis fasciatus	1

Table 48 Faunal data from Phase One at Nong Nor (from Higham et al. 1998, 119-202). MNI = minimum number of individuals

Nong Nor Phase One	
Animal	MNI
Large deer	31
Medium sized deer	3
Small deer	2
Bovid species	7
Turtle/tortoise	4
Cetaceans/dolphin	13
Crocodile	1
Molluscs	18727
Crabs	undisclosed
Weasel sharks	undisclosed
Whaler sharks	undisclosed
Rays	undisclosed
Clariidae	undisclosed, but most common = *Clarius batrachus*
Scariidae	undisclosed
Centropomidae	undisclosed
Channidae	undisclosed, but most common = *Channa striata*

Table 49 Faunal data from the mortuary phase at Nong Nor (from Higham et al. 1998, 315-317). MNI = minimum number of individuals

Nong Nor Mortuary Phase	
Animal	MNI
Bibos	1
Sus scrofa	18
Gallus	1
Canis familaris	30

Table 50 Faunal data from all phases at Khok Phanom Di (from Higham and Bannanurag 1991, 193-299). MNI = minimum number of individuals

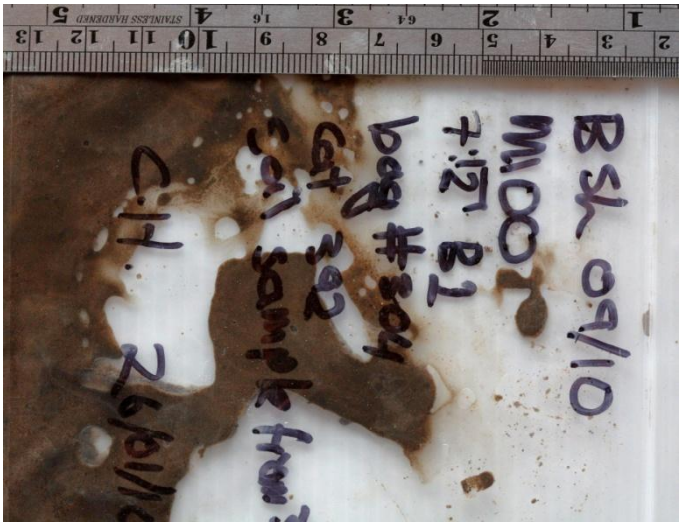
KPD All phases Animal	MNI Zone A	MNI Zone B	MNI Zone C	MNI total
Bovid sp.	0	5	18	23
Canis sp.				9
Large deer	12	33	67	112
Small deer				22
Macaque and langur	32	56	64	152
Pig				142
Crocodile	3	1		4
Rhinoceros	2		1	3
Frog sp.			1	1
Tiger			1	1
Felis sp.	1	5	21	27
Civet	5	10	30	45
Loris		1		1
Porcupine			1	1
Otter	3	7	21	31
Bandicoot			6	6
Rat	198	107	83	388
Crane	2			2
Stork	2	3		5
Pelican		1		1
Waterbirds	3	1	1	5
Duck species	1	1		2
Chicken	1		1	2
Other birds		1	2	3
Eel catfish				431
Seabass				498
Channa sp.				55
Clarius sp.				Unknown - only pectoral spines
Anabas testudineus				12
Crabs				8952
Turtle				24
Molluscs				691548

Appendix 5: Context Information and Photographs of the Sherds Analysed in this Study

Ban Non Wat V200 Layer 3 Spit 2, Gen. Spit Catalogue # 36053 1 large sherd	
Ban Non Wat P300 Layer 3 Surface of Spit 5, Feature 4 Context # 15600 3 sherds	
Ban Non Wat G104 Layer 6 Surface of Spit 2, Feature 16 Catalogue # 31535 1 sherd	

Ban Non Wat W200 Layer 7 Surface of Spit 3, Feature 20 Catalogue # 37209 2 sherds from a whole pot	
Ban Non Wat S400 Layer 6 Surface of Spit 1, Feature 24 Catalogue # 34413 2 sherds from a whole pot	
Ban Non Wat N96 Layer 4 Surface of Spit 9, Feature 10 Burial 685 Catalogue # 139199 3 sherds from a whole pot	

Ban Salao M100 Layer 2 Surface of Spit 1, Feature 34 K Catalogue # 035 1 sherd from a whole pot soil sample	

