To Mommy, Daddy, and Micky
To the subsistence folks and craftspeople of ancient Southeast Asia
To fellow researchers who are able to perform scientific work despite being at the fringes or peripheries of communities of practice
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POTTERY, CUISINE, AND COMMUNITY IDENTITY IN NEOLITHIC AND METAL AGE SOUTHEAST ASIA: BIOMOLECULAR AND ISOTOPIC INVESTIGATION OF ORGANIC RESIDUES

By
Michelle Sotaridona Eusebio

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This research investigates the culinary practices in Southeast Asia during the Neolithic and Metal Age (3000 BC-AD 500) by analysis of food residues recovered from earthenware pottery. With a focus on southern Vietnam, it addresses how the preparation and/or consumption of food varied between four different sites - Rạch Núi, An Sơn, Lò Gạch, and Gò Ô Chùa - to explore change and continuity of cuisine between succeeding time periods in the same region and inferred community identities based on shared cuisine. Organic residue analysis was conducted on sampled pottery vessels from four archaeological sites to identify former food contents (terrestrial animals and plants, aquatic resources). Data assayed include lipid biomarker compound distributions, compound-specific carbon isotopes of palmitic and stearic acids, as well as bulk carbon and nitrogen isotopes. A modern regional comparative reference collection was developed to facilitate interpretation of the biochemical results from prehistoric pottery. This reference collection is composed of experimental and ethnographic pottery samples with known cooking histories, as well as oils and fats from important species of flora and fauna from Southeast Asia. The results indicate that the
people who inhabited these sites in prehistory probably belonged to different communities of practice and may have distinct community identities based on their culinary practices. Despite this distinctiveness, there is a possible continuity of culinary practices involving the usage of earthenware pottery vessels to prepare and serve plant and aquatic food sources from Neolithic to Metal Age. This continuity is also demonstrated by the usage of pottery for preparing and serving a common plant food source available within the vicinities of three inland sites. This research is the first microregional and diachronic survey of food residues in Southeast Asia that aims to explore identity based on shared practices. This research demonstrates that prehistoric Southeast Asia provides an ideal spatial and temporal case study to compare with other regions with respect to diversity of cuisine and identity.
Countries in Southeast Asia (SEA), such as Vietnam, Indonesia, and the Philippines, are renowned for their rich diversity of cuisine. The unique tastes and characteristic ingredients used to prepare their food make its cuisine popular throughout the world. Yet we know almost nothing about the early development and variation in these cuisines, which potentially have their origins more than 2000 years BP. Thus, to evaluate the development of popular contemporary cuisines across the region, an understanding of the emergence of ancient foodways in the region is required (Twiss 2012). “Foodways” comprises the interconnected stages (Anderson 1971) of “the production and procurement, processing, cooking, presentation, and eating” of food (Atalay and Hastorf 2006:283). In this dissertation, I focus on aspects of cuisine (Pavao-Zuckerman and DiPaolo Loren 2012) or culinary practice (Fuller 2005), which comprises the preparation and consumption of food (Anderson 1971). I adopt a chaîne opératoire perspective (sensu Jones 2002; Leroi-Gourhan 1983) to clarify the role of food and its importance to maintaining and promoting community identity based on shared cuisines in SEA.

The chaîne opératoire approach of foodways is novel in Southeast Asian research and helps to contextualize aspects of food acquisition, preparation, and consumption. In SEA, research on prehistoric diet has largely focused on “subsistence strategies” through identification and analysis of animal and plant remains—how people acquired food through foraging of wild resources and/or production of domestic plants and animals (e.g., Bellwood 2005, 2013; Fuller et al. 2010; Higham 2014; Paz 2002; Piper et al. 2009, 2012; Weber et al. 2010). Similarly, analyses of prehistoric pottery
recovered from Southeast Asian archaeological sites have been largely typological, focused on the identification of transregional similarities of form, decoration, and composition to establish patterns of human migration and contact (e.g., Hung et al. 2011; Rispoli 2007; Rispoli et al. 2013). Some ethnographic studies have focused on how local Southeast Asian communities utilize ceramics in food preparation and distribution (e.g., Cort and Lefferts 2013; Ono 2006; Skibo 1992), as well as how present-day cultural diversity and identity revolve around food preparation and consumption (e.g., Janowski and Kerlogue 2007; Van Esterik 2008). However, it is not clear how food items were prepared and served in conjunction with pottery that would allow for constructive discussion of food in relation to cultural variation, change, and continuity—in this case, for people in SEA during the Neolithic and Metal Age (3000 BC-AD 500).

Towards this end, I approach the study of foodways using practice theory (Bourdieu 1977; de Certeau 1984; Giard 1998; Giddens 1984) and the concept of Community of Practice (Wenger 1998). These two theoretical approaches provide the potential to critically evaluate the role of pottery and use of different food resources in the cuisines of prehistoric SEA. In concert with chaîne opératoire, these approaches permit me to explore and transcend the normative details of “subsistence strategies” and culture history towards an evaluation of the variation in cuisines between different sites of the same time period, change and continuity of cuisines between succeeding time periods in the same region, as well as community identities based on shared cuisine.
In this dissertation, I analyze four prehistoric pottery assemblages recovered from well-excavated sites in southern Vietnam and combine technofunctional analysis (Rice 1987; Skibo 2013) of sampled pottery with organic residue analysis (Evershed 2008b) to establish linkages between pottery and culinary practices. The coupling of technofunctional attributes and identified food categories permits me to explore fundamental questions regarding how foods were prepared and served on sampled pottery: Do culinary practices reflect the available food resources and/or culturally conditioned practices in prehistoric SEA? Are there similarities and differences in the culinary practices between the sites of the same period? Are there changes and continuities in culinary practices between the Neolithic sites and Metal Age sites in the same geographic region? What local and regional resources are being combined and utilized in the production of cuisines? What are the community identities of these people who occupied these sites based on their shared culinary practices?

**Research Goals and Methods**

There is a dearth of research on the early development and variation of cuisines in SEA, specifically with respect to how food items were prepared and served with the use of pottery. In this dissertation, I attempt to provide new data to contribute towards a constructive discussion of food in relation to cultural variation, change, and continuity. Specifically, the goals of this dissertation include: (1) to explore prehistoric culinary practices and identities in the region, (2) to conduct organic residue analysis on sampled pottery vessels from well-excavated archaeological sites in southern Vietnam as a case study, and (3) to compile and analyze a comparative modern Southeast Asian reference collection based on pottery samples with known cooking histories and local food sources.
To explore these goals, I conducted organic residue analysis on sampled pottery vessels \((n=113)\) from four well-excavated archaeological sites in Long An Province, southern Vietnam: Rạch Núi (Neolithic, 1500-1200 BC; Oxenham et al. 2015), An Sơn (Neolithic, 2200-1300 BC; Bellwood et al. 2011), Lò Gạch (Metal Age, ~750 BC Piper 2013), and Gò Ô Chùa (Metal Age, ca. 1000 BC; Reinecke 2012). Each of these settlement sites is situated near a tributary of the Mekong River. Plant, terrestrial animal, and aquatic food resources have characteristic suites of biomolecular markers that can assist in the identification of food types prepared and/or served with recovered pottery vessels. Further, stable carbon isotope ratios \(\delta^{13}C\) of palmitic (C16) and stearic (C18) acids provide the means to differentiate six defined food categories including C\(_3\) and C\(_4\) plants, terrestrial ruminant and nonruminant animals, and aquatic freshwater and marine food resources (Craig et al. 2007; Evershed et al. 1999; Regert 2011). In this dissertation, I establish the degree to which these food categories may be securely identified using biomolecular markers (lipids) in archaeological food residues on pottery from SEA. To aid in this objective, I compiled and analyzed a comparative modern Southeast Asian reference collection based on pottery samples with known cooking histories \((n=20)\) and local food sources \((n=26)\) derived from experimental cooking and ethnographic contexts. The integration of results from organic residue analysis with technofunctional descriptions of analyzed pottery allowed me to explore the association of identified foods with pottery form (restricted pot, unrestricted pot, jar, open bowl, restricted bowl, or small cup and/or bowl) and function (processing, storage/transfer, cooking, or serving), and to assess how defined food categories were prepared and/or served in sampled vessels.
Organization

This dissertation is composed of ten chapters. Chapter 1 provides an introduction to this research and reviews key research questions regarding prehistoric foodways in SEA. Chapter 2 reviews the anthropological approaches adopted to frame the interpretative narrative of the dissertation based on the results. It starts with the introduction of chaîne opératoire approach of foodways as an avenue to examine past social phenomena and organizations, transcending studies focused on “subsistence strategies” and requisite environmental reconstructions. I justify my focus on cuisine or culinary practice as an identity marker using the lens of practice theory and the concept of community of practice, and conclude with how these approaches may be operationalized through the analysis of pottery form, function, and previous food contents. SEA provides a suitable spatial and temporal case study for comparison with other geographic regions and studies that examine prehistoric cuisine and identity.

Chapter 3 provides a review of the geography and geology of SEA. I review the prehistoric archaeology of the region with an emphasis on the Neolithic and Metal Age, and summarize the previous studies on food and ceramics in the region. I argue that the chaîne opératoire approach of foodways should be incorporated to infer past culinary practices and community identities. I introduce southern Vietnam, the regional focus of this dissertation, and review its geologic, geographic, and cultural history, and relevant ethnographic studies germane to this research. The four archaeological sites sampled in this dissertation are also presented.

In Chapter 4, I review the field of organic residue analysis, with an emphasis on the extraction and analysis of lipid residues on pottery. I highlight how these methods may be applied to the assessment of ancient foodways from food acquisition,
preparation, and consumption to not only clarify past subsistence practices, but also to better understand cuisines. I review different lipid groups used as biomarkers, with a focus on fatty acids and discuss the viability and challenges of organic residue analysis, with an emphasis on the application of these methods in the tropics, including SEA.

Chapter 5 details sample selection of modern reference materials for experimental and ethnographic pottery with known cooking histories from SEA and their analysis using gas chromatography-mass spectrometry (GC-MS). Experimental pottery was used to cook selected foodstuff from SEA including pig, chicken, rice, millet, freshwater and marine fishes, coconut, and swamp cabbage. In addition to cooking single food items in modern pottery, mixed cooking was also done. Ethnographic pottery was also sampled, having been used to cook and serve traditional dishes in Vietnam and the Philippines. I conclude Chapter 5 with a discussion of the GC-MS results of these comparative samples, their archaeological implications, and recommendations for further work.

Chapter 6 details the compound specific isotopic analysis of palmitic (C16) and stearic (C18) acids in extracted lipid residues from the modern samples using gas chromatography-combustion-isotopic ratio mass spectrometry (GC-C-IRMS). Modern biological samples of select flora and fauna from SEA are included with the experimental and ethnographic reference materials. The modern compiled database is then compared with data from the literature. Chapter 6 also presents a discussion of the bulk stable isotope ratio analysis of carbon ($\delta^{13}$C) and nitrogen ($\delta^{15}$N) isotopes of charred surface residues of select modern pottery, floral and faunal samples. I compile
these isotopic results into a modern SEA database, discuss their archaeological implications, and provide recommendations for further work.

In Chapter 7, I review the technofunctional analysis of the pottery sampled from the four sites in prehistoric southern Vietnam, and focus on their perceived role as functioning implements in food preparation and consumption. I adopt a life history approach in accordance with the chaîne opératoire perspective. The background and methods of technofunctional analysis are provided and the results (and their implications) are presented for each site. I also provide notes on the post-breakage and discard stages of pottery, review the excavation context of pottery sampled in this dissertation, and discuss the future research potential of these samples.

Results and interpretation from the organic residue analysis of prehistoric pottery samples from SEA are discussed in Chapters 8 and 9. In Chapter 8, I detail the preparation of prehistoric pottery samples for organic residue analysis. The results of organic residue analysis are presented by site, with comparison to the results from modern pottery, flora, and fauna presented in Chapters 5 and 6. Chapter 9 integrates the results presented in Chapter 8 and the results of technofunctional analysis of pottery presented in Chapter 7. Finally, Chapter 10 concludes this dissertation with a summary of key findings and recommendations for further work.

**Significance**

This dissertation is the first microregional and diachronic survey of food residues in SEA oriented towards defining the community identities based on shared culinary practices. It focuses on pottery recovered from four well-excavated sites in southern Vietnam. The results address the preparation and presentation of food, rather than simply its acquisition, as well as the inferred role of pottery and food in the culinary
practices of the people who lived at these sites in the Neolithic and Metal Age. My approach permits me to build upon orthodox approaches used to assess subsistence "strategies" via analysis of resource availability, paleoenvironments, and human paleodiet through the analysis of recovered biological remains and associated material culture. I draw upon the theoretical lens of practice (Bourdieu 1977) and the perspective of community of practice (Wenger 1998) to examine patterns of pottery use and food consumption across controlled spatial and temporal scales. The application of organic residue analysis combined with technofunctional analysis of sampled vessels not only provides complementary evidence of plant and animal resources exploited as food, but also informs on the variation, change, and continuity between the culinary practices.

My research contributes novel, independent sets of data and fresh interpretation to complement ongoing discussion of Neolithization processes (Bellwood 2005, 2013), sociopolitical developments during the Neolithic-Metal Age transition (Higham 2014), as well as food and social diversity (Twiss 2012) in the archaeology of SEA and other geographic regions. Specific food items at sites may be identified by their presence/absence based on studies of recovered animal and plant remains. However, culinary practices can only be deduced by evaluating how key food items were prepared and/or served with pottery vessels and other material culture. The community of practice perspective has the potential to document ancient communities and examine cultural diversity (White 2009, 2012) against "models prioritizing homogeneous Neolithic waves of advance" (White 2009:37-38) and "oversimplified technological transmission models" (White and Hamilton 2009:378). Variation in culinary practices between Neolithic sites may further demonstrate if the Neolithization process is actually more
heterogeneous, which has been already demonstrated with material culture (see, for example, Sarjeant 2014b). The temporal variation in culinary practices between Neolithic sites and Metal Age sites can contribute to the assessment of sociopolitical developments involved during the Neolithic-Metal Age transition. The variations in culinary practices and community identities in this microscalar case study can contribute to broader social diversity, whereby prehistoric SEA contexts provide a fresh spatial and temporal case study to compare to other key geographic regions and studies that examine prehistoric cuisine and identity. After all, “there is ample room for research on food and social diversity in a wide variety of regions and time periods that are as yet underserved in the literature, such as central, eastern, and southeastern Asia” (Twiss 2012:378).

My research also contributes to the field of organic residue analysis in that I directly address bias in the preservation of established lipid biomarkers in archaeological pottery recovered from tropical contexts using modern comparative reference materials. Further, the compound specific isotope results generated from modern experimental and ethnographic pottery as well as flora and fauna and contribute to a modern database that may be viewed in broader comparative context. The results of compound specific isotopic analysis generated from modern experimental and ethnographic pottery, as well as flora and fauna, contribute new C16 and C18 fatty acid data to better understand the food sources from prehistoric SEA. Recovery of food residues in pottery used by different prehistoric communities of people in southern Vietnam contributes to our detailed knowledge of the history and development of regional cuisines.
My research promotes understanding and appreciation of culinary heritage in SEA prior to state formation and contact with the West and the New World. This dissertation fosters inter-institutional collaboration [University of Florida, Australian National University, University of Washington, Southern Institute for Sustainable Development (Vietnam), and Long An Provincial Museum (Vietnam)] that promotes and builds capacities for the integration of biomolecular and anthropological approaches to advance knowledge about Southeast Asian prehistory. It also demonstrates that organic residue studies of pottery provide novel data to address important research questions, which should foster future collaborations. This work contributes to the construction of a millennia-long history of Asian cuisine specifically focused on the roots of modern Vietnamese cuisine. The food and cuisines of the living descendants of prehistoric populations from MSEA are now a global phenomenon because of the growing population of Asian Americans and Asian immigrants.
Beyond Subsistence: The *Chaîne Opératoire* of Foodways

In our enthusiasm for subsistence, we forgot about food. People don’t eat species, they eat meals.

—Andrew Sherratt
*Paleoethnobotany: From Crops to Cuisine*

From the past to the present, food is not only a form of sustenance required for individual maintenance and physiology (Fischler 1988), it is the social glue that binds people together (Atalay and Hastorf 2006; Pollock 1992). Food is symbolic capital because its distribution is controlled by individuals in power, and is aspired by those who want to be powerful (Wesson 1999). Food can also assume other kinds of symbols and, thus, has its own language depending upon context (Levi Strauss 1997; Douglas 1997; Meigs 1997; Sahlins 1976; Sobo 1997). Food is associated with various memories, experiences, and moments (Giard 1998; Holtzman 2006), and some food items assume historical and political significance (Braudel 1981). For example, sugar arguably shaped modern history (Mintz 1985). Lastly, food is an expression of politics (Appadurai 1981), worldviews (Pollock 1992; Richards 1939), group identities (deFrance 2006; Parker-Pearson 2003; Pollock 1992; Twiss 2007; 2012), and cultural heritage (Di Giovine and Brulotte 2014).

There is growing advocacy in anthropological archaeology to build upon research focused on food acquisition and diet, with increased emphasis on ancient foodways (Atalay and Hastorf 2005, 2006; Twiss 2007, 2012) as a means to examine past social phenomena and organizations. “Foodways” comprises the interconnected stages...
(Anderson 1971) of “the production and procurement, processing, cooking, presentation, and eating” of food (Atalay and Hastorf 2006:283), including disposal from the preceding stages (Fig. 2-1). Each stage of foodways, from food acquisition (production and procurement) to disposal, represents a different dimension of human-food interaction (Twiss 2012). As such, foodways also includes food distribution and storage (Fuller 2005; Goody 1982), and myriad facets that can be referred to as “food systems” (Gumerman 1997; Samuel 1996).

Foodways is parallel to chaîne opératoire (Fig. 2-1; Jones 2002; Twiss 2012), which means “operational sequence.” In such a sequence, “techniques involve both gestures and tools, organized in a chain by a veritable syntax that simultaneously grants to the operational series their fixity and their flexibility” (Leroi-Gourhan 1964:164; 1993:114; as cited in Schlanger 2005:27). In other words, it is a series of processes or stages involving natural raw materials that are chosen, formed, and altered into useful cultural products (Schlanger 2005). The chaîne opératoire approach (Schlanger 2005; Tostevin 2011) has been widely used in archaeological (e.g., studies of lithic and pottery production) and anthropological studies (e.g., Coupaye 2009). In studies of foodways, this approach has been applied specifically, for example, to the making of soufflés (Schlanger 1990) and pies and puddings (Yentsch 2012), or more generally to craft and food production (Arthur 2014). The stages in chaîne opératoire are archaeologically traceable, since the plants, animals, and inorganic artifacts utilized by people in their everyday lives are left behind in the archaeological record. Applying the chaîne opératoire perspective to archaeological problems can inform upon the daily lives of the people during the past, since technical systems consist not only of tools, raw materials,
energy, and their physical/environmental context, but also the knowledge, skills, symbolic representations, and social frameworks of the people in question. Thus, *chaîne opératoire* can provide context to interpret immobile archaeological remains beyond the reconstruction of past techniques, towards the active processes of the past (Schangler 2005).

The research presented in this dissertation adopts a *chaîne opératoire* perspective (*sensu* Jones 2002; Leroi-Gourhan 1993) to clarify the role of food and its importance in maintaining and promoting community identity based on shared cuisines in Southeast Asia (SEA). The *chaîne opératoire* of foodways is comparable to the “life history” of food, which consists of the acquisition, preparation, presentation, eating, and distribution of foods, as well as their conscious avoidance (Marciniak 2005). The majority of food-related research in the archaeology of SEA has been focused on subsistence strategies (Binford 1992; Ellen 1994), which are food acquisition practices that include food procurement (hunting, gathering, and fishing) and production (agriculture and animal management) (see Fig. 2-1; Dennell 1979), based on the analyses of plant and animal remains (see Chapter 3). Building on and complementing these subsistence-related studies, this dissertation research will reveal aspects of food processing, cooking, presentation, and eating (Atalay and Hastorf 2006) or the stages of preparation and consumption of food (Fig. 2-1; Anderson 1971). These stages contribute to the concept of cuisine (Fig. 2-1; Pavao-Zuckerman and DiPaolo Loren 2012) or culinary practice, coupled with the combination of available food resources and food preferences in a given region. In this regard, cuisine is culturally distinct and serves as an identity marker (Fuller 2005).
Indeed, the study of foodways allows the assessment of past social phenomena and organizations, beyond the interpretation of subsistence strategies and associated environmental reconstructions (Twiss 2012). Chapter 2 presents a discussion on social diversity (or ‘identities’) in relation to foodways, practice theory and its usage in archaeology, community identity, as well as community of practice perspective and its application in archaeological case studies. This ends with how these approaches are operationalized through the examination of ceramics or pottery with respect to their form, function, and previous food contents. It also provides an introduction to prehistoric SEA, a suitable spatial and temporal case study for comparison with other geographic regions and studies that examine prehistoric cuisine and identity.

**Social Diversity = Identity**

The fundamental premise of studies on ancient foodways and social diversity is that different diets, food preferences, and/or foodway activities signify different social identities (Hastorf and Weismantel 2007; Parker Pearson 2003; Twiss 2007, 2012). Following Twiss (2007:2), identity is “the affiliation of an individual or group with a selected broader group and not with other groups” and each identity can be linked to particular foodstuffs and cuisine. In general, identity is equivalent to the sense of belonging in a group. Numerous identities are established by encounters between people. The choice and agency of individuals are necessary for acquisition and maintenance of their identities. Their active roles then make their identities historical, dynamic, and constantly transforming. Thus, the process of identity building does not cease, but rather is a continuous process (Diaz-Andreu and Lucy 2005).

Since archaeologists often specialize in material culture, they are ideally situated to address concepts of identity (Diaz-Andreu and Lucy 2005). By examining cultural
artifacts, the engagements between the material world and the expression of social identity, both individual and group, can be inferred through archaeology. As archaeologists also operate on deeper time scales, archaeology can provide a chronological perspective on past identities (Diaz-Andreu and Lucy 2005). In this case, foodways as culturally conveyed behavior incorporates symbolic material culture (including food) into its activities, such as food processing and consumption (Lucy 2005; Twiss 2007). Food is utilized to express actual and desired identities, emphasizing membership in one group and not in another group (Twiss 2007). Consistent usage of specific food items strengthens criteria of identity (Smith 2006). Thus, food and foodways, including all activities and stages involved in food production, consumption, and disposal, can be social markers of group affiliation, and this process may be explored archaeologically (Lucy 2005; Twiss 2012).

Specific foodway practices are indicators of specific cultures (Twiss 2007) and are the results of a complex interplay between culture and environment (Twiss 2012). The above premises are illustrated in several archaeological case studies linking foodways and identity in historic native Eastern Woodlands (Briggs 2015, 2016), ancient Phoenicia (Delgado and Ferrer 2011), India (Fuller 2005), northern Europe (Janik 2003), Fiji (Jones and Quinn 2010), Philippines (Junker 2001; Junker and Niziolek 2010), eastern Indonesia (Lape 2000, 2004, 2005), Ethiopia (Lyons 2007), Netherlands (Shuman 2008) and northern Greece (Urem-Kotsou and Kotsakis 2007; Valamoti 2003). Foodways also can change through time (e.g., Haaland 2012; Gijanto and Walshaw 2014; Grillo 2014; Valamoti 2003), which can inform on the impact of introduced technologies (e.g., pottery and metallurgy) as well as associated changes in lifestyle.
(Parker Pearson 2003), social organization (Gumerman 1997), and identity (Twiss 2007, 2012). However, there is often long-term stability and continuity of culinary practices despite the recent introduction of newer food items in particular regions (Haaland 2007; Fuller and Rowlands 2011). This can be attributed to the actual life-sustaining staple and social glue that are the particular foodways practices, rather than the food (Briggs 2015).

The approaches related to the chaîne opératoire perspective that consider all the stages of production and utilization of material culture have the capabilities to deduce identities because the knowledge brought to bear in the manufacturing and usage of artifacts, including the means of executing things, is socially and historically constructed (Lucy 2005). Collective identities are facets of social practice that have to be constantly created and reproduced, and are most operational when collective means of executing things can be demonstrated (Lucy 2005). In her review of foodways, Twiss (2012) outlines how identities (e.g., economic, ethnic, gender, religious) may be deduced from assessing several stages of foodways through the archaeological record.

**Practice Theory**

In anthropological archaeology, practice theory is a prominent mode of discourse that can address aspects of agency, identity, and materiality (Cipolla 2014). Practice theory encourages archaeologists to assess not only extensive cultural processes, but also the roles of the individuals in recreating their social and cultural situations. It focuses on the repetitive connections between individuals and their environments, which are composed of other individuals, collectivities, and material culture. These inter-relations shape the options, behaviors, and practices of the individuals. Practice theory facilitates discussions on action, context, history, identity, culture contact and
interaction, as well as cultural continuity and change (Cipolla 2014). Specifically, in the discussion of identity, approaches related to practice theory focus on the means that the individuals and groups establish, transact, maintain, and reproduce social identities through material culture (Cipolla 2014; Diaz-Andreu and Lucy 2005).

**Unconscious dispositions and embodied practices**

The theory of practice, as stipulated by Bourdieu (1977), suggests that cultural reproduction unknowingly happens in the ordinary facets of day-to-day living. These practices function within the repetitive connections between individuals and their environments. The practices and the resulting representations of individuals are formed at the same time, as well as impacting future practices, from the practices and representations of others surrounding them. This is actually a feedback loop described as follows:

The structures constitutive of a particular type of environment (e.g. the material conditions of existence characteristic of a class condition) produce *habitus*, systems of durable, transposable dispositions, structured structures predisposed to function as structuring structures, that is, as principles of the generation and structuring of practices and representations which can be objectively “regulated” and “regular” without in any way being the product of obedience to rules, objectively adapted to their goals without presupposing a conscious aiming at ends or an express mastery of the operations necessary to attain them and, being all this, collectively orchestrated without being the product of the orchestrating action of a conductor (Bourdieu 1977:72).

Practice theory depends upon the notion of *habitus*, which is a term previously introduced in the work of Marcel Mauss (Cipolla 2014). Habitus is a distinctive model of embodied dispositions that define how individuals act, experience, and perceive the world (Bourdieu 1977). As stated below, it is a stable but exchangeable set of generative schemes:
The habitus, the durably installed generative principle of regulated improvisations, produces practices which tend to reproduce the regularities immanent in the objective conditions of the production of their generative principle, while adjusting to the demands inscribed as objective potentialities in the situation, as defined by the cognitive and motivating structures making up the habitus (Bourdieu 1977:78).

Aside from reintroducing and defining habitus, Bourdieu (1977) also introduced the notion of doxa (Cipolla 2014). Doxa is a phenomenon in which the permanence of social structures as well as the staying power of the societal classification schemes and power regimes are entirely reliant on the supposed natural order. Doxa is thus taken for granted as belief, since what is actually social seems to be natural. Doxas can be questioned and challenged when alternative means of living are introduced, which makes them subject to political and social change. Further, Doxas may be reinstated via orthodoxy or repeatedly confronted via heterodoxy once challenged and dissolved.

Practices are thus the combination of habitus, doxa, and individual actions. Each individual has a historically distinct exposure to different groups, social situations, and classes, which comprises the habitus of that individual. The practices are products of habitus (Bourdieu 1977).

Related to the notion of habitus and the cuisine or culinary practice, which is the focus of this research, is the notion of taste rooted in habitus (Bourdieu 1984). Tastes or preference behaviors reflect social class differentiation or economic means; thus, social identities can be determined by tastes. Taste is also determined by the choices connected to an individual’s early learning in the household (i.e., cooking), which remain despite the improved social class and newly acquired taste of the individual. With changing circumstances of the individual, the change in the taste for food will be slow and some practices will not change to adjust with the new situation. In addition, cuisine
is not only about the foodstuff being eaten, but also the proper behavior when eating. The latter includes seating arrangements, serving rules, appropriate utensils and plates, etc. Proper behavior or etiquette drastically differs according to social class (Bourdieu 1984). Although Bourdieu highlighted cuisine, Giard (1998) critiqued the emphasis on consumption or the serving and eating of food. Nothing was discussed about food preparation or “doing-cooking” (Giard 1998), to be discussed below.

**Structure and agency**

The theory of structuration is the theory of practice established by Giddens (1984) to bridge the disparate focuses on the social whole and individual experiences, rather than to subsequently focus on social practices arranged across space and time (Cipolla 2014). The highlights of this theory are notions of structure and agency. “Structure” is composed of the rules and resources that are necessary for making a similar social practice happen across space and time possible. Social practices assume progressively systematic forms as they are repeated across space and time. According to Giddens (1984:25):

> Analyzing the structuration of social systems means studying the modes in which such systems, grounded in the knowledgeable activities of situated actors who draw upon rules and resources in the diversity of action contexts, are produced and reproduced in interaction.

Parallel to the notions of habitus (Bourdieu 1977) and doxa (Cipolla 2014), practical consciousness is the state in which social proliferation happens as individuals choose and participate in practices (Giddens 1984). It is a domain of mindfulness and certainty of an individual that occurs between discursive consciousness and unconscious motivation. The former involves the capability to expound and express their drive for behaving in a particular manner and the latter is an aspect that individuals are unmindful
of having. Thus, it covers the rationalizations for why individuals participate in practices that they are aware of, but cannot freely expound. Giddens (1984:9) also provided the following definition of “agency” as the capability of doing things, with an emphasis on knowledgeable agent:

Agency concerns events of which an individual is the perpetrator, in the sense that the individual could, at any phase in a given sequence of conduct, have acted differently.

Thus, the theory of structuration states that there is a relationship between human agency and social structure, as well as the structure recreated by the repeated actions of individual agents. Related to this theory is the notion of “duality of structure,” whereby sets of agents and structures are not independent from each other, but embody a duality. Then,

the structural practices of social systems are both medium and outcome of the practices they recursively organize (Giddens 1984:25).

Both Bourdieu (1977) and Giddens (1984) explore the roles played by individuals in materializing the social structures across space and time (Cipolla 2014). For these theories to be useful in archaeology, the archaeological record should not be considered a direct reflection of the past, but should be treated as the remains of past material conditions that were regulated and placed in order by past social practices (Barrett 1988).

**The practice of everyday life**

The theory of practice by de Certeau (1984) places a large emphasis on everyday life, with notions of strategies and tactics as its highlights. Because of its repetitiveness and unconsciousness, everyday life is different from other practices of day-to-day existence. “Strategies” are done by “producers,” which are institutions and
structures of power, whereas “tactics” are done by “consumers,” whereby individuals act on their surroundings, determined by strategies. More emphasis is placed on tactics engaged by the subjugated consumers, which are cautious, resourceful, used limitedly, and grasped quickly within physical and psychological spaces created and ruled by more powerful entities. Numerous everyday or routine practices, such as talking, reading, moving around, shopping, and cooking, are assumed to be tactical from the beginning. These tactics, done by ordinary individuals, are forms of creative resistance to societal repressions. The notion of tactics highlights the recurrent association between individuals and social structures, with the recognition of the roles played by individuals in operating and forming the system despite restrictions and unplanned consequences of action (de Certeau 1984).

Specifically, doing-cooking

Although de Certeau (1984) only briefly mentioned cooking as a routine practice, Giard (1998) specifically researched and wrote on this practice. Coined as “doing-cooking,” this practice was discussed in terms of cooking as (a) nourishing arts, (b) having histories, (d) having rules of the art, and (c) gesture sequences (Giard 1998). Her discussion is the closest application of practice theory focused on foodways, specifically cuisine or culinary practice.

Any food regarded as edible is already considered a cultural item, even during its acquisition (Giard 1998). Geography, choices, habits, and preferences, or the overall culture, define whether a certain food item is edible. Humans do not sustain themselves with natural nutrients, rather with cultured foodstuffs and dishes that are selected and prepared based on the cultural norms peculiar to each area in a particular time span. In Giard’s (1998) discussion, food selection and preparation comprise the cultural practice
of cooking, which plays a central role in the everyday life of the people regardless of their social and economic situation, and considers tradition and innovation, as well as mixing the past and the present. The following passage alludes to the practices of cooking as the nourishing arts that provide pleasure:

I discovered bit by bit not the pleasure of eating good meals (I am seldom drawn to solitary delights), but that of manipulating raw material, of organizing, combining, modifying, and inventing. I learned the tranquil joy of anticipated hospitality, when one prepares a meal to share with friends in the same way in which one composes a party tune or draws: with moving hands, careful fingers, the whole body inhabited with the rhythm of working, and the mind awakening, freed from its own ponderousness, flitting from idea to memory, finally seizing on a certain chain of thought, and then modulating this tattered writing once again. Thus, surreptitiously and without suspecting it, I had been invested with the secret, tenacious pleasure of doing-cooking (Giard 1998:153).

Several reasons are discussed why doing-cooking is considered as a nourishing art (Giard 1998). First, the culinary activities provide a venue for happiness, pleasure, and discovery for individuals doing these activities, despite the fact they require intelligence, imagination, and memory. Second, each individual who does cooking can generate his or her own style and means to navigate the existing and conventional techniques. Third, doing-cooking is the vehicle for a simple, modest, and enduring practice that is frequently done across space and time, ingrained in the relationships between individuals and with self, identified by family histories, and tied to childhood memory. Fourth, culinary production needs a multiple memory for apprenticeship, observed gestures, and consistencies to be able to recognize when certain gestures or steps must be done for desirable outcomes, which are properly cooked and delicious dishes. Fifth, culinary production also needs a programming mind, along with multiple memories, in order to coordinate the requisite steps and sequences in preparing and serving food. Lastly, resourcefulness and creativeness are important in situations when,
for example, leftovers need to be repurposed as a new dish, an ingredient and/or proper utensil is/are missing, and unexpected guests need to be served (Giard 1998).

Doing-cooking is full of histories, where three factors affect food and culinary practices (Giard 1998) or foodways as a whole. First, the natural history of a society in a given geographic area defines the available animal and plant food sources, the characteristic of land for food production, and the climate conditions. Second, the material and technical history, alongside with natural history, includes techniques of land management for food production, introductions and adjustments of animal and plant food sources from other geographic areas, yield enhancement from fertilizers and soil enrichment, as well as techniques of food preservation and preparation.

Humans are preoccupied with the need to store and protect their food with their knowledge and techniques, as well as the availability of necessary resources. For food items introduced into new geographic areas to endure, these foodstuffs should be accepted by the local inhabitants and incorporated into their culinary practices. Third, social and economic history includes price of food commodities, market fluctuation, predictability and abundance of supplies, as well as their rationing. All of these characterize either prosperity or shortage in a society. Social and economic status can be gleaned from the combination of ingredients in a dish and dishes in a menu. Detailed recipes can be records of instances of abundance. Thus, the three factors outlined above also account for diversity in food and culinary practices, as people do not eat the same food, have different means of preparing food, and display different manners while consuming food. Diversity is usually associated with regional cultural history, but could
be a consequence of material necessities gradually installed through tradition, leading to the establishment of regional cuisine (Giard 1998).

Cooking, like art, has a language with four distinct elements: the raw materials or ingredients; the cooking utensils, vessels (pots and pans), and equipment; the descriptions of how cooking must be done; as well as the nomenclature of finished products (Giard 1998). These elements are evident in recipes and cookbooks, where they are written as instructions, or rules to follow. Cooking as gesture sequences is related to having rules, and it is the closest to the chaîne opératoire approach adopted in this research. Gesture sequences are the succession of techniques and steps; moreover, they are also accounted for by differences or diversity in culinary practices, as shown by the following passage:

Doing-cooking thus rests atop a complex montage of circumstances and objective data, where necessities and liberties overlap, a confused and constantly changing mixture through which tactics are invented, trajectories are carved out, and ways of operating are individualized. Every cook has her repertoire, her grand operatic arias for extraordinary circumstances and her little ditties for a more familial public, her prejudices and limits, preferences and routine, dreams and phobias. To the extent that experience is acquired, style affirms itself, taste distinguishes itself, imagination frees itself, and the recipe itself loses significance, becoming little more than an occasion for a free invention by analogy or association of ideas, through a subtle game of substitutions, abandonments, additions, and borrowings. By carefully following the same recipe, two experienced cooks will obtain different results because other elements intervene in the preparation: a personal touch, the knowledge or ignorance of tiny secret practices (flouring a pie pan after greasing it so that the bottom of the crust will remain crispy after baking), an entire relationship to things that the recipe does not codify and hardly clarifies, and whose manner differs from one individual to another because it is often rooted in a family or regional oral tradition (Giard 1998:201).

A certain gesture or technique endures as long as it is still useful, maintained by the performance of its practitioners, and their agreement. It is amended according to
necessity and convenience. Its staying power depends on the faith in its necessity, convenience, being operational, benefits, and possible success (Giard 1998).

Past gestures or techniques related to cooking or culinary practices, in general, changed through time alongside with the changes in associated material culture and subsistence economy (Giard 1998). As a technology, cooking is a sequence of actions that leave a recognizable trail of remains (Morrison 2012). Archaeologists are in an excellent position to assess culinary practices because of the ubiquity of ancient remains related to foodway activities (Klarich 2010; Lyons 2012; Rodriguez-Alegria and Graff 2012). The wealth of the social fabric depends on the diversity of these practices and techniques that provide form to everyday life (Giard 1998). Therefore, archaeologists should be studying cooking in the past because of its direct involvement with food acquisition, manufacturing of cooking tools, and serving of food in everyday meals and occasional larger meals, such as feasts, as well as related notions of gender, work, politics, economic life, cultural life, and social differentiation (Rodriguez-Alegria and Graff 2012).

**Practice Theory in Archaeology of Foodways**

As seen from the preceding discussions, practice theory essentially covers the complete *chaîne opératoire* of foodways or life history of food, with Bourdieu’s (1984) take on consumption and Giard’s (1998) focus on cooking. Archaeological studies on foodways and culinary practices do draw on practice theory (e.g., Atalay and Hastorf 2005, 2006; Hastorf 2012; Lightfoot et al. 1998; Morell-Hart 2011, 2014; Robb 2007). In response to culture-historical and processual approaches, practice theory is often advocated in studies focused on the origins of food production, especially agriculture (e.g., Bruno 2009; Denham 2004, 2007, 2008, 2009, 2011).
Atalay and Hastorf (2005, 2006) provided a narration on the foodways at the 9000-year-old Neolithic site Çatalhöyük, Turkey. They assessed different stages or activities based on analyses of plant and animal remains, sediments, lithics, ceramics, as well as the architectural structures found in the site. They also took into account the seasonality and range of probable food items involved, as well as the timing and venues of activities. They equated foodways to habitus (Bourdieu 1977) practice. The meals shaped the lives of the participants in food preparation and consumption. These also served as foundations of sociality, since food is the “social glue” that bound people together. Through revealing the habitus of the people, their lived experience can also be revealed. Through the study of foodways (and cuisine), the sociality and the temporality of an enduring settlement can be deduced.

In a separate work, Hastorf (2012) focused on cooking or food preparation, in general, and the position of the cooks in the settlement. The cooks were the ones who molded the people that they fed in Çatalhöyük, while applying food codes or tactics (after de Certeau 1984). These tactics were their means to express themselves within their families. The material remains of foodways, including the placement of the kitchen, can also tell us about the position of the cook(s) in the family, the family itself, and the community, as well as if cooks cooked together or by themselves, if people ate publicly or privately, and if the kitchen is in the hidden or visible part of the house. It is interesting to note that cooking was done around the ovens inside the house during the winter and on the roofs outside during the summer, as shown by the remains of plants and animals on the interior floor and exterior roof surfaces. The area surrounding the oven was the core of the house, indicating the central position or authority of the cook.
The oven was transferred to a more salient location through time, suggesting the increasing importance of the cook in family life. This coincided with the changes in pottery forms and decorations from Neolithic to Chalcolithic, suggesting the increasing importance of food presentation. The cooks could have been the elders, based on the evidence of exposure to smoke inhalation in their skeletal remains, or the women, based on the fetal burials located near the ovens. These cooks retained and continued their family traditions (Hastorf 2012).

Robb (2007) interpreted the foodways in Neolithic Italy (Central and Southern Italy including Sicily and Malta, ~6000–3000 BC) through the archaeological evidence of food procurement and preparation. He included senses (taste, smell, texture, appearance, and sound), technological and economic systems, the symbolic and moral values of food, social relations involved, and the time and space associated with consumption as factors characterizing foodways. He emphasized cuisine as “a coherent, institutionalized and meaning-laden set of food practices” (Robb 2007:120) and referred to cooking as “a highly channeled fraction of a chaîne opératoire” (Robb 2007:121). The foods in Neolithic Italy were categorized as those never or seldom eaten, domesticated plants (grains and legumes) that are base of life, flavoring substances (spices, fats, sugar, and salt) that could have made life worth living, and choice domestic animals (mostly cattle). Based on the burned structures found in many Neolithic sites, earth-pit cooking was a distinct food preparation method that involved large quantities of food and labor. He interpreted the Neolithic cuisine as habitus (Bourdieu 1977) also, similar to Atalay and Hastorf (2005, 2006), and as taskscape
(Ingold 1993), which means “temporality and spatiality of everyday activities” (Robb 2007:54).

Morell-Hart (2011, 2014) developed a linguistically oriented, practice-based approach in her analyses of diverse plant remains (macrobotanicals, starches, and phytoliths) in artifacts and sediments from four precolonial sites in northwestern Honduras to interpret foodways and ethnobotanical practice during the Formative and Classic Maya. As a leading characteristic of everyday life, foodways are created via practice, and sequentially forged future practices are part belief and part custom, both of which impact *doxa* and *habitus* (Morell-Hart 2014). Patterning after Saussurean model, her approach is composed of paradigmatic (vertical) and syntagmatic (horizontal) axes of practices. Paradigms are available options, concepts, or activities directed by practices that are revealed along the syntagmatic axis. There are two sets of paradigms, which are associated things (“tool” and “taxon”) and “activity.” The latter is inferred via analogy from ethnography and ethnohistory. Syntagms are potential associations formed between options, concepts, or activities from the paradigmatic axis. Concretely, the combinations of food-related remains from the archaeological record reveal syntagmatic relations of foodways, which are the remains of daily practices (Morell-Hart 2011, 2014). Based on the above approach, Morell-Hart (2014:14) described foodways as follows:

“Grammars” of foodways—the articulated paradigms and sytagms—are instantiated, maintained, transformed, and reiterated through the daily practice that is turn shaped by these “grammars.” Such iterations and reiterations, through daily meals and feasts, can result in the innovation of foodways and the production of novel forms of recipes, practice, process, and performance.
Plant related foodway practices in precolonial northwestern Honduras involved cultivation of domesticated plants, processing of wild plants, and prominence of underground storage organs (calathea and manioc). Some combinations of food, tools, and other elements of practice were continuous over time, whereas some changed (Morell-Hart 2011).

As seen in the cases of Neolithic Çatalhöyük (Atalay and Hastorf 2005, 2006) and Italy (Robb 2007), as well as precolonial Honduras (Morell-Hart 2011, 2014), practice theory helps connect food acquisition, especially agriculture, with other facets of foodways. Bruno (2009) suggested that practice theory may enhance how we understand the tempo, character, and consequences of the early adoption of agriculture. Present-day and ethnohistorical accounts attest that foodway practices from food acquisition to consumption are highly ordered and embody a prominent facet of daily life. By assessing the material remains of these practices, we can trace how several of these practices organized the nature of food acquisition and the prospects for change can be identified (Bruno 2009). Practice theory thus allows us to assess the processes that made traditions persist for extended periods of time (Hodder and Cessford 2004). The means and timing in which these traditions were assimilated relies, in part, on existing cooking technologies and recipes (Atalay and Hastorf 2006). This then permits consideration of the “unintended consequences” (Giddens 1984) in the study of the origins of agriculture and the subsequent effects of the transition to agriculture on the environment (Bruno 2009).

at Kuk swamp in the highlands of Papua New Guinea. Denham suggests that archaeological and environmental approaches should be contextual, rather than simply providing regional histories that serve as unidimensional views of people, practices, and places in the past (Denham 2004, 2008). Contingency should be included in the interpretation of early agriculture based on the archaeobotanical, archaeological, and paleoecological evidence, where considering the agricultural practices in present-day New Guinea is requisite and constructive (Denham 2007). This framework allows us to see the diversity of agricultural practices in various local areas, rather a unified interpretation of early agriculture based on the conflation of evidence from geographically dispersed areas (Denham 2009).

Denham (2011) also proposed a multidimensional conceptual framework to describe early agriculture and plant cultivation as a category of human-environment interactions with three dimensions: spatial scales, transformative mechanisms (multiple socioenvironmental, historical acts that change each other through time), and temporalities of associated phenomena. This framework emphasizes the social aspects aside from the biophysical ones. Drawing on Giddens (1984), the ultimate cause of early agriculture cannot be singular, social or biophysical only, because of the duality of human-environment relations. The treatments of time as continuous, processes as cumulative, as well as the temporality of things as continuous or semicontinuous, were critiqued. The rates of change are barely considered, and the rate of accruement of domestication traits is a function of multiple domains connected to the domestication relationship in a human-environment context. Drawing also on phenomenology
(Heidegger 1962; Ingold 2000), Denham critiqued the archaeology of early agriculture for treating time as chronological, rather than as a lived experience (Denham 2011).

Perhaps, the most often-cited case study on the application of practice theory in archaeology is the work of Lightfoot et al. (1998) and their examination of interethnic multiethnic households composed of Native Californian women (Kashaya Pomo) and Native Alaskan men (Alutiiq) at Fort Ross, a 19th century Russian colony in northern California. The authors argued that trash deposits and middens, which are formed by the accumulation of debris from mundane tasks in human-modified environments, provide abundant opportunities to evaluate daily practices, culture change, and persistence. The authors developed an approach that takes into account the material residues of daily practices and space utilization in multiethnic settings. The significant part of this approach is investigating the set of routinized practices in multiscalar research, which is widely diachronic and comparative. This approach is based on an important principle of practice theory that individuals will reiterate their standards and beliefs in organizing their day-to-day activities. The habitual actions that govern the domestic lives of the people provide the patterned accumulated material remains that can be recovered from the archaeological record. The organization of daily life can be determined by examining the arrangement and utility of space, order of domestic activities, and spatial patterns of garbage disposal. Thus, evaluating habitual practices of domestic life and space organization in archaeological context can best address change and persistence in multiethnic situations of establishing social identities. The structural tenets of the Russian colonizers were replicated in the wider colonial landscape based on the arrangement of ethnic neighborhoods, whereas the principles
and beliefs of Alutiiq men and Kashaya Pomo women were most reflected at their practices in community and households. Assigning depositional events as the units of analysis helped in their study of habitual practices. This identifies features and depositional events that build up because of the routines that people repeatedly do. Advanced field techniques as well as recording and interpreting microstratigraphy and microformation processes were utilized to evaluate habitual practices in archaeological contexts. Therefore, the detailed diachronic and comparative study of habitual practices provides an improved contextual approach for assessing culture change and persistence (Lightfoot et al. 1998).

Lightfoot et al. (1998) highlighted the disposal practices of the people alongside with their food preparation practices. The two ethnic groups, Alutiiq and Kashaya Pomo, can be differentiated through their disposal practices. The Alutiiq accumulated their trash, mostly from food, within large common areas of the house that served as living room, kitchen, and workshop. The trash recovered from older floors was occasionally covered with fresh grass or a clean sand layer to make the interior surfaces appear decent. Thus, the Alutiiq disposed of their trash by frequent house remodeling and floor construction. In contrast, the Kashaya Pomo strictly disposed of their trash and regularly cleaned inside and around their houses. There was a clear separation between residential and midden areas. For multiethnic households composed of these two ethnic groups then, the notions of order and cleanliness of the Kashaya Pomo were enacted, possibly by the women. They regularly swept the houses and disposed of their trash far from their houses (Lightfoot et al. 1998).
Community Identity

As shown by the archaeological case studies linking food and identity, including those that utilized practice theory, food and foodway practices are prominent in the formation of sense of belongingness and affiliation with groups, collectives, and communities (Delgado and Ferrer 2011). Food plays a role in the creation and depiction of communities, as well as in the articulation, manipulation, or maintenance of group solidarities, collective social memories, and cultural identities (Delgado and Ferrer 2011; Marciniak 2005). Communities can be entities demarcated by social boundaries, marked by the patterning of material culture remains in the archaeological record, based on the technical choices of the members of the communities. The *chaîne opératoire* approach is useful for inferring social boundaries and communities because of the fact that technical choices, which are sources of variation or diversity in material culture patterning, occur in every stage or step of a *chaîne opératoire* (Stark 1998).

“Community” is “a social relationship, a sense of interdependence and belonging” (Hegmon 2002:263). It may be defined as “a group of individuals who live in proximity to one another within a geographically limited area, who have face-to-face interaction on a regular basis, and who share access to resources in their local sustaining areas” (Varien 1999:4). Being a member of a community is part of an individual’s social identity (Hegmon 2002). Communities are characterized by the shared practices of their members and the means by which they can be recognized. They have geographic, demographic, and social aspects, and can be recognized in the archaeological record through the residues of practices done by the individual members. Thus, community is a very useful concept in archaeological research (Hegmon 2002). It is also a socially
important unit of analysis, as its scale is larger than a household, but smaller than a region (Canuto and Yaeger 2000).

The concept of community, as used in archaeological research, has been reviewed by Knapp (2003) and Mac Sweeney (2011). The “geographic community” as defined by Mac Sweeney (2011:32) is focused on solidarity of residential closeness and shared space. Relationally, communities may be considered as imagined communes with common notions of interest and identity, which are sustained through social practice. This “community” parallels Knapp’s (2003:559) notion of community structured as the “sense of place.”

Equating community as social identity and dealing with how community identity can be gleaned from analyzing material culture came from two developments in archaeology (Mac Sweeney 2011). First, archaeology began to deviate from purely empirical approaches and lean toward tackling identity, subjectivity, and social meaning. Second, the “spatial turn” with notions of phenomenology, experience, and embodied practice were incorporated into archaeological interpretation. Community then was pitched as a vibrant model of social identity, which is tied to the notion of “shared geographical space and common lived experience through the active use of shared social practices” (Mac Sweeney 2011:28).

“Community identity” (Knapp 2003; Mac Sweeney 2011), based on cuisines or culinary practices, is the notion of identity considered in this research. Other notions of identity, such as gender, rank, religious, and ethnic identities (Diaz-Andreu and Lucy 2005), are not applicable because of the time depth involved, and ethnohistorical and ethnographic references are not useful for framing relevant hypotheses to assess
identity. One can probably consider ethnic identity; however, the creation of ethnic identities is an ongoing historical process and not static, but situational (Lucy 2005). It is not satisfactory to simply assume that any group identity is equivalent to ethnic identity. Group identity only forms at specific historical moments and around social grounds that are not necessarily ethnic, where group members have notions of shared descent or ethnicity (Mac Sweeney 2009). As seen in the culture history of the case study area in this research, which is southern Vietnam (see Chapter 3), the people who lived in this area during prehistory cannot be called Vietnamese, Khmer, or Funanese, and not everyone living in the same area today is Vietnamese or Khmer. It is not possible to infer if people during prehistory had a concept of ethnic identity. Thus, it is inappropriate to infer anything about ethnic identity in prehistoric southern Vietnam. Community identity is more appropriate to infer, since it is both socially created and flexible. Depending on historical situations, it may also form or dissolve (Mac Sweeney 2011).

To grasp the undercurrents of community identity, we should examine the mental construct of a community through social practice, as well as the creation, affirmation, and contestation of the sense of community belonging (Mac Sweeney 2011). Social experience and practice establish the sense of community, and shared experiences and practices continually construct and reconstruct identity (Canuto and Yaeger 2000). Community identity is defined as follows:

…it is a particular form of social ideology that emphasizes sameness and cohesion rather than difference and differentiation. There will always be some things that members of a community share and some things that they do not. ….. It emphasizes what is shared, so that social differences are played down and temporarily pushed aside. It focuses on creating, consciously and artificially, a sense of “us” (Mac Sweeney 2011:38).
The sense of location or the geographic sense of shared experiences is what makes community identity distinct from other types of group identity. It is because shared experiences happen when individuals are living together. These lived experiences are performed in several social relationships, where performances leave noticeable material residues. These remains of material culture offer evidence for the lived experience of identity. Inferring community identity with archaeology mainly relies on material culture, which offers evidence for performances of community and the notion of being united (Mac Sweeney 2011).

Knapp (2003) and Mac Sweeney (2011) applied their interpretative frameworks for community identity on their case studies in a Bronze Age Phorades smelting site in Cyprus and a Late Bronze-Early Iron Age site in western Anatolia (Aphrodisias and Beycesultan sites), respectively. The works of Lewis (2007) in ancient southwest Arabia, Delgado and Ferrer (2011) in ancient Phoenicia, and Metheny (2013) in historic Pennsylvania provide case studies related to foodways that invoke the notion of community identity. Through multiple lines of evidence from quotidian and ritual contexts of food production, distribution, and consumption in ancient southwest Arabia, Lewis (2007) demonstrated that investigating the means of how people perceived, manipulated, and interacted with their natural and human-modified landscapes can aid in clarifying the role of foods in perceiving cultural and community identities during the past. Delgado and Ferrer (2011) demonstrated that staple and everyday food had prominent roles in the formation of feelings of belongingness in a community and network in ancient Phoenicia along the Mediterranean coast. The practice of sharing food was important in the creation of social relations with relatives and community
members (Delgado and Ferrer 2011). Metheny (2013) demonstrated that the daily practices of sharing food and eating together established and asserted the social and economic ties between individuals and groups that are important in the creation and maintenance of communities, identity, and place in the historic mining town of Helvetia, Pennsylvania.

**Community of Practice**

In this research, community identity (Knapp 2003; Mac Sweeney 2011) is examined through “community of practice” (Wenger 1998). A community of practice is composed of individuals who collectively learn and practice activities through mutual and constant engagement. Their shared ideas, memories, skills, practices, and subsequent relationships are what make them identify and/or perceive themselves as a part of a community (Lave and Wenger 1991; Wenger 1998). In general, communities of practice are described as follows:

Groups of people who share a concern and passion for something they do and learn how to do it better as they interact regularly (Wenger 2012:1).

As a theory of learning, the community of practice perspective begins with the premise that the central process of how we learn and become who we are is grounded in our involvement in social practice. Rather than the individual or social institutions, the principal unit of analysis is the informal “communities of practice” that individuals establish while going after their shared enterprise over time. This theory examines the juncture of issues of community, social practice, meaning, and identity (Wenger 1998).

“Communities of practice are everywhere” (Wenger 1998:6). Everyone belongs to several communities of practice at any given situation, place, and time. These communities of practice are an important part of our everyday lives, very informal, and
ubiquitous. We can differentiate some communities of practice according to our kind of membership, whether we are core or peripheral members (Wenger 1998). Further discussions demonstrate that the characteristics of communities of practice are parallel to those of community, compatible with community identity, as well as involve the duality between practice and identity.

Communities of practice are communities that were constructed over time because of their continuous quest of a shared enterprise (Wenger 1998). Their practices are products of collective learning over time, reflecting the quest for enterprises and the accompanying social relations. There are six basic aspects of practice, namely, practice as meaning, practice as community, practice as learning, practice as boundary, practice as locality, and knowing in practice (Wenger 1998).

“Practice is about meaning as an experience of everyday life” (Wenger 1998:52). The meaning is situated in the process of negotiation of meaning, which involves participation and reification. The duality between participation and reification is important for experiencing meaning and practice, as well as to the negotiation of meaning. The process of negotiation of meaning is, in the first place, human engagement in the world. Participation is the social experience of living in the world based on being a member in social communities and being actively involved in social enterprises. The process of reification, fundamental to any practice, provides form to our experience by manufacturing objects that solidify this experience into “thingness.” It is not only a process but also its product. Abstractions, tools, symbols, stories, terms, and concepts may be created by any community of practice that reifies the practice into a solidified form. These products of reification are not only tangible, material objects but
are also impressions of these practices, which are symbols of infinite stretches of human meanings (Wenger 1998). From an archaeological standpoint, these products of reification are actually material remains of various practices that may be recovered in the archaeological record. The duality between participation and reification indicated that the two processes are not opposites, but are distinct and complementary dimensions that interact with each other (Wenger 1998).

Linking practice and community produces a more manageable characteristic of the notion of practice, which can be differentiated from less manageable notions of culture, activity, or structure, and describes a special kind of community, which is a community of practice (Wenger 1998). This linkage has three characteristics that make practice the source of unity in a community, namely, mutual engagement, a joint enterprise, and a shared repertoire. Being a member of community of practice is defined by mutual engagement. Work is necessary to achieve the kind of unity that translates mutual engagement into a community of practice. Thus, any practice has the work of “community maintenance” as its core. Both variation and uniformity make engagement in practice probable and fruitful. A community of practice is established from a variety of members through their mutual engagement, where members have overlapping, rather than complementary capabilities. Interpersonal relationships among members also arise from mutual engagement in practice, rather than from idealized notion of community. A joint enterprise is a negotiated enterprise based on agreement, and uniformity among members of a community of practice is not expected. It is also an indigenous enterprise, since communities of practice are not autonomous bodies. Communities of practice were developed according to their historical, social, cultural, and institutional contexts.
with particular resources and limitations. Relations of mutual accountability result from negotiating a joint enterprise, in which individual members evaluate what matters, what is important, what to do, to pay attention to, to talk about, to justify, to display, and what is good enough, or not. The shared repertoire includes actions, ideas, and things that the members have created or embraced and become involved in during the existence of a community of practice. It merges both reificative and participative facets. The repertoire of practice is a resource for the negotiation of meaning because of its two characteristics, namely, history of mutual engagement and being innately uncertain. Actions, ideas, and things as having noticeable histories of interpretation and mutual engagement are not hindrances, but rather useful resources for the production of new meanings and can be engaged in new circumstances. With the three characteristics just discussed, communities of practice are “a force to be reckoned with” and “hold the key to real transformation” (Wenger 1998:85).

Community of practice is also defined by a temporal dimension, since its establishment takes time that is enough for mutual engagement in the pursuance of an enterprise to share substantial learning (Wenger 1998). Thus, “communities of practice can be thought of as shared histories of learning” (Wenger 1998:86). Participation and reification are forms of memory, sources of continuity and discontinuity, and channels that can direct the development of practice. Practices developed as shared histories of learning are a blend of participation and reification entangled over time. Communities of practice are capitalized in reification, whereby things or artifacts, ideas, and words reveal particular perspectives they are inclined to reproduce (Wenger 1998).
Communities of practice should be acknowledged as a “fact of social life” and they are significant loci of “negotiation, learning, meaning, and identity” (Wenger 1998:133).

The establishment of a community of practice is parallel to the negotiation of identities, making practice and identity deeply connected (Wenger 1998). Identity is characterized as negotiated experience, community membership, learning trajectory, nexus of multimembership, and a relation between the local and the global. When one becomes a member of a community of practice, one experiences competence and is recognized as competent. There are three dimensions of competence that become dimensions of identity, namely mutuality of engagement, accountability to an enterprise, and negotiability of a repertoire. Thus, competence reflects the identity and membership in a community of practice of an individual (Wenger 1998).

**Community of Practice in Archaeology of Pottery Manufacturing and Culinary Practices**

The concept of community of practice has been successfully utilized in studies focused on ancient pottery manufacturing traditions (see Stark 2006). Sassaman and Rudolphi (2001), for example, interpreted pottery manufacturing traditions in the prehistoric southeastern United States (US) as participants in multiple communities of practice. Stark (2006) discussed how community of practice, alongside with anthropology of technology framework and practice theory, had been applied in studies of glaze-decorated ceramics from the late prehistoric southwest US, after the mid-thirteenth century AD, to infer glaze ware innovation and adoption, ceramic change, as well as social units. Eckert et al. (2014) did compositional analyses of Santa Fe black-on-white pottery from the Late Coalition/Early Classic Transition (AD 1250-1350) in New Mexico, southwest US. Based on their combined mineralogical and chemical
compositional data of pottery from five village sites, they argued that there were at least three different communities of practice. Similar designs indicated a single community of identity, and the producers of black-on-white pottery were deliberately maintaining their identity through pottery designs during the transitional period (Eckert et al. 2014).

On the Iberian Peninsula, Kohring (2011) evaluated how social complexity operates at multiple scales, refocusing her analysis of Bell Beaker pottery production during the Copper Age, from the broader Middle Guadiana Basin to the smaller San Blas local community, through the lens of both practice (Bourdieu 1977; Giddens 1984) and community of practice (Wenger 1998). In another, related work, Kohring (2013) highlighted the consonance between chaîne opératoire and community of practice approaches while exploring the connection between conceptual social knowledge systems and technological practices. She considered how communities of practice form technological knowledge, which then resonates back to their conceptual knowledge framework and emerges in their future practices, related to pottery production (Kohring 2013).

Several applications of community of practice perspective, alongside with the related situated learning model (Lave and Wenger 1991), focused on studies of culinary practices, are emerging (e.g., Allard 2014; Duke 2015). Duke (2015) applied the situated learning model (Lave and Wenger 1991) to assess the diversity of food preparation and choices during the Moche Period in the Jequetepeque Valley, northern Peru. Culinary practices are informed and learned by individual group members who both keep and personally modify these practices. Despite the absence of recipes with complete instructions and suggestions, it is still possible to explore communities of
culinary practice through the ubiquity and diversity of archaeological remains related to food preparation and consumption. This is demonstrated by the whole ceramic cooking vessel recovered from the site, with remains of llama inside as well as a variety of associated food remains, smaller vessels, and stone tools surrounding the vessel. This scenario was also interpreted as the intersection of craft and culinary practices, where the knowledge of how to produce pottery vessels and lithic tools, as well as how to prepare food, are skills learned by a member of overlapping communities through participation and mimicry, observation and experimentation, as well as trial and error (Duke 2015).

Drawing also on the community of practice perspective (Lave and Wenger 1991), alongside theory of social space production (Lefebvre 1991), Allard (2014) considered the roles of foodway practices, such as meat procurement and hunting, in the identification and place-making processes of traders and indigenous people during the late 18th-century fur trade in the western Great Lakes, based on her analysis of faunal remains from a trading post in central Minnesota. The mobility, foodway-related skills, which the traders learned from indigenous people and old timers, and then shared foodways, integrated the different groups of people into a community of practice established in the context of fur trading. The fur traders were allowed to create a new sense of place in a new landscape by their mobility related to food procurement practices, making themselves identify as both and nonlocal (Allard 2014).

Recently, community of practice has been advocated as a key approach to examine the intersections between crafts, such as pottery manufacturing, and culinary practices, to reveal social identities (Gokee and Logan 2014) and to address practices
at multiscalar dimensions (Stahl 2014). This concept was utilized by Roddick and Hastorf (2010) to demonstrate that shared practices and sense of community convey the nondiscursive facets of traditions. This supported their diachronic examination of practices related to pottery production as well as food preparation and consumption during the Formative Period in the southern Titicaca Basin. The communities of practice by craft and by culinary practices may overlap by the membership of individuals who are both craft specialists and cooks (Gokee and Logan 2014). This concept was also the basis of Brigg’s (2016) proposal that the persistence of hominy foodways is parallel to the resistance of the Moundville Mississippian standard jar to change its attributes, since the jar is a specialized culinary tool for nixtamalizing maize.

Along with practice theory, the community of practice perspective has the potential to critically examine patterns between ancient communities and cultural diversity, as advocated by White (2011) and demonstrated by several recent ceramic studies in SEA. For example, Chiu (2012) examined the roles played by the Lapita pottery during the expansions of Austronesian-speaking people from Island SEA to the Pacific. She argued that their significance and roles differ from one local community to another, from one context to another, and these differences must be emphasized. This pottery could have been utilized as a reified symbol by the people originating from different backgrounds to express that they wanted to belong to the local community they had transferred into. The process of pottery production, involving well-perceived symbols, can be understood using a community of practice perspective, where people belonging in a house-based group probably indicated their rank in social networks,
engaged in exchange networks, and became more prominent in their communities probably scattered across several islands (Chiu 2012).

In this research, I intend to reveal the community identities in prehistoric southern Vietnam through communities of practices, based on inferred cuisine (e.g., Allard 2014). The next and last section further discusses how this was approached. This work complements the existing work on pottery in the region (e.g., Sarjeant 2012, 2014a,b) that can further reveal the distinct or overlapping communities of practices of pottery production and culinary practices.

**Operationalization: Food and Ceramics in Culinary Practices**

Of the material evidence associated with food, pottery appears to be one of the most powerful tools for investigating both the social aspect of consumption and related issues, such as social relationships and social identity. It is the multiplicity of meanings of ceramic vessels which makes them such a rich source of information on these issues. On the one hand, through the choices made during manufacture and use, ceramic vessels embody the elements of the identity of their makers and users. On the other hand, as an integral part of the practices related to food preparation and consumption, pots embody the perceptions which a particular society has of food (Urem-Kotsou and Kotsakis 2007:26).

By viewing artifacts through the lens of culinary practices, it is possible to grasp the social and economic factors that influenced the past (Graff 2012). As shown by the above quotation, ceramics or pottery are considered compelling artifacts for examining social relationships and identities based on foodways, as well as for examining how specific societies perceived food in the past. The study of technology, form, and former food contents of pottery vessels may offer insights into how people construct and convey their identities through food consumption (Urem-Kotsou and Kotsakis 2007). The usage of pottery is deeply connected with the production, storage, and consumption of animal and plant food sources; therefore, this connection must be
examined (Jones 1999). This can be done through the chaîne opératoire approach of foodways.

Figure 2-2 shows the chaîne opératoire for ceramic manufacture and usage. Although there are numerous studies focusing on pottery manufacturing in SEA, the focus of this research is on the use of pottery (Fig. 2-2) as it is connected to cuisine, which is inside the trapezoid in the chaîne opératoire of foodways (Fig. 2-3). It is the same rectangle in Figure 2-1, which covers cuisine. Completing the chaîne opératoire of foodways is the key to connect disparate studies on food and ceramics in archaeology. In this research, this is done by technofunctional and organic residue analyses of earthenware pottery from prehistoric SEA. Resulting data are interpreted to explore the questions posed in Chapter 1, which are framed in accordance with practice theory and community of practice perspective to evaluate variation in cuisines between different sites of the same time period, change and continuity of cuisines between succeeding time periods in the same region, as well as community identities based on shared cuisine.

Form and Function through Technofunctional Analysis

Technofunctional analysis includes the analysis of technology and form of pottery vessels to infer intended use and use-alteration analysis (surface attrition and carbon deposition) to infer actual use (e.g., Rice 1987; Skibo 2013). Functional categories of sampled vessels focus on form (restricted pot, open pot, jar, open bowl, restricted bowl, or small bowl) and function (processing, storage/transfer, cooking, or serving). As shown in Chapter 7, this analysis focused on the role of pottery as implements used in food preparation and consumption.
Former Food Contents through Organic Residue Analysis

Organic residue analysis (Evershed 2008) provides a suitable biomolecular technique to contextualize the direct relationship between pottery use and the preparation and consumption of different food products, to assess similarities and differences in culinary practices, and to track changes and continuities of these practices (e.g., Jones 1999; Pecci 2014). This analysis relies on analytical organic chemical techniques to infer the characteristics and the source of the organic residues, which survived as actual contents, surface residues, and absorbed residues on pottery (Evershed 2008b; Heron and Evershed 1993). It also provides us the capability to see the dynamic use of food, rather than a somewhat static view of food usage often based on the analyses of animal and plant remains (Jones 1999). This method is further discussed in Chapter 4 and applied in Chapters 8 and 9 to archaeological pottery.

Application: Prehistoric Southeast Asia

Present-day cultural diversity and identities in SEA revolve around cuisines. Some ethnographic studies in the region have focused on how local Southeast Asian communities utilize ceramics, specifically pottery, in food preparation and distribution (e.g., Ono 2006; Skibo 1992). However, as further discussed in Chapter 3, it is not the same case in prehistoric SEA. It is not clear how food items were prepared and served in conjunction with pottery that would allow for constructive discussion of food in relation to cultural variation, change, and continuity, as well as its importance in maintaining identity based on shared cuisine. The identification of variations in culinary practices and community identities can contribute to an understanding of broader social diversity in prehistoric SEA. Southeast Asian contexts also provide a suitable spatial and
temporal case study for comparison with other geographic regions and studies that examine prehistoric cuisine and identity.

Prehistoric southern Vietnam provides a case study from SEA to explore culinary practices and community identities because of the ubiquity of pottery in archaeological sites and in present-day culinary practices, as further discussed in Chapter 3. Cooking pots in the form of open bowls are only used to prepare and serve a fish stew. This specific culinary practice is one of differences between southern Vietnam and central and northern Vietnam. This presents the possibility that an association between a specific pottery form and function with identified food categories can be examined archaeologically, as done in Chapters 7-9.
Foodways: A Chaîne Opératoire


Figure 2-2. *Chaîne opératoire* or life history of ceramics (modified after Fig. 2 in Ross 1982).
Figure 2-3. *Chaîne opératoire* of foodways including animal and plant food sources as well as material culture, with emphasis on ceramics (modified after Fig. 1 in Fuller 2005:762).
CHAPTER 3
FOODWAYS THROUGH CERAMICS IN NEOLITHIC-METAL AGE SOUTHEAST ASIA

Introduction

Southeast Asia (SEA) is part of the larger Indo-Pacific region that is situated east of South Asia and south of East Asia. SEA may be divided into mainland (MSEA) and island (ISEA) regions (Fig. 3-1). MSEA includes Myanmar (Burma), Cambodia, Laos, Peninsular (West) Malaysia, Thailand, and Vietnam. ISEA includes Malaysian Borneo, Brunei, Singapore, East Timor, Indonesia, and the Philippines. As will be seen later, Taiwan is historically included in ISEA (Bellwood 1997, 2004, 2011; Bellwood et al. 2011).

From around 1.8 million to 10,000 years BP, MSEA was connected to Sumatra, Borneo, and Java (Sunda shelf islands), forming the large subcontinent of Sundaland that was an extension of the Asian continent. Taiwan was once connected to the Chinese Mainland. However, the Philippines and Eastern Indonesia or Wallacea (Sulawesi, Moluccas, and Lesser Sundas) were never connected to Asia or Australia (Bellwood and Glover 2004).

The climate in SEA is tropical (Bellwood and Glover 2004; Heaney 1991; Hutterer 1983) and can be divided into humid tropical and seasonally dry tropical environments. The humid tropics are characterized by low latitude (< 5°) with high annual temperatures and more rainfall than evaporation in a year. The seasonal tropics, or subtropics, are characterized by higher latitudes (> 5°) with one or two dry seasons in a year where evaporation exceeds rainfall (Hutterer 1983). The higher the latitude, the longer the dry season (Bellwood and Glover 2004). Major terrestrial environments
include tropical rainforest, tropical seasonal rainforest, tropical deciduous forest, savanna woodland and grassland, montane forest, and swamp forest (Corlett 2009).

SEA can also be divided into four biogeographic subregions (Fig. 3-2): Indochina and the more southern Sundaic subregion that meet at the Kangar-Pattani Line on the Thai-Malay Peninsula, the islands of Wallacea in ISEA, east of Borneo, and the Philippines (Woodruff 2010). Although SEA only covers 4% of the earth’s land area, it has very high species diversity and 20-25% of the earth’s plant and animal species are found in this region. This is partly a consequence of SEA being a transitional area between the continental Asian and Australian biogeographic regions, its low latitude in the humid tropics, its long geological history, and the environmental subregions outlined above (Woodruff 2010). Detailed geological and environmental histories of the region can be found in the work of Boomgaard (2007), Corlett (2009), Gupta (2005), Voris (2000), and Woodruff (2010). Cook and Jones (2012) and White (2011) provide useful syntheses for MSEA, specifically.

Complementing the great environmental and biological diversity of SEA is the rich cultural diversity of its people, from past to present. This can be attested by the archaeology of the region (e.g., Bellwood 1997; Glover and Bellwood 2004; Higham 2014; White 2011). Chapter 3 continues with an overview of the people in the region prior to the introduction of agriculture and metallurgy. It then provides an overview of the Neolithic and Metal Age, which are the time periods germane to this dissertation. It also provides a review of key studies focused on SEA food and ceramics, and I argue that the chaîne opératoire approach of foodways should be incorporated to infer culinary practices and community identities. Chapter 3 ends with an introduction to southern
Vietnam, outlining its geographic, geologic and cultural history, with emphasis placed on the rich ethnographic accounts that lend support to the objectives of this dissertation. Finally, the background for the four archaeological sites included in this dissertation is presented.

**Pre-Neolithic Southeast Asia**

Throughout SEA, foraging was a “broad spectrum” enterprise across terrestrial and maritime biomes (Bellwood 1997; Higham 2014; Hutterer 1976; White 2011) prior to the introduction of agriculture, and this included the cultivation of tubers and fruit trees (Barker and Richards 2012; Latinis 2000). Syntheses by Bellwood (1987, 1997) for ISEA and Higham (1996, 2002, 2014) for MSEA provide important scenarios of the foraging populations that occupied SEA prior to changes in subsistence for some populations with the arrival of farmers and associated changes in material culture associated with the Neolithic period (Bellwood 1997). Pre-Neolithic people were well adapted to inland rainforest (including uplands), open areas and coastal environments, subsisting on a variety of food resources through hunting, trapping, fishing, and collecting wild animals (e.g., pigs and deer), wild plants (seeds and nuts), and aquatic resources (e.g., fishes and shellfishes) (Bellwood 1987, 1997; Higham 1996, 2002; Higham et al. 2011). Palm leaves were utilized for matting and basketry in ISEA (Glover 1981, as cited in Bellwood 1987). Pottery could have already been manufactured and utilized in some areas of MSEA (Higham 1996, 2002).

Based on the work of Barker (2005) and Barker et al. (2007), White (2011) noted the sophisticated capabilities of early, anatomically modern humans in the region to remove toxins via the processing of tubers and nuts. They also exhibited delayed-return behaviors, which necessitate forward planning and resource processing for a few days.
or weeks. Following the bamboo hypothesis of Bar-Yosef et al. (2012), White (2011) also noted that pre-Neolithic people likely utilized bamboo as a food resource and for other purposes as well, depending on the species.

Although Bellwood (1997) stated that the people were mainly hunting and gathering, he acknowledged that the people in Borneo were already tending and planting trees for nuts and fruits. Based on his work in Borneo and synthesis of Holocene settlements in ISEA, Barker (2006) and Blench (2012) noted that pre-Neolithic populations in ISEA (i.e., prior to the arrival of Austronesian-speaking people) were not only foragers, but had developed forest horticulture and were vegeculturalists (sensu Blench 2012) rather than farmers. In fact, the vegeculture or vegetative propagation of tuberous plants observed in ISEA represents the earliest form of plant tending in the tropical rainforests of SEA (Barton and Denham 2011). This form of noncereal agriculture and swiddenlike practice may have resulted from pre-existing foraging practices in the New Guinea highlands (Denham 2011). Vegeculture was compatible with the mobile lifestyle of hunter-gatherers because of the minimal efforts involved in processing and exploiting tubers. Such low-level production limited the advancement of hierarchy, in contrast to higher-level production of cereal agriculture (e.g., rice), which encouraged the development of hierarchy, and promoted sedentism and changes in social organization, production, and distribution (Denham and Barton 2006). Vegetative crops (e.g., bananas, sugarcane, taro, greater yam, sago) may well have spread from New Guinea to ISEA prior to the spread of rice with Austronesian-speaking farmers (Denham 2011; Donohue and Denham 2010).
Two notable claims have been made to support the notion that the gathering of wild rice and its cultivation before the Neolithic period occurred prior to the expansion of Austronesian-speaking farmers. Based on work at Khok Phanom Di in Thailand, Higham (1995) suggested that the people were collected and processed wild rice from coastal and lacustrine swamplands with shell knives. The harvest of wild rice complemented the residential mobility of the hunter-gatherers, since gathering wild rice was technically undemanding (Higham 1995), although this latter claim has been refuted by Higham (2002). Recent palynological work at Loagan Bunut Lake, Sarawak, Malaysia by Hunt and Premathilake (2011) suggested that rice was already exploited by 11,200-7000 BP and domesticated by 8000 BP (Barker et al. 2011), the latter being 4000 years before the arrival of Austronesian speaking farmers and domesticated rice (Barker and Richards 2012). Indeed, Barton (2009) suggested that rice-based agriculture in Borneo may have been adopted by hunter-gatherers already engaged in management of plant domesticates such as greater yam, taro, and bananas. It also seems plausible that the transition toward rice dependency as a staple food occurred even after the proposed period of rice domestication.

The flooding of Sundaland during the early Holocene was important in the development of the maritime lifestyle of the hunter-gatherers in ISEA (Barker and Richards 2012). Archaeological research in ISEA has demonstrated that this lifestyle was technologically sophisticated, where the people utilized not only lithic tools (Szabo et al. 2007; Ono et al. 2010) but also shell (O’Connor et al. 2011; O’Connor and Veth 2004; Szabo et al. 2007) and bone tools (Rabett 2005; see also Rabett and Piper 2012 for a regional coverage). O’Connor et al. (2011) recently reported evidence for pelagic
fishing of species such as tuna and sea turtle, dated to ca. 42,000 years BP at Jerimalai shelter in East Timor, Indonesia. Most notable was their claim that the site produced the earliest evidence for fish hook manufacture in the world.

Early foragers in Southeast Asian tropical environments scheduled their movements and subsistence activities based on the variation in the availability of resources caused by monsoon cycles (Rabett and Barker 2010). They also practiced philopatricy or systematic return to landscape location (White 2011). They played a role in the distribution and clustering of plant food resources and were agents in the formation and care of their environments. Thus, their foraging strategies in tropical environments were adaptive (Rabett and Barker 2010). The next section discusses the period that started with the arrival of farmers from the North, which is the Neolithic Age.

**Neolithic Southeast Asia**

Much attention has focused on the spread of early farming “Neolithic” communities from southern China into MSEA (ca. 3000-2000 BC) and ISEA (ca. 2000-1500 BC) (Bellwood 2005, 2011, 2013; Higham 2002, 2014). Austroasiatic-speaking farmers in MSEA and Austronesian-speaking farmers in ISEA seem to have shared a common language, and were associated with the elements of a “Neolithic material cultural package” (Bellwood 1997, 2005, 2013; Bellwood et al. 2011a; Higham 2014) that included cereal agriculture (rice and millet), soybean, domesticated animals (pigs and dogs), particular pottery types (incised and impressed, red slip), ground stone tools, shell artifacts, jade ornaments, spindle whorls, reaping/shell knives, and bark cloth beaters. Upon their arrival, these intrusive farmers interacted with long-established hunter-gatherers (Bellwood 2005, Higham 2014). This section continues with separate discussions on the Neolithic of MSEA and ISEA.
Mainland Southeast Asia

In MSEA, the Austroasiatic speaking farmers from the north arrived multiple times in the south using coastlines and rivers as their principal thoroughfares (Higham 2014). The Neolithic period in MSEA is characterized by the extensive adoption of rice and millet agriculture, occupation of inland tributary valleys where rice was cultivated, management of domestic cattle, pigs, chickens, and dogs, terrestrial and maritime foraging (Higham 2014). People had both agricultural and aquatic orientations. They produced cereals, tubers, and vegetables and managed livestock, as well as fished a diversity of species using boats (Blench 2015; Sidwell and Blench 2011). There is actually no uniform response to subsistence since food security depends on local environments and culture. Domestic plants and animals only played a minor role in the diet of Neolithic communities (Oxenham 2015). They buried their dead in a variety of ways, either in extended supine position (primary burial) associated with pottery vessels and sometimes large, bivalve shells, or inside large pottery vessels (secondary burial). Pottery with impressed and incised (i&i) patterns and painted designs, as well as stone adzes, are examples of some of the material culture associated with the Neolithic of MSEA. The people also made yarn used in weaving with ceramic spindle whorls (Higham 2014). The role of food is already prominent in mortuary rituals, where pig bones accompanied burials and complete fish skeletons were contained inside pottery vessels (Higham 2012).

The above orthodox description of the Neolithic in MSEA is an outline of the “two layer” hypothesis, which states that the Austroasiatic-speaking farmers were the second wave of immigrants who arrived in the area (Higham 2015). In contrast, an alternative view argues for population continuity with a lengthy transition from predominantly
hunting and gathering to predominantly farming with local origins of agriculture and little to no influence from outside. Rice agriculture is likely a recent occurrence that followed widespread, diverse agricultural systems that included horticulture and shifting cultivation of other crops (White 2011). This alternative model is termed the “regional continuity model” (Higham 2015).

Aside from a northern homeland in China proposed by the two-layer hypothesis, three alternative locations have been proposed as the homeland of the Austroasiatic-speaking people (Blench 2015). First, Van Driem (2011, 2012) proposed a western homeland based on linguistic evidence from the northeastern portion of the Indian subcontinent (near the northern Bay of Bengal) and the Indo-Burmese borderlands. Second, Diffloth (2005) proposed a western homeland based on the floral and faunal terms, which are said to rule out a temperate homeland (China) and favor a tropical and humid location near the Bay of Bengal. Third, Sidwell and Blench (2011) proposed the Southeastern Riverine Hypothesis with the Mekong Basin as the homeland based on linguistics, anthropology, and archaeology. The Austroasiatic-speaking people were fisher-foragers that lived along the river. One of their cultural markers is the i&i pottery (Sidwell and Blench 2011).

Island Southeast Asia

In ISEA, the orthodox explanation for how these islands were continuously populated during the Neolithic is the Out-of Taiwan hypothesis (Bellwood and Dizon 2008). It stated that at around 3000 BC, the proto-Austronesian-speaking agriculturists from China migrated to Taiwan, and by 2000 BC, the Austronesian-speaking people migrated from Taiwan to ISEA (Bellwood 2005, 2011). This inference is based on work at Neolithic settlements in the Philippines and Central Indonesia, dating to between
2000 and 1500 BC. Shifting cultivation of rice under conditions of periodic stress was suitable for human dispersal, since intensive wet rice production was impossible because of limited labor (Bellwood 2011). Red slipped pottery with dentate- and circle-stamped designs, shell tools, as well as polished stone adzes are examples of the material culture associated with the Neolithic of ISEA (Bellwood 2004).

The main alternative view on the dispersal of people with their pottery in ISEA is the Nusantao Maritime Trade and Communication Network hypothesis, developed by Solheim (1984-1985, 2000, 2006). These migrating people were called the Nusantao, whose lifestyles were mainly maritime-oriented, but they also had knowledge regarding terrestrial resources. They may have been Austronesian-speaking people, but their origin or homeland was not Taiwan, but rather the southeastern part of ISEA, between Eastern Mindanao Island of the Philippines and Northeast Indonesia. In contrast to the North-South movement of Austronesian-speaking farmers from Taiwan down to ISEA and Pacific (Bellwood 2005; Bellwood et al. 2011), the Nusantao people moved from South to North and were able to reach present-day South China, Japan, and Korea. The Nusantao culture is claimed to be older than the “Austronesian” of the Neolithic (2500-4000 years BP). The proto-Austronesian language was used to facilitate barter or trade. The proposed maritime network from SEA to Korea and Japan (based on archaeological evidence in these areas) is multidirectional, with lots of nodes (Solheim 2006). Bulbeck (2008) provided an integrated view on the migration of Austronesian-speaking people. Cereal (rice) agriculture is already well-established in Taiwan; however, the southward spread is associated with maritime foraging and trade (Bulbeck 2008).
Denham (2013) recently argued that there is no substantial evidence for an Austronesian dispersal with cereal agriculture and animal husbandry from Taiwan to ISEA. Rather, early agriculture was based on noncereal plants that were cultivated and domesticated in ISEA and New Guinea and early animal husbandry was based on animal domesticates that originated from Mainland Asia (Denham 2013). Thus, the Neolithic material culture package did not spread together because domestic animals and plants would have had alternate migration routes (Blench 2012; Donohue and Denham 2010; Denham 2013), The Austronesian-speaking people were not farmers, but fisher-voyagers (Blench 2012).

For the whole of SEA, other scholars argued that the Neolithic is not about the spread of agriculture with the dispersal of people (after Barker and Richards 2012; Blench 2012; Spriggs 2011, 2012; White 2011); rather, it means the exchange of material and information (Barker and Richards 2012), spread of religious or lifestyle ideology (Blench 2012), is a process of identity formation (Spriggs 2011), and the spread of agriculture along with the spread of technological systems (White 2011). As we shall see in the next section, the Metal Age, specifically the Bronze Age is MSEA, is very much debated, similar to the Neolithic Age.

**Metal Age Southeast Asia**

The Metal Age of SEA was said to be a “force to reckon with” (Loofs-Wissowa 1983:1), as it is the transitional period from prehistoric to historic and contemporary SEA. In MSEA, the Metal Age is subdivided into the Bronze and Iron Ages (Higham 2014). In ISEA, it is simply Metal Age because various metal technologies and material culture arrived in the area at the same time (Bellwood 1997), in contrast to defined separate initial arrivals of bronze and iron metallurgies in MSEA (Higham 2014).
The beginning of the Bronze Age is a matter of significant debate in MSEA, but this period likely started by around 1000 BC with the arrival of bronze metallurgy in MSEA from the Yellow and Yangtze Valleys in China (Higham 2002, 2014, 2015; Higham et al. 2011, 2015; Rispoli et al. 2013). Recent chronologies from Northeast Thailand, based on 105 radiocarbon dates, placed the beginning of the Bronze Age by the spread of copper-based technology from the early states of China in the late 11th century BC (Higham et al. 2015). This view is referred to as the “short chronology model” (SCM; Higham 2014; Higham et al. 2015).

