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The Suitability of List L<sup>A</sup>T<sub>E</sub>X Text Formatter  
for Thesis Preparation by Technical and  
Non-technical Degree Candidates

Seungki Kwak

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## Abstract

### The Suitability of List L<sup>A</sup>T<sub>E</sub>X Text Formatter for Thesis Preparation by Technical and Non-technical Degree Candidates

Seungki Kwak

Chair of the Supervisory Committee:  
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- It demonstrates the solutions to a variety of formatting challenges found in thesis production.
- It serves as a template for a real dissertation.

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<sup>1</sup>See Appendix A to obtain the source to this thesis and the class file.

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## Dedication

to my dear wife, JeeIn

# 1

## Subsistence change, Emergence of agriculture, and Rice

### INTRODUCTION

In this chapter, I will briefly discuss about the past and current archaeological approaches in relation to the emergence of agriculture. Then, the topic will be narrowed down to the central part of the Korean peninsula and traditional perceptions about transition from foraging to farming among the Korean archaeologists will be mentioned. Lastly, I will clarify the goal and methods of this thesis.

## THE TRANSITION FROM FORAGING TO FARMING AND THE EMERGENCE OF AGRICULTURE

The process of the transition from foraging to farming and the emergence of agriculture are long standing topics of archaeological investigation (Binford, 1968; Childe, 1951; Flannery, 1972, 1976; Redman, 1978). The emergence of agriculture and its role in subsistence is one of the most studied domains in the academic field of archaeology. The intensification of agriculture and the control over agricultural surpluses have been linked to the origins of socio-political complexity (Childe, 1951; Earle, 2002; T. Douglas Price, 1995; B. D. Smith, 1989; Welch & Scarry, 1995). A recent collection of papers in *Current Anthropology* (Vol. 52, 2011) indicates the importance of this topic and diversity of approaches to the transition from foragers to farmers. Current approaches to understanding the subsistence change from foragers to farmers would fall into four categories: (1) population pressure model, (2) climatic fluctuation model, (3) cultural or social model, and (4) evolutionary model.

One of the most well-known approaches is the population pressure model (Binford, 1968; M. N. Cohen, 1977, 2009; Flannery, 1972, 1976). This approach starts with the idea that farming is backbreaking, time-consuming, and intensive-labor work. Based on the ethnographic analysis in the Kalahari Desert of South Africa, Binford suggested that even in a marginal area, food collecting was a successful adaptation (1968). Therefore, he argued that human groups would not have become farmers, unless they had no other choice. Population pressure was therefore suggested as a proper agent for the origin of agriculture: more people required more food. The best solution to the problem, according to Binford, was farming, which provided a higher yield of food per a unit of land. However, at the same time, the intensification of agriculture required more labor to harvest food. Cohen (1977, 2009) argued for an intrinsic tendency of growth of human population, which is responsible for the initial spread of the human species out of Africa, and the subsequent colonization of Asia, Europe, and the Americas. Along with this population growth, after about 10,000 BC there was an increase in the use of less desirable resources in many areas. Cohen argued that the only successful way to cope with increasing population and declining resources was agriculture.

The second approach emphasizes climate fluctuation. The role of the rapid climate change in the process of subsistence change is certainly a factor to be considered at various specific points in time (Belfer-Cohen

& Goring-Morris, 2011). Bar-Yosef (2011) argued for rapid climatic fluctuation as the main factor in the origin of the cultivation of various wild plants in East and West Asia. The model is based on the idea that the origin of cultivation was motivated by the vagaries of the climatic fluctuation of the Younger Dryas around 10,000 B.C. within the context of the mosaic ecology which affected the communities that were already sedentary or semi-sedentary. By examining paleoclimatic records with available archaeological phenomena, Bar-Yosef proposed that while the rapid climatic fluctuation served as a trigger of the beginning of cultivation at the end of the Younger Dryas, such changes continue to influenced the Holocene period of both East and West Asia.

The third category of approaches focuses more on cultural or social aspects. Cauvin (1994) argued that the important changes associated with the subsistence change from foraging to farming were conceptual as much as, or more than just material (i.e. food production). Specifically, he suggested that farming was led by the emergence of new conceptual ideas such as new cosmology, religious practice, and symbolic behavior. For Cauvin, this transition allowed foragers to view their habitat in a different way and promoted a more active exploitation on their environment. Based on the archaeological phenomena of four cultural areas in China, Cohen (2011) argued that the Early Neolithic culture in China, which involved the farming of millet and rice, was invented and spread with a wide range of information exchange and broad social networks rooted in the interactions of Late Paleolithic hunter-gatherer societies (D. J. Cohen, 2003). Recent studies showed that the agricultural origins took place in relatively abundant environments, not in places where little food was available(1995). This partially supports the idea that the subsistence change from foraging to farming might not be solely explained by the economic aspect.

More recent approaches are based on evolutionary perspectives (Gremillion & Piperno, 2009; Winterhalder & Kennett, 2006, 2009). Among them, the most prominent one is based on the evolutionary ecology. The evolutionary ecology emerged from an earlier perspective known as ‘cultural ecology’, which focused on the dynamic relationship between human society and its environment (Steward, 1972). Evolutionary ecologists have emphasized human ability to reason and optimize their behavior. In this view, the cultural and behavioral change is explained as a form of phenotypic adaptation to changing social and ecological conditions, applying the assumption that organisms are designed by natural selection to respond

to their environment in ‘fitness-enhancing ways’ (Boone & Smith, 1998, p. 141; Cannon & Broughton, 2010); Winterhalder & Smith, 1992). Hunter-gatherers operate based on the premise of efficiency to obtain sufficient food. Food is ranked by the energy value it contains; and lower-ranked resources such as seeds are demanded, only as higher-ranked ones become unavailable. In this view, the subsistence change to farming is explained as adding new resources. Current evolutionary approaches to the subsistence change from foragers to farmers have expanded to sub-disciplines such as Niche construction Theory (Bleed & Matsui, 2010; Crawford, 2011).

#### WHAT WE KNOW SO FAR? THE FACTS

The studies that I have mentioned above show that in some parts of the world, farming spread rapidly and patchily from one place to another. However, it spread very slowly in other areas; in some places people did not become farmer for up to a millennium after their initial contact with agriculture, or never became farmers at all. Sometimes these areas are environmentally segregated (e.g. Alps or Pyrenees), but can be also defined by social factors (Robb, 2013). If we think of places that show evidence of farming (for example, Europe, which is the most thoroughly studied region in relation to the emergence of agriculture and spread of farming), there are several underlying characteristics these areas have in common [Robb (2013); Whittle & Cummings (2007)].

#### MIGRATIONS OF FARMERS

Though it is highly varied in form, it is true that there were actual movements of farmer/farmers from one place to another. However, at the same time, there is no real evidence for massive migration in terms of single big wave of movement that covered large landscape. In fact, most archaeologically traceable human movements are ‘opportunistic leap-frog’ (Boland, 1990; Robb, 2013, p. 658) migrations. These movements seem to involve small group of people with no typical single origin, resulting in a complicated form of migration without homeland.

## GENETIC STUDIES

Unfortunately, unlike the initial optimistic views (Cavalli-Sforza, Menozzi, & Piazza, 1994), the results of genetic studies are quite ambiguous and inconclusive. Though several researches showed that there is genetic discontinuity between hunter-gatherers and early farmers and between hunter-gatherer and modern populations in some places (Malmström et al., 2009; Rowley-Conwy, 2009), other studies suggest that both incoming and indigenous peoples contributed to the gene pool of modern population (Bramanti et al., 2009; M. Richards, 2005).

## FIRST CONTACT

In many cases, when there is contact between foragers and farmers, the former often adopt new subsistence strategies (such as farming) little by little for their own sociopolitical purposes (Robb, 2013). This is somewhat different from the traditional view that new economic practices (based on the farming and the animal domestication) with innovative technologies (notably, pottery and new types/forms of stone tools) rapidly spread into the foraging context as a ‘package’, completely transforming society to fully farming community (Childe, 1951).

Summing up, if there is any conclusion that archaeologists can reach would be the transition from foragers to farmers and spread of farming occurred in a ‘mosaic way’ (Robb, 2013, p. 659). This means the transitions occurred around the world had various and diverse pathways. This diversity motivates us to investigate the specific manifestations of this transition in different parts of the world and better understand the different ways that people made this profound transformation.

## THE ROLE OF THE INTENSIVE RICE AGRICULTURE IN THE CENTRAL PART OF THE KOREAN PENINSULA

According to the recent report from the Food and Agriculture Organization of the United Nations (FAO), the average annual rice consumption per person in Brunei and Vietnam is 245 Kg and 166 Kg

(Faostat 2011). These two countries mark the 1st and 2nd in rice consumption in the world. The average annual rice consumption per person in South Korea in 2011 was 88 Kg (the Korea National Statistical Office). However, according to historical records, the annual South Korean rice consumption per person around the 18th century was about 173 Kg. Though the westernized life style of South Korea reduced its annual rice consumption rate, rice is still the mainstay of its modern diet, and has been so for at least 2,000 years. The Koreans' attachment to rice is remarkable. The word for 'meal' in Korean is 'bab', which also and originally means 'steamed rice'. Regardless of their economic status, way of life, or ideological inclination, steamed rice was and is an essential dish throughout the nation. For the Koreans, 'A bowl of rice is equivalent to love and affection' (Woo, 2012). In this regard, one of the main topics of Korean archaeology over the last 50 years has been investigating the process of the subsistence change from hunter-gatherers to intensive rice farmers. However, despite continuous attempts to reveal the overall pattern of the change and accumulations of data, we still lack information on some of the most basic parameters involved in the role of the intensive rice agriculture in the prehistoric Korean Peninsula.

The central part of the Korean Peninsula (Figure 1.1) contains a vast amount of archaeological data related to subsistence change in the deeper past. This region has provided rich archaeological records documenting its general culture history. Its earliest known occupants were Paleolithic foragers dated as old as about 200,000 years ago (J. C. Kim et al., 2010). Clear evidences show that the full-dress farming was practiced in this region around 3,400 BP (G.-A. Lee, 2003, 2011). Solid evidences of dry fields, irrigated rice paddies and harvesting tools have been found (T. Yoon and J. Bae 2010). However, due to the lack of paleobotanical evidences from this period, the detailed information about when rice became the mainstay of the Korean diet is not yet known. Therefore, the study of the transition from hunter-gatherers to farmers and the role of the intensive rice agriculture in this transition has been integral to anthropological debates.