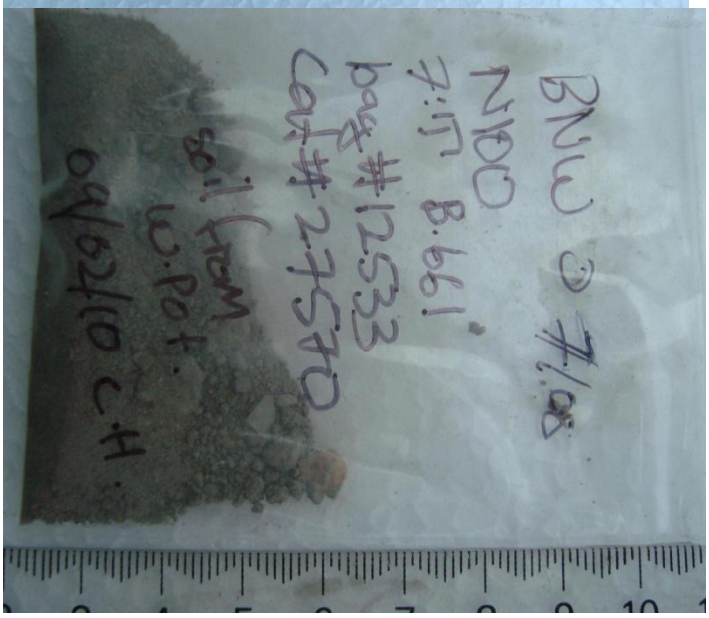
Ban Salao M100 Layer 7 Surface of Spit 2 Burial 1 Catalogue # 391 1 sherd from a whole pot soil sample	
Ban Salao M100 Layer 7 Surface of Spit 2 Burial 1 Catalogue # 392 soil sample only	

Ban Salao M100 Layer 7 Surface of Spit 2 Burial 1 Catalogue # 393 1 sherd from a whole pot Soil sample	

Ban Salao M100 Layer 7 Surface of Spit 2 Burial 1 Catalogue # 388 1 sherd from a whole pot Soil sample	

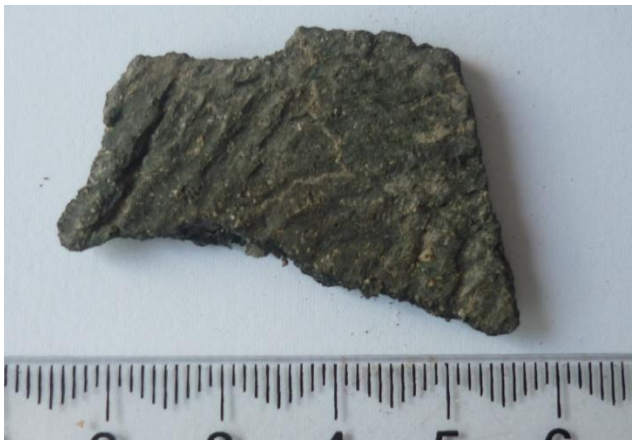
Ban Salao M100 Layer 7 Surface of Spit 2 Catalogue # 390 2 sherds from a whole pot Soil sample	

Ban Salao M100 Layer 7 Surface of Spit 2 Burial 1 Catalogue# 389 1 sherd from a whole pot Soil sample	

Ban Non Wat N100 Layer 7 Surface of Spit 1 Burial 661 Catalogue # 27570 1 whole pot Soil Sample	 

Ban Non Wat N100 Layer 5 Surface of Spit 2 Burial 654 Catalogue # 27321 1 whole pot	

Ban Non Wat N96 Layer 6 Surface of Spit 7, Feature 15 Burial 689 Catalogue # 39354 1 whole pot Soil Sample	
Ban Non Wat Burial 341 Catalogue # 19630 2 Sherds	

Ban Non Wat Burial 494 Catalogue # 23105	
Ban Non Wat Burial 245 Catalogue # 13627	
Ban Non Wat Burial 534 Catalogue # 25813 2 larger and 1 small sherd	

Ban Non Wat Burial 238 Catalogue # 14103	
Ban Non Wat Burial 568 Catalogue # 26379	
Ban Non Wat Burial 513 Catalogue # 23663	

Ban Non Wat Burial 456 Catalogue # 18338	
Ban Non Wat Burial 494 Catalogue # 23109	
Ban Non Wat Burial 245 Catalogue # 13624	

Ban Non Wat Burial 464 Catalogue # 19904	
Ban Non Wat Burial 390 Catalogue # 21285	
Ban Non Wat Burial 497 Catalogue # 26152	

Ban Non Wat Burial 375 Catalogue # 17719	
Ban Non Wat Burial 225 Catalogue # 12127	
KPD #2199 A1 B.10 SP.11	

KPD #35 A1.B63.SP!	
NN A4 U23 2:3 #896	
NN 917 A4U25 2A:1 131	

NN 977 A8-14 2 104 23	
NN 8? 1013 A8U36-7 2/3 87	
KPD 164 6 A1-A SP^1	

KPD #2286 10 S.13 10	
KPD #1884 10 S.6 11	
KPD A142:3 U40-41 1000	

KPD 2563 10:2^5/29 10 (c)3	
KPD 2325 10 S.14 11	
KPD 2311 10 S. 13 11	
KPD 2280 10 S. 11 10	

KPD 2271 10 S. 12 10	
KPD 1694 10 S.3 lens 14	
KPD 2567 10 S.25 7	
NN 1004 A6U14 2:5 190? 141	

NN 998 A6U14 2:3 #193?	
NN 967 A6U16-17 2:3 152?	
NN 551 B.109	
NN U40-1 A14 U40-1 2:3	

NN 887 A5 U17-18 2 Ai/887	