The Bronze Age is characterized by metal tools and ornaments that were cast in copper and bronze, such as axes, spearheads, chisels, bangles, fishhooks, bells, and anklets (Higham 2014). These were cast in bivalve molds made of sandstone or clay, which have hollowed portions resembling the outline of the metal artifacts. Crucibles with bronze scoria indicated casting of bronze artifacts. Most of the settlements were found in slightly elevated ground near low-terrace soils and bodies of water. The people harvested rice and millet, maintaining domestic animals similar to the Neolithic for consumption and ritual purposes. They hunted, trapped, fished, and collected shellfish, and were involved in salt production. Cemeteries, established for centuries, indicated their commitment to a sedentary lifestyle. Adults and infants were buried with prestige goods. Some of these burials are interpreted as an aggrandizement of social display, or starburst (Higham 2014). The role of food is also prominent in mortuary rituals, where bones of pigs, cattle, and chicken, including complete fish skeletons (as well as shellfish and bird’s eggs) were found inside pottery vessels. These vessels, filled with food, were interpreted as those used for feasting (Higham 2012, 2014).
Alternatively, it has been proposed that bronze metallurgy in MSEA started as early as 2000 BC through the technological system transmission from Seima-Turbino, in Southern Siberia, in the area between the Altai Mountains and Dneiper River (White and Hamilton 2009, 2014). This view has been coined the long chronology model (LCM; Higham 2015; Higham et al. 2015).

Regardless of the precise timing, the arrival of metallurgy had significant impacts on social organization, as shown by the appearance of bronze and copper tools as offerings in select mortuary contexts (O’Reilly 2000). Social organization during the Bronze Age was proposed to be either hierarchy, characterized by the presence of social elite and ranking, including starburst social display (e.g., Higham 1989, 2011, 2014), or heterarchy (see Crumley 1979, 1995), characterized by the absence of social elite and ranking (e.g., Eyre 2011; O’Reilly 2000; White 1995; White and Eyre 2011; White and Pigott 1996).

Nevertheless, the Bronze Age in MSEA was different from that in other parts of the world, where the arrival of bronze technology coincided with the rise of urbanism or states (O’Reilly 2000). The rise of states or chiefdoms, and urbanism, is more prominent in the period that followed the Bronze Age, i.e., the Iron Age (Higham 2014).

**Iron Age in Mainland Southeast Asia**

The Iron Age in MSEA likely started around 400-500 BC and ended by around AD 400-500 (Higham 2014). The knowledge of iron metallurgy could have arrived from China or India, or a local innovation. This period is characterized by expanding exchange networks and increasing social inequality, compared to the Bronze Age. Two different cultural trajectories happened during the Metal Age. First was the rise of Dong Son chiefdoms in northern Vietnam that were only short-lived because of their...
incorporation into the Chinese Han Empire. Their most significant cultural artifacts are their bronze drums. Second, local communities developed more complex social organizations, with a trend toward centralization (Higham 2014). These communities, such as those inhabiting the Mekong Delta, Coastal Vietnam, Chao Phraya Valley, as well as peninsular Thailand and Malaysia, became participants in a wider interaction sphere, broadly expanding their maritime exchange networks into the Mediterranean Area, South Asia, and East Asia. One of these networks was the Southern Silk Route, which involved the Roman Empire to the west and the Chinese Empire to the east (Bellina and Glover 2004; Higham 2014). The spice trade, with the involvement of Moluccan spices (clove, nutmeg, and mace), has been credited for the Indianization of SEA (Bellina and Glover 2004). Beans from South Asia (mungbean and horsegram) were also introduced into MSEA at this time (Castillo and Fuller 2010). The early coastal polities flourished around the 2nd century BC to the 3rd century AD and the first coastal city states followed to prominence around the 3rd to 6th century AD (Manguin 2004).

Moated sites with ramparts, such as Co Loa in northern Vietnam (see Kim 2013, 2015; Kim et al. 2010), constructed earthworks for controlling the flow of water, boat burials, and evidence of warfare also characterized the Iron Age sites in MSEA (Higham 2014). In addition to iron smelting and forging, glass-making was practiced. Red-on-buff painted vessels, rouletted wares, kundika and kendi pottery, stamped and molded ceramics, bronze vessels with a central cone, semiprecious stone and glass ornaments (glass and carnelian beads and jewelry), spears and swords, coins and seals, as well as large stone slab tombs and megalithic structures all are characteristic material culture associated with the MSEA Iron Age (Bellina and Glover 2004; Higham 2014). Rice
cultivation was done in larger land areas and by plowing with the aid of water buffalo, thus producing greater surplus. The abundance of iron may signify the availability of more agricultural tools for more efficient rice cultivation. The people also managed cattle and pigs (Higham 2014). The role of food remained prominent in mortuary rituals, where limb bones of pig and cattle, complete fish skeletons, as well as rice grains were found inside pottery vessels (Higham 2012).

The Iron Age of MSEA overlaps with the Metal Age of ISEA (Pryce 2014). Whereas the Bronze and Iron Ages can be distinguished as separate cultural entities in MSEA, that cannot be done in ISEA because there are no sites in ISEA that can be exclusively identified as Bronze Age sites (Basa 1991).

**Metal Age in Island Southeast Asia**

In ISEA, the Metal Age (ca. 500 BC-AD 500) is characterized by the synchronous appearance of copper/bronze, iron/steel, gold, silver, and trade goods from Vietnam, India, and China (Bellwood 1997; Pryce 2014). The Austronesian-speaking farmers were proposed to apparently disperse from ISEA to MSEA and the Pacific Islands (Bellwood 1997, 2005; Bellwood et al. 2011a). Similar to MSEA, ISEA was also involved in a wider interaction sphere and the expanding maritime exchange networks (Bellwood 1997; Spriggs 2000). One of these networks is the Sa Huynh-Kalanay Interaction Sphere in the South China Sea around 500 BC-AD 100. This is manifested by the shared material culture between MSEA and ISEA, such as distinct incised and stamped pottery styles, jar burials, precious stones, and baked-clay jewelry (Hung et al. 2013). Roulette ware, molded pottery, and glass and stone beads from India were found in various sites across ISEA; however, the Dong Son bronze drums from northern Vietnam were only found in Indonesian sites (Bellwood 2004). It is hypothesized that the method
of rice farming was wet-field (irrigated and/or terraced) agriculture (Bellwood 1997). Linguistic evidence may imply a later introduction of a rice-based economy along with metal technology in ISEA (Paz 2002).

**From State Development Until Contact with the West**

Early urban states in SEA were developed from the chiefdoms during the Iron Age in MSEA (Higham 2014) and Metal Age in ISEA (e.g., Junker 2000). The components of Indian culture, such as religion, scripts, Sanskrit language, and architecture, were integrated into indigenous cultures. These are evident through the Sanskrit names of several state leaders (Higham 2014). The small urban states were characterized by moated settlements surrounded by hydraulic works and earthen ramparts as well as connected to proximal bodies of water (Stark 2015). One of these states is Angkor, which existed from AD 802 to 1431 in Cambodia (see, e.g., Higham 2012, 2014; Stark 2004). The period after the collapse of large empires, such as Angkor, is described as the early modern period (ca. AD 1450-1800). It is characterized by the development of local craft industries, multi-ethnic diasporic communities in port cities, and standardized currencies. Europeans arrived in SEA to search for luxury goods and precious metals, as well as colonized most of the territories in the region (Stark 2014).

The next section returns the discussion to the Neolithic and Metal Age, since this research only covers these two major periods that precede development of states. It comments on the prevailing food and ceramic studies of the region, suggesting that the chaîne opératoire approach of foodways connects studies on food and ceramics. It also discusses how assessing ancient foodways contributes to the studies of past sociocultural diversity in SEA.
Ceramics in Foodways of Prehistoric Southeast Asia

Finding Foodways in Southeast Asian Archaeology

Ceramics or pottery are assumed to have been used as food containers or as equipment to prepare food and/or serve food. However, pottery as a defining marker for Neolithic food production or associated with domesticated cereals and animals, may not always hold (Bellwood 2013). It may not be related to the spread of agriculture in MSEA, as shown by the morphological and technological diversity of i&i pottery (White 2011). Pottery containing food offerings or food for mortuary feasting is prominent in burials during the Bronze Age in MSEA (Higham 2014). Other than the obvious, however, the association of pottery with various food items has not been critically evaluated in prehistoric SEA. Indeed, there are several assumptions that are embedded within the debates on farming-language dispersals and foraging-farming transitions in the region that are useful to assess with respect to how pottery is associated with diverse food sources.

In the case of rice, there is a lack of evidence of processing and consumption of rice to link rice agriculture with the dispersal of Austronesian-speaking farmers in ISEA (Donohue and Denham 2010; Paz 2002). This is because most of the evidence for the presence of domesticated rice is from temper within the fabric of pottery (Castillo and Fuller 2010; Denham and Donohue 2010; Paz 2002). However, pottery with rice chaff as temper indicates threshing of rice grains prior to cooking and their incorporation into the clay matrix used in pottery production (Bellwood 2011). The organic component from rice chaff incorporated in pottery is destroyed during firing; thus, only rice residues used in cooking are supposed to be present in a pot if that pot has been used to cook rice. It is possible that rice was prepared in other kinds of cooking vessels, such as
those made from bamboo (Hayden 2011). The individual internodes of bamboo can be converted into containers for cooking, storing, and transporting food (White 2011). It is also possible that the rice-based economy actually spread with metal technology, since intensive and irrigated cultivation of rice was impossible without metal farming implements (Paz 2002).

Instead of rice, the cooking pots could have been used to prepare food products (e.g., oil, soup) from aquatic resources that cannot be prepared in bamboo tubes or other vessels made of perishable plant materials (Hayden 2011). Different food preferences for aquatic resources are possible based on subsequent archaeological findings. In northern SEA, specifically in Batanes Islands, Philippines, the preference for pelagic fish such as dolphin fish is characteristic in the present-day and can be traced back to the Neolithic. The same is the case for the processing techniques involved (Campos 2013). In Borneo, specifically at the Bukit Tengkorak site, Sabah, Malaysia, however, prehistoric inhabitants preferred inshore coral fishes, a similar pattern found at Lapita sites in the Western Pacific and markedly different from contemporary Neolithic sites in ISEA. The present-day inhabitants, who are the Sama people, prefer to eat fish and root crops, rather than rice, as their carbohydrate source. They also prefer to cook their fish and root crops in pottery ovens (Ono 2006).

In the case of terrestrial animal sources, wild terrestrial meat was likely preferred for consumption despite the arrival of domesticated animals during the Neolithic (Cucchi et al. 2009; Piper et al. 2009). This was based on the greater abundance of the remains of wild animals, such as wild pigs and deer, than those of domesticates, such as domestic pigs in sites of ISEA. Probably, domestic pigs were kept for ritual and
ceremonial functions, based on present-day practices of some indigenous people in SEA (Cucchi et al. 2009; Piper et al. 2009). If this is indeed the case, wild meat was more likely to be prepared in pottery vessels for consumption. As discussed above, domesticated animals (pigs, chickens, dogs) are argued to have had a different route of dispersal from that of earthenware pottery (Blench 2012; Denham 2013). Thus, these animals are not necessarily associated with people producing, using, and carrying pottery.

Plants and animals could have been domesticated primarily to serve as luxury foods used exclusively in feasting contexts based on observations of traditional societies in SEA and examination of their luxury foods used in feasts (Hayden 2003). Feasting provides an impetus to intensify and increase production of luxury and staple foods, and can ultimately lead to the domestication of wild species and the conversion of a luxury to a staple food. Domesticated animals are sometimes killed only for feasting and sacrifice. The rice plant is a sacred and secular plant, a symbol of rank, and important in ceremonies and rituals in SEA (Hayden 2003). Thus, domesticated plants and animals could have been more associated with pottery in ritual and feasting contexts.

As seen from the preceding paragraphs, some of the main issues regarding the conflicting narratives of SEA prehistory concern the association of pottery vessels with types of food items prepared in them – domesticated and/or wild animals and plants – and the identity of the people carrying them, whether they were farmers, maritime traders, or fisher-voyagers. Based on the studies of discarded floral and faunal remains, the majority of the literature treats food in terms of modes of subsistence in association
with the environment, mode of subsistence (especially agriculture) in association with dispersal of people, and change or continuity of modes of subsistence during the foraging-farming transition.

Less frequently tackled are issues beyond subsistence, such as food preference, possible continuities in tradition, symbolic association, rituals, and feasting, human-food entanglement, cuisine, and foodways. Although Higham (2012, 2014) highlighted the importance of food in mortuary rituals and feasts based on various animal remains found alongside burials and inside mortuary pots, there are no further elaborations beyond the role of food in subsistence and status, such as the possible trends and meanings of the placement of animal limbs with burials and whole fish skeletons inside mortuary pots in connection with the identities of interred individuals. Water buffaloes, pigs, and rice served on tradeware ceramics have prominent roles in ritual feasting, which served to reproduce social relations among coastal and riverine chiefdoms in 10th-19th century Philippines (Junker 2001). Specifically, in the Tanjay region of central Philippines, meat for feasting was prepared in earthenware cooking pots and rice wine was prepared in ceramic fermenting jars (Junker and Niziolek 2010).

Animal remains can also be markers of identity, such as religious identity in the historical period, as demonstrated by the significant change in foodways in the Banda Islands, Eastern Indonesia involved a sharp drop in pig remains after Islamization and changes in settlement patterns caused by cultural differences in food consumption (Lape 2000, 2004, 2005). Multiple examples from animal remains, ceramics (tradeware and earthenware pottery), and starches on ceramics from Banda Island plantation sites
showed various strategies of social adaptations to colonialism, based on foodways (Jordan 2015).

Other than animal and plant food sources, salt also served as an important commodity since prehistory to cook, process (via fermentation), and preserve food (Yankowski et al. 2015). Similarities and differences in the use of salt to process fish with rice, to produce fermented fish products, can be demonstrated to be deeply linked with cultural identities from prehistoric times to the present. The stoneware vessel types used for fermenting fish, which vary among several regions, can also be linked to the diversity of traditions and identities (Yankowski et al. 2015).

**In Between Ends: Finding Food on Ceramics in Southeast Asian Archaeology**

Works by Jordan (2015), Junker (2001), Junker and Niziolek (2010), Ono (2006), as well as Yankowski et al. (2015) have contextualized the association between food and ceramics, especially earthenware pottery, in prehistoric archaeology of SEA. They highlight the functionality of pottery between manufacturing and disposal or discard, whereby pottery vessels were likely involved in foodways or used to prepare and serve food. However, the majority of analyses of pottery from archaeological sites in SEA are oriented towards production or manufacturing (typological and petrographic), with emphasis on the identification of transregional similarities and differences in form, decoration and composition, to establish patterns of human migration, contact, and identity (e.g., Hung et al. 2011; Rispoli 2007; Rispoli et al. 2013).

As mentioned in Chapter 2, completing the _chaîne opératoire_ of foodways is the key to connect studies on food and ceramics in SEA archaeology. It also extends the studies of ceramics towards their complete life histories, beyond the _chaîne opératoire_ of their production and manufacture (to be further discussed in Chapter 7). Two
examples of synthetic work covering broad geographic areas demonstrate this point. Kharakwal and colleagues (2004) showed that the spread of cord-impressed pottery in East Asia, South Asia, and SEA is strongly associated with rice agriculture because of the occurrence of this type of pottery in early rice-growing areas, and because particular forms are specific for rice cooking. Fuller and Rowlands (2011) have a broader geographic and food coverage, and demonstrated the long-term continuities of culinary traditions involving staple cereals, ceramics, and pottery use, despite introductions of newer food items through trade and exchange in Eurasia.

Specific examples involved the ethnoarchaeological work done among the Kalinga people in Northern Philippines, where Skibo (1992) and Kobayashi (1994) observed the usage of pottery in daily foodways and its material consequences (e.g., use-alteration) that are useful for archaeological studies. Lawless (2008) provided a detailed review on Kalinga foodways, including beliefs, rites, taboos, and diseases, as well as the practice of cooking using earthenware pots. More ethnographic work in the Philippines that mentions the usage of pottery in foodways includes work done by Scott (1990) in the Visayas of Central Philippines, Ewing (1963) among the Tausugs of southern Philippines, and Javellana (2015) in a colonial-era kitchen in Manila.

More ethnographic work done by Goto (2011) in northern Maluku as well as Ellen and Glover (1974) in Central Maluku, Indonesia on pottery production and usage has demonstrated that particular pottery types have specific form and function, and is associated with food items prepared and/or served in them. Ellen and Latinis (2012) proposed that the production and use of pottery ovens to cook sago originated locally in Central Maluku based on ethnographic and archaeological evidence.
In MSEA, Cort and Lefferts (2013) highlighted the use of stoneware jars in the highlands of central Vietnam, northeastern Cambodia, and southern Laos for rice beer production and drinking, as well as rituals. In Cremin’s (2014) discussion of earthenware stoves from Angkorian period and other areas of SEA, she questioned the absence of these stoves in prehistoric or pre-Angkorian sites despite their presence in prehistoric sites of the Lower Mekong and ISEA, suggesting that this observation can be explained by how prehistoric and Angkorian societies prepared and presented their food.

The above inquiries on how ancient societies prepared and presented their food with pottery as well as ethnoarchaeological and ethnographic accounts are worth pursuing in Southeast Asian archaeology to assess ancient foodways and culinary practices, and to contribute to the studies of past sociocultural diversity. Cultural diversity in SEA is closely associated with environmental diversity, tracing back to prehistory, and it was recently advocated that future studies using wider environmental and technological approaches should focus on investigating diversity (White 2011). The research in this dissertation seeks to complement and contribute to these studies on diversity by using technofunctional and biomolecular approaches to infer ancient culinary practices.

**Finding Cuisine and Identity in Southeast Asian Archaeology**

Along with Central Asia, East Asia, Australia, Africa, early Islamic Middle East (Western Asia), and post-contact Oceania, Twiss (2012) identified SEA as one of the major geographic regions where research opportunities on the archaeology of food and social diversity are plentiful. The wealth of material culture, especially pottery, of prehistoric and precolonial SEA, focusing on Neolithic and Metal Age in this research, presents an opportunity to extend the treatment of food in SEA archaeology from
subsistence to foodways. It will allow not only the clarification of the association of
earthenware pottery with particular events and subsistence communities, but also
contributes to the assessment of social diversity based on foodway practices.

The ethnographic literature on SEA is very rich in illustrating social diversity
based on the link between social identities and culinary practices (see, for example,
Anderson 2007; Fernandez 1986; Janowski 2011; Joaquin 1988; Lefferts 2005; Lerida
and Garay 2010; Lipoeto et al. 2001). Although focusing on Malaysian foodways,
specifically nonya cuisine, Anderson (2007) synthesized archaeological and historical
sources to trace the fusion of SEA and Chinese foodways as well as culinary practices
since prehistory.

As mentioned in Chapter 2, practice theory and the community of practice
perspective have the potential to critically examine patterns between ancient
communities and cultural diversity against “models prioritizing homogeneous Neolithic
waves of advance” (White 2009:37-38) and “oversimplified technological transmission
models” (White and Hamilton 2009:378) in SEA. Variation in culinary practices between
Neolithic sites may further demonstrate that the Neolithization process is more
heterogeneous in SEA than originally thought, an assumption supported by recent
studies of variation in material culture (e.g., Sarjeant 2012, 2014a, 2014b for pottery).
The temporal variation in culinary practices between Neolithic and Metal Age sites can
thereby contribute data useful for the assessment of sociopolitical developments during
the Neolithic-Metal Age transition.

The relational approaches of practice theory and the community of practice are
intended to be utilized in this research to explore community identities in a microscalar
case study within the larger SEA. Practice theory provides the clear potential to address cultural variation at smaller spatial and temporal scales, where the outcomes can later contribute to address variation at larger scales. Due to the time depth involved, ethnohistorical and ethnographic references cannot be used to frame salient hypotheses concerning common notions of identities, such as gender, rank, religion, and ethnicity. However, a community of practice perspective can be constructive towards the establishment of community identity, where members of a community have shared ideas, skills, and practices. It also provides the potential to explore community identities through the intersections of pottery and food studies. With accessible detailed work by others on pottery, this intersection can be accomplished in the future with the examination of culinary practice informed by data derived from work such as the research presented in this dissertation.

This microscalar case study focuses on the four prehistoric sites in southern Vietnam that are close to one another and possess clearly defined time depth, where there are two sites each for the Neolithic and Metal Age. The last section will detail the geography and culture history of this region, discuss the four prehistoric sites involved, and justify why this area provides a good case study to explore culinary practices and community identities.

**In Focus: Mekong River Delta of Southern Vietnam**

The Mekong River Delta (Fig. 3-3) of southern Vietnam is a tide-dominated delta formed by the Mekong River system and is one of the biggest deltas in Asia (Nguyen et al. 2000). For the purpose of this research, this delta is referred to as southern Vietnam. The Mekong River is 4300 km long and is one of the longest rivers in Asia. It starts in the Tibetan Plateau of China, then passes through Myanmar, Laos, Thailand, and
Cambodia before entering Vietnam. In Vietnam, the Mekong River splits into its main
eastern branch (also called the Mekong River) and the Bassac River as its western
branch, then further splits into nine courses when it flows toward the South China Sea
(Nguyen et al. 2000). The Mekong and Bassac River branches are also locally known
as the Tien and Hau rivers, respectively (Cosslett and Cosslett 2014). The Mekong
River Delta forms a border with Cambodia to the north (Cosslett and Cosslett 2014),
and is bounded by the South China Sea to the southeast, the Gulf of Thailand to the
west, the Vàm Cỏ Đông river to the northeast, and a Late Pleistocene terrace to the
north (between 8°30’-11°00’N and 10°30’-106°50’E) (Nguyen et al. 2000). Its climate is
humid subtropical and the area is in the monsoon region, with six months of rainy
season and six months of dry season. Mean annual rainfall on the delta is 1700 mm, but
rainfall can increase to more than 2000 mm towards the Gulf of Thailand. The mean
annual temperature range is 27-30°C, while the range of annual evaporation is 1020-
1240 mm (Nguyen et al. 2000).

The larger deltaic plain is actually about 62,520 km², where 52,100 km² belongs
to Vietnam and 10,420 km² belongs to Cambodia (Nguyen et al. 2010). The Mekong
Delta has a 2000-m thickness of sediments that accrued during the Cenozoic during a
series of transgressive-regressive cycles (Nghi et al. 1991). The oxidized Pleistocene
alluvial surface can be found below Holocene sediments (Kolb and Dornbusch 1975).
As seen in Figure 3-3, the Delta is divided into five areas based on peculiar
circumstances of depositional process and neotectonic movement, namely the Plain of
Reeds, Longxuyen Quadrangle, Central Area, Eastern Coastal Area, and Camau
Peninsula (Nguyen et al. 2000). Twelve provinces comprise the Vietnamese territory
(Fig. 3-4), namely, Long An, Dong Thap, An Giang, Kien Giang, Tra Vinh, Hau Giang, Soc Trang, Tien Giang, Vinh Long, Ben Tre, Bac Lieu, and Ca Mau. It also has one modern city, which is Can Tho City. The Mekong River enters the delta in the first four provinces at the north (Cosslett and Cosslett 2014). As of 2011, 17.33 million people live in the Mekong Delta (General Statistics Office 2012). The delta is the third most populous region in Vietnam (Cosslett and Cosslett 2014). The majority of the people are ethnic Viet. The delta is also the home of the majority of the Khmer people outside Cambodia, since this region was previously a part of the Khmer empire (General Statistics Office 2012). Other people living in the delta are the Chinese, Muong, and foreigners (Cosslett and Cosslett 2014).

The pottery samples analyzed in this dissertation were excavated from four prehistoric sites in the Mekong Delta Region of southern Vietnam. They are all located in Long An province (Fig. 3-5), where two of them are of Neolithic Age (Rạch Núi and An Sơn) and two of them are of Metal Age (Lò Gạch and Gò Ô Chùa). Detailed culture history as well as synthesis and assessment of the archaeology of Long An Province can be found in the work of Tran (2012). Figure 3-5 shows the locations of the four sites. In Long An, archaeological sites are suggested to belong to two cultural periods (prehistoric and Óc Eo periods) and three geographic zones: alluvial (An Sơn), delta lowland (Lò Gạch and Gò Ô Chùa), and the coastal plain (Rạch Núi) (Tran 2012). All of these sites are prominent in the culture history of the Mekong River Delta; thus, their descriptions are incorporated in the discussion of culture history that follows.

Pre-Neolithic

The Mekong River Delta has a unique prehistory from the rest of MSEA, since no Hoabinhian foragers had occupied the delta when the first Neolithic settlers arrived
(Piper and Oxenham 2014). As explained by its geological history (e.g., Hanebuth et al. 2012; Nguyen et al. 2000, 2010; Proske 2010; Ta et al. 2005), the delta was still being formed and most of the area was still submerged (Proske et al. 2010, 2011) when the Hoabinhian hunter-gatherers were already occupying northern Vietnam (Higham 2014).

The formation of the Mekong River Delta started 8000 years BP during a constant sea level after a rapid rise from 8800 to 8200 years BP (Hanebuth et al. 2012; Nguyen et al. 2010). At 7500-7000 years BP, the sea level rose again by about 5 m, resulting in sediment aggradation that formed the mainly fine-grained topset sedimentary deposits (Nguyen et al. 2000, 2010). Then, there was the maximum Holocene transgression and sea waves enclosed the northern uplands of the Late Pleistocene terrace, basement rock, and weathered land by around 6000-5000 years BP. The great deltaic plain was produced by delta progradation during the highstand and regressions of sea level for the last 4550 years BP (Nguyen et al. 2000). This highstand of around 2.5 m began 6000 years BP and lasted for about 1000 years before the sea level slowly fell to its present level. The progradation rate for 5300-3500 years BP was 17-18 m/yr, while it was 13-14 m/yr for the last 3500 years (Ta et al. 2001).

The development of the Mekong Delta since the mid-Holocene sea level highstand can be assessed from the northern part of the delta (Proske et al. 2010, 2011). The regressions have produced many peculiar relict beach ridges (locally known as “giong”), which are useful in differentiating former coastlines and assessing the development of the delta. This development also involved the transition from marine to terrestrial environments as the delta prograded. By 5680 years BP, mangrove forests thrived in the Plain of Reeds and Longxuyen Quadrangle (Nguyen et al. 2000). These
forests were dominated by *Rhizophora* during the mid-Holocene highstand. Then, *Ceriops* and *Bruquiera* dominated after the following regressions and progradations. After the transition to a terrestrial environment, freshwater vegetation with a prominent swamp signature took over, with *Arecaceae*, *Fabaceae*, *Moraceae/Urticaceae*, and *Myrsinaceae* (Proske et al. 2010). Mangrove marshes also thrived in the Ca Mau Peninsula and present coastlines (Nguyen et al. 2000).

**Neolithic**

What appear today to be mounds or elevated settlements along the deltaic landscape are actually products of 4000 years of human modification of surface topography (Reinecke 2012). The pioneer Neolithic settlers, arriving from the north, established the first sedentary settlements in the Mekong Delta region of southern Vietnam by around 2000-1500 cal yr BC (Piper and Oxenham 2014). These earliest Neolithic settlements were found in the northern part of the delta along the Vàm Cỏ Đông, Vàm Cỏ Tây, and Đồng Nai drainage systems (Nishimura and Nguyen 2002). They also have material culture (e.g., pottery styles and decorations, stone and shell artifacts) similar to the settlements in Thailand and Cambodia (Nishimura and Vuong 1997; Sarjeant 2014b). Many of the Neolithic settlements in southern Vietnam are deeply stratified, which presents opportunities to assess their establishment with their development and construction techniques. These well-designed settlements were conceived and built by people with previous knowledge of settlement construction. Their floor surfaces were commonly constructed with shell lime mortar, as seen in the sites of An Sơn, Lộc Giang, and Rach Núi. Subsistence strategies include small-scale crop production and animal management, alongside hunting and gathering that have important economic roles (Piper and Oxenham 2014).
Rạch Núi

Rạch Núi (N10°32’50”/E106°39’55”) is located where the Vàm Cỏ Đông, Vàm Cỏ Tây, and Đồng Nai Rivers meet near the town of Can Giuoc (Fig. 3-6; Oxenham et al. 2015). It is a manmade mound dated to 1500-1200 BC, with a height of 5-6 m, a diameter of ~75 m, and an area between 2800 and 4000 m². Among the four sites featured in this research, Rạch Núi is nearest to the coast, ~22 km distant. The central and southern extent of this mound is presently much occupied by buildings of Linh Sơn pagoda built in 1867, while a modern village and associated roads are located along the immediate southern and eastern boundaries. Nipa (Nypa fruticans) and mangrove-forested tidal swampland encircled the mound. The site was excavated in 1978, 2003, and 2012 (Oxenham et al. 2015; Tran 2012).

The height of the mound, which is composed of more than a dozen phases of earthen platforms and elevated refined wooden structures, resulted from the continuous construction, modification, and reconstruction on the same location for about 100-150 years (Oxenham et al. 2015). It seems that land clearance and maybe levelling of the ground was done prior to the initial phase of construction. Several shallow pits dug into the blue gray alluvial or marine clay have been uncovered, and these probably resulted from extracting clay for floor construction and pottery production. These were filled with organic wastes and pottery sherds. There are at least 15 thin creamy white or gray hard surfaces or artificial platforms with burnt areas caused by human activities above these pits. Closer inspection of these surfaces with clay and pottery sherds reveals that platform construction became sophisticated over time. Lime mortar with burnt shells was used as a bonding agent. This site represents the earliest use of lime mortar for construction in SEA. Evidence of short-lived, above-ground structures are vertical
postholes and horizontal beam slots, as well impressions and burnt remains of materials used to make the floors and other structures. One of these materials was bamboo, based on the morphological assessment of charcoal fragments. Inhabitants practiced reconstruction every 10-15 years or perhaps slightly more. Charred termite frass in all phases of construction supports the assumed rapid replacement of wooden structures. It also seems that they demarcated private and communal spaces. All in all, the site was constructed with careful planning and sophisticated skills (Oxenham et al. 2015).

A total of 650,202 pottery sherds, weighing 7693 kg, were excavated from Rach Núi, making pottery the most abundant item of material culture recovered from the site (Oxenham et al. 2015). The majority (84%) was coarse ware with calcareous sand temper and irregular rim shapes apparently reflecting rapid hand construction. A few sherds have fiber and mineral sand tempers. Decorations below the rims are vertical, low-relief cord-marked or combed patterns. This pottery was locally made and was used as construction material for floors after its utilitarian role had ended. Their egg-shaped or globular shape suggests they were not used as serving vessels and their opening was too wide for water storage. The high density of these pottery sherds suggests the site was probably a location for industrial or extractive activity. The minority (16%) was fine ware with mineral sand temper, thin walls, complex rim form typology, and manufactured with a slow wheel, based on striations in the pottery sherds. Pottery types included open bowls and globular vessels with everted rims. Possible repairs were done on some vessels, based on perforations (Oxenham et al. 2015). The sand-tempered pottery may have been imported from the Đòng Nai river region, whereas the shell-tempered pottery may have been produced locally (Sarjeant 2014b). Other ceramic
materials, such as stoves for cooking (cà rang), clay pellets for hunting or playing, discs, balls used as fishing weights, and “thumb pots” probably for crabbing, along with mostly unshouldered lithic adzes, shouldered turtle shell adzes, shell beads, and bone artifacts were also recovered (Oxenham et al. 2015).

For their subsistence, the people of Rạch Núi managed tubers, fruits, some mangroves, domesticated animals and foraged for wild and aquatic resources based on the recovered archaeobiological remains (Oxenham et al. 2015). They consumed domesticated millet, rice, dogs, and pigs. Some animals that they hunted and fished were catfishes, turtles, crocodiles, monitor lizards, macaques, and langurs. Based on the amount of rice and millet remains recovered, these cereals were likely imported from other communities in the Đồng Nai River Basin. Rice grains were stored as unthreshed spikelets. Foxtail millet grains were the first to have been identified in a Vietnamese archaeological site. Aside from the remains of wild tubers and fruits, remains of sedges were also found. The inhabitants of the site targeted Geloina coaxans and Cerithidea obtusa among the shellfish. Crabs were also foraged along with fishes, such as catfishes (Siluriformes), particularly Bagridae (naked catfishes), and snakeheads (Channidae, Perciformes). All these aquatic resources are found in freshwater and brackish riverine systems. Aside from pigs and dogs, nonhuman primates such as macaques, water birds such as ducks, and rats were also found. The high frequency of primate mandibles suggests that monkeys were regarded as trophies. Rats are known as pests in the settlement. The abundance of wild animals alludes to the strong reliance of past inhabitants on foraged resources (Oxenham et al. 2015).
An Sơn

An Sơn (Fig. 3-7) is located on the edge of the active Vàm Cỏ Đống floodplain in An Ninh Tay commune, Đức Hoà District. It is 75 km from the sea, making this site farther from the coast than Rạch Núi (Bellwood et al. 2011; Nishimura and Nguyen 2002). The site is 300 m east of the Vàm Cỏ Đống River. It is also a manmade mound dating to 2300-1200 BC, with a height of ~5 m, lengths and widths of 160 and 90 m, respectively, an area of ~1.5 ha, and possesses human burials. Other Neolithic sites, such as Lộc Giang and Đông Canh Nong, are nearby, since the Vàm Cỏ Đống floodplain has a suite of sites dating from the late 3rd-2nd millennium BC (Bellwood et al. 2011; Nishimura and Nguyen 2002). The site was excavated in 1978, 1997, 2004, 2007, and 2009 (Tran 2012).

Based on the excavation of the eastern edge of the mound in 1997, the site has a 4-m depth of cultural deposits that are divided into four cultural phases based on changes in pottery forms and radiocarbon dates (Nishimura 2002; Nishimura and Nguyen 2002). The mound has a series of compact and horizontal silt floors with post molds as deep as 50 cm (Nishimura and Nguyen 2002). These floors are probably house floors that were regularly renovated with riverine silt (Nishimura 2002). The excavation of Trench 2 in 2009 uncovered possible successive rake-out deposits from the mound, with a high density of large pottery sherds, including the remains of cà rang (cooking stoves), which are characteristic of assemblages found in the Vàm Cỏ Đống area. This area may have been a cooking area based on finds such as freshwater gastropod shells, fish bones, baked clay lumps, and soil concretions formed from either intensive cooking or soaking of animal fat into the ground (Bellwood et al. 2011).
A total of 35 human burials, with associated stone tools, shell beads, and pottery vessels as grave goods, were uncovered at the eastern area of the mound (Bellwood et al. 2011). Seven of these (six skeletons supine extended, and one separate skull) were excavated in 2009. Cranial and dental attributes suggested that the inhabitants had genetic traits associated with both migrant (Bronze–Iron Age Dong Son population of northern Vietnam, modern Vietnamese, and other modern East Asians) and indigenous (earlier Holocene Jomon and Hoabinhian) populations, respectively. These findings supported the two-layer model of peopling of SEA during the Holocene (Bellwood et al. 2011; Willis and Oxenham 2013b). One of these burials is that of a young female with an unborn baby, perhaps suggesting that she and her child suffered health complications that contributed to their deaths (Willis and Oxenham 2013a).

The majority of material culture in An Sơn differs from that in Rạch Núi (Sarjeant 2014b). Materials associated with human burials included complete pottery vessels and sherds (some having rice chaff as temper), shell beads, as well as stone adzes (Sarjeant 2014b). The pottery assemblage had distinct local features, such as the common wavy and serrated rims. Some decorations and shapes, such as i&i designs (see Rispoli 2007), are similar to those in central and northeastern Thailand of the same period (Bellwood et al. 2011), even with the wider Neolithic MSEA, and other sites in southern Vietnam, such as Bình Đà, Cái Văn, Đình Ông, and Lộc Giang (Nishimura 2002; Sarjeant 2012, 2014b). Decorations changed through time from cordmarking and punctate stamping to more intricate and wide-ranging roulette-stamped and incised motifs. Pottery forms had carinations and concave rims (Sarjeant 2014b). Detailed analysis suggested that characteristic forms were manufactured with a mental template.
based on the tradition of the community, and there is a consistent manufacturing method, but with innovations. These local innovations made the identity of the inhabitants distinct from other communities in southern Vietnam (Sarjeant 2014a, 2014b). Many pottery sherds seemed to be intentionally broken based on refitting analysis. Some sherds were ground and recycled as temper (Nishimura and Nguyen 2002). Other ceramic materials, such as stoves for cooking (cà rang), clay pellets for hunting small animals or birds and playing (toys/marbles), fired clay lumps, roundels, and beads, along with shouldered and unshouldered ground and polished lithic adzes, lithophones, shell beads, bone fish hooks and needles, stone implements with a ground circular center, and ivory artifacts were also recovered (Bellwood et al. 2011; Nishimura and Nguyen 2002; Sarjeant 2014b).

The main subsistence strategies of the people who lived in An Sơn were food production and foraging of terrestrial and aquatic resources based on the analysis of recovered remains (Bellwood et al. 2011; Piper et al. 2012) that mainly included domestic dogs and pigs (Piper et al. 2012). The oldest pig remains were dated to 2862-2234 cal yr BC. Turtles from the Geomydidae family (pond, box, and water turtles) dominated the terrestrial wild vertebrates. Other wild resources are deer (Cervus/Rusa spp.), monitor lizard (Varanus spp.), mouse deer (Tragalus napu), crocodile (Crocodylus cf. porosus), the large Indian civet (Viverra zibetha) or large-spotted civet (Viverra megaspila), and monkey (Cercopithecidae). The majority of faunal remains were fishes, such as snakehead (Channidae), swamp eel (Synbranchidae), climbing perch (Anabas testudineus), river catfish (Clariidae), barramundi (Centropomidae), tire track eels (Mastacembelidae), and glassy perchlets (Chandidae) (Bellwood et al. 2011, Piper et al.)
Remains of domestic rice (*Oryza sativa japonica*) were identified as husks used as temper for pottery (Bellwood et al. 2011; Sarjeant 2014b). Other plant remains included grasses, Cyperaceae (sedges), Palmae (palms), Panicoideae (grass), Chloridoideae (grass), Phragmites (wetland grass), Andropogonea (grass), Commelinaceae (flowering plants), Bambusoideae (bamboo), and millet-type grasses (Sarjeant 2014b).

The Neolithic sites discussed above showed no evidence of maritime subsistence (Bellwood et al. 2011, Oxenham et al. 2015; Piper et al. 2012). Rather, these suggested movements and interactions of peoples along the Mekong River and its tributaries (Sarjeant 2014b). Evidence from ceramics, such as the i&i decorations, supported the proposed riverine origins of the Austroasiatic-speaking people (Sidwell and Blench 2011). In addition, there are two major ceramic cultures: one in the area along the Vàm Cỏ Đông River and another in the area along the Đồng Nai River (Sarjeant 2014b). Rạch Núi exhibited similar but different construction techniques from those of An Sơn and Lộc Giang. The two latter sites are near each other and are very similar based on their stratigraphic profiles. In An Sơn and Lộc Giang, alluvial silts and loams were used to build the floor surfaces and ground-level habitation was probably constructed. At Rạch Núi, broken pottery, shell lime mortar, and shells were used to construct the floor surfaces in both ground-level and stilt houses (Piper and Oxenham 2014).

**Metal Age**

Rather than separating Bronze and Iron Ages, Vietnamese archaeologists identify archaeological cultures from the second half of the 2nd millennium BC to the 1st-
2nd centuries AD as belonging to the Metal Age (Tran 2012). To avoid confusion, the Bronze and/or Iron Age sites included in this research are classified as Metal Age sites.

There are more Bronze Age (1500-500 BC) settlements in the Đồng Nai River Valley than there are Neolithic settlements (Proske 2010). Aside from bronze casting similar to the rest of MSEA, the people in the Mekong Delta also specialized in salt-making during the Bronze Age (Reinecke 2009, 2012). Salt production provided them opportunities to create a surplus, which could be traded, since salt was in huge demand in interior regions, far from the sea (Reinecke 2009).

During the Iron Age (500 BC-AD 100), the people who lived along the Mekong River Delta were participants in Maritime Trading Networks with South and East Asia, as well as SEA (Higham 2014; Manguin 2004). It has been proposed that the strengthened trade with South Asia and the influx of mass-produced stone and glass beads in SEA contributed to the development of state-level society in the region (Carter 2015).

Lò Gạch

Lò Gạch (E105°43’50”/N10°54’58”) is located on the western bank of the Vàm Cỏ Tây River. It is a settlement site with multiple layers of intentionally laid surfaces, sediment accumulation, raised platforms for structures, and middens dating from c. 1100 cal yr BC to 650 cal yr BC, with ~1.5 m of archaeological deposits (Bui 2008; Piper 2013). The site displays construction methods similar to those at Rạch Núi (Neolithic) and material culture similar to that of Gò Ô Chùa (Metal Age), making this a possible transitional site between Neolithic and Metal Age (Bui 2008; Piper 2013). For the purpose of this research, the site is assigned to the Metal Age based on the
observations during its excavation in 2014. The site was also excavated in 2006 (Tran 2012).

The material culture recovered from this site included pottery sherds, stone axes, stone and clay molds, iron axes and nails, bone tools and jewelry, remains of cupreous metal production, and clay pedestals or stands (Bui 2008; Piper 2013; Reinecke 2009; Tran 2012). Recovered archaeobiological remains included fishes, turtles, pigs, deer, rice, and Job’s tears (personal observations). Analyses of materials recovered from the excavation in 2014 and writing of related articles are in progress.

Gò Ô Chùa

Gò Ô Chùa (N11°00’24”/E105°46’00”, “pagoda hill”) is located near the Vàm Cô Tây and Vàm Cô Đông Rivers, c. 2 km south of the Vietnamese-Cambodian border, and 140 km from the coast (Reinecke 2010). The site is 450 m long, 150 m wide, up to 4 m high, and has three mounds, the northern, central, and southern mounds. The total area is 60,000 m². It was a salt-boiling and occupation site during the Bronze Age (c. 1000-500 BC) and burial site during the Iron Age (400-100 BC) (Reinecke 2012). It was proposed that the site was the largest salt production center during its time. The site was excavated in 1997, 2003, 2005, 2006, and 2008 (Tran 2012).

Excavations at all three mounds uncovered cultural deposits, such as pottery, clay pedestals, hearths, middens, and human burials, up to 2.5 m thick (Reinecke 2010, 2012; Tran 2012). The lowest layers, representing the transition from Neolithic to Bronze Age, have no evidence of significant salt-making activities. The settlement and salt making were first initiated in the northern area of the site by c. 1000 BC. Then, the salt-making areas extended into the central mound by 800 BC and into the southern mound after another 100 years (Reinecke 2012). Since there are no halophytes, salt-
saturated soils, or salt springs around the site, it is possible that the people who produced salt lived near the sea, or alternatively the condensed seawater brine for refining or boiling may have been imported from the coast. The latter scenario may be supported by the 14th century Chinese account “Aobu tu,” as long as there were convenient water routes, available clay and firewood, proximity to trade routes, and safety from disasters and enemies. In 2006, a 1.5 m-deep feature was uncovered, with many clay pedestal fragments and two oval-shaped buff-colored burnt clay structures underneath. The western portions of each of clay structure had a fireplace with charcoal. These features may have been parts of salt-boiling kilns, although the details of the features were not clear enough for definitive interpretations. No pottery with prescribed form and large volume capacity, which would qualify as a salt-boiling pot was recovered. Thus, it is possible that the vessels used for boiling salt were made of organic materials, such as bamboo, coconut, or palm spathes (Reinecke 2010).

The majority of the artifacts uncovered from excavations were fragments of clay pedestals or stands, which support the premise that the site was an industrial salt-boiling area during the Bronze Age (Reinecke 2010, 2012). Those 130,000 pedestal fragments were classified into four different types that differ in the shapes of upper parts. Most have three horn-shaped points and range in height from 22 to 30 cm. These clay pedestals were low-fired or unfired (sun-dried), since these become smudgy when wet (Reinecke 2010). Also referred to as briquetage fragments, the orientation of these pedestals is the one having finger-like protrusions at the upper part (Proske et al. 2009). However, not everyone agrees that the clay pedestals found in Lò Gách, Gò Ô Chùa, and other sites in the Plain of Reeds were used for salt making. For instance, it has also
been suggested that the three-pronged clay pedestals were used to support pottery vessels during drying and/or firing (Vuong 2011). However, the 10-15-cm ceramic discs provide further evidence for salt-making at the site (Reinecke 2010).

Seventy-five human burials, including seven jar burials for infants, were uncovered from the site (Reinecke 2010; Tran 2012), but only 52 have been analyzed (Francken 2012; Francken et al. 2010). Except for the jar burials, these were dated to 7th-13th centuries AD and composed the largest cemetery in the Mekong Delta region. There could be more than 1000 individuals actually buried in Gò Ô Chùa during the Iron Age, Chenla, or Angkor period, and they were not related to the salt makers who occupied the site a millennium before (Reinecke 2010). The seven infant burials inside the jars were dated to 1000-500 BC or during the Bronze Age (Francken 2012; Francken et al. 2010). The clay pedestals, however, became incorporated into the burials along with the offerings, such as complete pottery vessels with food remains, arrowheads, spears, chisels, daggers, ring ornaments, bronze axes, bronze jewelry, ivory bracelets with incised line decorations, amulets made of tiger teeth and remains of crocodiles, as well as glass or stone beads and bracelets (Francken 2012; Reinecke 2010; Tran 2012). Radiocarbon dates suggest that the cemetery spanned a period of at least 300 years (Francken 2012; Reinecke 2010).

Individuals were interred singly with clear grave cuts, and were buried lying on their backs, near one another, and mostly oriented to the southeast (Francken 2012; Francken et al. 2010; Reinecke 2010). One burial was oriented to the west-north-west. Twenty-one adult individuals were classified as males and 20 as females. These previous inhabitants of Gò Ô Chùa were mostly relatively healthy, well-adapted to their
surroundings, subsisting on food low in carbohydrates (sugars and starches), and did not experience substantial growth disruption. The males exhibited an average height taller than that of present-day Vietnamese and comparable to other prehistoric skeletons from Cambodia and Thailand. Females showed higher levels of dental caries and likely had diets different from the males. Indicators of occupational stress suggested that some of these individuals were involved in heavy mechanical work (Francken 2012; Francken et al. 2010). Teeth of some of individuals exhibited evidence of the cultural practice of tooth staining (Francken 2012). Also included with some of the burials was an entire pig skull and jawbones (Reinecke 2010).

The pottery at Gò Ô Chùa was mostly sand-tempered in the lower layers and fiber tempered in the upper layers (Tran 2012), with diverse decoration, such as black painting, stamping, combing, and incising of various motifs and designs. The forms were described as pot, bowl, dish, angular and round-shouldered jar, basin, and high-stem cup. Other material culture recovered suggests metallurgy and pottery production, such as clay potter’s anvil, bronze axes and bracelets, iron tools, and clay casting molds (Tran 2012). Shouldered lithic axe, axe fragments, chisels, quadrangular axe, and an atypical wedge-shaped axe were also recovered from the earliest layers of the site (Reinecke 2012). Based on the animal remains found as grave goods, such as pig jawbones, entire pig skull, tiger-tooth amulets, ornaments and tools made from bone, antler turtle shell, animal and fish bones inside small pottery vessels, the subsistence strategies of the previous occupants of the site included animal management, hunting, and fishing (Francken 2012; Reinecke 2010). The pottery from two Metal Age sites discussed above is broadly similar in both form and construction (personal observation).
From Óc Eo/Funan Period to the Present

The Óc Eo period (from the 1st century AD to probably the 12th century AD) in southern Vietnam overlaps with the Iron Age that, for the MSEA, lasted to ca. AD 400-500 (Higham 2014; Vo 2008). The archaeological sites and artifacts belonging to the Óc Eo culture supported the notion that southern Vietnam was a prominent part of Funan (2nd-7th century AD; Le 2015), which was a delta trading state and a major manufacturing center (Higham 2014). The period and accompanying culture were named after Óc Eo, which is a well-researched site in Thoai Son district of An Giang Province (1st-6th century AD) by L. Malleret in 1944 and Vietnamese archaeologists since 1975 (Vo 1990). This site was a city with a 3-m by 1.5-m rectangular enclosure, five ramparts, four moats, an area of 450 ha, and a large canal that bisected the site (Higham 2014). The Óc Eo culture is usually characterized by brick structures and locally crafted artifacts made of gold, bronze, tin, glass, precious and semiprecious stones, clay, as well as other raw materials (Le 2008; Vo 1990). It also included artifacts that are evidence of trade with the western Roman Empire and the eastern Han Empire (Higham 2014). Typical ceramics of Óc Eo style are orange ware, Phimai black, and kendis (Bùi et al. 2001; Manguin 2004; Higham 2014). Many of the artifacts found in temple architectural complexes, cemeteries, and settlement sites are related to ancient Hindu belief that penetrated the delta through trading networks in the coasts and river systems. These include sculptures representing the supreme gods, temple consecrated deposits (such as gold plaques), and artifacts used in everyday life (such as lingas) (Le 2015). Flood-recession farming could have been practiced since this period (Higham 2014). The Óc Eo site was connected through a 70-km canal that passed through a series of settlements including Angkor Borei, which was a contemporary, moated and
walled site covering an area of 300 ha in southern Cambodia (Manguin 2004; Stark 2015). As the maritime trade in the 6th century declined, the Funan declined as the center of power also and were replaced by the inland kingdom of Chenla (Higham 2012, 2014).

Southern Vietnam was then a part of the Chenla (mid 6th-8th centuries) and Angkor (AD 802-1431) empires (Higham 2014; Stark 2015). The region became incorporated into Vietnam in 1698 (Taylor 2014; Woods 2013), colonized by France as Cochinchina during the mid-19th century, and returned to Vietnam in June 1949. The region is also known as Kampuchea Krom, in recognition of the fact that it was once part of the Angkor or Khmer Empire and Cambodia or Kampuchea. People who lived in this region were mostly Khmer Kroms until many Vietnamese settled in the area (Taylor 2014).

**Exploring Cuisine and Community Identity in Southern Vietnam**

Southern Vietnam provides a good case study to explore culinary practices and subsequent community identities because of the ubiquity of pottery in archaeological sites and its present-day culinary practices. One can observe in Long An Province that earthenware cooking pots in the form of open bowls are only used to prepare and serve fish stew (personal observation). This specific culinary practice is distinct from those of central and northern Vietnam. In addition, cará rang (earthenware cooking stoves) are still manufactured and utilized in southern Vietnam. Large stoneware jars are still used to ferment fish (with salt and other ingredients) to produce fish sauce (personal observation). No specific account of this culinary practice is available for southern Vietnam, even in the ethnography on the Khmer Kroms living in the region (e.g., Taylor 2014). However, clay jars were mentioned as storage vessels for water. Nevertheless,
the ethnography by Taylor (2014) puts huge emphasis on the dependence of Khmer Kroms on rivers to sustain their foodways and sense of community. Fishing and rice agriculture dominate the foodways of the Khmer Kroms; thus, their cuisine is focused around aquatic resources and rice (Taylor 2014). The importance of rice can also be attested by the practices involved in the Tet or New Year festival, during which glutinous rice is eaten to consolidate kinship relationships, and rice delicacies and wine are offered to the ancestors. Wives play an important role in rice agriculture, and have an exclusive role in transplanting rice seedlings (Nguyen 2007). This gender-specific role seems to be similar to the one observed in the vicinity of Lò Gạch site (personal observation).

One ethnographic study germane to this dissertation research is that of the culinary practices of Hội Anese cuisine in Hội An City, central Vietnam (Avieli 2011), where their cuisine is composed mainly of five elements, namely com (steamed rice), rau (fresh greens), canh (soup), kho (‘dry’, fish), and nuoc nam (fish sauce). Rice is the most important food, and plain rice is eaten daily whereas glutinous rice is eaten during special occasions. The importance of aquatic resources, such as fish, is associated with the intimate relationship of the Vietnamese with water (many Vietnamese are part-time fishermen). Fish are usually cooked into a “dry” dish or soup, where these cooking practices are similar to those in Long An Province. The use of fish sauce as a condiment to accompany fish consumption is prevalent, and its prominent taste is a cultural marker of Vietnamese cuisine. Fish sauce is also an agent of commensality because all members of the family dip their food into a common bowl of fish sauce during meals. Plants in the form of leafy vegetables are essential for a balanced meal,
where they may be served fresh/raw or cooked and served to counterbalance the rice and fish. Their daily meal structure reflects their cosmology, involving the balance between am (yin) and duong (yang) as well as the five elements of earth (rice), water (soup), wood (greens), metal (dry dish), and fire (fish sauce) (Avieli 2011).

The above examples highlight the specific use of earthenware pottery for preparing and serving aquatic resources, and the importance of aquatic resources, leafy plants, and rice in present-day southern Vietnam suggests that an association between a specific pottery form and function, and identified food categories, can be examined archaeologically. It is also possible that prominent food items during the past and the present in the region are similar or overlapping. These possibilities are explored in Chapters 7-9 with the methods discussed in Chapters 4 and 7.
Figure 3-1. Map of Southeast Asia (from www.mapsnworld.com).

Figure 3-2. Biogeographic map of SEA (Woodruff 2010:921).
Figure 3-3. Mekong River Delta of southern Vietnam (Nguyen et al. 2000:429).

Figure 3-4. The provinces of Mekong River Delta of southern Vietnam (Coslett and Coslett 2014:26).
Figure 3-5. Partial map of Mekong River Delta, with locations of the sites for this research in red oblongs. Courtesy of Tran Thi Kim Quy and Dang Ngoc Kinh.
Figure 3-6. Map of Rạch Núi site (Oxenham et al. 2015:6).

Figure 3-7. Map of An Sơn site (Tran 2010:34; after Fig. 5 in Bellwood 2010).
CHAPTER 4
ORGANIC RESIDUE ANALYSIS OF LIPIDS FROM CERAMICS: A VIEW FROM THE TROPICS

Introduction

Just like the Arthurian and Alfredian legends, organic residue analysis is still a relatively romantic area of study, possibly one of the last in archaeological sciences. It is an area where the noble chemist can go forth and slay molecular dragons and so rescue beautiful archaeologists in distress. Fortunately burning food was not a royal prerogative and consequently one important source of chemical residues is that burnt on pots by careless cooks. Charred residues are not the only source of organic residues from the past, they also occur in a natural state, or perhaps one should say in an uncharred state, typified by dyes, amber, and resins. It has also been discovered that some chemicals penetrate the pottery fabric similar to ink into blotting paper, when the pot is being used.

—John Evans

*Organic Residues in Pottery of the Bronze Age in Greece*

Evershed (2008b:895) defined the analysis of organic residues as a field that “utilizes analytical organic chemical techniques to identify the nature and origins of organic remains that cannot be characterized using traditional techniques of archaeological investigation.” Specifically, on pottery vessels and other ceramic containers, organic residues survive as actual contents, surface residues, and absorbed residues (Evershed 2008b; Heron and Evershed 1993). The actual contents are rarely preserved *in situ* as vessel fills (Evershed 2008b). Then, the visible surface residues are deposits or encrustations observed on both the interior and exterior walls of vessels. These may be derived from soot deposited along the outer wall during the heating of the vessel over a fire or from charred food or other biological material on the interior surface (Heron and Evershed 1993; Regert et al. 2003). Furthermore, there are absorbed residues resulting from contact and absorption of the vessel’s contents into porous and permeable ceramic walls during vessel use. These are classified as having food and nonfood origins; the food residues are the most widely encountered residues from food
prepared, usually with heat and/or mechanical action, and consumed or stored in pottery vessels (Evershed 2008b). The non-food residues in pottery vessels are a consequence of manufacturing processes and the application of sealants to permeable fabrics (Heron and Evershed 1993; Regert et al. 2003).

The analysis of organic residues is guided by the Archaeological Biomarker Concept, which suggests that the molecular structure and isotopic compositions of key components of residues can be related to the compositions of plants and animals exploited by humans in the past (Evershed 2008b). Since organic residues offer a plethora of information on previous contents, function, local and regional economies, and technologies (Evershed 2008b; Heron and Evershed 1993; Regert et al. 2003; Spiteri et al. 2011), this approach can challenge orthodox archaeological hypotheses and provide novel insights into past human subsistence practices (Evershed 2008b). For example, organic residue analysis of pottery can contradict invalid views on diet and economy (Spiteri et al. 2011).

Along with considering the archaeological context of organic residues on pottery and relevant data from other materials, their analysis can address key issues regarding ancient food preparation and consumption practices, alimentary practices, introduction of particular food items, changes in subsistence practices and resource exploitation, relationships between form and function for different types of pottery vessels, how specific materials were used and functioned, vessel technology, trade and exchange, as well as mobility (Heron and Evershed 1993; Kimpe et al. 2004; Oudemans 2007; Pecci 2014; Regert et al. 2003; Roffet-Salque et al. 2016). In accordance with the chaîne opératoire framework adopted in this research, the organic residue analysis of food and
nonfood natural products can provide insights into the practices from their acquisition to usage by the ancient people (Nigra et al. 2015; Regert et al. 2003). In broader spatial and temporal scales, inferring food-related practices and pottery use from organic residue analysis of a large number of samples from various sites, areas of the world, and periods can shed light on diachronic sociopolitical changes as well as social relations between different areas of the same site and different sites of the same period (Pecci 2014).

As seen in the above-mentioned applications, the field of organic residue analysis, which is a branch of biomolecular archaeology, is interdisciplinary (McGovern and Hall 2016). This is because the chemical data gathered from this kind of analysis must be corroborated with relevant data from other bioarchaeological remains, contexts, artifacts analyzed, geography, and environment, ethnographic and ethnohistorical sources if applicable, and from other disciplines. The key to this interdisciplinarity is the development of working hypotheses, where many well preserved samples from dated contexts must be assessed. Even formerly analyzed samples must be reassessed with currently improving procedures (McGovern and Hall 2016). The development and the interdisciplinarity of organic residue analysis are attested by much published research, summarized in a number of overview papers (e.g., Beck 2008; Evershed 1993, 2008b; Evershed et al. 1999; Heron and Evershed 1993; Kaluzna-Czapinska et al. 2016; Malainey 2011; McGovern and Hall 2016; Nigra et al. 2015; Oudemans 2007; Pecci 2014; Roffet-Salque et al. 2016; Skibo and Deal 1995; Spiteri et al. 2011; Steele 2013) and edited volumes (e.g., Barnard and Eerkens 2007). The most recent review by Roffet-Salque et al. (2016) provided a comprehensive summary on the themes and
research questions at different scales of analysis that organic residue addresses, as well as commodities that can be detected.

Chapter 4 provides a review of the field of organic residue analysis, focusing on the extraction and analysis of lipid residues on pottery. Historical background will not be discussed, as it is already available in some of the seminal overviews (see Beck 2008; Evershed 2008b; Kaluzna-Czaplinska et al. 2016; Pecci 2014). Rather, it will highlight the application of the field to assessing ancient foodways from food acquisition, then preparation, to consumption; it has not only aided in the determination of past subsistence practices, but also tackled questions about culinary practices or cuisines. Discussion of different lipid groups used as biomarkers, with details on fatty acids, their extraction from artifacts (mainly pottery) and further processing, as well as their analyses for biomolecular profiling and stable isotopes, will follow. Taking into account the building of comparative modern reference materials described in Chapters 5 and 6, Chapter 4 will also include mention of the viability and challenges of organic residues analysis. It will end with how this field has fared in the tropical areas of the world, including Southeast Asia, where the environment is thought to be very challenging for the preservation of organic residues.

**Foodways Through Organic Residue Analysis of Ceramics**

Organic residue analysis is typically applied to assessing ancient foodways from food acquisition, then preparation, to consumption and discard (sensu Twiss 2012); it has not only aided in the determination of past subsistence practices, but has also tackled questions about culinary practices or cuisines (Isaksson 2010; Saul et al. 2014). Coupled with technofunctional analysis of sampled pots (e.g., Cramp et al. 2013; Urem-Kotsou et al. 2002), it allows one to contextualize the direct relationship between pottery
use and the preparation and consumption of different food products (Fuller 2005; Notarstefano et al. 2011). This also allows us to have a view into past gastronomic realms (Spiteri et al. 2011), everyday lives, and social relations (Notarstefano et al. 2011). For the purpose of further discussion, foodways is divided into subsistence and cuisine. Subsistence strategies (Binford 1992; Ellen 1994) are food acquisition practices that include food procurement (hunting, gathering, and fishing) and production (agriculture and animal management). Cuisine or culinary practice (Fuller 2005) comprises the preparation (processing and cooking) and consumption (serving and eating) of food (Anderson 1971).

The findings from organic residue analysis can aid in the determination of past subsistence practices by corroborating the findings from bioarchaeological remains or serving as proxy data in cases where macroremains barely survive, if at all. Two case studies on animal management demonstrate the former. Outram and colleagues (2012) tracked the variation in pastoralism during the later Bronze Age in Kazakhstan with zooarchaeological and organic residue analyses. Hoekman-Sites and Giblin (2012) combined their data from organic residue analysis of pottery as well as isotopic analyses of human and animal remains to reveal management of domestic animals during the Neolithic and Copper Age in the Great Hungarian Plain. It was suggested that organic residue analysis provides an important source of proxy data for subsistence in cases where there is a dearth of ancient organic remains, including animal bones (Dudd et al. 1999; Mukherjee et al. 2007, 2008) under highly acidic and wet conditions (Cramp et al. 2014b; Kwak and Marwick 2015; Smyth and Evershed 2014, 2015). Despite the absence of faunal remains from the features where pottery was recovered,
Dudd et al. (1999) were able to find evidence for animal husbandry in Neolithic England through their analysis of Grooved and Peterborough Wares; the latter were found to be associated only with ruminant animal sources. Cramp and colleagues (2014b) were able to provide evidence of dairy farming in southern Finland, where only burnt animal bones were preserved in acidic soils and the area is beyond the present-day limits of agriculture. Kwak and Marwick (2015) were able to critically assess the orthodox crop-dominated view of subsistence in the prehistoric central Korean Peninsula and to show that organic residue analysis has the potential to overcome the limitations of acidic environments.

Organic residue analysis not only can track similarities and differences, as well as continuities and changes in subsistence strategies, but can also track the use of cuisines and pottery (Saul et al. 2014; Spiteri et al. 2011). Personal and social identities, alongside with food evaluations and preferences, revolve around cuisines or culinary practices (Saul et al. 2014). Cuisines can be archaeologically traced by deducing the patterns of combination and selective exclusion of food as a reaction to wider socioeconomic contexts. Following a cuisine perspective, food is a portion of several evaluation processes in several stages of foodways from food acquisition to consumption (Parker-Pearson 2003). Organic residue analysis of pottery offers possibilities to assess food preferences during their preparation, which is critical in evaluating food in a wider sociocultural context. Along with other recent advances in biomolecular methods to analyze materials from various microcontexts, this approach allows for more specific inferences and contributes to finer resolution of datasets that meet the demands of post-modern interpretations at smaller time scales. By knowing
the patterns of food preferences and selection at the scale of the community, the factors underlying why food became important can be gleaned. It is better to understand food evaluation processes if food data are integrated with the material culture of cuisine or foodways (e.g., pottery), to evaluate changes in cuisines parallel to historical transitions, say, agricultural development. Thus, cuisine is defined as a socially acceptable food combination based on food values, which are evaluated against the appropriate or perceived characteristics of foodstuff and related technologies in fulfilling their roles in provisional sociocultural contexts. The study of cuisine then is a glimpse into preferences and decision making of the people being studied (Saul et al. 2014).

The above framework on cuisine and food values (Saul et al. 2014) was applied on a case study in the late 5th to early 4th century BC in the southern Baltic Area of northern Europe, using results from lipid residue analysis (Craig et al. 2011) and plant microfossil analyses of phytoliths (Saul et al. 2013) and starches (Saul et al. 2012) of food crusts on pottery. Results showed that there was continuity in the processing of marine resources on pottery from late Mesolithic to Neolithic. Results from organic residue analysis and zooarchaeological analysis, however, did not necessarily match because of preferences for certain animal food sources to be prepared on pottery, depending on the cuisine. People preferred to process plant and marine food sources together and to process terrestrial sources on pottery separately. Dairy products were exclusively processed in small cup-sized beakers, which could be related to the initial, limited acceptability of this food source because not all early Neolithic people were lactose tolerant. Thus, the feasibility of utilizing the cuisine perspective increases with
identification resolution afforded by recovery and analysis of micro- and molecular remains of food (Saul et al. 2014).

The food culture model (Isaksson 2010) can complement the above cuisine perspective based on food value (Saul et al. 2014), since both call for the interpretation of data from organic residue analysis, integrated with other food-related remains and archaeological contexts. This model is useful for tracking probable flows of food culture signals in any archaeological material (Isaksson 2010, Fig. 4-1). It starts with the transformation of foodstuffs from nature context to menu context when humans consider them edible. From production to consumption, residues are possibly left behind in various contexts. Food signals from these residues reflect foodway or culinary practices and contingent proof of menus. The food culture model also helps us to predict the possible scenarios of these practices and the resulting residues (Isaksson 2010).

Although the food culture model appears to be straightforward, it is not because the movement of food culture signals varies depending on the cognitive concepts, ideas, and values of the people involved (Isaksson 2010). Some of these abstractions may not be archaeologically traceable. These are spatial organization of subsistence, meal order, meal customs, culinary arts, meal companionships, and gastronomy. Changes in food culture signals may be a consequence of innovation, borrowing, and distortion. These complications have to be taken into account, where contextual considerations are necessary for using the food culture model. The model also calls for the application of different analytical techniques, the establishment of contextual comparability between sites for inter-site studies, and a contextually stratified sampling approach. The food culture model was developed and applied in an early Medieval
settlement in Sweden. Data from pollen and organic residue analysis of pottery provided evidence for the production and preparation of hemp, respectively. Data from organic residue analysis and bone chemistry did not match in showing fish consumption, because of the difficulty of detecting lipid residues from lean lacustrine fish. The use of pottery does not reflect daily food consumption because there are other ways of preparing food without the need for pottery. Thus, in assessing subsistence data, it is essential to consider the consequences of foodways as cultural practices (Isaksson 2010).

Organic residue analysis then facilitates the assessment of similarities and differences in foodway or culinary practices, and the means to track changes and continuities of these practices (Isaksson 2010; Pecci 2014; Urem-Kotsou and Kotsakis 2007). For example, it was shown in the Baltic region of northern Europe that there was continuity in the preparation and consumption of aquatic resources during the agricultural transition (Craig et al. 2011). However, this was not the case in the neighboring northeast Atlantic, where early farmers rejected the exploitation of aquatic resources in favor of dairy farming (Cramp et al. 2014a). These contradictory findings in northern Europe during the transition to agriculture demonstrate that this method can address the diversity of culinary practices. Cramp et al. (2014a) also showed that there was an increase in the exploitation of aquatic resources and a decline in dairy farming from the Bronze Age to the Viking Age. Within the Northeast Atlantic region, Smyth and Evershed (2015) noted that their analysis of Neolithic pottery from Ireland indicated less evidence of meat processing compared to Neolithic pots from England. These studies
showed that this technique can assess spatial and temporal similarities and differences in culinary practices.

Organic residue analysis is also helpful in addressing the discard stage of foodways (sensu Twiss 2012). This is demonstrated by the case in Bronze Age Kazakhstan, where the findings of Outram et al. (2011) demonstrated that horse meat played a significant role in funerary rituals as grave goods in pottery vessels. The key to how this technique can trace past food culture signals from food acquisition to discard (Isaksson 2010) is the archaeological biomarkers (Evershed 2008b).

Archaeological Biomarker Concept

Molecular Biomarkers

Archaeological “biomarkers,” also known as “chemical fingerprints,” are the chemical compounds or molecules in organic residues that provide information about what humans were doing in the past (Evershed 2008b), especially related to their exploitation of natural products (Regert et al. 2003). Specifically, for food residues, these “biomarkers” should allow us to identify what plants and animals were prepared and/or served in the pottery vessels (e.g., Evershed 2008b; Heron and Evershed 1993; Skibo and Deal 1995; Spiteri et al. 2011). The most common and established biomarkers used in archaeology are lipids because they are better preserved than other biomolecules, say, carbohydrates and proteins (Evershed 1993).

Although complications arise because of alteration of organic molecules in the burial environment, it is still possible to identify sources of residues based on recovered biomarkers (Hallberg and Meyers 2004). This is a consequence of their strong covalent C–C bonding, which is typical of most organic matter that survives deposition and diagenesis in sediments. Reduction-oxidation reactions and other transformations do
not affect their carbon skeleton and their precursors can be traced by means of the remaining structure of the molecule (Hallberg and Meyers 2004). If biomarkers are altered from their original state, they are called natural degradation markers (Regert et al. 2003). The chemical components of organic residues are the ones representing the archaeological information that these residues contain. With appropriate separation and identification techniques, these preserved and altered components can still be identified using the Archaeological Biomarker Concept. This concept states that the structure and even isotopic compositions of components can be related to the compositions of plants and animals exploited by humans in the past. Biomarkers are also used in other fields such as organic geochemistry (Evershed 2008b). This biomarker principle underlies the retrieval of archaeological information from biomolecules (Briggs et al. 2000).

Analytical techniques require molecular-level resolution because of complexities such as mixtures of organic materials caused by human activity and compositional alteration that results from decay during burial (Evershed 2008b). The use of chromatographic and/or mass spectrometric methods is suggested. The assignment of specific sources of residues based on biomarkers demands a high degree of rigor. Thus, archaeological and paleoecological contexts are important to eliminate irrelevant sources of residues. The question that must be asked (Evershed 2008b:899) should be “is the presence of a constituent of a residue based on an observed biomarker consistent with the archaeology and paleoecology of the settlement, region and/or period from which the find derived?” In principle, the more unique the structures are to a given source, the more confident one can be as to the identification of that source.
The biomarker concept is similar to the chemotaxonomic principle (Heron and Evershed 1993).

With respect to altered structures, the ability to recognize their original constituent, or source of an organic residue, is a powerful aspect of the biomarker approach (Evershed 2008b). This requires knowledge of the involved chemical mechanisms and pathways and also the precursors, based on coherency of their carbon skeletons. From structural alterations, additional information of the life history of the residues and associated artifacts can be inferred. Aside from the fact that we can determine the chemical compositions of organic commodities exploited by humans in the past, we can also appreciate how these materials can be altered after processing and/or deposition (Evershed 2008b).

**Modern Comparative Reference Materials**

Biomarkers are particular compound structures present in contemporary plant and animal natural products known as reference materials (Deal et al. 1991). These represent the combinations or ratios of various compounds that one can use to infer a source (Evershed 1993). In selecting contemporary materials for comparative purposes, it is important to know what plants and animals were exploited in antiquity (Deal et al. 1991). The reference material should be representative of the real sample and there should be similarity between reference material and sample in matrix composition, content, and physical status (Quevauviller et al. 1995). The results of experimental studies and laboratory cooking simulations of contemporary foodstuffs can also be included in the database, whose development is an integral component of organic residue research (Evershed et al. 1991; Heron and Evershed 1993). Modern pottery sherds with known cooking history or impregnated with water extracts of contemporary
materials can be used as reference materials for residue analysis (Fankhauser 1994; Hill and Evans 1987). Reference materials can be commercially available compounds or can be synthesized in the laboratory to establish relationships between chemical composition of contemporary materials and the source from which they originate (Regert et al. 2003). For better archaeological interpretations, reference materials for residue analysis can include the remains of plants and animals found on the site from which the organic residues come (e.g., Skibo and Deal 1995) or could originate from the same geographic location as the artifacts (Dudd et al. 2003), from experimental archaeology (e.g., Charters et al. 1997; Evershed 2008a; Fankhauser 1994), or from ethnoarchaeology (e.g., Skibo 1992).

Producing reference materials from experiments also determines the feasibility of identifying potentially preserved residues (Skibo and Deal 1995). Degradation of organic molecules is simulated in the laboratory and their fate can be ascertained under controlled conditions (e.g., Evershed 2008a; Malainey et al. 1999a, 2007; Reber and Evershed 2004b; Solazzo and Erhardt 2007). Results of these experiments then aid in the identification of organic constituents of archaeological residues (e.g., Malainey et al. 1999b; Malainey 2007; Solazzo and Erhardt 2007). Aside from simulating degradation, experiments are also performed to determine how organic molecules are incorporated into or distributed within different parts of an artifact, say, a pottery vessel, during use (e.g., Evershed 2008a; Charters et al. 1997). Experimental and ethnographic materials must be analyzed in combination (Evershed 2008a).

Ethnographic (or ethnoarchaeological) materials, such as modern, used pots, can be used as reference materials (Evershed 2008a). They bridge a practical gap that
provides insights into the impacts of continual artifact usage that would be impossible to simulate in experiments (e.g., Skibo 1992). Haslam (2006:402) suggested that “the individual resonance of the findings of residue analyses with people can be used to provide a more nuanced understanding of past actions, which in turn allows better integration and communication of those findings within and outside the archaeological community.”

The production and collection of modern reference materials are, respectively, parts of experimental and ethnoarchaeological studies, which are applicable for studying resource management, food security, and sustainability in present-day societies (Metheny 2015). They contribute insights that are undetectable in archaeological and written records, and provide critical analogs for the ritual, social, cultural, and symbolic practices that cannot be directly identified in the archaeological record. Experimental archaeology allows for the assessment of the workings of prehistoric technologies, provides comparative information for the practices that are not carried out today, explores correlations between subsistence, technological transformation, and cognitive advances by proceeding beyond replication, provides applications for exploring social organization and cultural practice, discovers novel means to recover data, and incorporates multi- and interdisciplinary approaches. Ethnoarchaeology allows for fine-tuning the collection of relevant data and incorporation of analytical methods. It also allows the utilization of relational analogies to infer social organization and cultural practice, where past subsistence practices, technologies, and food have broader implications. Thus, the knowledge from experimental and ethnoarchaeological studies, integrated with archaeological studies, is relevant for
understanding past foodway practices (subsistence and culinary practices), food
technologies, human adaptations to social and environmental stresses, and their
applications to contemporary concerns (Metheny 2015).

The possibilities provided by the integration of findings from comparative modern
reference materials, produced from experimental and ethnoarchaeological studies, and
analyses of archaeological materials related to foodways, are mainly from the
biomarkers of food culture signals. The most common and established among the
biomarkers used in archaeology are lipids because they are better preserved than other
biomolecules such as carbohydrates and proteins (Evershed 1993).

**Lipids**

Lipids are the most common organic residues analyzed from archaeological
contexts, as they are moderately resistant to chemical and microbial deterioration
(Brown and Brown 2011). Lipids are substances synthesized by living organisms that
are soluble in or extractable with organic solvents, and insoluble in water (Bhat et al.
2009; Bianchi and Canuel 2011; Killops and Killops 2005). They are classified into two
categories: those that are converted into a water-soluble matter upon saponification or
alkaline hydrolysis (oils, fats, and waxes) and those that are not (resins, sterols) (Bhat et
al. 2009; Brown and Brown 2011). Oils (liquids) and fats (solids) are formed by the
attachment of three fatty acids to the glycerol molecule \([\text{HOCH}_2\text{CH(OH)CH}_2\text{OH}]\) by
ester linkages to form a carboxylic ester (see Fig. 4-2). Oils may be extracted from
plants and animal products (Lambert 1997; Morrison and Boyd 1992). Waxes, in
contrast, are mixtures containing esters of long-chain saturated and unsaturated fatty
acids (14-36 carbons) with long chain alcohols (16-36 carbons). They also have some
free acids, alcohols, and hydrocarbons (Bhat et al. 2009).
As a class of biomolecules, lipids are essential for the structure and function of cells in living organisms (Bowsher et al. 2008; Horton et al. 1995). Unlike other biomolecules, lipids have widely varied structures with diverse biological functions. As water-insoluble or only sparingly water-soluble organic compounds, lipids are either hydrophobic (nonpolar) or amphiphatic (with nonpolar and polar regions). Biological membranes are comprised of amphiphatic lipids. The triacylglycerols (fats and oils) function as intracellular storage molecules for metabolic energy of some organisms. Fats also serve as thermal insulation and padding for animals. Waxes in cell walls, exoskeletons, and skins serve as surface protection for some organisms (Bianchi and Canuel 2011; Horton et al. 1995; Matthews et al. 2000).

Lipids as archaeological biomarkers permit the differentiation of major food types, such as terrestrial meat (e.g., Dudd et al. 1999; Evershed et al. 1997, 2002; Mottram et al. 1999; Mukherjee et al. 2007, 2008; Regert 2011), aquatic resources (e.g., Craig et al. 2007; Cramp and Evershed 2014; Evershed et al. 2008; Hansel et al. 2004, 2011; Hansel and Evershed 2009; Heron and Craig 2015; Regert 2011), and plants (e.g., Copley et al. 2001; Evershed et al. 1994; Kimpe et al. 2001; Reber et al. 2003, Reber and Evershed 2004a; Steele et al. 2010). The discussion on different lipid biomarkers follows, which is based on the organic geochemistry perspective (see Bianchi and Canuel 2011; Killops and Killops 2005), from isoprenoids (steroids, hopanoids, and terpenoids), to long-chain waxes, to acylglycerides and fatty acids.

**Isoprenoids**

Isoprenoids are compounds with multicyclic structures, derived from the five-carbon isoprene unit (Bianchi and Canuel 2011). They can be differentiated according to their basic carbon skeletons, functional group composition, number of isoprene units,
number of cyclic structures, linkages between isoprene units, as well as number and placement of double bonds; hence, they are a versatile class of biomarkers. They can be acyclic and cyclic. The cyclic isoprenoids are steroids, hopanoids, and triterpenoids (Bianchi and Canuel 2011), which are some of the most useful biomarkers preserved in the archaeological record.

**Steroids**

Steroids are lipids that possess a characteristic tetracyclic carbon skeleton, which is the perhydrocyclopentano-phenathrene nucleus (Bhat et al. 2009). They are synthesized via enzymatic oxidation and cyclization of squalene (Brown and Brown 2011; Killops and Killops 2005). This process produces cycloartenol and lanosterol, which are the precursors of plant and animal (and fungal) steroids, respectively. Further oxidation and decarboxylation of lanosterol produces cholesterol, which is the precursor of steroids in animals. Cholesterol and related compounds belong to the subclass of steroids called sterols or steroidal alcohols (Killops and Killops 2005). They are 3-monohydroxy steroids having a C27, C28, or C29 skeletal structure that are crystalline and widely distributed in nature (Bhat et al. 2009). Steroids are minor constituents of plants and animals but are diagnostic to particular food resources (Heron and Evershed 1993) and they are useful biomarkers because animal sterols are different from plant sterols. Zoosterols, such as cholesterol and derivatives, are usually found in animals, while phytosterols, such as campesterol, stigmasterol, and sitosterol, are found in plants (Bhat et al. 2009; Evershed 1993). Hence, when well preserved as archaeological residues, they are useful for distinguishing animal from plant food sources (Evershed 1993). It was recently proposed that ergosterol, a fungal sterol, can be a potential biomarker for yeast and alcohol fermentation in ancient pottery (Isaksson et al. 2010).
**Hopanoids**

Also known as bacteriohopanoids, because they are commonly found in eubacteria, hopanoids are triterpenoids with five-membered E ring and various functional group compositions that include alkenes, ketones, acids, and alcohols (Bianchi and Canuel 2011; Killops and Killops 2005). Their potential as biomarkers for bacterially fermented beverages was recently realized when the hopanoids from the ethanol-producing bacterium *Zymomonas mobilis* were identified from organic residues recovered in pottery vessels used for *pulque* production from fermented agave sap in Prehispanic Teotihuacan, Mexico (Correa-Ascencio et al. 2014).

**Terpenoids**

As major constituents of resins and related products, terpenoids have been found to survive in a variety of archaeological contexts (Pollard and Heron 1996). Terpenoids are versatile molecules because of their adhesiveness, insolubility in water, inflammability, healing and poisoning properties, fragrance, plasticity, vitreosity, colorability, pigment mediability, and resistance to spoilage (Gianno 1990a). Resins from plants are important as gums, perfumes, flavorings, food preservatives, incense, materials for torches and military pyrotechniques, poisons, feeding deterrents, pigments, medicines, and contraceptives (Bowsher et al. 2008; Brown and Brown 2011; Loomis and Croteau 1980). They are synthesized by plants, marine organisms, and fungi, by head joining of isoprene units. Terpenoids are classified according to the number of isoprene units. Their skeletons occur as open chains as well as in various cyclic forms (Bhat et al. 2009; Killops and Killops 2005).

Regert and colleagues (2008), as well as Crowther et al. (2015), recently provided a botanical classification and geographic distribution of commercial resins.
used in antiquity (see also Lambert et al. 2002 and Lampert et al. 2002). Chemical classification distinguishes between diterpenoids and triterpenoids. Diterpenoid resins have four isoprene units with 20 carbons (Bhat et al. 2009; Killops and Killops 2005). They are usually from the plant families of Coniferae (Pinaceae, Cupressaceae, and Araucariaceae) and Leguminosae. The Manila copal from *Agathis dammara/Agathis alba* is a resin from the family Araucariaceae (Mills and White 1994).

Triterpenoid resins have six isoprene units with 30 carbons (Bhat et al. 2009; Killops and Killops 2005). These are produced by flowering plants, i.e. angiosperms. They are known as dammars, mastic, elemi, myrrh, and frankincense (Mills and White 1994; Regert et al. 2008). Dammars are from the trees of the subfamily Dipterocarpoideae of the family Dipterocarpaceae. Mastic is from the *Pistacia* tree of the Anacardiaceae family. Elemis are from *Canarium* sp.; specifically, *Manila elemi* is from *Canarium luzonicum*, which grows in the Philippines (Mills and White 1994). Myrrh is from *Commiphora* sp. and frankincense or olibanum is from *Boswellia* sp. (Regert et al. 2008). Triterpenoids are sorted into three series, namely, the oleanoids (e.g., β-amyryrin), ursanoids (e.g., α-amyryrin), and lupanoids (e.g., lupeol) (Bianchi and Canuel 2011; Killops and Killops 2005). The natural product chemistry of the di- and triterpenoid constituents of many plant resins is investigated to determine the botanical sources of archaeological resins. Altered forms of natural resins provide challenges, but raise opportunities to determine ancient technologies involved in production (Evershed 2008b; Regert et al. 2003).

Other types of terpenoids are monoterpenoids and sesquiterpenoids, which have two and three isoprene units, respectively, are usually essential oils from plants.
(Bowsher et al. 2008; Killops and Killops 2005; Loomis and Croteau 1980). Volatile ones are responsible for floral scents common in traditional medicinal plants (Brunke et al. 1993). In addition, half of the oleoresins produced by conifers are monoterpenes (Gijzen et al. 1993), having two isoprene units with ten carbons (Killops and Killops 2005).

**Long-Chain Alkyl Compounds**

Long-chain alkyl compounds are acyclic compounds that include hydrocarbons, alcohols, aldehydes, ketones, wax esters, and probably other functional groups (Evershed 1993). They serve as protective coatings, are usually in mixtures of many compounds, and have high melting points (Killops and Killops 2005). They are usually found as plant waxes and beeswax in archaeological materials (Evershed 1993).

**Plant waxes**

Long-chain alkyl compounds in mixtures found in the leaf waxes of higher plants have chemotaxonomic values (Evershed et al. 2001). These natural waxes contain relatively similar classes of compounds but the relative proportions of the individual components can be used as “fingerprints” to identify the specific origin of an unknown ancient wax. These compounds can be long-chain alcohols, ketones, aldehydes, wax esters, alkanes, etc. They can also be fully saturated and contain few reactive functional groups, making them resistant to decay over time (Evershed 1993). These saturated compounds are long-chain alkanes with odd numbers (23-35) of carbons (Killops and Killops 2005). These waxes can provide archaeological information that is difficult to obtain by direct evidence (Evershed et al. 2001). An example of these waxes is the leaf wax of *Brassica olearacea* or cabbage that contains n-nonacosane, nonacosen-15-one, and nonacosen-15-ol in the total lipid extracts of several Late Saxon and early Medieval
potsherds recovered from the sites of Raunds and West Cotton in the United Kingdom. These provide evidence of early processing of *Brassica* vegetables and past exploitation of leafy vegetables (Evershed 1993; Evershed et al. 2001). Another example is the detection of *n*-dotriacontanol as a biomarker for maize (Reber et al. 2003, Reber and Evershed 2004a), which opened up the possibility of detecting other cereal staples in the archaeological record. Although there are problems in the detection of lipid biomarkers in carbohydrate-dominated cereal grains, Reber and Evershed (2004b) suggested exploring long-chain alkanes or alkanols that can serve as characteristic biomarkers.