The transition from foragers to farmers in the Korean peninsula has been described as the subsistence change from hunter gathering to intensive rice farming around 3,400 BP (Ahn, 2000; B. Kim, 2006; J. Kim, 2003, 2006; Norton, 2000, 2007). B. Kim (2006) argued that an agricultural economy based heavily on rice spread suddenly and swiftly into the foraging context with few evidences of a transitional period. However, recent paleobotanical data on the southern part of the Korean peninsula have revealed that

people were more dynamic and varied than is posited by the models focused on the intensive rice farming (Crawford and Lee 2003; G. Lee 2003, 2011). For example, along with rice, they utilized other crops such as millet, soybean, and azuki for their subsistence. These new data require an alternative model which could explain the role of the intensive rice agriculture in this period.

This thesis investigates the role of the intensive rice agriculture as a subsistence strategy in the central part of the Korean peninsula, contributing new data that will establish the chronology of subsistence over the last 3,400 years. This research will provide an insight into when rice became the mainstay of the Korean diet. Low hills with gentle slopes embracing meandering rivers in this region were continuously occupied for as much as 4,000 years, and large inland habitation sites developed in this condition provide the multiple lines of subsistence data that are required for this study. The central hypothesis in this research is that a wide range of resources were utilized along with rice between 3,400 and 2,000 BP. This hypothesis contrasts with the rice-centered models, which assume rice to be the most dominant subsistence resource since 3,400 BP.

The primary goal of this research is re-evaluating the conventional rice-centered models to better understand the overall pattern of subsistence strategies and assess the weight of rice in it. To achieve this goal the study (1) tests the hypothesis that a wide range of resources were utilized along with rice between 3,400 and 2,000 BP., and (2) establishes a general chronology of subsistence during this period, incorporating in that work the organic geochemical analysis and luminescence dating of the pottery excavated from four large inland habitation sites in the central part of the Korean peninsula.

In Korean archaeology, pottery is one of the primary analytical resources, being abundant in almost every archaeological assemblage in the Korean Peninsula since 6,000 BP. However, despite intensive relative chronology-building, almost no attention has been given to analyzing the fabric of the pottery itself. Studies have showed that high-temperature boiling using pottery is particularly effective in the preparation of various resources (Stahl 1989; Wandsnider 1997). This represents a serious gap in our understanding of prehistoric subsistence in Korea during the critical time of the transition from foragers to farmers. The methods proposed here allows me to test prevailing rice-centered models, first by identifying what was stored and cooked in the pots, and second by dating the pots directly and absolutely. By doing so, the

study establishes a general chronology of subsistence between during 3,400 and 2,000 BP. The results of my research provide critical information about the role of intensive rice agriculture in the prehistoric Korean diet.

In this thesis a total of 138 potsherds were collected for the organic geochemical analysis and eight sherds were dated with luminescence dating. Based on the results of organic geochemical analyses, each potsherd was assigned to a different food class. Then, these potsherds were be placed in time, based on the results of luminescence dating and available AMS radiocarbon dating. By doing so, I was able to achieve the primary goal of this research: re-evaluate conventional rice-centered models to better understand the overall pattern of subsistence strategies and assess the weight of rice in it.

## SUMMARY

In this chapter, I have briefly discuss about various approaches in relation to the origin of agriculture. Then, the focus was narrowed down to the central part of the Korean peninsula. The traditional perceptions about transition from foraging to farming among the Korean archaeologists was state, and the goal as well as methods of this thesis were clarified.

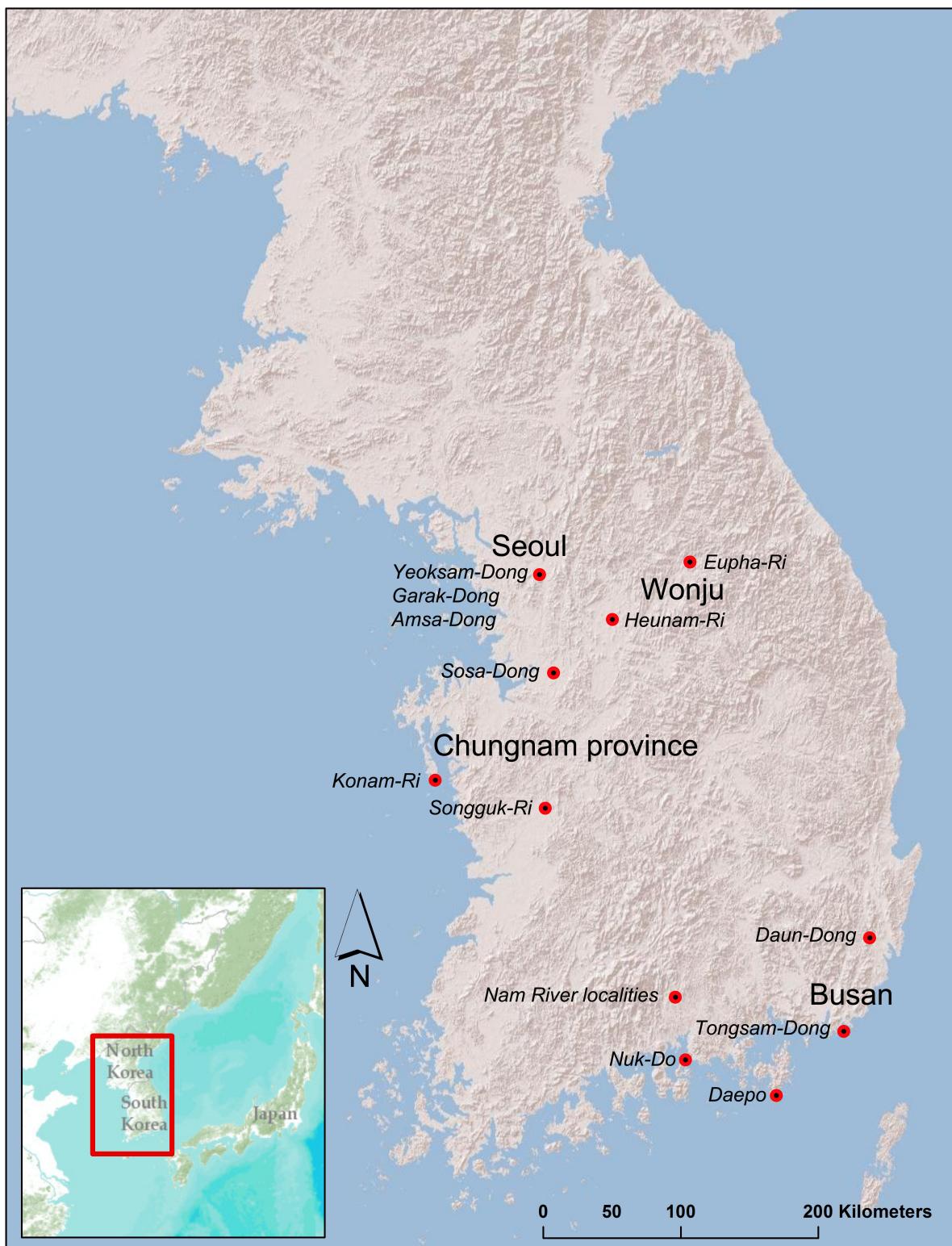


Figure 1.1: Location of the sites mentioned in the text

# 2

## Background and Central Hypothesis

### INTRODUCTION

In this chapter, first I will discuss the history and social context of Korean archaeology focusing on Japanese annexation of the country. Then, I will elucidate the current views on the transition from foragers to farmers and development of rice agriculture in the Korean Peninsula in detail. The problems with these existing studies will be stated based on the recent scientific evidence. Lastly, I will clarify main hypothesis of this thesis.

## ARCHAEOLOGY IN KOREA - ITS BRIEF HISTORY AND SOCIAL CONTEXT

The whole Korean peninsula is populated with Koreans. Though there are some regional dialects, in regard of its culture and language Korea includes no recognized minorities. Therefore, traditionally, the Korean prehistory is frequently formulated in Korea with reference to ethnicity, perceiving the elucidation of the formation of the Korean people to be the chief purpose of archaeology. In the twentieth century, the Korean peninsula underwent a series of dramatic political upheavals. This political fluctuation began with the Japanese annexation of the country in 1910. The liberation of the Korean peninsula in 1945 after the end of the World War II was followed by the Korean War (1950-1953) and the subsequent establishment of two competing states: the Republic of Korea (South Korea) and the Democratic People's Republic of Korea (North Korea). This political context established a particular and unique social milieu, which critically influenced archaeological practices. The modern practices of archaeology in Korea were first conducted by Japanese archaeologists such as Tadashi Sekino, Ryuzo Torii, and Ryu Imanishi during the colonial period. Archaeological remains, which are inherently subject to a variety of interpretations, were easily exploited to justify the Japanese colonization of Korea (Kim, 2008). Through this, Japanese archaeologists tried to claim that the Korean people were characterized by "a lack of independence" and "a servile attitude towards bigger nations." Though it seems that this is a typical example of "Colonialist archaeology" of Trigger (1996; 2008), there is a huge difference between the one and the other. The colonizers were Japanese, not Europeans. Though one might argue this is unimportant, in fact, it is. While European colonizers did not have any cultural or historical similarities with Native Americans, Japan and Korea have actively been interacting to each other since the Late Neolithic Age. For this reason, the archaeological phenomena of Korea and Japan are quite similar. Therefore, Japanese archaeologists who practiced archaeology in Korea argued that all prehistoric/historic material cultures were handed down from the Japanese isles to the Korean peninsula. The primary character of the "Colonialist archaeology" defined by Trigger is denigrating native peoples by presenting the primitive aspects of their archaeological phenomena. However, in this case, the Japanese justified their colonization by emphasizing the overall similarities and excellences of the prehistoric/historic material cultures of Korea and Japan.

As in many postcolonial nations, the Korean archaeology after the liberation from the Japanese coloniza-

tion has taken a central role in refashioning national identity and restoring national pride (Kim, 2008). Especially in South Korea, archaeological phenomena have been being interpreted as evidences of migration and cultural diffusion throughout the Eurasian continent. Highlighting harmonious blending of different cultural traits and emphasizing cultural interactions over a vast region may appear to contradict nationalism which assumes the ethnic superiority. However, it should be noted that such interpretations describe the ancient Koreans as a people with a grandiose geographical scope whose life was not confined to a small peninsula. The interpretations of the archaeological phenomena in Korea often intentionally aim at suggesting creativity and superiority of the Korean people. Based on this, some archaeologists have recognized nationalism in the Korean archaeology and have described the current Korean archaeology as “nationalist archaeology” (Kim, 2008; Trigger, 2008).

However, in the middle of the 1990's, archaeology in Korea started to make various voices. The 2nd generation Korean archaeologists who were educated in the United Kingdom and the United States as ‘graduate students’ began to conduct their own researches in Korea. Though they were highly influenced by the nationalism of the Korean archaeology from the first generation archaeologists, they also learned major theoretical frameworks and empirical methodologies from decent universities in US and UK. Currently, on one hand, these scholars are trying to avoid an extreme nationalism, and on the other, they are also concerned about the imperialist aspect of their knowledge originated from UK and US.

#### CHULMUN FORAGERS AND MUMUN FARMERS - WHERE EVERYTHING STARTED

This dissertation investigates the process of transition from foraging to farming and the role of agriculture as a subsistence strategy during this transition in the central part of the prehistoric Korean Peninsula (Figure 2.1a). The period in question has been called the Mumun pottery period (c.f. Bale 2011: 3390-2290 calibrated years (cal.) B.P.). The traditional periodization scheme of the prehistoric Korea is based on the decorative attributes consistently found on the potteries that existed over specific time periods: 9950-3390 B.P. is the Chulmun (or ‘comb-pattern’) Pottery Period and 3390-2290 cal. B.P. is the Mumun (or ‘undecorated’) Pottery Period (Norton 2007; Bale 2011). Sometimes the former and the latter are respectively regarded as the Neolithic and Bronze Age of Korea (Ahn 2004; Norton 2007). The be-

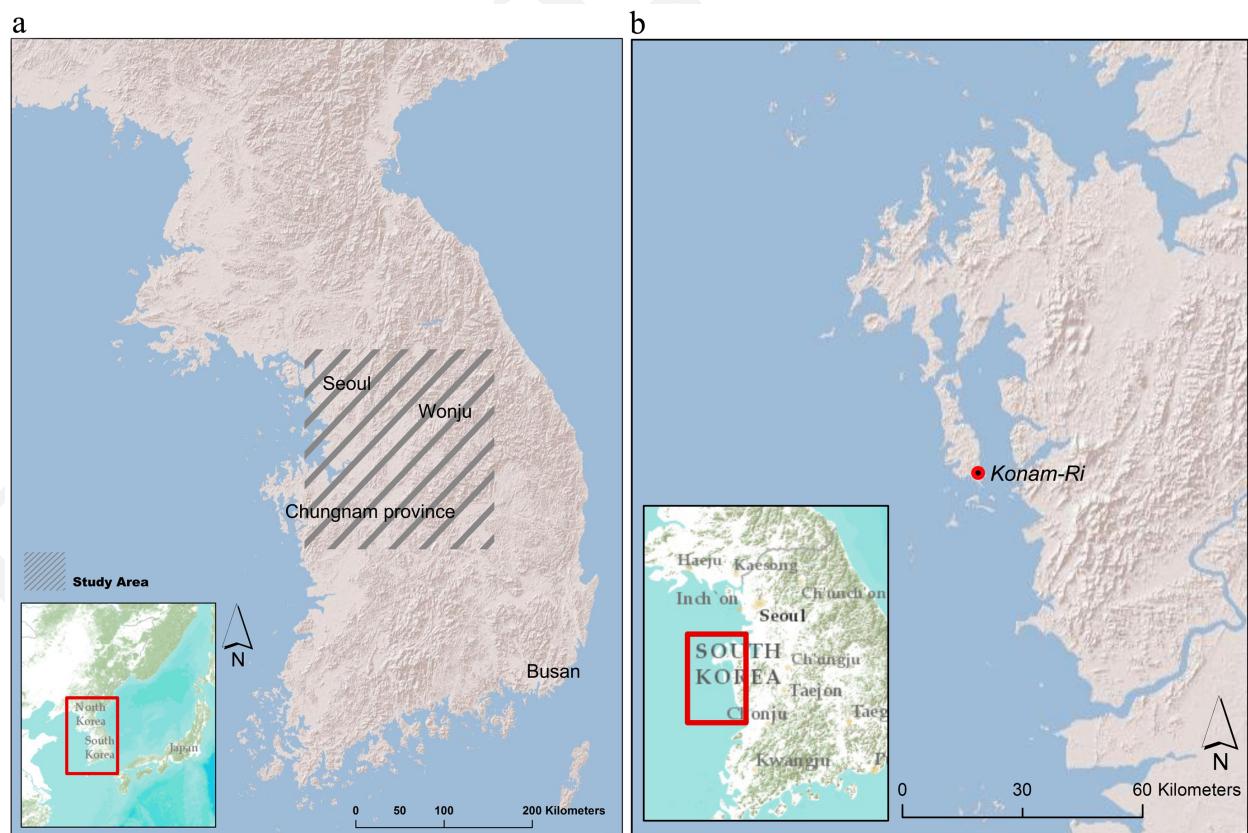


Figure 2.1: (a) The indication of the central part of the Korean Peninsula (b) The location of the Konam-Ri shell midden

ginning of the Mumun Period has an important role in the Korean archaeology, for it has been linked with the beginning of the agricultural society. The Mumun Period, named after its representative patternless feature of pottery, is known for intensive rice farming, instead of hunting and gathering of the Chulmun Period. Also, with this economical evolution, the society became more complex and social hierarchy emerged. ‘Mumun’, term meaning ‘undecorated’, is the most common feature of the pottery in this period. Ahn Jae-ho devised this influential ‘Chulmun-Mumun’ periodization based on diagnostic changes in pottery decoration, pit-house architecture, interior pit-house features, and stone tool types (J. Ahn 1991, 2000, 2001). Ahn’s chronology assumes that changes in pottery decorative attributes and plan-shapes of pit-houses are time-sensitive. According to him, the Mumun periodization scheme has the following internal stages: Incipient, Early, Middle, and Late.

Korean archaeologists have been focusing on the differences between the overall archaeological assemblages of the Chulmun and Mumun periods. Now, I will briefly examine the different aspects of the archaeological assemblages from the two periods.

To begin with, in the case of pottery, the fundamental characteristics of the Chulmun Period pottery are the comb-shape pattern and the pointed bottom, which show some variations as the phases go by (Figure 2.2a). Some pieces of the Chulmun Period pottery from the Gangwon province (Figure 1.1) have the flat bottom, but this shape is considered as an exception to the general form of the Chulmun Period pottery. On the other hand, all the Mumun Period pottery have the flat bottom; the major part of their body does not have any pattern. Some patterns still existed, but confined to the extreme upper body. During the incipient stage of Mumun, potteries had a pinched clay strip attached to the outside of the rim and body (S. Cheon 2005; 1.1; 2.4a). Early Mumun potteries have both rim-punctuations and lip-scoring. This combination of attributes is sometimes referred to as Yeoksam-dong-style pottery (B. Lee 1974; Figure 1.1; 2.4c) after the site where they first uncovered. Another pottery style of the Early Mumun, Garak-dong (B. Lee 1974; Figure 1.1; 2.4b), is named after a site in Seoul, but settlements with this pottery tradition are found clustered in the tributary valleys of the Geum-gang River. Garak-dong style deep-bowls have appliquC rims (or double rim) with short slanted lines that are incised just below where the rim attaches to the body. The last type of the Early Mumun potteries is the Heunam-ri-style pottery,

which is a combination of Yeoksam-dong and Garak-dong styles (J. Ahn 2000:49; J. Kim 2001; S. Lee 2005; Figure 1.1; Figure 2.4d). From the Middle Mumun Period, potteries become completely undecorated. The most dominant one is Songguk-Ri-style pottery (Figure 1.1; Figure 2.4e) which has elongated and curved shapes with everted rims in comparison with Early Middle Mumun pottery (Norton 2007).

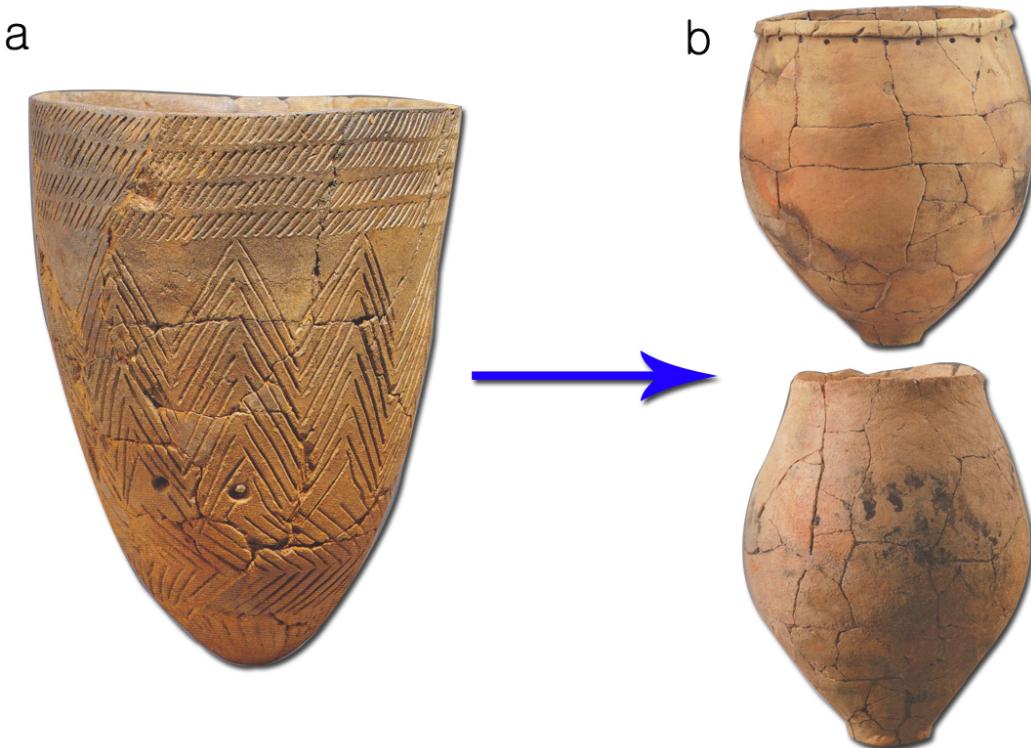


Figure 2.2: The Chulmun and the Mumun Period Potteries (a): Chulmun pottery with comb-shape pattern and the pointed bottom (b): Mumun potteries with patterns mostly on rim (upper-right; Heunam-ri-style pottery) and with no pattern (down-right; Songguk-Ri-style) (modified from T. Yoon and J. Bae 2010)

The manufacturing technique of stone tools shows too discrepancies between the two periods. Though polished stone tools started to be used in the Chulmun Period, their qualities and the skill of their production are relatively poorer than those of the Mumun Period (Figure 2.3a). The stone tools of the Mumun Period including the polished stone arrowhead and dagger, which were excavated in the central part of the Korean peninsula, are very elaborate and exquisite (Figure 2.3b). Also, from the middle of the Mumun

Period, we begin to observe bronze ware.