**Beeswax**

Beeswax is one of the best known examples of natural wax that was an important commodity in antiquity and thus has special significance in archaeology (Evershed 1993; Evershed et al. 2001). Its composition is stable and can be reliably used for archaeological interpretation (Evershed 1993). Aside from honey, beeswax is an additional product created by wild or domesticated bee colonies (Thomas and Mannino 2001). It can be applied against the inner surface of newly fired pots while still warm to serve as a sealant for the storage of liquids. It is also used as polish and fuel that can be burned in lamps (Evershed et al. 1997, 2001; Thomas and Mannino 2001), paint for rock art (Watchman and Jones 2002), and as a component of royal seals (Cassar et al. 1983). The beeswax lumps preserved in archaeological contexts from Coppergate, York, United Kingdom were identified from the remains of identified bees, and when burned had a characteristic odor (Thomas and Mannino 2001). Aside from its odor, beeswax is composed of wax esters (even-numbered monoesters derived from palmitic and oleic acids and the similar hydroxymonoesters derived from 15-
hydroxypalmitic acid), long-chain alcohols, and \( n \)-alkanes, the last two being odd-numbered hydrocarbons (Evershed et al. 2001; Garnier et al. 2002; Namdar et al. 2007). It is identified on the basis of distribution of \( n \)-alkanes (C\(_{23}\) to C\(_{33}\)) and long-chain palmitic acid wax esters (C\(_{40}\) to C\(_{52}\)). The composition can be altered during decay. At highly degraded states, there is a loss of the shorter-chain components. Beeswax has been observed in residues of lamp oil from ceramic vessels used during the Neopalatial period at the settlement of Mochlos on the north coast of East Crete (Evershed 2001). Recently, large-scale research of Roffet-Salque et al. (2015) identified beeswax in pottery vessels from Neolithic Europe, the Near East, and North Africa. It demonstrated the exploitation of products from honeybees (\textit{Apis mellifera}) by farming communities since 7000 cal yr BC and provided the first biomarker-based distribution map of this species.

**Acylglycerols and Fatty Acids**

Acylglycerols (or glycerides) are esters of glycerols with one to three similar or different fatty acids in the form of fats and oils (Bianchi and Canuel 2011; Brown and Brown 2011; Killops and Killops 2005). The three hydroxyl (\(-\text{OH}\)) groups of glycerol reacts with one, two, or three fatty (carboxylic) acids to form, respectively, either a monoacylglycerol (MAG, monoglyceride), diacylglycerol (DAG, diglyceride), or a triacylglycerol (TAG, triacylglyceride). The latter usually serve as energy reserves. The fatty acids with 12 to 36 carbons in each chain may comprise the acylglycerols, with those having 16, 18, and 20 carbons most common. Saturated fatty acids with 16 and 18 carbons dominate the acylglycerols of animal fats, while unsaturated (one or more double bonds) fatty acids with 18 to 22 carbons dominate those of plant oils. The higher the degree of unsaturation (the number of double bonds), the lower the melting point.
This explains why animal fats are usually solid and why plant oils are usually liquid (Bianchi and Canuel 2011; Brown and Brown 2011; Killops and Killops). The triacylglycerol with the presence of the ester groups (see Fig. 4-2) may be broken down into its component glycerol and fatty acids by saponification or hydrolysis (Mills and White 1994). This can happen during burial, when the glycerol linkages may break or be dissolved in groundwater leaving the fatty acids behind and available for analysis and use as biomarkers for specific oils (Lambert 1997). In hydrolysis, when the splitting is carried out either with water alone (which requires much higher temperature), or with mineral acid, it produces free fatty acids that may be analyzed. Hydrolysis can also result from the enzymatic action initiated by bacteria or fungi. In saponification, however, fatty acids can react with aqueous alkali [e.g., sodium hydroxide (NaOH) and potassium hydroxide (KOH)] to yield salts or soaps and glycerol (Mills and White 1994).

Fatty acids as biomarkers will be further discussed in the next section.

**Focus on Fatty acids**

Fatty acids are the simplest lipids (Horton et al. 1995). They have a general formula R–COOH, where “R” represents a hydrocarbon chain (4-36 carbons) and COOH is the functional group of carboxylic acids (Bhat et al. 2009; Horton et al. 1995). Fatty acids can be free or bound fatty acids (Bianchi and Canuel 2011). They are components of many complex types of lipids, including wax esters, triacylglycerols, glycerophospholipids, and sphingolipids. They are distinct from one another by the length of their hydrocarbon tails, the degree of unsaturation (the number of carbon-carbon double bonds) and the positions of the double bonds in the chain. Most of them have a $pK_a$ (acid dissociation constant) of about 4.5 to 5.0 and are, therefore, ionized at physiological pH. Either their International Union of Pure and Applied Chemistry
(IUPAC) names or common names can be used to refer to these fatty acids. The latter are used for the most frequently encountered fatty acids. Their shorthand notation uses two numbers separated by a colon: the first refers to the number of carbon atoms in the fatty acids and the second refers to the number of carbon-carbon double bonds. The positions of the double bonds are indicated as superscripts following the $\Delta$ symbol; for example, palmitate is 16:0, oleate is 18:1, and arachidonate is 20:4 $\Delta^{5,8,11,14}$ (Horton et al. 1995).

Since fatty acids are synthesized by the sequential addition of two-carbon units, the number of carbon atoms is always even and ranges from 12 to 20 in the most abundant fatty acids (Horton et al. 1995). Saturated fatty acids are the ones with no carbon-carbon double bond. Usually, they are waxy solids at room temperature. If fatty acids have at least one carbon-carbon double bond, they are classified as unsaturated. They can be monounsaturated with only one carbon-carbon double bond or polyunsaturated with two or more double bonds. The length of the hydrocarbon chain and the degree of unsaturation (or number of carbon-carbon double bond) affect the melting point of fatty acids, the longer their chain, the higher their melting point. As the number of carbon-carbon double bonds is increased, fatty acids become more fluid (Horton et al. 1995) and more susceptible to oxidation (Mills and White 1994). The following discussion focuses on how fatty acids differ between plant and animal food sources, as well as between terrestrial and aquatic sources.

**Plant Oils**

The mono-, di-, and triunsaturated fatty acids that are highly susceptible to rapid oxidative degradation are most abundant in plant oils and other lipid oxidation products
(Evershed et al. 2001). They may be found in pottery vessels and sherds excavated from exceptionally arid sites. They may be lost in the archaeological record through groundwater leaching, but may be recovered in waterlogged deposits. Some examples of plant oils are radish oil (C_{24}, both saturated and monounsaturated fatty acids), castor oil (dominated by riconoleic acid or $\Delta^9$ 12-hydroxy octadecenoic acid), and palm kernel oil (high abundance of C_{12} and C_{14} saturated fatty acids). These compounds were detected from lipid extracts recovered from pottery excavated in the Near East (Evershed et al. 2001). Palm fruit lipids, dominated by C_{12} fatty acid, in pots excavated from Qasr Ibrim, Egyptian Nubia have also been detected (Copley et al. 2001a, 2001b).

**Animal Adipose Fats**

The animal adipose fats are the most common lipids from animal sources found in archaeological pottery (Evershed et al. 2001; Regert 2011). They have a high content of saturated fatty acids, which increases the likelihood for survival during burial (Evershed et al. 2001). Adipose fats can occur in lard and tallow form, and usually consist of more than 99% acylglycerols. Muscle fat and meat have large amounts of phospholipids and cholesterol. The animal fat in meat has palmitic, stearic, and oleic acids (Gordon and Mellon 1998). The distribution of different fatty acids is due to their stepwise hydrolytic degradation. The molecular characteristics that can be used to differentiate degraded animal fats are the distribution of fatty acids, including branched chain and odd carbon-number components, compositions of monounsaturated fatty acids, and triacylglycerol distributions (Evershed et al. 2001, 2002a). The animal adipose fats in the archaeological record are abundant in C_{16:0} and C_{18:0} fatty acids, have medium amounts of unsaturated fatty acids (palmitoleic, oleic and linoleic), and
have several fatty acids with an odd number of carbon bonds (Damodaran et al. 2007; Evershed et al. 2002a).

**Ruminant vs nonruminant animals:** Based on fatty acid composition, ruminant and nonruminant animals can be distinguished in organic residues (Evershed et al. 2002a; Regert 2011). For ruminant animals, the fat collection from lamps has a higher C\textsubscript{18:0} content of \textit{n}-alkanoic acids distribution. This observation is consistent with that from ruminant animals whose lamp extracts were used for fuel in West Asia and Europe and have significant abundance of branched-chain and odd carbon numbered, straight chain components (specifically C\textsubscript{15:0}, C\textsubscript{17:0}, and C\textsubscript{19:0}). The dimethyl sulfide esters of monounsaturated acids in lamp extracts exhibit a complex mixture of positional isomers of octadecenoic acid that appears in the fat of ruminant animals such as sheep and cattle. Also characteristic of ruminant animals are high contents of saturated \textit{n}-alkanoic acids, presence of positional isomers of monounsaturated alkenoic acids, and branched chain components that have been identified in lamp extracts (Mottram et al. 1999). On the other hand, \textit{Z}-9-octadecenoic acid was detected in extracts from the dripping dishes during spit-roasting of nonruminant or monogastric animals, such as pigs (Evershed et al. 2001, 2002; Mottram et al. 1999).

**Animals vs Plants**

Animal and plant sources, as mentioned above, can be differentiated by the presence of cholesterol and sitosterol (or their derivatives and degradation products), respectively (Heron and Evershed 1993). The ratios between palmitic (C16) and stearic (C18) fatty acids are also used to differentiate between animal and plant sources, where it is assumed that fatty acids degrade at the same rate over time. The C16/C18 is about 1 for animal fats, while C16 is much greater than C18 (C16/C18 ~5) for plants (Regert et
Comparison of C16/C18 values between modern (usually experimental) and ancient samples allows inference of possible sources of archaeological residues (e.g., Eerkens 2005, 2007; Skibo 1992; Romanus et al. 2007). However, the use of fatty acid ratios has recently been proven to be unreliable because of the different rates of degradation across time and geographic area (e.g., Spiteri et al. 2011). Post-exavation processing may also affect fatty acid ratios. Aside from knowing the different C16/C18 ratio signatures of fatty acids in different organisms, the effects of the noncellular matrix environment of an artifact and its surrounding environment must be accounted for after the recovery of an artifact (Rider et al. 2006).

Aquatic Resources

Aquatic resources, such as fishes and marine mammals, have a complex lipid composition compared to plant oils and terrestrial animal fats (Cramp and Evershed 2014; O'Keefe 1999). This poses a challenge for accurate identification and quantification of fatty acids derived from aquatic animals (O'Keefe 1999). Palmitic acid tends to be represented at least twice as much compared to stearic acid, a pattern similarly observed with plants (Olsson and Isaksson 2008). Although they share the same fatty acids with terrestrial animals, aquatic animals have long-chain (16 carbons and above) unsaturated fatty acids, such as palmitoleic acid, 9-eicosanoic/gadoleic acid, 5,8,11,14-eicosatetraenoic/arachidonic acid, 5,8,11,14,17-eicosapentaenoic/timnodonic acid, 1-docosenoic/erucic acid, 4,7,10,13,16,19-docosahexaenoic/cervonic acid, and 15-tetracosanoic/nervonic acid (Brown and Heron 2003; Cramp and Evershed 2014; Fankhauser 1994). These fatty acids oxidize more rapidly than those present in vegetables and terrestrial animals (O'Keefe 1999). In effect, aquatic animal fats may be undetectable in archaeological remains because they
break down over time in some burial environments (Cramp and Evershed 2014; Hansel and Evershed 2009).

However, the more stable altered products of these unsaturated fatty acids in the form of dihydroxy acids (DHYAs) and \( \omega \)-(o-alkylphenyl)alkanoic acids (APAAs) are useful as biomarkers for aquatic resources (Cramp and Evershed 2014). The \textit{erythro} and \textit{threo} (vicinal) dihydroxy acids are derived from \( \text{C}_{16-22} \) \( Z \)-monounsaturated alkenoic acids and preserved in the ‘bound’ phase of organic residues. They have been detected in residues on pottery samples from coastal sites in Santa Catarina State, Brazil (Hansel and Evershed 2009; Hansel et al. 2011). The C16, C18, C20, and C22 \( \omega \)-(o-alkylphenyl)alkanoic acids are derived from the prolonged heating of unsaturated alkanoic acids (C16:\( n \), C18:\( n \), C20:\( n \), and C22:\( n \); \( n=1-3 \)) on pottery matrix at 270°C (Evershed et al. 2008; Hansel et al. 2004). The potential of these biomarkers was first realized with experiments by Evershed et al. (2008), whereby AAPAs were derived from heating unsaturated alkanoic acids or complex unsaturated fatty acyl lipids at a high temperature with the help of metal oxides and salts within the pottery matrix. These AAPAs can also probably be produced from the succession of polymerization reactions that occur during the formation of charred surface residues (Craig et al. 2007). It is noted that C20 and/or C22 AAPAs must also be detected to ensure that the source of these AAPAs is aquatic, since C16 and C18 AAPAs can also be produced from heating vegetable oils (Cramp and Evershed 2014).

Isoprenoid fatty acids, namely, 3,7,11,15-trimethylhexacosanoic acid (phytanic acid), 2,6,10,14-tetramethylpentadecanoic acid (pristanic acid), and 4,8-12-trimethyltridecanoic acid (4,8,12-TMTD), are also important aquatic biomarkers
(Ackman and Hooper 1968, 1970; Cramp and Evershed 2014). However, phytanic acid also occurs at high concentrations in ruminant animals. It also has two diastereoisomers based on the configurations of three chiral carbons at positions 3, 7, and 11, which are 3S,7R,11R,15-phytanic acid (SRR) and 3R,7R,11R,15-phytanic acid (RRR). Marine or aquatic resources have higher SRR/RRR ratios than ruminant animals, making it possible to distinguish aquatic sources from ruminant animals (Lucquin et al. 2016a). Although originally proposed as biomarkers for marine resources processed in pottery from coastal sites only (Evershed et al. 2008; Hansel et al. 2004), isoprenoid fatty acids and AAPAs can also be identified in organic residues of freshwater resources processed in pottery from inland sites [Craig et al. 2007, 2011; Kwak and Marwick 2015 (isoprenoid fatty acids only)]. Thus, these two groups of compounds and the DHYAs may serve as biomarkers for aquatic resources, in general, from freshwater, brackish, and marine environments (Heron and Craig 2015). However, lean fishes and freshwater shellfishes do not produce C20 unsaturated fatty acids and isoprenoid fatty acids in substantial amounts, and thus these fatty acids are not typically preserved in the archaeological record (Olsson and Isaksson 2008; Reber et al. 2015).

Detecting AAPAs only allows for the identification of aquatic resources that were actually cooked or processed by heating in pottery vessels because of the fact that they are degradation products from cooking aquatic resources (Evershed et al. 2008; Hansel et al. 2004). Baeten and colleagues (2013) proposed additional biomarkers, C17:1 and C19:1 fatty acids that co-occur with isoprenoid fatty acids, characteristic of aquatic animal products that do not require heating to be formed. These fatty acids open the possibility for detection of raw and fermented products from aquatic resources.
Biomarkers for aquatic resources have been detected in charred surface residues (or foodcrusts) and absorbed residues of archaeological pottery (see Cramp and Evershed 2014; Heron and Craig 2015), including some of the earliest pottery in the Northern Hemisphere (e.g., Craig et al. 2007, 2011, 2013; Cramp et al. 2014a,b; Farrell et al. 2014; Heron et al. 2013, 2015; Horiuchi et al. 2015; Lucquin et al. 2016b; Solazzo and Erdhardt 2007; Tache and Craig 2015) and Southern Hemisphere (e.g., Colonese et al. 2014). The preparation and analyses of lipid residues from ceramics to detect biomarkers from aquatic and terrestrial (animal and plants) resources prepared and consumed on pottery vessels and other ceramics are discussed next.

**Preparation and Analyses of Lipid Residues from Ceramics**

Several preparative and analytical procedures may be performed on organic residues in archaeological ceramic samples (Kaluzna-Czaplinska et al. 2016). This discussion includes only the procedures adopted in Chapters 5, 6, and 8, and others being considered for further assessment of the archaeological pottery samples included in this research based on their nature and provenience.

**Extraction and Further Processing Prior to Analyses**

Research on archaeological lipid residues utilizes the chloroform-methanol solvent system for extracting lipids (e.g., Evershed et al. 1990; Charters et al. 1997; Fankhauser 1994), a procedure modified from the classic lipid extraction method by Folch and colleagues (1957). Occasionally, dichloromethane replaces chloroform. This solvent system is a combination of organic and aqueous components, in which all nonlipid substances will join the aqueous component, which is methanol, and lipid substances will join the organic component, which is chloroform or dichloromethane (Folch et al. 1957). An aliquot of the resulting total lipid extract (TLE) is usually
saponified to separate the fatty acids in the acidic fraction from the neutral fraction, which contains sterols, terpenoids, long-chain waxes, and other unsaponifiable lipids (Kaluzna-Czapłinska et al. 2016). The separation of different lipid groups can also be done through column separation (Nichols 2011).

**Conventional sonication extraction**

As attested in the review by Kaluzna-Czapłinska et al. (2016), the most commonly encountered method of extracting lipids from pottery is sonication (e.g., Evershed et al. 1990; Charters et al. 1997; Fankhauser 1994), which breaks up any particle aggregates to aid dissolution of organic components into the solvent. Centrifugation is also done with sonication to separate the solvent and target components from insoluble materials, such as the pottery sediments. After the organic layer is collected from the sample test tube or vial and transferred into another, the organic solvent is removed by placing the sample under a stream of nitrogen, leaving the lipid extract (Pollard et al. 2007).

**Derivatization**

An aliquot of TLE and the unsaponifiable neutral fraction are usually derivatized with N,O-bis(trimethyl)silyl trifluoroacetamide (BSFTA) for the lipid compounds to be converted into trimethylsilyl (TMS) derivatives or esters/ethers (TMSEs) (Evershed et al. 1990). The fatty acids in the acidic fraction are also usually derivatized with boron trifluoride in methanol to convert them into fatty acid methyl esters (FAMEs) (e.g., Fankhauser 1994; Bianchi and Canuel 2011). Derivatization is necessary for the lipid components to be converted into their more volatile form, which can be analyzed with gas chromatographic techniques (Evershed et al. 2001).
Alkaline treatment

The chloroform (or dichloromethane)-methanol extraction method has a drawback, since it only extracts the “free” lipids that are not chemically bound to the ceramic matrix or contained within a larger organic polymer (Copley et al. 2005; Craig et al. 2004; Regert et al. 1998). Thus, this method is unable to release all the lipid contents from archaeological sherds (Craig et al. 2004; Regert et al. 1998). These bound lipids are lipid oxidation products that include short-chain dicarboxylic acids, hydroxy acids, long-chain hydroxyl and dihydroxy acids, which are possible covalently bound into the ceramic matrix (Regert et al. 1998). Alkaline treatment or saponification of the remaining pottery sample after extraction is done to release these recalcitrant compounds to increase lipid yields (Craig et al. 2004; Regert et al. 1998). Also, catalytic hydrolysis (open-system pyrolysis assisted by high hydrogen gas pressure) is also done along with solvent extraction and alkaline saponification to recover more covalently bound molecular lipid species, such as straight chain hydrocarbons (Craig et al. 2004). Alkaline treatment to release DHYAs that serve as biomarkers for plant oils and aquatic resources, respectively, has been done by Copley et al. (2005) and Hansel et al. (2011).

Direct acidified methanol extraction

Correa-Ascencio and Evershed (2014) developed the direct acidified methanol extraction method in response to time-consuming preparation and low lipid recovery common with conventional extraction. Furthermore, this new method facilitates the analysis of a large number of pottery samples to tackle essential archaeological questions. The lipids from the ground pottery sample are extracted via methanol catalyzed with sulfuric acid (H₂SO₄-MeOH 2% v/v, 70°C, 1hr), whereby the fatty acid methyl esters in the extracts are present along with unsaponifiable lipids that are usually
found in the neutral fraction after saponification. Based on their reanalysis of previously processed samples from different geographic regions, Correa-Ascencio and Evershed (2014) achieved higher lipid yields with greater efficiency, with the time spent for the preparation only 20% of that of the conventional, combined extraction-derivatization method. Papakosta et al. (2015) also suggested the use of this acid-catalyzed direct extraction and methylation of absorbed organic residues for very small and very old samples. To increase lipid yield, they applied this procedure to the remaining insoluble sample after conventional solvent extraction.

**High pressure liquid extraction**

As discussed in the previous two sections, others attempting to increase lipid yields have resorted to alkaline treatment and direct acidified methanol extraction after having very low yields with the conventional sonication extraction method. Gregg and Slater (2010), however, promoted the use of microwave assisted liquid chromatography in a microwave-assisted reaction system (MARS), followed by column separation of several lipid components. They developed this method after the conventional solvent extraction method only delivered organic residues from six out of 231 Neolithic pottery sherds recovered from calcareous or alkaline soil conditions in the Middle East. The microwave-assisted method is more efficient and delivered higher yields of organic residues from 34 out of 65 pottery samples analyzed, including 16 that did produce good yields with the conventional extraction method. High pressure and temperature aid in the extraction with this microwave-assisted method, in which the conditions are similar to the accelerated solvent extraction method (Gregg and Slater 2010).

The accelerated solvent extraction (ASE) method, recently developed by Dionex (Nichols 2011), was the method used to extract lipid residues from pottery in this
research. This method has proven to be very efficient in extracting lipid compounds from various materials (e.g., Rahmat Ullah et al. 2011; Fines-Neuschild et al. 2015); however, it seems to be rarely utilized in the extraction of organic residues from archaeological materials, such as pottery (e.g., Gjesfjeld 2014; Kwak 2015; Lanehart 2015). ASE should not be confused with Automated Soxhlet Extraction used in some research on organic residues (see Kaluzna-Czapinska et al. 2016).

**Nondestructive extraction**

Considering the interests in the former contents and use of rare pottery pieces, the nondestructive extraction method was suggested. It was first developed by Gerhardt et al. (1990), who poured the extraction solvents (chloroform and methanol) separately into small ancient Greek figure vases, then allowed the solvents to be absorbed into the pottery matrix. They then transferred out, reduced, and analyzed the resulting extracts for greater efficiency and less separation. Vanderveen (2011) used this method on precolonial, indigenous vessels from the Dominican Republic. The lipid residues were extracted by sonicating the pottery sherd drenched in the solvent inside the beaker. The results in terms of the composition and yield are almost similar between the nondestructive method with the whole pottery sherd and the conventional extraction method with the ground pottery sample. The limiting factor for this method to be feasible is the size of the ultrasonic bath (Vanderveen 2011). In both case studies, the nondestructive method produced good yields and maintained the integrity and appearance of the pottery (Gerhardt et al. 1990; Vanderveen 2011). This opens possibilities for analyzing rare, irreplaceable pottery pieces without destroying the samples and widens the research scope (Vanderveen 2011).
Analysis for Molecular Profiling of Lipids

After the lipid extracts and/or their fractions have been derivatized, they are generally analyzed with gas chromatography, where they separate into rank order according to differences in structure and mass. Then, with mass spectrometry, the different molecules are further separated, under the powerful force of a strong magnetic or electric field, again according to variations in mass and other structural properties (Jones 2001). The interpretation of results is done by comparing the resulting chromatograms and mass spectra of samples with those of the reference collection or standards from different substances (e.g., Fankhauser 1994). The analytical techniques discussed in Chapter 4 are those adopted in Chapters 5, 6, and 8.

Gas chromatography

Gas chromatography (GC) is a powerful technique for the qualitative and quantitative analysis of a wide range of materials in diverse areas as environmental, clinical, and food analysis, as well as petroleum and chemical production (Cserhati and Forgacs 1999). With GC, the sample is vaporized and injected onto the head of a chromatographic column (Skoog et al. 1998). The elution is brought about by the flow of an inert gas that transports the analyte through the column. Gas liquid chromatography, which is more common and is usually referred to as gas chromatography, is based upon the partition of analyte between a gaseous mobile phase and a liquid phase immobilized on the surface of an inert solid. Each compound has a characteristic retention time, which is determined from the resulting chromatogram (Skoog et al. 1998). The usual GC detector used for preliminary analysis of residue extracts, before running them using more sophisticated gas chromatographic techniques, is the flame ionization detector (FID) (e.g., Charters et al. 1997; Copley et al. 2001b; Kimpe et al. 2004). There are
studies that use only GC-FID to analyze fatty acid compositions (e.g., Malainey et al. 1999a, 1999b). The detector is attached to the end of the capillary column and it burns the eluents in a mixture of hydrogen and air at a particular temperature to pyrolyze the components, producing ions and electrons (Pollard et al. 2007).

**Mass spectrometry**

Mass spectrometry (MS) has become an important technique for the organic chemist and was used with remarkable success for solutions with many structural problems, and it is widely used for many natural products such as amino acids, fatty acids, steroids, carbohydrates, antibiotics, and others (Biemann 1964; Djerassi 1964). MS is different from other familiar forms of spectroscopy because it does not involve electromagnetic radiation. Instead, there are chemical manipulations such as ionization and fragmentation (Lambert et al. 1998). Molecular MS is used for the identification and structural elucidation of a wide variety of organic compounds. To obtain the mass spectrum of a certain compound, the analyte is bombarded with a stream of electrons that lead to the loss of an electron by the analyte and formation of the charged species or molecular ion. As a radical ion, it has the same molecular weight as the original compound. The collision between energetic electrons and analyte molecules gives enough energy to let the molecules leave in an excited state. Relaxation allows the fragmentation of analyte molecules into ions of lower molecular masses. The positive ions are then sorted through the slit of mass spectrometer according to their difference in \( m/z \). The highest peak at the mass spectrum is the base peak (Skoog et al. 1998).

MS has several variations that are used in archaeology. One of them is Direct Temperature resolved Mass Spectrometry, where it is possible to distinguish between the molecular weight, volatile part, cross-linked part of a solid sample by gradually
raising the temperature of the probe. It also gives insight into the physical conditions that have allowed many compounds to survive long-term burial (Oudemans et al. 2007). Another is electrospray ionization mass spectrometry/MS (ESI-MS/MS) that permits a more thorough investigation of the chemical structure of the various components of the sample (Regert et al. 2003).

**Gas chromatography with mass spectrometry**

Gas chromatography with mass spectrometry (GC-MS) and its variants characterize chemical residues with remarkable precision (Evershed 2008b; Regert 2011). It gives two-dimensional identification with GC retention time and a mass spectrum for each component. The GC-MS instrument has three components, namely, the gas chromatograph, the mass spectrometer, and a data system. The usual stationary phase in GC columns is a liquid. The plot of total ion current (TIC) against time gives a chromatogram similar to that obtained from GC. Samples must be both volatile and thermally stable, where the functional groups are protected by derivatization of extracts (Harvey 1995). The use of GC-MS made a major impact in organic residue analysis. Soft ionization techniques, such as electrospray ionization, which converts from ions in solution to ions in gas phase, were developed for the preserved polar and high molecular weight residues from artifacts (Regert et al. 2003). GC and GC-MS are the preferred techniques to analyze residue extracts obtained through solvent extraction (Heron and Evershed 1993). Other techniques, such as high temperature–gas chromatography (HT-GC) and HT-GC/MS, are used to derive detailed compositional information directly from extracts without chemically degrading them to release their simpler fatty acid (Evershed et al. 1990, 1999). In addition, pyrolysis techniques do not require sample preparation, can be performed on very small samples (Oudemans and
Boon 1991), and can provide an overall picture of the different kind of constituents present in a microsample (Regert et al. 2003). These are flash pyrolysis GC-MS (py-GC/MS) (McCobb et al. 2004; Regert et al. 2003), Curie-point pyrolysis (Cu-py) MS, and Cu-Py-GC/MS (Oudemans and Boon 1991). A nondestructive GC-MS method, which is solid-phase microextraction (SPME) GC-MS, is being used to analyze volatile organic compounds emitted by artifacts (Lattuati-Derieux et al. 2006).

**Viability and Challenges of Organic Residue Analysis**

Archaeological residues are best preserved anaerobic environments where it is constantly wet or dry, there is constant low temperature, it is mildly acidic, at burial depths where microbial decomposition is reduced, residues are protected by clay or another mineral matrix mainly through adsorption, and there is low nutrient availability (Fankhauser 1994). Briggs (1999) noted that the transfer of organic molecules into the archaeological record is controlled by the nature and composition of the surrounding microorganisms, depositional conditions (physicochemical and microbial), and controls on the longer-term survival of the molecules (such as the surrounding lithology or matrix). The temperature, light exposure, degree of waterlogging or desiccation, and reduction-oxidation conditions in the environment control the preservation and decay of organic molecules. Alternating wet and dry conditions are detrimental to residue survival (Evershed 2008b). The site of preservation must either be waterlogged (marine, lacustrine, or fluvial), warm/dry, or frozen (Regert et al. 2003). The mineral matrices or inorganic apatite phase of bone and the fabric of pottery offer environments in which organic molecules are partially preserved from microbiological degradation if these molecules are contained within pore spaces inaccessible to enzymes from microbes and if adsorbed on surfaces (Evershed 2008b; Heron and Evershed 1993). Also, the
entrapment of organic molecules during use through microencapsulation in carbonized surface residues also inhibits access of degradation microorganisms (Heron and Evershed 1993). Aside from the kind of artifact and environment, the likelihood of organic molecules to survive in the archaeological record also depends on the reactivity of their present functional groups and their chemical solubility. The more polar the molecules are, the more susceptible they are to decay, especially if nitrogen and phosphorus are present (Evershed 2008b). During deposition, bacterial and fungal lipases from surrounding soil or sediments cause hydrolysis of lipids into separate fatty acids or even esterification into other compounds (Brune and Gotz 1992; Galliard 1980; Lazar and Schroder 1992).

The challenges faced in the study of natural products preserved in archaeological environments or organic residues derive from their highly complex compositions, their degraded state, and the presence of uncharacterized polymeric components (Regert et al. 2003). Even before burial, organic molecules such as lipids from pottery may already have been destroyed by extensive heating. Evidence of the formation of long-chain ketones from the condensation of long-chain carboxylic acids in archaeological pottery is provided by the structural and isotopic studies. These ketones result from the fact that the cooking vessels from which the potsherds originated have been subjected to extensive heating during the processing of their contents in antiquity. They are similar to those produced by via biosynthesis in higher plants, such as waxes, so caution must be taken in the interpretation of the origin of long-chain ketones in pottery (Evershed et al. 1995). On the other hand, several ethnoarchaeological and experimental findings
mentioned by Skibo and Deal (1995) demonstrate that lipids can withstand heat and remain unchanged.

There are other complications involved in the residual lipids aside from their degradation through hydrolysis and oxidation. These include postburial and post-excavation contamination, but are manageable since they can be identified by biomarkers (Evershed 1993). Postburial contamination is caused by soil and bacterial lipids. Soil lipids are easy to detect and not a serious problem, since they are negligible. This can be done by comparison of the composition of the lipid extracts of the sherds and their adhering burial soil (Heron et al. 1991). Detection of bacterial lipids is more difficult, since many lipids produced by microorganisms are also produced by plants and animals. Bacteria have characteristic fatty acids (e.g., iso- and anteiso-C₁₅ and C₁₇), but these are also present in the tissues of ruminant animals. Post-excavation contamination includes the growth of bacteria and fungi on samples stored under inappropriate conditions (warm or humid), phthalate plasticizers from plastics used in storing the samples, and from the handler’s skin. Phthalate plasticizers are easily recognized from their characteristic retention time and mass spectra. Handling of artifacts may introduce skin lipids, which are squalene (one of the major lipid components of human fingerprints) and cholesterol. Squalene is readily recognized from its mass spectrum analyses, but a large number of double bonds make it very susceptible to oxidation, so that it is unlikely to survive in antiquity, and their presence in lipid extracts is a strong indication of post-excavation contamination (Evershed 1993). To reduce the risk of these kinds of contamination during analysis, it is ideal to analyze freshly excavated and unwashed sherds or artifacts (Skibo and Deal 1995).
Contamination could also be caused by organic matter in the clay that was used to make the pot, organic temper additions, or kiln fuel. However, it is very unlikely that these will be preserved unless low temperatures were attained during firing (Heron and Evershed 1993).

**Detection of Mixing of Food Items**

If a vessel was used to cook or store a single item, then identification of that residue from the vessel’s content has the highest possibility of success. However, in reality, the majority of prehistoric vessels were used to cook or store several different food items used to create a dish (Baeten et al. 2013; Skibo and Deal 1995). To resolve this complication, single-use and multiuse vessels can be identified through pure (individual compounds from specific foods) and impure biomarkers (mixture of compounds, using percentage compositions) (Skibo and Deal 1995). Also, identified biomarkers and isotopic signatures (to be discussed later) from organic residues can detect mixing of different food products (e.g., Copley et al. 2001a, 2001b; Evershed et al. 1995). Baeten et al. (2013) recently demonstrated the mixing of ruminant meat, fish, and leafy vegetables in preparation of stews or repeated usage of cooking pots through the detection of degradation products of C18:1 fatty isomers (difference in C=C positions) from ruminant fats, C17:1 and C19:1 fatty acids that can be useful to detect raw or fermented aquatic products, and different carbonyl (C=O) positions of mid-chain ketones that can differentiate animal and plant sources.

**Bulk Carbon and Nitrogen Stable Isotopes in Charred Surface Residues**

In addition to identifying specific molecular structures, possible former food contents may also be elucidated using stable carbon ($\delta^{13}$C) and nitrogen ($\delta^{15}$N) isotope ratios derived from residues in recovered pottery (Beehr and Ambrose 2007a, 2007b;
DeNiro 1987; Evershed 2009). Variation in δ¹³C values is principally caused by differences in the photosynthetic pathway of the primary producers (plants). C₃ plants use the Calvin-Benson cycle and include temperate shrubs, trees, leafy herbaceous plants, tubers, legumes, and cold- and shade-tolerant grasses. C₄ plants, by contrast, use the Hatch-Slack cycle and include arid-adapted and tropical grasses. C₄ plant foods are enriched in ¹³C and exhibit less negative δ¹³C values than C₃ plants. For C₃ plants, the δ¹³C values range from -34 to -23‰, whereas C₄ plants exhibit δ¹³C values from -16 to -8‰ (Beehr and Ambrose 2007a,b; Evershed 2009). δ¹⁵N values reflect differences in trophic level because nitrogen is ubiquitous in protein (Beehr and Ambrose 2007a, 2007b; Evershed 2009). Primary and secondary consumers, such as animals, tend to have higher δ¹⁵N values than primary producers, i.e., plants (Evershed 2009). Aquatic resources tend to have higher δ¹⁵N values than terrestrial resources (Heron and Craig 2015). Marine and freshwater resources can be distinguished by δ¹³C, in that marine resources have higher δ¹³C than freshwater resources because marine source carbon is bicarbonate (Craig et al. 2007; Heron and Craig 2015). Bulk isotopic analysis of δ¹³C and δ¹⁵N is conducted using GC-Isotope Ratio Mass Spectrometry (GC-IRMS) (Asche et al. 2003; Evershed 2009; DeNiro 1987).

**Compound Specific Isotopic Analysis of Lipid Compounds**

Compound specific isotopic analysis (CSIA) uses the carbon in organic compounds to further clarify the potential sources of residues from pottery and these data complement those from recovered molecular structures (Evershed 2009). Since palmitic (C16) and stearic (C18) fatty acids are the dominant and most stable fatty acids, they are typically used with CSIA to identify specific sources of residues.
Three food categories (plants, terrestrial animals, and aquatic resources) may be differentiated by biomolecular compounds and further differentiated into six food categories (C\textsubscript{3} vs. C\textsubscript{4} plant oils, ruminant vs. nonruminant terrestrial animals, freshwater vs. marine resources) that have different C16 and C18 δ\textsuperscript{13}C values (Craig et al. 2007; Evershed et al. 1999; Regert 2011). Plant oils with C\textsubscript{3} signatures have values between those of ruminant and nonruminant animal fats (Steele et al. 2010). Ruminant adipose fats can also be distinguished from dairy products through CSIA (Regert 2011). CSIA of fatty acids is a method for which accurate and precise knowledge of isotopic composition at natural abundance level is important. The analysis at natural levels provides information on the biogenetic and geographic origin of lipids that is invaluable for research into archaeology and environment. This technique uses gas chromatography–combustion–isotope ratio mass spectrometry (GC-C-IRMS) technique (Meier-Augenstein 2002; Evershed 2009; Evershed et al. 1994). This allows the stable carbon isotope compositions of biomarkers to be determined with high precision (Evershed et al. 1999; 2001; Evershed 2009; Regert 2011).

By combining molecular profiling and stable isotope analyses, the application of organic residue analysis (Evershed 2008b) provides a “chemical fingerprint” which can secure the association between pottery use, food resources, and food preparation or service. The next and last section discusses how this field has fared in tropical areas.

**Organic Residue Analysis of Lipids in the Tropics**

Although organic residue analysis has developed in recent years, the method seems to be underutilized in Asia, Africa, and South America (Evershed 2008b). Most of the published and available work in this field, with good preservation and identification of organic residues is concentrated in areas outside of the tropics or far from the
equator, especially in Europe and Northern Americas (see Kaluzna-Czaplinska et al. 2016). This section is a survey of works on the analyses of organic residues from tropical areas, located between the Tropic of Cancer in the Northern Hemisphere \(23^\circ 27''\text{N}\) and the Tropic of Capricorn in the Southern Hemisphere \(23^\circ 27''\text{S}\). It will only focus on the analysis of lipid residues in archaeological ceramics.

**Americas**

Tropical America is composed of Mesoamerica, the Caribbean, and the northern part of South America. Three case studies were noted in the Mesoamerican area (Coyston 2002; Seinfeld 2010; Correa-Ascencio et al. 2014). Coyston (2002) analyzed Preclassic (1200 BC-AD 250) and Classic (AD 250-900) Maya vessels from Guatemala with GC-MS. Although only fatty acids were detected, there is a variation of medium to long-chain, odd and even, as well as saturated and unsaturated types that are useful for determining several fatty acid ratios. Bulk carbon and nitrogen stable isotopic analyses were also done on charred surface residues. Seinfeld (2010) performed both bulk and compound-specific isotopic analyses on the Maya pottery samples from Belize. It was not indicated, however, if other lipid compounds were preserved in pottery because no molecular profiling with GC-MS was reported. In addition to hopanoids, which indicate pulque production at precolonial (150 BC-AD 650) Teotihuacan in semi-arid highland Central Mexico, Correa-Ascencio et al. (2014) were also able to detect plant waxes, alkanes, alkanols or alcohols including the maize biomarker (C32 alkanol), long-chain fatty acids, diterpenoids from coniferous resins, plant sterols (campestanol and sitostanol), hydroxyacids, and AAPAs. The chain lengths of the AAPAs were not specified, so it is not clear if they are indicators of aquatic resources or just plant oils.
Only one complete study is found for the Caribbean area, where Vanderveen (2006) utilized nondestructive extraction method and GC-MS to assess precolonial pottery from the Dominican Republic. Medium- to long-chain saturated (straight and branched) and monounsaturated fatty acids, C18:2 as the only polyunsaturated fatty acid, even-numbered alcohols from C14 to C32, odd-numbered alcohols from C13 to C29, and dehydroabietic acid were recovered and identified. Odd-numbered alcohols are not indicative of any food source, and the dehydroabietic acid could be a contaminant from packaging of samples or from resin slip on pottery (Vanderveen 2006).

The only case study in South America within the tropics is the work of Hansel et al. (2004, 2006, 2011) on pottery from coastal precontact (ca. 10th century AD) sites in Santa Catarina Island, Brazil. The lipids preserved remarkably on the pottery from this area, since C16, C18, and C20 AAPAs, DHYAs, other fatty acids, as well as long-chain alcohols and alkanes were identified. This is one of the case studies for which the potential of AAPAs and DHYAs as biomarkers for aquatic or marine resources was first realized. Based on the coordinates of the island (21°66′S, 48°55′E), the sites are situated in the area just north of the Tropic of Capricorn (23°27′S) (Hansel et al. 2004). Thus, the local climate may not be typical of that in tropical areas and is favorable for the preservation of various lipid biomarkers.

Africa

Only two published works were found on tropical areas of the African continent (Fraser et al. 2012; Crowther et al. 2014). Fraser et al. (2012) utilized GC-MS and CSIA to assess archaeological (AD 1463-1553) and modern medicine pots from the Tong Hills of the Upper East Region of Northern Ghana. Fatty acids, alkanes, and alcohols
were detected in archaeological pots, indicating plant sources. CSIA of C16 and C18 fatty acids indicated C\textsubscript{3} plant sources, in contrast to the C\textsubscript{4} plant sources in modern medicine pots (Fraser et al. 2012). Crowther et al. (2014) used GC-MS to analyze the amorphous residues from a 7\textsuperscript{th}-early 8\textsuperscript{th} century CE brass artifact, probably an incense burner, from a trading port in Tanzania. The residue was identified as Zanzibar copal based on the detected labdane diterpenoids. This study added to the evidence of trade within the Indian Ocean (Crowther et al. 2014). On the other side of the Indian Ocean, it is noted that no published work was found for the South Asian region.

**Oceania**

Northern Australia and the Pacific Islands were considered in the search for case studies in Oceania. Hill et al. (1985) were able to identify fatty acids from organic residues on 3000-year-old pottery samples from Natunuku, Fiji with gas liquid and high pressure liquid chromatographic techniques. High amounts of lauric and oleic acids could be indicative of utilization of plants from the Lauraceae group (e.g., cinnamon), while high amounts of myristic could be indicative of utilization of plants from the Myristicaceae family. Efforts were made to establish modern comparative reference materials in the area by analyzing local plant food sources with less sophisticated techniques (Hill and Evans 1987, 1989, 1990, Hill 1988a).

**Southeast Asia**

Hill (1988b) also analyzed archaeological pottery samples from the neighboring region of Southeast Asia. He subjected eight sherds and their associated residues, excavated from the site of MAD 1 in Malaysia, to wide-ranging chemical analyses. The site provides the central chronological key for the Madai-Baturong pottery assemblages as a whole since its stratigraphic layers correspond to the Atas and Idahan periods. The
sherds from the bases of cooking pots contained burnt food residues on their interior surfaces. The residues have traces of wood tar or resin, high levels of lauric acid, significant amounts of myristic and palmitic acids, oleic acid, as well as waxes based on the analysis with gas liquid chromatography. The palmitic acid seemed to indicate coconut as a probable source, while myristic acid would suggest a plant of the Myristicaceae family, such as nutmeg. The lauric, palmitic, and oleic acids suggest a member of the Lauraceae family, such as cinnamon, while palmitic and oleic acids indicate some form of palm oil.

In Central Vietnam, the interior residue remains from four ovoid jars excavated from Go Nam, Quang Nam Province, Central Vietnam (2nd-3rd century AD) were analyzed using Fourier transform infrared (FTIR) spectroscopy. The jars were identified as storage vessels for unsaturated oils, which could be a palm oil (Glover et al. 2004).

In the Philippines, only one study was published on analysis of absorbed organic residues. Skibo (1992) successfully extracted fatty acids from ethnographic and archaeological pots of the Kalinga, Northern Luzon. The archaeological pots were actually ethnographic pottery, already thrown in middens; however, identification of the source of fatty acids could not be done because of significant decomposition, based on the dominance of palmitic acid, indicative of adipocere (Skibo 1992, 2013). For precolonial pots, Bolunia (2005), in collaboration with a chemical laboratory, started an analysis on food residues/lipids found in earthenware pots from a 15th century burial site in Calatagan, Batangas. Findings from these pots indicate that they were likely used for cooking plant sources more than meat (Bolunia, pers. comm. 2010). On the other hand, Rider-Troeger (pers. comm. 2006, 2010) analyzed lipids and proteins from pottery
excavated at the Dimolit site, Northern Luzon. Although the protein analysis was more conclusive than that of lipids, results were not published because dating of the pots was inconclusive.

Archaeologically, Taiwan is considered to be part of Southeast Asia. Yang and March (2012) analyzed pottery and soil samples from refuse pits in the Yiou-Hsian-Fan site of southern Taiwan, dating to the Niao-Sung (NS, ca. 1800-1400 BP) and Niou-Chou-Tz (NCT, ca. 3800-3400 BP) cultures via GC/GC-MS. Medium- to long-chain, saturated and unsaturated fatty acids were from residues on pottery from both cultures, indicative of plant sources (Yang and March 2012).

In Thailand, Hauman (2012) combined isotopic and fatty acid analyses of absorbed residues from pottery excavated from the prehistoric Khok Phanom Di, Nong Nor, Ban Non Wat, and Ban Salao sites in Thailand using GC-MS and GC-IRMS. Medium- to long-chain, saturated and unsaturated fatty acids, as well as alkanes were detected. The pots probably contained $C_3$ plant, fish, or mammals feeding on $C_3$ plants. Some samples came from mortuary contexts, where findings can provide insights on customs related to honoring the dead. Her work showed that lipid residues can be preserved in the subtropics, which are not conducive for the survival of organic material because of monsoons and long dry seasons (Evershed 2008b). Kanthilata et al. (2014) recently identified 20 saturated and unsaturated fatty acids from residues on floor sediment samples from the prehistoric Ban Non Wat and Nong Hua Raet sites in Thailand through GC-FID and GC-MS. These fatty acids indicate that they were related to the activities associated with floor formation and possibly from ruminant animal sources (Kanthilata et al. 2014).
The rest of the works for Southeast Asia are studies on resin residues. Gianno (1990b) analyzed the resins from 15th century AD shipwrecks in Thailand and Saipan with FTIR and GC-MS. Triterpenoid resins from Dipterocarpeae and benzoin resins from the *Styrax* sp. tree were identified. The latter are used as medicine and incense (Gianno 1990b). In Vietnam, Edwards et al. (1997) analyzed archaeological and contemporary resins with FT-Raman spectroscopy. Moreover, in Mainland Southeast Asia, Lampert et al. (2002) analyzed resin residues from the Bola Merajae site in Indonesia, Han Xa site in Vietnam, and Noen U-Loke site in Thailand. The resins were from the pine and dipterocarp trees, based on the terpenoids detected with GC-MS (Lampert et al. 2002, 2003). Burger and colleagues (2009, 2010, 2011) recently analyzed archaeological resins from shipwreck sites around Southeast Asia, along with modern dammar resins, with GC-MS. Some of these resins are associated with ceramics and confirmed to be dammar resins due to the characteristic terpenoids.

**Conclusions**

Overall, there is a paucity of accessible works on organic residue analysis of lipids from archaeological materials, especially ceramics, recovered from tropical areas. None can be found from the South Asian region. Most are found in Southeast Asia, and this is in part due to limited access to unpublished materials (course and conference papers). Studies on resin terpenoids have been done. Sterol and hopanoid biomarkers are only reported in case studies from the tropical Americas. Terpenoid biomarkers were reportedly detected in the majority of the tropical areas surveyed, as they are present in the Americas, Africa, and Southeast Asia, but absent in Oceania. Fatty acids, sometimes with long-chain alcohols and alkanes, were reported to have been recovered from all the tropical areas with accessible works. It appears that the terpenoids and the
fatty acids are the most preserved lipids in tropical areas. The AAPAs are only reported from areas that seem to not have a typical tropical climate, which are the semi-arid highlands of central Mexico and a Brazilian island located at the boundary of the tropical and subtropical region. The DHYAs are only reported from the latter area. In addition, the temporal contexts of the samples are precolonial, which is younger than those from mid-Holocene and deep prehistoric contexts. It seems that the AAPAs and DHYAs are only preserved in areas with an atypical tropical environment and from younger temporal contexts.

This dearth of known works in the tropics is perplexing and raises a few questions. Are the tropical environments more challenging for the preservation of lipid biomarkers, where many of them are useful as food culture signals that can track ancient foodway or culinary practices? The archaeological pottery samples from riverine and coastal environments of Southeast Asia examined in Chapters 8 and 9 contribute insights into this matter. Are the archaeological materials that come from the tropics not explored for organic residues simply because of lack of interest or inability to incorporate the method into archaeological projects? Or is the potential of the method to contribute to and expand upon inquiries about the past simply not realized in most areas of the tropics? This dissertation continues with the analyses of modern reference materials in Chapters 5 and 6, followed by the archaeological pottery samples in Chapters 7-9.
Figure 4-1. Model provided by Isaksson (2010) to interpret food culture signals from archaeological contexts.

Figure 4-2. A triacylglycerol (accessed from www.bio.miami.edu/~cmallery/255/255chem).
CHAPTER 5
RESULTS OF LIPID PROFILING WITH GAS CHROMATOGRAPHY-MASS SPECTROMETRY ANALYSIS ON EXPERIMENTAL AND ETHNOGRAPHIC POTTERY WITH KNOWN COOKING HISTORIES FROM SOUTHEAST ASIA

Tracking Plants and Animals in Southeast Asia

There is a need for a more comprehensive account of the early history of plants and animals in Southeast Asia (SEA). Towards this end, work should build upon studies focused on food origins, dispersal, and acquisition to its role in foodways, as well as on other quotidian and ritualistic activities during the past. Detailed studies focused on archaeological science can contribute by tracking micro (e.g., phytoliths, pollen, starches, small bones, and scales) and molecular (e.g., lipids, proteins, and alkaloids) aspects of food remains preserved in material culture (e.g., lithic blades, pottery vessels, ceramic stoves, and grindstones). As a case in point, this dissertation focused on tracking the plant and animal food sources in archaeological pottery from SEA, where organic residue analysis on sampled pottery vessels was done to identify their former food contents and elucidate past culinary practices in the region. In order to interpret the organic chemical data from archaeological pottery, a comparative reference collection from modern materials was constructed.

Part of the reference collection constructed for this dissertation includes contemporary earthenware pottery vessels with known histories of cooking (experimental and ethnographic) food items with cultural significance in SEA, past and present. Domesticated rice (Oryza sativa), foxtail millet (Setaria italica), pig (Sus scrofa), and chicken (Gallus gallus) are elements of the “Neolithic material culture package” brought by migrating farmers (Bellwood 2013). The remains of rice grains were identified in the An Sơn (Bellwood et al. 2011) and Rạch Núi (Oxenham et al. 2015)
sites. The remains of foxtail millet were identified in Rạch Núi (Oxenham et al. 2015). The remains of domestic pig were identified in An Sơn (Piper et al. 2012). The remains of chicken were identified in key prehistoric sites of Thailand (Higham 2014). Freshwater and marine fishes were important in the past and are important in present foodways in areas near bodies of water. For example, the remains of catfish (Siluriformes) are ubiquitous in Rạch Núi near a tributary of the Mekong River (Oxenham et al. 2015), and the remains of dolphinfish (Coryphaena hippurus L.) were identified in Neolithic coastal sites of the Batanes Islands, Philippines (Campos 2013). Coconut (Cocos nucifera), particularly its “milk” (Lim 2012), and swamp cabbage (Ipomoea aquatic) (Austin 2007) are common plant sources in present-day cuisines of SEA.

Chapter 5 reports the preparation and/or collection as well as lipid profiling with gas chromatography-mass spectrometry analysis of used, modern pottery vessels as comparative reference materials. Experimental pottery was that used for cooking several important food sources in SEA, either a single food item or a combination of several ingredients. Ethnographic pottery is that used for cooking and serving traditional dishes in Vietnam and the Philippines. Chapter 5 discusses the results of the organic residue analysis of these used modern pottery vessels, their archaeological implications, and recommendations for further work.

Experimental Pottery: Cooking Important Food Items of Southeast Asia

Single Food Items

Cooking experiments were conducted by boiling various food items mentioned above in modern earthenware cooking pots at various locations in the Philippines and Vietnam from 2008 to 2015. One type of food item was cooked for each cooking pot.
For animal meat, cereals, and vegetables, boiling with water was done as a method of cooking to extract the fat from the meat so that it could potentially be absorbed into the porous matrix of the pots. Before the pots were used for cooking, they were sterilized with boiled water for approximately 1 h to remove adhering debris. For the fishes used in experimental cooking, Fishbase (www.fishbase.org) and Mongabay (fish.mongabay.com) were used to aid in matching local names with scientific and more common vernacular names.

Quezon City, Philippines

Experimental pottery prepared during Fall 2008 and 2009 was part of the author’s previous work (Eusebio 2010). In Fall 2008, pure and fresh coconut milk (250 g) was boiled in a low-fired mid-reddish brown earthenware pot (assigned as E16 for this work, Fig. 5-1). In Fall 2009, wagwag rice (E2, Fig. 5-2), pork from pig (E3, Fig. 5-3), and freshwater fishes from the Philippines (E4, Fig. 5-4) were cooked in separate black earthenware cooking pots. Wagwag is a traditional rice variety eaten in Pampanga, Central Luzon, Philippines. One pot was assigned as a blank or control (E1).

Each food item was cooked five times in its assigned pot. A number of cups of rice were cooked in succession in the following order, totaling 3 kg: 3, 3, 2, 2, and 2 cups. Five different pork meat portions (Fig. 5-5, at 500-590 g each, were cooked in succession from 1 h and 10 min to 2 h, until the meat was very tender. Freshwater fishes (Fig. 5-6) were cooked in succession from 21 to 31 min, until the meat was tender, in the following order: Tilapia (Oreochromis sp., four pieces weighed 0.650 g), middle portion of Imelda or maya-maya (Hypophthalmichthys nobilis, whole fish weighed 2.6 kg), middle and tail portions of Imelda, head portion of Imelda, and white
pompano (*Trachinotus blochii*, one piece weighed 500 g). The fish locally known as *white pompano* is a marine fish, however the one used for cooking lived in a freshwater pond. This has implications for the results of the lipid profiling of pot assigned as E4, where the fishes cooked were actually freshwater and marine. In Fall 2012, two black earthenware cooking pots (Fig. 5-7) were bought in Mega-Q Mart, Cubao, Quezon City. These pots and those assigned as E1-E4 were manufactured by hand in Tarlac, Central Luzon, Philippines using the paddle and anvil technique. A total of 2.542 kg chicken was bought from Landmark grocery in Trinoma Mall, Quezon City. Five different portions, which are named after the cut part and intended recipe, were considered as follows: *recado* (440 g), *tinola* (552 g), *adobo* (572 g), wings (478 g), and drumsticks (500 g). Each portion was cooked in the pot (assigned as E5, Fig. 5-8) for 1 h. One kilogram of *tinawon* rice was bought from the market in Banaue, Ifugao (Fig. 5-9). This variety of rice is one of the heirloom varieties in the Cordillera region of Northern Luzon, Philippines. In contrast to the *wagwag* rice cooked in pot E2, *tinawon* rice grains were not fully milled and still had husks. It was cooked in the pot (E6, Fig. 5-10) thrice (3x) with two cups for each cooking.

In Summer 2014, three earthenware cooking pots were purchased in the same place where pots E1-E6 were bought. A total of 2.5 kg of five various marine fishes (Fig. 5-11) were bought from Farmers Market, Cubao, Quezon City at 500 g for each species. These fishes were *tawilis* (bombon sardine, *Sardinella tawilis*), *alumahan* (long jawed mackerel, *Rastrelliger kanagurta*), *tambakol* (yellow-fin tuna, *Thunnus albacares*), *galunggong* (round scad, *Decapterus punctatus*), tulingan (skipjack tuna, *Katsuwonus pelamis*). *Tawilis*, which is endemic to Taal Lake in Luzon, Philippines and classified as
a freshwater fish, is a marine fish based on its evolutionary history, as Taal Lake was a part of Balayan Bay until the eruptions of the Taal volcano in 1754 (Willette et al. 2014). After cleaning and recording, each fish was cooked for 30 mins in its assigned pot (E14, Fig. 5-12). After the last fish was taken from the pot, the remaining water was further boiled until almost all water had evaporated. A bundle of *kangkong* or swamp cabbage (Fig. 5-13) weighing 1.288 kg was purchased from Puregold grocery store. It was divided into five portions. The first four portions were separately cooked in their own pot (E15, Fig. 5-14) for 30 min. The fifth portion, composed mainly of stems, was cooked for 50 min. After removing all the cooked stems, the remaining water was further boiled until it had almost all evaporated.

All cooking was done on a gas stove. All pottery used for experimental cooking, including the collected ethnographic pots (E19-E22, discussed in next section) from the Philippines, were sundried, curated, documented, and broken. Fragments from each pot were divided for export to Gainesville, Florida and for archival storage in Quezon City, Philippines. Several fragments from select pots (E2-E6 and E19-E22) were buried, with permission (Fall 2012), on the grounds of the Archaeological Studies Program, University of the Philippines.

**Long An, Vietnam**

All experimental cooking in Long An, Vietnam was done in conjunction with the development of an ichthyology reference collection (Appendix A) compiled by Fredeliza Campos to facilitate the identification of fish bones recovered from archaeological sites in southern Vietnam. In Fall 2012, three big, brown unrestricted earthenware pots with covers (Fig. 5-15) and a clay stove (*cà rang*, Fig. 5-16) were bought from Kiet An store (Fig. 5-17) in Tan An City public market and May Tre La shop (Fig. 5-18), respectively,
near Long An Provincial Museum. The first pot, assigned as E7 (Fig. 5-19), was used to cook five varieties of brackish water fishes by boiling in freshwater (2012 VN16-VN20, Fig. 5-20, Appendix A). Cooking activities were done at the back of Long An Provincial Museum. In Spring 2014, the cooking of 36 different inland freshwater fishes in two small brown unrestricted earthenware pots (E9 and E12, Fig. 5-21, Appendix A) was conducted during ongoing excavations at Lộc Giang and Lò Gạch, prior to the author’s arrival to participate in fieldwork at Lò Gạch (Fig. 5-22). It is assumed that at least ten species of fishes were cooked in each pot (Fig. 5-23). Another big unrestricted cooking pot (E13, Fig. 5-14), was used to separately cook three pieces of a marine fish (family Carangidae). All cooking pots used during Spring 2014 were bought from the market in Vinh Tri Commune, Vinh Hung District, Long An province. All cooking was done on the clay stove. By boiling these fishes in the earthenware cooking pots, the oils were extracted and incorporated into the matrix of their respective pots, and the meat was easily separated from the bone. Cooked fish bone was further cleaned and curated for the ichthyology reference collection.

**Gainesville, Florida**

Foxtail millet grains (Fig. 5-25), which were imported from China and weighed 908 g (2 lbs), were bought from the Eastern Market, an Asian grocery store, in Gainesville, Florida. The original plan was to buy and cook foxtail millet on the pot in Long An, Vietnam; however, it was not available nor had millets been used in the area despite their remains having been recovered and identified at Rạch Núi (Castillo 2014; Oxenham et al. 2015). This millet was cooked in its own pot (E8, Fig. 5-26) five times, with one cup for each round. The foxtail millet grains were first roasted, and then cooked in water until the water was absorbed and the grains became soft and fluffy. All
cooking was done on a gas stove. The cooking pot used was the same as those assigned as E1-E6 and E14-E15, which was bought from the same store then brought to Gainesville, Florida from Quezon City, Philippines.

**Mixed Cooking**

Cooking, in combination with different processes and different ingredients, was conducted to explore the effects of mixing on the lipid profile. Two pots bought with pot E7 during Fall 2012 were used for this purpose. The second pot (E17, Fig. 5-27) was used for cooking freshwater fishes (2012 VN23-VN31, Appendix A) by frying with Meizan vegetable oil and boiling in water. Meizan vegetable oil is composed of refined olein oil and soybean oil, as well as RBD (refined, bleached, and deodorized; Ghazani et al. 2014) canola oil (www.calofic.com.vn). Thus, the organic residues on this pot were derived from a mixture of fish and vegetable oils. The third pot E18 (Fig. 5-28) was used to cook two fish-based dishes. The first dish was a modified version of Cá Kho Tộ (Fig. 5-28a), in which the freshwater fishes (2012 VN16 and VN17, Appendix A) were cooked by stewing with white sugar, garlic, onions, chili peppers, ginger, black pepper, and soy sauce. This southern Vietnamese dish calls for fish sauce, rather than soy sauce. This dish is further discussed in the next section. The second dish is a modified version of fish sarciado (Fig. 5-28b), in which the freshwater fishes (2012 VN18-VN20 Appendix A) were cooked by stewing with garlic, onions, tomato, salt, pepper, eggs, soy sauce, and tofu (bean curd from soy milk). This Filipino dish does not have soy sauce and tofu as its ingredients. Thus, the organic residues on the third pot were derived from a mixture of fish, chicken eggs, vegetable oils, spices, sugar, and soy products. All cooking was done in a clay stove. The effects of mixing on the lipid profile are also explored with ethnographic cooking pots collected from Vietnam and the Philippines.
The pottery used for experimental cooking (E7, E17, and E18), including the collected ethnographic pots (E10 and E11, discussed below), during Fall 2012 in Vietnam were sundried, curated, documented, and broken. The fragments were divided for export to Gainesville, Florida and burial in the grounds of Long An Provincial Museum (except for E11) after obtaining permission. The pots used during Spring 2014 (E9, E12, and E13) were exported as whole vessels to Gainesville, but were broken during transit.

**Ethnographic Pottery: Background and Collection**

Since there are communities, including restaurants, that still use earthenware pottery for preparing and serving food in SEA, six ethnographic cooking pots from Vietnam and the Philippines were collected in Fall 2012, and included as part of modern reference collection materials. As previously mentioned in Chapter 3, used modern pottery can bridge a practical gap that provides insight into the impacts of continual artifact usage that would not be possible to simulate in experiments (Evershed 2008a).

**Long An Province, Southern Vietnam**

Clay pots were collected and used to serve *Cá Kho Tô* (braised caramelized fish stew), since some restaurants in southern Vietnam use earthenware to prepare and serve traditional dishes. Two small unrestricted cooking vessels used for preparing and serving *Cá Kho Tô* were collected from Phong An restaurant (E10, Figs. 5-29 and 5-30) and Thuy Ta restaurant (E11, Figs. 5-31 and 5-32), both in Tan An City, Long An province. The owner of Thuy Ta restaurant was also interviewed about the use of clay pots in preparation and serving of food that consequently led to the collection of pot E11 (Fig. 5-33). The interview, with the help of Do Thi Lan, Nguyen Thi Sau, and Fredeliza Campos, is part of the ethnoarchaeological survey on the food-related activities of
people using earthenware ceramics, and was approved by the Institutional Review Board (Protocol #2012-U-1089). Although the questionnaire used as a guide was in English (Appendix B), the interview was conducted in Vietnamese and the responses were translated into English by Do Thi Lan (Appendix C).

The Thuy Ta restaurant is owned by Luu Quoc Cuong and was opened in 1995. It is run by five household members and 35 employees. The four cooks are males, and one of them is the chief cook. There are also 11 helpers in the kitchen. For cooking, the restaurant uses around 30 pots per day and different types of pots may be used for special occasions. They use the pots several times until they are broken, but they do not recycle broken and discarded pots. They usually cook fish, pig ribs, and goat (the latter in a different restaurant). For the fish, they usually cook Cá loc (Channa sp. prob. gachua, snake-head fish), Cá lang (Hemibagrus wyckii), Cá rô (Anabas testudineus, climbing perch), and Cá kèo (Pseudapocryptes lanceolatus Bloch, pointed-tail goby) bought from the fresh market in Tan An City. These fish were acquired by hand catching, netting, spearing, and basket-catching. The pots and clay stoves (cà rang) were also purchased from the Tan An City market. It is better to cook using a clay stove as opposed to an electric or gas stove, since the dish is sweeter and retains its natural odor. The most frequently ordered dishes in the restaurant are the Cá Kho Tộ or braised caramelized fish stew in a pot, and another dish that is a sort of sour soup.

The main ingredients in Cá Kho Tộ at Thuy Ta, aside from the fish, include fish sauce, pepper, sugar, garlic, chili, onion, and monosodium glutamate (MSG). First, cooking oil, small spring onion, and garlic are placed inside the pot, and water is added. When the water boils, the fish and the spice mixture (fish sauce, sugar, and MSG) are
added. The mixture becomes very thick after 15-20 min. To make the taste pleasant, black and chili peppers are added on the surface. Coconut oil is usually used as cooking oil and serves as a lining on the pot for aromatic purposes. Caramelized sugar makes the pot durable. It was observed that the Cá Kho Tộ in pot E11 had pork fat (Fig. 5-31b), which was not observed in the same dish on pot E10. The organic residues on both pots from two restaurants represent mixtures of fish, vegetable oils, spices, and sugar, as well as the pork fat in pot E11.

Quezon City, Philippines

Barrio Fiesta restaurant, owned by the Ongpauco family, specializes in traditional Filipino cuisine and is one of the major restaurant chains in the Philippines that use earthenware pottery to prepare and serve their food. The first Barrio Fiesta restaurant was opened in 1958 in Caloocan City, Metro Manila (Aspiras 2012). It presently has several branches across Metro Manila. Two used low-fired brown restricted pots that were collected in one of the branches inside the SM City North Edsa mall in Quezon City (Fig. 5-34). It was observed that the pots were used for heating and serving food only. It also seemed that the pots were being reused, in that a justification was required to collect the used pots.

The first pot (E21, Fig. 5-35) was used for heating and serving a dish called Kuhol sa Gata (snails in coconut milk). This dish is not usually served in the pot. It was heated and served inside the small pot on top of a small earthenware stove, upon request. It is a traditional dish in northern Luzon, Philippines, particularly with the Ga’dang people of Bayombong, Nueva Viscaya (Berdos et al. 2015). The main ingredients include snails, coconut milk, leafy vegetable (e.g., swamp cabbage), and spices (e.g., chili pepper, onion, ginger, and black pepper) (Jasa 2015). Except for the
New World spices, the other ingredients all are possible sources of organic residues in prehistoric pots from SEA.

The second pot (E22, Fig. 5-36) was used for heating and serving a dish called Kare-Kare (meat stew in peanut sauce). It is one of the main specialties of Barrio Fiesta and is usually served in the pot. It is a traditional meat stew with a thick peanut sauce. The usual ingredients include ox tail, tripe, a protein (usually pork leg, but could be replaced with beef, chicken, or fish), sliced banana flower bud, pechay or bochoy (Brassica rapa), string beans, eggplant, ground peanuts (and/or peanut butter), achiote or annatto seeds, toasted ground rice, garlic, onion, salt, and pepper. Shrimp paste is used as a side condiment (Merano 2009). Thus, the organic residues in this pot include a mixture of protein (usually terrestrial, but perhaps fish), vegetables, rice, peanuts, and spices. This combination is not expected from the organic residues derived from prehistoric pots from precolonial Philippines and pre-Western contact in SEA, because peanuts and annatto/achiote were introduced after contact via Colombian exchange, specifically Spanish colonization of the Philippines (Hammons 1973; Nunn and Qian 2010).

**Kalinga Province, Northern Philippines**

Two used black restricted earthenware pots from separate households in Talalang, Kalinga Province, northern Luzon were also acquired. The locality differs from the ethnoarchaeological work of Skibo (1992), which was in Guina-ang, Kalinga. One of the pots collected was unwashed after use (E19, Fig. 5-37) and the other was washed (E20, Fig. 5-38). The pots were probably used for cooking fish soup by boiling, possibly with vegetables, based on their odor, and it is useful to compare results of their analysis with those of Skibo (1992).
Sample Preparation and Analysis: Preliminary Work

The procedure followed for this preliminary work was modified from the Standard Operating Procedures for lipid residue analysis (modified from Craig et al. 2004, 2007; Evershed et al. 1990; prepared by Val Steele and outlined in Saul 2011) and from Spiteri (2012). The extraction, methyl derivatization, and analyses of samples E1-E7, E10, and E11 were performed with the facilities of the Biomedical Mass Spectrometry Core, Clinical and Translational Science Institute (BMS, CTSI) in the University of Florida. Prior to extraction and other laboratory procedures, all glassware and equipment was cleaned with acetone, methanol, dichloromethane, and/or hexane before use.

Preparation of Pottery Samples for Extraction

The preparation of pottery samples for lipid extraction was done by sampling an approximately 2 cm x 2 cm fragment (5 g) for each pot collected. Pottery samples were collected using a fiberglass cutoff disk attached to a Dremel tool. The exposed surface was gently sanded off using the cutoff disk. Each sampled fragment was ground into a fine powder using a clean mortar and pestle, and sample powder was transferred into a labeled, pre-cleaned scintillation vial.

Solvent Extraction: Sonication and Centrifugation

The conventional sonication-centrifugation extraction method was done for the preliminary work (modified from Folch 1957; Fankhauser 1994; Charters et al. 1997). For each sample, ~1 g of pottery powder was weighed using a Mettler Toledo AB54-S analytical balance and loaded into a clean, labelled 11-cm test tube with Teflon cap. For every batch, one test tube was used as a method blank, to which no pottery powder was added. Another test tube was used as a pottery blank (E1), and powder from an
unused modern earthenware pot was transferred into it. Two batches of extraction were done: E1-E7 and E1, E10, & E11. For each sample, a known amount of internal standard [1 mg/ml pentadecanoic (C15) acid] was added into the test tube (20 µL for the first batch and 40 µL for the second batch). Lipids were extracted with 3 aliquots (2 mL each) of 2:1 v/v dichloromethane:methanol by ultrasonication (Fischer Scientific FS30 sonicator) and centrifugation (Eppendorf Centrifuge 5810R, 3000 rpm for 10 min). The resulting extract was transferred into another test tube. Then, 2 ml of 0.9% NaCl was added. The extract was shaken with vortex mixer (Fischer Vortex Gen 2) and was allowed to settle. The upper layer was discarded. The extract was washed with 2 ml of 1:1 v/v methanol:ultrapure water (UPW) and allowed to settle. The upper layer was discarded. The lower layer or the lipid extract was then dried under a nitrogen (N₂) stream at 30°C using a Multivap 118 nitrogen evaporator.

**Saponification**

Saponification was done to separate the neutral and acidic lipid fractions. For each sample, 3 ml 0.5 M methanolic NaOH (NaOH in 50:50 methanol:H₂O) was added to the dried extract in closed test tubes and heated at 70°C for 1 h on a pre-heated thermal block (Thermolyne Type 16500 Dri-Bath) and cooled. The neutral fraction was extracted with 3 aliquots (2 mL each) of hexane, and the upper layer was transferred into another test tube labelled with “NF.” The neutral fraction was then reduced to approximately 2 mL with N₂ at 30°C and stored at -80°C. The remaining fraction after the extraction of the neutral fraction was acidified to pH 3 with 1-2 mL 1M HCl. The acidic fraction was extracted with 3 aliquots (2 mL each) of hexane, and the upper layer was transferred into another test tube labelled with “AF.” The acidic fraction was then evaporated to dryness with N₂ at 30°C and stored at -80°C.
**Derivatization: Methylation**

The dry acidic fraction from the saponification process was derivatized into fatty acid methyl esters (FAMEs) by adding 200 µL boron trifluoride (BF₃, 14% w/v)-methanol complex and heating in closed test tubes at 70 °C for 30 min on a pre-heated thermal block. The reaction was then quenched with 100 µL UPW and cooled. The FAMEs were extracted with 3 aliquots (2 mL each) of hexane and the upper layer was transferred into another test tube. The FAMEs were reduced and transferred to 2 mL GC vials and stored at -20°C before analysis.

**Gas Chromatography-Mass Spectrometry**

Gas chromatography-mass spectrometry (GC-MS) of FAMEs was performed with an Agilent Technologies 6890N Network GC System, equipped with an Agilent Technologies 7683B Series Injector and interfaced with an Agilent Technologies 5793 Inert Mass Selective Detector. The inlet mode was splitless and the injection volume was 1 µL with an Agilent Technologies 7673 injector and syringe size of 1 µL. The system was set to scan the range of m/z=50-500, with a solvent delay of 4.25 min. The GC-MS runs were done with a Thermo TR-5MS capillary column (30m × 250 µm, 0.25 µm film thickness) and constant flow mode (1.0 mL/min). The oven temperature was step programmed at 50°C for 3 min, then from 50°C to 300°C at 8°C min⁻¹, and held at 300°C for 10 min. The total run time for each sample was 44.25 min. Each FAME sample was immediately covered with new caps after analysis and stored at -80°C for reruns and compound specific isotopic analysis (CSIA).

**Qualitative and Quantitative Analyses**

The identification of fatty acids was based on the retention times already established in BMS, CTSI, National Institute of Standards and Technology (NIST)
Reference Library spectra (NBS75K.L), and relevant published literature, with the help of Thermo Xcalibur program. The quantification of identified fatty acids, except for contaminant peaks (e.g., plasticizers), was performed by automatic integration with the Thermo Xcalibur program to determine the fatty acid yields using the following formula:

\[
\text{Fatty acid yield} = \left( \frac{\text{Area}_{\text{Sample}}}{\text{Area}_{\text{Internal Standard}}} \right) \times \left( \frac{\text{Weight}_{\text{Internal Standard}}}{\text{Weight}_{\text{Pottery Sample}}} \right)
\]  

(5-1)

**Sample Preparation and Analysis: Continued Work**

Sample preparation and analysis of pottery samples for post-preliminary work was conducted in the Organic Geochemistry and Stable Isotope Laboratories of the Department of Geological Sciences, University of Florida. The procedures followed were modified from the existing laboratory protocol at the Organic Geochemistry Laboratory and Standard Operating Procedures for lipid residue analysis (modified from Craig et al. 2004, 2007; Evershed et al. 1990; prepared by Val Steele and outlined in Saul 2011).

**Preparation of Pottery Samples for Extraction**

For absorbed organic residues, the preparation of pottery samples for lipid extraction follows that described for the preliminary work with a few exceptions. Samples E1-E7 and E10-E16 were ground into powder with a ceramic mortar and pestle, while samples E8 and E17-E22 were ground into powder with a Rocklabs Bench Top Ring Mill. Charred surface residue samples (E8, E14, and E15) were scraped off respective pottery fragments, pulverized with mortars and pestles, and transferred into clean scintillation vials.

**Solvent Extraction: Accelerated Solvent Extraction**

All subsequent work was conducted using accelerated solvent extraction (ASE, Dionex ASE 300) to extract the lipids on ground pottery sherd and charred surface...
residues (modified from Folch 1957; Fankhauser 1994; Charters et al. 1997; Nichols 2011; Fig. 5-39). The Dionex ASE 300 has a capacity for extracting organic compounds from up to 12 samples. As mentioned in Chapter 3, ASE utilizes high temperature and pressure to extract organic compounds, such as lipids, from solid and semi-solid samples (Richter et al. 1986).

For each sample, ~0.5-1 g of pottery powder or 100-200 mg of charred surface residues was weighed and loaded into a fiberglass filter paper and placed into a precleaned and labelled 34-mL metal extraction cell with quartz sand interspersed between each sample. For each batch, including the first extraction cell, which served as the method blank, a known amount of internal standard [10-30 µL 1 mg/mL heneicosanoic acid methyl ester (C21 FAME) for E1-E11 and 10 µL 1 mg/1mL tetratricontane (C34 n-alkane) for E17-E22] was added prior to ASE extraction for quantification purposes. The solvent mixture of 2:1 v/v dichloromethane (CH$_2$Cl$_2$ or DCM):methanol (CH$_3$OH or MeOH) was used to elute the total lipid extracts (TLEs) into 250 mL clear glass collection bottles. Each sample was extracted three times with 50 mL solvent mixture at 1500 psi, 100°C, and 25 minutes. Each resulting lipid extract was then reduced and transferred into a 2-mL GC vial with the aid of hexane and/or DCM in a Flexivap Work Station with N$_2$ at 30°C. The lipid extract was dried and reconstituted with 500 µL of hexane and stored in a refrigerator or freezer prior to further processing.

Prior to extraction and other laboratory procedures, all glassware, quartz sand, and fiberglass papers used were sterilized by combustion in an oven at 450°C. The paraphernalia that cannot be combusted for sterilization were solvent-cleaned with MeOH, DCM, and/or hexane before being used. The ASE cells were set up by
assembling the cells, placing one fiberglass filter paper on the inner bottom surface of the cell, partially filling with quartz sand, placing another fiberglass filter paper on top of the sand, then pouring quartz sand to almost fill the cell, but with allowance for the sample, then placing another fiberglass filter paper atop the sample, and closing the cell with the top cap. The ASE cells were further cleaned before the samples were loaded by pre-extraction with the same above-mentioned solvent system and extraction specifications, except 15 minutes was used for every cell rather than 25 minutes. Samples were loaded sandwiched between the two fiberglass filter papers.

**Saponification**

The saponification procedure used in subsequent work followed a slightly different protocol from the preliminary work. For each sample, only 2/5 of the 500 µL TLE was used for this process; accordingly, 200 µL of extract was transferred into a labelled 11-cm test tube and dried with N₂. Then, 2 mL of 1M methanolic NaOH or KOH (NaOH or KOH in 50:50 or 90:10 methanol:H₂O) was added to the dried extract. Extracts in closed test tubes were heated at 70°C for 1 h (2 h for saturated samples) on a pre-heated thermal block (Fischer Scientific Isotemp) and subsequently cooled in an ice bath for 30 min. The neutral fraction was extracted with 3 aliquots (2 mL each) of hexane, and the upper layer was transferred into another test tube labelled “NF.” The neutral fraction was reduced to less than 2 mL with N₂ at 30°C, transferred to a 2-mL vial, and stored at -80°C. The remaining fraction after the extraction of the neutral fraction was acidified to pH 2 with 0.5 mL of 3M HCl. The acidic fraction was extracted with 3 aliquots (2 mL each) of hexane, and the upper layer was transferred into another test tube labelled “AF.” The acidic fraction was evaporated to dryness with N₂ at 30°C for methyl esterification and stored at -20°C.
Derivatization: Silylation

To acquire the lipid profile of each sample, 1/5 of the 500 µL TLE was derivatized into trimethylsilyl esters/ethers (TMSEs) by silylation. Accordingly, 100 µL of extract was transferred into a low-volume or high-recovery GC vial and then dried with N₂. Then, 30 µL N,O-bis(trimethylsilyl)triflouracetamide (BSTFA) with 1% trimethylchlorosilane (TMCS) and 60 µL acetonitrile (ACN) were added into the dry extract. Closed and oxygen-free vials with sample extracts and reagents were heated on a pre-heated thermal block at 70°C for 30 minutes. The derivatized samples were then cooled, dried with N₂, reconstituted to 250 µL with hexane, and stored at -20°C before analysis.

Neutral fractions were also derivatized as TMSEs with the same procedure above to confirm the presence of other lipid compounds aside from fatty acids in the samples. A known volume of internal standard [1 mg/ml C21 FAME or hexatriacontane (C36 n-alkane)] was added before reconstitution to 250 µL in some samples for quantification purposes. TMSEs must be analyzed within two days after being prepared by silylation.

Derivatization: Methylation

The dry acidic fraction from the saponication process was esterified by methylation into fatty acid methyl esters (FAMEs) by adding 100 µL boron trifluoride (BF₃, 14% w/v)-methanol complex and heating in closed test tubes at 70°C for 30 min on a pre-heated thermal block. The reaction was then quenched with 100 µL UPW and cooled. Resultant FAMEs were extracted with 3 aliquots (2 mL each) of hexane and the upper layer was transferred into another test tube. The FAMEs were reduced and transferred to low-volume or high-recovery GC vials, then dried and reconstituted to 250 µL with hexane, and stored at -20°C before analysis. A known volume of internal
standard (1 mg/ml C21 FAME) was added before reconstitution to 250 µL in several samples (E12-E16) for quantification purposes.

**Gas Chromatography-Mass Spectrometry**

The GC-MS analyses of TMSEs and FAMEs were performed with a Shimadzu GC-MS QP2010s, equipped with a Shimadzu AOC-2-s Auto Sampler. The inlet mode was splitless, and the injection volume was 1 µL with Shimadzu AOC-20i Auto Injector and syringe size of 10 µL. The system was set to scan the range of \( m/z = 50-650 \), with a solvent delay of 2.59 min. The GC-MS runs were done with Rtx-5MS capillary column (30m × 250 µm, 0.25 µm film thickness) and constant flow mode (1.20 mL/min). For the analyses of TMSEs from TLEs and neutral fractions, the oven temperature was programmed from 125°C for 1 min, then from 125°C to 330°C at 7.5°C min\(^{-1}\), and held at 330°C for 10 min, with helium as the carrier gas. The total run time for each sample was 37.5 min. For the analysis of FAMEs from acidic fractions, the oven temperature was programmed from 125°C for 1 min, then from 125°C to 330°C at 7.5°C min\(^{-1}\), and held at 330°C for 16 min. The total run time for each sample was 44.33 min. Each sample was analyzed twice. The derivatized extracts were immediately covered with new caps after analyses and stored at -80°C for reruns and CSIA.

**Qualitative Analysis**

The identification of lipid compounds was based on the retention times of the standards, National Institute of Standards and Technology (NIST) Reference Library spectra (NIST107), and relevant published literature with the help of GCMSsolution and Thermo Xcalibur programs. Table 5-1 is the compilation of abbreviations used for lipid compounds discussed in this work. Table 5-2 shows how a lipid profile derived from pottery residues can elucidate possible food source(s) by three principal categories of
terrestrial animals, aquatic resources, and plants based on the analysis of TLE (Evershed et al. 1990, Evershed et al. 2002a). Table 5-3 is an overview of mass fragmentation patterns of different lipid groups, which are used to aid in identifying lipid compounds alongside with the mass spectral library and available literature.

**Quantitative Analysis (Integration and Quantification)**

The quantification of identified lipid compounds, except for contaminant peaks (e.g., plasticizers), was performed by combined automatic and manual integration with the Thermo Xcalibur program to determine the TLE yield, using the following formula:

\[
TLE = \frac{\text{Area}_{\text{Sample}}}{\text{Area}_{\text{Internal Standard}}} \times \frac{\text{Weight}_{\text{Internal Standard}}}{\text{Weight}_{\text{Pottery Sample}}} \quad (5-2)
\]

**Results and Discussion**

This section presents the results as lipid profiles derived from the organic residue analysis of used modern earthenware pottery as comparative reference materials. Table 5-4 is the complete list of these pottery samples with assigned sample number, description and provenience, as well as their status. Not all samples were analyzed. The experimental pots used for cooking single food items were prioritized for analysis to assess similarities and differences in lipid components among food items (rice, millet, swamp cabbage, coconut milk, pig, and chicken, as well freshwater and marine fishes) and among food categories (cereals, other plants, domesticated animals, and aquatic resources). The ethnographic pots from southern Vietnam were also prioritized for analysis because the area where they were acquired is the focus of this research with archaeological pottery.

Table 5-5 is the tally of the lipid compounds from the pottery samples that underwent analysis. These compounds were detected and identified from the GC-MS analyses of total lipid extracts (TLEs) derivatized as trimethylsilyl esters/ethers and
acidic fractions derivatized as fatty acid methyl esters (FAMEs). Neutral fractions were analyzed only to confirm the presence of non-fatty acid components found in chromatograms of TMS derivatives from TLEs. Lipid compounds are arranged according to type and carbon chain length. Table 5-5 also includes the amounts computed as TLEs or lipid concentrations based on detected and confidently identified compounds from TLEs. Nonlipid components, such as sugars, and contaminants, such as plasticizers and those from column bleed during analysis, were not included in the computations. TLEs only account for the amount of lipids absorbed on the pottery fabric or the absorbed residues. The blank and unused pottery (E1) yielded only palmitic (C16) fatty acid in amounts < 5 µg/g. The implication for both modern and archaeological pottery samples is that the ideal yield for organic residue analysis in terms of TLE is >5 µg/g, to ensure that the lipids came from the pottery contents rather than contamination (Charters et al. 1997).

Amounts of TLEs for the rest of the analyzed pots in Table 5-5 are relative because calculations were done semi-quantitatively, where internal standards were utilized to estimate the amounts of individual compounds (Reber et al. 2015). Ideally, a GC with flame ion detector (FID) should be utilized to quantify the lipid components accurately, given the method’s robustness and sensitivity; however, this approach does not identify organic compounds and standards and all components are needed to confidently identify and quantify the compounds. This could not be done in this study because not all lipid components have available commercial standards. The GC-MS can identify compounds, based on their mass fragment patterns, down to their compound names if they are available in the mass spectra library, or down to their
compound class, using their characteristic \( m/z \) fragments, if the compound names are not available in the mass spectra library. However, the GC-MS tends to underestimate the amounts of compounds during quantification because the MS detectors are less sensitive than FID. Thus, the amounts of TLE computed are based on semi-quantification (Reber et al. 2015). The samples included for preliminary work were also calculated for fatty acid yields (Appendix D).

Previous GC-FID analysis of E2-E4 pots (Eusebio 2010) showed that cooking several times leaves substantial, detectable lipid residues absorbed on the pots. This is the reason why cooking of food items in pots E5-E9 and E12-E18 was done multiple times. There is no guarantee that cooking food items only once in a pot leaves substantial organic residues, unless a viscous liquid was boiled in the pot. This is true in the case of pot E16, for example, where it already produced a good fatty acid profile from the previous analysis with GC-FID after heating or boiling coconut milk on it only once (Eusebio 2010).

The fat or oil content of particular foodstuffs affected the outcome of organic residue analysis, as shown by the TLEs of the highest-yielding E3 and E16 pots used to, respectively, cook pork multiple times and boil coconut milk once (Table 5-5). Pots E3 and E5 were expected to have TLEs of the same magnitude, since fatty acid yields of pots E5 and E3 from preliminary work were 2367 and 2213 µg/g, respectively. Pot E14 was expected to have a TLE that has the same magnitude as pot E4, because of the same frequency of cooking fish, i.e., five times, with roughly a half kilo of fish for each cooking. Although E7 also had a frequency of cooking of three times, with five varieties of freshwater fishes, some of these varieties represented less than a half kilo.
Prolonged cooking for around four hours in the afternoon accounts for the unexpectedly high TLE for pot E13 that was used for cooking only three pieces of a marine fish. Pot E12 was expected to have the highest TLE among the pots because of its highest frequency of cooking; however, one variety or species of fish was cooked for each instance. Furthermore, many species or varieties of fish cooked in pot E12 are small and weighed less than half a kilogram.

What follows is a discussion of the detected and identified lipid components in terms of food groups and food items, starting with cereals. The majority of the results discussed are based on the data acquired through Shimadzu GC-MS QP2010s in 2015. Pots E5, E8, E14, and E15 were re-analyzed with a Thermo Trace 1310 Gas Chromatograph and a Thermo TSQ 8000 Triple Quadrupole Mass Spectrometer (specifics discussed in Chapter 6) in 2016 to recalculate TLE amounts and clarify their lipid compositions.

**Cereals: Rice and Millet**

Domesticated rice (*Oryza sativa*) and foxtail millet (*Setaria italica*) are cereal staples that were domesticated in China and brought to SEA during the Neolithic (Bellwood 2013). At present, rice is the only main staple cereal in SEA. Foxtail millet is still one of the most important crops in semi-arid regions of East Asia (China, Japan, and Korea), Russia, and India (Li and Wu 1996; You 1993), but as previously discussed, does not seem to be present in southern Vietnam although its remains have been identified in Rạch Núi (Oxenham et al. 2015). Similar to other cereals, rice and millet are mainly starchy carbohydrates, and thus lipids are only a minor component, making detection of their residues in archaeological pottery difficult (see Reber and Evershed 2004; Sivak and Preiss 1998).
Two pots (E2 and E6) were similarly used for cooking rice in the Philippines. The main difference between these two pots was not the frequency of cooking, but the variety of rice cooked in these pots. Milled *wagwag* rice with husks completely removed was cooked in pot E2, while partially milled *tinawon* rice with remaining husks was cooked in pot E6. This difference has implications for their resulting lipid profiles (Figs. 5-40 and 5-41). Both pots had evidence for C12, C14, C16, C18, and C18:1 fatty acids. Pot E2 also exhibits a C22 fatty acid, whereas pot E6 exhibits C16:1 and C20 fatty acids. Detected fatty acids of rice in this research concurs with the fatty acid composition of rice reported in the literature (e.g., Lugay and Juliano 1964; Taira and Chang 1986), except that the amount of C18:1 seems to be greater than that of C18. Pots E2 and E6 and the pot used for cooking foxtail millet (E8) all exhibit lower amounts of absorbed TLEs compared to most pots used to cook animal protein, as expected because of the high content of starch in rice and millet. These pots also exhibit the fewest fatty acids derived from absorbed residues retrieved from pots included in this research.

Other than fatty acids, rice grains, especially with husks, also contain plant sterols or phytosterols, tocopherols, and \( \gamma \)-oryzanol (Kim 2013; Zubair et al. 2012). The latter is a mixture of phytosteryl ferulates in rice bran (Mandak and Nystrom 2012; Miller et al. 2003). None of these compounds was detected and identified in the analysis of the two rice pots; however, a TLE peak at 35.49 min in pot E6 (Fig. 5-42) has a characteristic mass spectrum of \( m/z = 183, 239, 257, 281, 439, \) and 495. This is possibly a steryl ferulate based from \( m/z = 239, 439, \) and 495; however, the combination of mass fragment peaks does not match any of the steryl ferulates reported.
in the literature (Evershed et al. 1988; Miller et al. 2003) This pattern may be attributed
to the remaining husk in the rice cooked in pot E6, since this peak is absent in pot E2
used to cook rice without husks. This unknown component must be further explored.
Assuming that prehistoric rice grains were not milled to the extent that they are in the
present-day, the non-fatty acid compounds, especially steryl ferulates, may be
molecular biomarkers for rice if preserved in ancient pottery used to cook rice.

For pot E8 used to cook foxtail millet, the analyses of absorbed and charred
surface residues (latter assigned as CSR 12) produced from cooking are discussed.
Similar to the rice pots previously discussed, the absorbed residues (Fig. 5-43) from
cooking foxtail millet also exhibit evidence for C12, C14, C16, C18:1, and C18 fatty
acids. They also have glycerol, C18:2 fatty acids, and a sugar compound, identified as
levogluicosan. The latter indicates processing of plant foods (Poulain et al. 2016). The
charred surface residue (Fig. 5-44) from cooking foxtail millet also has C14, C16:1, C16,
C18:1, C18, and C20 fatty acids. It also has C18:2 and C24 fatty acids. Detected fatty
acid profiles in these pots concur with the fatty acid composition of millets in the
literature (e.g., Kim 2013; Liang et al. 2010), including the dominance of C18:2 fatty acid
(Liang et al. 2010; Pang et al. 2014). Monoacylglycerides (MAGs) with C16 and C18:1
fatty acid chains were also identified, along with the glycerols, and may represent
degradation products from triacylglycerides (TAGs) since evidence exists that foxtail
millet has MAGs, however, there is some evidence that millets may have TAGs (e.g.,
Evers et al. 1999; Liang et al. 2010). Based on the abundance of components and
intensities of the peaks in the TLE profiles of absorbed and charred surface residues,
fewer lipid components are observed in absorbed residues than in charred surface
residues. One explanation for this pattern could be that some of the components in charred surface residues may have already been sealed within the interior surface of the pot, preventing further absorption of oils on the pot fabric. This could explain why pot E8 has very low amounts of TLE among the experimental pots.

There are four component peaks in the TLE profile of the charred surface residues that were unidentified using the mass spectral library. The first, at 27.52 min (Fig. 5-45), could be a sitosterol based on the characteristic mass fragments (m/z) of M⁺ = 486, [M-129]⁺ = 357, and base peak of m/z = 129. Sitosterol is actually a dominant phytosterol in foxtail millet bran oil (Pang et al. 2014). The second at 27.32 min (Fig. 5-46) could be miliacin or olean-18-en-3β-ol methyl ether in underivatized form based on characteristic mass fragments of M⁺=440, [M⁺-15]=425, significant ions at m/z = 177, 189, 204, and 218. Miliacin and other pentacyclic triterpene methyl ethers (PTMEs) are used as tracers in sediments for tracking millet cultivation in antiquity, including broomcorn millet (e.g., Bossard et al. 2013; Jacob et al. 2008). Two other unidentified peaks at 25.53 (Fig. 5-47) and 25.74 min (Fig. 5-48) have, respectively, m/z = 73, 129, 132, 217, 243 and m/z = 72, 243, 498. These could be phytosterols or PTMEs.

Component peaks from 8.07 to 10.20 min in the TLE profile of charred surface residues (Fig. 5-44) were detected and identified as sugar molecules. These exhibit characteristic peaks at m/z = 73, 147, 191, 204, 217, 361 (Simoneit et al. 2004). Foxtail millet is also known to contain free sugar molecules (e.g., Malleshi et al. 1986). Although sugar molecules are not included in this research, they are worth exploring to identify potential carbohydrate-rich food sources in charred surface residues, along with starch grains. Based on the case of foxtail millet, some carbohydrate-rich foods may be
difficult to identify as minor lipid components in absorbed pottery, and may be more detectable in charred surface residues. Since fatty acids from SEA cereals also occur in other food sources, other molecular biomarkers, such as phytosterols and PTMEs, may provide better indicators if preserved in pottery and other artifacts used for their processing and preparation.

**Swamp Cabbage and Coconut Milk**

Pots E15 and E16 were used, respectively, to cook swamp cabbage five times, and coconut milk once. Although no paleoethnobotanical remains of these two food items have been recovered/identified in prehistoric SEA to date, swamp cabbage and coconut milk are two plant sources that were likely used in the past, and their oils should be absorbed in pottery. Swamp cabbage likely originated from China (Prasad et al. 2008), whereas coconut likely originated in ISEA (Gunn et al. 2011; Lim 2012). Pots E15 (Fig. 5-49) and E16 (Fig. 5-50) both exhibit C8, C9, C10, C12, C14, C16:1, C16, C18:1, C18, C20, C22, and C24 fatty acids that support the identification of swamp cabbage (Doka et al. 2014; Fan et al. 2014) and coconut (Lim 2012).

The coconut milk pot (E16) has more fatty acids (C18:2 and C19) that are not found in the swamp cabbage pot (E16). The C24 fatty acid in pot E16 was only detected in the analysis of FAMEs (Fig. 5-51). Pot E16 also exhibits glycerol, MAGs with C8, C10, C12 (2 isomers), C14, C16, C18:1, and C18 fatty acid chains, diacylglycerides (DAGs) with C12 fatty acid chains (two isomers), and TAG with C12 fatty acid chains. Two pairs of DAGs detected in pot E16 were not identified using the mass spectra library, but do show characteristic peaks of m/z = 129 and 145. A pair of DAGs at 26.6 and 27.083 min also has m/z = 541, and another pair at 28.48 and 28.80 min has m/z = 569. As attested by Reber et al. (2015), DAGs and TAGs cannot be identified in a
straightforward manner by simple mass spectrometry. The variety of lipid compounds, except for DAGs, observed in pot E16 are in agreement with Marina et al. (2009), Lim (2012), Pollard et al. (1961, glycerol only). Glycerol and DAGs could have been decomposition products of TAGs, consistent with the composition of coconut.

As shown in the TLE profile of E16 (Fig. 5-50), coconut milk is dominated by C12 fatty acid and exhibits the highest calculated amount of TLE in all pots assayed in this research. In contrast to all the food items that were experimentally cooked in the pots, the coconut milk pot produced good yields, and a good resultant chromatogram, despite the fact that the coconut milk was only cooked once and for a short time. The high calculated TLE is attributed to the fact that the coconut milk heated in the pot is a pure and viscous liquid (Simuang et al. 2004), which tends to be better absorbed in pottery matrices (Regert 2007). It is important to note that coconut milk lacks C16:1 fatty acids, and most plants have no C16:1 fatty acid (Skibo 1992). In contrast to the descending pattern of peaks for C12, C14, C16, and C18 fatty acids observed in the TLE lipid profile for E16, the corresponding FAMEs profile (Fig. 5-51) is dominated by C14 fatty acids. One explanation for this pattern could be that there is incomplete transfer of C12 fatty acids during the saponification process. Previous analysis of FAMEs with GC-FID (Fig. 5-52) produced a similar pattern to the TLE profiles for the four fatty acids observed in this work.

With these findings, it is possible to infer whether coconut milk, or any product from the palm family (Arecaceae), may have been processed in antiquity. The pattern produced by C12, C14, C16, and C18 fatty acids in the TLE profile of coconut milk is similar to that observed for palm fruit lipids detected in Nubian pottery from Qasr Ibrim,
Egypt (Fig. 5-53), FAMEs from modern date seeds (Fig. 5-54) and a TLE profile for an archaeological date recovered from the same site (Fig. 5-55) (Copley et al. 2001). Based on two different profiles of FAMEs from pot E16 (Fig. 5-51 and 5-52), C12 or C14 fatty acids could be the dominant component peak, however both C12 and C14 fatty acids occur in greater amounts than C16 and C18 fatty acids. In all profiles related to coconut milk and date palms, the component peak of C18:1 fatty acid is greater than that of C18. Thus, the patterning of these five fatty acids promises to be a good biomarker of food sources from the palm family, Arecaceae.

Despite the large contrast in the TLE and FAME profiles of pots E15 and E16, both have minor components of C22 diol as well as C24 and C26 alcohols (or policosanols). These compounds were not found in the literature on swamp cabbage and coconut milk, with the exception of the policosanols in coconut (Moura Fe et al. 1975). C22 diol is mentioned as one of the long-chain compounds produced during the production of suberin, associated with wound healing in plants (Dean and Kolattukudy 1976). Suberin, with cutin, is an apoplastic aliphatic biopolymer in the specialized protective surface tissues of plants (Franke et al. 2005). C24 (~21.7 min, m/z = 103 and 411, Fig. 5-56) and C26 (~23.6 min, m/z = 103 and 439, Fig. 5-57) alcohols are policosanols commonly found in plant oils (e.g., Jung et al. 2011). This suggests that these long-chain lipid compounds may be useful indicators for waxy plants, including those that produce a viscous liquid, along with other plant-related biomolecular markers. These three compounds are further discussed below.

The pot used for cooking swamp cabbage (E15, Fig. 5-49) also had other fatty acids (C11, C16:1, C21, and C28; C15 and C17 in trace amounts) and mid-long-chain
alcohols (C12, C14-C16, C20-C23, C27-C30, and C32) that were not found in the coconut milk pot (E16). It also had levoglucosan, alkanes (C17-C21 and C24) and ω-hydroxy acids (C20, C22, and C24). Aside from C16 and C18 fatty acids, the other dominant components were C22 alcohol and C22 ω-hydroxy acid (see Fig. 5-49).

Levoglucosan, indicative of plant food processing (Poulain et al. 2016), was also identified in the absorbed residues of the foxtail millet pot (E8). The ω-hydroxy acids and mid-long-chain alcohols are known to be lipid composition of suberin and cutin in plants (Franke et al. 2005). The mid-long-chain fatty alcohols and alkanes are further discussed in Chapter 8, as these are significant in several prehistoric archaeological pottery vessels analyzed in this research.

All pots used for cooking plant food sources exhibit C16/C18 fatty acid ratios ≥ 2, a consequence of the low abundance of C18 in plants (Gunstone 2004; Heron and Evershed 1993; Steele et al. 2010). The other usual long-chain waxes that provide evidence for the preparation of plant sources in pottery, such as wax esters (e.g., C44-C52 with fatty acid moieties C18-C24) and mid-chain ketones (e.g., nonacosan-15-one) (Cramp et al. 2013; Evershed 1993), however, were not detected in the pots analyzed in this research. No plant sterols (Evershed 1993; Gunstone 2004) were detected in absorbed organic residues. The possible sitosterol in the charred surface residues on pot E8 remains to be confirmed. Discussion of pots used to cook terrestrial and aquatic animal sources, which are expected to have different lipid profiles from those of plants, follows.
Terrestrial Animals: Pig and Chicken

Pots E3 and E5 were used to cook pig and chicken, respectively, five times. Remains of wild and domesticated pigs were ubiquitous in prehistoric SEA (e.g., Piper et al. 2009, 2012), but prehistoric chicken has only been recovered in Thailand (Higham 2014). It is assumed that domestic pigs and chickens were important food resources in prehistoric SEA and that the fats from these species would incorporate into pottery fabric better than most plants, as seen with the high TLEs calculated for pots E3 and E5. This suggests that during mixed cooking, animal fat residues may mask those from other food sources, such as those derived from plants.

Both E3 and E5 pots have C8, C9, C10, C12, C14, branched C15, C16:1, C16, C18:2, C18:1, C18, C20:1, C20, and C24 fatty acids (From Figs. 5-58 to 5-61). Pot E3 has C22 and C23 fatty acids (Fig. 5-60), whereas pot E5 has C6, C7, C10:1, 2-C11:1, C11, and C13 fatty acids (Fig. 5-61). In general, these two pots exhibit evidence for even-chained saturated and unsaturated fatty acids, as well as odd-chained saturated and branched fatty acids in their TLE and FAME profiles. Both have dioic acids or $\alpha,\omega$-dicarboxylic acids, based on their FAME profiles (Figs. 5-60 and 5-61), and MAGs based on their TLE profiles (Figs. 5-58 and 5-59). Dioic acids are products of burning of fat (Evershed et al. 2002a; Regert 2011). Pot E5 has 2-C11:1 fatty alcohol, DAGs, and C12 TAG. As mentioned before, DAGs are difficult to identify with mass spectrometry. Aside from 1,2- and 1,3-C12 DAGs, as well as 1,2 and 1,3-C16 DAGs, three pairs of DAGs were detected based on characteristic peaks of $m/z = 129$ and 145. The first pair at 26.86 and 27.17 min has $m/z = 541$. The second pair at 28.44 and 28.77 min has $m/z = 569$. The third pair at 30.21 and 30.68 has $m/z = 597$. Pot E5, having more lipid
components than pot E3, especially the acylglycerides, could be attributed to pot E5 being more recently prepared (in 2012) than pot E3. Many lipid components could have already been degraded in pot E3, which was prepared in 2009. Also, the MAGs and DAGs detected in both pots could be degradation products from the TAGs in pork and chicken (Dudd 1999).

In both the TLE and FAME profiles, pots E3 and E5 have contrasting fatty acid ratios. Pot E3 has C16/C18 ratios of 1.80 (TLE) and 1.39 (FAMEs), both of which are < 2. Pot E5 has C16/C18 ratios of 3.20 (TLE) and 3.42 (FAMEs), which are > 2. Both pots exhibit C16 > C18, which is in agreement with the work of Dudd (1999) and Regert (2011). Surprisingly, no cholesterol nor other animal sterols and their derivatives (Evershed 1993; Gunstone 2004; Heron and Evershed 1993) were detected in the TLE profiles and their neutral fractions for these two terrestrial meat pots. Similar to pots used for cooking plant sources, no secondary long-chain ketones were detected, even though they are usually produced by heating fatty acids at very high temperatures (> 300°C; Evershed et al. 2002a). Fatty acids with carbon chain length < C14 are not expected to be detected in archaeological residues. Acylglycerides and sterols are rarely preserved (Regert 2011). It seems then that the only useful implications of these two experimental pots for finding terrestrial meat residues are the high, calculated TLEs and differences in the C16/C18 fatty acid ratios between pork and chicken meat.

Chapter 6 further explores how pots E3 and E5, along with C16 and C18 fatty acids from pig and chicken bones, may be differentiated based on CSIA.

**Aquatic Resources: Freshwater and Marine Fishes**

As shown by the ubiquity of fish remains in many archaeological sites in SEA, freshwater and marine fishes have prominent roles in prehistoric foodways. Pots E4,
E7, E12, E13, and E14 were used to cook various fishes in several combinations, amounts, frequencies, and locations (Tables 5-4 and 5-5). All of these pots have C12, C14, C16:1, C16, C18:2, C18:1, and C18 fatty acids (Figs. 5-62 to 5-71). C18:2 fatty acid is found as FAME in all five pots (Figs. 5-63, 5-65, 5-67, 5-69, and 5-71). A short-chain (C9) fatty acid is found in pots E7 (Fig. 5-64) and E12 (Fig. 5-66). C19 fatty acid is found on pots cooked with freshwater fishes (pots E4, E7, and E12). Phytanic acid, an isoprenoid fatty acid, as FAME is found on pots cooked with higher frequency and amounts of marine fishes (E4 and E14, Figs. 5-63 and 5-71, respectively), but not in pot E13, which had the least amount of marine fish. 4,8,12-trimethyltridecanoic acid (4,8,12-TMTD), another isoprenoid fatty acid, as FAME is also found in pot E4 (Fig. 5-63). All of these pots have C20 and C22 fatty acids, except pot E13, with respect to the latter. C23 fatty acid was only detected in pot E7 and E12, C24 fatty acid is only detected in pots E7, E12, and E14, as well C26, which was only detected in pot E12 as FAMEs. Some of the unsaturated fatty acids were also only detected as FAMEs, such as C18:3 fatty acid on pot E12, C20:1 fatty acid on pots E4, E7, and E13, C22:1 and C24:1 fatty acids on pots E7 and E12, as well as C22:6 fatty acid in pot E12. The long chain alcohols found in pots E15 and E16 were also detected in pots E12 and E14 (Figs. 5-67 and 5-70), those with the highest frequencies of cooking freshwater and marine fishes. C22 diol as well as C24 and C26 alcohols are found in pot E14 (Fig. 5-70), whereas only C24 alcohol is found in pot E12 (Fig. 5-67). Pot E14 also has C20, C21, C22, C28, and C30 alcohols and ω-hydroxy C22 fatty acid (Fig. 5-70). A mid-chain alcohol of C16 is also found in pot E12 (Fig. 5-67). Fatty alcohols are also known to be found in fishes, similar to plants (Mendez-Antolin et al. 2008), but likely are only minor components in fishes.
because they would have to occur in much higher frequencies to be detected.

Discussion of other lipids, including ω-(o-alkylphenyl)alkanoic acids (AAPAs), acylglycerides, and cholesterol, and the implications of the findings from the pots cooked with aquatic sources will be discussed later with two ethnographic pots.

**Ethnographic Pottery from Long An, Vietnam**

The analyzed ethnographic pots were both used to prepare and serve a southern Vietnamese dish, *Cá Kho Tộ* (braised caramelized fish stew in clay pot), but from different restaurants in Long An, Vietnam. The cook at Thuy Ta Restaurant used or added pork fat during the preparation using pot E11, a technique not used at the Phong An restaurant where pot E10 was used. Thus, the goal here was to assess the effect of pork fat being mixed with fish and other ingredients on the resulting data. Results from these two ethnographic pots also show the range of fatty acids detected from the experimental pots used for cooking freshwater fishes from Southern Vietnam (E7, E12, and E13; from Figs. 5-72 to 5-75), with an addition of C20:2 fatty acid (Figs. 5-73 and 5-75). C19 and C24:1 fatty acids are missing in pot E11. They were probably masked by fats from pork. Similar to E7, E12, and E13, isoprenoid fatty acids were not detected in these ethnographic pots. Following Cramp and Evershed (2014), isoprenoid fatty acids are usually not expected in pots used for cooking freshwater fishes. The much higher computed TLE for pot E11 than E10 could possibly be a consequence of the former having a higher frequency of use than the latter (Table 5-5), as evidenced by the missing handle of pot E11 (Fig. 5-31). To fully assess the similarities and differences between these two pots used to prepare a common dish, further processing of extracts for other kinds of analysis must be explored.
On Pots Used for Cooking Fish

All pots used for cooking fish, experimental and ethnographic, have C16/C18 fatty acid ratios of at least 2 in both their TLE and FAME profiles. This means that the yield of palmitic acid (C16) is at least twice that of stearic acid (C16 \( \approx 2 \times C18 \)) in all pots used to cook fishes (E4, E7, E12, E13, E14, E10, and E11), which supports the identification of fish, based on the \( n \)-alkanoic acid profile (Olsson and Isaksson 2008). It can also be observed that these pots exhibit a range of fatty acids similar to the pots used for cooking terrestrial animals (E3 and E5), except for many unsaturated fatty acids. The pots used for cooking fish in Vietnam (E7, E12, and E11) also show evidence for C22:1 and C24:1 fatty acids, which are both indicators of aquatic resources (Cramp and Evershed 2014). Aquatic resources are abundant in long-chain mono- and polyunsaturated fatty acids, many of which are not found in terrestrial and mammalian food sources (Cramp and Evershed 2014; Dudd 1999). However, their survival and detection in archaeological artifacts are unlikely because of the fact that they are already degraded compounds (Regert 2011). Isoprenoid fatty acids are another suite of aquatic biomarkers that were originally proposed for marine resources (Cramp and Evershed 2014; Evershed et al. 2008; Hansel et al. 2004) but they can also be found in pottery from a few inland sites, which were used to prepare freshwater resources (for example, Kwak and Marwick 2015). These fatty acids were not detected in the pots from Vietnam (E7, E12, E13, E10, and E11) used to cook freshwater fish; however, phytanic acid and 4,8,12-TMDT were detected in the pot used to cook fish from the Philippines (E4). The presence of isoprenoid fatty acids in E4 could be stem from the fact that one of the fish cooked in this pot was a marine variety, despite the fact that the majority of the fish cooked in that pot were freshwater.
The ω-(o-alkylphenyl)alkanoic acids (AAPAs; Cramp and Evershed 2014) from C16\(\text{n}\) (\(n=1\)-3) and C18\(\text{n}\) fatty acids were detected based on the fragmentation patterns from the mass spectra (\(m/z = 105, 262, \) and 290) of pots E7, E12, E10 and Ell. However, C20\(\text{n}\) (\(m/z = 318\)) and/or C22\(\text{n}\) (\(m/z = 346\)) AAPAs must also be detected to ensure that the AAPAs are from aquatic resources because C16\(\text{n}\) and C18\(\text{n}\) AAPAs can also be produced by heating vegetable oils (Cramp and Evershed 2014; Olsson and Isaksson 2008). None of these AAPAs were detected from pots E4, E13 and E14, which is surprising since these pots were used to cook marine fishes. Only three peaks of C16\(\text{n}\) AAPAs in E7 were detected (Fig. 5-76). Only C16\(\text{n}\) and C18\(\text{n}\) AAPAs were detected in pot E12 (Fig. 5-77), which had the highest frequency of cooking fish. Based on the comparison of mass spectra for eight isomers of C18 AAPAs as FAMEs (Cramp and Evershed 2014) with those from the pot E12, six out of eight isomers were probably detected (Figs. 5-78 to 5-84). Only C16\(\text{n}\) and C18\(\text{n}\) AAPAs are also detected on pots E10 (Fig. 5-85) and E11 (Fig. 5-86) that were used for cooking and serving a fish-based dish. One possible reason is that the temperatures of the pots during the experimental cooking did not reach the requisite temperature of 270°C, the threshold required to produce many of the C16-C22 AAPAs (Evershed et al. 2008). Boiling does not usually reach pottery temperature of 300°C at which point food begins to char (Skibo 2013). In the case of the ethnographic pots (E10 and E11), stir frying or dry cooking was done and the temperature of the pottery was able to reach 300-400°C (Skibo 2013)—more than enough to produce AAPAs from unsaturated fatty acids (Evershed et al. 2008). However, no C20\(\text{n}\) and C22\(\text{n}\) AAPAs were detected on these ethnographic pots. The other possible reason could be that not all fish, specifically the lean types, produce
C20:3 alkanoic or fatty acid that can be decomposed into C20:3 AAPAs (same with C22:n) (Olsson and Isaksson 2008). If the detection of known biomarkers for aquatic resources seems to be challenging for modern earthenware pots used to cook aquatic resources, the same would probably be the case for archaeological pottery.

Although acylglycerides from aquatic resources prepared on archaeological pottery were not expected to be preserved (Regert 2011), a few were detected on the modern pottery and are worth discussing. All pots used for preparing fish, except for pot E13, have MAGs, as seen in Table 5-5. Only pots E7, E10, and E11 have two isomers of C16 DAG; no TAGs were detected. Other possible, but unidentified acylglycerides, were detected in pots E12, E10 and E11 based on \( m/z = 129 \). The one at 35.42 min also has a \( m/z = 385 \), which is found in pots E12, E10, and E11. The one at 36.3 min also has a \( m/z = 397 \), which is found in pots E10 and E11, but not in E12. It is possible that the latter acylglyceride is not from fish, but from the other ingredients prepared with fishes in the ethnographic pots based on the finding that it is not found in pot E12, which was used only to cook fish.

Cholesterol, which is the main sterol biomarker for animal fats (Evershed 1993; Gunstone 2004), is found as a minor component in all pots used for preparing fish based on produced TLE and neutral fraction profiles (e.g., Fig. 5-81), with the exception of pot E4, with only the neutral fraction profile as proof. Surprisingly, it was not found on pots E3 and E5 used for cooking terrestrial meat (pork and chicken), despite multiple extractions and analyses of the TLEs and neutral fractions. This can be attributed to the fact that some fish have higher amounts of cholesterol than terrestrial meat (Pirronen et
al. 2002), as probably is the case with the fish cooked in the pots. The cholesterol in
pots E3 and E5 could have been degraded or lost, and already undetectable.

**Conclusions and Further Work**

In general, the frequency of cooking, viscosity, lipid composition and amount of
food items, as well as probably the property of the pots used for experimental and
ethnographic cooking, affected the organic residues that were incorporated and
preserved in pots. The pots used for plant sources, such as starch-rich cereals (rice and
millet) and swamp cabbage, have low lipid yields, despite multiple uses. This likely
indicates the tendency for terrestrial animal residues to mask them during mixed
cooking; thus, it would be difficult to detect them. However, the unidentified components
detected in pots E6 and E8 used to cook, rice (with husks) and millet, respectively, are
worth further exploration, since they could be possible biomarkers. With the case of
foxtail millet, carbohydrate-rich food may tend to seal the interior surface of the pottery
vessel and hinder the absorption of lipid compounds on the pottery fabric. Cereals, such
as millet, may have a better chance to be identified from charred surface residues on
archaeological pottery. Other molecular biomarkers, such as phytosterols and PTMEs,
could be better indicators if preserved on archaeological artifacts used for food
processing and preparation. Sugar molecules are also worth exploring for identifying
carbohydrate-rich plant food sources in charred surface residues, alongside study of
starch grains. The pots used for preparing animal meat more than once had high lipid
yields. The detection of cholesterol and/or its derivatives, which would indicate animal
food sources, seems to be challenging, as not all pots used for cooking animal meat
yielded cholesterol. The detection of known biomarkers for aquatic resources (C16:\n-C22:n AAPAs and isoprenoid fatty acids) also seems to be challenging because the
pots used for cooking aquatic resources yielded either no or only a few of these biomarkers. For several modern pots discussed in Chapter 5, a very few acylglycerides were unexpectedly detected, especially a few TAGS, perhaps because they are better detected and identified with high-temperature GC and GC-MS that use a DB-1HT column (Dudd 1999; Evershed et al. 1992).

Experimental cooking of important food sources in SEA was done with the following in mind: “Experimental studies are an indispensable aspect of investigations of organic residues from archaeological ceramics” (Evershed 2008a:27). Ethnographic pots were also collected because they were used for recent preparation of food for daily consumption. They may provide insights because of their long-term use, which is not the case for the experimental pots (Evershed 2008a). These experimental and ethnographic pots are useful comparative reference materials, since they provide insights into the detection and identification of different food sources from the region. The feasibility of detecting and distinguishing different food items provides the potential to track plants and animals in archaeological pottery with good preservation of lipids between food acquisition and consumption – food preparation – to complete the chaîne opératoire (sensu Leroi-Gourhan 1993) of foodways (sensu Jones 2002).

In further work, the remaining pots will be analyzed for their lipid profiles. All experimental and ethnographic pots discussed here in Chapter 5 underwent stable isotopic analyses with other modern flora and faunal materials of SEA. All of these modern materials underwent compound-specific isotopic analysis (CSIA) of δ¹³C from C16 and C18 fatty acids, with the intention of building a corresponding database for SEA. The charred surface residues on some modern pots and biological materials were
analyzed for bulk isotopes ($\delta^{13}$C and $\delta^{15}$N) to contribute to the existing database in the region. The relevant additional methods and results are discussed in Chapter 6. The findings in Chapters 5 and 6 are compared with findings from pottery recovered from SEA archaeological sites in Chapter 8. I recommend that the modern comparative reference collection be extended to other food sources, such as plants used as vegetables, medicines, and spices; terrestrial ruminant animals; and nonfish aquatic resources. I also recommend exploring the effects of burial on lipid composition of modern pots used for food preparation, by extracting and analyzing lipids before and after the pots are buried in the soil. With this in mind, fragments of pots E1-E7, E10-E11, and, E17-E22, which were prepared and collected from 2008 to 2012, and buried in the ground at the Long-An Provincial Museum, Tan An City, Long An, Vietnam and Archaeological Studies Program, University of the Philippines, Quezon City, Philippines should be excavated and analyzed in the future, alongside surrounding burial soils.
Figure 5-1. Pot E16 used to boil coconut milk once. A) Close-up view and B) normal view (Photos by M.S. Eusebio).

Figure 5-2. Pot E2 used to cook wagwag rice five times (Photo by M.S. Eusebio).

Figure 5-3. Pot E3 used to cook pork five times (Photo by M.S. Eusebio).

Figure 5-4. Pot E4 used to cook freshwater and marine fishes five times (Photo by M.S. Eusebio).
Figure 5-5. Portions of pork cooked in pot E3. A) Adobo cuts, B) country style slices, C) pata slices, D) menudo cuts, and E) pork cubes (Photos by M.S. Eusebio).

Figure 5-6. Fishes cooked in pot E4. A) *Tilapia* (freshwater), B white *pompano* (marine), and C) white *maya* (freshwater) (Photos by M.S. Eusebio).
Figure 5-7. Two earthenware cooking pots used for experimental cooking in Fall 2012 (Photo by M.S. Eusebio).

Figure 5-8. Pot E5 used to cook chicken five times. A) Drumstick and B) *tinola* cuts (Photos by M.S. Eusebio).

Figure 5-9. *Tinawon* rice in the public market of Banaue, Ifugao, northern Luzon, Philippines (Photo by M.S. Eusebio).
Figure 5-10. Mixing *tinawon* rice (with husks) and water in pot E6 (Photo by M.S. Eusebio).

Figure 5-11. Fishes cooked in pot E14. A) *Tawilis*, B) *tambakol*, C) *tulingan*, D) *galunggong*, and E) *alumahan* (Photos by M.S. Eusebio).

Figure 5-12. Pot E14 used to cook marine fishes five times (Photo by M.S. Eusebio).
Figure 5-13. A bundle of *kangkong* or swamp cabbage (Photo by M.S. Eusebio).

Figure 5-14. Pot E15 used to cook swamp cabbage five times (Photo by M.S. Eusebio).

Figure 5-15. An unrestricted earthenware cooking pot with cover in Long An, Vietnam (Photo by M.S. Eusebio).
Figure 5-16. Earthenware stoves or *cà rang* in Long An, Vietnam (Photo by M.S. Eusebio).

Figure 5-17. Kiet An store in Tan An City public market, Long An, Vietnam (Photo by M.S. Eusebio).

Figure 5-18. May Tre La shop in Tan An City, Long An, Vietnam (Photo by M.S. Eusebio).
Figure 5-19. Pot E7 used to cook five varieties of freshwater (brackish) fishes three times. A) VN17, B) VN16, and C) VN18-VN20 (Photos by M.S. Eusebio).

Figure 5-20. Five varieties of freshwater (brackish) fishes cooked in pot E7. A) VN16, B) VN17, C) VN19, D) VN18, and E) VN20 (Photos by Fredeliza Campos).

Figure 5-21. Fredeliza Campos cooking fish as reference materials in pots E9 and E12 (Photo by M.S. Eusebio).
Figure 5-22. Lò Gạch archaeological site, Long An, Vietnam (Photo by M.S. Eusebio).

Figure 5-23. Pots E9 and E12 used to cook inland freshwater fishes at least ten times. A) Pot E9 and B) pot E12 (Photos by M.S. Eusebio).

Figure 5-24. Pot E13 used to cook three pieces of a marine (brackish) fish three times (Photo by M.S. Eusebio).
Figure 5-25. Foxtail millet grains imported from People’s Republic of China and bought from Eastern Market, Gainesville, Florida (Photo by M.S. Eusebio).

Figure 5-26. Pot E8 used to cook foxtail millet five times (Photo by M.S. Eusebio).

Figure 5-27. Pot E17 used to cook freshwater (brackish) fishes by A) frying and B) boiling (Photos by M.S. Eusebio).
Figure 5-28. Pot E18 used to cook freshwater (brackish) fishes as A) modified Cá Kho Tộ and B) modified Fish Sarsiado (Photos by M.S. Eusebio).

Figure 5-29. Pot E10 used for preparing and serving Cá Kho Tộ at Phong An restaurant (Photo by M.S. Eusebio).

Figure 5-30. Phong An restaurant, Tan An City, Long An, Vietnam (Photo by M.S. Eusebio).
Figure 5-31. Pot E11 used for preparing and serving Cá Kho Tộ 2 with pork fat at Thuy Ta restaurant. A) Top view and B) pork fat on the spoon) (Photos by M.S. Eusebio).

Figure 5-32. Thuy Ta restaurant, Tan An City, Long An, Vietnam (Photo by M.S. Eusebio).

Figure 5-33. Interview with the owner of Thuy Ta restaurant (Photo by M.S. Eusebio).
Figure 5-34. Dinner with two dishes served on pots E21 (right) and E22 (left) at Barrio Fiesta restaurant in Quezon City, Philippines (Photo by M.S. Eusebio).

Figure 5-35. Pot E21 used for preparing and serving *Kuhol sa Gata* (Snails in Coconut Milk) at Barrio Fiesta restaurant (Photo by M.S. Eusebio).

Figure 5-36. Pot E22 used for preparing and serving *Kare Kare* (Meat Stew in Peanut Sauce) at Barrio Fiesta restaurant (Photo by M.S. Eusebio).
Figure 5-37. Used and unwashed pot E19 collected from Talalang, Kalinga, Philippines (Photo by M.S. Eusebio).

Figure 5-38. Used and washed pot E20 collected from Talalang, Kalinga, Philippines (Photo by M.S. Eusebio).

Figure 5-39. Dionex 300 Accelerated Solvent Extractor used for extracting organic compounds from the majority of the samples included in this research (Photo by M.S. Eusebio).
Table 5-1. Abbreviations for lipid compounds discussed in the results, and in the tables and figures that follow, along with chemical and common names (after Chemical Book 2016; Christie 2015; Fankhauser 1994).

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Common Name</th>
<th>Chemical Name</th>
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<tbody>
<tr>
<td>C6 fatty acid (FA)</td>
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<td>Chemical Name</td>
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<td>C19 alkane</td>
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<td>Eicosane</td>
<td>Icosane</td>
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<td>Lipids</td>
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<td>Plant sources</td>
<td>a. C16 FA &gt;&gt; C18 FA (or ≈ 2C18)</td>
<td>a. Gunstone 2004;</td>
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<td>b. Plants &gt; Animals: C12, C14, C16, and C18:2 FAs; usually in plants: C20, C22, C24, and C26 FAs</td>
<td>b. Steele et al. 2010</td>
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<td></td>
<td>d. Plant sterols and derivatives</td>
<td>d. Evershed 1993;</td>
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<td>Aquatic resources</td>
<td>a. Dominated by C16 FAs (or C16 &gt;/≈ 2C18)</td>
<td>a. Olsson and Isaksson 2008</td>
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<td>b. Long-chain monounsaturated FAs: C16:1, C20:1, C22:1, and C24:1 FAs</td>
<td>b. Cramp and Evershed 2014</td>
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<td>c. At least one of isoprenoid FAs: 3,7,11,15-trimethylhexacosanoic acid (phytanic acid, SRR&gt;RRR), 2,6,10,14-tetramethylpentadecanoic acid (pristanic acid), and 4,8,12-TMTD</td>
<td>c. Cramp and Evershed 2014; Hansel et al. 2004; Lucquin et al. 2016; Evershed et al. 2008; Regert 2011</td>
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<td>d. C16-C22 AAPAs derived from unsaturated C16-C22 FAs</td>
<td>d. Evershed et al. 2008; Hansel et al. 2004</td>
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<td>e. Co-occurrence of C17:1(\Delta^8,9,10) and C19:1(\Delta^9,10,11) FAs with isoprenoid FAs</td>
<td>e. Baeten et al. 2013</td>
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<tr>
<th>Compound Group</th>
<th>Mass Fragmentation Patterns</th>
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<tr>
<td><strong>Fatty acids as TMSEs</strong></td>
<td>Strong [M-15]^+; [M^+] (molecular ion peak) is usually present; significant peaks at m/z = 73+75+117+129+132+145.</td>
</tr>
<tr>
<td><strong>Fatty acids as FAMEs</strong></td>
<td>Weak [M^+]; [M-32]^+ and [M-31]^+; significant peaks m/z=74 and 87.</td>
</tr>
<tr>
<td><strong>Dicarboxylic acids as TMSEs</strong></td>
<td>[M–15]^+ and [M–131]^+; the latter is only observed for diacids with carbon atoms of 5 or more.</td>
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<tr>
<td><strong>ω-(ω-alkylphenyl)alkanoic acids</strong></td>
<td>Base peak at m/z = 105 (both as TMSEs and FAMEs); significant peak at m/z = 91 (as FAMEs).</td>
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<tr>
<td><strong>Dihydroxy acids as TMSEs</strong></td>
<td>m/z=73+215/315/317</td>
</tr>
<tr>
<td><strong>Sterols/Phytosterols</strong></td>
<td>Noticeable [M^+], [M-15]^+ and [M-90]^+; base peak at m/z=129, [M-129]^+ also present.</td>
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<tr>
<td><strong>Alkanes</strong></td>
<td>Weak [M^+]; [M-29]^+ present; fragments with decreasing intensity due to missing alkyl groups (m/z=57+71+85+99+...).</td>
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<td><strong>Long-chain alcohols</strong></td>
<td>Weak [M^+]; strong [M-15]^+; [CH2OSi(CH3)3]^+ at m/z=103 differentiates n-alcohols from TMSEs of long-chain fatty acids. Significant peaks: m/z=57+75+83+103+111.</td>
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<tr>
<td><strong>Wax esters</strong></td>
<td>Weak [M^+]; base peaks: [C_{14}H_{31}O_{2}]^+ at m/z=229, [C_{16}H_{33}O_{2}]^+ at m/z=257 and [C_{18}H_{35}O_{2}]^+ at m/z=285.</td>
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<td><strong>Monoacylglycerols (MAGs)</strong></td>
<td>Weak [M^+] and [M-15]^+; [M-90]; [M-CH2OSi(CH3)3]^+ = 1-MAG isomer; [(CH3)_3SiOCH=CHCH2OSi(CH3)3]^+ at m/z=2-MAG isomer</td>
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<td><strong>Diacylglycerols (DAGs)</strong></td>
<td>[M^+] usually missing; weak [M-15]^+ and [M-90]; significant ions at m/z=129+145.</td>
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<td><strong>Triacylglycerols (TAGs)</strong></td>
<td>Minor peaks of [M^+] and [M-158]^+</td>
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<tr>
<td><strong>Pentacyclic triterpenes</strong></td>
<td>[M^+]; [M^+-15], and significant ions at m/z=218+203/204+189+/or 177</td>
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<tr>
<td>E1</td>
<td>Blank pot (Unused cooking pot, Philippines)</td>
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<tr>
<td>E2</td>
<td>Rice pot (5x cooking by boiling, traditional Central Luzon, Philippine variety)</td>
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<tr>
<td>E3</td>
<td>Pork pot (5x cooking by boiling, Philippines)</td>
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<td>E4</td>
<td>Fish pot (5x cooking by boiling, mixed freshwater-marine Philippine fishes)</td>
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<td>E5</td>
<td>Chicken pot (5x cooking by boiling, Philippines)</td>
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<td>E6</td>
<td>Rice pot (3x cooking by boiling, traditional Ifugao, Philippine variety)</td>
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<td>E7</td>
<td>Fish pot (3x cooking by boiling, five estuarine-freshwater varieties in Vietnam)</td>
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<td>E8</td>
<td>Foxtail millet pot (5x cooking by boiling, imported from China to Gainesville, FL)</td>
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<tr>
<td>E9</td>
<td>Inland freshwater fishes 1 (10x or more cooking by boiling, Vietnam)</td>
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<tr>
<td>E10</td>
<td>Ča Kho Tộ 1 pot (fish only, ethnographic pot, cooking by stir frying) from Phong An Restaurant, Tan An City, Long An, Vietnam</td>
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<tr>
<td>E11</td>
<td>Ča Kho Tộ 2 (fish with pork fat, ethnographic pot, cooking by stir frying) from Thuy Ta Restaurant, Tan An City, Long An, Vietnam</td>
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<tr>
<td>E12</td>
<td>Inland freshwater fishes 2 (10x or more cooking by boiling, Vietnam)</td>
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<td>E13</td>
<td>Marine fish pot (3x separate cooking for three pieces of a fish from Carangidae family, left cooking for the whole afternoon, Vietnam)</td>
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<td>E14</td>
<td>Marine fish pot (5x cooking by boiling, Philippines)</td>
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<td>E15</td>
<td>Swamp cabbage pot (5x cooking by boiling, Philippines)</td>
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<td>Mixed cooking pot 1 (frying and boiling freshwater fishes, Vietnam)</td>
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<td>Mixed cooking pot 2 (two fish-based dishes, Vietnam)</td>
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<td>Washed cooking pot (Kalinga province, Philippines)</td>
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<td>Snails in Coconut Milk pot (Barrio Fiesta, Quezon City, Philippines)</td>
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<td>Pork Stew in Peanut Sauce pot (Barrio Fiesta, Quezon City, Philippines)</td>
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<td>TLE (µg/g)</td>
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**Fatty Acids (in FAMEs only if \(x\) is in bold font)**

- C6:0
- C7:0
- C8:0
- C9:0
- C10:0
- C12:0
- C13:0
- C14:0
- 4,8,12 TMTD
- br.C15:0
- C16:1
- C16:0
- C18:3
- C18:2
- C18:1 (A)
- C18:1 (B)
- C18:0
- C19:0
- C20:2
- C20:1
- Phytanic acid
- C20:0
- C22:6
- C22:1
- C22:0
- C23:0
- C24:1
- C24:0
- C26:0
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**Diacylglycerides** *(DAGs, m/z = 129 and 145)*

**Triacylglyceride** *(TAG)*

**Other Possible Acylglycerides**

| m/z=385 | x | x | x |
| m/z=397 | x | x |

**Other Unidentified Compounds**

| m/z = 73, 129, 132, 217, 243, 243, 498 |

Note: Detected compounds are organized according to type and by carbon chain length (*C*<sup>x</sup>;<sup>y</sup>, where *x* = number of carbons in the main chain and *y* = number of double bonds). Acylglycerides, such as DAGs (after Reber et al. 2015), and other unidentified compounds are difficult to be identified through library search but recognized through characteristic *m/z* values. Only includes results from data acquired using Shimadzu GC-MS QP2010s.

aDetected compounds are both from absorbed and charred surface residues. TLE is computed from the absorbed residues, similar to the rest of the samples.
Figure 5-40. Partial gas chromatogram of TLE from pot E2. In all chromatograms, “IS” means internal standard and “CT” means contaminant.

Figure 5-41. Partial gas chromatogram of TLE from pot E6.
Figure 5-42. Unidentified component peak at 35.49 min, with its mass spectrum, in the TLE profile of pot E6, probably a steryl ferulate.

Figure 5-43. Partial gas chromatogram of TLE from pot E8, which is acquired through Trace 1310 Gas Chromatograph with Thermo TSQ 8000 Triple Quadrupole MS.
Figure 5-44. Partial gas chromatogram of TLE from charred interior surface residues on pot E8.

Figure 5-45. Unidentified component peak at 27.52 min, with its mass spectrum, in the TLE profile of charred interior surfaces residues on pot E8, probably sitosterol.
Figure 5-46. Unidentified component peak at 27.32 min, with its mass spectrum, in the TLE profile of charred interior surfaces residues on pot E8, probably miliacin.

Figure 5-47. Unidentified component peak at 25.53 min, with its mass spectrum, in the TLE profile of charred interior surfaces residues on pot E8.
Figure 5-48. Unidentified component peak at 25.74 min, with its mass spectrum, in the TLE profile of charred interior surfaces residues on pot E8.

Figure 5-49. Gas chromatogram of TLE from pot E15, which is acquired through Trace 1310 Gas Chromatograph with Thermo TSQ 8000 Triple Quadrupole MS.
Figure 5-50. Gas chromatogram of TLE from pot E16.

Figure 5-51. Partial gas chromatogram of FAMEs from pot E16.
Figure 5-52. Gas chromatogram of FAMEs from pot E16 acquired through GC-FID (from Eusebio 2010).

Figure 5-53. Partial gas chromatogram of the TLE of an ancient pottery from Qasr Ibrim, Egyptian Nubia used for processing palm fruits (Figure 1 in Copley et al. 2001:595).
Figure 5-54. Partial gas chromatogram of the FAMEs of a modern date seed (Figure 2 in Copley et al. 2001:595).

Figure 5-55. Partial gas chromatogram of the TLE of an archaeobotanical remain of date from Qasr Ibrim, Egyptian Nubia used for processing palm fruits (Figure 3 in Copley et al. 2001:596).
Figure 5.56. Component peak of tetracosanol (C24-OH) and its mass spectrum from the neutral fraction profile of pot E15.

Figure 5.57. Component peak of hexacosanol (C26-OH) and its mass spectrum from the TLE profile of pot E15.
Figure 5-58. Gas chromatogram of TLE from pot E3.

Figure 5-59. Gas chromatogram of TLE from pot E5.
Figure 5-60. Gas chromatogram of FAMEs from pot E3.

Figure 5-61. Gas chromatogram of FAMEs from pot E5.
Figure 5-62. Gas chromatogram of TLE from pot E4.

Figure 5-63. Gas chromatogram of FAMEs from pot E4.
Figure 5-64. Gas chromatogram of TLE from pot E7.

Figure 5-65. Gas chromatogram of FAMEs from pot E7.
Figure 5-66. Gas chromatogram of TLE from pot E12.

Figure 5-67. Partial gas chromatogram of FAMEs from pot E12.
Figure 5-68. Gas chromatogram of TLE from pot E13.

Figure 5-69. Partial gas chromatogram of FAMEs from pot E13.
Figure 5-70. Gas chromatogram of TLE from pot E14, which is acquired through Trace 1310 Gas Chromatograph with Thermo TSQ 8000 Triple Quadrupole MS.

Figure 5-71. Partial gas chromatogram of FAMEs from pot E14.
Figure 5-72. Gas chromatogram of TLE from pot E10.

Figure 5-73. Gas chromatogram of FAMEs from pot E10.
Figure 5-74. Gas chromatogram of TLE from pot E11.

Figure 5-75. Gas chromatogram of FAMEs from pot E11.
Figure 5-76. Mass ion chromatograms of AAPAs in the FAMEs of pot E7 at $m/z=105$, 262, 290, 318, and 346.

Figure 5-77. Mass ion chromatograms of AAPAs in the FAMEs of pot E12 at $m/z=105$, 262, 290, 318, and 346.

Figure 5-78. Partial mass ion chromatogram of FAMEs from pot E12 at $m/z=105$ showing the detected possible isomers of C18:$n$ AAPAs, in comparison with that of Cramp and Evershed (2014) in the inset.
Figure 5-79. Partial mass ion chromatogram of FAMEs from pot E12 at \textit{m/z}=105 showing the detected possible isomer 6 of C18:\textit{n} AAPA and its mass spectrum, in comparison of the latter with that of Cramp and Evershed (2014) in the inset.

Figure 5-80. Partial mass ion chromatogram of FAMEs from pot E12 at \textit{m/z}=105 showing the detected possible isomer 5 of C18:\textit{n} AAPA and its mass spectrum, in comparison of the latter with that of Cramp and Evershed (2014) in the inset.
Figure 5-81. Partial mass ion chromatogram of FAMEs from pot E12 at m/z=105 showing the detected possible isomer 4 of C18:n AAPA and its mass spectrum, in comparison of the latter with that of Cramp and Evershed (2014) in the inset.

Figure 5-82. Partial mass ion chromatogram of FAMEs from pot E12 at m/z=105 showing the detected possible isomer 4 of C18:n AAPA and its mass spectrum, in comparison of the latter with that of Cramp and Evershed (2014) in the inset.
Figure 5-83. Partial mass ion chromatogram of FAMEs from pot E12 at $m/z=105$ showing the detected possible isomer 1 of C18: $n$ AAPA and its mass spectrum, in comparison of the latter with that of Cramp and Evershed (2014) in the inset.

Figure 5-84. Partial mass ion chromatogram of FAMEs from pot E12 at $m/z=105$ showing the detected possible isomer 0 of C18: $n$ AAPA and its mass spectrum, in comparison of the latter with that of Cramp and Evershed (2014) in the inset.
Figure 5-85. Mass ion chromatograms of AAPAs in the FAMEs of pot E10 at m/z=105, 262, 290, 318, and 346.

Figure 5-86. Mass ion chromatograms of AAPAs in the FAMEs of pot E11 at m/z=105, 262, 290, 318, and 346.
Figure 5-87. Cholesterol and its mass spectrum from the neutral fraction profile of pot E10.
Isotopes Beyond Subsistence and Diet

It is only through close integration of stable isotope investigations with primary bioarchaeological observations that a detailed understanding of foodways, including the full chaîne opératoire of management, procurement, preparation, consumption and discard, becomes possible. Production and procurement of food are most clearly evidenced through zooarchaeology and archaeobotany, but, increasingly, isotopic information is helping to refine our understanding of farming regimes and animal management practices. Processing and cooking are some of the most challenging aspects of foodways to address archaeologically, but, alongside taxonomic identification of plant and animal remains, stable isotope determinations as part of lipid residue analyses help tie subjects like storage, cooking and processing to material culture, and hence cultural identity.

—Amy Bogaard and Alan K. Outram

Palaeodiet and Beyond: Stable Isotopes in Bioarchaeology

As demonstrated by the above quotation, recent advances in isotopic analysis have enabled archaeologists to move beyond subsistence and diet toward the full chaîne opératoire of foodways that includes inferences about past culinary practices (Bogaard and Outram 2013). Analysis of organic residues on material culture remains is accomplished by combining biomolecular markers (e.g., profiling of lipids) with stable isotope ratios from carefully selected samples.

In many archaeological contexts, however, most lipid residues are not preserved because of the vagaries of diagenesis in unconducive burial environments. Occasionally, non-diagnostic palmitic acid (C16) and stearic acid (C18) components of lipid residues are recovered, but their specific stable carbon isotope ratios ($\delta^{13}C$) are very useful diagnostic markers (Evershed 2008b). In this regard, compound specific isotopic analysis (CSIA) of organic compounds, C16 and C18 fatty acids in this case,
are helpful to deduce the potential sources of residues on pottery and other items of material culture (Evershed 2009). Of the three food categories (plants, terrestrial animals, and aquatic resources) that can be differentiated by biomolecular compounds, CSIA provides the means to further differentiate these categories into six: C$_3$ and C$_4$ plant oils, ruminant and nonruminant terrestrial animals, and freshwater and marine food resources (Fig. 6-1). Ruminant animal sources can be further divided into adipose meat and dairy products using CSIA methods (Craig et al. 2007; Evershed et al. 1999; Regert 2011).

Together with faunal and floral identification, CSIA derived from ancient pottery can facilitate inferred linkages between material culture (i.e., pottery) and foodways, as to how animals and plants were prepared and consumed (e.g., Outram et al. 2012; Steele et al. 2010), which, in turn, may be used to infer aspects of social identity and organization in the past (sensu Twiss 2007, 2012). In order to apply this approach, modern reference databases for CSIA, based on animal fats, which comprised the majority of work (e.g., Dudd 1999), and plant oils, which is less common (e.g., Steele et al. 2010), were established to differentiate organic residues by faunal and floral categories. These reference databases, surveyed by Gregg et al. (2009) and Spiteri (2012), were based on isotopic data from modern terrestrial and aquatic animal species in Britain and have been indiscriminately utilized for comparison purposes against isotopic data from residues on archaeological materials from various localities.

The treatment of “regional” databases as universal reference collections has been challenged by Gregg et al. (2009; see also Gregg 2009) because of known geographic differences between the δ$_{13}$C of the C16 and C18 fatty acids from Middle
Eastern modern animals (ruminant adipose meat and dairy products, wild boar), and those from northern and central Europe (Copley et al. 2003, 2005a-d; Spangenberg et al. 2006). Therefore, reference databases for isotopic analyses are area-specific because of myriad factors. Isotopic data from residue studies of material culture should be compared with modern reference materials gathered from the same vicinity, region, and environment as the archaeological site being studied (Gregg et al. 2009). For example, Spiteri (2012) established a reference database for comparison with isotopic data of pottery residues from archaeological sites in the Mediterranean region and noted differences in isotopic values between northern Europe and her study sites. Similar reference databases have also been established in Central Asia (e.g., Outram et al. 2009, 2012) and East Asia (e.g., Craig et al. 2013 and Lucquin et al. 2016 for Japan; Kwak 2015 for South Korea; Yang and March 2012 for Taiwan).

Several modern databases have been developed for human paleodiet reconstruction in SEA (e.g., Garong 2013; King 2006) that can be used to assess bulk carbon and nitrogen stable isotope ratios of charred food residues on pottery; however, no modern reference database for SEA is available for the CSIA of organic molecules that can then be applied to surface and absorbed residues of prehistoric pottery. Chapter 6 then has the following objectives: (1) to establish a modern SEA reference database for CSIA of organic residues, (2) to compare this database with other reference databases developed for other geographic areas, and (3) to infer former food contents on archaeological materials, such as pottery vessels, from SEA using this newly developed reference database.
Chapter 6 details the CSIA of C16 and C18 fatty acids in extracted lipid residues from modern reference materials with gas chromatography-combustion-isotopic ratio mass spectrometry (GC-C-IRMS). This work builds on the existing modern databases for CSIA from other geographic regions and for bulk stable isotopic analysis in SEA. The modern comparative reference material comprises the sampled experimental and ethnographic pottery analyzed and discussed in Chapter 5, as well as samples of modern flora and fauna that are archaeological significant in SEA. The \( \delta^{13}C \) of C16 and C18 fatty acids from these modern pottery and biological samples constitutes the comparative reference database for CSIA in SEA. The \( \delta^{13}C \) values of C16 and C18 fatty acids from these materials are then compared with the \( \delta^{13}C \) values in the available literature to assess differences between SEA and other regions. These differences will be demonstrated after the discussion on the background of compound-specific stable isotope ratios of lipids that follows this section. In relation to the third objective, the \( \delta^{13}C \) values of C16 and C18 fatty acids from archaeological pottery are compared to those from the SEA reference database to facilitate the identification of food sources represented by recovered residues.

Also included in Chapter 6 is the bulk stable isotopic analysis for \( \delta^{13}C \) and \( \delta^{15}N \) of charred surface residues of several modern pottery and biological samples. These results contribute to a growing body of literature using isotopic analysis in SEA to infer past and present foodways. Chapter 6 concludes with archaeological implications of the results and recommendations for further work.

**Compound Specific Stable Isotope Ratios of Lipids**

Continuing the discussion of isotopic analysis of organic residues in Chapter 4, this section further elaborates on how CSIA of lipids helps to distinguish specific
sources of organic residues by food categories. I build upon their utility in various archaeological contexts and discuss the complications and challenges for future research. Palmitic (C16) and stearic (C18) acids are the most common lipid compounds utilized for CSIA because of their presence in all living organisms (Evershed 2009), and these compounds are the most persistent in the archaeological record (Evershed 2008b). The δ¹³C values of these two fatty acids from modern animal and plant lipids are distinguishable mainly as a consequence of different biosynthetic reactions during lipid synthesis (Evershed et al. 2002b). As previously mentioned in Chapter 4, the δ¹³C values of plants depend on the photosynthetic pathways they utilize, either the C₃ (Calvin-Benson) cycle or the C₄ (Hatch-Slack) pathway (Evershed 2009; Warinner 2014).

The relative amount of C₃ versus C₄ plants consumed by an organism will affect its δ¹³C value (DeNiro and Epstein 1978). This is because the δ¹³C values of ingested food are not altered by the consumers (DeNiro and Epstein 1978). Thus, the bulk and compound specific δ¹³C values of tissues and biomolecules of consumers reflect the food that they eat. This justifies the controlled feeding experiments done in the United Kingdom (see Copley et al. 2003; Dudd and Evershed 1998; Evershed et al. 2002b; Mukherjee et al. 2005) and Mediterranean area (see Spiteri 2012) to establish modern reference databases for identifying animal sources of organic residues on archaeological materials, in which inputs from C₄ plants were avoided to reflect the dominantly C₃ environments of these areas during prehistory (Mukherjee et al. 2005).

It is also noted that the isotopic compositions of consumed material and the tissue being studied depends on various factors, such as nutritional status, biosynthetic
pathways, the kind of tissue and its turnover rate (Evershed et al. 2002b; Stott et al. 1997; Tieszen et al. 1983). Because of discrimination against $^{13}$C during the synthesis of lipids in all organisms, adipose tissue has $\delta^{13}$C values that are 3‰ more negative than the diet (DeNiro and Epstein, 1977), as demonstrated by the work of Tieszen et al. (1983). In addition, different animal taxa have physiologies that affect how diet is assimilated into their consumer tissue; thus, the different $\delta^{13}$C values of C16 and C18 fatty acids help to differentiate between the fats from major animal categories. However, isotopic values from present-day domesticated animals are not comparable to prehistoric taxa because of the supplements fed to them as part of intensive farming, selective breeding that affects fat composition, and burning of fossils fuels since the industrial revolution.

As shown in Figure 6-1, the $\delta^{13}$C values of C16 and C18 fatty acids can differentiate between the following major animal categories: ruminant and nonruminant animals, and freshwater and marine sources (Craig et al. 2007; Evershed et al. 2002b). Fats from nonruminant animals are isotopically heavier and have less negative $\delta^{13}$C values than those of ruminant animals (Evershed et al. 2002b). Further, ruminant adipose fats can be differentiated from dairy products that come from ruminant animals because of the differences between the metabolic pathways of these two fat sources. The $\delta^{13}$C values of C18 fatty acid in the latter are more negative than those in the former (Copley et al. 2003).

The “canopy effect” also affects the $\delta^{13}$C values of animal fats, and plants in dense forests are relatively depleted in $^{13}$C (Mukherjee et al. 2005). In dense forest, plants closer to the forest floor exhibit more negative $\delta^{13}$C values and, consequently, the
animals feeding on those plants also exhibit more negative $\delta^{13}C$ values. This is a consequence of the photosynthetic recycling of CO$_2$ with depleted $^{13}C$ from rotting leaf litter and the lower efficiency of plants to use water at low light levels. Canopy effect can be observed in animals from forest and riverine environments. For example, forest dwelling wild boars/pigs have more negative $\delta^{13}C$ values than domesticated pigs (Mukherjee et al. 2005).

Marine plants absorb dissolved carbon dioxide (CO$_2$) from their surrounding water, rather than from the atmosphere (Chisholm et al. 1982; Mukherjee et al. 2005), thus there is continual exchange of carbon with marine bicarbonate (Sealy 2001). Thus, marine food sources exhibit various combinations of fatty acids, which are associated with an array of metabolic processes (Spangenberg et al. 2006) and the isotopic fractionation of carbon from dissolved CO$_2$ (Sealy 2001). Therefore, the $\delta^{13}C$ values of marine plants, and consequently their consumers, are more positive than those of terrestrial plants because of differences in carbon sources between marine and terrestrial plants. Although marine phytoplankton fractionate carbon roughly the same as the terrestrial plants, they have different photosynthetic mechanisms (Chisholm et al. 1982). The range of carbon isotope values for marine food sources overlaps with that for C$_4$ plants and their consumers. This complicates the assessment of samples from environments with both marine and C$_4$ plant food sources (Mukherjee et al. 2005). Although terrestrial and marine sources are distinguishable by virtue of their ranges of $\delta^{13}C$ values of C16 and C18 fatty acids, the latter have values close to those of nonruminant animals (e.g., pigs). Thus, CSIA data must be corroborated with biomarker
analyses to guarantee a secure identification of marine sources (Copley et al. 2004; Evershed et al. 2008; Hansel et al. 2004).

The burning of fossils fuels since the Industrial Revolution must be corrected for in modern materials, and the correction must be $1.6\ \%$ less negative or more positive than the acquired value. This correction is used to adjust the values from modern reference materials so that they are comparable with archaeological materials. Different corrections may be used in different geographic areas, such as $1.6\ \%$ for Central Europe (Spangenberg et al. 2006) and $1.5\ \%$ for SEA (Pushkina et al. 2010). The most common correction used is $1.14\ \%$ (see, for example, Craig et al. 2011 for Northern Europe and Spiteri 2012 for the Mediterranean area), which is the deviation of $\delta^{13}C$ of atmospheric CO$_2$ due to the fossil fuel burning since the Industrial Revolution (Friedli et al. 1986). These temporal and environmental differences in carbon isotope values can be accounted for by comparison of $\Delta^{13}C$ values, which are calculated by subtracting $\delta^{13}C$ of C16 fatty acid from that of C18 fatty acid, from modern reference materials and archaeological materials (Mukherjee et al. 2005). The variation in $\Delta^{13}C$ values is a consequence of differences in the biosynthesis and routing of C16 and C18 fatty acids in different animal categories. Thus, $\Delta^{13}C$ values are also utilized to distinguish between ruminant adipose meat and dairy products, nonruminant animal meat, and marine resources (Evershed et al. 2002b).

Much work has been conducted on the CSIA of animal fats; however, limited work to date has focused on the CSIA of C16 and C18 fatty acids from modern plant oils to build a comparative reference database for archaeological studies (Steele 2008; Steele et al. 2010), in this case modern oils from C$_3$ plants (e.g., almond and olive) in
the eastern Mediterranean region. As shown in Figure 6-1, the range of δ13C values overlap with those of freshwater fishes (Steele 2008; Steele et al. 2010). A few other studies are also available, but were done to assess their authenticity and geographic sources (e.g., Liu et al. 2012; Spangenberg and Ogrinc 2001). There is much work on the δ13C values of C16 and C18:1 fatty acids from modern oils (e.g, Spangenberg et al. 1998; Woodbury et al. 1998). This could be because of the high abundance of C18:1 fatty acid and low abundance of C18 fatty acid in plant oils (Steele et al. 2010). However, the studies with δ13C values of C16 and C18:1 fatty acids from modern oils are less useful for the CSIA of C16 and C18 fatty acids on archaeological organic residues because δ13C values are incomparable between C18:1 and C18 fatty acids.

Although different food categories are distinguishable through δ13C values of C16 and C18 fatty acids, mixing of these categories actually happens during food preparation and consumption. To account for this, a mixing model (see Mukherjee et al. 2005) was constructed to calculate the theoretical δ13C values of C16 and C18 fatty acids from organic residues. As seen in Figure 6-2, theoretical mixing ellipses are demonstrated for the mixing of ruminant and nonruminant (pig) adipose fats in different proportions. In practice, however, mixing models are difficult to apply to assess the contribution of different animal fats because of several complications. It is impossible to quantify with precision the amount of mixing for every use and how many times a cooking vessel was used. To further add to these complications, people prepare animal foods with other natural products, such as beeswax, honey, and plants that may also affect the δ13C values of C16 and C18 fatty acids (Mukherjee et al. 2005). The next section further discusses the geographic variations observed in the literature.
Geographic Variations

As mentioned in Chapter 6, the values of δ\(^{13}\)C of C16 and C18 fatty acids from important food sources vary across geographic areas. This section further demonstrates these variations for animal food sources that are common between SEA and other areas, such as wild boar and domestic pigs, cows and deer, as well as freshwater and marine food sources. The δ\(^{13}\)C of C16 and C18 fatty acids of food sources from other areas are compiled in Appendix E.

Starting with wild boars and pigs, the δ\(^{13}\)C of C16 and C18 fatty acids from the Middle Eastern samples (Gregg et al. 2009) do not fall within the range of values from the Northern Atlantic (Dudd 1999). This is demonstrated in Figure 6-3 that shows the average values, ranges, and standard deviations of δ\(^{13}\)C values of C16 and C18 fatty acids from modern wild boar and domestic pigs in different geographic areas. δ\(^{13}\)C values for wild boar in the Middle East are carbon depleted in contrast to those in northern Europe (Craig et al. 2007), East Asia (Craig et al. 2013; Lucquin et al. 2016b), and the Mediterranean (Spiteri et al. 2012). Also shown in Figure 6-3 are δ\(^{13}\)C values for domestic pigs from the northern Atlantic (Dudd 1999) and Mediterranean (Spiteri 2012), which are generally \(^{13}\)C-enriched in comparison with wild boars, whereas the δ\(^{13}\)C values from the Mediterranean (Spiteri 2012) are more \(^{13}\)C-enriched in C16 fatty acid than those from the northern Atlantic (Dudd 1999).

Figure 6-4 shows δ\(^{13}\)C values of C16 and C18 fatty acids from modern ruminant animals from different geographic areas. The δ\(^{13}\)C values for both deer and cow tend to be more \(^{13}\)C-enriched in lower latitudes, such as in Mediterranean area (Spiteri 2012), than in higher latitudes, such as in northern Europe (Craig et al. 2007, 2012), northern Atlantic (Dudd 1999), and East Asia (Craig et al. 2013; Lucquin et al. 2016b). However,
the cows fed a predominantly C₄ diet in the Mediterranean (Spiteri 2012) are more ¹³C-enriched than cows fed with the common C₃ diet in the Mediterranean (Spiteri 2012) and northern Europe (Craig et al. 2012).

The graph in Figure 6-5 shows δ¹³C values of C₁₆ and C₁₈ fatty acids from modern freshwater and marine animal sources from different geographic areas. In this case, no noticeable latitudinal shift is observed for the freshwater sources because all areas lie at about the same latitude in the Northern Hemisphere. In the case of marine resources, those from the Mediterranean (Spiteri 2012), which is located at lower latitudes, have δ¹³C values that overlap with the northern Atlantic (Craig et al. 2007; Dudd 1999; Lucquin et al. 2016b) and northern Europe (Craig et al. 2011), which are both situated at higher latitudes. Based on this graph, there is a clear division between freshwater and marine sources.

In the case of poultry, no geographic comparison can be made because values for different poultry animals are geographically specific: ducks in East Asia (Craig et al. 2013), and chicken and geese in the northern Atlantic (Dudd 1999). In the case of plants, no geographic comparison was done because of the scarcity of available work and because plants from prehistoric contexts are geographically specific. However, geographic differences would matter after the Columbian Exchange when plant food sources were widely distributed outside of their native geographic areas (Nunn and Qian 2010). The following section details δ¹³C values of C₁₆ and C₁₈ fatty acids from important food sources of SEA, which will later be compared with the δ¹³C values from other geographic areas discussed above (compiled in Appendix E).
Materials and Methods

Experimental and Ethnographic Pottery

The preparation and collection of experimental and ethnographic pottery, as well as laboratory preparations were discussed in Chapter 5.

Biological Samples of Southeast Asian Food Items: Background and Collection

The majority of biological samples were collected during trips to Vietnam and the Philippines in Spring-Summer 2014. The first nine items were collected while participating in archaeological fieldwork at the Metal Age site of Lò Gạch, Long An, Vietnam (Fig. 6-6). The site is situated on the western bank of the Vàm Cồ Tây River, a tributary of the larger Mekong River, in an agricultural area. Aside from rice farming and fishing, people living in the area also manage pigs, dogs, ducks, chickens, and vegetable gardens. No evidence was observed for use of commercial fertilizers in their agricultural practices. The excavation team was served lunch daily, made of locally sourced food. Cooked bones from two pigs [B8 (Fig. 6-7) and B9 (Fig. 6-8)] and one chicken (B10, Fig. 6-9) were acquired from the village near Lò Gạch site. One variety of dried, salted freshwater fish, locally known as Cá chach (Macrognathus siamensis, B13) or the spot-finned spiny or peacock eel (Fig. 6-10), and 0.5 kg of a local variety of red rice (B3, Fig. 6-11) were acquired from the nearest public market in Vinh Tri Commune, Vinh Hung District, Long An province.

Although modern foxtail millet (Setaria italica), a C₄ plant, was not available in the area, the remains of another C₄ plant, Job’s tears (Coix lacryma-jobi), was also recovered from Lò Gạch and it is available within the vicinity of the site (Fig. 6-12). It is presently utilized as food and medicine in the region (Burnette 2012). Sedges (Scirpus sp. sensu lato), another C₄ plant, were also recovered at Rạch Núi (Castillo 2014) and
were also present in the immediate area of the Lò Gạch site (Fig. 6-13). An attempt was made to collect the rhizomes of sedges, as suggested by the archaeobotanical remains from Rạch Núi (Castillo 2014); however, at the time of fieldwork, the sedges were in the flowering stage and the rhizomes were not yet available. The plants of Job’s tears were also in the flowering stage and no grains were available. Thus, the leaves, flowers, and stems of Job’s tears (B1, Fig. 6-12) and sedges (B2, Fig. 6-13) were collected in lieu of foxtail millet.

After the excavation of Lò Gạch site, the fieldwork continued for two weeks at the Long An Provincial Museum in Tan An City, Long An, Vietnam. During the post-excavation work, six more varieties of dried freshwater and marine fish were purchased from the Tan An City Market. These included Cá loc [Channa sp. (prob. gachua), snake-head fish, freshwater fish, B14, Fig. 6-14], Cá kẹo (Pseudapycryptes lanceolatus Bloch, pointed tail goby, freshwater fish, B15, Fig. 6-15), Cá bo’ng cát bien (Sillago sp., sand borer sillaginid, marine fish, B16, Fig. 6-17), Cá sérc lò tho [Tricopodus sp. (prob. pectoralis), freshwater fish, B17, Fig. 6-18], Cá lù dừ (Micropogonias undulates, croaker fish, marine fish, B18), and Cá lư vị trâu (Cynoglossus microlepis, tongue sole, marine fish, B19, Fig. 6-19).

All biological samples collected in Vietnam were curated, recorded, and packed for export to University of Florida, Gainesville, Florida once permits from the US Department of Agriculture were granted. The pig and chicken bones were boiled in water for 2 h at 150°C and sundried for 4 h or more prior to packing. The leaves and stems of Job’s tears and sedge were also sundried for 4 h or more prior to packing. While the permits were being processed, these samples were stored in the office of the
Center for Archaeological Studies, Southern Institute of Sustainable Development, Ho Chi Minh City, Vietnam.

The collection of biological samples continued in several provinces of the Philippines. In the province of Zambales in Central Luzon, Philippines, two varieties of dried marine fish were acquired from the public market of San Felipe town or municipality. These fishes are anchovies (*Stolephorus indicus*, locally known as *dilis*, approximately two cups, B20, Fig. 6-20) and *salingasi/tabagak* (*Sardinella fimbriata*, fringe scale sardine, B21, Fig. 6-21). I originally intended to collect bones from chickens and pigs fed with organic or noncommercial diets at a farm as well as the *wagwag* variety of rice in the same town. However, seasonal butchery of chickens and pigs had occurred prior to my arrival in the second week of June (2014). My arrival also did not coincide with the harvest season of the *wagwag* rice (rice cooked on pot E2 in Chapter 5). The wagwag variety of rice is produced every six months for family consumption and is always fully milled. Arrangements for future collection of pig and chicken bones were made, including planned sampling of other sources of traditional rice varieties, such as in Panay Island of Central Philippines.

In Iloilo, Panay Island in Central Philippines, two varieties of dried marine fishes (100 g each) and three traditional varieties of rice (at 0.5 kg each) were also acquired from the public market in Iloilo City. These fishes are *sapsap* (*Leiognathus equulus*, ponyfish/slipmouth, B22, Fig. 6-22), which are imported from Roxas City, province of Capiz, and *guma-a* (*Pseudocaranx dentex*, white trevally, B23, Fig. 6-23), which are imported from the town of Dumangas, province of Iloilo. Both locations are in coastal areas. The black rice variety (B4, Fig. 6-24) was produced from the town of Dingle,
Iloilo, and it is also produced in other parts of the Philippines (goorganicphils.wordpress.com). The camoros (B5, Fig. 6-24) and bisaya (B6, Fig. 6-25) rice varieties are native varieties of Panay Island that were, respectively, produced from the towns of Dingle, Iloilo and Tapaz, Capiz. Unfortunately, the millet usually sold in the public market, which is imported from the neighboring island of Cebu, was not available during the acquisition of dried fish and rice from the public market.

Pig (B11, Fig. 6-26) and chicken (B12, Fig. 6-27) bones from the Philippines were acquired from Nuezca Café in Quezon City, a family-owned restaurant that prepares and serves meat dishes from managed animals raised with “organic” feeds from the family farm in the town of San Felipe, Zambales. “Organic” means that the animals produced for meat consumption were free-ranging and not fed with commercial feeds, which are usually made of corn.

The biological samples from the Philippines were also curated, recorded, and packed for export to University of Florida. The rice and dried fish samples were hand carried to Gainesville, Florida, since they were already processed for consumption and did not need permits for export. The pig and chicken bones were boiled in water for 2 h at 150°C and sundried for 4 h or more prior to packing. These were mailed to University of Florida once permits from the USDA and from the Bureau of Animal Industry in the Philippines were granted. While the permits were being processed, the animal bone samples were stored in the house of the author and in the house of the author’s family, both in Quezon City.

All the traditional varieties of rice acquired from Vietnam and the Philippines, including the tinawon variety cooked in pot E6, are generally known as “colored” rice
varieties, which have red, purple, or black kernels, the color produced by the large amount of anthocyanin pigment. These varieties are usually used for special occasions and for making rice delicacies in Asia (Chaudhary 2003). Unfortunately, the intended trip to Ifugao, Northern Luzon, Philippines to acquire *tinawon* in 2014 did not happen. Usually, fresh fish meat is collected and freeze-dried prior to export with proper permits; however, it was not possible during the 2014 trips in both Vietnam and the Philippines because of lack of time to arrange logistics for fishing and lack of access to a freeze-drying facility. Fortunately, the production of dried and salted fishes is prevalent in SEA. The dried fishes are the best alternatives because they are already processed for daily consumption, freeze-drying is not necessary prior to export, and no permits are necessary.

Additional biological samples were acquired in the supermarkets of Gainesville, Florida, given their origins in East and SEA. McCormick cloves (*Syzygium aromaticum*, dried flowers, B24, Fig. 6-28) and nutmeg (*Myristica fragrans*, seeds, B25, Fig. 6-29) were purchased from Publix supermarket, while the foxtail millet (*Setaria italica*, B7, Fig. 5-25), imported from China, was acquired from Eastern Market. Although cloves and nutmegs are historically from the Maluku province of Eastern Indonesia (see Singletary 2014; Spriggs 2000; Zumboich 2013), the origins of McCormick spices are uncertain because they are being produced outside their areas of origin and the McCormick company acquires a single type of spice from multiple geographic areas. Fortunately, a nutmeg seed (B26, Fig. 6-28) acquired from the Banda Islands, Maluku, Indonesia was sampled. In total, 26 biological samples were collected for the purpose of creating a reference database for CSIA.
Laboratory Preparations for Stable Isotopic Analysis

Laboratory preparations for bulk (δ\textsuperscript{13}C and δ\textsuperscript{15}N) and compound specific (δ\textsuperscript{13}C of C16 and C18 fatty acids) isotopic analysis were carried out on four different groups of materials, namely charred surface residues on six experimental pots prepared and analyzed in Chapter 5, floral samples, animal bone samples, and dried fish samples. All samples were prepared in the Bone Chemistry Laboratory at the Department of Anthropology, as well as in the Organic Geochemistry and Light Stable Isotope Mass Spectrometry Laboratories at the Department of Geological Sciences, University of Florida.

Charred surface residues were scraped from the interior surfaces of the pots, ground with a mortar and pestle, transferred into clean 20-ml glass scintillation vials, and submitted for bulk isotopic analyses. The following pots were sampled: two pots used for cooking inland freshwater fishes (assigned as CSR7 and CSR8 on pots E9 and E12, respectively); one pot used for cooking three marine fishes of the same species (CSR9 on E13), one pot used for cooking five species of marine fishes on separate occasions (CSR10 on E14); one pot used to cook swamp cabbage (Ipomoea aquatica) five times (CSR11 on E15); and one pot used to cook foxtail millet five times (CSR12 on E18). Remaining residues were retained for lipid extraction and archival storage.

In the case of floral samples, leaves and stems of Job’s tears (B1) and sedge (B2) were placed inside separate 400-ml beakers, each weighing ~7-8 g. Cereal samples (B3-B7) were poured into separate 50-ml beakers to the 30-ml level. These samples were cleaned by sonication with deionized distilled water twice for 10 min and dried in a warm oven. Cereals were transferred into 20-ml glass scintillation vials. The leaves and stems were wrapped with sterilized aluminum foil and placed inside ziplock
bags. A few cloves (B24) were transferred into 20-ml scintillation vials. Nutmeg (B25 and B26) was grated with a pre-cleaned grater onto sterilized aluminum foil and transferred into separate 20-ml glass scintillation vials. All plants samples were frozen at -80°C, freeze-dried, and ground into powder with a mortar and pestle. Ground plant samples were homogenized and weighed into tin capsules for bulk isotope analysis. Remaining samples were archived and retained for lipid extraction.

Animal bone samples (B8-B12) were boiled in deionized distilled for 2 h at 150°C after their arrival at the University of Florida, and then cleaned twice by sonication with water for 10 min and warmed in an oven to dry. At least 2 g of each bone sample was sampled and further cleaned. The epiphyses of the long bones were cut and the diaphyses were split in half with a hammer. Bone marrow was scraped and discarded. The bone material was then cleaned and sonicated in deionized distilled water until the water was clear. All bone fragments from all samples B8-B12 were then air-dried overnight, and ground with the aid of a Spex 6700 freezer mill.

Bone collagen was extracted from each of the five animal bone samples using the protocol followed in the Bone Chemistry Laboratory, which is a modified Longin-based method (Ambrose 1990; Longin 1971). It is customary to remove lipids from modern bone samples prior to collagen extraction. Ground bone samples utilized for obtaining collagen had lipids already removed for CSIA (discussed below). Bone samples B8-B12 were assigned laboratory numbers BC-2015-3599 to BC-2015-3592. For each sample, ~0.5 g of pre-extracted bone powder was weighed into a 15-ml graduated plastic Eppendorf centrifuge tube. Approximately 12 ml of 0.2 M HCl was poured into the centrifuge tube with the bone powder. Acid was refreshed every 24 h
until each sample had completely demineralized, a period of about 5-7 days. Every 24 h, the tubes were centrifuged for 10 min to let the bone sample undergoing reaction settle, the old acid was decanted off, and replaced with ~12 ml 0.2M HCl. Five days after the acid treatment started, each sample was rinsed in DI-dH2O to neutral pH. Each sample then received 0.125M NaOH to remove organic contaminants and potential humic acids. After 16 h, each sample was rinsed again with DI-dH2O (~3x) to neutral pH, and ~10 ml 10⁻³ M HCl was added to the tube, and then the entire demineralized sample and solution was transferred into a preweighed 20 ml-glass scintillation vial, loosely capped, and heated in an oven for 7 h at 95°C. Next, ~50 µL (3 drops) of 1 M HCl was added to each sample to maintain acidity and avoid absorption of atmospheric CO₂. Heating at 95°C continued for 5-6 h. The demineralized solution was transferred into the 15-ml centrifuge tube, centrifuged for 10 min to settle the remaining solid particles, and the solution was transferred back into the corresponding 20-ml glass vial, and reduced to ~2 ml by heating at 65°C. The resulting bone collagen was frozen, lyophilized (freeze-dried), and weighed to calculate % collagen yield prior to submitting samples for bulk isotopic analysis.

In the case of fish samples B13-B23, at least 2 g of meat was sampled from each fish by dissecting the meat from the bones. Fillets of samples B14, B17, and B23 were cleaned by sonication twice with water for 10 minutes to clean off mold and salt, then dried in a warm oven. All fish samples were frozen at -80°C, freeze-dried, and ground into powder with a mortar and pestle. Ground fish samples were weighed into tin capsules and submitted for bulk isotopic analyses. Remaining samples were archived and used for lipid extraction.
Gas Chromatography with Isotope-Ratio Mass Spectrometry for Bulk δ^{13}C and δ^{15}N

Generally, samples were weighed and loaded into tin cups, and δ^{13}C and δ^{15}N values were obtained using a Thermo Delta V Advantage Isotope Ratio Mass Spectrometer coupled with a ConFlo II interface linked to a Carlo Erba NA 1500 CNS Elemental Analyzer housed in the Light Stable Isotope Mass Spectrometry Laboratory, Department of Geological Sciences, University of Florida. Standards used were Vienna Pee Dee Belemnite (PDB) for δ^{13}C and and AIR δ^{15}N. Charred surface residue samples were run in duplicate, whereas floral and fish samples were run in triplicate, and animal bone samples were run in quadruplicate. The acquired δ^{13}C values were corrected for post-industrial carbon (PIC, Friedli et al. 1986), which is ~1.5‰ for SEA (Pushkina et al. 2010), so they could be compared with the δ^{13}C values derived from the residues obtained from archaeological materials.

Solvent Extraction of Lipids from Biological Materials

The extraction of lipids from modern pottery samples and associated charred surface residues was discussed in Chapter 5. The same extraction procedure was applied to biological samples, but with a few modifications. In the case of floral samples, lipids were extracted from ~1 g of leaves/stems (B1 and B2), ~0.5 g of spices (B24-B26), and ~5 g for cereals (B3-B7). The high amount for cereals is because of their very low lipid composition. Lipid extracts from millet grains (B7) and nutmeg (B25 and B26) had to be reduced, dried, and reconstituted in 20-ml glass scintillation vials with 10 ml hexane because of the difficulty of further reducing the extracts in 2-ml GC vials, as they are very starchy and viscous in texture. In the case of dried fishes (B13-B23), lipids were extracted from ~0.5 g of ground meat. The remaining meat after extraction was
archived. No internal standards were added during the extraction of lipids from floral and fish samples.

In the case of animal bone samples (B8-B12), lipids were extracted from ~1 g bone powder) and 10 µL internal standard [1 mg/1mL tetratriacontane (C34 alkane)] was added to each sample. The amount was increased to 1 g from 200 mg or 0.2 g, as specified by Craig et al. (2012) because of the partition of the remaining bone powder after collagen extraction (previously discussed), and for further processing with acidified methanol extraction (Colonese et al. 2015).

**Saponification and Methyl Esterification**

Saponification and methyl esterification of lipid extracts into fatty acid methyl esters (FAMEs) from modern pottery samples was discussed in Chapter 5. The same procedures were applied for biological samples, but with modifications. For each sample, only 1/5 (instead of 2/5) of the TLE was saponified because of the concentrated nature of biological samples. Plant extracts were dried from hexane and reconstituted with dichloromethane (DCM) because some plant components are insoluble in hexane. The heating time during saponification was increased to 2 h. The volume of boron trifluoride (BF₃, 14% w/v)-methanol complex was increased from 100 µL to 150 µL. The heating time during methyl esterification was increased from 1 to 2 h. It was anticipated that a modified procedure of Spangenberg et al. (1998) and Steele et al. (2010) for pure floral oils would be needed for floral extracts. However, it was not necessary, based on the pH, after the addition of base and acid during the saponification, following the procedure in Chapter 5.
Purification of Fatty Acid Methyl Esters

All FAMEs analyzed in 2016 were purified by eluting them through columns containing glass wool, 5% deactivated silica (SiO$_2$) gel, and sodium sulfate (Na$_2$SO$_4$), with the aid of DCM. Purification was done prior to the transfer and reconstitution of FAMEs into low-volume or 2-mL GC vials. The FAMEs from plant samples, including the charred surface residues (CSR12) on pot E8 used to cook foxtail millet, were purified a second time by eluting them through columns containing glass wool and deactivated 5% silver nitrate-impregnated silica gel, with the aid of hexane and ethyl acetate, because of the dominance and co-elution of unsaturated fatty acids (C18:2 and two isomers of C18:1 fatty acids). This purification procedure (e.g., Diefendorf et al. 2014, 2015) separated the saturated lipid compounds, through elution with hexane, and unsaturated lipid compounds, with ethyl acetate. The saturated fatty acid fractions from plant samples, supposed to contain C16 and C18 fatty acids, were submitted for CSIA.