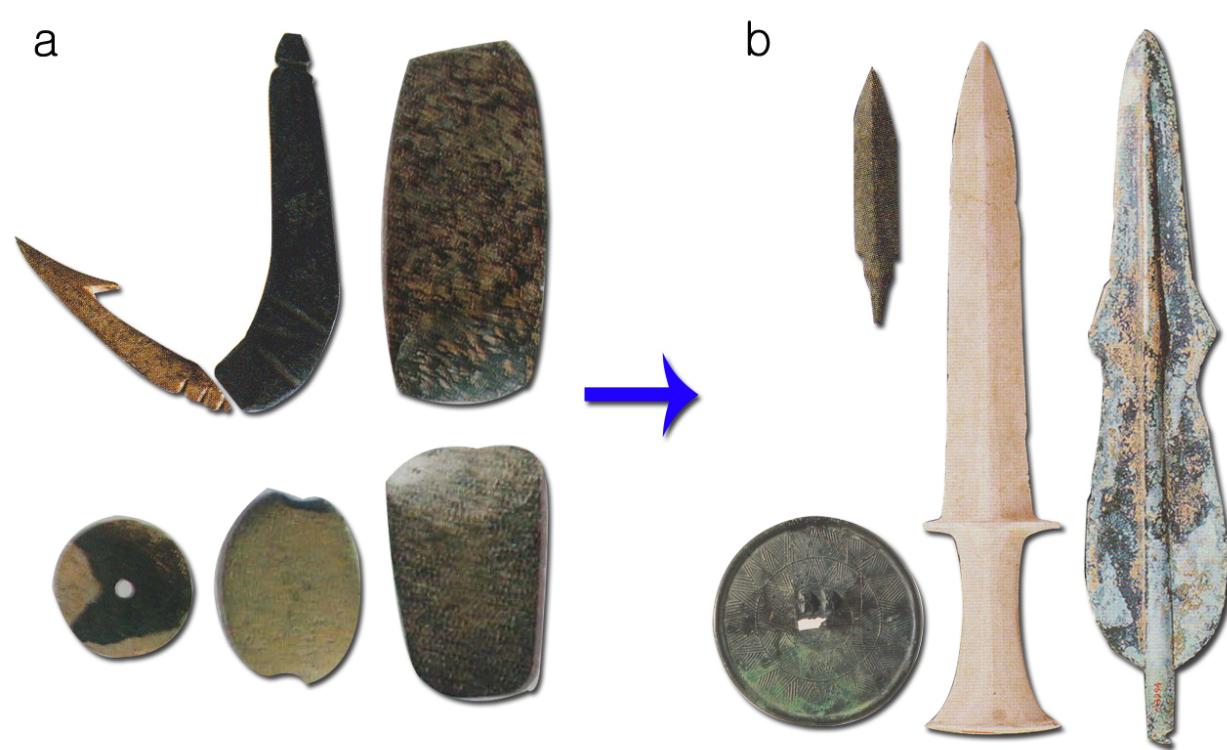


Figure 2.3: The Chulmun and Mumun Period tools (modified from T. Yoon and J. Bae 2010)

The form of habitations also changes. The Chulmun Period's houses have generally a round shape, but this shape was transferred into a rectangular style longhouse in the Mumun Period (Figure 2.5). Inside the longhouse, we can observe a row of 3 or 4 hearths for warming/cooking, which are not seen in that of the Chulmun Period. In a few words, the Chulmun Period's pottery with the pointed bottom and comb-shape pattern, and its polished stone tools and round-shape habitation were changed into the patternless flat-bottom pottery, elaborate polished stone tools and rectangular-shape habitation.

Together with these differences in characteristics of the archaeological assemblages of the two periods, Korean archaeologists assume that the most distinctive difference between the two periods consists in their subsistence strategies. Agriculture brought a great change into human life. Engaging in farming, human beings settled down for the first time. In the Korean Peninsula, it is argued that in the Mumun

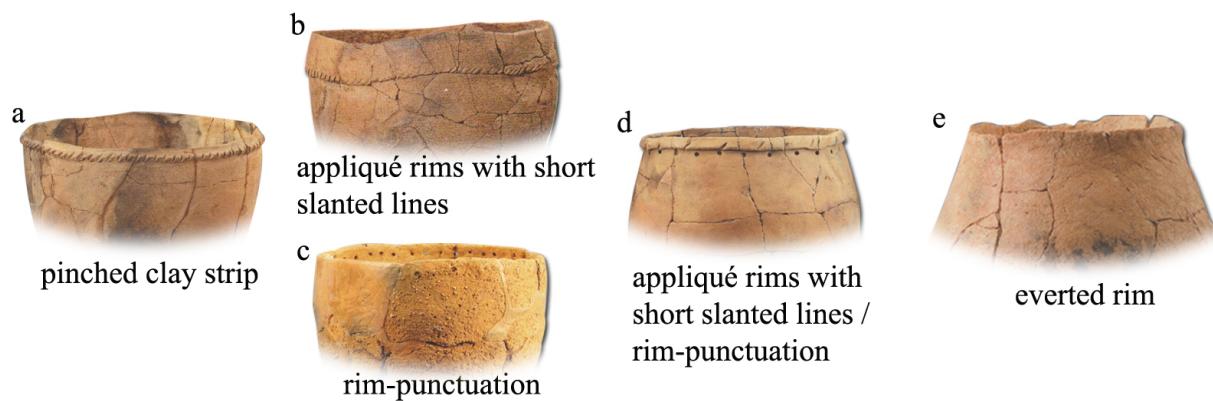


Figure 2.4: The patterns on Mumun potteries (a): pinched strip pottery (S. Cheon 2005) (b): Garak-Dong style pottery (B. Lee 1974) (c): Yeoksam-Dong style pottery (B. Lee 1974) (d): Heunam-Ri style pottery (Ahn 2000) (e): Songguk-Ri style pottery (Norton 2007)

period agriculture became the main means of living due to rice. Clear evidence including stone sickles (Figure 2.6a), “semi-lunar shaped” stone knife (Figure 2.6b), as well as dry field (Figure 2.6c) and irrigated rice paddies (Figure 2.6d) shows that full-dress farming was practiced in this region around the beginning of the Mumun Period (G. Lee 2003; 2011; T. Yoon and J. Bae 2010). Korean archaeologists think that agriculture was introduced in the Chulmun Period’s late phase and the rice agriculture spread widely in the Mumun Period’s early phase to be the principal subsisting way in the Mumun Period’s middle phase. They think that though agriculture was introduced during the Chulmun period, the main subsistence in this period was confined to hunting, fishing, and gathering. Normally, the start of the rice agriculture is treated as being very important; and the site that gave initially grains of rice, burned or not, is thought to have a critical meaning. However, what matters is not the start of the rice agriculture, but its general practice. Korea is an agrarian country even nowadays, and rice is still the staple food of the Korean people. Therefore, it is essential to know when the ancients of the Korean peninsula started to eat rice as staple food.

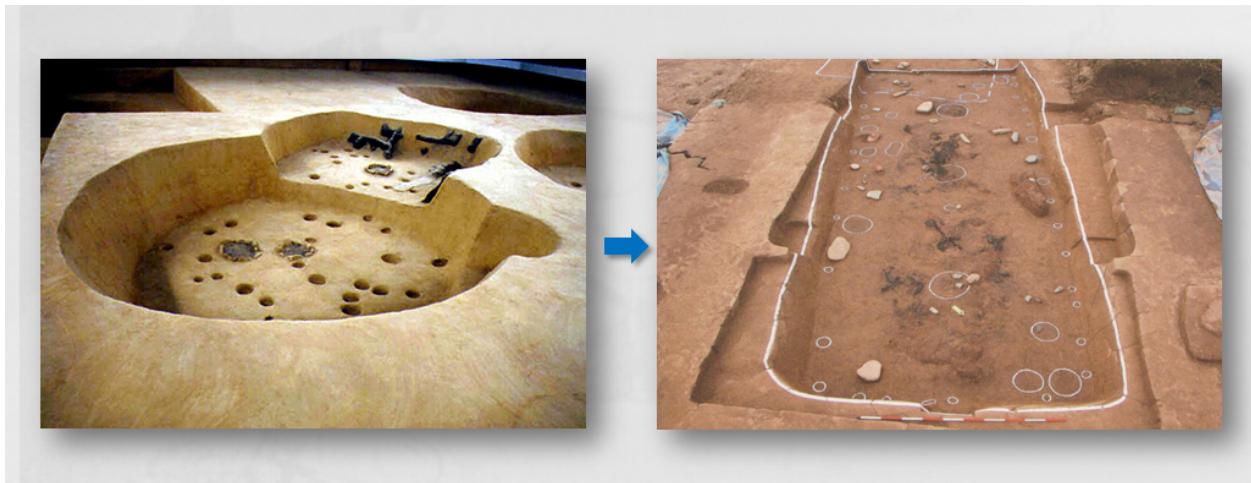


Figure 2.5: The Chulmun and Mumun Period habitations (modified from T. Yoon and J. Bae 2010)

#### CURRENT VIEWS ON THE TRANSITION FROM FORAGERS TO FARMERS AND DEVELOPMENT OF RICE AGRICULTURE IN THE KOREAN PENINSULA

The transition from foragers to farmers in the Korean peninsula has been approached by assuming a strict dichotomy between Chulmun hunter-gatherers and Mumun full-dress rice farmers (J. Ahn 2000; B. Kim 2006a). The transition was linked with multiple migration events coinciding with climate change (J. Kim 2003; 2006), or assumed to be driven by population growth (Norton 2000, 2007), or regarded as consequence of a risk reduction strategy (J. Lee 2001).