Gas Chromatography-Mass Spectrometry

FAMEs were analyzed with gas chromatography-mass spectrometry to ensure that the fatty acids were derivatized and to quantify the C16 and C18 fatty acids, along with the most abundant component, if not those two fatty acids. Quantification was done to determine the dilution factors (DF), where the basis for quantification is the known amount of internal standard [heneicosanoic acid methyl ester (C21 FAME)] added to the FAMEs prior to analysis. These DFs are applied for diluting or concentrating the FAMEs for submission to CSIA, for which the prescribed concentrations are in the range of 0.01-0.05 mg/ml. The majority of FAMEs from modern pottery were analyzed from 2013 to 2015 with an Agilent Technologies 6890N Network GC System with Agilent
Technologies 5793 Inert Mass Selective Detector and Shimadzu GC-MS QP2010s, as discussed in Chapter 5.

In 2016, the FAMEs from biological materials and few modern pottery samples were analyzed with a Thermo Trace 1310 Gas Chromatograph and a Thermo TSQ 8000 Triple Quadrupole Mass Spectrometer at the Organic Geochemistry Laboratory, Department of Geological Sciences. This GC-MS is also equipped with a Thermo Scientific Auto Sampler AS 1310. The injection volume was 1 μL with Thermo Scientific Auto Injector Al 1310 and syringe size of 10 μL. The inlet mode is split, with a ratio of 30:1 or 10:1. The system was set to scan the range of $m/z$=50-650, with a solvent delay of 5 min. The GC-MS runs were done with a Supelco Equity-5 capillary column (30 m × 250 μm, 0.25-μm film thickness) and constant flow mode (1.5 mL/min). The oven temperature was step-programmed with an initial temperature of 100°C, then temperature increases from 100°C to 193°C at 7°C min$^{-1}$, then from 193°C to 310°C at 5°C min$^{-1}$, and held at 310°C for 30 min, with helium as the carrier gas. The total run time for each sample was 56.68 min. Data were acquired and processed with Thermo Xcalibur. The derivatized extracts were immediately covered with new caps after analysis and stored at -20°C for reruns and CSIA.

**Compound Specific Isotopic Analysis for $\delta^{13}$C of C16 and C18 Fatty Acids with GC-C-IRMS**

The FAMEs were analyzed by CSIA for $\delta^{13}$C values of C16 and C18 fatty acids using a Hewlett Packard HP 6890 Gas Chromatography-Combustion-IRMS (GC-C-IRMS) fitted with Agilent DB-5 MS capillary column (30 m × 320 μm, 0.25 μm film thickness), at the Light Stable Isotope Mass Spectrometry Laboratory in the Department of Geological Sciences, University of Florida. The inlet was operated with splitless mode.
at 220°C. The oven was initially held at 80°C for 1 min, then ramped to 200°C at 10°C/min, then increased to 250°C at 6°C/min, and finally brought to 310°C at 7°C/min for 7 min. Helium was used as a carrier gas at a constant flow rate of 2 mL/min. The FAMEs were combusted over platinum (Pt), nickel (Ni), and copper (Cu) wires with oxygen (O₂) in helium (He, 1%, v/v) at 940°C. The raw data were acquired with ISODAT 3.0 software. Each sample was analyzed in duplicate or triplicate runs.

The δ¹³C values of C16 and C18 fatty acids were calibrated using FAME standard F8-3 mixture (by Arndt Schimmelmann in the Biogeochemical Laboratories, Indiana University) and corrected for the methyl group added from methanol during derivatization of fatty acids into FAMEs (Rieley 1994), as shown by the following mass balance equation (Gregg et al. 2009):

\[
δ^{13}C_{\text{measured}} = f \ δ^{13}C_{\text{C16 or C18 FAME}} + (1-f) \ δ^{13}C_{\text{CH3}},
\]  

(6-1)

where \(f = 16/17\) carbon atoms in the methyl ester of C16 fatty acid and \(f = 18/19\) carbon atoms in the methyl ester of C18 fatty acid. The latter was done by methylating the C16 and C18 fatty acid standards with known \(δ^{13}C\), along with the samples. However, the methyl correction values were inconsistent between C16 and C18 fatty acids.

Fortunately, the \(δ^{13}C\) of the methanol from the boron trifluoride (BF₃, 14% w/v)-methanol complex used for methylation can be directly measured using IRMS. Thus, the methyl corrections used were direct measurements of \(δ^{13}C\) from the methanol, which was the source of the methyl group attached to the fatty acids as FAMEs. The \(δ^{13}C\) values of the methyl group used for corrections were -55.24‰, -45.45‰, and -52.39‰ for samples, respectively, analyzed in March 2014, March 2015, and June 2015-2016. The corrected \(δ^{13}C\) of C16 and C18 fatty acids from the modern comparative materials were further
corrected for the deviation caused by post-industrial carbon (PIC, Friedli et al. 1986; ca. 1.5‰ for SEA, Pushkina et al. 2010).

**Results and Discussion**

**Bulk δ¹³C and δ¹⁵N from Charred Surface Residues and Biological Samples**

Table 6-1 shows the results obtained from bulk stable isotope analysis of modern reference materials for δ¹³C and δ¹⁵N, including sample codes used as labels in the corresponding plot of δ¹³C vs δ¹⁵N in Figure 6-31. The results are discussed sequentially according to the kinds of samples analyzed, namely, the charred surface residues on the experimental pots prepared in Chapter 5, plants, animal bones, and fish meat.

The charred surface residues kept intact on pots E9, E12-E15, and E8 were analyzed to see if the results of bulk stable isotopic analysis would be consistent with their respective expected ranges. Those from pots used for cooking inland freshwater fishes (CSR7 and CSR8 on pots E9 and E12, respectively) have δ¹³C values within the conventional range for freshwater resources, which are more negative than those of marine resources (see Craig et al. 2007), but have δ¹⁵N values lower than expected for aquatic resources (see Evershed 2009). The same is the case for those from pots used for cooking marine fishes (CSR9 and CSR10 on pots E13 and E14, respectively, see Table 6.1), with δ¹³C values within the conventional range for marine resources. The low δ¹⁵N values for charred surface residues on pots used for cooking fishes, in general, is surprising because higher values were expected, especially for those on pots used for cooking marine fishes. In the case of charred surface residues on the pot used for cooking swamp cabbage (CSR 11 on pot E15), the δ¹³C value fell within the
conventional range for C3 plants (from -22‰ to -33‰, after DeNiro 1987 and Evershed 2009). Its \( \delta^{15}N \) value is within the range for plants if referring to the synthetic work of DeNiro (1987), but higher if referring to the synthetic work of Evershed (2009). Only the charred surface residues on the pot used for cooking millet had \( \delta^{13}C \) and \( \delta^{15}N \) values that conformed to the ranges for C4 plants (from -8‰ to -21‰ for \( \delta^{13}C \), 5‰ and below for \( \delta^{15}N \); after Evershed 2009). The \( \delta^{13}C \) and \( \delta^{15}N \) values gathered for charred surface residues or carbonized remains should be useful as reliable reference materials because their isotopic records are supposed to be sealed by the burning process (DeNiro 1987). This was based on the difference between values from uncharred remains and corresponding modern plants (DeNiro and Hastorf 1985). However, direct comparison of values from modern and archaeological charred surface residues could be problematic because of the loss of some organic compounds, such as amino acids and carbohydrates, over long-term burial in the archaeological record. Amino acids and carbohydrates are more enriched in \(^{13}C\) than lipids. As a result, amino acids and carbohydrates should elevate \( \delta^{13}C \) values of charred residues on modern cooking pots compared to lipid-dominated residues characteristic of archaeological pottery (Heron and Craig 2015). The validity of the data from charred surface residues included in this work could depend on the type of food, whether animal or plant sources, that were cooked in the pot. Results for the charred surface residues on experimental pots are further discussed below.

The plant samples, including the charred surface residues from pots used to cook plant food sources (CSR11 and CSR 12 on pots E15 and E8, respectively), were divided into three groups according to their \( \delta^{13}C \) and \( \delta^{15}N \) values (Fig. 6-31) instead of
expected two groups of C₃ and C₄ plants. The C₃ plant group was further divided into two groups: those with low δ¹⁵N values (rice and McCormick spices) and those with high δ¹⁵N values [CSR11 on swamp cabbage pot (E15) and nutmeg from Banda Islands, Indonesia (B26)]. Those with high δ¹⁵N values could have originated from areas that are ¹⁵N enriched because of long-term use of natural fertilizers, such as animal manure, that can mimic trophic-level increases of δ¹⁵N (Bogaard et al. 2007) and/or valuesd from low-altitude areas that receive low amounts of precipitation (Szpak et al. 2013). Based on these findings, I cannot simply assume that high δ¹⁵N values indicate animal sources of food in the diet.

This work is the first to report δ¹³C and δ¹⁵N values of sedges (Scirpus sp. sensu lato) from southern Vietnam or the Mekong Delta region that has archaeobotanical evidence of their use as a prehistoric food source (Castillo 2014). This is also the first work to report isotopic data of two important spices of SEA, namely, cloves and nutmeg that were originally from and only grown in Eastern Indonesia. It is very fortunate and significant that one of the nutmeg samples was actually acquired from the former sole source of nutmeg, which is the Banda Islands in Maluku, Eastern Indonesia. Its δ¹³C and δ¹⁵N values are higher than the McCormick spice samples of unknown origin. This finding suggests that the two nutmeg samples came from different sources with different growing conditions.

Furthermore, the δ¹³C and δ¹⁵N values acquired in this work were compared with published data on similar food sources. More reliable comparisons can be done with δ¹³C values, but not with δ¹⁵N values, because of unknown differences in the soil conditions where the plants were acquired. The average value for δ¹³C (-10.49‰) of
Job’s tears from southern Vietnam is more negative than that in samples from Thailand (-8.1‰; in King 2006). The rice samples from the Philippines have higher \( \delta^{15}N \) values and more negative \( \delta^{13}C \) values than those from Vietnam. The average \( \delta^{13}C \) value from Vietnam (25.92‰) falls within the range of \( C_3 \) cereals, comprising various types of rice, of Thailand (from -26.2‰ to -23.4‰; in King 2006), and near the value for the Koshihikari rice in Vietnam (-25.1‰; corrected from -26.6‰; in Korenaga et al. 2010). The \( \delta^{13}C \) values of rice samples from the Philippines (-27.48‰, -27.81‰, and -27.58‰) were more positive or less negative than the rice samples from Thailand reported by King (2006). The average \( \delta^{13}C \) value of charred surface residues on the pot used for cooking swamp cabbage (-25.73‰ for CSR11 on E15) is more positive than the specimen of swamp cabbage in Thailand (-27.2‰; in King 2006).

The \( \delta^{13}C \) values of charred surface residues on the pots used for cooking foxtail millet (11.64‰ for CSR 12 on E8) and foxtail millet grains (11.62‰ for B1) are very similar. This substantiates the fact that charring preserves the isotopic signature. The \( \delta^{13}C \) values acquired from carbonized remains of plants, such as charred surface residues from cooking plant food, are reliable for archaeological reconstruction (DeNiro 1987). This assumption is also substantiated by the work of Yang et al. (2011) on foxtail and common millets from Northern China, which probably come from the same or a nearby region to where the foxtail millet grains used for this work originated.

Figure 6-31 also plots \( \delta^{13}C \) and \( \delta^{15}N \) values of modern animal bone collagen, including the pigs and chickens from Vietnam and the Philippines. The \( \delta^{13}C \) values for the chickens support a \( C_4 \) diet, whereas the pigs have lower \( \delta^{13}C \) values suggesting a more mixed \( C_3 \) and \( C_4 \) diet. Unfortunately, the \( \delta^{13}C \) and \( \delta^{15}N \) values from bone collagen
are not comparable to isotopic data of charred surface residues of prehistoric pottery because the composition of the latter is highly variable and fundamentally different from bone (Heron and Craig 2015). Despite this fact, the $\delta^{13}$C and $\delta^{15}$N values acquired from terrestrial animal samples provide some similarities and differences within SEA. As seen in Table 6-1, the pigs and chicken from the Philippines have higher $\delta^{15}$N values and more positive $\delta^{13}$C values than those from Vietnam. The $\delta^{13}$C values of chickens in southern Vietnam (-13.82‰) and the Philippines (-17.05‰) are more positive than those from Thailand (-19.97‰, corrected from -21.47‰ as an average value from domestic and wild chickens; in King 2006). The $\delta^{13}$C values of domestic pigs in Vietnam (-21.85‰ and -21.76‰) and the Philippines (-20.62‰) are similar in the value in a wild pig from Thailand (-19.7‰, corrected from -21.2‰ in King 2006). Low $\delta^{15}$N values are unexpected for the terrestrial animal samples acquired from SEA. It is possible that depleted carbon or more negative $\delta^{13}$C values and very low $\delta^{15}$N values characterize the diet of the animals from farming areas that are free from commercial fertilizers and/or fed with "organic," rather than commercial feeds.

For the fish samples, meat tissues were analyzed to acquire their $\delta^{13}$C and $\delta^{15}$N values. The values from fish meat, rather than bone collagen, are more appropriately compared with those from charred surface residues on prehistoric pottery. Based on the plot of $\delta^{13}$C vs $\delta^{15}$N (Fig. 6-31), there is a clear division between freshwater and marine fishes in terms of their $\delta^{13}$C from meat samples and charred surface residues on pots used for cooking fishes. The fish samples have different $\delta^{15}$N values, which could be a function of the length of the food chain in which a particular aquatic source was involved (Warinner 2014). Higher $\delta^{15}$N values indicate involvement in a longer food chain.
(DeNiro 1987). Most of the fishes have $\delta^{15}$N values higher than those of terrestrial
domesticated animals (pigs and chickens) and the majority of plants (Figure 6-31 and
Table 6-1).

The modern samples analyzed for bulk $\delta^{13}$C and $\delta^{15}$N ($n=26$) are too few to make
meaningful comparisons between different food categories and locations (between
Vietnam and the Philippines). Averaging of data was not done as in the works of
Garong (2013) and King (2006), given the need for more exhaustive sampling. The next
section discusses the results of the CSIA of modern reference materials. This includes
the assessment of the results from bulk stable isotopic analysis discussed in this section
if they reflect or correlate with those from CSIA.

**Compound Specific $\delta^{13}$C of C16 and C18 Fatty Acids from Modern Reference
Materials**

Table 6-2 shows the results obtained, including sample codes used as labels in
the corresponding plots of $\delta^{13}$C of C16 fatty acid vs $\delta^{13}$C of C18 fatty acid from Figures
6-32 to 6-37. Results are discussed sequentially according to the food sources
analyzed, namely, pigs, fishes, chickens, and plants.

Starting with the pigs (Figs. 6-32 and 6-33), the $\delta^{13}$C values of C16 and C18 fatty
acids for the pigs from Vietnam (B8 and B9) are $^{13}$C-depleted in contrast to those from
the Philippines (B11), including the pots used for cooking pork (E3 and E22). In the
case of aquatic resources, the $\delta^{13}$C values from salted, dried freshwater fishes (B13-
B15, and B17) and the pots used for cooking freshwater fishes (E7, E12, E17, E18,
E10, and E11) are similarly depleted. It is also the same case with those from salted,
dried marine fishes (B16 and B18-B23) and the pots used for cooking marine fishes at
the right side of that graph (E13 and E14), where their $\delta^{13}$C values are similarly
enriched. The pot used to cook both freshwater and marine fishes (E4) plots where the freshwater and marine fishes overlap, together with the two black pots from Kalinga in northern Philippines that were assumed to be used for cooking fishes and vegetables based on odor (E17 and E18). The values from the chickens (B10, B12, and E5) are $^{13}$C-enriched. Chickens available in the grocery stores in the Philippines were fed with commercial feeds containing corn, a C$_4$ plant. The chickens used for cooking in pot E5 were acquired in the grocery. A conscious effort was made to collect bones of chickens fed with an “organic” diet in both Vietnam and the Philippines. Results of pot E5, however, show the chickens still exhibit less negative δ$^{13}$C values than those exhibited by the chickens in the Northern Atlantic (Dudd 1999). All these chickens thus seemed to have C$_4$ diets, regardless if they were fed with “commercial” or “organic” feeds.

In the case of plants (Figs. 6-32 and 6-34), completing the results from CSIA was challenging because of the dominance of unsaturated acids (C18:2 and two isomers of C18:1 fatty acids) and the co-elution of C18:1 fatty acid with C18 fatty acid in biological samples of rice (B3-B6) and foxtail millet (B7) as well as in the charred surface residues on the pot used for cooking foxtail millet (CSR12 on E8). The former was not an obstacle for the pots used for cooking plant food sources as well as biological samples of Job’s tears (B1), sedge (B2), cloves (B24), and nutmegs (B25 and B26) because the C16 fatty acid still dominated over C18 and unsaturated fatty acids. However, the FAMEs from cloves and nutmegs have other complications. In the case of the cloves, eugenol, which is its predominant component (Singletary 2014), joined the fatty acids in the acidic fraction of the oil extract and its amount is much greater than the C16 and C18 fatty acids. Eugenol has an aromatic benzene ring and a methyl group (Singletary
2014), and the latter makes eugenol have an overlapping chemical behavior with FAMEs. In the case of the nutmegs, the amount of C14 fatty acid is much greater than the C16 and C18 fatty acids, since C14 fatty acid or myristic acid is the dominant fatty acid and component of nutmeg (Aborased and El-Alfy 2016). Dilution of FAMEs according to the concentrations of eugenol and C14 fatty acids for cloves and nutmegs, respectively, would result in the inability of GC-C-IRMS to detect C16 and C18 fatty acids and acquire the necessary δ^{13}C values. FAMEs from samples B24-B26 were still diluted according to the concentrations of C16 fatty acid. The helium backflush was adjusted to start after the elution times of these dominant components.

Although only the FAMEs from rice (B3-B6) and foxtail millet (B7) samples, as well as the charred surface residues (CSR12) on pot E8 used to cook foxtail millet, needed to be purified for a second time with 5% silver nitrate impregnated silica gel, all FAMEs from modern plant samples underwent this second purification procedure to separate the saturated fatty acids, which include the C16 and C18 fatty acids, from unsaturated fatty acids. The δ^{13}C values of C16 and C18 fatty acids from Job’s tears, sedge, and spices before and after purification with 5% silver nitrate impregnated silica gel can be compared. However, this purification procedure was unable to bring C16 and C18 fatty acids into the desired fraction supposedly containing saturated fatty acids eluted by hexane. No C16 and C18 fatty acids appeared during the CSIA of fatty acids. Thus, no data were acquired from the CSIA of rice (B3-B6) and millet (B7 and CSR 12) samples. It seemed that the method was not appropriate for separating saturated and unsaturated fatty acids, which are polar compounds. It is routinely used for separating saturated and unsaturated alkanes, which are apolar compounds (Diefendorf et al.)
Although this procedure seemed to work with thin layer chromatography that uses silica-based plates (Wilson and Sarjent 2001), it did not work with supercritical fluid chromatography (Simon and Cocks 1994). This argentation column chromatography is more appropriate to separate unsaturated fatty acids according to their degrees of saturation (Hoque et al. 1973). Urea fractionation or crystallization is the appropriate procedure to separate saturated and unsaturated fatty acids after the acidic fraction is acquired from the saponification procedure (Hidajat et al. 1995; Campra-Madrid and Guil-Guerrero 2002); however, no literature on the use of this procedure for CSIA and organic residue analysis was available to assess if this had ever been done for those purposes.

As expected (Figs. 6-32 and 6-34), C₄ plants [Job’s tears (B1), sedge (B2), and foxtail millet (E8)] have more positive δ¹³C values of C₁₆ and C₁₈ fatty acids than the C₃ plants [rice (E2 and E6), swamp cabbage (E15), coconut (E16), cloves (B24), and nutmegs (B25 and B26). There is a wide variation among the C₃ plants, where the pots used for cooking rice without husks (E2) and coconut milk (E16) have more positive δ¹³C values than the others. Only the pots used for cooking rice with husks (E6) and swamp cabbage (E15), as well as the nutmeg from the Banda Islands, have δ¹³C values of C₁₆ and C₁₈ fatty acids within the range of those from the Eastern Mediterranean C₃ plant oils (Steele et al. 2010). The nutmegs from two different sources (B25 and B26) have different δ¹³C values of C₁₆ and C₁₈ fatty acids. The δ¹³C values of C₁₆ and C₁₈ fatty acids from cloves (B24) are more negative than those from other plant sources included in this work.
A case of possible mixing of animal and plant food sources (Mukherjee et al. 2005) is reported in this work. The $\delta^{13}C$ values of C16 and C18 fatty acids from pot E21 used for cooking freshwater snails with coconut milk and swamp cabbage, which are lumped together with those of marine fishes, seem to be not from the snails, but from the coconut milk. This can be demonstrated (Fig. 6-32) by almost similar values from this pot (E21) and from a pot used for heating coconut milk (E16). Thus, pot E21 is a case where plant lipids dominate animal lipids as a source for $\delta^{13}C$ values of C16 and C18 fatty acids (Mukherjee et al. 2005). If the mixing effect also occurred in the cases of the two mixed cooking experimental pots (E17 and E18) and the rest of the ethnographic cooking pots (E19, E20, and E22), the animal lipids seemed to dominate over other ingredients, some of which are from plants (vegetables and spices). Freshwater fishes were cooked on pots E17 and E18 with other ingredients. Their $\delta^{13}C$ values of C16 and C18 fatty acids within the range for freshwater sources are reasonable. For the pots acquired from Kalinga, Philippines (E19 and E20), marine fishes were probably cooked in these pots, given that their $\delta^{13}C$ values of C16 and C18 fatty acids fell in the range for marine sources. After all, it is feasible that marine fishes can reach inland and highland areas through transport and trade. Lastly, the $\delta^{13}C$ values of C16 and C18 fatty acids from the pot used for pork stew in peanut sauce (E22) are similar to values from the pot used for experimental cooking of pig meat (E5).

The CSIA of lipid extracts from both absorbed and charred surface residues from the same experimental pot was also explored in this work. These are the experimental pots used for cooking marine fishes from the Philippines (E14, CSR10 on E14) and foxtail millet (E8, CSR12 on E8). In the case of the first pot (E14), the $\delta^{13}C$ values of
C16 fatty acid from absorbed (E14) and surface (CSR10) residues are almost the same, but the δ¹³C value of C18 fatty acid from the absorbed residues is more positive (Figs. 6-32 and 6-33). This can probably be explained by the difference in the lipid composition between the absorbed and surface residues, where the former represented the average composition from several cooking episodes of different fish species and the latter probably represented its last cooking episode or the last fish species cooked in the pot. Thus, the δ¹³C values of C16 and C18 fatty acids from different types of residues on the same artifact are not expected to always be the same (Heron and Craig 2015; Mukherjee et al. 2008). In the case of the second pot (E8), no comparison was done between absorbed and charred surface residues because no values could be acquired for the latter.

Variation in Δ¹³C values was not pursued in this work because of missing animal sources in the present assemblage of modern reference samples. Examining the relationship of δ¹³C values of C18 fatty acid vs Δ¹³C values (subtracting δ¹³C of C16 fatty acid from that of C18 fatty acid) would differentiate between nonruminant adipose meat, ruminant adipose meat, dairy products, and marine sources. Ruminant meat sources and dairy products are lacking in this work, as the latter did not exist in prehistoric SEA. Only nonruminant meat sources (pigs and chickens) among the terrestrial animal sources are included in this work.

Since a few charred surface residues on experimental pottery and biological materials have results of both bulk and compound-specific isotopic analyses, we can compare their δ¹³C values from bulk samples against the δ¹³C values from C16 and C18 fatty acids. As seen in the values tallied in Table 6-3, all bulk δ¹³C values are more
positive than the $\delta^{13}C$ values from C16 and C18 fatty acids. This is because bulk samples have other nonlipid components that are more $^{13}C$-enriched than the more $^{13}C$-depleted lipids (DeNiro and Epstein 1977). In both bulk (Fig. 6-31) and compound specific isotopic analyses (Figs. 6-32 and 6-33), chickens are more $^{13}C$-enriched than pigs. The trends for plants are also the same, as shown in Figures 6-31 and 6-32 or 6-34.

In the case of the fishes, however, results from the bulk (Fig. 6-31) and compound specific isotopic analyses differ (Figs. 6-32 and 6-33). There is a division between freshwater and marine fishes based on the results of bulk stable isotopic analysis (Fig. 6-31), but there is a potential overlap between these two groups of fishes based on the results of CSIA (Figs. 6-32 and 6-33). The charred surface residues on pots E9 (CSR7) and E12 (CSR8) used for cooking inland freshwater fishes are clearly grouped with other freshwater fishes based on bulk stable isotopic analysis (Fig. 6-31). In contrast, the $\delta^{13}C$ values from C16 and C18 fatty acids of pot E12 are more positive than those from freshwater fish samples and other pots used for cooking freshwater fishes (Figs. 6-32 and 6-33). Similarly, the charred surface residues on pot E13 (CSR9) are clearly grouped with other marine fishes based on bulk stable isotopic analysis (Fig. 6-31). In contrast, the $\delta^{13}C$ values from C16 and C18 fatty acids of pot E13 are more negative than those from marine fish samples and other pots used for cooking marine fishes (Figs. 6-32 and 6-33). In addition, the $\delta^{13}C$ values from C16 and C18 fatty acids from pots E12 and E13 are close to each other (Tables 6-2 and 6-3) and fall in between the values from freshwater and marine fishes. This could be because the fishes cooked in pot E13 and probably some fishes cooked in pot E12 are from brackish waters, which
explains the contrast of the trends between the results from bulk stable isotopic analysis and CSIA. Aquatic sources from estuarine or brackish environments may exhibit inconsistencies in $\delta^{13}$C values. The results from CSIA of C16 and C18 fatty acids from fishes is further discussed in the next section.

The results reported here composed the initial modern comparative reference database for CSIA of organic residues for SEA, satisfying the first objective of Chapter 6. The next section satisfies the second objective, which compares this database with those available from other areas.

**Southeast Asia in Comparison with Other Geographic Regions**

This section compares the data from the previous section to corresponding data from other geographic areas, starting from animals to plants. Unfortunately, the higher $\delta^{13}$C values of C16 and C18 fatty acids from the chickens acquired in SEA are incomparable with those of carbon-depleted chickens of Northern Atlantic (see Dudd 1999; Evershed et al. 2002b). However, for pigs and fishes, as well as for rice, we can compare values from SEA with those from other areas.

In the case of the pigs (Fig. 6-35), both the $\delta^{13}$C values of C16 and C18 fatty acids from $^{13}$C-depleted pigs in Vietnam (B8 and B9) and those from $^{13}$C-enriched pigs in the Philippines (B11, E3, and E22) are outside the ranges of values from domestic pigs in European areas of Northern Atlantic (Dudd 1999) and the Mediterranean area (Spiteri 2012). Interestingly, the $\delta^{13}$C values from the pigs in Vietnam (B8 and B9) fall within the range of wild boars of the Middle East (Gregg et al. 2009). The same is the case for values from the pig fed with an organic diet in the Philippines (B11), which fall within the range of wild boars of the Mediterranean area (Spiteri 2012). This is despite
the fact that samples B8, B9, and B11 are from domestic pigs that lived in farming areas with no nearby forest. The $\delta^{13}$C values from the domestic pigs cooked in pots E3 and E22 from the Philippines are $^{13}$C-enriched compared to the domestic pigs in the northern Atlantic (Dudd 1999) and Mediterranean area (Spiteri 2012). It is a conundrum why values from domestic pigs with known organic diet fall within those from the wild pigs in other geographic areas. This pattern may be attributed to the fact the domestic pigs that were fed an organic diet were free-ranging and able to forage and consume food sources similar to those of wild boars, since the organic diet resembles the present-day natural diet of wild animals. Sampling wild boars from the region would help clarify this issue. The difference between the $\delta^{13}$C values from Vietnam and the Philippines, as well as within the Philippines, may reflect local variation within the Southeast Asian region. This cannot be substantiated with only five samples, and more samples from the region, including samples of wild boars, are necessary to clarify this.

In the case of the fishes (see Fig. 6-36), no differences were observed for $\delta^{13}$C values of both freshwater and marine fishes between those from SEA and other areas. Instead, what is emphasized here is the overlap between freshwater and marine fishes caused by the mixture of freshwater and marine fishes in pot E4, and probably in pots E19 and E20, as well as the fishes from brackish or estuarine waters in pot E13 and probably in pot E12. It was previously mentioned that marine fishes were probably cooked on the pots acquired from Kalinga, Philippines (E19 and E20). Freshwater fishes could have also been cooked in those pots, since they were acquired from an inland area (locality of Talalang) with access to a nearby river. Although the ranges for freshwater and marine sources are discrete in other areas, this is apparently not the
case in SEA. This graph (Fig. 6-36) shows the broad range in values for aquatic sources that can lead to overlaps between freshwater and marine resources, with no clear range for brackish or estuarine sources. This poses challenges for identifying specific sources of aquatic sources, and be a consequence of some aquatic organisms moving between freshwater, estuarine, and marine environments during their lifetime (Heron and Craig 2015). This is probably the case in deltaic areas, such as the Mekong Delta or southern Vietnam. Regardless of locations and environment, the use of pots for preparing aquatic food sources from various environments is not surprising as it is easy to transport such foods from one location or environment to another.

In the case of cereals (Fig. 6-37), we can only compare the data from the experimental cooking pots with the data from cooked rice and millet of East Asia (Taiwan) in the work of Yang and March (2012). The $\delta^{13}C$ values of C16 and C18 fatty acids from pots used for cooking rice (E2 and E6) are more positive than that observed for cooked rice in East Asia. In contrast, the values from the pot used for cooking foxtail millet (E8) are more negative than the range for cooked millet in East Asia. This finding is similar to the finding observed in the work of Yang and March (2012), in which the values from their pots used for cooking carbohydrate sources (rice and taro) are more positive than those of rice and more negative than those of millet. It is then possible that the graph (Fig. 6-37) indicates the effects of cooking with clay pots on the $\delta^{13}C$ values of cereals rather than geographic variation. Thus, the values from residues of modern cereals cooked on pottery could be more appropriate reference values than those from raw and cooked cereals for organic residue analysis of archaeological pottery. This
matter should be further explored with comparative data from raw and cooked rice and millet.

Conclusions and Further Work

Chapter 6 presents the results of bulk and compound specific stable isotopic analyses of modern used pottery and biological materials intended to be a comparative reference database for organic residue analysis in SEA. The $\delta^{13}$C and $\delta^{15}$N values from these materials are useful additions to those already available in the region. The $\delta^{13}$C values of C16 and C18 fatty acids reported here comprise the first modern comparative reference database for CSIA of archaeological organic residues for SEA.

There are clear differences between values from domestic pigs cooked in the pots from the Philippines and European areas, as well as between those from the Philippines and Vietnam. The latter probably indicates local variation within the Southeast Asian region, but more samples of domestic and wild pigs are needed to substantiate this. Finding pig residues on pottery from Southeast Asian archaeological sites based on compound specific isotopes would be more complicated because of this observed local variation, including complications involving organic diets, and reference databases from other regions seem not to apply to Southeast Asia. Also, the area where the freshwater and marine sources overlap in Southeast Asia warrants further exploration. The findings presented here have implications for interpreting archaeological residues on material culture from sites near both fresh and marine bodies of waters, especially if ancient occupants did not discriminate between cooking freshwater and marine resources in pottery.
Admittedly, this comparative database in incomplete. This is an endeavor in progress, to which missing animal sources, such as wild nonruminant animals, wild and domesticated ruminant animals, other poultry like ducks and goose, as well as other aquatic resources, such as shellfishes and marine mammals, should be added in the future. Chickens, and other terrestrial animals, with known pure C\textsubscript{3} diets should be sampled, as their isotopic values should be comparable with those from other geographic areas. If logistics permit, adipose (meat) tissue should be sampled because it is a more appropriate comparative material for the analysis of organic residues on archaeological materials. More indigenous varieties of rice and other cereals in SEA, cloves and nutmegs from their former sole source (Maluku Islands, Indonesia), as well as indigenous fruits, vegetables, and spices from the region should be added to the assemblage of floral reference materials. Mixing of different food categories should be further explored. Lastly, faunal and floral remains from archaeological sites in Southeast Asia, if possible, should also be added since they would make a suitable direct reference. These bioarchaeological remains should be analyzed for bulk and compound specific stable isotopes.

I also recommend exploration of other extraction and purification procedures. Acidified methanol extraction, which is a direct extraction and methylation procedure (Correa-Ascencio and Evershed 2014), is suggested for analysis of animal bones (Colonese et al. 2015). Urea fractionation or crystallization method (e.g., Hidajat et al. 1995; Campra-Madrid and Guil-Guerrero 2002) should be modified to separate C\textsubscript{16} and C\textsubscript{18} fatty acids from unsaturated fatty acids, which would make CSIA feasible for several plant samples, such as rice and millet grains in this work.
Chapter 8 discusses the results of the organic residue analysis of archaeological pottery from SEA, specifically southern Vietnam. It also assesses how the findings here in Chapter 6 and in Chapter 5 can assist in the interpretation of the results in Chapter 8. Prior to organic residue analysis in Chapter 8, these archaeological pottery are analyzed for their technofunctional attributes in Chapter 7.
Figure 6-1. Plot of $\delta^{13}C$ values of C16 and C18 fatty acids obtained from modern biological reference materials in the Northern Atlantic (or Great Britain, Copley et al. 2003; Dudd and Evershed 1998; Dudd et al. 1999), Northern Europe (Craig et al. 2011), Eastern Mediterranean Area (Steele et al. 2010), and East Asia (Japan, Craig et al. 2013) (graph modified from Fraser et al. 2012).
Figure 6-2. Plot of $\delta^{13}C$ values of C16 and C18 fatty acids from modern animals as sample confidence ellipses ($p=0.6834$) and theoretical mixing ranges (Fig. 6 in Mukherjee et al. 2005:83).
Figure 6-3. Plot of $\delta^{13}C$ values of C16 and C18 fatty acids obtained from modern wild boars and domestic pigs in the Northern Atlantic (or Great Britain, Dudd 1999), Northern Europe (Craig et al. 2007), Mediterranean Area (Spiteri 2012), Middle East (Gregg et al. 2009), and East Asia (Japan, Craig et al. 2013; Lucquin et al. 2016b).
Figure 6-4. Plot of δ^{13}C values of C16 and C18 fatty acids obtained from modern ruminant animals, which are deer and cows, in the Northern Atlantic (or Great Britain, Dudd 1999; Lucquin et al. 2016b), Northern Europe (Craig et al. 2007, 2012), Mediterranean Area (Spiteri 2012), Middle East (Gregg et al. 2009), and East Asia (Japan, Craig et al. 2013; Lucquin et al. 2016b).
Figure 6-5. Plot of $\delta^{13}$C values of C16 and C18 fatty acids obtained from modern freshwater and marine sources from the Northern Atlantic (or Great Britain, Dudd 1999; Craig et al. 2007; Lucquin et al. 2016b), Northern Europe (Craig et al. 2011), Mediterranean Area (Spiteri 2012), Middle East (Gregg et al. 2009), Canada (Tache and Craig 2015), and East Asia (Japan, Craig et al. 2013; Lucquin et al. 2016b).

Figure 6-6. Metal Age site of Lò Gạch, Long An, Vietnam (Photo by M.S. Eusebio).
Figure 6-7. Pig 1 bones (B8) from Long An, Vietnam (Photo by M.S. Eusebio).

Figure 6-8. Pig 2 (B9) from Long An, Vietnam. A) Soup dish and B) bones (Photos by M.S. Eusebio).

Figure 6-9. Chicken 1 (B10) from Long An, Vietnam. A) Stew and B) bones (Photos by M.S. Eusebio).

Figure 6-10. Salted, dried Cá chach (*Macrognathus siamensis*, spot-finned spiny or peacock eel, B13) from Long An, Vietnam (Photo by M.S. Eusebio).
Figure 6-11. Local variety of red rice (*Oryza sativa*, B3) from Long An, Vietnam (Photo by M.S. Eusebio).

Figure 6-12. Job's tears (*Coix lacryma-jobi*, B1) from Long An, Vietnam. A) Live plants and B) dried plants (Photos by M.S. Eusebio).

Figure 6-13. Sedge (*Scirpus* sp., B2) from Long An, Vietnam. A) Live plant and B) dried plant (Photos by M.S. Eusebio).

Figure 6-14. Salted, dried *Cá loc* (*Channa* sp. prob. *Gachua*, snakehead fish, B14) from Long An, Vietnam (Photo by M.S. Eusebio).
Figure 6-15. Salted, dried Cá kèo (*Pseudapocryptes lanceolatus* Bloch, pointed tail goby, B15) from Long An, Vietnam (Photo by M.S. Eusebio).

Figure 6-16. Salted, dried Cá bo'ng cá́t bien (*Sillago* sp., sand borer sillaginid, B16) from Long An, Vietnam (Photo by M.S. Eusebio).

Figure 6-17. Salted, dried Cá sặc lò tho [*Trichopodus* sp. (prob. *pectoralis*), snakeskin gourami, B17] from Long An, Vietnam (Photo by M.S. Eusebio).

Figure 6-18. Salted, dried Cá lù đù (*Micropogonias undulates*, croaker fish, B18) from Long An, Vietnam (Photo by M.S. Eusebio).
Figure 6-19. Salted, dried *Cà luỗi trâu* (*Cynoglossus microlepis*, tongue sole, B19) from Long An, Vietnam (Photo by M.S. Eusebio).

Figure 6-20. Salted, dried *Dilis* (*Stolephorus indicus*, anchovy, B20) from Zambales, Philippines (Photo by M.S. Eusebio).

Figure 6-21. Salted, dried *Salingası/Tabagak* (*Sardinella fimbriata*, fringe scale sardine, B21) from Zambales, Philippines (Photo by M.S. Eusebio).

Figure 6-22. Salted, dried *Sapsap* (*Leiognathus equulus*, ponyfish/slipmouth, B22) from Iloilo, Philippines (Photo by M.S. Eusebio).
Figure 6-23. Salted, dried *Guma-a* (*Pseudocaranx dentex*, white trevally, B23) Iloilo, Philippines (Photo by M.S. Eusebio).

Figure 6-24. Black rice (*Oryza sativa*, B4) and *camoros* rice (*Oryza sativa*, B5), respectively, from Iloilo and Capiz, Philippines (Photo by M.S. Eusebio).

Figure 6-25. *Bisaya* rice (*Oryza sativa*, B6) Capiz, Philippines (Photo by M.S. Eusebio).

Figure 6-26. Pig 3 (B11) from Zambales, Philippines. A) Soup dish and B) bones (Photos by M.S. Eusebio).
Figure 6-27. Chicken 2 (B12) from Zambales, Philippines. A) Soup dish and B) bones (Photos by M.S. Eusebio).

Figure 6-28. Cloves (*Syzygium aromaticum*, B24) from McCormick (Photo by M.S. Eusebio).

Figure 6-29. Nutmeg (*Myristica fragrans*, B25) from McCormick (Photo by M.S. Eusebio).

Figure 6-30. Nutmeg (*Myristica fragrans*, B26) from Maluku, Indonesia. A) Whole seed and B) cracked seed (Photos by M.S. Eusebio).
Table 6-1. Bulk stable isotope values (carbon and nitrogen) from charred interior surface residues on experimental pottery as well as modern plant, fish, and terrestrial animal samples.

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>Sample Description</th>
<th>wt. %C</th>
<th>wt. %N</th>
<th>Raw $\delta^{13}$C (‰ PDB)</th>
<th>Corrected $\delta^{13}$C (‰ PDB)</th>
<th>$\delta^{15}$N (‰ AIR)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSR 7</td>
<td>Inland Freshwater Fishes SV1 (on E9)</td>
<td>22.42</td>
<td>4.15</td>
<td>-26.49</td>
<td>-24.99</td>
<td>5.17</td>
<td>Very few</td>
</tr>
<tr>
<td>CSR 8</td>
<td>Inland Freshwater Fishes SV2 (on E12)</td>
<td>23.46</td>
<td>3.83</td>
<td>-28.31</td>
<td>-26.81</td>
<td>6.75</td>
<td>Very few</td>
</tr>
<tr>
<td>CSR 9</td>
<td>Marine Fish, SV (on E13)</td>
<td>18.08</td>
<td>4.96</td>
<td>-20.10</td>
<td>-18.6</td>
<td>8.06</td>
<td>Very few</td>
</tr>
<tr>
<td>CSR 10</td>
<td>Marine Fishes, Pup (on E14)</td>
<td>37.37</td>
<td>11.06</td>
<td>-16.80</td>
<td>-15.3</td>
<td>5.02</td>
<td>Extracted for lipids</td>
</tr>
<tr>
<td>CSR 11</td>
<td>Swamp Cabbage, Pup (on E15)</td>
<td>33.30</td>
<td>4.14</td>
<td>-27.23</td>
<td>-25.73</td>
<td>7.65</td>
<td>Extracted for lipids</td>
</tr>
<tr>
<td>CSR 12</td>
<td>Foxtail Millet, PRC (on E8)</td>
<td>54.18</td>
<td>2.72</td>
<td>-13.14</td>
<td>-11.64</td>
<td>3.30</td>
<td>Extracted for lipids</td>
</tr>
<tr>
<td>B1</td>
<td>Job's Tears (Coix lacryma-jobi, SV)</td>
<td>39.68</td>
<td>2.36</td>
<td>-11.99</td>
<td>-10.49</td>
<td>3.80</td>
<td>Leaves and stems</td>
</tr>
<tr>
<td>B2</td>
<td>Sedge (Scirpus sp., SV)</td>
<td>39.20</td>
<td>0.68</td>
<td>-13.38</td>
<td>-11.88</td>
<td>4.47</td>
<td>Leaves and stems</td>
</tr>
<tr>
<td>B3</td>
<td>Brown Rice (Oryza sativa, SV)</td>
<td>42.20</td>
<td>1.44</td>
<td>-27.42</td>
<td>-25.92</td>
<td>1.72</td>
<td>Grains</td>
</tr>
<tr>
<td>B4</td>
<td>Black Rice (Oryza sativa, Php)</td>
<td>42.69</td>
<td>1.72</td>
<td>-28.98</td>
<td>-27.48</td>
<td>2.51</td>
<td>Grains</td>
</tr>
<tr>
<td>B5</td>
<td>Camoros Rice (Oryza sativa, Php)</td>
<td>43.35</td>
<td>1.48</td>
<td>-29.31</td>
<td>-27.81</td>
<td>3.28</td>
<td>Grains</td>
</tr>
<tr>
<td>B6</td>
<td>Bisaya Rice (Oryza sativa, Php)</td>
<td>43.39</td>
<td>1.32</td>
<td>-29.08</td>
<td>-27.58</td>
<td>3.74</td>
<td>Grains</td>
</tr>
<tr>
<td>B7</td>
<td>Foxtail Millet (Setaria italica, PRC)</td>
<td>43.87</td>
<td>2.34</td>
<td>-13.12</td>
<td>-11.62</td>
<td>2.55</td>
<td>Grains</td>
</tr>
<tr>
<td>B24</td>
<td>Cloves (Syzygium aromaticum, McCormick)</td>
<td>53.19</td>
<td>1.18</td>
<td>-30.95</td>
<td>-29.45</td>
<td>1.27</td>
<td>Dried flower bud</td>
</tr>
<tr>
<td>B25</td>
<td>Nutmeg (Myristica fragrans, McCormick)</td>
<td>56.00</td>
<td>1.01</td>
<td>-30.87</td>
<td>-29.37</td>
<td>1.99</td>
<td>Seed</td>
</tr>
<tr>
<td>B26</td>
<td>Nutmeg (Myristica fragrans, Banda Islands)</td>
<td>ND</td>
<td>ND</td>
<td>-27.65</td>
<td>-26.15</td>
<td>9.01</td>
<td>Seed</td>
</tr>
<tr>
<td>B8</td>
<td>Pig 1, SV</td>
<td>42.98</td>
<td>15.05</td>
<td>-23.35</td>
<td>-21.85</td>
<td>4.36</td>
<td>C:N=3.3, yield: 21.94%</td>
</tr>
<tr>
<td>B9</td>
<td>Pig 2, SV</td>
<td>43.04</td>
<td>15.23</td>
<td>-23.26</td>
<td>-21.76</td>
<td>4.42</td>
<td>C:N=3.3, yield: 24.09%</td>
</tr>
<tr>
<td>B10</td>
<td>Chicken 1, SV</td>
<td>42.55</td>
<td>14.93</td>
<td>-15.32</td>
<td>-13.82</td>
<td>3.18</td>
<td>C:N=3.3, yield: 19.76%</td>
</tr>
<tr>
<td>B11</td>
<td>Pig 1, Php</td>
<td>42.93</td>
<td>15.03</td>
<td>-22.12</td>
<td>-20.62</td>
<td>3.11</td>
<td>C:N=3.3, yield: 19.89%</td>
</tr>
<tr>
<td>Sample Code</td>
<td>Sample Code Description</td>
<td>wt. %C</td>
<td>wt. %N</td>
<td>Raw $\delta^{13}$C (% PDB)</td>
<td>Corrected $\delta^{13}$C (% PDB)</td>
<td>$\delta^{15}$N (% AIR)</td>
<td>Remarks</td>
</tr>
<tr>
<td>-------------</td>
<td>------------------------</td>
<td>--------</td>
<td>--------</td>
<td>----------------------------</td>
<td>-------------------------------</td>
<td>-----------------------</td>
<td>---------</td>
</tr>
<tr>
<td>B12</td>
<td>Chicken 2, Php</td>
<td>41.96</td>
<td>14.28</td>
<td>-18.55</td>
<td>-17.05</td>
<td>2.93</td>
<td>C:N=3.4, yield: 17.68%</td>
</tr>
<tr>
<td>B13</td>
<td>Cá chach (Macroggnathus siamensis, spot-finned spiny or peacock eel)</td>
<td>ND</td>
<td>ND</td>
<td>-29.39</td>
<td>-27.89</td>
<td>4.58</td>
<td>Salted and dried meat</td>
</tr>
<tr>
<td>B14</td>
<td>Cá loc (Channa sp. (prob. Gachua, snake-head fish)</td>
<td>ND</td>
<td>ND</td>
<td>-27.42</td>
<td>-25.92</td>
<td>10.51</td>
<td>Salted and dried meat</td>
</tr>
<tr>
<td>B15</td>
<td>Cá kèo (Pseudapocryptes lanceolatus Bloch, pointed tail goby)</td>
<td>ND</td>
<td>ND</td>
<td>-26.28</td>
<td>-24.78</td>
<td>4.95</td>
<td>Salted and dried meat</td>
</tr>
<tr>
<td>B17</td>
<td>Cá sạc lò tho [Trichopodus sp. (prob. pectoralis), snakeskin gourami]</td>
<td>ND</td>
<td>ND</td>
<td>-23.23</td>
<td>-21.73</td>
<td>7.46</td>
<td>Salted and dried meat</td>
</tr>
<tr>
<td>B16</td>
<td>Cá bo'ng cát bien (Sillago sp., sand borer sillaginid)</td>
<td>ND</td>
<td>ND</td>
<td>-17.64</td>
<td>-16.14</td>
<td>13.63</td>
<td>Salted and dried meat</td>
</tr>
<tr>
<td>B18</td>
<td>Cá lù đù (Micropogonias undulates, croaker fish)</td>
<td>ND</td>
<td>ND</td>
<td>-17.19</td>
<td>-15.69</td>
<td>15.47</td>
<td>Salted and dried meat</td>
</tr>
<tr>
<td>B19</td>
<td>Cá lưỡi trâu (Cynoglossus microlepis, tongue sole)</td>
<td>ND</td>
<td>ND</td>
<td>-17.39</td>
<td>-15.89</td>
<td>13.81</td>
<td>Salted and dried meat</td>
</tr>
<tr>
<td>B20</td>
<td>Dilis (Stolephorus indicus, anchovy)</td>
<td>ND</td>
<td>ND</td>
<td>-18.75</td>
<td>-17.25</td>
<td>7.58</td>
<td>Salted and dried meat</td>
</tr>
<tr>
<td>B21</td>
<td>Salingsasi/Tabagak (Sardinella fimbriata, fringe scale sardine)</td>
<td>ND</td>
<td>ND</td>
<td>-17.10</td>
<td>-15.6</td>
<td>11.48</td>
<td>Salted and dried meat</td>
</tr>
<tr>
<td>B22</td>
<td>Sapsap (Leiognathus equulus, ponyfish/slipmouth)</td>
<td>ND</td>
<td>ND</td>
<td>-16.92</td>
<td>-15.42</td>
<td>10.14</td>
<td>Salted and dried meat</td>
</tr>
<tr>
<td>B23</td>
<td>Guma-a (Pseudocaranx dentex, white trevally)</td>
<td>ND</td>
<td>ND</td>
<td>-17.29</td>
<td>-15.79</td>
<td>10.13</td>
<td>Salted and dried meat</td>
</tr>
</tbody>
</table>
Figure 6-31. Bulk stable isotope values (carbon and nitrogen) obtained from charred surface residues on experimental pottery as well as modern plant, fish, and terrestrial animal samples. See Table 6-1, 6-2, or 6-3 for sample codes used as data legends.
<table>
<thead>
<tr>
<th>Sample Code</th>
<th>Sample Description</th>
<th>Sample Type</th>
<th>Provenience</th>
<th>$\delta^{13}$C (‰ PDB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>C16 FA</td>
</tr>
<tr>
<td><strong>Experimental Cooking Pots</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E2</td>
<td>Rice without husks (\textit{Oryza sativa}, 5x)</td>
<td>Absorbed residues</td>
<td>Central Luzon, Philippines</td>
<td>-25.55</td>
</tr>
<tr>
<td>E3</td>
<td>Pig (\textit{Sus scrofa}, 5x)</td>
<td>Absorbed residues</td>
<td>Philippines</td>
<td>-24.68</td>
</tr>
<tr>
<td>E4</td>
<td>Mixed freshwater-marine fishes (5x)</td>
<td>Absorbed residues</td>
<td>Philippines</td>
<td>-26.00</td>
</tr>
<tr>
<td>E5</td>
<td>Chicken (\textit{Gallus}, 5x)</td>
<td>Absorbed residues</td>
<td>Philippines</td>
<td>-20.13</td>
</tr>
<tr>
<td>E6</td>
<td>Rice with husks (\textit{Oryza sativa}, 3x)</td>
<td>Absorbed residues</td>
<td>Ifugao, Philippines</td>
<td>-28.66</td>
</tr>
<tr>
<td>E7</td>
<td>Freshwater fish pot (3x, 5 varieties)</td>
<td>Absorbed residues</td>
<td>Long An, Vietnam</td>
<td>-27.63</td>
</tr>
<tr>
<td>E8</td>
<td>Foxtail millet (\textit{Setaria italica}, 5x)</td>
<td>Absorbed residues</td>
<td>People's Republic of China</td>
<td>-23.71</td>
</tr>
<tr>
<td>CSR 12</td>
<td>Foxtail millet (\textit{Setaria italica}, 5x)</td>
<td>Charred surface residues on E8</td>
<td>People's Republic of China</td>
<td>-</td>
</tr>
<tr>
<td>E12</td>
<td>Inland freshwater fishes 2 (10x or more)</td>
<td>Absorbed residues</td>
<td>Long An, Vietnam</td>
<td>-26.08</td>
</tr>
<tr>
<td>E13</td>
<td>Marine fish (3x, three pieces of a fish from Carangidae family)</td>
<td>Absorbed residues</td>
<td>Long An, Vietnam</td>
<td>-25.82</td>
</tr>
<tr>
<td>E14</td>
<td>Marine fishes (5x)</td>
<td>Absorbed residues</td>
<td>Philippines</td>
<td>-20.65</td>
</tr>
<tr>
<td>CSR 10</td>
<td>Marine fishes (5x, on E14)</td>
<td>Charred surface residues on E14</td>
<td>Philippines</td>
<td>-20.7</td>
</tr>
<tr>
<td>E15</td>
<td>Swamp cabbage pot (\textit{Ipomoea aquatica}, 5x)</td>
<td>Absorbed residues</td>
<td>Philippines</td>
<td>-27.36</td>
</tr>
<tr>
<td>E16</td>
<td>Coconut milk (\textit{Cocos nucifera}, 1x)</td>
<td>Absorbed residues</td>
<td>Philippines</td>
<td>-25.02</td>
</tr>
<tr>
<td><strong>Ethnographic Cooking Pots</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E1</td>
<td>Blank/unused pot</td>
<td>Absorbed residues</td>
<td>Philippines</td>
<td>-24.39</td>
</tr>
<tr>
<td>E10</td>
<td>\textit{Cá Kho Tô} 1 (freshwater fishes only, cooking by stir frying)</td>
<td>Absorbed residues</td>
<td>Long An, Vietnam</td>
<td>-28.03</td>
</tr>
<tr>
<td>E11</td>
<td>\textit{Cá Kho Tô} 2 (freshwater fishes only, cooking by stir frying)</td>
<td>Absorbed residues</td>
<td>Long An, Vietnam</td>
<td>-28.28</td>
</tr>
<tr>
<td>E19</td>
<td>Unwashed, used probably for cooking fish and vegetables</td>
<td>Absorbed residues</td>
<td>Kalinga, Philippines</td>
<td>-25.39</td>
</tr>
<tr>
<td>E20</td>
<td>Washed, used probably for cooking fish and vegetables</td>
<td>Absorbed residues</td>
<td>Kalinga, Philippines</td>
<td>-25.46</td>
</tr>
<tr>
<td>E21</td>
<td>\textit{Kuhol sa Gata} (Snails in Coconut Milk)</td>
<td>Absorbed residues</td>
<td>Quezon City, Philippines</td>
<td>-25.31</td>
</tr>
<tr>
<td>E22</td>
<td>Kare (Pork Stew in Peanut Sauce)</td>
<td>Absorbed residues</td>
<td>Quezon City, Philippines</td>
<td>-23.84</td>
</tr>
<tr>
<td>B1</td>
<td>Job's Tears (Coix lacryma-jobi)</td>
<td>Leaves and stems</td>
<td>Long An, Vietnam</td>
<td>-16.05</td>
</tr>
<tr>
<td>B2</td>
<td>Sedge (Scirpus sp.)</td>
<td>Leaves and stems</td>
<td>Long An, Vietnam</td>
<td>-18.515</td>
</tr>
<tr>
<td>B3</td>
<td>Brown Rice (Oryza sativa)</td>
<td>Cereal grains</td>
<td>Long An, Vietnam</td>
<td>-</td>
</tr>
<tr>
<td>B4</td>
<td>Black Rice (Oryza sativa)</td>
<td>Cereal grains</td>
<td>Iloilo, Philippines</td>
<td>-</td>
</tr>
<tr>
<td>B5</td>
<td>Camoros Rice (Oryza sativa)</td>
<td>Cereal grains</td>
<td>Iloilo, Philippines</td>
<td>-</td>
</tr>
<tr>
<td>B6</td>
<td>Bisaya Rice (Oryza sativa)</td>
<td>Cereal grains</td>
<td>Capiz, Philippines</td>
<td>-</td>
</tr>
<tr>
<td>B7</td>
<td>Foxtail Millet (Setaria italica)</td>
<td>Cereal grains</td>
<td>People’s Republic of China</td>
<td>-</td>
</tr>
<tr>
<td>B24</td>
<td>Cloves (Syzygium aromaticum, McCormick)</td>
<td>Dried flower buds</td>
<td>McCormick Corporation</td>
<td>-34.61</td>
</tr>
<tr>
<td>B25</td>
<td>Nutmeg (Myristica fragrans, McCormick)</td>
<td>Seed</td>
<td>McCormick Corporation</td>
<td>-30.52</td>
</tr>
<tr>
<td>B26</td>
<td>Nutmeg (Myristica fragrans, Banda Islands)</td>
<td>Seed</td>
<td>Banda Islands, Indonesia</td>
<td>-28.155</td>
</tr>
<tr>
<td>B8</td>
<td>Pig 1 (Sus scrofa)</td>
<td>Bone</td>
<td>Long An, Vietnam</td>
<td>-31.24</td>
</tr>
<tr>
<td>B9</td>
<td>Pig 2 (Sus scrofa)</td>
<td>Bone</td>
<td>Long An, Vietnam</td>
<td>-31.04</td>
</tr>
<tr>
<td>B10</td>
<td>Chicken 1 (Gallus gallus)</td>
<td>Bone</td>
<td>Long An, Vietnam</td>
<td>-22.21</td>
</tr>
<tr>
<td>B11</td>
<td>Pig 3 (Sus scrofa)</td>
<td>Bone</td>
<td>Zambales, Philippines</td>
<td>-28.11</td>
</tr>
<tr>
<td>B12</td>
<td>Chicken 2 (Gallus gallus)</td>
<td>Bone</td>
<td>Zambales, Philippines</td>
<td>-23.29</td>
</tr>
<tr>
<td>B13</td>
<td>Cá chach (Macrognathus siamensis, spot-finned spiny or peacock eel)</td>
<td>Meat</td>
<td>Long An, Vietnam</td>
<td>-32.39</td>
</tr>
<tr>
<td>B14</td>
<td>Cá loc (Channa sp. (prob. Gachua, snake-head fish))</td>
<td>Meat</td>
<td>Long An, Vietnam</td>
<td>-31.7</td>
</tr>
<tr>
<td>B16</td>
<td>Cá bo'ng cáť bien (Sillago sp., sand borer sillaginid)</td>
<td>Meat</td>
<td>Long An, Vietnam</td>
<td>-22.305</td>
</tr>
<tr>
<td>B18</td>
<td>Cá lù đù (Micropogonias undulates, croaker fish)</td>
<td>Meat</td>
<td>Long An, Vietnam</td>
<td>-21.8</td>
</tr>
<tr>
<td>Sample Code</td>
<td>Sample Description</td>
<td>Sample Type</td>
<td>Provenience</td>
<td>$\delta^{13}$C (‰ PDB)</td>
</tr>
<tr>
<td>-------------</td>
<td>--------------------------------------------------------</td>
<td>-------------</td>
<td>------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>B20</td>
<td><em>Dilis (Stolephorus indicus, anchovy)</em></td>
<td>Meat</td>
<td>Zambales, Philippines</td>
<td>-22.48 -22.85</td>
</tr>
<tr>
<td>B21</td>
<td><em>Salingasi Tabagak (Sardinella fimbriata, fringe scale sardine)</em></td>
<td>Meat</td>
<td>Zambales, Philippines</td>
<td>-20.54 -21.27</td>
</tr>
<tr>
<td>B22</td>
<td><em>Sapsap (Leiognathus equulus, ponyfish/slipmouth)</em></td>
<td>Meat</td>
<td>Iloilo, Philippines</td>
<td>-21.34 -22.30</td>
</tr>
<tr>
<td>B23</td>
<td><em>Guma-a (Pseudocaranx dentex, white trevally)</em></td>
<td>Meat</td>
<td>Iloilo, Philippines</td>
<td>-21.32 -21.1</td>
</tr>
</tbody>
</table>
Figure 6-32. Plot of $\delta^{13}$C values of C16 and C18 fatty acids obtained from modern reference materials acquired in Southeast Asia (except B24 and B35 acquired in Gainesville, FL). Legends: Squares – modern pottery samples; circles – biological samples; red squares – pig pot; yellow squares – chicken pot; light blue square – freshwater fish pots; blue squares – marine fish pots; dark blue square – mixed freshwater and marine fish pot; red violet squares – mixed cooking pots; brown squares – ethnographic pots from Vietnam; gray squares – ethnographic pots from Kalinga, Philippines; yellow orange square – pig in peanut sauce pot; yellow green square – snails in coconut milk pot; green yellow squares – plant pots; red circles – pigs; yellow circles – chickens; light blue circles – freshwater fishes; dark blue circles – marine fishes; yellow green circles – plants; CSR – charred surface residues inside the pot.
Figure 6-33. Plot of $\delta^{13}C$ values of C16 and C18 fatty acids obtained from modern animal samples and modern pottery used for cooking animal food sources acquired in Southeast Asia. Legends: Squares – modern pottery samples; circles – faunal samples; red squares – pig pot; yellow squares – chicken pot; light blue square – freshwater fish pots; blue squares – marine fish pots; dark blue square – mixed freshwater and marine fish pot; red violet squares – mixed cooking pots; brown squares – ethnographic pots from Vietnam; gray squares – ethnographic pots from Kalinga, Philippines; yellow orange square – pig in peanut sauce pot; yellow green square – snails in coconut milk pot; red circles – pigs; yellow circles – chickens; light blue circles – freshwater fishes; dark blue circles – marine fishes; CSR – interior charred surface residues.
Figure 6-34. Plot of $\delta^{13}$C values of C16 and C18 fatty acids obtained from modern floral samples and modern pottery used for cooking plant food sources acquired in Southeast Asia (except B24 and B35 acquired in Gainesville, FL). Legends: Green yellow squares – modern pottery samples used for cooking plants; yellow green circles – floral samples.
Table 6-3. Results as $\delta^{13}$C from bulk and compound specific isotopic analyses of modern reference materials, which are consolidated from Tables 6-1 and 6-2.

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>Sample Description</th>
<th>Provenience</th>
<th>$\delta^{13}$C (% PDB)</th>
<th>$\delta^{13}$C (% PDB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C16 FA</td>
<td>Sample Code</td>
<td>Sample Description</td>
<td>Provenience</td>
<td>$\delta^{13}$C (% PDB)</td>
</tr>
<tr>
<td>CSR 10</td>
<td>Marine fishes (5x, charred surface residues on E14)</td>
<td>Philippines</td>
<td>-15.3</td>
<td>-20.7</td>
</tr>
<tr>
<td>CSR 12</td>
<td>Foxtail millet (<em>Setaria italica</em>, 5x, (charred surface residues on E8))</td>
<td>People's Republic of China</td>
<td>-11.64</td>
<td>-</td>
</tr>
<tr>
<td>B1</td>
<td>Job's Tears (<em>Coix lacryma-jobi</em>)</td>
<td>Long An, Vietnam</td>
<td>-10.49</td>
<td>-16.05</td>
</tr>
<tr>
<td>B3</td>
<td>Brown Rice (<em>Oryza sativa</em>)</td>
<td>Long An, Vietnam</td>
<td>-25.92</td>
<td>-</td>
</tr>
<tr>
<td>B4</td>
<td>Black Rice (<em>Oryza sativa</em>)</td>
<td>Iloilo, Philippines</td>
<td>-27.48</td>
<td>-</td>
</tr>
<tr>
<td>B5</td>
<td>Camoros Rice (<em>Oryza sativa</em>)</td>
<td>Iloilo, Philippines</td>
<td>-27.81</td>
<td>-</td>
</tr>
<tr>
<td>B6</td>
<td>Bisaya Rice (<em>Oryza sativa</em>)</td>
<td>Capiz, Philippines</td>
<td>-27.58</td>
<td>-</td>
</tr>
<tr>
<td>B7</td>
<td>Foxtail Millet (<em>Setaria italica</em>)</td>
<td>People's Republic of China</td>
<td>-11.62</td>
<td>-</td>
</tr>
<tr>
<td>B24</td>
<td>Cloves (<em>Syzygium aromaticum</em>, McCormick)</td>
<td>McCormick Corporation</td>
<td>-29.45</td>
<td>-34.61</td>
</tr>
<tr>
<td>B8</td>
<td>Pig 1 (<em>Sus scrofa</em>)</td>
<td>Long An, Vietnam</td>
<td>-21.85</td>
<td>-31.24</td>
</tr>
<tr>
<td>B10</td>
<td>Chicken 1 (<em>Gallus gallus</em>)</td>
<td>Long An, Vietnam</td>
<td>-13.82</td>
<td>-22.21</td>
</tr>
<tr>
<td>B12</td>
<td>Chicken 2 (<em>Gallus gallus</em>)</td>
<td>Zambales, Philippines</td>
<td>-17.05</td>
<td>-23.29</td>
</tr>
<tr>
<td>B14</td>
<td>Cá loc (<em>Channa</em> sp. prob. Gachua, snakehead fish)</td>
<td>Long An, Vietnam</td>
<td>-25.92</td>
<td>-31.7</td>
</tr>
</tbody>
</table>
Table 6-3. Continued

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>Sample Description</th>
<th>Provenience</th>
<th>$\delta^{13}C$ (% PDB)</th>
<th>$\delta^{13}C$ (% PDB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B17</td>
<td>Cá sặc lò tho [Trichopodus sp. (prob. pectoralis), snakeskin gourami]</td>
<td>Long An, Vietnam</td>
<td>-21.73</td>
<td>-26.21</td>
</tr>
<tr>
<td>B16</td>
<td>Cá bo’ng cát bien (Sillago sp., sand borer sillaginid)</td>
<td>Long An, Vietnam</td>
<td>-16.14</td>
<td>-22.305</td>
</tr>
<tr>
<td>B18</td>
<td>Cá lù đù (Micropogonias undulates, croaker fish)</td>
<td>Long An, Vietnam</td>
<td>-15.69</td>
<td>-21.8</td>
</tr>
<tr>
<td>B20</td>
<td>Dilis (Stolephorus indicus, anchovy)</td>
<td>Zambales, Philippines</td>
<td>-17.25</td>
<td>-22.48</td>
</tr>
<tr>
<td>B21</td>
<td>Salingasi Tabagak (Sardinella fimbriata, fringe scale sardine)</td>
<td>Zambales, Philippines</td>
<td>-15.6</td>
<td>-20.54</td>
</tr>
<tr>
<td>B23</td>
<td>Guma-a (Pseudocaranx dentex, white trevally)</td>
<td>Iloilo, Philippines</td>
<td>-15.79</td>
<td>-21.32</td>
</tr>
</tbody>
</table>
Figure 6-35. Plot of $\delta^{13}C$ values of C16 and C18 fatty acids obtained from modern pig samples and modern pottery used for cooking pork meat acquired in Southeast Asia against several ranges of $\delta^{13}C$ values of C16 and C18 fatty acids obtained from modern wild boars and domestic animals in Northern Atlantic (or Great Britain, Dudd 1999), Northern Europe (Craig et al. 2007), Mediterranean Area (Spiteri 2012), Middle East (Gregg et al. 2009), and East Asia (Japan, Craig et al. 2013; Lucquin et al. 2016b). Legends: Squares – modern pottery samples; circles – faunal samples; red squares – pig pot; yellow orange square – pig in peanut sauce pot; red circles – pigs.
Figure 6.36. Plot of δ^{13}C values of C16 and C18 fatty acids obtained from modern fish samples and modern pottery used for cooking fishes acquired in Southeast Asia against several ranges of δ^{13}C values of C16 and C18 fatty acids obtained from modern aquatic sources, freshwater and marine, in Northern Atlantic (or Great Britain, Dudd 1999; Craig et al. 2007; Lucquin et al. 2016), Northern Europe (Craig et al. 2011), Mediterranean Area (Spiteri 2012), Middle East (Gregg et al. 2009), Canada (Tache and Craig 2015), and East Asia (Japan, Craig et al. 2013; Lucquin et al. 2016b). Legends: Squares – modern pottery samples; circles – faunal samples; light blue square – freshwater fish pots; blue squares – marine fish pots; dark blue square – mixed freshwater and marine fish pot; red violet squares – mixed cooking pots; brown squares – ethnographic pots from Vietnam; gray squares – ethnographic pots from Kalinga, Philippines; light blue circles – freshwater fishes; dark blue circles – marine fishes; CSR – charred surface residues inside the pot.
Figure 6-37. Plot of δ\(^{13}\)C values of C16 and C18 fatty acids obtained from modern pottery used for cooking cereals, against ranges of δ\(^{13}\)C values of C16 and C18 fatty acids obtained from cooked cereals in East Asia (Taiwan, Yang and March 2012). Legends: Squares – modern pottery samples used for cooking cereals; diamonds – cooked cereals; yellow square – pottery used for cooking millet from China; light brown square – pottery used for cooking rice without husks; brown square – pottery used for cooking rice with husks.
CHAPTER 7
BETWEEN MANUFACTURE AND DISPOSAL: THE LIVES OF POTS IN THE NEOLITHIC AND METAL AGE SETTLEMENTS OF SOUTHERN VIETNAM

Introduction

The analyses of pottery from archaeological sites in Southeast Asia (SEA) are largely oriented towards their manufacture, i.e., typological and petrographic analyses, with emphasis on the identification of transregional similarities and differences of form, decoration, and composition to establish patterns of human migration, contact, and identity (Hung et al. 2011; Rispoli 2007; Rispoli et al. 2013). In contrast there has been little analytical study on the functionality of pottery between manufacturing and disposal or discard, where pottery vessels were most likely being used to prepare and serve food. The settlement sites of Rạch Núi (Oxenham et al. 2015) and An Sơn (Bellwood et al. 2011) during the Neolithic, as well as Lò Gạch (Piper 2013) and Gò Ô Chùa (Reinecke 2012) during the early Metal Age in southern Vietnam, presented an opportunity to bridge this gap. Pottery recovered from these sites were was disposed as refuse in middens, incorporated into floors as recycled construction materials, served as containers for burial offerings, and/or simply deposited into occupational layers.

In accordance with the chaîne opératoire perspective, Chapter 7 adopts the life history approach to pottery (Knappett 2012), focusing on its functionality. This is in contrast to, but complements many studies on pottery that adopt the chaîne opératoire perspective, but focus only on production or manufacture (e.g., Balbaligo 2015; Sarjeant 2014) and/or assess if pottery still has roles upon its discard or disposal, such as grave offerings (e.g., Barretto-Tesoro 2008). Blanco-Gonzalez (2014:442) stated that “the social life of any artifact consists of a continuum with a series of stages from its birth or manufacture to its death or discard.” In these stages, these artifacts, such as pottery,
have different intertwined relationships with people (Appadurai 1986). These stages are archaeologically traceable, especially the stage when artifacts are being used by the people for their everyday living, allowing us to evaluate the whole chaîne opératoire or operational sequence and the cultural biography of the artifacts. The culture biographical approach allows insight into the manufacture, use, and disposal of these things, which can lead us to understand the practices of past communities. Physical evidence found on artifacts is useful to infer the cultural practices involving the use of these items (Blanco-Gonzalez 2014).

Chapter 7 then focuses on the role of pottery as functioning implements, specifically in food preparation and consumption, rather than as culture-historical indices (Ashley 2010). Assessing the role of pottery in foodways or culinary practices provides possible inferences from daily practices to sociopolitical organizations (Ashley 2010). The lives of pots can be established (Tomkins 2007) through technofunctional analysis, as applied here in Chapter 7 to explore the lives of pots sampled from the four sites in prehistoric Southern Vietnam as they participated in the foodway practices of occupants during prehistory.

**Technofunctional Analysis**

Technofunctional studies include the analysis of technology and form of pottery vessels to infer intended use and use-alteration analysis (surface attrition and carbon deposition) to infer actual use (Hally 1983; Kobayashi 1994; Orton et al. 1993; Rice 1987; Rye 1981; Skibo 1992, 2013). It can also be referred to as “technological ceramic analysis” (Rice 1987:310) or analysis of “technofunction” (Skibo 1992).
Analysis of Technology and Form of Pottery Vessels to Infer Intended Use

The analysis of technology and form of the pottery vessels to infer intended use or function, such as cooking, storage, transport and serving, is done by assessing their clay, temper, surface treatments, shape, and thickness (Gibbs and Jordan 2013; Skibo 1992, 2013). It can also address the “affordances” (Knappett 2005) or suitability of pottery vessels to perform multiple functions (Gibbs and Jordan 2013). One may ask, are the vessels the “Swiss Army Knife” of the pottery world (Skibo 2013)?

Clay. Rice (1987) provided an overview of different properties of clay based on their deposition, particle size, chemical composition, and mineralogy. Generally, the clay is suitable for manufacturing ceramic vessels if it passes the criteria of plasticity, workability, and resistance to cracking and deformation when dried. Plasticity is the ability of the clay to be shaped into a desired form when wet and maintain that form afterwards. Clay with finer particles has better plasticity and resistance to cracking and deformation when dried (Rice 1987). Clay may be sourced through chemical analysis (Glascock 1992; Neff and Bove 1999) of the clay and petrographic studies of ceramic cross sections (Stoltman 1989, 1991). Often it is assumed that the clay source is close to where the potters lived (Gosselain 1994), unless social and political factors affect the procurement of clay by the potters (Fowles et al. 2007; Gosselain 1994; Stark et al. 2000).

Temper. The temper used to manufacture ceramic vessels can be identified by examining the cross section of a sherd (Orton et al. 1993), which makes it more accessible to an archaeologist than the examination of clay using more sophisticated equipment. Temper is nonplastic inclusions (Bronitsky and Hamer 1986) mixed with the clay to modify the properties of the clay according to the intended function of the
ceramic vessels to be manufactured. These properties are the potential of clay to dry out, plasticity, workability, resistance to cracking and deformation, firing behavior, porosity, density, and heat conductivity. Different temper materials have different properties and contribute to modifying the properties of clay. They can be plant (e.g., fiber) and animal materials (e.g., shell) and mineral-rich materials (e.g., sand) (Rice 1987). The following paragraphs are focused on fiber, shell, and sand temper materials that are common in Southeast Asian earthenware pottery (Miksic 2003).

Schiffer and Skibo (1987) examined the different temper materials (plant fiber, animal manure, and sand) in Southeast US archaeological pottery and experimental pottery to assess the effect of temper on ease of manufacture, cooling effectiveness, heating effectiveness, portability, impact resistance, thermal shock resistance, and abrasion resistance. Their work provides a guide to how temper materials affect the production and performance of pottery vessels. For example, fiber temper could have been used to manufacture water storage jars and cooking pots. The fibrous or organic inclusions leave pores after the firing of the pottery vessels intended for use as water storage jars. These pores allow water to permeate the vessel walls and evaporate, resulting in the cooling of water inside the jar. The fiber temper also improves the heat conductivity of cooking vessels (Schiffer and Skibo 1987). Further, Skibo et al. (1989) compared the effects of organic and mineral (sand) temper materials. They demonstrated that organic temper improves the qualities for pottery manufacture (rigidity and shape retention) as well as provides reduced weight for better portability (Skibo et al. 1989).
The work of Bronitsky and Hamer (1986) demonstrated that finely ground temper (e.g., fine sand) and burnt shell temper improved the durability of pottery vessels (impact and thermal-shock resistance). Work reported by Rye (1976) in Papua New Guinea may be more applicable to Southeast Asian contexts because of geographic proximity. It was demonstrated that when beach sand containing calcite, shell, and other calcium carbonate-rich materials was used as temper, seawater must be used to wet the clay mixture and counter the disadvantage of lime spalling, or, salt can be added after firing to serve as an inner slip. The contrasting properties of water and cooking pots are also provided and can serve as a guide for determining the intended function of the pottery vessel based on their mechanical performance characteristics (Rye 1976).

**Surface Treatments**

The surface treatments of pottery vessels after firing are employed to manipulate their mechanical performance characteristics, such as thermal shock resistance, resistance to spalling, evaporative cooling, heating effectiveness, resistance to abrasion, and prehensibility (Rice 1987). The experimental work by Schiffer et al. (1994) demonstrated that texturing, application of organic coatings (resin), and smudging of the interior and/or exterior surfaces of cooking pots affect their resistance to thermal shock cracking and thermal spalling. Skibo et al. (1997) explored the relationship between different surface treatments and abrasion resistance. Smudged and resin-coated treatments provided better resistance to abrasion than the slip/polished and textured surfaces. They also provided a rule of thumb for archaeologists, stating that low-fired and highly porous prehistoric cooking pots should have some organic coatings to decrease permeability when boiling food. This is because organic coatings undergo biodegradation and are rarely observed in prehistoric pottery (Skibo et al. 1997).
In addition, Pierce (2005) demonstrated that textured, corrugated vessels have advantages over plain vessels in terms of handling, control over cooking, and use-life. Longacre et al. (2009) showed that the immersion of newly fired pottery vessels in a bed of rice chaff improved their aesthetic appeal because of their shiny black appearance. The smudge from the rice chaff also improved the heating effectiveness and decreased the water permeability of the ceramics that can be suitable both for cooking and storing water (Longacre et al. 2000).

**Vessel shape**

The forms or shapes of ceramic vessels determine their suitability to perform particular tasks, such as cooking food, storing water or other liquids, and serving food or drinks (Hally 1986; Rice 1987) and affect their mechanical performance characteristics (Braun 1983; Hally 1986), such as the suitability to accept inward and outward placement of material (Braun 1983). Hally (1986), Linton (1944), and Reid (1989) provided guidelines on how to assess the function of a ceramic vessel based on its form. For example, cooking pots generally have a rounded or pointed bottom for even distribution of heat during cooking, and they have slightly restricted openings to maintain moisture but still permit easy placement of contents (Hally 1986; Linton 1944; Reid 1989). Blitz (1993), De Boer (2001), Junker and Niziolek (2010), and Mills (1999) provided guidelines for assessing pottery vessels used for non-household gatherings, such as feasts. Frink and Harry (2008) cautioned that the relationships between form, function, and other mechanical performance characteristics are not generalizable in all environments and cultures.
Vessel thickness

The thickness of pottery vessels varies according to their function (Rice 1987). Thinner walls are preferred for cooking pots to allow efficient thermal conductivity and resistance against thermal shock (Braun 1983). Thicker walls and bases are preferred for stability with storage vessels when they are placed on the ground and help avoid moisture transfer between the inside and outside of the vessel (Rice 1987).

Use-Alteration Analysis for Inferring Actual Use

Use-alteration analysis is done to infer how the pottery vessels were actually used, which could be the same or not as the intended function (Arthur 2002; Hally 1983, 1986; Skibo 1992, 2013). Use alterations are the chemical and/or physical changes that occur at the surfaces of ceramic vessels as a consequence of usage. Manufacturing, mode of action, contents, time and frequency of use, and context of use affect the appearance of use alterations. The determination of pottery usage based on these traces makes reconstruction of the past firmer (Skibo 1992). It is the most detailed way to identify “actual vessel use” (Oudemans 2007).

Hally (1983, 1986) identified three use alterations from his analysis of whole and partial vessels recovered from domestic structures and burial contexts at two Barnett phase sites in northwest Georgia. These include sooting, oxidation discoloration (or firing cloud), and interior surface pitting, which are all visible to the naked eye. The processes by which they are produced were also identified. Soot deposition on the exterior surface is usually the only one examined to identify function, obviously cooking. It is a by-product of fuel combustion. It was thought to be primarily composed of distilled resin, oxidized resin, and free carbon. Oxidation discoloration is caused by the oxidation of carbonaceous material present in the vessel walls. This could be used to identify
cooking or heating vessels. Interior surface pitting has three distributional patterns: pitting restricted to the vessel base and lower walls, pitting restricted to a band encircling the vessel wall above the base, and overall pitting. It could be a consequence of thermal shock, chemical corrosion, and physical abrasion. Use alteration analysis not only provides direct evidence of how vessels were actually used and hence how different morphological types were used, but also allows the investigator to distinguish between vessel types having single or multiple uses, or unique or unusual uses (Hally 1983).

Skibo (1992, 2013) provided general guidelines for the analysis of use-alterations in ceramic vessels and classified the use alterations into surface attrition, carbon deposition, and absorbed residues. The latter is not included in technofunctional analysis here, but is discussed in depth in Chapter 4. Surface attrition, due to use, includes various forms of abrasive and nonabrasive processes caused by cooking, cleaning, and storing of pots. Specifically, for ceramics, it is defined simply as the removal or deformation of ceramic surfaces (Skibo 1992, 2013). Matson (1965) recommended that vessel wear patterns should not be ignored in analyzing pottery. He suggested that abrasion and scratches on various areas of the vessel provide evidence for use. These include “sludge deposits” at the bottom of water pots, deletions to a ceramic surface, and deposits within the pot, and serve as the basis for use alteration studies. Nonabrasive forms of attrition are caused by processes such as salt erosion, common in water storage vessels, or spalling of the surface of cooking vessels as they are placed over heat. On the other hand, abrasion is the principal form of use attrition and it is defined as a trace that was formed by removal or deformation of material on the
surface of the ceramics caused by mechanical contact, such as the sliding, scraping, or striking action of an abrader (Skibo 1992). In his study of Kalinga pots, Skibo (1992) noted evidence for surface attrition in both interior and exterior surfaces of particular pottery parts. These included abrasions, scratches, pits, rims being worn flat, rims chipped, impact marks, thermal spalls, and removal of surface. Recently, Van Keuren and Cameron (2015) analyzed surface abrasions on White Mountain Red Ware whole vessels to interpret the biographies of these vessels. The localized areas of the abrasions at the upper exterior surfaces indicated that the vessels were positioned and rotated for display so the interior design would be more visible.

Further, pottery vessels used for brewing alcoholic drinks or fermenting food can be identified because fermentation produces acids that erode the interior surfaces or cause pitting of pottery vessels (Arthur 2002, 2003; Vukovic 2009, 2011). This was demonstrated by use-alteration analyses of pottery used by the Gamo in southwestern Ethiopia (Arthur 2002, 2003) and Early Neolithic Blagotin, Central Serbia (Vukovic 2009, 2012). Furthermore, the erosion of pottery surfaces during burial in high salinity or acidic environments, where both interior and exterior surfaces of low-fired ceramics are affected, can be differentiated (O’Brien 1990). The combination of use-alteration and morphological analyses of Early Neolithic Blagotin pottery allowed Vukovic (2009, 2011) to categorize the assemblage according to basic functional classes: food processing (pitting and surface erosions due to fermentation, wet-mode and dry-mode cooking (to be discussed next), as well as storage (lacking use-wear traces) (Vukovic 2009, 2011).

Carbon deposition results from combustion of organic matter and deposition of the resultant carbonized matter on/into the porous and permeable ceramic wall (Skibo
This is also called the *visible surface residues*, which are deposits or encrustations observed on both the inner and outer walls of vessels. These may be derived from soot deposited on the surface of the outer wall during the heating of the vessel over a fire or from charred food or other biological material on the interior surface of the vessel (Heron and Evershed 1993).

The analysis of Kalinga cooking pots by Kobayashi (1990, 1994) provided a model for the formation of carbon deposits on ceramic vessels. In contrast to exterior carbon deposits, interior carbon deposits penetrate beneath the vessel surface. In archaeological pots, these deposits absorbed into the wall from the interior surface can be observed in cross sections of broken pieces, especially on or near the bottom. Rice and meat/vegetable cooking pots can be differentiated based on the placement of carbon deposits in the pots (Kobayashi 1994). Interior carbonization patterns, which are an atypical cooking pattern, also indicate decoction or extraction of active plant ingredients through boiling, as indicated by the majority of Powell Plain and Ramey Incised jars of the Cahokian Mississippian period, used for preparing ritual drinks (Miller 2015). This pattern is usually seen as a zone of oxidation below the shoulder and at the base, which is formed by the lowering of water level during the boiling of plant material. Other pottery vessels of the same assemblage indicated dry- and wet-mode cooking (Miller 2015).

As shown by the case study of Neolithic ceramics of Makriyalos, Greece, Urem-Kotsou et al. (2002) cautioned the use of pottery vessels from archaeological contexts and encouraged the integration of organic residue analysis. Oxidation discoloration and sooting clouds could be from manufacturing, rather than from cooking. Interior surface
residues might not be from the processing and cooking of food, but rather from the preparation of nonfood products, such as birch tar (Urem-Kotsou et al. 2002). Duddleson (2008) also integrated organic residue analysis into his study of surface attritions and carbon deposits on pottery vessels and sherds from Schultz site, Plains Woodland in Nebraska. Attrition and carbon deposits indicated cooking, cleaning, and transport or storage. Organic residues detected indicated the preparation of large herbivore (bison and deer) and/or leafy or root plant sources, rather than oily or seed plant sources (Duddleson 2008).

Aside from previously mentioned case studies, many studies in the Americas on pottery that employed technofunctional analysis (Briggs 2016; Kobayashi 1986, 1990; Sassaman 1993; Roddick 2000; Van Keuren 2004; Skibo and Blinham 2008; Wallis 2011) ventured beyond culture-historical reconstructions (Braun 1983). In East Asia, Lee (2013) employed technofunctional analysis of pottery from late Neolithic and the Early Bronze Age Korea to assess ethnic or regional identity formation in comparison with that already established by the analysis of stylistic variations. In the case of southern Vietnam described here in Chapter 7, results of technofunctional analysis are integrated with those of organic residue analysis of selected pottery samples in Chapter 8, as well as with allied studies of recovered organic remains and other material cultural remains, to infer community identities based on culinary practices (Chapter 9).

**Neolithic and Metal Age Settlements of Southern Vietnam**

Southern Vietnam in Mainland SEA has a number of deeply stratified prehistoric settlement sites in the form of mounds. Similar to pottery vessels from other sites, their life history is composed of elaboration (birth), initial roles (utilitarian lifespan), post-breakage steps, as well as discard and abandonment (death) (Blanco-Gonzalez 2014).
We know, based on the excavation of these sites that the pottery discarded was refuse in middens, served as containers for burial offerings, was simply deposited into an occupational layer, and/or incorporated into floors as recycled construction materials in mounds. The latter was done after post-breakage steps. This research tackles their initial roles, which later complement studies on the birth of this pottery. The four settlement sites in Long An Province are briefly described below, as detailed discussion is already available in Chapter 3.

Two sites belong to the Neolithic period: Rạch Núi, located where the Vam Co Dong, Vam Co Tay, and Dong Nai Rivers meet near the town of Can Giuoc, and An Sơn, located near Vam Co Dong in An Ninh Tay commune, Duc Hoa District. Rạch Núi is a manmade mound dating to 1500-1200 BC that is 5-6 m high with a diameter of ~75 m and an area between 2800 and 4000 m² (Oxenham et al. 2015). An Sơn is another manmade mound dating to 2300-1200 BC that is ~5 m high with and length of 160 m and width of 90 m, an area of ~1.5 ha, and human burials (Bellwood et al. 2011; Nishimura and Nguyen 2002). The majority of material culture, especially pottery, from these two sites is different (Sarjeant 2014), in contrast to the two Metal Age sites, which display greater similarity.

Lò Gạch is located on the western bank of the Vam Co Tay River. It is a settlement site with multiple layers of intentionally laid surfaces and sediment accumulation dating from ca. 1100 cal yr BC to 650 cal yr BC, with ~1.5 m of archaeological deposits demonstrating construction methods similar to those in Rạch Núi (Neolithic) and material culture similar to that of Gò Ô Chùa (Metal Age), making this a possible transitional site between the Neolithic and Metal Age (Bui 2008; Piper
2013). However, for the purpose of this research, the site is tentatively assigned to Metal Age based on the observations during its excavation in 2014. Gò Ô Chùa is located near the Vàm Cỏ Tây and Vàm Cỏ Đông Rivers, about 2 km south of the Vietnamese-Cambodian border (Reinecke 2010). The site is 450 m long, 150 m wide, and has three mounds, the northern, central, and southern mounds. It is a salt-boiling and occupation site that dates to the Bronze Age (ca. 1000-500 BC) and the burial site dates to the Iron Age (400-100 BC) (Reinecke 2012). The technofunctional analysis and the subsequent organic residue analysis of the pottery from these four sites contribute to the discussion of development from the Neolithic to Metal Age in southern Vietnam.

**Materials and Methods**

Pottery samples from four prehistoric sites in southern Vietnam were sampled in 2012 and 2014 from Long An Province, Vietnam. In late 2012 (Eusebio 2015), post-excavation analysis of material excavated from Rạch Núi was conducted at the Long An Provincial Museum, Tan An City, Vietnam. I selected and collected the pottery samples recovered during the 2008, 2009, and 2012 excavations of the Gò Ô Chùa, An Sơn, and Rạch Núi sites, respectively, in storage at the Long An Provincial Museum. In 2014, I participated in the excavation of Lò Gạch, and collected freshly excavated and unwashed pottery samples on-site, and participated in the post-excavation work in Long An Museum (Eusebio 2014). I also collected additional samples from An Sơn site, targeting those from Trench 2 that yielded evidence of cooking activities.

After exporting the archaeological pottery with government permission from Ho Chi Minh City, Vietnam to Gainesville, Florida, technofunctional analysis of the pottery

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1 Updated and extended from Supplementary Material I in Eusebio 2015.
samples was conducted at the Florida Museum of Natural History (FLMNH) and Department of Anthropology in the University of Florida. Tables 7-1, 7-2, 7-3, and 7-4 provide the inventories of collected pottery samples. It was assumed that one sherd was equivalent to one pottery vessel, unless more than one sherd could be partially reconstructed together into a bigger pottery fragment. The rims collected were at least 3 cm long. Each vessel was treated as one sample. The samples were divided based on those with rims, those obviously identified as shoulders of pottery vessels, bases with stand, and body sherds, as well as the trenches from which they were excavated at each site. As shown from Tables 7-1 to 7-4 below, there were 93 samples collected from Rạch Núi, 68 from An Sơn, 33 from Lò Gạch, and 58 from Gò Ô Chùa.

The following attributes were recorded (Appendix F; Hally 1983; Kobayashi 1994; Orton et al. 1993; Rice 1987; Rye 1981; Skibo 1992, 2013): rim diameter with orifice percentage, rim and lip thicknesses, lip forms, rim forms, vessel forms, surface treatment or presence of design, temper, firing cores, and use alteration. The ultimate goal was to relate form, paste, potential function, surface attritions, and carbon deposition to the detected food contents through residue analysis of samples. Rim diameters and orifice percentages were determined with a rim diameter chart by finding the best correspondence between the interior edge and nested arcs. The rims were measured for rim and lip thicknesses using calipers at 3 cm and 0.5 cm from the orifice, respectively. For samples with everted rims, the distance from the rim edge to the inflection at the neck and the thickness at the inflection were also measured. In situations where the distance from the rim edge to the inflection at the neck was less than 3 cm, the thickness at the inflection was equated with rim thickness. Rim forms
were documented if restricted or unrestricted. Lip forms were documented if tapered, folded, rounded, flat, and flaring. The vessel forms were documented by drawing the profiles of the rims with a contour gauge and a pencil. The classification of vessel forms into restricted and open pots, restricted and open bowls, small cups and/or bowls, restricted pots/jars, jars, and stoves in this research was adopted and modified from the one followed in the Florida Gulf coast (see Wallis 2011; Wiley 1949), which can easily be reconciled with the classification systems being used already in SEA, specifically for southern Vietnam (Sarjeant 2012, 2014a,b). The presence of soot and surface attritions was also noted.

All rims as well as selected shoulder and body sherds were characterized for pottery paste and firing cores following Orton et al. (1993). The fresh breaks were examined under a Bausch and Lomb StereoZoom 5 microscope at 8x magnification and compared to the Wentworth sand size reference chart to determine the size of inclusions or temper. The relative abundances of inclusions were also documented by using the percentage inclusion chart of Matthew et al. (1991). The cores were compared with the stylized cross-sections in the work of Rye (1981). The charred interior surface residues were examined and photographed using a Zeiss Discovery V8 Stereomicroscope in the Department of Anthropology. All attributes recorded were tallied in a Microsoft Excel 2010 spreadsheet (Appendix G). The computation of numbers of samples (n), averages, standard deviations, minimum values, and maximum values was done with the formula function of Microsoft Excel 2010. Histograms on orifice diameter distributions were also constructed with Microsoft Excel 2010.
Results and Discussion

Based on the 167 samples with rims collected from Rạch Núi (n=70), An Sơn (n=38), Lò Gạch (n=25), and Gò Ô Chùa (n=34) sites in southern Vietnam (Table 7-1), the average orifice diameter, rim thickness, and lip thickness of those from Rạch Núi are smaller than those from the other three sites. Those from An Sơn have the widest range of orifice diameters. Those from Gò Ô Chùa have the narrowest range of orifice diameters and largest average rim thickness. Those from Lò Gạch and Gò Ô Chùa have larger average lip thicknesses than those from Rạch Núi and An Sơn.

When the samples with rims and stands were sorted according to their vessel forms (Table 7-6), the majority of them are restricted pots (38.24%). Other forms are open bowls (25.88%), restricted bowls (5.29%), open pots (2.94%), restricted pots/jars (16.47%), jars (4.12%), stove (1.77%), and small cups and/or bowls (3.53%), and plates and/or bowls with stand (1.77%).

Restricted pots (Fig. 7-1) are restricted vessels with their height greater than their maximum width, which is somewhere between the opening and the base of the vessels. Open pots (Fig. 7-2) are similar to restricted pots, but their maximum width is at their opening and they are considered unrestricted vessels. Open bowls (Fig. 7-3) are unrestricted vessels with their height less than their maximum width, which is at the opening. Restricted bowls (Fig. 7-4) are similar to open bowls, but their maximum width is somewhere between the opening and the base of the vessels. Small cups and/or bowls (Fig. 7-5) are smaller versions of pots and bowls, respectively. Restricted pots/jars (Fig. 7-6) could be small jars of about 30 cm tall as archaeologists working in

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2 Updated and extended from the section on “Results and Discussion: Technofunctional Analysis” in Eusebio 2015
Vietnam would classify them, which have orifice diameters of 12-17 cm. Jars (Fig. 7-7) were classified based on the knowledge of the shape of modern ethnographic and archeological earthenware jars in the region (Miksic 2003). They are similar to restricted pots but have thicker walls and are taller than regular restricted pots (Rice 1987). Stoves (Fig. 7-8) are classified and labelled as cà rang by the archaeologists who excavated the above-mentioned sites. These are used as equipment for cooking with wood and fire, rather than as vessels for food. Without labels, their rim fragments can be classified as open bowls based on their profiles. In addition, plates and/or bowls with stand (Fig. 7.9) are incomplete, unrestricted vessels with stands, but without rims. What follow are observations on the collected pottery from the four sampled sites.

**Rạch Núi**

The majority of samples collected from Rạch Núi are restricted pots, followed by restricted pots/jars (Table 7-6). Other sampled vessels include open bowls, restricted bowls, open pots, and small cups and/or bowls. Although none of the collected samples is identified as a stove (cà rang), it is noted that stoves have been excavated from the site (Oxenham et al. 2015). The majority of these samples have orifice diameters from 12 to 20 cm (Figure 7-10). Twenty-nine samples have sand only as temper and many of them were mislabeled as fiber (organic) tempered (“FT”). Sherds are usually initially sorted as fiber tempered (FT) and sand tempered (ST) during cataloguing at the museum. Others samples from Rạch Núi have combinations of sand, crushed shell, lime, grog, and/or organic temper. Two of these samples have non-abrasive surface attritions (Fig. 7-11) such as pitting and surface erosion on their interior surface (Vukovic 2011) which could indicate fermentation. The majority of sampled pottery have
has textured surfaces from cordmarking (Fig. 7-12). Only one plain rim sherd was collected from Rạch Núi.

The majority of the samples from Rạch Núi are lime-encrusted, since the pottery sherds were recycled as materials for mound construction after disposal (Piper et al. 2013; Fig. 7-13). The soot on the interior surface of two rim sherds from Rạch Núi (Fig. 7-14) is possibly from burning activities related to the construction of the mound rather than from cooking. Probable wood bark or fiber can also be detected upon closer inspection of the soot with microscope. The soot is covered with lime. Thus, it is difficult to assess if lime-covered samples were used for cooking. One of the sherds was observed to have fiber matting covered with lime, probably bamboo impressions. The findings from the analysis of wood remains will shed further light on the organic materials adhering to several samples from Rạch Núi. In sum, pottery samples with non-abrasive surface attritions could have been used for processing (e.g., fermenting), while other samples could have been used for storing or transporting and serving food.

**An Sơn**

At An Sơn, most samples collected were identified as open bowls (Table 7-6), with many having wavy rims. Other samples are restricted pots, restricted pot/jars, jar, restricted bowls, small cup and/or bowls, and stoves (cà rang). As shown in Figure 7-15, this site has the widest range of orifice diameters, from 10 to 40 cm. Their tempering materials are mostly sand and fiber, where the latter can be found in jars, restricted pots, and restricted pots/jars. The differences between sand and organic tempered vessels can easily be observed through fresh breaks and weight of fragments, where sand-tempered sherds are usually heavier than fiber-tempered sherds of equal size. Shell and/or lime are also combined with either organic or sand temper in most of the
samples. Some sherds have both organic and sand tempers; a few of them have grog and/or shell/lime temper. Three sampled sherds could have also been used for fermentation, as indicated by non-abrasive attritions on their interior surfaces (Fig. 7-16).

Many of the pottery vessels (Fig. 7-17), including the stoves (Fig. 7-18), have textured surfaces from cordmarking. The stoves are different from the present-day plain earthenware stoves (Fig. 7-19) in the Long An Province. Texturing of the stoves from An Sơn could reflect the same principle as texturing the cooking pots, which provides longer use-life and cooking efficiency (Pierce 2005). The fragments of one stove have an abundance of interior charred surface residues (Fig. 7-20), possibly from burned firewood that had been used for cooking. Some of the samples with profiles of open bowls have signs of burning on their exterior surface (Fig. 7-21). A few sherds with plain and combed surfaces were also collected from this site. The pottery samples collected from An Sơn could have been used for processing (e.g., fermentation), cooking, storage or transport, and serving.

Lò Gạch

In Lò Gạch, a majority of the samples were identified to be open bowls (Table 7-6), with some of them having wavy profiles (Fig. 7-22), followed by restricted pots (Fig. 7-23). Other samples are restricted bowls, open pot, restricted pots/jars, jars, and small cup and/or bowl. As shown in Figure 7-24, the orifice diameters of the Lò Gạch rims ranged from 10 to 32 cm. Some of the pottery rim sherds excavated from the sites have orifice diameters of 34-40 cm that can fit in the round features uncovered in Trench 1, of almost the same diameter range. Three peculiar samples with no rims are tentatively identified as plates and/or bowls with stands (Figs. 7-9, 7-25, and 7-26). Tempering
materials observed are organic, sand, limestone and/or shell, and grog. Many of them have plain exterior surfaces.

Two samples could have also been used for fermentation, as indicated by non-abrasive attritions on their interior surfaces (Fig. 7-27). Three body sherds have charred surface residues on their interior surfaces, and are indicative of cooking in two of these sherds. Upon closer inspection of these sherds under the stereomicroscope, one of these sherds has burnt fish bones (Fig. 7-28) and the other one has plant impressions (Fig. 7-29). The charcoal stuck on the interior surface of another sherd appears not to be associated with the use of that pot, rather a wood fragment that was deposited together with that sherd (Fig. 7-30). It is difficult to assess the pottery for attritions because many of them are covered with rust-like stains, salt crystals, and/or lime in their interior and exterior surfaces (Fig. 7-31). In addition, many pottery sherds that were excavated but not sampled have charred surface residues with silicified husks from rice on both interior and exterior surfaces (Fig. 7-32). These could be from construction activities rather than the original use of the vessels.

For the three plates and/or bowls with stands, I observed that they all have charred plant remains from the scraped sediments on their top interior surfaces (Fig. 7-33) and possible plant impressions (Fig. 7-34). The scratches on the smoothed top surface of one of them (Fig. 7-26) were first thought to be due to a sharp metal implement. However, closer inspection indicated that they were more likely plant impressions (Fig. 7-35). These pottery samples were probably used for serving plant food sources. In general, the pottery from Lò Gạch could have been used for processing (e.g., fermentation), cooking, storage or transport, and serving food.
Gò Ô Chùa

In Gò Ô Chùa, the majority of the samples were identified as restricted pots, followed by open bowls (Table 7-6). Other forms are restricted bowls, open pots, restricted pot/jars, and jars. As shown in Figure 7-36, the majority of the samples with rims have orifice diameters from 17 to 24 cm. Their tempering materials are mostly organic, which are mostly found in jars, restricted pots, and restricted pots/jars. Many of these also have sand, shell/lime, and/or grog as additional tempering materials. Only one sample has sand temper, without organics but with shell/lime temper. A majority of them also have plain surfaces. Other samples from Gò Ô Chùa have checkered stamped, combed, cord-marked, incised, incised and impressed, and burnished surfaces. Three samples have indications of having been used for fermenting food through non-abrasive attritions on their interior surfaces (Fig. 7-37). One of them has charred interior surface residues (Fig. 7-38) and another one has firing clouds (Fig. 7-39), which indicate that they were used for cooking. Other samples could have been used for storage or transport and serving food. Similar to samples from the previous three sites, a few samples are also lime encrusted. The site of Gò Ô Chùa was classified as a prehistoric salt production center because of the 10-20 million fragments of clay stands or briquetages uncovered during its excavation (Proske et al. 2009; Reinecke 2010, 2012). These fragments are found in much fewer numbers in Lò Gạch. It is also hypothesized that these clay stands were actually used for pottery manufacturing or production (Vương 2011).

Implications of Results from Technofunctional Analysis

Generally, the common use alterations from the samples are presence of soot, firing clouds, pedestalled tempers, and non-abrasive surface attritions (pitting and
surface erosions [Vukovic 2011]). The charred surface residues on the interior surfaces of the samples are either burnt food remains from cooking activities or burnt plant remains stuck on the surfaces during depositional activities, such as floor construction in the sites. Many samples have firing clouds that could be from cooking activities and/or firing of pottery. The presence of firing clouds was the basis for sampling shoulder and body sherds, which means they probably came from cooking pots. Pedestalled tempers are commonly found in samples with organic and lime tempering materials. The non-abrasive attritions (pitting and surface erosions, after Vukovic 2011) in the interior surfaces of several samples across the site are probably from pottery vessels used to prepare and/or serve fermented food items, similar to the making of fish sauce by fermenting fish and salt in present-day Vietnam.

Tempering materials observed from the samples are organic (probably rice husks), sand, grog, shell, lime (or limestone), with different textures, abundance, and combinations. The potters used a single material or a combination of temper materials. For cooking pots, organic or fiber temper could have been used for their manufacture to improve their heat conductivity. Since organic tempers leave pores after the firing of the pottery vessels, they were also utilized for making jars for storage. These pores allow water to permeate the vessel walls and evaporate, resulting in the cooling of water or any liquid inside the jar (Schiffer and Skibo 1987). These can be identified in the samples from restricted pots, jars, and restricted pots/jars from An Sơn, Lò Gạch, and Gò Ô Chùa sites. Organic tempering materials commonly observed are probably rice husks. Other temper materials (sand, grog, shell, lime, and limestone) could have also
been used for improving the workability of the clay and thermal shock resistance of pottery (Bronitsky and Hamer 1986; Rye 1976).

The majority of the vessel samples collected from the Rạch Núi and An Sơn sites have cord-marked exterior surfaces, while plain vessels dominate those from Lò Gạch and Gò Ô Chùa site. Aside from aesthetic purposes, texturing via cord marking, stamping, and impressing could have been intended to make the pottery vessels easier to handle, more durable (longer use-life), and/or more effective for cooking (Pierce 2005). Burnishing or coating was done to increase the resistance of the vessels to abrasion and decrease their permeability (Skibo et al. 1997).

**Lives of Pots: Initial Stages**

After their elaboration or birth during their manufacture, the pottery vessels in the four settlement sites of Southern Vietnam had various functions. Based on the presence of charred residues on interior surfaces and/or firing clouds, some pottery vessels were used for cooking, where some contents were burnt and stuck inside the vessels. Restricted pots could have also been used for cooking, similar to some present-day earthenware cooking pots in SEA (for example, see Skibo 1992 for the Philippines; Fig. 7-40), since restricted openings can retain heat and moisture while retaining the ease of adding ingredients during cooking (Rice 1987; Reid 1989). Their rounded bottom allows for the even distribution of heat (Rice 1987). Pottery vessels with thin walls have efficient thermal conductivity and resistance against thermal shock (Braun 1983). The temper chosen for manufacturing cooking pots usually allows greater efficiency of heat transfer (Skibo et al. 1989), less thermal stress, and longer cooking time (Braun 1983). The temper also allows improvement in the workability, plasticity, resistance against cracking and deformation of the clay (Rice 1987), and durability of the cooking pot while
undergoing repeated heating and cooling (Graff 2012). Prehistoric cooking pots are usually low-fired and highly porous and the potters should have applied an organic coating, as seen in some samples, to reduce water permeability during the boiling of food (Skibo et al. 1997). The vessel height and size are usually manipulated, whether the cooking pots are intended for use at small or large gatherings. The ceramic vessels for cooking are usually bigger for large gatherings (Junker and Niziolek 2010). The restricted pot from Rạch Núi with an orifice diameter of 36 cm could have been used to prepare food for large gatherings.

Stoves labelled as cà rang are portable equipment used for cooking with wood and fire. The portability of those stoves could have provided options to the previous occupants of Rạch Núi and An Sơn sites to cook their food in different parts of the sites and surrounding areas at their convenience. The use of earthenware stoves continues in southern Vietnam (Fig. 7-41). This case is similar to that of coastal Borneo, where pottery stoves were found in the Neolithic site of Bukit Tengkorak, and the present-day Sama people also produce, distribute, and use the earthenware stove for food preparation (Ono 2006). The use of portable earthenware stoves from the past to the present is common in East and SEA (Cremin 2014). They were probably used for cooking food with pottery vessels or by grilling the food over fire. Similar to the seafaring communities in SEA, such as the Sama, the people during the Neolithic in Rạch Núi and An Sơn could have carried these stoves in their boats while sailing in the tributaries of Mekong River.

Those identified as jars and restricted pots/jars could have been used for storage of water or other liquids, fermentation of food items based on non-abrasive attritions on
their interior surfaces, and/or transport. Pottery vessels for storage were usually manufactured with restricted openings to avoid the spillage of food or liquid content (Rice 1987). In contrast to the cooking pots, storage vessels are manufactured with thicker walls and bases for stability while placed on the ground, and to avoid moisture transfer between the outside and inside of the vessel. The porosity and permeability are manipulated depending on whether the storage is long-term or short-term. High porosity and permeability are avoided for long-term storage; thus, surface treating of the ceramic vessels is done to reduce permeability (Rice 1987). This could be the case for jars and restricted pots/jars with slip or burnish. On the other hand, those with no slip or burnish could have been intended for short-term storage only. The clay and temper were manipulated to reduce porosity (Rice 1987). The porosity for short-term storage allows evaporative cooling of the content. The storage ceramic vessels vary in size and height depending on the food or liquid items to be stored (Rice 1987). Vietnam and many areas of SEA are known at the present for making fish sauce through fermenting fish and salt in jars (Fig 7-42). It is possible that this was being practiced during prehistoric times, as indicated by the non-abrasive surface attritions on a few vessels.

Open pots, open bowls, restricted bowls, small cups and/or bowls, and plates and/or bowls with stand could have been used for serving food (with dipping access) or drinks (with pouring access) (Rice 1987). Those designed for serving food usually have wide, unrestricted or slightly restricted openings as well as a shallow profile, while those designed for serving drink have narrow, restricted openings and higher profiles. Bowls are usually manufactured with unrestricted openings to allow for easy and immediate access of contents, with handles, and with flat bases. The emphasis could be more on
their display or communicative roles during consumption, rather than on the mechanical properties important for ceramic vessels used in food preparation and storage. Thus, surface treatments could be more elaborative in serving ceramic vessels (Rice 1987). This can also be true of open bowls from An Sơn and Lò Gạch. The former have wavy rims and cord-marked designs. The latter have wavy profiles and smoothed or burnished exterior surfaces. The plates and/or bowls with stand from Lò Gạch were probably used for serving plant foods based on the plant remains and impressions on their top interior surfaces.

Open bowls and pots, as well as unrestricted small cups and/or bowls could have also been used for cooking or maybe heating of food to be served, aside from serving. This probability is based on the observation in Southern Vietnam that the earthenware vessels for cooking, as well as for heating and serving in restaurants, have unrestricted forms, similar to those of open bowls and small cups and/or bowls (Fig. 7-43, Fig. 7-41). This interpretation is supported by pottery rims from An Sơn that have unrestricted profiles and burnt exterior surfaces (Fig. 7-21). This is similar to the case of pottery vessels from the Barnett phase of Northwest Georgia, where bowls were utilized for heating and serving food (Hally 1986). However, this contradicts the notion that cooking pots should have restricted openings so that they can retain heat and moisture while cooking (Rice 1987). These unrestricted vessels were probably intended for use in stewing rather than for boiling food, where liquid must evaporate and it is more convenient to add ingredients in the middle of the cooking process.

**Post-Breakage Steps and Discard**

It was common that people threw pottery in middens and deposited pots for ritual or burial purposes, as seen in many archaeological sites. Some whole vessels were
associated with human burials in An Sơn (Bellwood et al. 2011) and Gò Ô Chùa (Franken 2012). However, a huge number of pottery sherds, especially the majority of those from Rạch Nuí and numerous ones from Trench 1 in Lò Gạch, were not really thrown away, but rather had an enduring post-breakage role in constructing and maintaining the structures, such as floors, in the settlement sites of southern Vietnam. These sherds, as previously mentioned, are encrusted with lime and, occasionally, burnt fiber in charred and/or silicified forms. These encrustations are not a consequence of foodway-related practices but are from construction-related activities, as they were embedded in floors made of lime mortar. This case of pottery recycling is similar to the case of the Tzeltal (Mexico) and Wanka (Peru), where some fragments of cooking pots and water jars were recycled for construction, such as paving or filling the damp, muddy portions of patio areas around houses and pathways (Deal and Hagstrum 1995). The pots in these sites were also recycled to make new pots, as indicated by the grog temper made of crushed pottery in some of the samples. As reviewed by Deal and Hagstrum (1995), reuse and recycling of pottery are common among modern-day pottery-using communities in Thailand and India. Thus, it is possible that the practice of reusing or, more appropriately, recycling pottery (after Vukovic 2015) was also widespread in prehistoric communities, as demonstrated in southern Vietnam. In fact, Vukovic (2015) documented the recycling of pottery sherds as tools, raw material (grog temper), and construction material for oven foundations, as well as the reuse of whole and partly damaged vessels in Late Neolithic Vinca, Serbia.
Conclusions and Further Work

In between manufacturing and disposal, the earthenware pottery from the four settlement sites in southern Vietnam had various roles in the preparation, storage, and serving of food during their initial stages. Their lives as utilitarian pots are continuously explored through the organic residue analysis of selected samples in Chapters 8 and 9. The findings here in Chapter 7 will be verified with those from organic residue analysis in Chapter 8 to address how foods were prepared in and/or served in sampled pottery vessels. Examining the interactions between people, pottery, and food during the preparation and serving of food contributes to understanding of the daily lives and identity of prehistoric communities.

After the pottery was broken, it had continuous and enduring post-breakage roles in these prehistoric communities. They became important materials in the maintenance of the structures where the previous occupants dwelt. Similar to the An Son site (Sarjeant 2012, 2014a,b), I recommend that detailed typological and petrographic analyses of pottery assemblages from the other three sites be done. It is possible that there is a correlation between the most commonly utilized pottery form and the most commonly reused and recycled pottery form, similar to the case of cooking and water-carrying jars of the modern Tzeltal Maya in Mexico (Deal and Hagstrum 1995). The linkage between the recycled pottery and rhythms of life in these settlement sites, the latter based on the regularity of maintaining floor surfaces (after Boivin 2000) with broken pottery, plant materials, and lime mortar, is also possible. This is worth exploring, especially in recently excavated Rạch Núi and Lò Gạch sites. In Rạch Núi (Oxenham et al. 2015), the site was probably occupied between 45 and 210 years with
13 (dated) major phases of reconstruction. Assuming the more conservative range of 210 years, replacement of platforms would have occurred every 10-15 years or more and several replacements of occupational surfaces could have been annual, within a single phase (Oxenham et al. 2015). A similar pattern can be gleaned from Lò Gạch, but materials and records from the recent excavation are still under analysis. Thus, exploring the lives of pots after manufacturing contributes to the understanding of their roles in the daily and cyclical practices of their previous owners who lived in these prehistoric settlements in southern Vietnam.
Table 7-1. Inventory of sampled pottery from Rạch Núi site.

<table>
<thead>
<tr>
<th>Trench</th>
<th>With rim</th>
<th>Shoulders</th>
<th>Body</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>29</td>
<td>0</td>
<td>7</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>3</td>
<td>8</td>
<td>41</td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>0</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>Total</td>
<td>70</td>
<td>3</td>
<td>20</td>
<td>93</td>
</tr>
</tbody>
</table>

Table 7-2. Inventory of sampled pottery from An Sơn site.

<table>
<thead>
<tr>
<th>Trench</th>
<th>With rim</th>
<th>Shoulders</th>
<th>Body</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26</td>
<td>9</td>
<td>14</td>
<td>49</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>2</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>38</td>
<td>11</td>
<td>19</td>
<td>68</td>
</tr>
</tbody>
</table>

Table 7-3. Inventory of sampled pottery from Lò Gạch site.

<table>
<thead>
<tr>
<th>Trench</th>
<th>With rim</th>
<th>Shoulders</th>
<th>Bases with Stand</th>
<th>Body</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>33</td>
</tr>
</tbody>
</table>

Table 7-4. Inventory of sampled pottery from Gò Ô Chùa site.

<table>
<thead>
<tr>
<th>Trench*</th>
<th>With rim</th>
<th>Shoulders</th>
<th>Body</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>10</td>
<td>14</td>
<td>44</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>34</td>
<td>10</td>
<td>14</td>
<td>58</td>
</tr>
</tbody>
</table>

*Trench 1 is in the Northern Mound. Trenches 2-4 are in the Central Mound (Reinecke 2012).

Table 7-5. Orifice diameter and rim thickness summary statistics of sampled vessels with rims from four archaeological sites in Long An Province, southern Vietnam.

<table>
<thead>
<tr>
<th>Site</th>
<th>Orifice Diameter (cm)</th>
<th>Rim Thickness (mm)</th>
<th>Lip Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rạch Núi</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>Mean 17.7</td>
<td>8.33</td>
<td>6.09</td>
</tr>
<tr>
<td></td>
<td>Std. Dev. 4.06</td>
<td>1.74</td>
<td>1.32</td>
</tr>
<tr>
<td></td>
<td>Minimum 11</td>
<td>4.50</td>
<td>2.44</td>
</tr>
<tr>
<td></td>
<td>Maximum 36</td>
<td>11.72</td>
<td>9.36</td>
</tr>
<tr>
<td>An Sơn</td>
<td>38</td>
<td>38</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Mean 22.84</td>
<td>8.34</td>
<td>7.99</td>
</tr>
<tr>
<td></td>
<td>Std. Dev. 8.10</td>
<td>2.52</td>
<td>1.94</td>
</tr>
<tr>
<td></td>
<td>Minimum 10</td>
<td>3.71</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>Maximum 40</td>
<td>15.76</td>
<td>14.14</td>
</tr>
<tr>
<td>Site</td>
<td>Orifice Diameter (cm)</td>
<td>Rim Thickness (mm)</td>
<td>Lip Thickness (mm)</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------------------</td>
<td>--------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Lò Gạch</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Mean</td>
<td>21.76</td>
<td>8.54</td>
<td>9.35</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>6.02</td>
<td>2.66</td>
<td>5.95</td>
</tr>
<tr>
<td>Minimum</td>
<td>10</td>
<td>3.32</td>
<td>4.86</td>
</tr>
<tr>
<td>Maximum</td>
<td>32</td>
<td>13.65</td>
<td>36.80</td>
</tr>
<tr>
<td>Gò Ô Chùa</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>32</td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td>Mean</td>
<td>20.16</td>
<td>9.26</td>
<td>9.52</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>3.97</td>
<td>2.76</td>
<td>2.85</td>
</tr>
<tr>
<td>Minimum</td>
<td>12</td>
<td>5.01</td>
<td>5.95</td>
</tr>
<tr>
<td>Maximum</td>
<td>28</td>
<td>18.57</td>
<td>19.37</td>
</tr>
</tbody>
</table>

Table 7-6. Summary of vessel forms of sampled pottery with rims \((n=167)\) and stands \((n=3)\) from four archaeological sites in Long An Province, southern Vietnam.

<table>
<thead>
<tr>
<th>Vessel form</th>
<th>Rạch Núi</th>
<th>An Sơn</th>
<th>Lò Gạch</th>
<th>Gò Ô Chùa</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open bowls ((25.88%))</td>
<td>6</td>
<td>18</td>
<td>11</td>
<td>9</td>
<td>44</td>
</tr>
<tr>
<td>Restricted bowls ((5.29%))</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>Open pots ((2.94%))</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Restricted pots ((38.24%))</td>
<td>38</td>
<td>6</td>
<td>6</td>
<td>15</td>
<td>65</td>
</tr>
<tr>
<td>Restricted pots/Jars ((16.47%))</td>
<td>20</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>28</td>
</tr>
<tr>
<td>Jars ((4.12%))</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Stove ((1.77%))</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Small cups and/or bowls ((3.53%))</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Plates and/or bowls with stand ((1.77%))</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Total ((100%))</td>
<td>70</td>
<td>38</td>
<td>28</td>
<td>34</td>
<td>170</td>
</tr>
</tbody>
</table>
Figure 7-1. An example of a restricted pot from Gò Ô Chùa, Trench 2, Level 11 (Photo by M.S. Eusebio).

Figure 7-2. An example of an open pot from Gò Ô Chùa, Trench 1, Level 10 (Photo by M.S. Eusebio).

Figure 7-3. An example of an open bowl pot from An Sơn, Trench 1, Layer 10 (Photo by M.S. Eusebio).
Figure 7-4. An example of a restricted bowl from Rạch Núi, Trench 3, Layer 2/3 (Photo by M.S. Eusebio).

Figure 7-5. An example of a small cup/bowl from An Sơn, Trench 1, Layer 10 (Photo by M.S. Eusebio).

Figure 7-6. An example of a restricted pot/jar from Rạch Núi, Trench 3, Layer 2/20 (Photo by M.S. Eusebio).
Figure 7-7. An example of a jar from Gò Ô Chúa, Trench 2, Level 10 (Photo by M.S. Eusebio).

Figure 7-8. A reconstructed stove (cà rang) from Rạch Núi [12RNH3L2-20 A1 & 12 RNH3L2-21C3 (not sampled)] (Photo by M.S. Eusebio).

Figure 7-9. An example of a plate and/or bowl with stand from Lò Gạch, Trench 2, Context 205 (Photo by M.S. Eusebio).
Figure 7-10. Frequency distribution of orifice diameters of sampled pottery from Rạch Núi site (Photo by M.S. Eusebio).

Figure 7-11. A pottery sherd from Rạch Núi, Trench 2, Layer 4/2 with non-abrasive surface attrition on its interior surface (Photo by M.S. Eusebio).
Figure 7-12. Pottery sherds from Rạch Núi, Trench 1 with cordmarked design (Photo by M.S. Eusebio).

Figure 7-13. An example of a lime encrusted pottery sherd from Rạch Núi, Trench 2, Feature 2 (Photo by M.S. Eusebio).

Figure 7-14. Two rim sherds from Rạch Núi, Trench 3, Layer 2 with soot on their interior surface (Photo by M.S. Eusebio).
Figure 7-15. Frequency distribution of orifice diameters of pottery from An Sơn site.

Figure 7-16. Three pottery sherds from An Sơn with non-abrasive surface attrition. A) Trench 1, Layer 13; B) Trench 1, Layer 3; C) Trench 2, Layer 3-2 (Photos by M.S. Eusebio).

Figure 7-17. A body sherd of a vessel from An Sơn, Trench 2, Layer 2-3 with cordmarked design (Photo by M.S. Eusebio).
Figure 7-18. Fragments of two stoves (cà rang) with cordmarked design from An Son site. A) Trench 1, Layer 2-3 and B) Trench 1, Layer 8 (Photos by M.S. Eusebio).

Figure 7-19. Used earthenware stove (cà rang) in present-day southern Vietnam. A) Side view and B) top view (Photos by M.S. Eusebio).

Figure 7-20. Fragments of a stove (cà rang) from An Son, Layer 10 with A) exterior surface and B) interior surface with charred residue (Photos by M.S. Eusebio).
Figure 7-21. Open bowls with charred surface residues on their exterior surfaces from An Sơn, Trench 1. A) Layer 13 and B) Layer 14 (Photos by M.S. Eusebio).

Figure 7-22. Open bowl with wavy profile from Lò Gạch, Trench 3, Feature 3-3 (Photo by M.S. Eusebio).

Figure 7-23. Restricted pot with everted rim from Lò Gạch, Trench 3, Context 305 (Photo by M.S. Eusebio).
Figure 7-24. Frequency distribution of orifice diameters of sampled pottery from Lò Gạch site (Photo by M.S. Eusebio).

Figure 7-25. Plate and/or bowl with stand from Lò Gạch, Trench 1, Context 105. A) Top view and B) side view (Photos by M.S. Eusebio).
Figure 7-26. Plate and/or bowl with stand from Lò Gạch, Trench 3, Context 302. A) Side view and B) top view with cross section (Photos by M.S. Eusebio).

Figure 7-27. A) Partially reconstructed restricted pot from Lò Gạch, Trench 1, Context 104 with B) non-abrasive attrition on its interior surfaces (Photos by M.S. Eusebio).

Figure 7-28. A body sherd with A) charred residues and B) fish bones (2x x 5x) on C) its interior surface (1.25x x 5x) from Lò Gách, Trench 2, Feature 2-14 (Photos by M.S. Eusebio).

Figure 7-29. A body sherd with A) charred residues and B) plant impressions (2x x 5x) on its interior surface from Lò Gách, Trench 2, Context 204 (Photos by M.S. Eusebio).
Figure 7-30. A body sherd with charred residues on its interior surface from Lò Gạch, Trench 2, Context 205 (Photo by M.S. Eusebio).

Figure 7-31. Sherds with A) lime and rust-like stains from Lò Gạch, Trench 1, Feature 1-113 left and B) salt crystals from Trench 2, Context 204 (Photos by M.S. Eusebio).

Figure 7-32. A sherd with charred surface residues and silicified husks (probably of rice) from Lò Gạch, Trench 1, Feature 1-119 (Photo by M.S. Eusebio).
Figure 7-33. Scraped sediment with charred plant remains (1x x 5x) from the top surface of plate and/or bowl with stand from Lò Gạch, Trench 1, Context 105 (Photo by M.S. Eusebio).

Figure 7-34. Possible plant impressions (3.2x x 5x) on the top surface of a plate and/or bowl from Lò Gạch, Trench 2, Context 203 (Photo by M.S. Eusebio).

Figure 7-35. Possible plant impressions (8x x 5x) on the top surface of a plate and/or bowl from Lò Gạch, Trench 3, Context 302 (Photo by M.S. Eusebio).
Figure 7-36. Frequency distribution of orifice diameters of sampled pottery from Gò Ô Chùa site. Two rims are excluded from assessment of orifice diameter due to their orifice percentages being < 5%.

Figure 7-37. Pottery vessels from Gò Ô Chùa with non-abrasive attritions on their interior surfaces. A) Trench 2, Level 11; B) Trench 1, Level 10; C) Trench 1, Layer 11) (Photos by M.S. Eusebio).
Figure 7-38. A body sherd from Gò Ô Chùa, Trench 1, Level 10 with charred surface residues on its interior surface (Photo by M.S. Eusebio).

Figure 7-39. A shoulder/body sherd with firing cloud from Gò Ô Chùa, Trench 1, Level 11 (Photo by M.S. Eusebio).

Figure 7-40. Used cooking pot from present-day Kalinga, northern Philippines (Photo by M.S. Eusebio).
Figure 7-41. Modern earthenware stoves (*cà rang*) in present-day southern Vietnam being used for cooking at the back of Long An Provincial Museum in 2012 (Photo by M.S. Eusebio).

Figure 7-42. Large stoneware jars at the Lò Gạch site, with fermenting fish sauce inside (Photo by M.S. Eusebio).

Figure 7-43. Small open bowls used for heating and serving fish stew in present-day southern Vietnam. A) Top view and B) side view (Photos by M.S. Eusebio).
CHAPTER 8
ORGANIC RESIDUE ANALYSIS OF ARCHAEOLOGICAL POTTERY FROM SOUTHEAST ASIA

Introduction

Chapter 8 presents the organic residue analysis of archaeological pottery with the analytical techniques utilized in Chapters 5 and 6. These pottery samples originated from four prehistoric sites in Southeast Asia (SEA), situated within the Mekong Delta of southern Vietnam. As mentioned in Chapters 2-7, the sites in southern Vietnam comprise the principal case study utilizing organic residue analysis of prehistoric pottery to survey culinary practices across space and time in a microregion. This chapter presents sample preparation, analysis, and results followed by discussion, including the implications of modern comparative reference materials analyzed and discussed in Chapters 5 and 6.

Laboratory Preparations and Analyses

The laboratory preparations and analyses discussed in Chapters 5 and 6 were also applied to the archaeological pottery analyzed. This section discusses specific, modified, and additional procedures applied to the archaeological samples. Samples A1-A6 were included in preliminary work using the facilities of the Biomedical Mass Spectrometry Core, Clinical and Translational Science Institute (BMS, CTSI) at the University of Florida. Samples A7-A127, W1-W13, CSR2-CSR4, and S1 were included in the continued work performed using the facilities of the Organic Geochemistry and Stable Isotope Laboratories in the Department of Geological Sciences, University of Florida (Appendix H). Samples A3-A6 were reprocessed and reanalyzed in these laboratories. Samples A19-A21, A41, and A99 are not included in this research. “A” indicates absorbed residues from archaeological pottery, “W” indicates whole pottery
sherds, “CSR” indicates charred surface residues, and “S” indicates surrounding soil associated with a pot. The procedures were modified from the existing laboratory protocol at the Organic Geochemistry Laboratory and Standard Operating Procedures were used for lipid residue analysis (modified from Craig et al. 2004, 2007; Evershed et al. 1990; prepared by Val Steele and outlined in Saul 2011; Spiteri 2012), as discussed in Chapters 5 and 6.

**Preparation of Pottery Samples for Lipid Extraction**

The majority of archaeological pottery processed for absorbed organic residues (A1-A127) was prepared by sampling approximately 5 g from a 2 cm x 2 cm fragment for each sample. The fragments from samples A1-A18 and A89-A98 were ground into fine powder with clean mortars and pestles, whereas the fragments from samples A22-A87 and A100-A127 were ground into powder with a Rocklabs Bench Top Ring Mill. For charred surface residues (CSR2-CSR6), bulk samples were scraped from the interior portions of pottery fragments and then pulverized with mortars and pestles.

**Solvent Extraction**

Lipids were extracted from samples A1-A6 with the conventional sonication-centrifugation extraction method (modified from Folch 1957; Fankhauser 1994; Charters et al. 1997) and from samples A7-A127, CSR2-CSR4, and S1 with an accelerated solvent extraction (ASE) method. The solvent mixture of 2:1 v/v dichloromethane (CH₂Cl₂ or DCM):methanol (CH₃OH or MeOH) was used to extract the organic residues as total lipid extracts (TLEs). A known amount of internal standard was added to the samples prior to the extraction for quantification purposes [40 µL 1 mg/ml of pentadecanoic (C15) acid for samples A1-A6, 10 µL 1 mg/mL heneicosanoic acid methyl ester (C21 FAME) for samples A7-A18 and CSR4, as well as 10 µL 1 mg/1mL
tetratriacontane (C34 branched alkane) for samples A22-A127, CSR2, CSR3, CSR5, and repeated extractions of samples A3-A6 with ASE].

For small samples (W1-W11) and rare (W12 & W13) pottery sherds from the PA1 site (Lape 2000, samples meant to serve as geographic control), a nondestructive extraction method (modified from Vanderveen 2006, 2011) was followed, using the same solvent mixture. The samples were first placed into small glass beakers and rinsed with ultrapure water (UPW) via sonication for 1 min, dried in a warm oven, and weighed. The UPW used for rinsing the samples was archived for future starch extraction and analysis using these samples. For small pottery sherds (samples W1-W11, less than 3 cm x 3 cm), each sample was placed into a solvent-cleaned and labeled 34-mL metal extraction cell with fiberglass filter papers and quartz sand. No internal standard was incorporated prior to extraction. The ASE proceeded as usual with 11 samples and a blank, and no sample was transferred into the first extraction cell. The rare pottery sherds (W12 and W13), with punctuated design and a possible incision, are slightly bigger than 3 cm x 3 cm and did not fit into the extraction cell. For these samples, lipids were extracted from the sherds by placing them into beakers filled with the solvent mixture and sonicating two times for 20 min (with a 10 min break in between), following Vanderveen (2006, 2011). The extracts were then decanted and filtered into 250-mL clear glass collection bottles, and archived similarly with other lipid residue extracts.

**Further Processing and Analyses of Lipid Residues on Archaeological Pottery**

Further processing [derivatization into trimethylsilyl esters/ethers (TMSEs), saponification, and derivatization into fatty acid methyl esters (FAMEs)] and analyses of lipid residues on archaeological pottery were conducted as described in Chapters 5 and...
6. Gas chromatography-mass spectrometry (GC-MS) of FAMEs from samples analyzed in 2013 (A1-A6) was performed with an Agilent Technologies 6890N Network GC System, equipped with an Agilent Technologies 7683B Series Injector and interfaced with Agilent Technologies 5793 Inert Mass Selective Detector. For samples analyzed in 2014-2015 (A7-A31, CSR4), the GC-MS analyses of lipid derivatives as TMSEs were performed with a Shimadzu GC-MS QP2010s (Chapter 5). For samples analyzed in 2016 (A3-A6, A32-A87, A100-A127, CSR2-CSR5, and S1), the GC-MS analyses of lipid derivatives as TMSEs were performed with a Thermo Trace 1310 Gas Chromatograph with Thermo TSQ 8000 Triple Quadrupole Mass Spectrometer (Chapter 6). All FAMEs were purified by eluting them through columns containing glass wool, 5% deactivated silica (SiO$_2$) gel, and sodium sulfate (Na$_2$SO$_4$), with the aid of DCM prior to the GC-MS analysis in 2016 using the latter GC-MS equipment (Chapter 6).

Further, FAMEs underwent compound specific isotopic analysis (CSIA) for $\delta^{13}$C values of C16 and C18 fatty acids using a Hewlett Packard HP 6890 Gas Chromatography-Combustion-IRMS (GC-C-IRMS). The $\delta^{13}$C values of C16 and C18 fatty acids were only calibrated using FAME standard F8-3 mixture (Arndt Schimmelmann in Biogeochemical Laboratories, Indiana University) and corrected for the methyl group added from methanol during derivatization of fatty acids into FAMEs (Rieley 1994), as described in Chapter 6 (Equation 6-1). Correcting $\delta^{13}$C of C16 and C18 fatty acids for the deviation due to post-industrial carbon (PIC, Friedli et al. 1986), similar to what was done for modern samples in Chapter 6, is unnecessary and was not done for residues on archaeological materials.
Qualitative and Quantitative Analysis

The identification of lipid compounds was based on the retention times of the standards, National Institute of Standards and Technology (NIST) Reference Library spectra (NIST107), AOCS Lipid Library (http://lipidlibrary.aocs.org), Amber Research Laboratory Database (http://cima.ng-london.org.uk/arl/), and published literature using GCMSsolution and Thermo Xcalibur programs, as described in Chapter 5 for modern experimental and ethnographic pottery. Tables 8-1 and 8-2, respectively, summarize abbreviations of lipid compounds mentioned here in Chapter 8 and present possible food sources for three principal categories of terrestrial animals, aquatic resources, and plants based on the analysis of TLE (Evershed et al. 1990, 2002). Table 8-3 summarizes identified lipid compounds with additional details from the mass spectra library and the literature. The quantification of identified lipid compounds, except for contaminant peaks (e.g., plasticizers), was performed by combined automatic and manual integration using the Thermo Xcalibur program to determine TLE yields (Equation 5-2 in Chapter 5).

Preparation and Analysis of Bulk Stable Isotopes $\delta^{13}C$ and $\delta^{15}N$ from Charred Surface Residues

Prior to lipid extraction and analysis, the charred surface residues from five pottery sherds (CSR2-CSR6) were analyzed for bulk stable isotopes ($\delta^{13}C$ and $\delta^{15}N$). Prior to sampling, these interior surface residues were examined using a Zeiss Discovery V8 Stereomicroscope and photographed. Charred residues from each sample were then scraped from the pottery sherd using a scalpel, ground with mortar and pestle, and stored in a glass scintillation vial. The surface residues were divided into two subsamples, A and B. Subsample A was left untreated whereas subsample B
was treated with 0.1M HCl, rinsed with deionized distilled H₂O to neutrality, and oven-dried at 60°C. This was done to assess differences in δ¹³C values between treated and untreated residues caused by the possible presence of interfering inorganic carbon (Brodie et al. 2011), since the surrounding environments of the samples were lime or carbonate rich. Both untreated and treated samples were analyzed for δ¹³C and δ¹⁵N using GC-C-IRMS coupled with a ConFlo II interface linked to a Carlo Erba NA 1500 CNS Elemental Analyzer in the Stable Isotope Mass Spectrometry Laboratory, Department of Geological Sciences, University of Florida. Standards used were Vienna Pee Dee Belemnite (PDB) and atmospheric N₂ (AIR) for δ¹³C and δ¹⁵N, respectively. Results for treated samples run in duplicate are reported here. Because the samples originated from carbonate rich contexts, results from treated samples are more reliable than those from untreated samples.

**Results and Discussion**

This section presents results from the organic residue analysis of archaeological pottery with GC-MS, GC-IRMS, and GC-C-IRMS. For pottery samples from prehistoric Vietnam (Table 8-4), a total of 119 were processed and analyzed. These are absorbed organic residues from 113 pottery sherds (Appendix I), five charred interior surface residues on pottery sherds, and one soil sample associated with one pottery sherd. The latter was analyzed to assess contamination from the surrounding soil. For charred surface residues, lipids were only extracted from four out of five samples. All 113 pottery sherds sampled were selected from all the samples collected from southern Vietnam and analyzed for their technofunctional attributes in Chapter 7. Although organic residues were extracted from 23 samples recovered in prehistoric eastern Indonesia (samples A89-A98, W1-W13 from PA1 site, see Lape 2000), they were not analyzed.
because of logistical problems. The samples from southern Vietnam were prioritized for analyses because their interpretation addresses the questions posed in this research, which are discussed in Chapter 9.

Similar to the case of modern pottery samples in Chapter 5, the amount of TLEs recovered were relative because of the semi-quantitative calculations, where internal standards were utilized to estimate the amounts of individual compounds (Reber et al. 2015). As discussed in Chapter 5, rather than GC-MS, GC with flame ion detector (FID) is a more appropriate instrument to use for accurate quantification of lipid components because of its sensitivity, despite the fact that it does not identify organic compounds. Also, there is a tendency for the GC-MS to undervalue the amounts of compounds, since the MS detectors are less sensitive than FID (Reber et al. 2015). The GC-FID was not used for the archaeological materials because the types of lipid compounds preserved and detected are unknown until analyses are completed. Also, the standards for all components are needed to identify and quantify the compounds, and not all lipid components have available commercial standards. The compounds contained in archaeological samples and detected by GC-MS were identified based on their characteristic mass fragment (m/z) patterns through the mass spectra library and available literature (online databases and published articles). To assess the preservation of recovered lipid residues, TLE computations were calculated for confidently identified compounds or compound types only. Identified contaminants, such as plasticizers and those from column bleed during analysis, were not included in calculations. Ideally, calculated TLEs should be at least 5 μg/g to ensure that the lipids derive from the pottery contents rather than contamination (Charters et al. 1997).
samples included for preliminary work were also calculated for fatty acid yields (Appendix D).

Not all lipid extracts were saponified and derivatized as FAMES to acquire the δ\textsuperscript{13}C values of C16 and C18 fatty acids through CSIA (Table 8-4). All samples included in preliminary work (A1-A6) underwent CSIA. For samples A7-A100 (except A89-A98) and CSR 4 from southern Vietnam, samples that underwent CSIA were selected based on the amounts of their C16 and C18 fatty acids during the GC-MS analysis of their extracts as TMSEs. Both fatty acids should have at least 1 µg/g to ensure reliable δ\textsuperscript{13}C values from the C16 and C18 fatty acids. For samples A101-A128, CSR2, CSR3, and CSR5, the samples processed for CSIA were selected based on evaluation of the light yellow or brown color of their reduced lipid extracts, which are more likely to yield reliable δ\textsuperscript{13}C values based on previously screened samples [A7-A100 (except A89-A98)]. This is a consequence of uncertainty brought about by problems related to GC-MS, where it was unknown if the analysis of these extracts as TMSEs was possible. Fortunately, these extracts were still analyzed as TMSEs after the aliquots of some of them were already saponified and derivatized as FAMEs for CSIA. As discussed below, some of the samples selected for CSIA actually have TLEs of less than 5 µg/g and have amounts of C16 and C18 fatty acids of less than 1 µg/g. However, they still delivered reliable δ\textsuperscript{13}C values that are different from the method blanks with fewer C16 and C18 fatty acids. A recent study shows that it is still possible to acquire δ\textsuperscript{13}C values of C16 and C18 fatty acids from very old samples with low yields and few recovered target compounds (Papakosta et al. 2015). Results are further discussed specifically for each site of southern Vietnam, then overall for all four sites, with comparison with the results
from modern comparative reference materials discussed in Chapters 5 and 6, as well as the degree to which food categories may or cannot be securely identified through lipid biomarkers and isotopic signatures.

Rạch Núi

Rạch Núi is a Neolithic mound dating to 1500-1200 BC and located where the Vam Co Dong, Vam Co Tay, and Dong Nai Rivers meet near the town of Can Giuoc, Long An, Vietnam (Oxenham et al. 2015). The previous occupants of Rạch Núi subsisted on five food categories based on the analyses of biological remains (Oxenham et al. 2015): C₃ (e.g., rice) and C₄ (e.g., foxtail millet, sedge) plants, nonruminant (e.g., pig, dog) and ruminant animals (e.g., deer), as well as freshwater (some are brackish) resources (e.g., catfishes, snakehead fishes, shellfishes). Of the four sites analyzed in this dissertation, Rach Núi is closest to the coast, and prehistoric people would have had more immediate access to maritime food resources. This site was discussed in detail in Chapter 3.

From Rach Núi, 27 pottery sherds were processed for organic residue analysis with GC-MS (Tables 8-5 and 8-6). Eight samples had calculated TLEs > 5 μg/g, whereas 13 had calculated TLEs < 5 μg/g and no lipid compounds were detected in six samples. With the exception of two samples, only fatty acids were detected from the organic residues extracted. One sample (A114 RN24) produced long-chain alkanes, isopropyl palmitate (an ester), and 4-methoxy cinnamic acid, all of which are indicative of plant food sources (Table 8-6), however, C16 and C18 fatty acid yields were low, (< 1 μg/g). Another sample (A123 RN25) also had low C16 and C18 fatty acid yields but
exhibited evidence for C16 and C18 MAGs. Both samples were not considered for CSIA.

Eleven out of 27 samples were further processed for CSIA (Tables 8-5 and 8-6). As shown in Figure 8-1, two out of 11 samples were enriched in $^{13}$C with more positive $\delta^{13}$C values of C16 and C18 fatty acids. The two $^{13}$C-enriched samples may indicate the processing of C$_4$ plants and/or marine resources, whereas the remaining samples indicate the processing of C$_3$ plants and/or freshwater resources. Comparison with isotopic values of modern reference materials (Chapter 6) suggests that terrestrial animals were not processed in these pots (or left no observable residues). General findings from Rach Núi support the presence of both C$_3$ and C$_4$ plants, as well as freshwater food sources. Elevated $\delta^{13}$C values are also consistent with brackish or estuarine food resources, such as those identified in food remains excavated from the site.

**An Sơn**

An Sơn is a Neolithic mound dating to 2300-1200 BC and located near Vam Co Dong in An Ninh Tay commune, Duc Hoa District, Long An, Vietnam (Bellwood et al. 2011; Nishimura and Nguyen 2002). The previous occupants of An Sơn subsisted on five food categories based on the analyses of biological remains (Piper et al. 2012; Sarjeant 2014b): C$_3$ (e.g., rice) and C$_4$ (probably sedge) plants, nonruminant (e.g., pig, dog) and ruminant animals (e.g., deer), as well as freshwater and some brackish water resources (e.g., turtles, eels, snakehead fishes, shellfishes). This site was discussed in detail in Chapter 3.

From An Sơn, 27 pottery sherds and charred surface residues on one of these sherds were processed for organic residue analysis with GC-MS (Tables 8-7, 8-8, and
These surface residues (CSR3) on a fragment of a stove or cà rang (A119 AS27) were also processed for bulk stable isotopic analysis (Table 8-8). Five samples had calculated TLEs of > 5 μg/g, whereas 17 samples had calculated TLEs of < 5 μg/g (including the charred surface residues) and no lipid compounds were detected in six samples. The majority of the organic residues recovered from the samples had only fatty acids (Tables 8-8 and 8-9). Four samples had organic residues with alkanes, whereas two of them had C16 and C18 MAGs (A3 AS1 and A4 AS2) and two of them had long-chain alcohols (A27 AS6 and A51 AS15). Two of the pottery samples (A119 AS27 and A27 AS6) had terpenoids, specifically triterpenoids that are produced by plants of the families Burseraceae and Dipterocarpaceae (Lampert et al. 2002). The identified terpenoids are β-amyrenone, α-amyrone, and nor-β-amyrone (Brettell et al. 2013; Lampert et al. 2002).

The TLE profiles of two pottery samples, A27 AS6 (Table 8-8) and A51 AS15 (Table 8-9), with long-chain alcohols are shown in Figures 8-2 and 8-3, respectively. Both pottery vessels are plain, unrestricted, and fiber-tempered open bowls from Trenches 1 and 3, respectively. Pot A27 AS6 produced a brownish yellow residue during extraction, whereas A51 AS15 produced a brown extract. Remarkably, both pottery vessels seem to have previously contained similar plant sources based on their prominently common detected compounds, which are C24 fatty acid, C24 and C26 alcohols, and tetracosanyl palmitate (a C40 wax ester). In both samples (Figs. 8-2 and 8-3), the peak (at ~28.6 min) representing C24 alcohol is the most prominent. As we will see later, the triad of C24 and C26 alcohols with tetracosanyl palmitate or C40 wax ester as well as the prominence of C24 alcohol are also observed in a few samples from
the two Metal Age sites. The abundance of mid-to-long-chain fatty acids, alkanes, and alcohols indicate plant food sources (Correa-Ascencio et al. 2014; Roffet-Salque et al. 2016).

Triterpenoids are known to originate from resins of plants from Burseraceae and Dipterocarpaceae families, which are applied on pottery vessels as slip or sealant (Lampert et al. 2002). Since pot A27 AS6 has no remnant of pottery slip on its surfaces, a few detected terpenoids probably indicate remnants of slip or sealant that was absorbed into the clay matrix. Another significant point about pot A27 AS6 is that it is the only pot with chemical compound evidence of processing of aquatic resources. Phytanic acid, one of the isoprenoid fatty acids indicative of aquatic resources (Cramp and Evershed 2014) was detected and identified from the analysis of FAMEs from this sample (Fig. 8-4). Although phytanic acid can also be found in ruminant animals (Lucquin et al. 2016a), it was deduced that it originated from a freshwater resource based on CSIA evidence discussed below.

Both absorbed (A119 AS27) and charred interior surface residues (CSR3) of the stove or cà rang were analyzed to assess if drippings from the food cooked directly via roasting, or indirectly as spillage from the cooking vessel, would be detected and identified. As shown in Figure 8-5, the absorbed organic residues are composed mainly of terpenoids derived from the firewood (α-amyrone, nor-β-amyrone, and β-amyrenone). The presence of a polynuclear aromatic hydrocarbon (PAH, benz[a]anthracene) indicates burning of wood in an open fire (Poulain et al. 2016). Perhaps the sources of firewood on pot A119 AS27 and resins used as possible slip or sealant on pot A27 AS6 are similar or related. As discussed below, the charred residue (CSR3) also underwent
bulk carbon and nitrogen isotopic analysis. The analysis resulted to values that support the use of a C₃ plant. The data from the firewood in this prehistoric stove can serve as a comparative reference for C₃ plants in the area.

The absorbed residues from ten pottery sherds and the charred surface residues from An Sơn were further processed for CSIA. As shown in Figure 8-6, the δ¹³C values of C₁⁶ and C₁₈ fatty acids fall within the range of freshwater aquatic resources and C₃ plants based on the comparative reference materials established in Chapter 6. Comparison with modern comparative reference materials also eliminated the possibility of terrestrial animals being processed in these pots. Findings from this site support the presence of both C₃ plants and freshwater food sources.

Lò Gạch

Lò Gạch is a Metal Age settlement site (ca. 1100 to 650 cal yr BC) with multiple layers of intentionally laid surfaces and sediment accumulation, located on the western bank of the Vam Co Tay River (Bui 2008; Piper 2013). Based on preliminary observations during the 2014 excavation, the previous occupants of Lò Gạch had subsisted on five food categories: C₃ (e.g., rice) and C₄ (Job’s tears) plants, nonruminant (e.g., pig) and ruminant animals (e.g., deer), as well as freshwater resources (e.g., freshwater fishes). Analysis of faunal remains is not yet conclusive as to whether marine resources are absent from this site. This site was further discussed in detail in Chapter 3. Although pottery samples from the other three sites were collected from museum collections, those from this site were collected during the 2014 excavation. A majority of the samples were collected as freshly excavated and unwashed sherds, with the expectation that samples from this site would produce the highest yields.
All 33 pottery sherds and charred surface residues on two of these sherds from this site (CSR4 on A100 LGA31 and CSR5 on A111 LGA32) were processed for organic residue analysis with GC-MS (Table 8-10). The absorbed residues from five of these pottery sherds and charred surface residues on the two sherds were further processed for CSIA. The charred surface residues on two pottery sherds and those on another sherd (CSR6 on A112 LGA33) were also processed for bulk stable isotopic analysis. Soils (S1) associated with a sample that yielded several lipid compounds (A78 LGA16; fatty acids, alkanes, and alcohols) were also analyzed to assess environmental contamination. In contrast to the expectation of higher yields from freshly excavated and unwashed samples, the Lò Gạch site had the lowest yields. Only six of the 33 samples had calculated TLEs of > 5 μg/g, whereas 20 had TLEs of < 5 μg/g (including the charred surface residues). No lipid compounds were detected in nine samples. Some samples that had calculated TLEs of < 5 μg/g and did not yield lipid residues had light green or brown extracts. It is possible that these samples contained nonlipid compounds that are not derivatizable by BSFTA and/or cannot be detected by GC-MS.

A majority of the samples (Tables 8-11, 8-12, and 8-13) had only fatty acids in their residues. A few of them had a variety of organic compounds. Figures 8-7 and 8-8, respectively, show the TLE profiles of pots A78 LGA16 (Table 8-11) and A111 LGA32 (Table 8-12). Both pottery vessels with yellow-green extracts have fatty acids, alkanes, and C24 and C26 alcohols. Although pot A78 LGA16 had a TLE yield of > 5 μg/g, the amounts of C16 and C18 fatty acids were insufficient for the sample to be considered for CSIA. Collection of freshly excavated samples from Lò Gạch site also presented an opportunity to collect soil adhering to sampled pottery and to later assess possible
contamination caused by lipid migration from the surrounding soil into the pottery clay matrix during long-term burial (Heron et al. 1991). The soil (S1) associated with pot A78 LGA16 was analyzed to assess the validity of the findings from the absorbed residues, as this pot was the first from the site to deliver good results in terms of molecular profiling. As seen in Table 8-11, the soil has very few lipid compounds and negligible concentrations in contrast to the abundance of lipid compounds and higher concentrations in absorbed residues. C23 alkane and C24 alcohol found in the soil could have migrated from the pottery clay matrix into the surrounding soil. Thus, I conclude that the absorbed residues on the pot originated from its former food content. As seen in Figure 8-7, pot A78 LGA16 has fatty acids, alkanes, and alcohols similar to pot A111 LGA32 (Fig. 8-8). Pot A108 LGA28 also has fatty acids and alkanes, but its TLE yield is < 5 μg/g (Table 8-13). Both pots A111 LGA32 and A108 LGa28 have one of the PAHs (benz[a]anthracene) that could indicate contact of the pottery vessels with open fire (Poulain et al. 2016).

Similar to pots A27 AS6 and A51 AS15 from the An Son site, the absorbed residues on pot A111 LGA32 also exhibit the triad of C24 and C26 alcohols with tetracosanyl palmitate or C40 wax ester (see Fig. 8-8). The latter is missing in pot A78 LGA16. Pot A111 LGA32 also has a higher lipid yield (Table 8-12) than that of pot A78 LGA16 (Table 8-11). It also has adhering soil, but soils have not been analyzed to date to check for contamination because of unavailability of the GC-MS after the extracts from the last 31 samples were analyzed as TMSEs. The charred surface residues on pot A111 LGA32 (CSR5) only exhibit evidence for fatty acids. Based on the supporting results from the bulk stable isotopic analysis of the charred surface residues (CSR5,
discussed below) and the CSIA of the extracts from both absorbed and charred surface residues, pot A111 LGA32 formerly contained C₃ plant and freshwater sources. This sample demonstrated the corroboration of results from lipid profiling and CSIA of both absorbed and adhering interior charred residues as well as from bulk stable analysis of charred interior surface residues. As discussed below, results from A111 LGA32 have implications for other pottery samples with similar lipid composition.

All but two pottery samples have organic residues with amounts of C16 fatty acid greater than those of C18 fatty acid. One of two exceptions is pot A104 LGA24, for which the TLE profile is shown in Figure 8-9. Although this pot had good C16 and C18 fatty acid yields, its organic residues have not yet been processed and analyzed for CSIA. Based on the criteria set in Table 8-2, the former content of this pot is probably a terrestrial animal food source.

Pot A112 LGA33 could have previously contained a plant food source based on its lipid composition (Table 8-12), but its organic residues have not been processed to date for CSIA. As discussed below, its adhering charred interior surface residues were analyzed for bulk stable isotopes. The results have values corresponding to a C₃ plant. However, the residue is not associated with the usage of that pot, but rather, represents a wood fragment that was deposited together with the sherd.

The absorbed residues from five pottery sherds and the charred surface residues on two pottery sherds from Lò Gạch were further processed for CSIA. The δ¹³C values of C16 and C18 fatty acids fall within the range of freshwater aquatic resources and C₃ plants based on the comparative reference materials established in Chapter 6 (Figure 8-
10). However, based on the TLE profile of pot A104 LGA24, there remains the possibility that terrestrial meat may have been processed in the pot.

One of the charred surface residues (CSR4 on pot A100 LGA31) has a more negative $\delta^{13}C$ value for C18 fatty acid than C16 fatty acid, which makes the paired $\delta^{13}C$ values (Table 8-12) fall within the range for ruminant animals. But results from bulk isotopic analysis, as discussed later, and remains of small fish bones incorporated into these residues, indicate the $\delta^{13}C$ values of C16 and C18 fatty acids may be attributed to freshwater resources. This sample can be used as a reference material for freshwater resources in the area. Unfortunately, the absorbed residues on pot A100 LGA31 had low C16 and C18 fatty acid yields, and could not be assayed for CSIA.

**Gò Ô Chùa**

Gò Ô Chùa is another Metal Age site [Bronze Age (ca. 1000-500 BC) to Iron Age (400-100 BC)], with three mounds located near the Vàm Cổ Tây and Vàm Cổ Đồng Rivers, around 2 km south of the Vietnam-Cambodia border (Reinecke 2010). Based on what is only known from published site materials and archaeobiological remains stored at the Long An Museum, the previous occupants of Gò Ô Chùa subsisted on nonruminant animals and aquatic resources; the latter are freshwater and possibly brackish. Despite the lack of archaeobotanical studies for this site, it can still be said that plants were also utilized as food at this location. This site was discussed in detail in Chapter 3.

From Gò Ô Chùa, 26 pottery sherds and charred surface residues from one of these sherds were processed for organic residue analysis with GC-MS (Tables 8-14, 8-15, and 8-16). These surface residues were also processed for bulk stable isotopic analysis. Absorbed residues from 15 of these pottery sherds and the charred surface
residues from one sherd were further processed for CSIA. Thirteen samples had calculated TLEs of > 5 µg/g, whereas nine had calculated TLEs of < 5 µg/g (including the charred surface residues). No lipid compounds were detected in five samples; however, several pottery vessels represent novel evidence about plant usage at this site.

Four of these pottery samples that were recovered from the earliest occupational levels of one of the mounds (Trench 1 in Northern Mound) at Gò Ô Chùa produced dark-colored organic residues upon extraction and contained numerous detected lipid compounds (Table 8-15). Figures 8-11, 8-12, 8-13, and 8-14, respectively, show the TLE profiles of pots A120 22, A84 GOC17, A5 GOC1, and A6 GOC2. Similar to pots A27 AS6, A51 AS15, A78 LGA 16, and A111 LGA32 from the previous two sites, the organic residues from these four pots from Gò Ô Chùa also exhibited the triad of C24 and C26 alcohols with tetracosanyl palmitate or C40 wax ester as well as the prominence of C24 alcohol. All four pots also had fatty acids, alkanes, alcohols, and terpenoids. These lipid compounds indicate that plant products were processed in these pots. Their TLE chromatograms are almost similar, except that pot A6 GOC2 has the least organic residues, or the lowest TLE (Fig. 8-14). Among the four pots, only pot A85 GOC17 has a rim and body (Fig. 8-12). Pot A5 GOC1 has the most number of identified terpenoids (Figure 8-13; Table 8-15; Brettell et al. 2013; Lampert et al. 2002), with β-amyrenone being the most prominent and common to all pots with terpenoids. These terpenoids are probably from resins that were used as a sealant or slip for the pots. Pot A5 GOC1 also has salicylic acid, which is additional proof that plant products were processed in this pot.
The lipids from the charred surface residues (CSR2) on pot A120 GOC22 were also analyzed as TMSEs with GC-MS and underwent CSIA. The molecular profile is similar to that of absorbed residues (Table 8-15), including C24 and C26 alcohols as well as C40 wax ester. CSIA revealed that the charred surface residues exhibit more negative δ\(^{13}\)C values of C16 and C18 fatty acids than those of absorbed residues. As discussed below, results from bulk stable isotopic analysis indicate that the charred residues derive from aquatic food sources in addition to plant sources. Thus, the data from both absorbed and charred surface residues can be a reference for the mixture of plants and aquatic sources. In addition, pot A120 GOC22 (Fig. 8-11) displayed two key differences from pots A84 GOC17, A5 GOC1, and A6 GOC2. First, its absorbed residues have complete assemblages of fatty acids from C8 to C28 and alkanes from C15 to C33. Second, the peak that indicates C16 fatty acid is more prominent than the peak for C24 alcohol. This is in contrast to other pots that contain the triad of C24 and C26 alcohols with tetracosanyl palmitate or C40 wax ester (except A78 LGA16). This probably indicates that pot A120 GOC22 had more than one main source of C16 fatty acid.

Two pottery vessels from the Central Mound at the site had diterpene resin acids in their organic residues (pots A122 GOC 24 and A121 GOC23 in Table 8-16), in addition to fatty acids, alkanes, and alcohols indicating processing of plant sources. Figure 8-15 shows the TLE chromatogram of pot A122 GOC24, in which three of the resin acids (sandaracopimaric acid, isopimaric acid, and dehydroabietic acid) were identified (Brettell et al. 2013). These findings indicate that resins from plants of the Pinaceae family were also used as slip or sealant on pottery, probably in addition to
resins from plants of the Burseraceae and Dipterocarpaceae families. Dehydroabietic acid was also identified in pot A121 GOC23 (Fig. 8-16). This pot is another one of two pots with the amount of C16 fatty acid greater than that of C18 fatty acid. Based on the criteria set in Table 8-2, the former content of this pot probably included a terrestrial animal food source. This pot is also the only one that exhibits a possible \( \omega-(\omega-\text{alkylphenyl})\text{octadecanoic acid} \) (C18 AAPA, Fig.8-17), which may derive from plant and/or aquatic sources (Cramp and Evershed 2014).

Four other pots in Trench 1 from the Northern Mound (pots A83 GOC16, A87 GOC20, A127 GOC26, and A128 GOC27 in Table 8-15) and two pots in Trench 2 (pots A126 GOC25 and A88 GOC21 in Table 8-16) from the Central Mound have lipid components indicating plant sources were previously processed in them. The rest of the sampled pots from Gò Ô Chùa only exhibit fatty acids, mostly C16 and C18 fatty acids. PAHs indicate contact of the pottery vessels with open fire (Poulain et al. 2016) also occurred for pots A83 GOC16, A127 GOC26 (benz[a]anthracene) and A6 GOC2 (phenanthrene and 2-phenyl-naphthalene) (Tables 8-15 and 8-16).

As shown in Figure 8-18, six out of 15 samples that underwent CSIA have more positive \( \delta^{13}\text{C} \) values than the other nine samples. One of these samples is pot A37 GOC6 (Fig. 8-19), which has the most positive pair of \( \delta^{13}\text{C} \) values from C16 and C18 fatty acids. Carbon-13-enriched samples may indicate the processing of C\(_4\) plants and/or marine resources. Despite the site being the farthest from the coast, marine sources may have reached the site through riverine transport from the coast. If saltwater was transported from the coast to be converted into salt inland (Reinecke 2010, 2012), it is possible that other goods, including marine sources, were also transported from the
sea to inland sites. Another possibility is that the site was closer to the coast during its occupation (Reinecke 2010, 2012). More positive $\delta^{13}$C values may also indicate estuarine food sources from brackish waters. Carbon-13-depleted samples indicate the processing of $C_3$ plants and freshwater resources. Comparison with modern comparative reference materials established in Chapter 6 suggest that terrestrial animals were not processed in these pots. Interestingly, based on the TLE profile of pot A121 GOC23, terrestrial meat may have been processed in this pot.

**General Results from Southern Vietnam**

**Lipid yields and molecular profiles**

Out of 117 samples (113 pottery sherds and four charred surface residues) processed for organic residue analysis, 32 (27.35%) had calculated TLEs > 5 $\mu$g/g, whereas 59 (50.43%) had calculated TLEs < 5 $\mu$g/g and no lipid compounds were detected in 26 (22.22%) samples (Table 8-17). The percentage of samples with significant organic residues (TLEs > 5 $\mu$g/g) less than 50% is not surprising, given that the samples originated in a tropical location with alternating dry and wet conditions (Evershed 2008b) and of antiquity of at least 2000 years BP. Lò Gạch has the least samples with significant residues. This could be a consequence of the trenches in this site being near the riverbank, where the rise and fall of the water table affected the early occupational layers and the associated artifacts. Gò Ô Chùa has the best preservation of organic molecules on pottery, which is attested to by almost half of the samples having a significant amounts of organic residues. The three samples with the highest calculated TLEs are from this site (A120 GOC22, A84 GOC17, A5 GOC1; Table 8-15). The samples from this site also exhibit the greatest variety of lipid compounds detected.
and identified. In contrast, the samples from Rạch Núi exhibit the least variety of lipid compounds. Perhaps, this can be attributed to the fact that the pottery sherds sampled from this site were recovered from secondary contexts, as fill material for the construction of floors on the site. Consequently, the microenvironment is highly alkaline from these pottery fragments being mixed with lime. At An Sơn, it was expected that the pottery samples from Trench 2, which is assumed to have been the cooking area, would yield significant and meaningful organic residues. However, only one (Table 8-9) sample had a TLE > 5 µg/g. Based on the yields of samples with calculated TLEs < 5 µg/g and presence of lipid compounds peculiar to plant sources in several samples, the majority of pottery from prehistoric southern Vietnam were probably used to prepare and serve plant foods, in particular leafy and waxy plants. The plethora of results indicating plants sources and the dearth of results indicating animal food sources are further discussed in the next section.

**Compound specific isotope analysis**

Based on the general results from CSIA (Fig. 8-20), relatively $^{13}$C-enriched samples may indicate the processing of $C_4$ plants and/or marine resources. Relatively $^{13}$C-depleted samples indicate the processing of $C_3$ plants and/or freshwater resources. Samples with $\delta^{13}$C values of C16 and C18 fatty acids that fall within the gray area where freshwater and marine resources overlap, as discussed in Chapter 6, may indicate the processing of aquatic resources from brackish/estuarine areas and/or from both freshwater and marine resources. Comparison of $\delta^{13}$C values of C16 and C18 fatty acids from archaeological samples, with modern comparative reference materials for SEA established in Chapter 6, eliminated the possibility of terrestrial animals being
processed in these pots. There are more samples that underwent CSIA \((n=45)\) than those with TLESs \(> 5 \mu\text{g/g} \,(n=32)\). Some of the samples with calculated TLEs \(< 5 \mu\text{g/g}\) had at least \(1 \mu\text{g/g}\) of C16 and C18 fatty acids. Three other samples with both calculated TLEs \(< 5 \mu\text{g/g}\) and the amounts of C16 and C18 fatty acids \(< 1 \mu\text{g/g}\) were processed and analysed first as FAMEs for CSIA, before as TMSEs, to get the TLE profile. It is surprising that they were still able to deliver reliable \(\delta^{13}\text{C}\) values that were different from the method blanks with fewer C16 and C18 fatty acids. As long as the processing of extracts is not prone to contamination, it is possible to achieve reliable results despite the low amounts of target fatty acids (Papakosta et al. 2015).

**Bulk stable isotopes**

As shown in Table 8-18, the charred interior surface residues from five body sherds underwent bulk stable carbon and nitrogen isotopic analysis. Published literature and the results of the modern reference materials in Chapter 6 were utilized to interpret \(\delta^{13}\text{C}\) and \(\delta^{15}\text{N}\) values from these charred surface residues. The charred residues on one sherd from Gò Ô Chùa (CSR2) and one from Lò Gạch (CSR4), the latter of which was associated with fish bone remains, had \(\delta^{13}\text{C}\) and \(\delta^{15}\text{N}\) values that seem consistent with freshwater fishes. The residues on another sherd from Lò Gạch (CSR5) had \(\delta^{13}\text{C}\) and \(\delta^{15}\text{N}\) values consistent with freshwater resources. The results were initially interpreted as indicating a plant origin for the charred residues. The \(\delta^{15}\text{N}\) values of freshwater fish meat (Chapter 6), were observed to be as low as 4.58 ‰ (lower than 5.74 ‰ in CSR5. The charred interior surface residues on the fragments of a stove or cà rang have \(\delta^{13}\text{C}\) and \(\delta^{15}\text{N}\) values corresponding to a \(\text{C}_{3}\) plant, which are attributable to the firewood used for cooking. The charred material on another sherd from Lò Gạch
also exhibits values corresponding to a C$_3$ plant. However, it appears that the actual residue is not associated with the usage of that pot, but rather to a wood fragment that was deposited together with the pottery sherd.

**Combined results from absorbed and charred surface residues**

By combining results of the $\delta^{13}$C and $\delta^{15}$N values of four of five samples composed of charred food remains (CSR2, CSR3, CSR4, and CSR5) with results from GC-MS and CSIA, including results of the analyses of absorbed residues from associated pottery fragments, the four pairs of charred interior surface residues and pottery sherds can be used as comparative reference materials for other archaeological samples from the same site and geographic area. Pot A119 A27 with CSR3 can serve as a reference for predominantly plant food sources. Pots A111 LGA32 with CSR5 (Table 8-12) and A120 GOC with CSR 2 (Table 8-15) can serve as reference materials for mixtures of C$_3$ plants and aquatic sources. Pot A100 LGA 31 with CSR4 can serve as a reference material for freshwater sources.

**Possible sources of food residues**

Based on the lipid compositional and stable isotopic results, the possible sources of the food residues were assigned as follows: (1) “none” is assigned to those samples with no TLE yield and “negligible” is assigned to those samples with TLEs < 5 $\mu$g/g with no lipid compounds that can specifically indicate plants or animal sources; (2) “plants” are assigned to organic residues that were only analyzed with GC-MS and with lipid compounds indicating plant sources. Whether these plants are C$_3$ or C$_4$ cannot be determined because the samples did not undergo CSIA; (3) “C$_3$ plants and aquatic (freshwater or brackish) sources” are assigned to organic residues that have lipid composition and stable isotope results supporting the presence of these two food
sources; (4) “C₃ plants and possibly aquatic (freshwater, brackish, or marine) sources” are assigned to organic residues that have lipid composition securing the presence of plant source(s), but with results from CSIA that indicate C₃ plants and/or freshwater, brackish, marine, or mixed aquatic sources; and (5/6) “(C₃/C₄) plants and/or freshwater/marine source(s)” are assigned to organic residues mostly with only C16 and C18 fatty acids and for which the results of CSIA either fall within the ranges of C₃ plants and freshwater sources, or C₄ plants and marine sources. Because the archaeological sites experienced changing distance from the rivers and sea through time, and the fact that there are numerous river channels within the Mekong delta, utilization of aquatic sources from freshwater, brackish, and marine environments seems most likely, regardless of the distance of the sites from the sea.

Possible sources of nonfood residues

Lipids from nonfood sources suggest that plants that produce triterpenoids and diterpene resin acids were used as pottery slip or sealant. Triterpenoids usually originate from resins of plants belonging to the Burseraceae (e.g., *Canarium luzonicum*) and Dipterocarpaceae (commonly known as *dammar* resins; e.g., *Dipterocarpus alatus* Roxb.) families, which are present in SEA (Lampert et al. 2002). It is a possible that dammar resins were used as slip or sealant on many pottery vessels with triterpenoids in their organic residues. However, not all terpenoids were identified with the aid of the mass spectra library, the works of Brettell et al. (2013) and Lampert et al. (2002), or the database of Amber Research Laboratory (cima.ng-london.org.uk/arl/). Many terpenoid compounds seem to have co-eluted and some of them may be sterol compounds. The component peaks with the same retention times across samples with terpenoids do not have the same mass spectra. Additional separation procedures are required to increase
the resolution and identify the terpenoids and confirm if they are dammar resins or not (see Burger et al. 2009, 2010, 2011). Diterpenoids, specifically diterpene resins (Keeling and Bohlmann 2006), were also detected and identified with the aid of the work of Brettell et al. (2013). These terpenoid compounds usually originate from resins of plants belonging to Araucariaceae and Pinaceae families (Lampert et al. 2002). Similar to the triterpenoids, not all diterpene resins were identified. At least it can be said that there were two possible main plant sources of resins that were used as slip and sealant on pottery.

As demonstrated by pot A119 AS27 (Fig. 8-5, Table 8-8), plants that produce resins with triterpenoids are also used as firewood. Triterpenoids also originate from mangrove trees of the Rhizophoraceae family (Basyuni et al. 2007). Mangrove trees are abundant on riverbanks near the archaeological sites included in this research, and they are utilized as a source of firewood for production of charcoal and pottery, and for construction. The remains of mangrove wood (Rhizophora sp.) were identified in Rạch Nuí (Ceron 2014). Thus, firewood from mangrove trees, along with other plants having triterpenoids in their resins, is a possibility for pot A119 AS27, which is a stove.

The occurrence of PAHs in pot A119 AS27 and a few other pots indicates exposure of pottery vessels to an open fire during cooking (Poulain et al. 2016). However, knowing the depositional history of several samples, the PAHS may also indicate burning activities during mound construction. As discussed in Chapter 7, many pottery fragments sampled for this research were incorporated into mound floors as recycled construction materials.
Pottery with organic residues from a specific but unknown plant source

Aside from pot A119 AS27, the other eight pots with terpenoids in their organic residues are those that also have a suite of fatty acids, alkanes, and alcohols. Their dominant long-chain alcohol or policosanol, the one with the most prominent peak, is \( n \)-tetracosanol (C24-OH), followed by \( n \)-hexacosanol (C26-OH). These samples are compiled in Table 8-19. All except pot A78 LGA16 exhibit the triad of C24 and C26 alcohols with tetracosanyl palmitate or C40 wax ester. Three of them have viscous residue extracts from organic- or fiber-tempered earthenware pottery, which are pots A27 AS6, A5 GOC1, A84 GOC17. Another pot with sand temper, A120 GOC22, also has a viscous residue and has the highest calculated TLE. Two of the samples with the lowest TLE yields are also from sand-tempered pottery (A78 LGA16 and A111 LGA32). All of these samples were recovered from three of the four sites that are clustered further inland (An Sơn, Lò Gạch, and Gò Ô Chùa). An Sơn is a Neolithic site, while Lò Gạch and Gò Ô Chùa are Metal Age sites. None of the pottery samples from Rạch Núi exhibit residues similar to those in Table 8-19. All of these samples, except pots A51 AS51 and A111 LGA32, also have relatively common unidentified components in their organic residues. Table 8-20 describes these unidentified components with their retention times and mass fragment patterns, including their presence and absence across the majority of pottery samples in Table 8-19. These unidentified components all occur in pots A27 AS6, A5 GOC1, and A120 GOC22, and only one of them is missing from pot A84 GOC17. These compounds should be further explored and identified, as they will provide more clues for inferring the former contents of these pots.

The lipid composition of the eight pottery vessels featured in Table 8-19 mainly indicate that plant sources, possibly leafy plants with waxy substances, were prepared
and/or served in these pots (Correa-Ascencio et al. 2014; Roffet-Salque et al. 2016). As previously discussed in Chapter 5, the dominant policosanols detected in the organic residues in these pots are minor components of two noncereal plant food items that underwent experimental cooking with modern earthenware pottery. These two food items are swamp cabbage (Ipomoea aquatica) and coconut milk (Cocos nucifera). Swamp cabbage is a common leafy vegetable eaten in SEA (Lim 2002), and coconut milk is a common cooking condiment for viands, desserts, and snacks (Austin 2007). Although it seems that the organic residues on few of the archaeological pottery have the combination of policosanol abundance of swamp cabbage and viscosity of coconut milk, it cannot be said that these two plant sources were prepared and/served in these prehistoric pots. The dominant policosanol of swamp cabbage is \( n \)-docosanol (C22-OH), rather than \( n \)-tetracosanol (C24-OH), based on the TLE profile of the organic residues from the pot used for boiling swamp cabbage (pot E15, Fig. 549). Coconut milk is a very viscous liquid that can saturate the clay matrix of the pot; however, it is mainly composed fatty acids and acylglycerides (pot E16, Fig. 50). The organic residues on the pots from prehistoric southern Vietnam also did not exhibit the expected pattern for coconut milk, which is the dominance of C12 and C14 fatty acids, and amounts of C16 and C18 fatty acids less than those of the dominant fatty acid (Fig. 50).