Until recently, quantitative analyses of marine resources from coastal shell middens have been the primary data source for investigating patterns of subsistence in Korea (J. Lee 2001, 2006; Norton 2000, 2007; cf. G. Lee 2011). For example, J. Lee (2001) argued that people used farming as a risk-reduction strategy against the declining sea level on the east and south coasts, as the ratio between the population and marine resources became imbalanced after 4,000 BP. By comparing the results of the analyses of marine resources from the shell middens of the west, east, and south coasts, J. Lee argued that farming emerged to overcome the loss of marine resources along the east and south coasts.

Similarly, Norton (2000) emphasized population growth as one of the key factors for the adoption of rice

farming along coastal settings. He examined the remains of marine resources from the Konam-Ri shell midden (Figure 2.1b), located on the west coast of the Korean peninsula. Based on the result of this examination, he suggested that the differential processing of large fish might be an evidence of residential stability. Residential stability, he argued, led to the increased population throughout the hunter-gathering stage. This increase, and the associated increased human predation, caused a decrease in the size of fish and other favored taxa, and subsequently pushed the hunter-gatherers to adopt rice farming (Norton 2000).

J. Kim (2003, 2006) suggests a combination of environmental fluctuation and subsequent human migrations from northern latitudes as a major factor of the agricultural transition in the central part of the Korean peninsula. Based on paleoclimate data for the early Holocene East Asia, he argued that because of cooling climate and decreasing temperature around 4,000-3,000 BP, the farmers in the Jilin-Duman regions along the current border with China might have migrated to the central part of the Korean peninsula, which was better suited for farming. He presented a sudden change in household pattern and the presence of finely ground stone daggers around the central part of the Korean peninsula as evidences of these migrations. In addition, Kim assumes that the mobility of indigenous hunter-gatherers was constrained when immigrant rice farmers blocked their way to resource patches. The inaccessibility of foraging areas enhanced the transition of hunter-gatherers to farmers (J. Kim 2006).

Lastly, B. Kim (2005; 2006a; 2006b) focused on the emergence of a complex society associated with an intensive rice agriculture around 2,600BP. By correlating regional scale survey data from the south-eastern Chungnam province (Figure 1.1) with its soil productivity for rice agriculture based on a site catchment analysis of the region, Kim argued that the emergence of a social hierarchy and the subsequent social complexity were driven by the rapid spread of the intensive rice agriculture into foraging contexts. He asserted that this rapid transition is exemplified by the sudden presence of harvesting tools of ground stone.

There are two underlying key ideas that these studies have in common, but both are problematic. The first two studies assume that shell middens can represent the general process of subsistence change from foragers to farmers in the central part of the Korean peninsula. Since a peninsula, consequently the Korean Peninsula is a part of a continent, the data from the coastal shell middens cannot represent the subsistence

of the inland, which includes considerably large habitation sites. Next, all the four studies assume rice to be a dominant subsistence resource since 3,400 BP, without considering the possibility of the utilization of a more wider range of resources for subsistence.

According to archaeobotanical evidences from the southern part of the Korean peninsula, which includes the Daundong site in Ulsan and several localities within the context of the Nam River in Jinju (Oun I, Okbang 1,2,4,6 and 9, Sangchon B), the diet of the ancient farmers of the region included various resources such as millet, soybean, and azuki between 3400 and 2,600 B.P. (Crawford and Lee 2003; G. Lee 2003, 2011) (Figure 1.1). I assume the subsistence pattern might be similar in the central part of the Korean peninsula during this period, though we lack, for the moment, clear paleobotanical evidences to test this assumption. Therefore, the re-evaluation of those rice-centered models is required, and the general chronology of subsistence during this period has to be established.

#### THE CENTRAL HYPOTHESIS OF THIS THESIS

Studies have shown that in some cases, the initial domestication of crops and subsequent agriculture appeared as a part of the complex foraging economies in an affluent environment (Price and Bar-Yosef 2011; Price and Gebauer 1995) and hunting, gathering and fishing persisted well after farming was introduced (Boric 2002; Craig et al. 2011; Galili et al. 2002; Milner et al. 2004). In the Yangtze River Valley in China, for example, as well as in the Sub-Saharan Africa and the eastern North America, evidences of very early domestication come from settlements situated in zones with very rich resources which are associated with river valleys, and in none of these areas does domestication appear to have developed within a context of population growth forcing humans into marginal environmental zones (Smith 2007). New strategies such as agriculture were initiated by relatively complex hunter-gatherers in circumstances where risk is affordable. Then why did these foragers invest their efforts in agriculture when there was no immediate risk? The key idea for the reply to this question is that an increased sedentism was a “pre-requisite” for the advent of agricultural societies, for complex hunter-gatherers are characterized by a relatively large population and sedentism (Price and Gebauer 1995: 8). Recent case studies in the eastern North America by Smith (1995; 2007; 2011) are good examples. Smith argued that many of our present domesticated plants

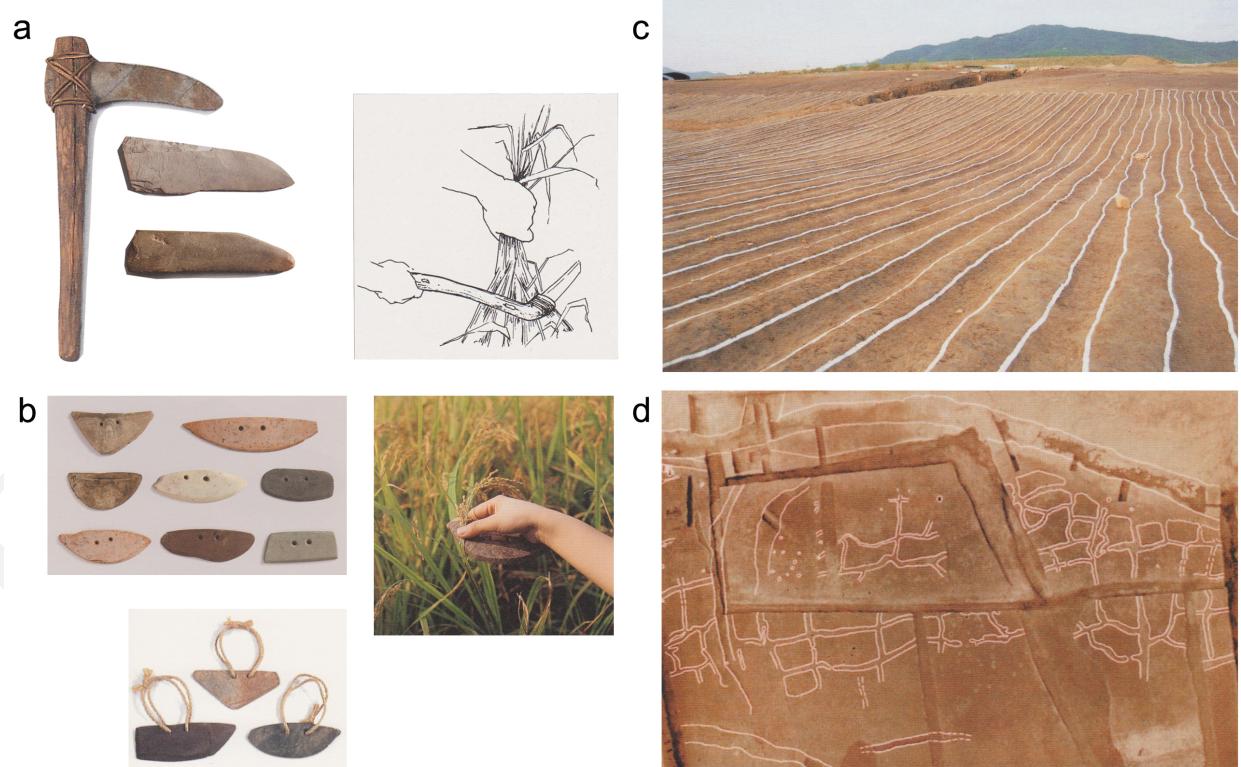


Figure 2.6: The evidence of full-dress farming in the central part of the Korean peninsula: (a) stone sickle, (b) semi-lunar shaped knife, (c) excavated dry field, and (d) irrigated rice paddy (all modified from T. Yoon and J. Bae 2010)

originated from the weeds growing in the open habitats created by rivers (e.g. floodplain), and they were easily adapted to open areas in the habitats disturbed by human sedentary settlements. Those weeds that invaded open areas in human settlements eventually became domesticated in conformity with the natural outcome of the selective relationship between people and plants within a stress-free environment (Smith 2007; 2011). Even the Jomon Japan, the period that is traditionally considered as giving an “affluent” hunter-gathering context based on sedentism, showed clear evidences of plant domestication (Obata et al. 2007). Recently, Crawford (2011) stressed that the orthodox view that the Jomon sustained hunting and gathering for millennia in a naturally rich environment is oversimplification if not correct.

This situation could have existed in the prehistoric Korea. We have solid evidences of a long-term, permanent occupation of the peninsula by complex hunter-gatherers at various places since around 6,000 BP. At the Amsa-Dong Site (Figure 1.1) in the south-east Seoul, at least 12 houses, a significant amount of pottery and different types of ground stone tools such as arrow points, spear points and sickles, were excavated (H. Lim 1985). Considering that the site was not fully excavated, and based on the scale of the houses as well as the diversity of ground stone artifacts, we can easily assume that this provides clear evidences for sedentism. The house structures and seasonality of the faunal assemblages at the Tongsam-Dong site (Figure 1.1) in the southern part of the Korean Peninsula indicate that people lived there year-round on a permanent basis (J. Lee 2001). We have pollen data from 5,500 BP to 2,600 BP showing that there were specific subsistence solutions which include distinctive combinations of wild (e.g. acorn (*Quercus acutissima* Carr.), Manchurian walnut (*Juglans* spp.)), possibly managed (e.g. chenopod (*Chenopodium* sp.), panicoid grass (*Paniceae*)), and domesticated (e.g. foxtail (*Setaria italica* ssp. *italica*) and broomcorn millet (*Panicum miliaceum*), possibly soybean (*Glycine max*), azuki (*Vigna angularis*) and beefsteak plant (*Perrilla frutescens* (L.) Britt)) plants (G. Lee 2011: S326). On the other hand, though we lack the evidence of faunal remains due to the high acidity of sediment in the Korean peninsula, it is still possible that hunting and fishing may have persisted along with farming after its introduction (cf. Craig et al. 2011; Milner et al. 2004).

In this regard, the prevailing rice-centered models, which assume rice to be the most dominant subsistence resource since 3,400 BP., are misleading. My hypothesis is that there was utilization of a wider range of

animals and plants resources along with rice among ancient farmers in the central part of the Korean peninsula between 3,400 and 2,000 BP. What is overlooked in the subsistence studies of the prehistoric Korea is the distinction between the first adoption of crops and the later development of intensive agriculture (G. Lee 2011). The migrants (cf. J. Kim 2006), if there were any, probably needed time to adjust themselves to the local environmental conditions, particularly for rice agriculture, which required complicated irrigation techniques. As G. Lee (2011) noted, rice may have played a minor subsistence role at this time, and it may not have served as a driving factor of the emergence of social complexity.

## SUMMARY

In this chapter, first I have discuss the history and social context of Korean archaeology focusing on series of political upheavals related to Japanese annexation. Next, I elucidated the current studies on the transition from foragers to farmers and development of rice agriculture in the Korean Peninsula. Then, the problems with these existing ideas stated based on the recent scientific evidence from the Korean peninsula and Japan. Lastly, I clarified main hypothesis of this thesis in detail.

# 3

## Methodological background, Research design and analytical procedure of Luminescence dating

### INTRODUCTION

To evaluate my hypothesis and to establish a general chronology of subsistence from 3,400 to 2,000 BP, I used the organic geochemistry and luminescence dating methods on the pottery excavated from three major inland sites in the central part of the Korean peninsula. In Korean archaeology, pottery is one of the main objects for archaeological analysis, being abundant in the Korean Peninsula in almost every archaeological assemblage in the sites that post-date 6,000 BP. This abundance allowed archaeologists to

develop a detailed Korean archaeological chronology based on the pottery shape, size and decoration. Though this intensive chronology-building has much contributed to Korean archaeology, almost no attention has been given to analyzing the fabric of pottery itself. This is a surprising omission and represents a serious gap in our understanding of prehistoric technology and subsistence. The above methods allow us to identify what was stored and cooked in the pots as well as to date them directly, so that we can understand how subsistence changed over time. Accordingly they let me directly test the hypothesis posited precedently: that there was utilization of a wider range of resources among ancient farmers in the central part of the Korean peninsula between 3,400 and 2,000 BP and rice seems to have played no more than a minor role in subsistence during this period. In this chapter, I will discuss about the methodological background, Research design and analytical procedure of Luminescence dating. I will elucidate some of the main principles of luminescence dating and its application history to the Korean archaeology. I will also describe the laboratory analysis process in detail.

#### LUMINESCENCE DATING IN ARCHAEOLOGY

In terms of pottery chronology, archaeologists have used stratigraphy that indicates a depositional event: when the artifacts were buried together, not specifically when they were manufactured. Dating these depositional events or “occupations” (Dunnell 1971; Raffeny 2008) is a usual goal but it is not quite same as dating manufacturing events. Archaeologists have not always distinguished occupational event and manufacturing event in practice (cf. Feathers 2009). In addition to stratigraphy, another method employed by archaeologists was seriation based on the physical characteristics of the potteries. However, this also has an inherent problem because transmission of the physical characteristics can occur across space (Dunnell 1970; Feathers 2009). To ascertain that seriations are mainly entangled to time, they must be restricted in space. Lack of control over spatial variation means it is difficult to tell whether there are sequential or special differences between each stage of seriation. The radiocarbon dating somewhat fitted with those traditional approaches, for this well-known absolute dating method mostly does not date the potteries themselves but nearby organic remains (e.g. Charcoal). This means the dating event inevitably has a variable relation to the target event of pottery manufacture.

Luminescence dating dates manufacturing event: when the pottery was made. To understand the chronology of subsistence, what archaeologists need to know is cooking event. Since cooking event is more likely associated with manufacturing event than depositional event, luminescence dating is probably the most suitable method for creating subsistence chronology.

### 3.3 LUMINESCENCE: THE PRINCIPALS

Luminescence dating is an absolute dating method that has been used both intensively and extensively in the field of archaeology and earth sciences. It is based on the emission of light, luminescence, from minerals. In case of pottery, burnt flints, or burnt stones, the dated event is the last heating of the objects. Another common application is dating sediments. In this case, the event being dated is the last exposure of the mineral grains to light. The age range which the method can be applied is from a century or less to over one hundred thousand years.

Radioactivity is ubiquitous in the natural environment. Luminescence dating utilizes the radioactive isotopes of elements such as uranium (U), thorium (Th) and potassium (K) (Feathers 2003). Naturally occurring common minerals such as quartz and feldspars act as dosimeters, showing the amount of radiation to which they have been exposed (Duller 2008). A common characteristic of these naturally occurring minerals is that when they are exposed to the light emitted by radioactive decay, they tend to store some proportion of the energy delivered by the radiation within their crystal structure. The minerals accumulate this energy as exposure to radioactive decay continues through time. When this energy is released at some later date, these minerals release the energy in the form of light. This light is what we call luminescence.

Luminescence is explained by the solid state energy band theory (Aitken 1985; 1998; McKeever and Chen 1997). The interaction between radiation and the crystal structure provides energy to electrons that can be raised from valence band to the conduction band. Because of this stage, electrons become trapped within the crystal. In ideal situation, electrons cannot be trapped within the crystal structure, but this is possible because of defects within the structure. The electrons may be stored (and accumulated) at these defects for certain period. By the time these electrons are released, they lose the energy delivered by the radiation,

and may emit part of that energy in the form of a single photon of light (Duller 2008).

The reason we can use this phenomenon for dating lies in the fact that this energy stored in minerals can be reset by two processes. The first process is by heating the material to the temperature above about 300°C: the process that occurs in a hearth or kiln during firing of pottery. The second is exposure to daylight, as may occur during erosion, transportation, or deposition of sediments. Either of these processes releases any existing energy, and thus set the ‘clock’ to zero (Duller 2008). Therefore, in luminescence dating, the event being dated is the last resetting of this clock, either by heat or light.

Measurements of the brightness of the luminescence signal can be used to calculate the total amount of radiation that the sample absorbed during the period of burial. If this can be divided by the amount of radiation that the sample receives from its surroundings per year, this will give the duration of time that the sample has been receiving energy: the age (Duller 2008).

$$\text{age} = \frac{\text{total amount of radiation exposed during burial (equivalent dose)}}{\text{amount of radiation received each year (dose rate)}}$$

There are a number of naturally occurring minerals that emit luminescence signals, including quartz, feldspars, and calcite. Among them, quartz and feldspar are the most suitable and ubiquitous material for dating (cf. Feathers 2003; 2009). The luminescence age is the period of time that has passed since the sample was heated or exposed to daylight. The age is given as the number of years before the date of measurement. Since there is no designate datum for luminescence ages, the date of measurement must be noted. The term BP (before present) should never be used for calculating luminescence age, for BP designates specific datum point and is only proper for radiocarbon ages.

The energy that stored within minerals’ crystal structure can be released using a number of laboratory methods.

#### THERMOLUMINESCENCE

Heating the sample at a certain rate from room temperature up to 700°C releases the trapped electrons within the crystal structure. The resulting signal from this process is called thermoluminescence (hereafter

TL). Typically the TL signal comes with a series of peaks (Figure 3.1). Each peak may indicate a single type of trap within the mineral, and commonly the signal is comprised of several traps. Although it is not always possible to identify the source of electrons precisely, in most cases TL signal observed at highest temperature originates from trap that is deepest below the conduction band (more energy is required to release electrons from deeper traps, and therefore this occurs at higher temperature).

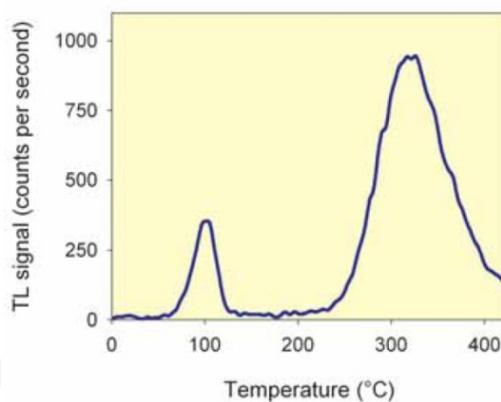


Figure 3.1: A typical thermoluminescence signal (commonly referred to as a “glow curve”) that shows multiple traps (Duller 2008; cf. Feathers 2003:1495)

#### OPTICALLY STIMULATED LUMINESCENCE

A second way of releasing the electrons stored within minerals is by exposing them to laboratory light (Huntley et al 1985). As soon as the mineral exposed to light, luminescence is emitted from the mineral grains. The signal is termed optically stimulated luminescence (hereafter OSL) and Figure 3.2 shows the signal from quartz during the stimulation. As measurement continues, the electrons in the traps are emptied away and the signal starts to decrease drastically (Figure 3.2).

A similar signal is observed from other minerals including feldspar. However, OSL signal from feldspars decreases more slowly than that from quartz (Duller 2008). Unlike TL, the OSL signal does not show multiple traps. Thus, before measuring the luminescence signal, it is important to thermally pretreat the sample to make sure that the measured signal is from the deepest traps. This is achieved by heating the

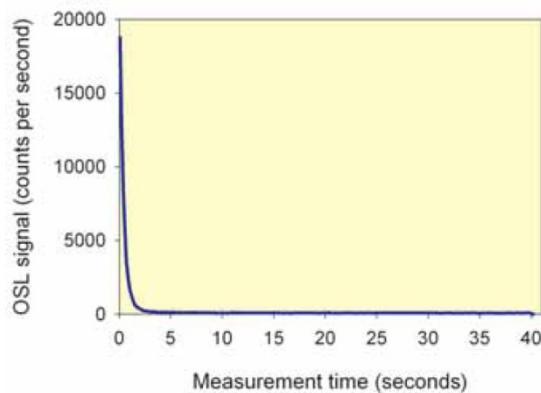


Figure 3.2: A typical optically stimulated luminescence signal from quartz grain (Duller 2008)

sample before measurement so that the shallow traps (whose electrons are unstable over the burial period) are emptied, leaving only the electrons in deeper, stable traps - this heating is called a preheat (Duller 2008: 6; Feathers 2003).

The light used to stimulate the minerals is restricted to certain range of LED lights. Blue light emitting diodes are most widely used type for generating OSL signal from both quartz and feldspar. Another method of stimulation is using LEDs that emit beyond the visible part of the light spectrum: infrared stimulated luminescence (hereafter IRSL). IRSL is only observed from feldspars, for quartz does not produce an IRSL signal when the sample in room temperature (Duller 2008). Using these different characteristics of quartz and feldspar against the infrared light, a method for assessing the purity of quartz separated from feldspar for luminescence measurements can be provided.