Nonetheless, the long-chain alcohols or policosanols are useful indicators for waxy plants (Jung et al. 2011), including those that produce a viscous liquid, along with other plant-related biomolecular markers. However, these fatty alcohols are also known to be present in fish (Mendez-Antolin et al. 2008). As discussed in Chapter 5, the two policosanols, C24-OH and C26-OH, were also detected on pots used for cooking.
freshwater (pot E12, Fig. 5-66) and marine (pot E14, Fig. 5-70) fish, with the highest frequencies in minor amounts. Thus, it is possible that the pottery vessels containing these policosanols were also used to prepare and/serve aquatic sources in multiple frequencies. This was taken into consideration when interpreting the results of organic residue analysis.

Pottery samples containing policosanols (Table 8-19) display a range of δ\(^{13}\)C values of C16 and C18 fatty acids. For pots that were determined to have processed both C\(_3\) plants and aquatic resources, pot A120 has the most \(^{13}\)C-enriched or more positive δ\(^{13}\)C values, pot A111 LGA32 has the most \(^{13}\)C-depleted or more negative δ\(^{13}\)C values, and pot A27 AS6 has δ\(^{13}\)C values of C16 and C18 fatty acids that are intermediate. Based on the δ\(^{13}\)C values of C16 and C18 fatty acids, as well as other results from pot A111 LGA32 that specifically point to a mixture of C\(_3\) plants and freshwater sources, differences in δ\(^{13}\)C values of C16 and C18 fatty acids across the rest of the pots in Table 8-19 could be a consequence of the variety of aquatic sources from different environments prepared and/or served together with a particular plant source. Pots A120 GOC22 and A84 GOC17 have δ\(^{13}\)C values of C16 and C18 fatty acids within the range of marine sources. Pots A111 LGA51 and A51 AS15 have δ\(^{13}\)C values of C16 and C18 fatty acids within the range of freshwater fishes. Pots A27 AS6, A5 GOC1, and A5 GOC2 have δ\(^{13}\)C values of C16 and C18 fatty acids within the gray or overlapping area between freshwater and marine resources.

Plants prepared and/or served in several of the pottery vessels have \(n\)-tetracosanol (C24-OH) as the dominant policosanol component, followed by \(n\)-hexacosanol (C26-OH). Since the triterpenoids only occurred in pottery samples with
the particular biomolecular profile exclusive to pots in Table 8-19, other than the stove with firewood (A119 AS27), it is also possible that the terpenoids are also lipid components of this particular plant source, rather than coming from the resins used as slip or sealant. This plant source can be waxy leafy vegetables, similar to the Chinese cabbage that has C26-OH as its dominant policosanol (Baek et al. 2016).

Rice was dismissed as a possible source because the grain is dominantly starch and has no policosanols, based on the findings from experimental cooking discussed in Chapter 5. However, rice husks or rice bran cannot be dismissed, as it is assumed that the rice consumed in prehistory was not fully milled to remove the husks. It was also documented that one of the methods to make fish sauce in Thailand is by fermenting fish with rice bran and salt in storage jars (Heckman 1979:196, as cited by Lefferts 2005). Pot A84 GOC17 could have been used for fermenting food based on its eroded interior surface (Vuković 2009). A pungent aroma was observed when the pottery fragment was being sampled by drilling, which makes pot A84 GOC17 a likely fish sauce jar. However, no aquatic biomarkers were detected and identified from the analysis of residues from this pot to confirm this. If the organic residues from prehistoric pottery in southern Vietnam actually contain fish sauce made with rice bran, it would suggest that a variety of serving, cooking, and storage pots may have organic residues of similar biomolecular profile because fish sauce is produced in storage jars, used for cooking, and used as condiment during meals. However, the dominant policosanol of rice bran is \( n \)-triacontanol (C30-OH), not C24-OH (Jung et al. 2008; Liu et al. 2008). Thus, the rice bran as the plant source of organic residues on archaeological pots is also dismissed.
Consumed vegetables and fruits are traditionally preserved by fermentation in Asia (Swain et al. 2014). In Vietnam, in particular, the most popular are mustard, beet, and eggplant (Nguyen et al. 2013). Only the eggplant (*Solanum undatum* Lam.) has a history of domestication in SEA (Meyer et al. 2012), making this vegetable another possible source of organic residues. However, it is also dismissed because the dominant policosanol in both the fruit skin (Bauer et al. 2005) and leaves (Halinski et al. 2012) is *n*-octacosanol (C28-OH), not C24-OH. Meanwhile, it can be said that the former contents of these pots, an unknown plant with C₃ signature and *n*-tetracosanol (C24-OH) as the dominant policosanol component, link these three prehistoric sites, An Sơn, Lò Gạch, and Gò Ô Chùa, across space and time, as well as separate them from Rạch Núi. What this means for prehistoric southern Vietnam is further explored in Chapter 9.

**Prominence and Dearth of Food Sources as Organic Residues**

This section is the assessment of the degree to which food categories may or cannot be securely identified through lipid biomarkers and isotopic signatures based on the results from organic residue analysis in this work.

**Prominence of plants**

The use of pottery for the preparation and service of plant food sources is prominent based on the presence of lipid compounds peculiar to plant sources, in particular leafy and waxy plants, in several samples. These lipid compounds are the series of mid-to-long-chain fatty acids, alkanes, and alcohols, as well as one of the wax esters (Correa-Ascencio et al. 2014; Roffet-Salque et al. 2016). As shown in Table 8-3, fatty acids were identified by their characteristic mass fragments of *m/z* = 73, 75, 117, [M-15]+, and [M+]. The amount of C16 fatty acid is usually much more than twice than
the amount of C18 fatty acid (Steele et al. 2010). Alkanes were recognized by their characteristic mass fragments of $m/z = 57, 71, 85, 99, [M^+]$, and $[M-29]^+$; however, the peaks indicating the last two $m/z$ mass fragments often disappear in archaeological residues. The retention times of the C13-C40 alkane standards ran on similar periods with the samples aided to specifically identify the alkane compounds. Mid-to-long-chain alcohols were recognized by their characteristic mass fragments of $m/z = 57, 75, 103, 111, [M^+]$, and $[M-15]^+$, where the peak indicating $[M-15]^+$ is very prominent. The only wax ester detected, tetracosanyl palmitate (C40), was identified based on characteristic mass fragments of $m/z = 257$ (base peak) and 592 $[M^+]$. It is notable that in several samples with evidence of this wax ester (see Figures 8-2, 8-4, 8-7, 8-8, 8-11, 8-12, 8-13, and 8-14), it was the last compound the temperature programming of the Thermo Trace 1310 Gas Chromatograph with Thermo TSQ 8000 Triple Quadrupole Mass Spectrometer was able to elute. The maximum temperature was only 310°C. If the samples were run at the maximum temperature of 350°C and above using high-temperature (HT) GC-MS, more wax esters and other lipid compounds (e.g., mid-chain ketones and high-molecular-weight acylglycerides) might be eluted and detected (Evershed et al. 1990). Although plant sterols were not detected and identified, possible sterol derivatives could probably among some of the unidentified compounds alongside with unidentified terpenoids. Plant sterols and their derivatives could have also been useful for establishing the presence of plants on analyzed pottery (Evershed 1993).

The detection of plant waxes (long-chain fatty acids, alkanes, alcohols, and a wax ester) in pottery from prehistoric southern Vietnam provides novel archaeobotanical evidence at the molecular level of the exploitation of waxy and leafy plant food sources,
including the one with a particular lipid profile that occurs in eight samples, in Mekong Delta during prehistory. It is not certain if these plants were preserved in the archaeological record, since detailed archaeobotanical analyses for Rạch Núi, An Sơn, and Lò Gạch sites are ongoing. In the case of Gò Ô Chùa site, however, the plant biomolecular markers already serve as proxy evidence for plant usage since no floral remains were recovered and analyzed from its previous excavations.

In light of what we know from Chapter 4 regarding lipid biomarkers reportedly preserved in tropical SEA, this work contributes data for the preservation and detection of mid-long-chain alcohols and C40 wax ester to alkanes (Hauman 2012) and terpenoids (Burger et al. 2009, 2010, 2011; Gianno 1990b; Lampert et al. 2002, 2003) in the region. Based on the lipid profiling of pots used for cooking plant food sources in Chapter 5, plants with waxy lipid compounds and viscous extracts are more possible to be detected on archaeological organic residues. Following the work of Reber and Evershed (2004), the detection of starchy cereal food staples remains a major challenge. As discussed in Chapter 5, specific biomarkers for rice and millet useful for their identification as organic residues on the archaeological record still need to be determined. Plant specific biomarkers are necessary to establish the presence of plants in organic residues because the range of their δ13C values of C16 and C18 fatty acids overlap with aquatic sources, as demonstrated in Chapter 6. Lastly, there is a lot of work to be done to specifically identify the plant food sources with waxy and viscous substances, including novel methodological approaches in the laboratory in addition to more detailed chemical survey of plants native to the Mekong River Delta.
Less visibility of aquatic sources

Similar to the findings from modern earthenware pots used for cooking aquatic resources discussed in Chapter 5, it proved difficult to detect and identify established aquatic biomarkers (Cramp and Evershed 2014) in the organic residues from archaeological pottery. Phytanic acid, which is one of the isoprenoid fatty acids, was detected and identified in the FAME profile of only one sample that underwent CSIA (pot A27 AS6). The δ13C values of C16 and C18 fatty acids from this pot supports the phytanic acid derives from a freshwater source, rather than from ruminant animals (see Lucquin et al. 2016a). Aside from pot A27 AS6, only two other pottery fragments (pots A111 LGA32 and A120 GOC22) have both plant and aquatic sources in their organic residues, which were established through the bulk δ13C and δ15N values of charred surface residues (CSR5 and CSR2, respectively), as well as lipid profile and δ13C values of C16 and C18 fatty acids of both absorbed and charred surface residues. Only one pottery sample with charred surface residues (pot A100 LGA31) has secure identification of freshwater fish as its former contents, through the aid of small fish bone remains incorporated into the charred surface residues (CSR4) as well as bulk δ13C and δ15N values of charred surface residues. The fish bone remains actually established the δ13C values of C16 and C18 fatty acids for freshwater sources, rather than ruminant animals. Thus, the presence of aquatic sources on pottery residues can be better established or secured by having lipid profiling and stable isotope ratio results of both absorbed and charred surface residues. However, not all sampled pottery had charred residues attached to their interior surface. In the case of archaeological pottery from prehistoric southern Vietnam, not all interior residues are from their former contents.
because of many of them were recovered from their afterlife contexts as recycled materials for mound floor construction that involved burning.

Aside from isoprenoid fatty acids, $\omega$-(o-alkylphenyl)alkanoic acids (AAPAs) with C16, C18, C20, and C22 chains, were not detected and identified in almost all pottery with organic residues. Only one possible isomer of $\omega$-(o-alkylphenyl)octadecanoic acid (C18 AAPA, Fig. 8-17) was identified in the FAME profile of one of the samples (pot A121 GOC23) that underwent CSIA. By using the guide of Cramp and Evershed (2014:329), it is probably the fourth isomer ($n$=3) of C18 AAPA. This does not definitively identify the source of residues being aquatic because both plants and aquatic sources produce C18 AAPAs at high temperature (> 270°C) during cooking. There should also be C20:$n$ and/or C22:$n$ AAPAs along with C16:$n$ and C18:$n$ AAPAs to confirm the presence of aquatic sources in organic residues. I recommend the analysis of FAMEs with selected ion monitoring (SIM), because isoprenoid fatty acids and AAPAs occur at very low abundances and are possibly obscured by more abundant components (Cramp and Evershed 2014). I intended to explore this procedure after the FAMEs undergo CSIA; however, the GC-MS was not available for more analyses after CSIA of samples were concluded.

Aquatic sources and plants should have the amount of C16 fatty acid at least twice as much as the amount of C18 fatty acid (Olsson and Isaksson 2008), but this criterion cannot really be used for separating plants and aquatic sources unless the amount of C16 fatty acid is much greater than that of C18 fatty acids, which indicate plant sources (Spiteri et al. 2011). Unsaturated fatty acids are poorly preserved or rarely survive in the archaeological record (Cramp and Evershed 2014; Olsson and Isaksson
Further processing of FAMEs is also needed to assess the presence of other biomarkers for aquatic sources, such as C17:1$^{\Delta 8,9,10}$ and C19:1$^{\Delta 9,10,11}$ fatty acids, possibly indicating raw aquatic sources (Baeten et al. 2013), and dihydroxy acids (DHYAs, Hansel et al. 2011). FAMEs should be further derivatized as bis-(methythio)adducts to specify the positions of double bonds confirming the presence of C17:1$^{\Delta 8,9,10}$ and C19:1$^{\Delta 9,10,11}$ fatty acids (Baeten et al. 2013). DHYAs can be extracted and detected through their extraction from the “bound” phase of organic residues within the pottery matrix through the saponification of remaining pottery powder after solvent extraction (Hansel et al. 2011). Both these procedures were not done in this research.

In light of what we know from Chapter 4 regarding lipid biomarkers reportedly preserved in SEA and the rest of the tropical area, no other work had reported the detection and identification of phytanic acid and other isoprenoid fatty acids in archaeological food residues. There is also lot of work need to be done to fully assess the preservation and detection of aquatic biomarkers in the tropical contexts, not only in this work.

**Terrestrial animal sources: not on pottery or absence of evidence?**

The least visible food sources in the organic residues are the terrestrial animal sources, which can be divided into nonruminant and ruminant animals. This is in contrast to the ubiquity of terrestrial faunal remains in the sites where the pottery samples were also recovered (Oxenham et al. 2015; Piper et al. 2012; Francken et al. 2010; personal observations during excavation of Lò Gạch site in 2014). Only three pots demonstrate the possibility of terrestrial meat having been prepared and/or served on these vessels. Two pots (A104 LGA24 in Table 8-12 and A121 GOC23 in Table 8-16) showed the amount of C18 fatty acid greater than the amount of C16 fatty acid in their
TLE profiles, a pattern that supports the presence of terrestrial animal meat (Evershed et al. 2002a; Damodaran et al. 2007), specifically from ruminant animals (Regert 2011). However, the CSIA results for pot A121 GOC23 do not indicate ruminant animals according to the range established for Europe (see Fig. 6-1, Copley et al. 2003). I note that pot A127 GOC26 (Table 8-15) has almost the same amount of C16 and C18 fatty acids, with the amount of C16 fatty acid only slightly greater than C18 fatty acid. Pot A127 GOC26 also presents the possibility that it contained a terrestrial animal source, specifically of nonruminant animals (Regert 2011). All three of these pots (A104 LGA24, A121 GOC23, A127 GOC26) were recovered from Metal Age sites. The secure identification of terrestrial animal meat may indicate a possible subtle change in culinary practices from Neolithic to Metal Age. However, this could not be verified because of the absence (nondetection) of lipid biomarkers that usually indicate terrestrial animal fats, such as odd-numbered ketones (C29-C35), monounsaturated ketones with 33 and 35 carbons, oxidized fatty acids (Regert 2011), as well as animal sterols and their derivatives (Evershed 1993).

Based on the literature focused on terrestrial animal fats (e.g., Regert 2011; Evershed et al. 2002), it was anticipated that the most prevalent organic residues to be recovered would be that of terrestrial animal meat. Based on the high TLE yields of modern pots used for cooking terrestrial animal meat [pork (E3) and chicken (E5)] in Chapter 5, the fats from these species would incorporate into pottery fabric better than most plants and may even mask those from other food sources, such as those derived from nonwaxy and starch rich plant food sources. However, aside from the lack of lipid biomarkers that would simply satisfy the established criteria for terrestrial meat
according to literature, the findings from the comparative modern reference materials in Chapters 5 and 6 also posed some complications in establishing the presence of terrestrial animal meat in organic residues. Although short chain dioic acids or \( \alpha,\omega \)-dicarboxylic acids produced from burning of fats (Evershed et al. 2002a; Regert 2011) were detected in the FAMEs from pork (E3, Fig. 5-60) and chicken (E5, Fig. 5-61) pots, these were not detected in archeological pots. Acylglycerides, especially triacylglycerides, also proved to be difficult to detect and identify in modern pots used for cooking terrestrial animal meat.

As presented in Chapter 5, the fatty acid (C16/C18) ratios of pork (E3) and chicken (E5) pots are both at least 1, where the amount of C16 fatty acid is greater than that of C18 fatty acid. However, the C16/C18 ratio for chicken is actually > 2, similar to aquatic and plant sources. Thus, C16/C18 fatty acid ratios alone cannot differentiate poultry, aquatic, and plant sources. Knowing the differential preservation of fatty acids, fatty acid ratios as a sole criterion are not reliably useful to differentiate different food sources (Spiteri et al. 2011). Cholesterol, other animal sterols, and their derivatives could have been useful to establish the presence of terrestrial and aquatic meat in organic residues (Evershed 1993; Gunstone 2004). However, the results in Chapter 5 question their utility as biomarkers for animals. They were found in residues from pots used for cooking fishes but not in residues from pots used for cooking pork and chicken. This could be due to the differential amount of cholesterol and its differential degradation across different animal food sources. No animal sterols and derivatives were also detected on archaeological pottery analyzed in this research. Their presence in case would not simply establish then the presence of terrestrial and/or aquatic meat.
Other lipid biomarkers indicating terrestrial animal fats, such as odd-numbered ketones (C29-C35), monounsaturated ketones with 33 and 35 carbons, oxidized fatty acids (Regert 2011), should be detected and identified in pork pot (E3) but these biomarkers were not detected. This could be due to the fact that either they were not preserved even in a recently used cooking pot or the specifics of the GC-MS used in this work cannot detect these molecules. The maximum temperatures of the GC-MS used did not reach 350°C and above. These biomarkers, along with triacylgerides, may require HT GC-MS with a column that can handle the maximum temperature of 350°C and above for them to be eluted and detected (Evershed et al. 1990, 2002a).

Pork fat can be specifically identified by Z-9-octadecenoic acid, which is the only isomer of C18:1 fatty acid in pigs (Evershed et al. 2002a; Regert 2011). However, its detection also needs further derivatization of FAMEs into bis-(methythio)adducts to confirm the position of double bonds (Evershed et al. 2002a). This procedure was not pursued in this research. It could have been applicable if the pottery vessels were hypothesized to be exclusively used for preparing and serving pork; however, this is not applicable when pork is mixed with other animal meat or pottery vessels were used for preparing and serving different meat types at various occasions.

It was anticipated that the CSIA of reference materials for pigs and chickens in Chapter 6 would compensate for the complications from the results of lipid profiling in Chapter 5. However, it only brought more complications, making the identification of terrestrial animal meat in organic residues on archaeological pottery from SEA difficult. Taking the case of domestic pigs, local variation within SEA was observed between the δ¹³C values of C16 and C18 fatty acids of domestic pigs from the Philippines and
Vietnam (Fig. 6-35). Although the δ¹³C values of C16 and C18 fatty acids on the domestic pork cooked in pots from the Philippines are only more slightly ¹³C-enriched than those from Northern Atlantic and Mediterranean areas (Fig. 6-35), they cannot be useful to identify pork residues on pots from prehistoric Vietnam. All samples from organic fed domestic pigs in both the Philippines and Vietnam have δ¹³C values of C16 and C18 fatty acids within the range for wild boars in other geographic areas (Fig. 6-35), making their utility as reference materials to identify pork residues questionable. The lack of comparability of δ¹³C values of C16 and C18 fatty acids from chicken samples with those from the Northern Atlantic also makes their utility as reference materials to identify chicken residues questionable.

More work is needed to be done in terms of building the comparative reference database based on modern faunal materials, since detecting and identifying biomolecular and areal specific isotopic signatures for terrestrial animal meat in SEA are actually complicated based on data presented in Chapters 5 and 6. The present collection also lacks ruminant animals, such as deer and bovids. In light of what we know about organic residues on archaeological pottery in SEA to date, only the work of Hauman (2012) and Kanthilata et al. (2014) have mentioned terrestrial animal fats.

From negligible to absence of organic residues

As mentioned in the previous section, almost half of the samples exhibit negligible amounts of residues with TLE < 5 μg/g (Table 8-17). A number of them still have lipid compounds indicating plant waxes and some of them produced reliable results from CSIA. Thirty-eight out of 59 samples have no interpretable results and were assigned as “negligible” (Table 8-21). Twenty-six pottery vessels have negative results.
with TLE = 0 µg/g. Majority of the pottery with these negligible and negative results are in the form of open bowls and restricted pots (Table 8-21). Aside from the differential preservation of organic residues in several microenvironments within a site where pottery samples were buried into and recovered from, other factors are also considered to explain these low lipid yields. First, the function of these pottery vessels could have been used for storage/transport (pots and jars) and service (bowls, plates, and cups) of dry and solid food items, which are less likely to leave residues absorbed on the clay matrix (Oudemans 2007). Second, the frequency of usage for food preparation, such as processing and cooking, affects the amounts of organic residues absorbed in the clay matrix. It was demonstrated in Chapter 5 that a pottery used once would not guarantee absorption of organic residues in substantial amounts, unless the food involved has a very viscous liquid that would immediately saturate the clay matrix. Third and last, the nature of food or any commodity prepared on the pot greatly affects their detection as organic residues. For example, also demonstrated in Chapter 5, cereal staples would be challenging to detect because lipids are their minor components and their major component starch tends to send the interior surface of pottery, which prevent further absorption of plant oils into the clay matrix. Lastly, the actual components of organic residues in some of these pots could be other natural products that are nonderivatizable by the derivatizing agents used in this work and, subsequently, not detectable by the GC-MS. Other analytical techniques, such as liquid chromatography–MS, could be more appropriate for their analysis.
Concluding Remarks

In general, the results of organic residue analysis of prehistoric pottery samples from southern Vietnam indicate the preparation and service of plant and/or aquatic foodstuff on pottery. Although a majority of the samples analyzed from prehistoric southern Vietnam have calculated TLEs from $<5\ \mu g/g$ to $0\ \mu g/g$, the results from several samples demonstrated that organic residue analysis is also applicable to archaeological materials coming from tropical environments. Results from analyses of modern comparative materials in Chapters 5 and 6 provided insights into the interpretation of results here in Chapter 8, including the assessment on how foodstuff in SEA can be identified through lipid biomarkers and stable isotopes, including the complications involved. Unfortunately, the outgroup samples from the coastal PA1 site were not analyzed for biomolecular profiling and CSIA. Their potential as geographic controls thus cannot be discussed. Results from organic residue analysis also indicate the usage of plants as firewood for cooking and sources of resins as a slip and sealant for pottery. Implications of results from Chapter 8 for interpreting foodways and identity in the archaeology of the Mekong Delta in southern Vietnam are discussed in Chapter 9.
Table 8-1. Abbreviations of lipid compounds used in the discussion of the results, as well as in tables and figures that follow, with chemical and common names (after Chemical Book 2016; Christie 2015; Fankhauser 1994).

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Common Name</th>
<th>Chemical Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>C8 FA</td>
<td>Caprylic acid</td>
<td>Octanoic acid</td>
</tr>
<tr>
<td>C9 FA</td>
<td>Pelargonic acid</td>
<td>Nonanoic acid</td>
</tr>
<tr>
<td>C10 FA</td>
<td>Capric acid</td>
<td>Decanoic acid</td>
</tr>
<tr>
<td>C11 FA</td>
<td>Undecylic acid</td>
<td>Undecanoic acid</td>
</tr>
<tr>
<td>C12 FA</td>
<td>Lauric acid</td>
<td>Dodecanoic acid</td>
</tr>
<tr>
<td>C13 FA</td>
<td>Tridecylic acid</td>
<td>Tridecanoic acid</td>
</tr>
<tr>
<td>C14 FA</td>
<td>Myristic acid</td>
<td>Tetradecanoic acid</td>
</tr>
<tr>
<td>C15 FA</td>
<td>Pentadecylic acid</td>
<td>Pentadecanoic acid</td>
</tr>
<tr>
<td>4,8,12 TMTD</td>
<td>Trimethyltridecanoic acid</td>
<td>4,8,12 Trimethyltridecanoic acid</td>
</tr>
<tr>
<td>C16:1 FA</td>
<td>Palmitoleic acid</td>
<td>9-Hexadecanoic acid</td>
</tr>
<tr>
<td>C16 FA</td>
<td>Palmitic acid</td>
<td>Hexadecanoic acid</td>
</tr>
<tr>
<td>C17:1 FA</td>
<td>Margaric acid</td>
<td>Heptadecenoic acid</td>
</tr>
<tr>
<td>C18:2 FA</td>
<td>Linoleic acid</td>
<td>9,12-Octadecadienoic acid</td>
</tr>
<tr>
<td>C18:1 FA (A &amp; B)</td>
<td>Oleic acid</td>
<td>9-(and 11-) Octadecenoic acid</td>
</tr>
<tr>
<td>C18 FA</td>
<td>Stearic acid</td>
<td>Octadecanoic acid</td>
</tr>
<tr>
<td>C19 FA</td>
<td>Nonadecylic acid</td>
<td>Nonadecanoic acid</td>
</tr>
<tr>
<td>C20:2 FA</td>
<td>Eicosadienoic acid</td>
<td></td>
</tr>
<tr>
<td>C20:1 FA</td>
<td>Gadoleic acid</td>
<td>9-Eicosenoic acid</td>
</tr>
<tr>
<td>C20 FA</td>
<td>Arachidic acid</td>
<td>Eicosanoic acid</td>
</tr>
<tr>
<td>C21 FA</td>
<td>Heneicosylic acid</td>
<td>Heneicosanoic acid</td>
</tr>
<tr>
<td>C22:6 FA</td>
<td>Cervonic acid</td>
<td>4,7,10,13,16,19-Docosahexanoic acid</td>
</tr>
<tr>
<td>C22:1 FA</td>
<td>Erucic/Cetoleic acid</td>
<td>13- or 11-Docosenoic acid</td>
</tr>
<tr>
<td>C22 FA</td>
<td>Behenic acid</td>
<td>Docosanoic acid</td>
</tr>
<tr>
<td>C23 FA</td>
<td>Tricosylic acid</td>
<td>Tricosanoic acid</td>
</tr>
<tr>
<td>C24:1 FA</td>
<td>Nervonic acid</td>
<td>15-Tetracosanoic acid</td>
</tr>
<tr>
<td>C24 FA</td>
<td>Lignoceric acid</td>
<td>Tetracosanoic acid</td>
</tr>
<tr>
<td>C25 FA</td>
<td>Pentacosylic acid</td>
<td>Pentacosanoic acid</td>
</tr>
<tr>
<td>C26 FA</td>
<td>Creotic acid</td>
<td>Hexacosanoic acid</td>
</tr>
<tr>
<td>C27 FA</td>
<td>Heptacosylic acid</td>
<td>Heptacosanoic acid</td>
</tr>
<tr>
<td>C28 FA</td>
<td>Montanic acid</td>
<td>Octacosanoic acid</td>
</tr>
<tr>
<td>C32 FA</td>
<td>Lacceroic acid</td>
<td>Dotriacontanoic acid</td>
</tr>
<tr>
<td>C34 FA</td>
<td>Geddic acid</td>
<td>Tetratriacontanoic acid</td>
</tr>
<tr>
<td>C16:n AAPA</td>
<td>ω-(o-alkylphenyl)hexadecanoic acid</td>
<td></td>
</tr>
<tr>
<td>C18:n AAPA</td>
<td>ω-(o-alkylphenyl)octadecanoic acid</td>
<td></td>
</tr>
<tr>
<td>C20:n AAPA</td>
<td>ω-(o-alkylphenyl)eicosanoic acid</td>
<td></td>
</tr>
<tr>
<td>C22:n AAPA</td>
<td>ω-(o-alkylphenyl)docosanoic acid</td>
<td></td>
</tr>
<tr>
<td>C8 dioic acid</td>
<td>Suberic acid</td>
<td>Octanediolic acid</td>
</tr>
<tr>
<td>C9 dioic acid</td>
<td>Azelaic acid</td>
<td>Nonanediolic acid</td>
</tr>
<tr>
<td>C10 dioic acid</td>
<td>Sebacic acid</td>
<td>Decanediolic acid</td>
</tr>
</tbody>
</table>
Table 5-1. Continued

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Common Name</th>
<th>Chemical Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>C12–OH</td>
<td>Dodecanol</td>
<td>Dodecan-1-ol</td>
</tr>
<tr>
<td>C14–OH</td>
<td>Tetradecanol</td>
<td>1-Tetradecanol</td>
</tr>
<tr>
<td>C15–OH</td>
<td>Pentadecanol</td>
<td>Pentadecan-1-ol</td>
</tr>
<tr>
<td>C16–OH</td>
<td>Cetyl/palmityl alcohol</td>
<td>Hexadecan-1-ol</td>
</tr>
<tr>
<td>C18–OH</td>
<td>Steryl/octadecyl alcohol</td>
<td>1-Octadecanol</td>
</tr>
<tr>
<td>C22–OH</td>
<td>Behenyl alcohol</td>
<td>Docosan-1-ol</td>
</tr>
<tr>
<td>C24–OH</td>
<td>Lignoceryl alcohol</td>
<td>Tetracosan-1-ol</td>
</tr>
<tr>
<td>C26–OH</td>
<td>Hexacosanol</td>
<td>Hexacosan-1-ol</td>
</tr>
<tr>
<td>C28–OH</td>
<td>Montanyl alcohol/Octanol</td>
<td>Octacosan-1-ol</td>
</tr>
<tr>
<td>C30–OH</td>
<td>Melissyl/myrisyl alcohol</td>
<td>Triacontan-1-ol</td>
</tr>
<tr>
<td>C32–OH</td>
<td>Cetylic alcohol</td>
<td>Dotriacontan-1-ol</td>
</tr>
<tr>
<td>C34–OH</td>
<td>Tetratriacontyl alcohol</td>
<td>Tetratriacontan-1-ol</td>
</tr>
<tr>
<td>C16 MAG</td>
<td>Monopalmitin</td>
<td>Glycerol monopalmitate</td>
</tr>
<tr>
<td>C18:1 MAG</td>
<td>Monoolein</td>
<td>Glycerol monooleate</td>
</tr>
<tr>
<td>C18 MAG</td>
<td>Monostearin</td>
<td>Glycerol monostearate</td>
</tr>
<tr>
<td>C40 WE</td>
<td></td>
<td>Tetracosanyl palmitate</td>
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<tr>
<td>C15 alkane</td>
<td></td>
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<td>C16 alkane</td>
<td>Cetane</td>
<td>Hexadecane</td>
</tr>
<tr>
<td>C17 alkane</td>
<td></td>
<td>Heptadecane</td>
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<tr>
<td>C18 alkane</td>
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<td>Octadecane</td>
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<td>C19 alkane</td>
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<td>Nonadecane</td>
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<td>C20 alkane</td>
<td>Eicosane</td>
<td>Icosane</td>
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<td>C21 alkane</td>
<td></td>
<td>Heneicosane</td>
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<td>Docosane</td>
</tr>
<tr>
<td>C23 alkane</td>
<td></td>
<td>Tricosane</td>
</tr>
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<td>C24 alkane</td>
<td></td>
<td>Tetracosane</td>
</tr>
<tr>
<td>C25 alkane</td>
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<td>Pentacosane</td>
</tr>
<tr>
<td>C26 alkane</td>
<td></td>
<td>Hexacosane</td>
</tr>
<tr>
<td>C27 alkane</td>
<td></td>
<td>Heptacosane</td>
</tr>
<tr>
<td>C28 alkane</td>
<td></td>
<td>Octacosane</td>
</tr>
<tr>
<td>C29 alkane</td>
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<td>Nonacosane</td>
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<tr>
<td>C30 alkane</td>
<td></td>
<td>Triacontane</td>
</tr>
<tr>
<td>C31 alkane</td>
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<td>Hentriacontane</td>
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<tr>
<td>C32 alkane</td>
<td></td>
<td>Dotriacontane</td>
</tr>
<tr>
<td>C33 alkane</td>
<td></td>
<td>Tritriacontane</td>
</tr>
<tr>
<td>C34 alkane</td>
<td></td>
<td>Tetratriacontane</td>
</tr>
<tr>
<td>C35 alkane</td>
<td></td>
<td>Pentatriacontane</td>
</tr>
<tr>
<td>C36 alkane</td>
<td></td>
<td>Untriacontane</td>
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</tbody>
</table>

|  |                     | Hexatriacontane          |

431
Table 8.2. Molecular criteria for major food sources used in this study.

<table>
<thead>
<tr>
<th>Food category</th>
<th>Lipids</th>
<th>References</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>c. Long-chain waxes: fatty acids, alkanes, n-alkanols (mostly even-carbon n), and mid-chain ketones</td>
<td>d. Evershed 1993; Gunstone 2004</td>
<td></td>
</tr>
<tr>
<td></td>
<td>d. Plant sterols and derivatives</td>
<td>b. Fankhauser 1994</td>
<td></td>
</tr>
<tr>
<td>Animal, terrestrial</td>
<td>a. Large amounts of C16 and C18 FAs, medium amount of unsaturated (C=C, C18:1 and C18:2 FAs), and several odd numbered acids</td>
<td>a. Evershed et al. 2002a; Damodaran et al. 2007</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b. Animals &gt; Plants: C16:1 and C18 FAs</td>
<td>b. Fankhauser 1994</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c. Nonruminant: C16 FA &gt; C18 FA</td>
<td>c. Regert 2011</td>
<td></td>
</tr>
<tr>
<td></td>
<td>d. Ruminant: C16 FA &lt; C18 FA, phytanic acid (SRR&lt;RRR)</td>
<td>d. Lucquin et al. 2016; Regert 2011</td>
<td>d. R and S are configurations of chiral center</td>
</tr>
<tr>
<td></td>
<td>e. Cholesterol and derivatives</td>
<td>e. Evershed 1993; Gunstone 2004</td>
<td></td>
</tr>
<tr>
<td>Aquatic resources</td>
<td>a. Dominated by C16 FAs (or C16 &gt;/≈ 2C18)</td>
<td>a. Olsson and Isaksson 2008</td>
<td>b. Survival is usually unlikely.</td>
</tr>
<tr>
<td></td>
<td>b. Long-chain monounsaturated FAs: C16:1, C20:1, C22:1, and C24:1 FAs</td>
<td>b. Cramp and Evershed 2014</td>
<td>c. Raw and cooked, at low abundances</td>
</tr>
<tr>
<td></td>
<td>c. At least one of isoprenoid FAs: 3,7,11,15-trimethylhexacosanoic acid (phytanic acid, SRR&gt;RRR), 2,6,10,14-tetramethylpentadecanoic acid (pristanic acid), and 4,8,12-TMTD</td>
<td>c. Cramp and Evershed 2014; Hansel et al. 2004; Lucquin et al. 2016; Evershed et al. 2008; Regert 2011</td>
<td>d. Produced when pottery reaches a temperature of 270°C and above.</td>
</tr>
<tr>
<td></td>
<td>d. C16-C22 AAPAs derived from unsaturated C16-C22 FAs</td>
<td>d. Evershed et al. 2008; Hansel et al. 2004</td>
<td>e. No heating is required, possible indicators of fermented aquatic products.</td>
</tr>
<tr>
<td></td>
<td>e. Co-occurrence of C17:1Δ8,9,10 and C19:1Δ9,10,11 FAs with isoprenoid FAs</td>
<td>e. Baeten et al. 2013</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compound Group</th>
<th>Mass Fragmentation Patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fatty acids as TMSEs</strong></td>
<td>Strong [M-15]+; [M+] (molecular ion peak) is usually present; significant peaks at m/z = 73+75+117+129+132+145.</td>
</tr>
<tr>
<td><strong>Fatty acids as FAMEs</strong></td>
<td>Weak [M+]; [M-32]+ and [M-31]+; significant peaks: m/z = 74 and 87.</td>
</tr>
<tr>
<td><strong>Dicarboxylic acids as TMSEs</strong></td>
<td>[M-15]+ and [M-131]+; the latter is only observed for diacids with carbon atoms of 5 or more.</td>
</tr>
<tr>
<td><strong>ω-(o-alkylphenyl)alkanoic acids</strong></td>
<td>Base peak at m/z = 105 (both as TMSEs and FAMEs); significant peak at m/z = 91 (as FAMEs).</td>
</tr>
<tr>
<td><strong>Dihydroxy acids as TMSEs</strong></td>
<td>m/z = 73+215/315/317</td>
</tr>
<tr>
<td><strong>Sterols/Phytosterols</strong></td>
<td>Noticeable [M+], [M-15]+, and [M-90]+; base peak at m/z = 129, [M-129]+ also present.</td>
</tr>
<tr>
<td><strong>Alkanes</strong></td>
<td>Weak [M+]; [M-29]+ present; fragments with decreasing intensity due to missing alkyl groups (m/z = 57+71+85+99+..).</td>
</tr>
<tr>
<td><strong>Long-chain alcohols</strong></td>
<td>Weak [M+]; strong [M-15]+; [CH2OSi(CH3)3]+ at m/z=103 differentiates n-alcohols from TMSEs of long-chain fatty acids. Significant peaks: m/z = 57+75+83+103+111.</td>
</tr>
<tr>
<td><strong>Wax esters</strong></td>
<td>Weak [M+]; base peaks: [C14H31O2]+ at m/z = 229, [C16H33O2]+ at m/z = 257 and [C18H35O2]+ at m/z = 285.</td>
</tr>
<tr>
<td><strong>Monoacylglycerols (MAGs)</strong></td>
<td>Weak [M+]; [M-15]+; [M-90]; [M-CH2OSi(CH3)3]+ = 1-MAG isomer; [(CH3)3SiOCH=CHCH2OSi(CH3)3]+ at m/z = 2-MAG isomer</td>
</tr>
<tr>
<td><strong>Diacylglycerols (DAGs)</strong></td>
<td>[M+] usually missing; weak [M-15]+ and [M-90]; significant ions at m/z = 129+145.</td>
</tr>
<tr>
<td><strong>Triacylglycerols (TAGs)</strong></td>
<td>Minor peaks of [M+] and [M-158]+</td>
</tr>
<tr>
<td><strong>Pentacyclic triterpenes and triterpenols</strong></td>
<td>[M+], [M-15], and significant ions at m/z = 218+203/204+189+/or 177</td>
</tr>
<tr>
<td><strong>Triterpenoids</strong></td>
<td>From Dipterocarpaceae family: base peak at m/z = 69, 109, 143, 189, 203, 204, 218, or 262</td>
</tr>
<tr>
<td><strong>Diterpenoids/diterpene resin acids</strong></td>
<td>From Burseraceae family: base peak at m/z = 203, 218, 234, 248, 273</td>
</tr>
<tr>
<td></td>
<td>Base peak at m/z = 73, 121, 237, 239, 241, or 256. [M+] at m/z = 370, 372, or 374</td>
</tr>
</tbody>
</table>
Table 8-4. Amount and nature of analyzed samples from prehistoric sites in southern Vietnam.

<table>
<thead>
<tr>
<th>Sample type</th>
<th>Rạch Núi</th>
<th>An Sơn</th>
<th>Lò Gạch</th>
<th>Gò Ô Chùa</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pottery sherds for absorbed residues (A)</td>
<td>27</td>
<td>27</td>
<td>33</td>
<td>26</td>
<td>113</td>
</tr>
<tr>
<td>Charred interior surface residues (CSR)</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>CSR, bulk stable isotopes only</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Soil associated with pot (S)</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
<td>28</td>
<td>37</td>
<td>27</td>
<td>119</td>
</tr>
<tr>
<td>Processed for CSIA</td>
<td>11</td>
<td>11</td>
<td>7</td>
<td>16</td>
<td>45</td>
</tr>
</tbody>
</table>

Table 8-5. Breakdown of analyzed samples from Rạch Núi according to excavation areas.

<table>
<thead>
<tr>
<th>Excavation area</th>
<th>Number of samples</th>
<th>Processed for CSIA</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trench 1 (H1)</td>
<td>11</td>
<td>3</td>
<td>Northern slope of the mound</td>
</tr>
<tr>
<td>Trench 2 (H2)</td>
<td>11</td>
<td>6</td>
<td>Near Trench 1, periphery of the mound</td>
</tr>
<tr>
<td>Trench 3 (H3)</td>
<td>5</td>
<td>2</td>
<td>Far from Trenches 1 and 2, periphery of the mound</td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>
Table 8-6. Results of organic residue analysis of samples from Rạch Núi.

<table>
<thead>
<tr>
<th>Spel. No.</th>
<th>Site code</th>
<th>Accession code</th>
<th>TLE (µg/g)</th>
<th>δ(^{13})C(_{16:0}) (%)</th>
<th>δ(^{13})C(_{18:0}) (%)</th>
<th>Chemical compounds identified</th>
<th>Remarks, possible source(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A42</td>
<td>RN11</td>
<td>12RNH1L9/2B2 c.1009/2 -1</td>
<td>0.6</td>
<td>26.11</td>
<td>26.20</td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A43</td>
<td>RN12</td>
<td>12RNH1L21/1B21021/1</td>
<td>0.86</td>
<td>27.96</td>
<td>27.67</td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A23</td>
<td>RN7</td>
<td>12RNH1L27/1B21027/1</td>
<td>0</td>
<td></td>
<td></td>
<td>C16, C18, and C18:1 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A62</td>
<td>RN16</td>
<td>12RNH1F2C/1,2-1 c.1007</td>
<td>3.45</td>
<td>-26.11</td>
<td>-26.20</td>
<td>C16 and C18 fatty acids</td>
<td>C_3 plant and/or freshwater</td>
</tr>
<tr>
<td>A113</td>
<td>RN23</td>
<td>12RNH1F2G1-1</td>
<td>0.71</td>
<td></td>
<td>23.06</td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A7</td>
<td>RN3</td>
<td>12RNH1F2H(4)B8</td>
<td>2.98</td>
<td>27.96</td>
<td>27.67</td>
<td>C16 and C18 fatty acids</td>
<td>C_3 plant and/or freshwater</td>
</tr>
<tr>
<td>A63</td>
<td>RN17</td>
<td>12RNH1F3/1C8</td>
<td>6.06</td>
<td>-27.96</td>
<td>-27.67</td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A22</td>
<td>RN6</td>
<td>12RNH1F20/1.2(A6,B7,C7,C8)</td>
<td>0</td>
<td></td>
<td>23.06</td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A67</td>
<td>RN21</td>
<td>12RNH1F54/1A3</td>
<td>0</td>
<td></td>
<td>23.06</td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A123</td>
<td>RN25</td>
<td>12RNH1B-C5-6F92(3,4)-1</td>
<td>0.96</td>
<td></td>
<td></td>
<td>C12-C14, C16, C18 fatty acids; C16 &amp; C18 MAGs</td>
<td></td>
</tr>
<tr>
<td>A10</td>
<td>RN4</td>
<td>12RNH2L4/2 B3 2007/2</td>
<td>2.25</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A68</td>
<td>RN22</td>
<td>12RNH2L5-3C3</td>
<td>35.59</td>
<td>-28.18</td>
<td>-28.78</td>
<td>C12, C13, C14, C16, and C18 fatty acids</td>
<td>C_3 plant and/or freshwater</td>
</tr>
<tr>
<td>A44</td>
<td>RN13</td>
<td>12RNH2L5-3B7</td>
<td>1.11</td>
<td>27.20</td>
<td>27.96</td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A45</td>
<td>RN14</td>
<td>12RNH2L5-3C5</td>
<td>5.5</td>
<td>27.20</td>
<td>27.96</td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A25</td>
<td>RN9</td>
<td>12RNH2A6 L5/4</td>
<td>29.26</td>
<td>-27.20</td>
<td>-27.96</td>
<td>C16 and C18 fatty acids</td>
<td>C_3 plant and/or freshwater</td>
</tr>
<tr>
<td>A124</td>
<td>RN26</td>
<td>12RNH2L5-4A1</td>
<td>0.61</td>
<td>-28.90</td>
<td>-29.26</td>
<td>C16 and C18 fatty acids</td>
<td>C_3 plant and/or freshwater</td>
</tr>
<tr>
<td>A64</td>
<td>RN18</td>
<td>12RNH2L5-4C7-4, Feature 14</td>
<td>5.96</td>
<td>-29.12</td>
<td>-29.10</td>
<td>C16 and C18 fatty acids</td>
<td>C_3 plant and/or freshwater</td>
</tr>
<tr>
<td>A125</td>
<td>RN27</td>
<td>12RNH2 A4 c.2008/4-6</td>
<td>0.89</td>
<td>-28.41</td>
<td>-29.03</td>
<td>C16 and C18 fatty acids</td>
<td>C_3 plant and/or freshwater</td>
</tr>
<tr>
<td>A114</td>
<td>RN24</td>
<td>12RNH2L5-5 B1 c.2008/5</td>
<td>2.56</td>
<td></td>
<td></td>
<td>C9, C12, C16, and C18 fatty acids; C20-C27 alkanes; isopropyl palmitate; 4-methoxy cinnamic acid</td>
<td>Plants</td>
</tr>
<tr>
<td>A65</td>
<td>RN19</td>
<td>12RNH2L5-6C1 c.2008/6</td>
<td>311.79</td>
<td>-27.42</td>
<td>-26.92</td>
<td>C16 and C18 fatty acids</td>
<td>C_3 plant and/or freshwater</td>
</tr>
<tr>
<td>A24</td>
<td>RN8</td>
<td>12RNH2L6-1F1 c.2009/1-5</td>
<td>0</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td>C_3 plant and/or freshwater</td>
</tr>
<tr>
<td>A13</td>
<td>RN5</td>
<td>12RNH3L1C2</td>
<td>4.05</td>
<td>-32.16</td>
<td>-31.50</td>
<td>C16 and C18 fatty acids</td>
<td>C_3 plant and/or freshwater</td>
</tr>
<tr>
<td>A26</td>
<td>RN10</td>
<td>12RNH3L1/3C9</td>
<td>0</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A1</td>
<td>RN1</td>
<td>12RNH3L2/20D4 c.3002/20-1</td>
<td>17.04</td>
<td>-21.87</td>
<td>-23.57</td>
<td>C16, C18, and C18:1 FAs</td>
<td>C_4 plant and/or marine</td>
</tr>
<tr>
<td>A46</td>
<td>RN15</td>
<td>12RNH3L2/20D4 c.3002/20-4</td>
<td>1.18</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A66</td>
<td>RN20</td>
<td>12RNH3L2/22D2-3</td>
<td>0</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
</tbody>
</table>
Figure 8-1. Plot of $\delta^{13}C$ values of C16 and C18 fatty acids obtained from archaeological pottery of Rạch Núi site, southern Vietnam, against several ranges of $\delta^{13}C$ values of C16 and C18 fatty acids obtained from modern reference materials acquired in Southeast Asia. Legends: Gray circles – modern reference samples; light orange diamonds – absorbed residues from samples of Rạch Núi.

<table>
<thead>
<tr>
<th>Excavation area</th>
<th>Absorbed residues</th>
<th>Charred surface residues</th>
<th>Total</th>
<th>Processed for CSIA</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trench 1 (H1)</td>
<td>14</td>
<td>1</td>
<td>15</td>
<td>9</td>
<td>Dumping area</td>
</tr>
<tr>
<td>Trench 2 (H2)</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>1</td>
<td>Cooking area</td>
</tr>
<tr>
<td>Trench 3 (H3)</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>With unstratified deposits</td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
<td>1</td>
<td>28</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>
Table 8-8. Results of organic residue analysis of samples from Trench 1 in An Sơn.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Site code</th>
<th>Accession code</th>
<th>TLE (µg/g)</th>
<th>δ^{13}C_{16:0} (%)</th>
<th>δ^{13}C_{18:0} (%)</th>
<th>Chemical compounds identified</th>
<th>Remarks, possible source(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A69</td>
<td>AS16</td>
<td>09ASH1L2/3A1 Noi L2a</td>
<td>3</td>
<td>-29.27</td>
<td>-29.51</td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A115</td>
<td>AS23</td>
<td>09ASH1L2-3C5 Cà rang rim</td>
<td>0.21</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A70</td>
<td>AS17</td>
<td>09ASH1L3A3 Noi L2a</td>
<td>1.95</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A74</td>
<td>AS21</td>
<td>09ASH1L3B7 dia L1b</td>
<td>0.56</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A116</td>
<td>AS24</td>
<td>09AsH1L8A5 Cà rang rim</td>
<td>0</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A8</td>
<td>AS3</td>
<td>09ASH1L8A3 (Bo Khong Che, FT)</td>
<td>49.38</td>
<td>-29.27</td>
<td>-29.51</td>
<td>C16, C18, and C18:1 fatty acids</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A117</td>
<td>AS25</td>
<td>09ASH1L8B2-2 FT body</td>
<td>0.22</td>
<td>-27.55</td>
<td>-28.64</td>
<td>C16 and C18 fatty acids</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A47</td>
<td>AS11</td>
<td>09ASH1L9B10 FT rim</td>
<td>0.62</td>
<td>-27.26</td>
<td>-27.29</td>
<td>C16 and C18 fatty acids</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A118</td>
<td>AS26</td>
<td>09ASH1L10A2</td>
<td>0.46</td>
<td>-27.26</td>
<td>-27.29</td>
<td>C16 and C18 fatty acids</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A48</td>
<td>AS12</td>
<td>09ASH1L10A5NkL3-2</td>
<td>2.89</td>
<td>-27.97</td>
<td>-28.12</td>
<td>C16 and C18 fatty acids</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A119</td>
<td>AS27</td>
<td>09ASH1L10B9 Cà rang</td>
<td>30.96</td>
<td>-27.36</td>
<td>-27.60</td>
<td>C9-C12, C14, C16, and C18 fatty acids; hexyl-cinnamaldehyde; benz[a]anthracene; α-amyrene, nor-β-amyrene, β-amyrenone, and other unidentified terpenoids</td>
<td>Residues were absorbed from firewood on stove. Can serve as a reference for C₃ plants with CSR3.</td>
</tr>
<tr>
<td>CSR3</td>
<td>AS27</td>
<td>09ASH1L10B9 Cà rang</td>
<td>2.52</td>
<td>-25.90</td>
<td>-27.83</td>
<td>C12-C16 and C18 fatty acids</td>
<td>Burnt firewood. C₃ plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A4</td>
<td>AS2</td>
<td>ASH1L12-13-1 ST</td>
<td>2.63</td>
<td>-27.63</td>
<td>-28.16</td>
<td>C9, C10, C12, C16, and C18 fatty acids; C17-C20 and C23-C26 alkanes; C16 and C18 MAGs</td>
<td></td>
</tr>
<tr>
<td>A27</td>
<td>AS6</td>
<td>09ASH1L13B11 FT rim</td>
<td>578.05</td>
<td>-25.53</td>
<td>-26.51</td>
<td>C8-C28, C30, C32, C34, C36, and C18:1 fatty acids; phytanic acid, C16-C33 and C35 alkanes; C12, C22-C24, C26, C28, C30, C32, and C34 alcohols; tetracosanyl palmitate; β-amyrenone and few other unknown terpenoids</td>
<td>Viscous brownish yellow extract. Phytanic acid was detected from the FAME profile. C₃ plant and freshwater sources</td>
</tr>
<tr>
<td>A28</td>
<td>AS7</td>
<td>09ASH1L14B11</td>
<td>11.59</td>
<td>-27.19</td>
<td>-28.15</td>
<td>C16 and C18 fatty acids</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
</tbody>
</table>
Table 8-9. Results of organic residue analysis of samples from Trenches 2 and 3 in An Son.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Site code</th>
<th>Accession code</th>
<th>TLE (µg/g)</th>
<th>δ¹³C₁₆:₀ (%)</th>
<th>δ¹³C₁₈:₀ (%)</th>
<th>Chemical compounds identified</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>A3</td>
<td>AS1</td>
<td>09ASH2L2-3 C3-1 (20-30cm) ST</td>
<td>3.7</td>
<td>-29.26</td>
<td>-28.56</td>
<td>C9, C10, C12, C14, C16, C18:1, and C18 fatty acids; C16 and C18 MAGs; C17-C20 and C23-C27 alkanes</td>
<td>C3 plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A75</td>
<td>AS22</td>
<td>09ASH2L2-1A1 ST (1)</td>
<td>0.49</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A49</td>
<td>AS13</td>
<td>09ASH2L2B5A5 F1 (2)</td>
<td>0.63</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A11</td>
<td>AS4</td>
<td>09ASH2L3-1 D1-2 &amp; C1-2 (7)</td>
<td>0</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A50</td>
<td>AS14</td>
<td>09ASH2L3-1,2 D2 10-30 cm FT rim (3)</td>
<td>0.71</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A71</td>
<td>AS18</td>
<td>09ASH2L3-2A2 (20-30 cm) (4)</td>
<td>0.22</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A29</td>
<td>AS8</td>
<td>09ASH2L3-2E4 (35-40 cm) (6)</td>
<td>0</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A30</td>
<td>AS9</td>
<td>09ASH2L3-3 E4 40-50 cm -1 (9)</td>
<td>0</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A72</td>
<td>AS19</td>
<td>09ASH2L4-1D4 (70-80 cm) FT</td>
<td>0.93</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A73</td>
<td>AS20</td>
<td>09ASH2L4-1E4 (70-80 cm)</td>
<td>0.09</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A51</td>
<td>AS15</td>
<td>09ASH3L10A3 FT rim</td>
<td>52.16</td>
<td>-26.89</td>
<td>-27.87</td>
<td>C9, C12, C14, C16, C18, and C24 fatty acids; C20, C21, C25, and C27 alkanes; C24 and C26 alcohols; tetracosanyl palmitate (trace)</td>
<td>Brown extract. C3 plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A14</td>
<td>AS5</td>
<td>09ASH3L10B5 ST rim</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A31</td>
<td>AS10</td>
<td>09ASH3L10B10 FT rim</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 8-2. Gas chromatogram of TLE from pot A27 AS6.

Figure 8-3. Phytanic acid in the FAME profile of pot A27 AS6.
Figure 8-4. Gas chromatogram of TLE from pot A51 AS15.

Figure 8-5. Gas chromatogram of TLE from pot A119 AS27.
Figure 8-6. Plot of $\delta^{13}$C values of C16 and C18 fatty acids obtained from archaeological pottery of An Sơn site, southern Vietnam against several ranges of $\delta^{13}$C values of C16 and C18 fatty acids obtained from modern reference materials acquired in Southeast Asia. Legends: Gray circles – modern reference samples; dark orange diamonds (absorbed residues) and triangle (charred surface residues) – samples from An Sơn.

Table 8-10. Breakdown of analyzed samples from Lò Gạch according to excavation areas.

<table>
<thead>
<tr>
<th>Excavation area</th>
<th>Absorbed residues</th>
<th>Charred surface residues (CSR)</th>
<th>CSR (Bulk isotopes only)</th>
<th>Soil</th>
<th>Total</th>
<th>Processed for CSIA</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trench 1 (H1)</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>15</td>
<td>1</td>
<td>Main mound</td>
</tr>
<tr>
<td>Trench 2 (H2)</td>
<td>11</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>14</td>
<td>4</td>
<td>Edge of a mound</td>
</tr>
<tr>
<td>Trench 3 (H3)</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>2</td>
<td>Another mound, closest to the river</td>
</tr>
<tr>
<td>Total</td>
<td>33</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>37</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>
Table 8-11. Results of organic residue analysis of samples from Trench 1 in Lò Gạch.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Site code</th>
<th>Accession code</th>
<th>TLE (µg/g)</th>
<th>δ¹³C₁₆₀ (‰)</th>
<th>δ¹³C₁₈₀ (‰)</th>
<th>Chemical compounds identified</th>
<th>Remarks, possible source(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A32</td>
<td>LGa4</td>
<td>14 LGaH1B2 F1-62 29-4-14</td>
<td>0</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A52</td>
<td>LGa9</td>
<td>14 LGaH1A2F1-68 29-4-14</td>
<td>0.92</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A53</td>
<td>LGa10</td>
<td>14 LGaH1D1/E1 F1-85 3-5-14</td>
<td>1.34</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A54</td>
<td>LGa11</td>
<td>14 LGaH1C2/3/4/B2/3/4 F1-106</td>
<td>0</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A101</td>
<td>LGa21</td>
<td>14 LGaH1 D3/D2 F1-113 5-5-14</td>
<td>0.37</td>
<td>-27.90</td>
<td>-28.80</td>
<td>C16 and C18 fatty acids</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A16</td>
<td>LGa1</td>
<td>14 LGaH1 F1-138 8-5-14 - 1</td>
<td>0</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A110</td>
<td>LGa30</td>
<td>14 LGaH1 F1-138 8-5-14 -2</td>
<td>0.05</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A76</td>
<td>LGa14</td>
<td>14 LGaH1B2 C104 9-5-14 - 1</td>
<td>0.21</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A102</td>
<td>LGa22</td>
<td>14 LGaH1B2 C104 9-5-14 -2</td>
<td>0</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A77</td>
<td>LGa15</td>
<td>14 LGaH1D2 C104 9-5-14</td>
<td>0.19</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A33</td>
<td>LGa5</td>
<td>14 LGaH1D3 C104 9-5-14</td>
<td>0</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A103</td>
<td>LGa23</td>
<td>14 LGaH1B2 C105 9-5-14</td>
<td>0</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A78</td>
<td>LGa16</td>
<td>14 LGaH1D2 C105 9-5-14</td>
<td>13.69</td>
<td></td>
<td></td>
<td>C9-C14, C16, C18, C18:1, C20, C22, and C24 fatty acids; C18-C35 alkanes; C24 and C26 alcohols; benz[a]anthracene</td>
<td>Yellow green extract. Plant source. C16 and C18 fatty acids are less than 1 µg/g. Soil associated with above sample</td>
</tr>
<tr>
<td>S1</td>
<td>LGA16</td>
<td>14 LGaH1D2 C105 9-5-14</td>
<td>0.47</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids, C23 alkane; C24 alcohol</td>
<td></td>
</tr>
<tr>
<td>A81</td>
<td>LGa19</td>
<td>14 LGaH1 B1-3 C105 9-5-14</td>
<td>0.41</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>Sample Number</td>
<td>Site code</td>
<td>Accession code</td>
<td>TLE (µg/g)</td>
<td>(\delta^{13}C_{16:0}) (%)</td>
<td>(\delta^{13}C_{18:0}) (%)</td>
<td>Chemical compounds identified</td>
<td>Remarks, possible source(s)</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------</td>
<td>----------------</td>
<td>-----------</td>
<td>-----------------------------</td>
<td>-----------------------------</td>
<td>-----------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>A34</td>
<td>LGa6</td>
<td>14 LGaH2 F2-54 1-5-14</td>
<td>0</td>
<td></td>
<td></td>
<td>C9, C19, C12, C14, C16- C18, C18:1, C20, and C24 fatty acids, C12 alcohol; C18 MAG</td>
<td>One of the rare samples with C18 fatty acid &gt; C16 fatty acid in TLE profile. Possibly terrestrial animal meat.</td>
</tr>
<tr>
<td>A104</td>
<td>LGa24</td>
<td>14 LGaH2 B2 C203 26-4-14</td>
<td>9.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A35</td>
<td>LGa7</td>
<td>14 LGaH2 B2 C203/1 25-4-14</td>
<td>0.49</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td>Light green extract. Possible actual components are nonderivatizable by BSFTA</td>
</tr>
<tr>
<td>A55</td>
<td>LGa12</td>
<td>14 LGaH2 B1 C203/1 25-4-14</td>
<td>2.17</td>
<td>-30.39</td>
<td>-28.64</td>
<td>C16 and C18 fatty acids</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A17</td>
<td>LGa2</td>
<td>14 LGaH2 C1 C204/2 29-4-14 -- 1</td>
<td>0</td>
<td></td>
<td></td>
<td>C12-C18, C20, C22, and C24 fatty acids; C20- C27 alkanes; C24 and C26 alcohols; tetracosanyl palmitate</td>
<td>Yellow green extract. With data from CSR5, sample can be a reference material for C₃ and freshwater sources.</td>
</tr>
<tr>
<td>A111</td>
<td>LGa32</td>
<td>14 LGaH2 C1 C204/2 29-4-14 -- 2</td>
<td>16.21</td>
<td>-28.36</td>
<td>-27.76</td>
<td>C16 and C18 fatty acids</td>
<td>With data from bulk stable isotopes, can be a reference material for freshwater source.</td>
</tr>
<tr>
<td>CSR5</td>
<td>LGa32</td>
<td>14 LGaH2 C1 C204/2 29-4-14 -- 2</td>
<td>0.41</td>
<td>-26.18</td>
<td>-28.85</td>
<td>C16 and C18 fatty acids</td>
<td>With data from bulk stable isotopes only.</td>
</tr>
<tr>
<td>A105</td>
<td>LGa25</td>
<td>14 LGaH2 C205/3-2 3-5-14</td>
<td>0.21</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A106</td>
<td>LGa26</td>
<td>14 LGaH2 C205/3-3 3-5-14</td>
<td>0.18</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A79</td>
<td>LGa17</td>
<td>14 LGaH2A2 C205 2-5-14</td>
<td>2.4</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A112</td>
<td>LGa33</td>
<td>14 LGaH2C1 C205 2-5-14</td>
<td>8.12</td>
<td></td>
<td></td>
<td>C9-C20, C22, and C24 fatty acids; C16 alcohol; C18 MAG; plants</td>
<td></td>
</tr>
<tr>
<td>CSR6</td>
<td>LGa33</td>
<td>14 LGaH2C1 C205 2-5-14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A100</td>
<td>LGa31</td>
<td>14 LGaH2 F2-14 26-4-14</td>
<td>0.81</td>
<td>-28.28</td>
<td>-31.16</td>
<td>C16 and C18 fatty acids</td>
<td>With data from bulk stable isotopes and remains of fish bones, sample can be a reference material for freshwater sources.</td>
</tr>
<tr>
<td>CSR4</td>
<td>LGa31</td>
<td>14 LGaH2 F2-14 26-4-14</td>
<td>51.93</td>
<td>-28.28</td>
<td>-31.16</td>
<td>C14, C16:1, C16, C18:1, and C18 fatty acids</td>
<td></td>
</tr>
</tbody>
</table>
Table 8-13. Results of organic residue analysis of samples from Trench 3 in Lò Gạch.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Site code</th>
<th>Accession code</th>
<th>TLE (µg/g)</th>
<th>δ¹³C₁₆₀ (‰)</th>
<th>δ¹³C₁₈₀ (‰)</th>
<th>Chemical compounds identified</th>
<th>Remarks, possible source(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A107</td>
<td>LGa27</td>
<td>14 LGaH3A1 C302 5-5-14</td>
<td>0.07</td>
<td>-27.68</td>
<td>-27.39</td>
<td>C16 and C18 fatty acids</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A82</td>
<td>LGa20</td>
<td>14 LGaH3 F3-3 5-5-14</td>
<td>0.46</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A80</td>
<td>LGa18</td>
<td>14 LGaH3 F3-16 8-5-14</td>
<td>0.08</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A18</td>
<td>LGa3</td>
<td>14 LGaH3 A1 C303 8-5-14</td>
<td>6.33</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A108</td>
<td>LGa28</td>
<td>14 LGaH3 A2 C304 9-5-14</td>
<td>1.81</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids; C17, C18, C21-C23, C25, C27, C29, and C33 alkanes; benz[a]anthracene</td>
<td>Plant source</td>
</tr>
<tr>
<td>A109</td>
<td>LGa29</td>
<td>14 LGaH3 C2 C305 10-5-14</td>
<td>0.4</td>
<td>-27.15</td>
<td>-28.56</td>
<td>C16 and C18 fatty acids</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A56</td>
<td>LGa13</td>
<td>14 LGaH3 C2 C305 9-5-14 --1</td>
<td>2.23</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A36</td>
<td>LGa8</td>
<td>14 LGaH3 C2 C305 9-5-14 --2</td>
<td>0</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
</tbody>
</table>
Figure 8-7. Gas chromatogram of TLE from pot A78 LGA16.

Figure 8-8. Gas chromatogram of TLE from pot A111 LGA32.
A104 LGA24. 14LGAH2 B2 C203 26-4-14 Total lipid extract
Provenience: Context 203, 2014 Trench 2, Lò Gạch, SV

Figure 8-9. Gas chromatogram of TLE from pot A104 LGA24.
Figure 8-10. Plot of $\delta^{13}C$ values of C16 and C18 fatty acids obtained from archaeological pottery of Lò Gạch site, southern Vietnam against several ranges of $\delta^{13}C$ values of C16 and C18 fatty acids obtained from modern reference materials acquired in Southeast Asia. Legends: Gray circles – modern reference samples; light blue diamonds (absorbed residues) and triangles (charred surface residues) – Lò Gạch.

Table 8-14. Breakdown of analyzed samples from Gò Ô Chùa according to excavation areas.

<table>
<thead>
<tr>
<th>Excavation area</th>
<th>Absorbed residues</th>
<th>Charred surface residues</th>
<th>Total</th>
<th>Processed for CSIA</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trench 1 (H1)</td>
<td>15</td>
<td>1</td>
<td>16</td>
<td>9</td>
<td>Northern Mound</td>
</tr>
<tr>
<td>Trench 2 (H2)</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>3</td>
<td>Central Mound</td>
</tr>
<tr>
<td>Trench 3 (H3)</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>Central Mound</td>
</tr>
<tr>
<td>Trench 4 (H4)</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>Central Mound</td>
</tr>
<tr>
<td>Total</td>
<td>26</td>
<td>1</td>
<td>27</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>
Table 8-15. Results of organic residue analysis of samples from Trench 1 in Northern Mound of Gò Ô Chùa.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Site code</th>
<th>Accession code</th>
<th>TLE (µg/g)</th>
<th>δ¹³C₁₆:₀ (%)</th>
<th>δ¹³C₁₈:₀ (%)</th>
<th>Chemical compounds identified</th>
<th>Remarks, possible source(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A57</td>
<td>GOC11</td>
<td>08GOCH1L9-3</td>
<td>1.75</td>
<td></td>
<td></td>
<td>C18 fatty acid</td>
<td></td>
</tr>
<tr>
<td>A83</td>
<td>GOC16</td>
<td>08GOCH1L9-4</td>
<td>2.23</td>
<td></td>
<td></td>
<td>C12, C14, C16, and C18 fatty acids; C19-C33 and C35 alkanes; benz[a]anthracene</td>
<td>Plant source</td>
</tr>
<tr>
<td>A84</td>
<td>GOC17</td>
<td>08GOCH1L10-1</td>
<td>637.13</td>
<td>-24.20</td>
<td>-25.16</td>
<td>C8-C12, C14-C20, C22-C25, C27, and C28 fatty acids; C15, C16, C18-C29, and C31-C33 alkanes; C24, C26, C28, and C34 alcohols tetracosanyl palmitate; β-amyrenone and other unidentified terpenoid compounds</td>
<td>Golden yellow extract. C₃ plant and, possibly, mixed aquatic/estuarine source(s)</td>
</tr>
<tr>
<td>A85</td>
<td>GOC18</td>
<td>08GOCH1L10-2</td>
<td>0.59</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td>Plant source</td>
</tr>
<tr>
<td>A86</td>
<td>GOC19</td>
<td>08GOCH1L10-3</td>
<td>0.31</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td></td>
</tr>
<tr>
<td>A87</td>
<td>GOC20</td>
<td>08GOCH1L10-4</td>
<td>0.87</td>
<td></td>
<td></td>
<td>C18 fatty acids; C16-C24 alkanes</td>
<td></td>
</tr>
<tr>
<td>A37</td>
<td>GOC6</td>
<td>08GOCH1L10-8</td>
<td>57.19</td>
<td>-23.73</td>
<td>-23.38</td>
<td>C9-C13, C14, C16, C18:1, C18, and C20 fatty acids; C25 alkane</td>
<td>C₄ plant and/or marine source(s)</td>
</tr>
<tr>
<td>A127</td>
<td>GOC26</td>
<td>08GOCH1L10-12</td>
<td>185.52</td>
<td>-25.80</td>
<td>-25.20</td>
<td>C12, C14-C26, C18:1, C20:1, and C28 fatty acids; C18-C20 alkanes; C18 MAG; benz[a]anthracene</td>
<td>C₁₆ FA ≅ C₁₈ FA; C₃ plant and, possibly, mixed aquatic/estuarine source(s). Terrestrial meat is also possible.</td>
</tr>
<tr>
<td>A120</td>
<td>GOC22</td>
<td>08GOCH1L10 2/4</td>
<td>3386.1 2</td>
<td>-24.11</td>
<td>-25.45</td>
<td>C8-C28, C18:1 C32, and C34 fatty acids; C15-C33 alkanes; C24, C26, C28, C30, and C34 alcohols; tetracosanyl palmitate; β-amyrenone and other unidentified terpenoid compounds</td>
<td>Amber colored extract. C₃ plant and mixed aquatic/estuarine sources</td>
</tr>
<tr>
<td>CSR2</td>
<td>GOC22</td>
<td>08GOCH1L10 2/4</td>
<td>287.46</td>
<td>-25.65</td>
<td>-27.84</td>
<td>C9, C12, C14, C16, C18, C20-C24, and probably C16:1 fatty acids; C23-C25, C27, and C29 alkanes; C12, C24, and C26 alcohols; tetracosanyl palmitate</td>
<td>With data from bulk stable isotopes and molecular profile, sample can be a reference material for mixed C₃ plant-aquatic sources.</td>
</tr>
<tr>
<td>Sample Number</td>
<td>Site code</td>
<td>Accession code</td>
<td>TLE (µg/g)</td>
<td>δ¹³C₁₆:₀ (%)</td>
<td>δ¹³C₁₈:₀ (%)</td>
<td>Chemical compounds identified</td>
<td>Remarks, possible source(s)</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------</td>
<td>----------------</td>
<td>------------</td>
<td>--------------</td>
<td>--------------</td>
<td>-------------------------------</td>
<td>------------------------------</td>
</tr>
<tr>
<td>A5</td>
<td>GOC1</td>
<td>08GOCH1L11-1 Body FT Van Ky Thuat</td>
<td>1615.49</td>
<td>-25.70</td>
<td>-26.06</td>
<td>C8-C10, C12, C14-C18, C16:1 (tr.), C18:1, C20, C22-C24, and C26 fatty acids; C14-C33 and C35 alkanes; C16, C22-C24, C26, C28, C30, C32, and C34 alcohols; salicylic acid; tetracosanyl palmitate; Hydroxydammarenone, α-amyrone, nor-β-amyrone, β-amyrone, and other unidentified terpenoids</td>
<td>Dark brownish green extract. C₃ plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A6</td>
<td>GOC2</td>
<td>08GOCH1L11-3 Body FT Van Ky Thuat</td>
<td>33.21</td>
<td>-25.39</td>
<td>-26.13</td>
<td>C9- C12, C14, C16, C18, C20, and C22-C24 fatty acids; C17-C23, C25, C27, C29, C31, and C33 alkanes; C12, C16, C23, C24, C26, C30, and C32 alcohols, tetracosanyl palmitate; urs-12-en-3-one, and other unidentified terpenoids; phenanthrene and 2-phenyl-naphthalene</td>
<td>Brown extract. C₃ plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A128</td>
<td>GOC27</td>
<td>08GOCH1L11-4 Body FT Van Ky Thuat</td>
<td>1.27</td>
<td>-27.78</td>
<td>-29.42</td>
<td>C16 and C18 fatty acids; C17-C23 alkanes</td>
<td>C₃ plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A9</td>
<td>GOC3</td>
<td>08GOCH11L11-5 Mieng bat dia L7</td>
<td>2.69</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td>C₃ plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A38</td>
<td>GOC7</td>
<td>08GOCH1L11-6 Mieng</td>
<td>0</td>
<td></td>
<td></td>
<td>C16 and C18 fatty acids</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A58</td>
<td>GOC12</td>
<td>08GOCH1L11 3/5-1</td>
<td>7.94</td>
<td>-30.05</td>
<td>-30.75</td>
<td>C16 and C18 fatty acids</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
</tbody>
</table>
Figure 8-11. Gas chromatogram of TLE from pot A120 GOC22.
Figure 8-12. Gas chromatogram of TLE from pot A84 GOC17.
Figure 8-13. Gas chromatogram of TLE from pot A5 GOC1.
Figure 8-14. Gas chromatogram of TLE from pot A6 GOC2.
Table 8-16. Results of organic residue analysis of samples from Trenches 2-4 in Central Mound of Gò Ô Chùa.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Site code</th>
<th>Accession code</th>
<th>TLE (µg/g)</th>
<th>δ¹³C₁₆:₀ (‰)</th>
<th>δ¹³C₁₈:₀ (‰)</th>
<th>Chemical compounds identified</th>
<th>Remarks, possible source(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A59</td>
<td>GOC13</td>
<td>09GOCH2L10-1</td>
<td>13.71</td>
<td>-27.60</td>
<td>-26.32</td>
<td>C16 and C18 fatty acids</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A12</td>
<td>GOC4</td>
<td>09GOCH2L10-4</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>C₃ plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A126</td>
<td>GOC25</td>
<td>09GOCH2L10-5</td>
<td>13.81</td>
<td>-28.56</td>
<td>-28.61</td>
<td>C8, C9, C16, C18, and C22 fatty acids; C15-C19, C25, and C27 alkanes; C12, C15, and C18 alcohols; C18 MAG</td>
<td>C₃ plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A88</td>
<td>GOC21</td>
<td>08GOCH2L11</td>
<td>11.73</td>
<td>-26.40</td>
<td>-26.57</td>
<td>C10-C19 fatty acid; C16-C29 alkanes; C16 MAG</td>
<td>C₃ plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A39</td>
<td>GOC8</td>
<td>08GOCH2L13-2</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>C₃ plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A121</td>
<td>GOC23</td>
<td>08GOCH3L9-1</td>
<td>12.23</td>
<td>-26.91</td>
<td>-26.60</td>
<td>C9-C26, and C18:1 fatty acids; C16-C25, and C35 alkanes; C12, C14, and C18 alcohols; dehydroabietic acid</td>
<td>C₃ plant and, possibly, freshwater source(s). One of the rare samples with C18 fatty acid &gt; C16 fatty acid in TLE profile and possibly C18 AAPA in FAME profile. Terrestrial meat is also possible.</td>
</tr>
<tr>
<td>A15</td>
<td>GOC5</td>
<td>08GOCH3L9-2</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>C₃ plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A40</td>
<td>GOC9</td>
<td>08GOCH4L8</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>C₃ plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A122</td>
<td>GOC24</td>
<td>08GOCH4L9-1</td>
<td>2.42</td>
<td>-27.68</td>
<td>-27.60</td>
<td>C9, C10, C12, C14, C16, C18:1, and C18 fatty acids; C20 and C21 alkanes; C14, C15, and C18 alcohols; sandaracopimaric acid, isopimaric acid, dehydroabietic acid, and 4 other possible resin acids</td>
<td>C₃ plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A60</td>
<td>GOC14</td>
<td>08GOCH4L9-2</td>
<td>10.64</td>
<td>-28.11</td>
<td>-27.023</td>
<td>C16 and C18 fatty acids</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A61</td>
<td>GOC15</td>
<td>08GOCH4L9-3</td>
<td>7.96</td>
<td>-27.71</td>
<td>-26.62</td>
<td>C16 and C18 fatty acids</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
</tbody>
</table>
Figure 8-15. Gas chromatogram of TLE from pot A122 GOC24.
Figure 8-16. Gas chromatogram of TLE from pot A121 GOC23.

Figure 8-17. Possible C18 AAPA in A121 GOC23.
Figure 8-18. Plot of δ¹³C values of C16 and C18 fatty acids obtained from archaeological pottery of Gò Ô Chùa, southern Vietnam against several ranges of δ¹³C values of C16 and C18 fatty acids obtained from modern reference materials acquired in Southeast Asia. Legends: Gray circles – modern reference samples; dark blue diamonds (absorbed residues) and triangle (charred surface residues) – samples from Gò Ô Chùa.

Figure 8-19. Gas chromatogram of TLE from pot A37 GOC6.
Figure 8-20. Plot of $\delta^{13}C$ values of C16 and C18 fatty acids obtained from archaeological pottery of prehistoric southern Vietnam against several ranges of $\delta^{13}C$ values of C16 and C18 fatty acids obtained from modern reference materials acquired in Southeast Asia. Legends: Gray circles – modern reference samples; diamonds – absorbed residues from archaeological pottery; triangles – charred interior surface residues on pottery; light orange diamonds – samples from Rạch Núi; dark orange diamonds and triangle – samples from An Sơn; light blue diamonds and triangles – Lò Gạch; dark blue diamonds and triangle – samples from Gò Ô Chúa.
Table 8-17. Summary of total lipid extract yields of samples analyzed for organic residues.

<table>
<thead>
<tr>
<th>Amount of TLE</th>
<th>Rạch Núi</th>
<th>An Sơn</th>
<th>Lò Gạch</th>
<th>Gò Ô Chửa</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 5 µg/g</td>
<td>8</td>
<td>5</td>
<td>6</td>
<td>13</td>
<td>32</td>
</tr>
<tr>
<td>&lt; 5 µg/g</td>
<td>13</td>
<td>17</td>
<td>20</td>
<td>9</td>
<td>59</td>
</tr>
<tr>
<td>None (0)</td>
<td>6</td>
<td>6</td>
<td>9</td>
<td>5</td>
<td>26</td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
<td>28</td>
<td>35</td>
<td>27</td>
<td>117</td>
</tr>
</tbody>
</table>

Table 8-18. Table showing the bulk stable isotopic results for carbon and nitrogen isotopes from charred interior surface residues on archaeological pottery from prehistoric southern Vietnam.

<table>
<thead>
<tr>
<th>Processing code</th>
<th>Accession code</th>
<th>δ¹³C PDB</th>
<th>δ¹⁵N AIR</th>
<th>wt. %C</th>
<th>wt. %N</th>
<th>Remarks, possible source(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSR2 (on A120 GOC 22)</td>
<td>08 GOC H1L10 2/4</td>
<td>-25.50</td>
<td>7.37</td>
<td>16.01</td>
<td>1.15</td>
<td>Values correspond to freshwater source (Craig et al. 2007; King 2006; this research)</td>
</tr>
<tr>
<td>CSR3 (on A119 A27)</td>
<td>09 ASH1 L10B9 Cà rang</td>
<td>-28.07</td>
<td>3.67</td>
<td>11.65</td>
<td>0.14</td>
<td>C₃ plant used as firewood for cooking</td>
</tr>
<tr>
<td>CSR4 (on A100 LGA 31)</td>
<td>14 LGA H2B1 F2-14 HC</td>
<td>-25.91</td>
<td>8.26</td>
<td>19.69</td>
<td>2.09</td>
<td>With fish bones. Values correspond to freshwater source (Craig et al. 2007; King 2006; this research).</td>
</tr>
<tr>
<td>CSR5 (on A111 LGA32)</td>
<td>14 LGA H2C1 C204/2-2</td>
<td>-26.21</td>
<td>5.74</td>
<td>1.60</td>
<td>0.11</td>
<td>Values correspond to freshwater source (this research)</td>
</tr>
<tr>
<td>CSR6 (on A112 LGA 33)</td>
<td>14 LGA H2C1 C205</td>
<td>-26.32</td>
<td>4.49</td>
<td>5.12</td>
<td>0.08</td>
<td>C₃ plant, nonfood, wood deposited with the pot.</td>
</tr>
</tbody>
</table>
Table 8-19. Pottery samples with terpenoids and dominant policosanols: \( n \)-tetracosanol and \( n \)-hexacosanol.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Site</th>
<th>Site code</th>
<th>Accession code</th>
<th>TLE (µg/g)</th>
<th>( \delta^{13}C_{16:0} ) (%)</th>
<th>( \delta^{13}C_{18:0} ) (%)</th>
<th>Pottery description</th>
<th>Organic residue description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A27</td>
<td>An Sơn</td>
<td>AS6</td>
<td>09ASH1L13B11 FT rim</td>
<td>576.20</td>
<td>-25.53</td>
<td>-26.51</td>
<td>Plain, unrestricted, open bowl with mainly very fine organic temper. No slip and with burnt exterior</td>
<td>Viscous brownish yellow extract. Only sample with phytanic acid. C3 plant and/or freshwater/brackish source(s) Brown extract. Trace amount of tetracosanyl palmitate. C3 plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A51</td>
<td>An Sơn</td>
<td>AS15</td>
<td>09ASH3L10A3 FT rim</td>
<td>52.16</td>
<td>-26.89</td>
<td>-27.87</td>
<td>Plain, unrestricted, open bowl with mainly fine organic temper.</td>
<td>Brown extract. Trace amount of tetracosanyl palmitate. C3 plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A78</td>
<td>Lò Gạch</td>
<td>LGa16</td>
<td>14 LGaH1D12 C105 9-5-14</td>
<td>13.69</td>
<td></td>
<td></td>
<td>Restricted jar (( d_{rim}=10 ) cm) with incised design at the rim and coarse sand temper</td>
<td>Light green extract. C16 and C18 FAs are less than 1 µg/g. No tetracosanyl palmitate. Plant source</td>
</tr>
<tr>
<td>A111</td>
<td>Lò Gạch</td>
<td>LGa32</td>
<td>14 LGaH2 C1 C204/2 29-4-14 -- 2</td>
<td>16.21</td>
<td>-28.36</td>
<td>-27.76</td>
<td>Body sherd with cordmarked design, very coarse sand temper, and interior charred surface residues</td>
<td>Yellow green extract. Trace amount of tetracosanyl palmitate. With data from CSR5, sample can be a reference material for C3 and freshwater sources.</td>
</tr>
<tr>
<td>A84</td>
<td>Gò Ô Chùa</td>
<td>GOC17</td>
<td>08GOCH1L10-1</td>
<td>637.13</td>
<td>-24.20</td>
<td>-25.16</td>
<td>Plain, restricted pot with mainly very fine organic temper. Severely eroded interior.</td>
<td>Viscous golden yellow extract. Observed pungent aroma. C3 plant and, possibly, mixed aquatic/estuarine source(s)</td>
</tr>
<tr>
<td>A120</td>
<td>Gò Ô Chùa</td>
<td>GOC22</td>
<td>08GOCH1L10 2/4</td>
<td>3386.12</td>
<td>-24.11</td>
<td>-25.45</td>
<td>Body sherd with cordmarked design and medium sand temper Charred surface residues on pot A120 GOC 22.</td>
<td>Viscous amber colored extract. C3 plant and mixed aquatic/estuarine sources</td>
</tr>
<tr>
<td>CSR2</td>
<td>Gò Ô Chùa</td>
<td>GOC22</td>
<td>08GOCH1L10 2/4</td>
<td>287.46</td>
<td>-25.65</td>
<td>-27.84</td>
<td></td>
<td>Brown extract. Bulk stable isotopic results indicate aquatic source(s). Mixed C3 plant-aquatic sources.</td>
</tr>
<tr>
<td>A5</td>
<td>Gò Ô Chùa</td>
<td>GOC1</td>
<td>08GOCH1L11-1 Body FT Van Ky Thuat</td>
<td>1615.49</td>
<td>-25.70</td>
<td>-26.06</td>
<td>Plain body sherd from restricted pot with mainly fine organic temper.</td>
<td>Viscous dark brownish green extract. Fragrant aroma. C3 plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A6</td>
<td>Gò Ô Chùa</td>
<td>GOC2</td>
<td>08GOCH1L11-3 Body FT Van Ky Thuat</td>
<td>33.21</td>
<td>-25.39</td>
<td>-26.13</td>
<td>Body sherd with cordmarked design and mainly medium organic temper.</td>
<td>Brown extract. C3 plant and, possibly, freshwater source(s)</td>
</tr>
</tbody>
</table>
Table 8-20. Presence (\(\checkmark\)) and absence (\(\times\)) of unidentified components of organic residues of pottery samples with terpenoids and dominant policosanols: \(n\)-tetracosanol and \(n\)-hexacosanol.

<table>
<thead>
<tr>
<th>Retention time (min)</th>
<th>Mass fragments</th>
<th>A27 AS6</th>
<th>A78 LGA16</th>
<th>A5 GOC1</th>
<th>A6 GOC2</th>
<th>A84 GOC17</th>
<th>A120 GOC22</th>
<th>CSR2</th>
</tr>
</thead>
<tbody>
<tr>
<td>~11.47</td>
<td>67, 79, 91 (100), 95, 134, 161, 174, 202</td>
<td>/</td>
<td>X</td>
<td>/</td>
<td>X</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>~21.09</td>
<td>75 (100), 117, 130, 143, 177, 195, 269, 285, 309, 327</td>
<td>/</td>
<td>/</td>
<td>X</td>
<td>/</td>
<td>/</td>
<td>X</td>
<td>/</td>
</tr>
<tr>
<td>~22.06</td>
<td>73, 75, 117, 131 (100), 204, 208, 311, 358, 387</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>X</td>
<td>X</td>
<td>/</td>
<td>X</td>
</tr>
<tr>
<td>~22.28</td>
<td>73, 75, 117 (100), 129, 204, 217, 311, 329, 385, 401</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>X</td>
<td>/</td>
<td>/</td>
<td>X</td>
</tr>
<tr>
<td>~31.54</td>
<td>67, 81, 95 (100), 109, 163, 205, 219, 273, 297, 315, 358</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 8-21. Tally of results from organic residue analysis according to pottery form in four sites of southern Vietnam.

<table>
<thead>
<tr>
<th>Form</th>
<th>None⁸</th>
<th>Negligible⁹</th>
<th>Plants</th>
<th>C₃ plants and aquatic sources</th>
<th>C₃ plants and possibly aquatic sources</th>
<th>C₄ plants and/or freshwater sources</th>
<th>Freshwater fish</th>
<th>C₄ plants and/or marine sources</th>
<th>Terrestrial animal (slight possibility)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open bowl</td>
<td>8</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>Restricted bowl</td>
<td>2</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>Open pot</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Restricted pot</td>
<td>9</td>
<td>13</td>
<td>2</td>
<td>-</td>
<td>4</td>
<td>4</td>
<td>-</td>
<td>1</td>
<td>(2)</td>
<td>32</td>
</tr>
<tr>
<td>Restricted pot/jar</td>
<td>2</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>13</td>
</tr>
<tr>
<td>Jar</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7</td>
</tr>
<tr>
<td>Small cup and/or bowl</td>
<td>1</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>Plate and/or bowl w/ stand</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Stove</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Sherd*</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>12</td>
</tr>
<tr>
<td>Total</td>
<td>26</td>
<td>38</td>
<td>7</td>
<td>3</td>
<td>12</td>
<td>22</td>
<td>1</td>
<td>3</td>
<td>1 (+2)</td>
<td>113</td>
</tr>
</tbody>
</table>

⁸TLE = 0 μg/g
⁹TLE < 5 μg/g with no diagnostic lipid compounds
*Vessel form cannot be identified
CHAPTER 9
CUISINE AND COMMUNITY IDENTITY IN NEOLITHIC AND METAL AGE SOUTHEAST ASIA: A VIEW FROM SOUTHERN VIETNAM

From Measurements and Molecules to Cuisines and Identities

In considering pottery as a proxy, one can also usefully further explore the materiality of pottery, down to the molecular level.

—Jessica Smyth and Richard P. Evershed
Pottery, Archaeology and Chemistry: Contents and Context

In relation to the above quotation, Chapter 9 examines the interactions between people, pottery, and food during the preparation and serving of food by exploring the materiality of pottery from the morphological level in Chapter 7, to the molecular level in Chapter 8. It also completes the exploration of the lives of the pots as utilitarian pots from Chapter 7. Chapter 9 draws from the results presented in Chapters 7 and 8 to explore the research questions posed in Chapter 1. It presents the culinary practices and community identities in prehistoric Southeast Asia (SEA), based on the case study in Neolithic and Metal Age Mekong Delta in southern Vietnam. The interpretations of the results here in Chapter 9 are in accordance with the theoretical framework presented in Chapter 2, based on the combination of the chaîne opératoire perspective, practice theory, and community of practice perspective.

Overview of Methods

In Chapter 8, organic residue analysis (Evershed 2008b; Roffet-Salque et al. 2016) was conducted on sampled pottery vessels from four archaeological sites in Long An Province, southern Vietnam: Rạch Núi (Neolithic, 1500-1200 BC; Piper et al. 2014), An Sơn (Neolithic, 2200-1300 BC; Bellwood et al. 2011b; Nishimura and Nguyen 2002), Lò Gạch (Metal Age, 900-600 BC; Bui 2008; Piper 2013), and Gò Ô Chùa (Metal Age,
specifically, the analytical techniques used were gas-chromatography-mass spectrometry (GC-MS) to acquire the lipid compositions and quantities of organic residues and compound specific isotopic analysis (CSIA) to acquire the $\delta^{13}C$ values of dominant lipids (C16 and C18 fatty acids) with GC-combustion-isotopic ratio mass spectrometry (GC-C-IRMS). Bulk isotopic analysis ($\delta^{13}C$ and $\delta^{15}N$) values of charred residues from the interior surfaces of a few pottery fragments were measured with GC-IRMS. The results of organic residue analysis were ideally sorted into six identifiable food categories: C$_3$ and C$_4$ plants, nonruminant and ruminant terrestrial animals, and freshwater and marine sources.

Technofunctional analysis (Gibbs and Jordan 2013; Skibo 1992, 2013) of these pottery assemblages presented in Chapter 7 is prerequisite to inferring what foods were prepared in and/or served using sampled pottery vessels. Functional categories of sampled vessels focused on form (restricted pot, unrestricted pot, jar, open bowl, restricted bowl, or small cup/bowl) and function (processing, storage/transfer, cooking, or serving). Form of each sampled pottery vessel was conducted by systematic assessment of clay, temper, surface treatments, shape, and thickness. Use-alteration analysis was conducted to infer vessel function based on the chemical and/or physical changes on the surfaces of ceramic vessels that occurred during its use. Findings from technofunctional and organic residue analyses were integrated to assess if there was a correlation between six identifiable food categories and inferred function of pottery and to address culinary practices and community identities in the region.

**Overview of Results**

Earthenware vessels from the four settlement sites in southern Vietnam suggest different functions of pottery with respect to food preparation and consumption. Based
on the presence of charred residues on interior surfaces and/or firing clouds, some pottery vessels were used for cooking, where food remains were burnt and stuck inside the vessels. Restricted pots could have been used for cooking, similar to present-day earthenware cooking pots with restricted openings and everted rims in Southeast Asia. Restricted openings can retain heat and moisture while enabling addition of ingredients during cooking (Rice 1987; Reid 1989). Their rounded bottoms allow for the even distribution of heat (Rice 1987). Stoves (cà rang) were portable and used for cooking with wood and fire. Those identified as jars and restricted pots/jars could have been used for storage of water or other liquid, fermentation of food items based on non-abrasive attritions on their interior surfaces, and/or transport. Open pots, open bowls, restricted bowls, small cups and/or bowls, and plates and/or bowls with stand could have been used for serving food (with dipping access) or drinks (with pouring access) (Rice 1987). The plates and/or bowls with stands from Lò Gạch could probably have been used for serving plant foods based on the plant remains and impressions on their top interior surfaces. Open bowls and pots, as well as unrestricted small cups and/or bowls could have also been used for cooking or maybe heating of served foods, in addition to their use for serving.

Based on the organic residue analysis of selected samples in Chapter 8, many of the pottery vessels from prehistoric southern Vietnam were possibly used to prepare and serve plant food sources, specifically C_3 leafy plants with waxy substances. These findings are mostly based on the occurrences of mid-to-long-chain fatty acids, alkanes, and alcohols, as well as relatively negative δ^{13}C values of C16 and C18 fatty acids in many of the analysed samples, which indicate the processing of C_3 plants and/or
freshwater resources. Samples that are $^{13}$C-enriched may indicate the processing of C$_4$ plants and/or marine resources. Samples with $\delta^{13}$C values of C16 and C18 fatty acids that fall in between C$_3$ and C$_4$ plants may be indicative of processing of aquatic resources from brackish/estuarine areas and/or from both freshwater and marine resources.

Eight pottery vessels discussed in Chapter 8 (Table 8-19) have organic residues with long-chain alcohols (mainly C24 and C26 alcohols) and a wax ester (tetracosanyl palmitate, C40). These were possibly used to process waxy plants that produce a viscous liquid and, possibly, aquatic sources, and thus these pots may have had multiple uses. Four of these samples (pots A27 AS6, A5 GOC1, A84 GOC17, and A120 GOC22) have viscous residue extracts and exhibit the highest calculated total lipid extracts (TLEs). These may indicate that these pottery vessels had the highest frequencies of usage for the preparation and/or service of, probably, similar food sources. Three of these samples yielded results that indicate the pottery vessels were used for preparing and/or serving both C$_3$ plant and aquatic food sources (A27 AS6, A111 LGA32, and A120 GOC22). The $\delta^{15}$N values of the charred surface residues (CSR 2 and 5, respectively) on pots A111 LGA32 and A120 GOC22 indicate the presence of aquatic sources. The detection and identification of phytanic acid in the fatty acid profile of organic residues from pot A27 AS6, along with supporting $\delta^{13}$C values of C16 and C18 fatty acids, also indicate the presence of aquatic sources, probably brackish or mixed freshwater-marine sources.

Other reliable evidence for the cooking of freshwater foods in pottery comes from pot A100 LGA 31, where small fish bones were observed in its charred surface residues
and the δ^{15}N value indicates aquatic source(s). Three pottery vessels, pots A104 LGA24, A121 GOC23, and A127 GOC26, suggest terrestrial meat may have been prepared and served in them. Organic residue analysis also provided evidence on the nonfood-related usage of plants. Based on the analysis of pot A119 AS27 (a stove), the firewood used for cooking originated from C_{3} plants that produced triterpenoid-rich resins. The detection and identification of triterpenoids and diterpene resin acids indicate at least two sources of resins were possibly used as slip and sealant for the vessel. The presence of polynuclear aromatic hydrocarbons (PAHs) in a few samples indicates the exposure of pottery vessels to fire during cooking activities and/or during construction activities when the vessels were already being recycled as construction materials.

**Exploring Culinary Practices and Community Identities**

Results from Chapters 7 and 8 were used to explore the following questions posed in Chapter 1 focused on culinary practices and community identities: (1) Do culinary practices reflect the available food resources and/or culturally conditioned practices in prehistoric SEA? (2) Are there similarities and differences in the culinary practices between the sites of the same period? (3) Are there changes and continuities in culinary practices between the Neolithic sites and Metal Age sites in the same geographic region? (4) What local and regional resources are being combined and utilized in the production of cuisines? (5) What are the possible community identities of these people who occupied these sites based on their shared culinary practices?

The above questions address how community identities in Neolithic and Metal Age southern Vietnam may be expressed based on the similarities and differences in the ways that prehistoric communities processed, cooked, and served their food using
pottery vessels. Each vessel sampled, with results from both technofunctional and organic residue analyses, was assigned to one or more food categories previously described. The actual form and function of the vessel was also re-evaluated in the case that original findings from technofunctional analysis did not correlate with the results from organic residue analysis. For example, degradation products from cooking, such as ω-(o-alkylphenyl)alkanoic acids (AAPAs) for aquatic resources (Evershed et al. 2008), are expected only in cooking pots, but not in storage jars and serving bowls.

Statistical analyses (Drennen 2009) correlating data from technofunctional and organic residue analyses were not conducted in this dissertation, although it is understood that this should occur for publication. Results from organic residue analysis were mostly uniform in terms of inferred food sources, regardless of the attributes and inferred functions of pottery, and correlations are unlikely given the small sample size. However, basic correlation tests and principal components analysis will be conducted with these data to assess if food categories correlate with function, form, temper, and temper size of the pottery vessels.

To address Question 1, the number of food categories identified from chemical analyses of pottery samples was compared to the number of food categories identified from animal and plant remains based on available information for each site. This approach accounted for the possibility that the previous occupants of each sampled site did not use their pottery vessels to prepare and serve all their food. It is not necessary to prepare and serve all kinds of food in pottery, since there are alternative vessels made of plant materials that can be used (e.g., bamboo) and other ways of preparing
and serving food (e.g., drying/roasting) that do not necessitate the use of pottery vessels.

To address Questions 2 and 3, the findings from each site were assigned to their period of occupation, i.e., Neolithic or Metal Age. Comparisons of results was conducted between the two Neolithic sites (Rạch Núi and An Sơn), between the two Metal Age sites (Lò Gạch and Gò Ô Chùa), and between the Neolithic and Metal Age sites in southern Vietnam. The comparison of results between sites of the same period was done to compare culinary practices and, consequently, to specifically address Question 2. The number of food categories identified from chemical analyses of pottery samples was compared between Neolithic and Metal Age to assess continuity and/or changes in food preparation and presentation with the use of pottery and, consequently, to specifically address Question 3. For example, people during the Neolithic may have only cooked aquatic resources in pots, but by the Metal Age the people may have also cooked terrestrial animals in addition to aquatic food resources.

**Cuisines in Neolithic and Metal Age Southern Vietnam**

This section presents the interpretation on the culinary practices in prehistoric southern Vietnam based on the evaluation of results to address Questions 1-3 in the previous section. Tables 9-3, 9-4, 9-5, 9-6, and 9-7 present the combined results from technofunctional and organic residue analyses of archaeological pottery, respectively, from Rạch Núi, An Sơn, Lò Gạch, the Northern Mound in Gò Ô Chùa, and the Central Mound in Gò Ô Chùa. This interpretation is based on 48 of the 113 pottery vessels that underwent organic residue analysis and produced positive results.
Food Availability and Culinary Practices

Results of organic residue analysis demonstrate a lack of diversity of inferred food sources, which are mostly plants and/or aquatic sources, and lack of correlation between specific food categories and inferred functions of pottery. As a result, statistical analysis has not yet been performed between different food categories and functions, including correlating identified residues with vessel attributes of form, temper, and temper size. The results reflect culinary practices that are almost exclusive to the preferential use of earthenware pottery vessels for cooking and serving plant and aquatic food resources.

Rạch Núi

Rạch Núi (Table 9-1 and 9-2) presents several obstacles to interpret the culinary practices of its occupants during the Neolithic. First, the sampled pottery vessels lack discernible use alterations since pottery sherds were recycled as construction materials for floor renovations in the mound and were almost all covered with lime. It is difficult then to establish how these pots may have been used for processing, cooking, serving, or storage. Second, the organic residues recovered lack lipid molecules that are more diagnostic than fatty acids. The results from CSIA support use of C₃ and C₄ plants, as well as freshwater and marine sources. The site locality shows a diversity of both C₃ and C₄ plants (Table 9-11), with more wild and vegicultural resources and less economic, domesticated crops (rice and millet). Given the strategic location of Rạch Núi as both a riverine and coastal site, the preparation and consumption of diverse aquatic resources from various environments, are consistent with the observed range of δ¹³C values of C₁₆ and C₁₈ fatty acids. Perhaps, the preparation and consumption of terrestrial meat from mostly wild animals (Oxenham et al. 2015) did not involve ceramic
materials. Although there is evidence of butchery based on cut marks, no evidence of roasting of terrestrial animals over fire in an earthenware stove, instead of cooking them in the pot, can be discerned (Piper and Amano 2014). Table 9-1 presents the overall tally of results from organic residues in Rạch Núi according to pottery forms deduced in Chapter 7, while Table 9-2 specifically describes the pottery vessels with interpretable organic residues.

An Sơn

At the Neolithic site of An Sơn (Tables 9-3 and 9-4), it can be said that the sampled pots were used for preparation and consumption of C₃ plants and aquatic (freshwater or brackish) sources. Table 9-3 presents the results from organic residues in An Sơn according to pottery form, while Table 9-4 presents the sampled pottery vessels with interpretable organic residues. Two plain open bowls with fine organic temper from separate trenches (pots A27 AS6 from Trench 1 and A51 AS15 from Trench 3) have organic residues with the triad of C24 and C26 alcohols with tetracosanyl palmitate or C40 wax ester, as well as the prominence of C24 alcohol. It can be said that similar food sources, most likely waxy and leafy plants, were prepared and/or served in these two plain open bowls. However, this particular food item is also found in pottery vessels with different forms and attributes, from the two Metal Age sites. Thus, the preparation and service of these foodstuffs is not exclusive to a particular form of pot. In addition, the two vessels have slightly different profiles. It was already mentioned that pot A27 AS6 was also used for preparation and service of aquatic sources, probably brackish or mixed freshwater-marine sources. No marine sources were recovered from An Sơn; thus, only freshwater and brackish sources are the possibilities. Based on its form and burnt exterior surface, pot A27 AS6 was
probably used for both cooking and serving food similar to the usage of modern earthenware open bowls in southern Vietnam. Pot A27 AS6 was probably used more often than pot A51 AS15, given the higher calculated TLE of the former. The chemical analysis of absorbed and charred surface residues of pot A119 AS27, which is a stove, indicates that $C_3$ plants that produce triterpenoid resins were used as firewood during cooking. Based on the lipid compositions of their residues, several pottery vessels from An Sơn were probably used for preparing and/or serving plant food sources. Similar to Rạch Núi, the preparation and consumption of terrestrial meat probably did not involve ceramic materials. Although there is also evidence of butchery based on observed cut marks, no evidence of roasting terrestrial animals over fire or in an earthenware stove, instead of cooking them in the pot, could be discerned (Piper et al. 2012).

Lò Gạch

At the early Metal Age site of Lò Gạch (Tables 9-5 and 9-6), the sampled pots were used for preparation and consumption of $C_3$ plants and freshwater sources. Table 9-5 presents the results from organic residues according to pottery form, while Table 9-6 presents the sampled pottery vessels with interpretable organic residues. Pot A111 LGA32 from Trench 2 also has organic residues with the triad of C24 and C26 alcohols with tetracosanyl palmitate or C40 wax ester, as well as the prominence of C24 alcohol. It also has supporting results for freshwater sources from the analysis of associated charred surface residues (CSR5) and for both $C_3$ plants and freshwater sources from CSIA. The restricted jar with incised designed rim (pot A78 LGA16) seems to have been used to store a plant source similar to the one cooked in pot A111 LGA32, despite the lack of C40 ester in the organic residues. Both pots had coarse sand temper, in contrast to the plain organic temper in the pots from An Sơn with similar organic residues.
Another sand-tempered pot (A100 LGA31) was specifically used for cooking freshwater fish based on the remains of fish bones and the analysis of charred surface residues (CSR4). A plate and/or bowl with pedestal/stand (A107 LGA27) with medium organic temper represents a form peculiar to Lò Gạch. Although results from CSIA indicate C\textsubscript{3} plant and/or freshwater source(s), what appear as plant impressions on its interior surface lend support that the plate and/or bowl was used for serving plant food. Pot A104 LGA24, which is an open bowl with coarse sand temper and burnt residues on its exterior use, provided a remote possibility of terrestrial meat being cooked and served in this pot. These general findings correspond to the initial observations on floral and faunal remains recovered during the excavation of the site.

Gò Ô Chùa

At the early Metal Age site of Gò Ô Chùa (Table 9-7), the sampled pots were used for preparation and consumption of C\textsubscript{3} plants and aquatic sources. Table 9-7 presents the results of organic residues according to pottery form, while Tables 9-8 and 9-9 present the sampled pottery vessels with interpretable organic residues in Northern and Central Mounds, respectively. There are remarkable differences between results of organic residue analysis on the pottery from the Northern Mound, where Trench 1 (Table 9-8) is located, and the Central Mound, where Trenches 2-4 (Table 9-9) are located. These could be attributed to the Northern Mound being the first area to be settled and where salt making has been hypothesized ca. 1000 BC. The salt-making activity extended into the Central Mound by ca. 800 BC (Reinecke 2012).

The four pottery vessels from Gò Ô Chùa with similarities to vessels sampled from Lò Gạch and An Sơn were all recovered in the earliest levels, which could actually be one cultural layer, of Trench 1 in Northern Mound (Table 9-8). These are the pots
(A84 GOC17, A120 GOC 22, A5 GOC1, and A6 GOC2) that have organic residues with the triad of C24 and C26 alcohols with tetracosanyl palmitate or C40 wax ester. Two of these pots (A84 GOC17 and A5 GOC1) are plain restricted pots with fine organic temper, but they have striking differences. Pot A84 GOC17 has a severely eroded interior, indicating the use of this pot for fermenting food, and had a pungent aroma during its sampling with a cutting drill, as well as a viscous golden yellow residue. Pot A5 GOC1 has a firing cloud indicative of cooking by boiling, yielded a fragrant aroma during its sampling with a cutting drill, and had a viscous dark brownish green residue. It is possible that both pots were used for the same plant food source, but with different preparation process and mixed with different accompanying ingredients. The residues of pot A5 GOC1 had salicylic acid, which is not found in the residues of pot A84 GOC17. Salicylic acid is found in medicinal plants (Raskin 1992). It is possible that pot A5 GOC1 could have been used for decoction, where active plant ingredients were extracted from one or more plants by cooking them with boiling water (Miller 2015). One of these plants could be the C₃, waxy, and leafy plant also commonly found in seven other pottery vessels across the three sites. The other plant could be the one containing salicylic acid. The two other pottery vessels (pots A6 GOC2 and A120 GOC22) have cord-marked designs but differ in temper. Their form cannot be determined because their body sherd remnants have no indicative curvatures. Pot A120 GOC 22 has results from the analysis of absorbed and charred surface residues (CSR2) that support its use for cooking mixed C₃ plants and aquatic sources.

The only pot (A37 GOC6) from this site with ¹³C-enriched values of C16 and C18 fatty acids was also recovered from Trench 1. If this pot was used for preparing marine
sources, these may have been carried in saltwater from the coast to the site. Since the site lacks archaeobotanical studies to date, the use for C₄ plants cannot be assumed. Crucial lipid compounds indicative of aquatic and plant sources were not present in the residues of this pot. Pot A127 GOC26 also provided a remote possibility of terrestrial meat being cooked and served on this pot.

In the Central Mound (Table 9-9), three pots (A126 GOC25, A121 GOC23, and A122 GOC24) with organic temper have a distribution of n-alcohol compounds in their residues, different from policosanol (long-chain alcohol)-rich organic residues in the pots from the Northern Mound. Their organic residues contain alkanes and mid-chain alcohols, as well as fatty acids. This may indicate a plant stored in pot A126 GOC25, stored or cooked in pot A121 GOC23, and served in pot A122 GOC24 different from the policosanol-rich C₃ waxy and leafy plant prepared and served on pots recovered from the Northern Mound as well as from Lò Gạch and An Sơn. Pots A121 GOC23 and A122 GOC24 have slip or sealant made of resins from plants producing diterpene resin acids. Pot A121 GOC23 was originally assessed as a restricted jar, based on its rim; however, if the presence of C18 AAPA is confirmed, it could actually be a cooking pot as AAPAs are only produced through heating at high temperature (minimum of 270°C; Evershed et al. 2008). This pot also suggests the remote possibility of terrestrial meat being cooked and served. Another different C₃ plant was cooked or processed in pot A88 GOC21, with an almost completely restricted profile an estimated height, everted rim, cord-marked design, and coarse organic temper. This could be the same plant source that was prepared and served in pots A88 GOC16, A87 GOC20, A127 GOC26, and A128 GOC27. This is because the organic residues from these five
pots show evidence of alkanes and fatty acids, and the absence of alcohols. Based on the distribution of δ^{13}C values of C16 and C18 fatty acids of the pots analyzed, aquatic resources came from a variety of environments, if they were prepared and served in these pots.

**Summarized assessment for southern Vietnam**

Table 9-10 presents the overall tally of results from organic residues according to pottery forms deduced in Chapter 7. It also summarizes Tables 9-1, 9-3, 8-5, and 9-7. The pottery vessels with negligible and no organic residues could have been utilized for the storage, transfer, and service of either dry and solid foodstuff; involved in the preparation of foodstuff that do not contain much oils or fats; or were less frequently used. Table 9-11 also summarizes the foodstuffs that the previous occupants of the four prehistoric sites in southern Vietnam had subsisted on based on the knowledge of floral and faunal remains recovered, as well as the foodstuffs they prepared and/or served in their pottery vessels. This also aids in exploring the key research questions of this dissertation.

*Do culinary practices reflect the available food resources and/or culturally conditioned practices in prehistoric SEA?* The findings in this research, based on the similarities in food residues and archaeobiological remains, lean toward the culinary practices that generally reflect the culturally conditioned practices of the people in prehistoric southern Vietnam. Based on the findings from organic residue analysis, these people preferred to use pottery vessels for preparing and serving plants, occasionally in combination with aquatic sources. If the pottery vessels that yielded interpretable results are representative of the pottery assemblages of the four sites, people rarely used pots to prepare and/or serve terrestrial meat.
At all four sites (Table 9-11), the number of food categories identified from pottery residues is generally less than the number of food categories identified from recovered floral and faunal remains. At Rạch Núi, the number of food categories that were possibly contained in the pottery vessels range from 2 to 4 because results cannot separate plants and aquatic sources. Although marine sources, such as seawater fishes, were not identified at Rạch Núi, it is still possible they may someday be identified, as only 14% of the aquatic faunal assemblage has been analyzed to date (Campos 2014). At An Sơn, some freshwater sources are also classified as brackish (Piper et al. 2012). For both Metal Age sites, Lò Gạch and Gò Ô Chùa, the nonruminant and ruminant animals are lumped into one category as terrestrial animals because results from faunal analyses from both sites are not yet available and the results from organic residue analysis cannot be used for discriminating nonruminant from ruminant animal meat. For Gò Ô Chùa, the C\textsubscript{3} and C\textsubscript{4} plants are also lumped into one category because of the lack of archaeobotanical work to date. Absence of marine sources is always assumed at inland sites, such as Gò Ô Chùa. This site yielded only three food categories to consider (plants, terrestrial animals, and aquatic sources), making it appear that previous occupants prepared and served all their food using their pottery vessels. However, potential evidence for terrestrial meat was found in only three pots.

**Across Space**

*Are there similarities and differences in the culinary practices between the sites of the same period?* In the case of Neolithic sites, the previous occupants of both Rạch Núi and An Sơn prepared and served \textsuperscript{13}C-depleted food sources, which are C\textsubscript{3} plants and/or freshwater fishes, in their pottery. However, the previous occupants of Rạch Núi may have also prepared and served \textsuperscript{13}C-enriched food, which likely included some C\textsubscript{4}
plants and/or marine or estuarine sources, in their pottery (Fig. 9-1, Table 9-11). Thus, the prehistoric occupants of Роcч Nũi and An Sơn may have belonged to different communities of practice in terms of cuisines. This correlates to differences in their material culture, especially pottery (Sarjeant 2012a,b, 2014; Oxenham et al. 2015) and is not surprising, given the considerable distance between these two sites. Роcч Nũi is the closest to the coast among the four sites, whereas An Sơn is close to two Metal Age sites further inland.

In the case of Metal Age sites, the previous occupants of both Lò Gạch and Gò Ô Chùa also prepared and served $^{13}$C-depleted food resources, which are $C_3$ plants and freshwater fishes, using their pottery. However, the previous occupants of Gò Ô Chùa may have also prepared and served $^{13}$C-enriched food (Fig. 9-2, Table 9-11). This probably correlates to differential access to food sources despite similarities in material culture. The prehistoric occupants of Gò Ô Chùa could have had access to marine sources, given that there is evidence for transport of saltwater from the coast to the site for salt production. Thus, the prehistoric occupants of the Lò Gạch and Gò Ô Chùa sites belonged to different communities of practice in terms of cuisine.

**Across Time**

*Are there changes and continuities in culinary practices between the Neolithic sites and Metal Age sites in the same geographic region?* Although there are distinct communities of practice in terms of cuisines in both Neolithic and Metal Age, there is a continuity in the preferential preparation of $C_3$ and/or $C_4$ plants and aquatic food sources in pottery from Neolithic (Fig. 9-1) to the Metal Age (Fig. 9-2, Table 9-11). This continuity is observed in the sampled pottery vessels from the Neolithic (An Sơn) and Metal Age (Lò Gạch and Gò Ô Chùa) because observed organic residues show similar
lipid composition and isotopic signature, indicating similar patterns of use of similar plant resources. It seems that the arrival of metallurgy in southern Vietnam, along with associated sociopolitical changes, did not impact culinary practices. However, several pots \((n=3)\) from the two Metal Age sites may have been used for preparing and serving terrestrial animal meat. This may represent a subtle change in culinary practices from the Neolithic to Metal Age.

**Cuisines and Community Identities in Prehistoric Southern Vietnam**

This research provides evidence for broad similarities and some differences in culinary practices between the sites of the same period and possible continuity between the two prehistoric periods, i.e., Neolithic and Metal Age. Here, I conclude by addressing the last two research questions posed in Chapter 1 and present a scenario for possible community identities of Neolithic and Metal Age people in southern Vietnam.

*What local and regional resources are being combined and utilized in the production of cuisines?* In general, the prehistoric occupants of these four sites utilized and consumed many local foodstuffs. However, all available foods were not prepared and/or served based on the analysis of sampled pottery. The usage of pottery vessels demonstrates a C\(_3\) waxy and leafy plant with a specific biomolecular signature was likely available within the vicinities of An Sơn, Lò Gạch, and Gò Ô Chùa. This plant source was likely fermented and stored in jars as well as cooked by boiling in restricted pots. Stewing and serving of this food in an open bowl was also possible. The absence of this plant source at Rạch Núi may indicate that this food source was only available in a specific area far from Rạch Núi, or is an artifact of sampling.
Based also on the occurrence of lipid compounds indicating plant waxes in various combinations, plant food resources were clearly important in the maintenance and promotion of identities during prehistory. This emphasis on plant food sources in daily culinary practices still persists today in Vietnam, where vegetables and herbs are present in all major meals and fruits are present in minor meals. It is likely that the specific waxy and leafy plant food source supported by the organic residue analysis can still be found in the present-day diversity of plant food sources incorporated in the local cuisine of Vietnam.

Only four pottery vessels exhibit strong evidence for the preparation and/or service of aquatic resources, despite the ubiquity of these food resources based on excavated remains from these four sites. One pottery vessel attests to the fact that freshwater fish was cooked in the pot. The other three pottery vessels attest to the fact that plants and aquatic sources were cooked and served together in pottery vessels. This food combination (i.e., fish and vegetable soup or stew) still persists today in Vietnam and SEA, in general. This is demonstrated by the present-day diversity of recipes involving aquatic and plant sources that are cooked together in a vessel, which can be an earthenware or metal cooking pot. In some areas, the preference for cooking aquatic and plant sources in earthenware pots still persists because of the effect of the heated clay on the taste of the dish. Thus, the combined roles of pottery, or any cooking vessel, and the mixing of aquatic and plant sources in maintaining identities, could have originated in prehistory when the Mekong Delta in southern Vietnam was first settled.

A few pottery vessels presented the possibility that terrestrial animal meat was prepared and served in pottery. All three of the pottery vessels derive from the two
Metal Age sites. Perhaps terrestrial animal meat was prepared and served through other means and pottery vessels were unnecessary. Also, their importance could have been expressed in terms different from those for plant and aquatic food sources. For example, the keeping and display of mandibles from pigs and primates (Oxenham et al. 2015) by the previous occupants of Rạch Núi may express the importance they placed on these terrestrial animals.

The previous occupants of An Sơn locally produced their own domesticated food sources (rice, pigs, and dogs) (Piper et al. 2012), while the previous occupants of Rạch Núi probably imported rice and millet from other communities living in the Dong Nai river basin. The people of Rạch Núi relied more on locally foraged wild plants and noncereal crops, such as tubers, which they produced via vegeculture (Oxenham et al. 2015). Despite the proximity of the two Metal Age sites, the earliest occupants of Lò Gạch, and Gò Ô Chùa seem to have had differential access to food sources. Those from Gò Ô Chùa may have had increased access to marine sources imported from the coast, along with the seawater that they likely utilized for the production of salt (Reinecke 2012). In general, the available findings from archaeobiological remains and organic residues in this work highlight the importance of local food sources.

*What are the community identities of the people who occupied these sites, based on their shared culinary practices?* Contrasting findings between Rạch Núi (Tables 9-1 and 9-2) and An Sơn (Tables 9-3 and 9-4; Fig. 9-1) are related to contrasting material culture, environments, and, consequently, distinct community identities during the Neolithic. Similar findings between Lò Gạch (Tables 9-5 and 9-6) and Gò Ô Chùa (Tables 9-7, 9-8, and 9-9) could be related to similarities in their material culture, such
as plain pottery vessels and clay pedestals, during the Metal Age. However, these two sites also demonstrated contrasting signals (Fig. 9-2), which indicate that the previous occupants belonged to different culinary communities of practice caused by differential access to food sources. The presence of a $C_3$ waxy and leafy plant food source connects the Neolithic site of An Sơn to the two nearby Metal Age sites of Lò Gạch, and Gò Ô Chùa, as well as indicates the continuity of usage of this plant in prehistory. Its absence in Rạch Núi makes this Neolithic site distinct from the other three sites.

This research aims to demonstrate that the previous occupants of all four prehistoric sites, Rạch Núi, An Sơn, Lò Gạch, and Gò Ô Chùa, probably belonged to different communities of practice and had distinct community identities, based on inferred culinary practice. This distinctiveness is reflected in the differences between sites of the same period, in terms of access to specific food sources (in the case of Metal Age sites), different environments, and expression of material culture (in the case of Neolithic sites), especially related to their foodways. Despite this distinctiveness, there is a continuity of culinary practices, as $^{13}$C-depleted food sources were prepared and consumed by the people in southern Vietnam from Neolithic and Metal Age. Sites with access to $^{13}$C-enriched food represent separate periods. Local food sources serve as the social glue that binds the people within a community, represented in this research by a specific site, and between communities, where the latter is demonstrated by a common plant food source that was available within the vicinities of An Sơn, Lò Gạch, and Gò Ô Chùa. Last but not least, the prehistoric culinary practices and, in general, foodways described here overlap with those discussed in Chapter 3 on present-day southern Vietnam, with respect to plant and aquatic food sources.
Table 9-1. Tally of results from organic residue analysis according to pottery form in Rach Núi.

<table>
<thead>
<tr>
<th>Form</th>
<th>None&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Negligible&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Plants</th>
<th>C&lt;sub&gt;3&lt;/sub&gt; plants and aquatic sources</th>
<th>C&lt;sub&gt;3&lt;/sub&gt; plants and possibly aquatic sources</th>
<th>C&lt;sub&gt;3&lt;/sub&gt; plants and/or freshwater sources</th>
<th>Freshwater fish</th>
<th>C&lt;sub&gt;4&lt;/sub&gt; plants and/or marine sources</th>
<th>Terrestrial animal (slight possibility)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open bowl</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Restricted bowl</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Open pot</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Restricted pot</td>
<td>3</td>
<td>6</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>13</td>
</tr>
<tr>
<td>Restricted pot/jar</td>
<td>1</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>8</td>
</tr>
<tr>
<td>Jar</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Small cup and/or bowl</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Plate and/or bowl w/ stand</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Stove</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Sherd&lt;sup&gt;*&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>6</td>
<td>9</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>27</td>
</tr>
</tbody>
</table>

<sup>a</sup>TLE = 0 µg/g

<sup>b</sup>TLE < 5 µg/g with no diagnostic lipid compounds

<sup>*</sup>Vessel form cannot be identified
Table 9-2. Descriptions of pottery and organic residues of samples from Rạch Núi.

<table>
<thead>
<tr>
<th>Sple. No.</th>
<th>Site code</th>
<th>Accession code*</th>
<th>TLE (µg/g)</th>
<th>Pottery description</th>
<th>Organic residue description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A62</td>
<td>RN16</td>
<td>12RNH1F2C/1,2-1 c.1007</td>
<td>3.45</td>
<td>Restricted pot with coarse sand temper and cord-marked design</td>
<td>C₃ plant and/or freshwater source(s). CSIA values within gray area.</td>
</tr>
<tr>
<td>A2</td>
<td>RN2</td>
<td>12RNH1F2E/4c.1007-1</td>
<td>15.54</td>
<td>Unrestricted, open bowl with coarse sand temper and cord-marked design. Serving</td>
<td>C₄ plant and/or marine source(s)</td>
</tr>
<tr>
<td>A63</td>
<td>RN17</td>
<td>12RNH1F3/1C8</td>
<td>6.06</td>
<td>Restricted pot/jar with coarse sand temper and cord-marked design</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A68</td>
<td>RN22</td>
<td>12RNH2L5-3C3</td>
<td>35.59</td>
<td>Restricted pot/jar with everted rim, possible incised design, and shell temper</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A25</td>
<td>RN9</td>
<td>12RNH2A6 L5/4</td>
<td>29.26</td>
<td>Restricted pot (based on curvature of shoulder/body sherd) with fine shell temper and cord-marked design. Possible cooking pot based on firing cloud</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A124</td>
<td>RN26</td>
<td>12RNH2L5-4A1</td>
<td>0.61</td>
<td>Restricted pot with sand temper and cord-marked design. Possible cooking pot based on firing cloud.</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A64</td>
<td>RN18</td>
<td>12RNH2L5-4C7-4, Feature 14</td>
<td>5.96</td>
<td>Restricted small cup or bowl with medium organic temper and cord-marked design</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A125</td>
<td>RN27</td>
<td>12RNH2 A4 c.2008/4-6</td>
<td>0.89</td>
<td>Body sherd with coarse sand temper and cord-marked design</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A114</td>
<td>RN24</td>
<td>12RNH2L5-5 B1 c.2008/5</td>
<td>2.56</td>
<td>Restricted pot with coarse sand temper and cord-marked design</td>
<td>Possibly plant source(s).</td>
</tr>
<tr>
<td>A65</td>
<td>RN19</td>
<td>12RNH2L5-6C1 c.2008/6</td>
<td>311.79</td>
<td>Restricted pot/jar with medium shell temper and cord-marked design</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A13</td>
<td>RN5</td>
<td>12RNH3L1C2</td>
<td>4.05</td>
<td>Restricted pot with very fine shell temper and cord-marked design</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A1</td>
<td>RN1</td>
<td>12RNH3L2/20D4 c.3002/20-1</td>
<td>17.04</td>
<td>Restricted pot/jar with fine sand temper and cord-marked design</td>
<td>C₄ plant and/or marine source(s)</td>
</tr>
</tbody>
</table>

* Sampled pottery accession codes refer to year of excavation (first two numbers), site (initials), trench (H), layer or level (L), feature (F), context (C), and date of recovery.
Table 9-3. Tally of results from organic residue analysis according to pottery form in An Sơn.

<table>
<thead>
<tr>
<th>Form</th>
<th>None*</th>
<th>Negligibleb</th>
<th>Plants</th>
<th>C₃ plants and aquatic sources</th>
<th>C₃ plants and possibly aquatic sources</th>
<th>C₃ plants and/or freshwater sources</th>
<th>Freshwater fish</th>
<th>C₄ plants and/or marine sources</th>
<th>Terrestrial animal (slight possibility)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open bowl</td>
<td>2</td>
<td>3</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>Restricted bowl</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Open pot</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Restricted pot</td>
<td>1</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Jar</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Small cup and/or bowl</td>
<td>1</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Plate and/or bowl w/ stand</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Stove</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Sherd*</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>6</td>
<td>11</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>27</td>
</tr>
</tbody>
</table>

*aTLE = 0 µg/g  
bTLE < 5 µg/g with no diagnostic lipid compounds  
*Vessel form cannot be identified
Table 9-4. Descriptions of pottery and organic residues of samples from An Sơn.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Site code</th>
<th>Accession code*</th>
<th>TLE (µg/g)</th>
<th>Pottery description</th>
<th>Organic residue description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A8</td>
<td>AS3</td>
<td>09ASH1L8A3 (Bo Khong Che, FT)</td>
<td>49.38</td>
<td>Shoulder/body sherd from a possible cooking pot, based on the exterior firing cloud, with medium organic temper and cord-marked design</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A117</td>
<td>AS25</td>
<td>09ASH1L8B2-2 FT body</td>
<td>0.22</td>
<td>Shoulder/body sherd with very fine organic temper and cord-marked design</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A118</td>
<td>AS26</td>
<td>09ASH1L10A2</td>
<td>0.46</td>
<td>Unrestricted, open bowl with very fine sand temper, wavy rim, and cord-marked (but ~incised) design</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A48</td>
<td>AS12</td>
<td>09ASH1L10A5NhL3-2</td>
<td>2.89</td>
<td>Restricted, small cup or bowl with very fine sand temper and cord-marked design</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A119</td>
<td>AS27</td>
<td>09ASH1L10B9 Cà rang</td>
<td>30.96</td>
<td>Unrestricted, earthenware stove with cord-marked design/texture, coarse organic temper, and burnt firewood inside</td>
<td>Residues were absorbed from firewood on stove.</td>
</tr>
<tr>
<td>CSR3</td>
<td>AS27</td>
<td>09ASH1L10B9 Cà rang</td>
<td>2.52</td>
<td>Charred surface residues inside pot A119 AS27</td>
<td>Burnt firewood from C₃ plant</td>
</tr>
<tr>
<td>A4</td>
<td>AS2</td>
<td>ASH1L12-13-1 ST</td>
<td>2.63</td>
<td>Body sherd with medium sand and cord-marked design</td>
<td>C₃ plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A27</td>
<td>AS6</td>
<td>09ASH1L13B11 FT rim</td>
<td>578.05</td>
<td>Plain, unrestricted, open bowl with mainly very fine organic temper. No observable slip. Cooking and/or serving pot based on profile and burnt exterior.</td>
<td>Viscous brownish yellow extract Only sample with phytanic acid. CSIA values within gray area. C₃ plant and freshwater/brackish sources</td>
</tr>
<tr>
<td>A28</td>
<td>AS7</td>
<td>09ASH1L14B11</td>
<td>11.59</td>
<td>Restricted bowl with fine sand and cord-marked design</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A3</td>
<td>AS1</td>
<td>09ASH2L2-3 C3-1 (20-30cm) ST</td>
<td>3.7</td>
<td>Body sherd with very fine sand and cord-marked design</td>
<td>C₃ plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A51</td>
<td>AS15</td>
<td>09ASH3L10A3 FT rim</td>
<td>52.16</td>
<td>Plain, unrestricted, open bowl with mainly fine organic temper. Similar to pot A27 AS6, except for angled shoulder.</td>
<td>Brown extract. C₃ plant and, possibly, freshwater source(s)</td>
</tr>
</tbody>
</table>

* Sampled pottery accession codes refer to year of excavation (first two numbers), site (initials), trench (H), layer or level (L), feature (F), context (C), and date of recovery.
Table 9-5. Tally of results from organic residue analysis according to pottery form in Lò Gach.

<table>
<thead>
<tr>
<th>Form</th>
<th>None&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Negligible&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Plants</th>
<th>C3 plants and aquatic sources</th>
<th>C3 plants and possibly aquatic sources</th>
<th>C3 plants and/or freshwater sources</th>
<th>Freshwater fish</th>
<th>C4 plants and/or marine sources</th>
<th>Terrestrial animal (slight possibility)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open bowl</td>
<td>5</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>Restricted</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Open pot</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Restricted pot</td>
<td>2</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>7</td>
</tr>
<tr>
<td>Restricted pot/jar</td>
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<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Jar</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Small cup and/or bowl</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Plate and/or bowl w/ stand</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
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<tr>
<td>Stove</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Sherd*</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
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<td>0</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>33</td>
</tr>
</tbody>
</table>

<sup>a</sup>TLE = 0 µg/g
<sup>b</sup>TLE < 5 µg/g with no diagnostic lipid compounds
<sup>*</sup>Vessel form cannot be identified
### Table 9-6. Descriptions of pottery and organic residues of samples from Lò Gạch.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Site code</th>
<th>Accession code*</th>
<th>TLE (µg/g)</th>
<th>Pottery description</th>
<th>Organic residue description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A101</td>
<td>LGa21</td>
<td>14 LGaH1 D3/D2 F1-113 5-5-14</td>
<td>0.37</td>
<td>Shoulder/body sherd with medium organic temper and a few soot at the interior surface. Cooking pot</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A78</td>
<td>LGa16</td>
<td>14 LGaH1D2 C105 9-5-14</td>
<td>13.69</td>
<td>Restricted jar (dₘᵣₜ=10 cm) with incised design at the everted rim and coarse sand temper. Storage jar</td>
<td>Light green extract. C₁₆ and C₁₈ FAs are less than 1 µg/g. Plant source Based on C₁₈ FA &gt; C₁₆ FA in TLE profile, possibly terrestrial animal meat.</td>
</tr>
<tr>
<td>A104</td>
<td>LGa24</td>
<td>14 LGaH2 B2 C203 26-4-14</td>
<td>9.41</td>
<td>Unrestricted, open bowl with coarse sand temper. With few burnt stuff and plant impressions at its exterior. Cooking and serving food</td>
<td></td>
</tr>
<tr>
<td>A55</td>
<td>LGa12</td>
<td>14 LGaH2 B1 C203/1 25-4-14</td>
<td>2.17</td>
<td>Unrestricted, open bowl with medium organic temper. With impact marks.</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A111</td>
<td>LGa32</td>
<td>14 LGaH2 C1 C204/2 29-4-14 -- 2</td>
<td>16.21</td>
<td>Body sherd with cord-marked design, very coarse sand temper, and interior charred surface residues</td>
<td>Yellow green extract. C₃ and freshwater sources.</td>
</tr>
<tr>
<td>CSR5</td>
<td>LGa32</td>
<td>14 LGaH2 C1 C204/2 29-4-14 -- 2</td>
<td>0.41</td>
<td>Charred surface residues on pot A111 LGA32</td>
<td>C₃ and freshwater sources.</td>
</tr>
<tr>
<td>A100</td>
<td>LGa31</td>
<td>14 LGaH2 F2-14 26-4-14</td>
<td>0.81</td>
<td>Body sherd with medium sand temper and interior charred surface residues</td>
<td>Freshwater source(s) based on CSR4</td>
</tr>
<tr>
<td>CSR4</td>
<td>LGa31</td>
<td>14 LGaH2 F2-14 26-4-14</td>
<td>51.93</td>
<td>Charred interior surface residues on pot A100 LGA31</td>
<td>With remains of fish bones. Freshwater source(s). C₃ plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A107</td>
<td>LGa27</td>
<td>14 LGaH3A1 C302 5-5-14</td>
<td>0.07</td>
<td>Plate and/or bowl with pedestal/stand and medium organic temper. Scratches on top seem to be plant impressions. Used for serving food.</td>
<td></td>
</tr>
<tr>
<td>A108</td>
<td>LGa28</td>
<td>14 LGaH3 A2 C304 9-5-14</td>
<td>1.81</td>
<td>Unrestricted, open pot with fine limestone temper and wavy profile</td>
<td>Plant source</td>
</tr>
<tr>
<td>A109</td>
<td>LGa29</td>
<td>14 LGaH3 C2 C305 10-5-14</td>
<td>0.4</td>
<td>Unrestricted, open bowl with coarse limestone temper</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
</tbody>
</table>

* Sampled pottery accession codes refer to year of excavation (first two numbers), site (initials), trench (H), layer or level (L), feature (F), context (C), and date of recovery.
Table 9-7. Tally of results from organic residue analysis according to pottery form in Gò Ô Chùa.

<table>
<thead>
<tr>
<th>Form</th>
<th>None&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Negligible&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Plants</th>
<th>C&lt;sub&gt;3&lt;/sub&gt; plants and aquatic sources</th>
<th>C&lt;sub&gt;3&lt;/sub&gt; plants and possibly aquatic sources</th>
<th>C&lt;sub&gt;3&lt;/sub&gt; plants and/or freshwater sources</th>
<th>Freshwater fish</th>
<th>C&lt;sub&gt;4&lt;/sub&gt; plants and/or marine sources</th>
<th>Terrestrial animal (slight possibility)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open bowl</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Restricted</td>
<td>1</td>
<td>2</td>
<td>-</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>Open pot</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Restricted pot</td>
<td>3</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Jar</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Small cup</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Plate and/or</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>bowl w/ stand</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Stove</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Sherd*</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>9</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>(2)</td>
<td>26</td>
</tr>
</tbody>
</table>

<sup>a</sup>TLE = 0 µg/g  
<sup>b</sup>TLE < 5 µg/g with no diagnostic lipid compounds  
*Vessel form cannot be identified
Table 9-8. Descriptions of pottery and organic residues of samples from Trench 1 in Northern Mound of Gò Ô Chùa.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Site code</th>
<th>Accession code*</th>
<th>TLE (µg/g)</th>
<th>Pottery description</th>
<th>Organic residue description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A83</td>
<td>GOC16</td>
<td>08GOCH1L9-4</td>
<td>2.23</td>
<td>Plain unrestricted, open bowl with very fine organic temper. With interior firing cloud. Probably used for cooking and serving food.</td>
<td>Plant source</td>
</tr>
<tr>
<td>A84</td>
<td>GOC17</td>
<td>08GOCH1L10-1</td>
<td>637.13</td>
<td>Plain restricted pot with mainly very fine organic temper. Severely eroded interior with cracking. Probably used for fermenting and storing food.</td>
<td>Viscous golden yellow extract. Observed pungent aroma. C₃ plant and, possibly, mixed aquatic/estuarine source(s)</td>
</tr>
<tr>
<td>A87</td>
<td>GOC20</td>
<td>08GOCH1L10-4</td>
<td>0.87</td>
<td>Unrestricted, open bowl with very fine temper and cord-marked design. Probably used for serving.</td>
<td>Plant source</td>
</tr>
<tr>
<td>A37</td>
<td>GOC6</td>
<td>08GOCH1L10-8 Rim ST</td>
<td>57.19</td>
<td>Plain restricted pot with everted rim and very fine sand temper</td>
<td>C₄ plant and/or marine source(s)</td>
</tr>
<tr>
<td>A127</td>
<td>GOC26</td>
<td>08GOCH1L10-12 Binh vo L13</td>
<td>185.52</td>
<td>Plain restricted pot with everted rim and very fine organic temper. Probably cooking pot.</td>
<td>C16 FA ≃ C18 FA. CSIA values within gray area. C₃ plant and, possibly, mixed aquatic/estuarine source(s). Terrestrial meat is also possible.</td>
</tr>
<tr>
<td>A120</td>
<td>GOC22</td>
<td>08GOCH1L10 2/4</td>
<td>3386.12</td>
<td>Body sherd with cord-marked design, medium sand temper, and charred interior surface residues</td>
<td>Viscous amber colored extract. CSIA values within gray area. C₃ plant and mixed aquatic/estuarine sources. Brown extract. Mixed C₃ plant-aquatic sources.</td>
</tr>
<tr>
<td>CSR2</td>
<td>GOC22</td>
<td>08GOCH1L10 2/4</td>
<td>287.46</td>
<td>Charred surface residues on pot A120 GOC 22.</td>
<td></td>
</tr>
<tr>
<td>A5</td>
<td>GOC1</td>
<td>08GOCH1L11-1 Body FT Van Ky Thuat</td>
<td>1615.49</td>
<td>Plain shoulder/body sherd from restricted pot with mainly fine organic temper. Firing cloud in interior and exterior surfaces. Used for cooking.</td>
<td>Viscous dark brownish green extract. Fragrant aroma. CSIA values within gray area. C₃ plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A6</td>
<td>GOC2</td>
<td>08GOCH1L11-3 Body FT Van Ky Thuat</td>
<td>33.21</td>
<td>Body sherd with cord-marked design and mainly medium organic temper.</td>
<td>Brown extract. CSIA values within gray area. C₃ plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A128</td>
<td>GOC27</td>
<td>08GOCH1L11-4 Body FT Van Ky Thuat</td>
<td>1.27</td>
<td>Plain restricted pot with everted rim and very fine organic temper. Probably cooking pot.</td>
<td>C₃ plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A58</td>
<td>GOC12</td>
<td>08GOCH1L11 3/5-1</td>
<td>7.94</td>
<td>Plain restricted bowl with mixed fine sand and coarse organic temper.</td>
<td>C₃ plant and/or freshwater source(s)</td>
</tr>
</tbody>
</table>

* Sampled pottery accession codes refer to year of excavation (first two numbers), site (initials), trench (H), layer or level (L), feature (F), context (C), and date of recovery.
Table 9-9. Descriptions of pottery and organic residues of samples from Trenches 2-4 in Central Mound of Gò Ô Chùa.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Site code</th>
<th>Accession code*</th>
<th>TLE (µg/g)</th>
<th>Pottery description</th>
<th>Organic residue description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A59</td>
<td>GOC13</td>
<td>09GOCH2L10-1 Binh vo L12 Rim FT Tron</td>
<td>13.71</td>
<td>Plain restricted bowl with everted rim and very fine organic temper</td>
<td>C3 plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A126</td>
<td>GOC25</td>
<td>09GOCH2L10-5 Binh vo L13</td>
<td>13.81</td>
<td>Plain restricted jar with everted rim and very fine organic temper. Probably for storage.</td>
<td>C3 plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A88</td>
<td>GOC21</td>
<td>08GOCH2L11 Mieng Chon Loc</td>
<td>11.73</td>
<td>Restricted pot with everted rim, cord-marked design, and coarse organic (probably rice husks) temper. With almost complete profile (estimated height of ~14 cm). Highly weathered interior at the rim area. Used for cooking or processing food.</td>
<td>CSIA values within gray area. C3 plant and, possibly, freshwater source(s)</td>
</tr>
<tr>
<td>A121</td>
<td>GOC23</td>
<td>08GOCH3L9-1 Binh vo L9</td>
<td>12.23</td>
<td>Plain restricted jar with medium organic temper. Slightly eroded interior. Probably with cover based on the appearance of everted rim.</td>
<td>CSIA values within gray area. C3 plant and, possibly, freshwater source(s). Terrestrial meat is also possible. Maybe cooking pot instead due to possible C18 AAPA. With diterpene resin</td>
</tr>
<tr>
<td>A122</td>
<td>GOC24</td>
<td>08GOCH4L9-1</td>
<td>2.42</td>
<td>Plain unrestricted open bowl with everted rim and very fine organic temper. Probably for serving food.</td>
<td>C3 plant and, possibly, freshwater source(s). With diterpene resins</td>
</tr>
<tr>
<td>A60</td>
<td>GOC14</td>
<td>08GOCH4L9-2 Binh vo L13 Manh Mieng</td>
<td>10.64</td>
<td>Plain restricted jar with everted rim and very fine organic temper. With firing cloud at interior surface. Probably cooking pot</td>
<td>C3 plant and/or freshwater source(s)</td>
</tr>
<tr>
<td>A61</td>
<td>GOC15</td>
<td>08GOCH4L9-3 Binh vo L13 Manh Mieng</td>
<td>7.96</td>
<td>Plain restricted pot with everted rim and medium organic temper. With firing cloud at interior surface. Probably cooking pot.</td>
<td>C3 plant and/or freshwater source(s)</td>
</tr>
</tbody>
</table>

* Sampled pottery accession codes refer to year of excavation (first two numbers), site (initials), trench (H), layer or level (L), feature (F), context (C), and date of recovery.
Table 9-10. Tally of results from organic residue analysis according to pottery form in four sites of southern Vietnam.

<table>
<thead>
<tr>
<th>Form</th>
<th>None&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Negligible&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Plants</th>
<th>C&lt;sub&gt;3&lt;/sub&gt; plants and aquatic sources</th>
<th>C&lt;sub&gt;3&lt;/sub&gt; plants and possibly aquatic sources</th>
<th>C&lt;sub&gt;3&lt;/sub&gt; plants and/or freshwater sources</th>
<th>Freshwater fish</th>
<th>C&lt;sub&gt;4&lt;/sub&gt; plants and/or marine sources</th>
<th>Terrestrial animal (slight possibility)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open bowl</td>
<td>8</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>Restricted bowl</td>
<td>2</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>Open pot</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Restricted pot</td>
<td>9</td>
<td>13</td>
<td>2</td>
<td>-</td>
<td>4</td>
<td>4</td>
<td>-</td>
<td>1 (2)</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Restricted pot/jar</td>
<td>2</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>13</td>
</tr>
<tr>
<td>Jar</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7</td>
</tr>
<tr>
<td>Small cup and/or bowl</td>
<td>1</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>Plate and/or bowl w/ stand</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Stove</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Sherd&lt;sup&gt;*&lt;/sup&gt;</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>12</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>26</strong></td>
<td><strong>38</strong></td>
<td><strong>7</strong></td>
<td><strong>3</strong></td>
<td><strong>12</strong></td>
<td><strong>22</strong></td>
<td><strong>1</strong></td>
<td><strong>3</strong></td>
<td><strong>1 (+2)</strong></td>
<td><strong>113</strong></td>
</tr>
</tbody>
</table>

<sup>a</sup>TLE = 0 µg/g  
<sup>b</sup>TLE < 5 µg/g with no diagnostic lipid compounds  
*Vessel form cannot be identified
Table 9-11. Comparison of food categories between archaeobiological food remains and organic residues.

<table>
<thead>
<tr>
<th>Site</th>
<th>Archaeobiological food remains</th>
<th>Organic residues</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rạch Núi</td>
<td>C₃ plants: rice, tubers, fruits</td>
<td>C₃ plants and/or freshwater sources</td>
<td>Analyses of archaeobiological food remains are ongoing. Preliminary findings are available (Oxenham et al. 2015.)</td>
</tr>
<tr>
<td>(5 vs 2-4)</td>
<td>C₄ plants: foxtail millet, sedges</td>
<td>C₄ plants and/or marine sources</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nonruminant animals: pig, dog, macaques, etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ruminant animal: deer</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Freshwater sources: fishes, shellfishes, turtles, crabs (some are brackish)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>An Sơn</td>
<td>C₃ plant: rice</td>
<td>C₃ plants</td>
<td>Zooarchaeological analyses (Piper et al. 2012). Preliminary findings on archaeobotanical remains (Sarjeant 2014b)</td>
</tr>
<tr>
<td>(5 vs 2)</td>
<td>C₄ plant: sedges</td>
<td>Freshwater sources</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nonruminant animals: pig, dog</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ruminant animal: deer</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Freshwater source: fishes, turtles (some are brackish)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lò Gạch</td>
<td>C₃ plant: rice</td>
<td>C₃ plants</td>
<td>Based on preliminary observations during excavation. Analyses of archaeobiological food remains are ongoing.</td>
</tr>
<tr>
<td>(4 vs 3)</td>
<td>C₄ plant: Job’s tears</td>
<td>Freshwater sources</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nonruminant animal: pig</td>
<td>Terrestrial meat is a possibility</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ruminant animal: deer</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Freshwater source: fishes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gò Ô Chùa</td>
<td>C₃ plant: ?</td>
<td>C₃ plants</td>
<td>Analyses of faunal remains are ongoing.</td>
</tr>
<tr>
<td>(3 vs 3)</td>
<td>C₄ plant: ?</td>
<td>Freshwater sources</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nonruminant animal: pigs</td>
<td>C₄ plants and/or marine sources</td>
<td>Lapse in recovering floral remains from past excavations.</td>
</tr>
<tr>
<td></td>
<td>Ruminant animal: ?</td>
<td>Terrestrial meat is a possibility</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Freshwater source: fishes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 9-1. Plot of δ\textsuperscript{13}C values of C16 and C18 fatty acids obtained from archaeological pottery of Neolithic southern Vietnam against several ranges of δ\textsuperscript{13}C values of C16 and C18 fatty acids obtained from modern reference materials acquired in Southeast Asia. Legends: Gray circles – modern reference samples; diamonds – absorbed residues from archaeological pottery; triangles – charred interior surface residues on pottery; light orange diamonds – samples from Rạch Núi; dark orange diamonds and triangle – samples from An Sơn.
Figure 9-2. Plot of δ\(^{13}\)C values of C16 and C18 fatty acids obtained from archaeological pottery of Metal Age southern Vietnam against several ranges of δ\(^{13}\)C values of C16 and C18 fatty acids obtained from modern reference materials acquired in Southeast Asia. Legends: Gray circles – modern reference samples; diamonds – absorbed residues from archaeological pottery; triangles – charred interior surface residues on pottery; light blue diamonds and triangles – Lò Gạch; dark blue diamonds and triangle – samples from Gò Ô Chùa.
CHAPTER 10
CONCLUSIONS AND FURTHER WORK

This research demonstrated that a combination of anthropological, technofunctional, and biomolecular approaches provides insights into past foodways and identities. Specifically, it provided insights regarding the possible culinary practices and inferred community identities of the people who lived in the Mekong Delta of southern Vietnam during the Neolithic and Metal Age. The concept of community identities, based on shared culinary practices, aids in the interpretation of the results from organic residue and technofunctional analyses. Technofunctional analysis provided insights into the usage of sampled pottery in food preparation and service. Organic residue analysis of archaeological pottery provided insights into the kinds of food prepared and served on pottery in prehistoric southern Vietnam. Analysis of modern comparative reference materials aided in the interpretation of the residue results from the archaeological pottery samples.

Highlights

Chapters 2, 3, and 4, respectively, framed the theoretical, geographical, and technical bases of this dissertation. They bridged theory and method to address an anthropological issue set in the archaeological past of a particular geographic region, which is Southeast Asia (SEA). Chapters 2-4 also outline the principal goals of this research: (1) approaching archaeobiological remains beyond subsistence and toward the whole chaîne opératoire of foodways in the archaeology of SEA and (2) the use of organic residue analysis as a technique to uncover past culinary practices.

Chapters 5 and 6 involved the analyses of lipids from organic residues on modern pottery samples as well as fats and oils from modern fauna and flora of SEA.
Chapter 5, it was demonstrated that the frequency of cooking, viscosity, lipid composition and amount of food items, as well as probably the pottery of the pots used for experimental and ethnographic cooking, affected the organic residues that are incorporated and preserved in pots. The pots used for plant sources, such as starch-rich cereals (rice and millet) and swamp cabbage, have low lipid yields despite multiple uses. This likely indicates the tendency for terrestrial animal residues to mask them during mixed cooking; thus, it would be difficult to detect them. The long-chain lipid compounds can be useful indicators for waxy plants, such as leafy vegetables (e.g., swamp cabbage) and those producing a viscous liquid (e.g., coconut), with other known plant related biomolecular markers. The detection of key biomarkers, such as sterols and AAPAs, is challenging because not all pots used for cooking animal meat yielded cholesterol and the pots used for cooking fish did not yield the combination of AAPAs that would guaranty their identification. Chapter 6 presented the comparative reference database for bulk and compound specific stable isotopic analyses of organic residues on archaeological materials from SEA. The $\delta^{13}C$ and $\delta^{15}N$ values from these materials are useful additions to those already available in the region. The $\delta^{13}C$ values of C16 and C18 fatty acids reported here composed the initial modern comparative reference database. Chapter 6 also reported novel isotopic data from several important food sources in the prehistory of SEA (sedges, Job’s tears, cloves, and nutmeg).

Chapters 7 and 8, respectively, involved the technofunctional and organic residue analysis of archaeological pottery from prehistoric southern Vietnam. The technofunctional analysis of the earthenware pottery from the four settlement sites in southern Vietnam in Chapter 7 demonstrated that these pottery vessels had various
roles in the preparation, storage, and serving of food during their initial stages. The results of organic residue analysis of several of these pottery vessels in Chapter 8 are more indicative of their usage in the preparation and serving of plant food sources and less indicative of their usage for aquatic sources. The pottery vessels from two different periods and saturated with residues, could have been used for decoction or the process where active ingredients of plants are extracted through boiling (Miller 2015) or high frequency of usage. Their similarities of component peaks and δ¹³C values of C16 and C18 fatty acids may signify the use of common or related plant sources by the previous occupants, with possible continuity of this practice from the Neolithic to Metal Age.

Comparison of general results from Chapter 8 with those from Chapters 5 and 6 eliminated the possibility of terrestrial animals being processed in these pots. However, a few results from Chapter 8 provide some evidence for meat storage or preparation. Results from Chapters 7 and 8 are interpreted in Chapter 9. Although much more data are required, it seems that the previous occupants of these four prehistoric sites in Vietnam may have belonged to different communities of practice based on cuisines and also may have had distinct community identities. Further, the results suggest more broadly a continuity of culinary practices from the Neolithic to Metal Age.

Conclusions

This research led me to the following conclusions: First, the experimental and ethnographic pots are useful modern comparative reference materials because they provide insights into how detection and identification of different food sources from the region is feasible but challenging. Second, based on the observed local isotopic variation within SEA for domestic pigs, identifying pig residues on archaeological pottery, using only results from CSIA, would be challenging. Third, the CSIA of fish
samples and pottery samples used for cooking fish have implications for interpreting archaeologica l residues on material culture from the sites near both fresh and marine bodies of waters, and suggest previous occupants did not discriminate between cooking freshwater and marine resources in pottery. Fourth, the earthenware pottery from the four sites in prehistoric southern Vietnam played various roles in the preparation and consumption of food, possibly plant and/or aquatic foodstuff in pottery. Fifth, this research provides insights for exploring similarities and differences among culinary practices at sites from the same period, and suggests continuity between the two prehistoric periods, based on this case study in prehistoric southern Vietnam. However, the data generated in this research, alongside available evidence from archaeobiological and material remains, are not enough at present to formulate and test hypotheses regarding prehistoric culinary practices and identities.

**Recommendations for Further Work**

The following includes recommendations based on the findings of this research. First, remaining modern and archaeological pottery that was not analyzed for lipid profiles should be analyzed. Second, the modern comparative reference collection should be extended to other food sources in SEA, such as plants used as vegetables, medicines, and spices, terrestrial ruminant animals, and nonfish aquatic resources. Third, the effects of burial must be explored on lipid composition of modern pots used for food preparation by extracting and analyzing lipids before and after the pots are buried in the soil. This can be done using the few modern pottery samples that have fragments already buried in the soil in Vietnam and the Philippines. Fourth, missing animal and plant sources in the comparative database for CSIA must be added in the future. These include wild nonruminant animals, wild and domesticated ruminant
animals, other poultry like ducks and geese, and other aquatic resources, such as shellfish and marine mammals. Fifth, chickens, and other terrestrial animals, with known pure C₃ diets, should be sampled, as their resulting values will add to the corpus of data for other geographic areas. Sixth, mixing of different food categories should be further explored. Seventh, faunal and floral remains from archaeological sites in SEA, if possible, should be added as comparative reference materials because they would make a suitable direct reference for bulk and CSIA. Eighth, other extraction and purification procedures should be explored for both modern and archaeological materials. For example, the acidified methanol extraction (Colonese et al. 2015; Correa-Ascencio and Evershed 2014; Papakosta et al. 2015) can directly and more efficiently extract lipids and derivatize the fatty acids into fatty acid methyl esters for CSIA. The accelerated solvent extraction method should be adjusted to make acidified methanol extraction feasible. It is not viable at present because the extraction cells are made of metal, which would react with acidic reagents and be destroyed.

Furthermore, and specific for archaeological pottery from prehistoric southern Vietnam, I recommend that principal components analysis (PCA), using software designed for data from chromatographic and mass spectrometric techniques, should be done based on raw data files from organic residue analysis (Correa-Ascencio et al. 2014; Cramp 2008). This is feasible because the majority of archaeological samples were analyzed with the same GC-MS, despite the use of three different GC-MS instruments in this research. PCA of component peaks, each with a specific retention time and mass spectrum, can group the different pottery vessels based on subtle differences in their compound composition. Groupings of these pottery vessels may
reveal correlations to their form, function, and other attributes. Selected ion monitoring of fatty acid methyl esters from selected samples should be pursued to confirm presence and absence of aquatic biomarkers (Cramp and Evershed 2014). Also, it is recommended that more samples, in addition to the ones already analyzed, should be processed for CSIA. It was demonstrated toward the end of this research that low-yielding organic residues can produce reliable results as long as C16 and C18 fatty acids are present and chemical processing is contamination-free. The extracts from pottery vessels with various lipid compound types should undergo full column separation of their neutral fractions to accurately identify alkanes, terpenoids, sterols, long-chain alcohols, and other nonpolar lipids. Especially for pottery samples that have viscous organic residues that contain abundant lipid compounds and light green extracts that contain metabolites that are not derivatizable for gas chromatography-mass spectrometry (GC-MS), metabolomic studies with liquid chromatography-mass spectrometry (LC-MS) should be pursued to complement findings from GC-MS. Many natural products from plant sources could be more appropriately detected and identified by LC-MS if they are nonderivatizable for GC-MS.

In addition, I recommend that detailed typological and petrographic analyses of pottery assemblages from the other three sites be conducted, similar to work completed at An Son (Sarjeant 2014b). Starch and phytolith analyses could be pursued to further aid in the identification of plant sources prepared and served in pottery. Aside from pottery samples from coastal and insular sites serving as geographic controls, pottery samples from more recent periods (precolonial and historical) can serve as temporal controls to assess preservation of organic residues on archaeological materials from
different environments and time periods in SEA. Lastly, modern samples of possible plant sources processed on pottery from prehistoric southern Vietnam should be acquired and analyzed as additional comparative reference materials. Experimental cooking of these plant sources in modern pottery with different technofunctional attributes, such as temper, should also be explored and pursued.
APPENDIX A
LIST OF FISHES PREPARED FOR REFERENCE COLLECTION IN VIETNAM

Object A-1. Lists of fishes prepared for reference collection in Southern Vietnam
(prepared by Fredeliza Z. Campos from 2012 to 2016 .xlsx file 60KB).
# APPENDIX B

## QUESTIONNAIRE GUIDE FOR INTERVIEW ON THE USE OF CLAY POTS

---

**Questionnaire/Survey on the Selling of Clay Pots and Carang in Long An, Southern Vietnam**

<table>
<thead>
<tr>
<th>Date:</th>
<th>Place:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Name of Informant:</th>
<th>Age of Informant:</th>
<th>Gender of Informant:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Pottery and/or Carang store?</th>
<th>Name of the store:</th>
<th>Owner of Store:</th>
<th>Address:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Year the store was opened:</th>
<th>How many employees?</th>
<th>Do you use pots and/or carang for cooking?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>If yes, how often?</th>
<th>Everyday</th>
<th>If no, why?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekly</td>
<td>Monthly</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Do you use pots for cooking on special occasions?</th>
<th>If yes, what occasions?</th>
<th>Are pots for special occasions different from those of daily meals?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>No</td>
<td>Birthdays, Weddings</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>If no, why?</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Who is/are cooking?</th>
<th>Males</th>
<th>Females</th>
<th>Young</th>
<th>Old</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owners</td>
<td>Helpers</td>
<td>Relatives</td>
<td>Others</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Who make the pots and/or carang?</th>
<th>Males</th>
<th>Females</th>
<th>Young</th>
<th>Old</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owners</td>
<td>Helpers</td>
<td>Relatives</td>
<td>Others</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Where do they make the pots and/or carang?</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Where do they get the clay and other materials?</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>How do you make the pots and carang?</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Is there a particular schedule in making the pots and/or carang?</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>How production is organized?</th>
<th>Household</th>
<th>Business based</th>
<th>Centralized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Question</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------------------------</td>
<td>-----</td>
<td>----</td>
<td></td>
</tr>
<tr>
<td>Who buy(s) the pots and/or carang?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>What do the buyers use the pots and/or carang for?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How long do(es) a pot and/or carang last when used?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How do people discard pots and/or carang when it cannot be used anymore?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do people reuse a discarded pot and/or carang for other purposes?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Are there pots only used for special occasions (weddings, feast, big parties, etc.)?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>If yes, what are those pots?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is the carang used for pot cooking only?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Do people roast meat in carang?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>If yes, what do they roast in carang?</td>
<td>Fish</td>
<td>Pork</td>
<td>Chicken</td>
</tr>
<tr>
<td></td>
<td>Goat</td>
<td>Shells</td>
<td>Crab</td>
</tr>
</tbody>
</table>


### Questionnaire/Survey on the Use of Clay Pots in Long An, Southern Vietnam

<table>
<thead>
<tr>
<th>Date:</th>
<th>12/5/2012</th>
<th>Place:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of Informant:</td>
<td></td>
<td>Age of Informant:</td>
</tr>
<tr>
<td>Is it a restaurant? Name of Restaurant:</td>
<td>Thuy T. Restaurant</td>
<td>Owner of Restaurant:</td>
</tr>
<tr>
<td>Year the restaurant was opened:</td>
<td>1995</td>
<td>Year the family moved/lived in the house:</td>
</tr>
<tr>
<td>Do you use pots for cooking?</td>
<td>Yes</td>
<td>If yes, how often?</td>
</tr>
<tr>
<td>Address (for both house or restaurant):</td>
<td>51, Nguyen van Tao, Ward, Tam An city, Long An province</td>
<td></td>
</tr>
<tr>
<td>How many employees/household members?</td>
<td>5 employees</td>
<td></td>
</tr>
<tr>
<td>5 household</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Are pots for special occasions different from those of daily meals?</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Who is/are cooking?</td>
<td>Male</td>
<td></td>
</tr>
<tr>
<td>Owners</td>
<td>Males</td>
<td></td>
</tr>
<tr>
<td>Helpers</td>
<td>Females</td>
<td></td>
</tr>
<tr>
<td>Relatives</td>
<td>Young</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>Old</td>
<td></td>
</tr>
<tr>
<td>Do you wash and reuse the pots for cooking and serving food?</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Frequency of the use of the pot?</td>
<td>Once(1x)</td>
<td></td>
</tr>
<tr>
<td>Twice(2x)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thrice(3x)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Several times until broken(nx)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>How do you discard the pots that can no longer be used for cooking and serving?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you reuse discarded pots?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>If yes, how people reuse those discarded pots?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What do you cook in the pot?</td>
<td>Fish</td>
<td></td>
</tr>
<tr>
<td>Shells</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crab</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chicken</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beef</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>etc.</td>
<td>different restaurant</td>
<td></td>
</tr>
<tr>
<td>pig rib</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
If fish, what kinds/types of fishes are cooked and served in the pots?

<table>
<thead>
<tr>
<th>What are the sizes of the fishes?</th>
<th>Very small (0-10 cm)</th>
<th>Small (10-15 cm)</th>
<th>Medium (15-30 cm)</th>
<th>Large (30 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>With medium and big fishes, how do you cut them to fit in the pot?</td>
<td>Fresh market</td>
<td>Grocery</td>
<td>Direct from the river</td>
<td>Direct from the sea</td>
</tr>
<tr>
<td>Where do you get the fishes?</td>
<td>Hand catch</td>
<td>Netting</td>
<td>Angling (line and hook)</td>
<td>Spearing</td>
</tr>
<tr>
<td>How do people catch fishes?</td>
<td>Yes</td>
<td>No</td>
<td>Natural smell</td>
<td></td>
</tr>
<tr>
<td>Are some fishes seasonal in terms of availability?</td>
<td>Yes</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If yes, what are those fishes and their particular available time of the year?</td>
<td>Natural smell</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is the taste of the dish better when cooked in the pots?</td>
<td>Yes</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you use the carang?</td>
<td>Yes</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If yes, is the taste of the dish better when cooked in the carang compared to if cooked in gas/electric stove?</td>
<td>Yes</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Where do you buy the pots and the carang?</td>
<td>Tan An - Market</td>
<td>More sweet and Natural smell</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What dish(es) do you cook in the pots?</td>
<td>Fish sauce, pepper, sugar, garlic, chilli, sodium glutamate, onion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>What are the main ingredients?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How is/are they cooked?</td>
<td>Braise fish (using pot)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How long is/are their preparation and cooking time?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Favorite fish of the owner and why?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Favorite fish of the customers (most frequently ordered) and why?</td>
<td>Ca' lung</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How is/are they cooked?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To put cooking oil and small spring onion + galic. Then put water and waiting boiling water and putting fish and mixing spice (fish sauce, sugar, sodium glutamate...). After 15-20 minutes, mixture are very thick then to taste to pleasant to taste and putting pepper, chilli on the surface.
## APPENDIX D

### FATTY ACID YIELDS FROM PRELIMINARY WORK

Table D-1. Samples included in preliminary analysis.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Description</th>
<th>Fatty acid yield (μg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E2</td>
<td>Rice pot (5x cooking by boiling, traditional Central Luzon, Philippine variety)</td>
<td>23.58</td>
</tr>
<tr>
<td>E6</td>
<td>Rice pot (3x cooking by boiling, traditional Ifugao, Philippine variety)</td>
<td>13.45</td>
</tr>
<tr>
<td>E3</td>
<td>Pork pot (5x cooking by boiling)</td>
<td>2367</td>
</tr>
<tr>
<td>E5</td>
<td>Chicken pot (5x cooking by boiling)</td>
<td>2213</td>
</tr>
<tr>
<td>E4</td>
<td>Fish pot (5x cooking by boiling, Philippine fishes)</td>
<td>79.79</td>
</tr>
<tr>
<td>E7</td>
<td>Fish pot (5x cooking by boiling with 5 estuarine-freshwater varieties in Vietnam)</td>
<td>230</td>
</tr>
<tr>
<td>E10</td>
<td>Cá kho tộ 1 (fish only, ethnographic pot, cooking by stir frying) from Phong An Restaurant</td>
<td>408.9</td>
</tr>
<tr>
<td>E11</td>
<td>Cá kho tộ 2 (fish with pork fat, ethnographic pot, cooking by stir frying) from Thuy Ta Restaurant</td>
<td>647.5</td>
</tr>
<tr>
<td>A1</td>
<td>12RNH3L2/20D4, Layer 2, 2012 Trench 3, Rạch Núi (rim sherd)</td>
<td>17.04</td>
</tr>
<tr>
<td>A2</td>
<td>12RNH1F2E/4c.1007-1, Feature 2, 2012 Trench 1, Rạch Núi (rim sherd)</td>
<td>15.54</td>
</tr>
<tr>
<td>A3</td>
<td>09ASH2L2-3 C3-1 ST, 20-30cm, 2009 Trench 2, An Sơn (body sherd)</td>
<td>9.47</td>
</tr>
<tr>
<td>A4</td>
<td>ASH1L12-13-1 ST, Layers 12-13, 2009 Trench 1, An Sơn (body sherd)</td>
<td>4.63</td>
</tr>
<tr>
<td>A5</td>
<td>08GOCH1L11-1 Layer 11, 2008 Trench 1, Northern Mound of Gò Ô Chùa (shoulder sherd)</td>
<td>66.92</td>
</tr>
<tr>
<td>A6</td>
<td>08GOCH1L11-3 Layer 11, 2008 Trench 1, Northern Mound of Gò Ô Chùa (body sherd)</td>
<td>11.94</td>
</tr>
</tbody>
</table>
Object E-1. Compilation of $\delta^{13}C$ values of C16 and C18 fatty acids from different foodstuff in different geographic areas (.xlsx file 30KB).
# APPENDIX F

## POTTERY RECORDING FORM

**POTTERY DATA SHEET**


<table>
<thead>
<tr>
<th>Material ID No.</th>
<th>Date Recorded</th>
<th>Recorded by</th>
<th>Provenience (Trench, Layer)</th>
<th>Site</th>
<th>Code</th>
<th>Photograph No/s.</th>
</tr>
</thead>
</table>

### Details and Measurements:

<table>
<thead>
<tr>
<th>Portion</th>
<th>Characterization</th>
</tr>
</thead>
<tbody>
<tr>
<td>The pot</td>
<td>is only partly reconstructed.</td>
</tr>
<tr>
<td>Vessel part</td>
<td>Rim</td>
</tr>
<tr>
<td>Hardness</td>
<td>soft (can be scratched with a fingernail)</td>
</tr>
<tr>
<td>Feel</td>
<td>harsh (abrasive to the finger)</td>
</tr>
<tr>
<td>Texture</td>
<td>subconchoidal (breaks somewhat like the glass or fine)</td>
</tr>
<tr>
<td>Inclusions/temper</td>
<td>organic, sand or quartz, volcanic/gneous or nonquartz, grog, shell, limestone, limestone, flint, none, unknown</td>
</tr>
</tbody>
</table>

### Descriptions:

<table>
<thead>
<tr>
<th>Type</th>
<th>Percentage:</th>
<th>Size:</th>
<th>Softening:</th>
<th>Roundness:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>(middle)</td>
<td>(very)</td>
<td>(very)</td>
<td>(very)/smooth/rounded</td>
</tr>
<tr>
<td>Type 2</td>
<td>(middle and bottom)</td>
<td>(fine)</td>
<td>(good)</td>
<td>(very)/grooved/rounded</td>
</tr>
<tr>
<td>Type 3</td>
<td>(middle to bottom)</td>
<td>(very)</td>
<td>(very)</td>
<td>(very)/polished/rounded</td>
</tr>
</tbody>
</table>

### Surface Treatment:

<table>
<thead>
<tr>
<th>Punching</th>
<th>Dentate stamped</th>
<th>Simple stamped</th>
<th>Knife trimmed</th>
<th>Finger pinched</th>
<th>Wiped</th>
<th>Laminated</th>
</tr>
</thead>
</table>

### Interior Carbon Deposits - appearance:

| Type 1 | Light brown in color with no carbon layer on the surface |
| Type 2 | Black in color with no carbon on the surface |
| Type 3 | Black in color with a thin carbon layer on the surface, soot |
| Type 4 | Dark color with relatively thick more than 3 mm carbon layer, soot |

### Exterior Carbon Deposits - appearance:

<table>
<thead>
<tr>
<th>Type</th>
<th>Pits</th>
<th>Pedestalled temper</th>
<th>Scratches</th>
<th>Rim Chip</th>
<th>Abrasion</th>
<th>Thermal Spalls</th>
<th>Impact marks</th>
<th>Microscopic cracking</th>
</tr>
</thead>
</table>

### Exterior Altitude Inside:

<table>
<thead>
<tr>
<th>Type</th>
<th>Pits</th>
<th>Pedestalled temper</th>
<th>Scratches</th>
<th>Rim Chip</th>
<th>Abrasion</th>
<th>Thermal Spalls</th>
<th>Impact marks</th>
<th>Microscopic cracking</th>
</tr>
</thead>
</table>

### Exterior Altitude Outside:

<table>
<thead>
<tr>
<th>Type</th>
<th>Pits</th>
<th>Pedestalled temper</th>
<th>Scratches</th>
<th>Rim Chip</th>
<th>Abrasion</th>
<th>Thermal Spalls</th>
<th>Impact marks</th>
<th>Microscopic cracking</th>
</tr>
</thead>
</table>
# POTTERY DATA SHEET


<table>
<thead>
<tr>
<th>Material ID No</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Accession nos. of sherd(s) Involved</th>
<th>(or Catalog number, Indicate also number of sherd(s) involved)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Diameter (cm)</th>
<th>Thickness (mm, 2x)</th>
<th>body thickness (mm)</th>
<th>Weight:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>rim</td>
<td>lip @ 0.5 cm</td>
<td>rim @ 3 cm</td>
<td>height</td>
</tr>
<tr>
<td></td>
<td>office percentage</td>
<td>rim @ edge if everted</td>
<td>rim length</td>
<td>Height:</td>
</tr>
<tr>
<td></td>
<td>maximum</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Vessel</th>
<th>(earthenware, stoneware, porcelain)</th>
</tr>
</thead>
</table>

| Type according to site/regional system adopted by others: | |
|------------------------------------------------------||

<table>
<thead>
<tr>
<th>Morphology</th>
<th>(bowl, pot, cup, jar, jug, lamp, mortaria, plate, stove)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rim form</td>
<td>(restricted/unrestricted, straight or everted)</td>
</tr>
<tr>
<td>Lip form</td>
<td>(tapered, folded, rounded, flat, flaring, etc.- note terms used by others):</td>
</tr>
<tr>
<td>Shoulder</td>
<td>(rounded, angled, straight):</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Function</th>
<th>(processing like fermentation, cooking, serving, drinking, storage, or ritual)</th>
</tr>
</thead>
</table>

| Method of manufacture | |
|-----------------------||

<table>
<thead>
<tr>
<th>Firing</th>
<th>(Rim)</th>
<th>(coarse)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1/3/6/7/9/11</td>
<td>2/4/6/8/10</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Other observations</th>
<th>Unusual color, spotting from firing mishaps, etc.</th>
</tr>
</thead>
</table>

Illustrations: rim profile drawing, etc.
Object G-1. Southern Vietnam pottery attributes and other observations (.xlsx file 60KB).
Object H-1. Processing log for samples that underwent organic residue analysis (.xlsx file 49KB).
APPENDIX I
PHOTOGRAPHS OF POTTERY SAMPLES ANALYZED FOR ORGANIC RESIDUES

Object I-1. Photographs of pottery from prehistoric southern Vietnam analyzed for organic residues (.pdf file 30MB).
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BIOGRAPHICAL SKETCH

A reluctant anthropological archaeologist, Michelle Sotaridona Eusebio was a graduate student at the Department of Anthropology, University of Florida. Her main research interests are Southeast Asian archaeology, archaeological chemistry or biomolecular archaeology, and ancient foodways or cuisines. She is also interested in the uses of natural products from the past to the present, inclusion of historical cemeteries as heritage sites in the Philippines, making archaeology relevant to contemporary concerns in Southeast Asia, experimental and ethnoarchaeology, as well as integration of archaeological science and theory in research.

She was an undergraduate chemistry major in University of the Philippines (UP)-Diliman when she learned about chemical analysis and conservation of Egyptian wall paintings for her seminar class presentation topic, chemical and conservation laboratory in the National Museum of the Philippines, and Master of Arts/Science in Archaeology being offered in the same university. These made her decide that she wanted to be an archaeological chemist. She earned her BS Chemistry degree and passed the Chemistry Licensure Examination in 2002. The latter makes her a licensed chemist in her home country.

During the same year, Michelle enrolled in the MS Archaeology program at the Archaeological Studies Program (ASP) in the same university. After considering conservation work, ancient DNA analysis, and bone isotopic analysis, she chose to specialize in organic residue analysis. It is the closest parallel to natural products chemistry, which is a field that she could have specialized in if she pursued chemistry in graduate studies instead. While pursuing her master’s degree, she worked as part-time instructor, part-time chemist, and full-time copyeditor. She was also one of the former
associate editors of *Hukay: Journal for Archaeological Research in Asia and the Pacific.*

Aside from her master’s research on organic residue analysis of experimental and archaeological earthenware vessels in the Philippines, she was also involved in the cemetery and ancient animal DNA projects at UP ASP. She earned her MS Archaeology degree in 2010.

Also in 2010, Michelle enrolled in the Department of Anthropology, University of Florida for her Ph.D. studies, majoring in archaeology. Under the mentorship of Dr. John Krigbaum and her committee members, she continued her work on organic residue analysis for her doctoral dissertation work, involving several prehistoric, ethnographic, and experimental pottery analysis in Southeast Asia. While pursuing her doctoral degree, she also worked as a research and grading assistant. She was able to expand her archaeological fieldwork experiences from the Philippines to Vietnam. She co-organized three sessions in separate international conferences and coordinated a themed issue for *Journal for Indo-Pacific Archaeology.* She received her Ph.D. in Anthropology from the University of Florida in the summer of 2016.