#### LUMINESCENCE DATING AND ITS APPLICATION TO THE KOREAN ARCHAEOLOGY

The luminescence dating is a technique for dating once-heated materials, and is used by archaeologists primarily to date ancient ceramics and sediments (Feathers 2003). This technique can measure the time that has elapsed since the last exposure to heat and light of the materials constituting the object. As this exposure event generally occurred when pottery was made, the luminescence dating is ideal for dating ar-

chaeological ceramics (Feathers 2003). The optically stimulated luminescence dating (hereafter OSL), infrared stimulated luminescence dating (hereafter IRSL), and thermoluminescence dating (hereafter TL) methods employed for dating ceramics have been quite common in Europe and the United States for nearly two decades, but they are yet to be widely used in Korea. Given the abundance of ceramics in Korean archaeological records, it is surprising that the luminescence technique has not been more frequently employed. Though it has been mentioned considerably since its initial introduction (J. Choi et al. 2006; J. Choi et al. 2009), it has been used mainly in the field of geology (J. Bang et al. 2009). In archaeology, after its applicability was considered (D. Hong et al. 2001), it has only been employed to date sediments in Paleolithic archaeological sites (J. Kim et al. 2010). Probably the absence of archaeological luminescence dating of ceramics in Korea may be attributed to the uncritical acceptance of the relative chronologies. I partially agree to the detailed relative chronologies based on the decoration and style of potteries and their serviceable nature (H. Lee 2008; J. Bae 2007), but their applicability is quite low in subsistence change settings, for they are only based on the physical characteristics of pottery. Of course, the primary purpose of the luminescence dating in this research is to investigate the role of intensive rice farming and to establish the chronology of subsistence strategies over time by correlating the dates it obtained with the results of organic geochemistry analyses. However, with a systematic application of the luminescence dating, I was also able to grasp a glimpse of a more reliable chronology which can be easily applied to other archaeological studies. In 2011, I dated one potsherd from the archaeological deposit in Hongseong city, central part of the Korean peninsula. Using the thermoluminescence method, I was able to confirm that the potsherd was from the proto-historic period ( $280 \pm 86$  AD; U2516 in Table 3.1).

Lab. No	Depth (m)	Water Content (%)	Dose rate* (Gy/ka)	TL (De)	OSL (De)	IRSL (De)	Age
U3045	0.36	20.4	$5.532 \pm 0.277$	$8.712 \pm 0.91$	$8.586 \pm 0.331$	$7.215 \pm 0.361$	$280 \pm 86$ AD $11.665 \pm 1.423$

Table 3.1: The result of the luminescence dating (\*Dose rates are rounded to two decimal places, but calculation of the total dose rate was carried out prior to rounding)

All the samples for my research was dated at the Luminescence dating lab, Department of Anthropology, University of Washington. The Luminescence dating method enables the evaluation of the time that has passed since the mineral grains were crystallized, that is, since the grains were last exposed to daylight or heated to a few hundred degrees Celsius. Generally, as at the lab of the University of Washington, the method uses an optically and thermally sensitive light or luminescence signal emitted by minerals such as quartz and feldspar. For dating, the amount of absorbed energy (luminescence signal) per mass of mineral ( $1 \text{ J/kg} = 1 \text{ Gray}$ ) due to the natural radiation exposure since the last zeroing - known as the palaeodose - is determined by comparing the natural luminescence signal of the sample with that which is induced by the artificial irradiation (Preusser et al. 2008). The time having passed since the last daylight exposure/heating (the date of the sample) is obtained through dividing the palaeodose by the dose rate, the latter representing the amount of energy deposited per mass of mineral by the radiation exposure on the sample over a certain time (Preusser et al. 2008). The potsherds in this thesis was dated by using this formula, and both of the two general methods, TL, OSL, and IRSL will be applied. For a further clarification, the dates from the luminescence dating were correlated with those from AMS radiocarbon dating.

#### ANALYTICAL PROCEDURE

The luminescence dating method enables evaluation of the time that has passed since mineral grains crystallized, which means it can measure the amount of time since the grains' being last exposed to daylight, or heated to a few hundred degrees Celsius. Its technique was developed in an archaeological context, in Europe in the 1960s and 1970s, as a method of dating heated materials, primarily ancient ceramics and potteries (Feathers, 2003). It has been applied to a wide range of Quaternary researches such as landscape evolution, palaeoclimate, archaeology, and has been being refined since its early days. It dates the past exposure to heat and light, and because the events of this exposure are the actual events archaeologists are interested in, it has a strong merit over other dating methods (Feathers, 2003). In other words, in the luminescence method, the dating event is often the target event that the archaeologists are looking for. In this thesis, the luminescence dating was applied to eight archaeological ceramic samples.

#### SAMPLE PREPARATION - GRAIN SIZE

For the luminescence dating, determining the grain size is quite important, for there are advantages/disadvantages as well as different methods it occasions. Generally, fine grains (1-8 um) are more abundant than coarse ones; and they can be analyzed with samples of relatively small amount. They also require a relatively simple sample preparation process, and rely less on the external dose rate, which is often problematic in a complex ceramic environment. However, if samples include feldspar grains (which cannot be separated from other grains during the sample preparation procedure), one has to deal with the high fading rate of feldspar (Wintle, 1973).

One of the biggest advantages of using coarse grains (180-212 um) is the single grain analysis, which can be done only with coarse grains. Quartz grains are generally used for the analysis of coarse grains, because of its well-known properties and low fading rate. Since it is possible to minimize feldspar inclusion during the sample preparation process of coarse grain, we do not have to consider the fading of feldspar as a major variable. Also, because of the larger grain size and etching process during the sample preparation, the contribution of alpha radiation (which has a short range: 50um) is minimal. This is a huge merit, for alpha radiation is much less effective in producing luminescence than beta and gamma radiations. In case of analyzing fine grains, this 'low alpha efficiency' must be considered. However, using coarse grains for the analysis requires a complicated sample preparation process and a larger amount of sample. Also, it cannot be totally exempted from the high fading rate, because feldspar has to be used for the single grain analysis in some cases (feldspar typically has a bright luminescence signal, which enables dating older deposits than with quartz; Preusser et al. 2008) where quartz shows an extremely low luminescence signal. It has also been verified that the quartz of volcanic origin may show anomalous fading, just like feldspar (Bonde et al. 2001; Tsukamoto et al. 2007). In this Thesis, fine grains were used for the analyses, because of their small sample size and advantages that I mentioned above.

## GLASSWARE AND REAGENTS

All glassware was washed with Decon 90 (Decon laboratories), rinsed four times in distilled water. Analytical grade reagents (typically  $\geq 98\%$  purity) were used throughout.

## DOSE RATE MEASUREMENT

The dose rate is the amount of energy deposited per mass of mineral by the radiation exposure of the sample over a certain time (Preusser et al. 2008). For the dose rate measurement, the exposed parts of the potsherds were used (0.5-1 g). The dose rates were determined by alpha counting (Low level alpha counter 7286: Little more Science Engineering Co., DayBreak alpha counter 583: DayBreak), beta counting (Beta multi counter system RISØ GM-25-5: Risø National Laboratory), and flame photometry (Flame Photometer PFP-7: Jenway).

The water absorption percentages of the samples were measured. This is quite important for calculating the dose rate, as the attenuation of radiation is much greater if the sample is filled with water (Preusser et al., 2008). For measuring the water absorption percentage, the sample was saturated with deionizing water for several days. Then, the surface wetness was removed by gently dabbing it with a wet paper towel; and then it was immediately placed on the scale to weigh it. After the sherd was dried in a 50°C oven for several days to record its weight in its dry state. The water absorption percent is calculated as  $W = [(S/D)/D] * 100$ , where S is the saturated weight and D the dry weight.

Some component of the dose rate is produced by the ionizing cosmic radiation, and could be by the geographic location and burial depth of the sampled material (Prescott and Hutton, 1994). All information related to the latter points was obtained from the excavation records of the sites where the samples came from.

Alpha counting gives the current alpha activity rate. And based on this rate and the assumption of secular equilibrium, one can calculate the beta and gamma dose rate. However, by using the beta counter and flame photometry as well, we can enhance the validity of the alpha counting and the total dose rate measurement. This sort of advantage is available only if we utilize multiple tools at the same time.

## EQUIVALENT DOSE MEASUREMENTS

For measuring the equivalent dose (paleodose) of the pottery samples, TL (Thermo luminescence; Day-Break 11000 Automated TL system), OSL (Optically stimulated luminescence; RISØ TL/OSL system DA-15), and IRSL (Infrared stimulated luminescence; RISØ TL/OSL system DA-15) were utilized. Artificial laboratory irradiations were given by the Irradiator type 721/A (Little more Science Engineering Co.) and RISØ TL/OSL system DA-15. Fine grains (1-8 um fractions) were used for dating. The grains were obtained from the core part of the potsherds more than 2 mm away from any exposed surface. This was done by drilling, using tungsten carbide drill bits. For the TL analysis, the equivalent dose was determined by the slide method to obtain both of the advantages of the additive dose method and the regeneration method (Prescott et al., 1993). The slide method can deal with the matter of extrapolation as well as the process of zeroing simultaneously. These two problems cannot be solved at the same time in case of using either the additive dose method, or the regeneration method solely. As I mentioned above, for dating fine-grained samples, one has to deal with the low alpha efficiency. This is taken into account by determining the alpha efficiency factor: "b-value (Huntley et al. 1988)". It has been known that the alpha efficiency varies between quartz and feldspar (Huntley et al. 1988). The typical b-value of quartz and feldspar is respectively about 0.5 and more than 1.5. IRSL was applied to reduce the feldspar signal, for feldspar tends to be stimulated by infrared light (Roberts and Wintle, 2001).

## DETERMINING AGE

The time having passed since the last daylight exposure/heating of the pottery sample (Hereafter: age) was calculated through dividing the palaeodose by the dose rate. The final date of the sample was obtained through calculating the average of the three dates from TL, OSL, and IRSL. Normally, when conducting the luminescence dating on a pottery sample, its associated sediment is required for the precise dose rate measurement. However, since there was no associated sediments on my samples, I relied on the dose rate of the sample itself. Therefore, it was assumed that the dose rate of the sample was the same as (or at least approximate to) that of the associated sediment.

## SUMMARY

In this chapter, I have discuss about the methodological background, research design and analytical procedure of Luminescence dating. Some of the main principles of luminescence dating and its application history to the Korean archaeology were elucidated. I also described the laboratory analytical process in detail.

# 4

## Methodological background, Research design and analytical procedure of the organic geochemical analyses

### INTRODUCTION

In this chapter, I will discuss the methodological background, research design and analytical procedures of the organic geochemical analyses. I will outline a brief history of the organic geochemical analyses in the discipline of archaeology and elucidate the principles of the methods. I will also list some of the

implications related to the analyses. Lastly, the details about the specific laboratory experimental processes of this project will be mentioned.

#### CONCEPT OF BIOMOLECULAR ARCHAEOLOGY AND ORGANIC GEOCHEMICAL ANALYSIS

Biomolecular archaeology is the study of ancient biomolecules that can yield information relating to human activities in the past (Evershed 1993; 2008a; 2008b). This expanding field includes the study of various organic compound classes that provides vital information relating to complicated archaeological questions. The area of biomolecular archaeological researches includes (1) the use of collagen from skeletal remains to determine ancient dietary information (Corr et al., 2008; J. J. Lee, 2011; Reynard & Hedges, 2008; Richards, Pearson, Molleson, Russell, & Martin (2003); A. H. Thompson, Chaix, & Richards, 2008); (2) the analysis of DNA from archaeological materials to explore evolutionary origins and migratory patterns (C. J. Edwards et al., 2004; Ho et al., 2008; Jansen et al., 2002; Malhi et al., 2007; Vilà et al., 2001); and (3) the study of lipid biomarkers from a range of archaeological contexts relying on organic geochemical analyses for the reconstruction of culinary, economic and social practices throughout prehistory and history (R. Berstan et al., 2004; Bethell, Goad, Evershed, & Ottaway, 1994; 2005a; Copley et al., 2001; 2013; Oliver E. Craig et al., 2011; Dudd & Evershed, 1998; Evershed, Bethell, Reynolds, & Walsh, 1997; 2003; F. A. Hansel, Copley, Madureira, & Evershed, 2004; Reber & Evershed, 2004b; Regert, Vacher, Moulherat, & Decavallas, 2003). The organic geochemical analysis endeavors to determine the types of food groups that were cooked or stored within a pot by attempting to isolate and identify the specific organic compounds trapped in the fabric of its wall or adhering to its surface in residues (J. Eerkens, 2002; 2005; 2007; Evershed, Heron, & John Goad, 1990; Reber & Evershed, 2004a). Organic compounds have the advantage that they are often preserved within archaeological ceramics (S. Charters et al., 1993; M. S. Copley et al., 2005a, 2005b; Evershed, Arnot, Collister, Eglington, & Charters, 1994; Heron & Evershed, 1993), which is not the case in the other methods of diet reconstruction, such as examination of faunal and floral remains. In this regard, organic geochemical analysis has become an important method of investigation which archaeologists use to better understand the local diets and the function of ceramic artifacts. If we conduct it on the pottery, we will be able to understand past subsistence behaviors even in the ab-

sence of faunal or floral remains. The direct examination of remains of resources in the Korean peninsula is limited to shell middens, because the high acidity of sediment does not allow long-term preservation of bone or plant remains. Therefore, organic geochemical analysis could be a suitable method in this setting.

#### ORGANIC RESIDUES WITHIN ARCHAEOLOGICAL POTTERIES

Among all the compound classes I have mentioned above, solvent-extractable lipids are the most frequently recovered compounds from archaeological contexts (Evershed, 1993, 2008a, 2008b). Because of their stability against degradation and inherent hydrophobicity, they tend to persist at the original place of deposition more than other biomolecules. Due to these characteristics, lipids are nowadays the most widely studied organic compounds in the discipline of biomolecular archaeology.

Under favorable conditions, lipids are preserved at archaeological sites in association with a wide range of archaeological contexts, e. g. pottery, soils, human and animal remains and other deposits (Evershed, 1993; Evershed et al., 1999). Among them, potsherds are probably the most widely distributed at archaeological sites. Due to this reason, the pottery is one of the most extensively studied materials for the organic geochemical analysis.

Organic residues are found in association with archaeological pottery either as (1) charred remains on the inner or outer surface of the vessels, or, (2) absorbed within the fabric of their wall (Evershed, 2008b; Evershed et al., 1999). The residues both on their surface and in their fabric can provide invaluable information regarding the use of ancient pottery vessels. However the latter case is more commonly encountered, for the fired clay acts as a ‘trap’ or ‘net’, protecting and preserving lipids during burial (Evershed, Dudd, Lockheart, & Jim, 2001; Reber & Evershed, 2004a). Studies have shown that these compounds are relatively well insulated and preserved within that fabric over millennia (Jelmer W. Eerkens, 2001, 2005; Heron, Evershed, & Goad, 1991). The absorbed residues, unlike the visible ones, cannot be removed from a sample by washing or scraping, and remain within the ceramic matrix of a pot until extracted by solvents (Reber & Evershed, 2004a: p. 20).

During the usage of pottery vessels in prehistoric times (e.g. during culinary practices), fats, oils and waxes

originated from animals, insects or plant products become entrapped within the vessel wall. The fats and waxes are protected from microbial and chemical degradations as well as groundwater leaching by the ceramic matrix. These organic residues can be extracted from the potsherds and analyzed hundreds or even thousands of years after the pottery was discarded by ancient people. For example, in case of Great Britain, absorbed residues are typically detected in 50 to 60 % of all vessel studied (A. J. Mukherjee, 2004); however, the actual proportion is dependent on many factors including burial conditions and age (Evershed, 2008b). Though Fats and waxes can also be preserved as a form of charred or dried deposits adhering to the vessel wall, this class of residue is much less commonly observed.

The preservation of organic compounds in the porous walls of pottery was first recognized over 30 years ago, when the lipids extracted from archaeological potteries were analyzed by the gas chromatography (hereafter GC) (Condamin, Formenti, Metais, Michel, & Blond, 1976). This approach uses the ratio between the amounts of common fatty acids to determine particular classes of food (cf. Patrick 1985; Jelmer W. Eerkens, 2005; 2007). But it has a problem, for different kinds of fatty acids decompose at different rates over time due to oxidation and hydrolysis. Since such ratios are not stable over time, researchers have to rely on those of the fatty acids that decompose at similar rates. For example, Eerkens (2001, 2005; 2007) set up the criteria for distinguishing different food classes, based on four useful ratios involving eight fatty acids which are relatively common in archaeological residues ( $C_{12}:0/C_{14}:0$ ,  $C_{16}:0/C_{18}:0$ ,  $C_{16}:1/C_{18}:1$  and  $(C_{15}:0 + C_{17}:0)/C_{18}:0$ ). Upon these criteria, he was able to distinguish five different food classes which are: meat of terrestrial mammals, fish, seeds/nuts and berries, roots, and greens (Table 4.1). After these studies that attempted to determine the origins of the organic residues based on the proportions between individual compounds, more sophisticated mass-spectrometric instruments were employed and made it possible to identify a wide range of organic commodities within archaeological vessels.

Identification and characterization of lipid residues rely upon the comparison of chemical properties of lipid biomarker compounds that are complex organic molecular structures derived from organisms, and that are presented in both the archaeological ceramics and contemporary reference plants and animals. Such “biomarkers” can help scientists to reconstruct the dietary life of prehistoric peoples (Evershed, 2008a, Evershed (2008b); Heron & Evershed, 1993: pp. 267-270). This has been achieved by the high

temperature gas chromatography (hereafter HTGC) and gas chromatography - mass spectrometry (hereafter GC-MS) techniques that can acquire detailed molecular compositional information from the extracts. That information can subsequently be compared to that of modern reference materials. Through this method, scholars have identified terrestrial and marine animal fats, plant leaf waxes (e.g. cabbage and leek), beeswax, birch bark tar, and palm fruit (Table 4.2). But the biomarkers only occur in case of good preservation of the organic residues; more often we only have the degraded products. More recently, the use of soft ionization techniques in MS, such as electrospray ionization (ESI), has proven particularly useful in the structural characterization of high molecular weight compounds preserved within archaeological pottery like triacylglycerols (hereafter TAGs). They are more difficult to examine with the GC-MS technique (Mirabaud, Rolando, & Regert, 2007; Stear, 2008: p. 26).

ratio	State	terrestrial mammals	fish	Roots	greens	seeds/nuts and berries
C <sub>16</sub> :o/C <sub>18</sub> :o	Fresh	<3.5	4-6	3-12	5-12	0-9
	degraded	<7	8-12	6-24	10-24	0-18
C <sub>12</sub> :o/C <sub>14</sub> :o	Fresh	<0.15	<0.15	>0.15	>0.05	>0.15
	degraded	<0.15	<0.15	>0.15	>0.05	>0.15

Table 4.1: Criteria used to distinguish food types, based on fatty acid ratios (Eerkens 2005)

Most recently, the application of the compound-specific stable carbon isotope analysis (hereafter CSIA) by the gas chromatography-combustion-isotope ratio mass spectrometry (hereafter GC-C-IRMS) enabled a more specific characterization of the organic compounds within archaeological pottery. The stable carbon isotope analysis has become a powerful method for tracing diet patterns of animals, for the isotopic composition of animals depends upon the food they eat (Malainey, 2010). In archaeological settings, the method has been widely used on human remains for understanding human subsistence patterns by distinguishing C<sub>3</sub> diets (e.g. rice) from C<sub>4</sub> diets (e.g. millet) (Barton et al., 2009; Bentley, Tayles, Higham, Macpherson, & Atkinson, 2007). In the field of ceramic studies, Hastorf and DeNiro (1985) conducted the bulk carbon isotope analysis for charred organic residues on the surface of potsherds to understand the human diet. With the introduction of GC-C-IRMS, the stable carbon isotope value of individual compounds in a mixture can now be measured with high precision, providing a unique opportunity to

conduct the carbon isotopic analysis on the fatty acids that are insulated within the fabric of archaeological ceramics (H. R. Mottram, Dudd, Lawrence, Stott, & Evershed, 1999). Scholars have been successfully tracing the presence of C<sub>3</sub>, C<sub>4</sub> plants, animal fat, and aquatic resources (e.g. fish and mammals) on prehistoric potsherds through CSIA (2013; Oliver E. Craig et al., 2011; Cramp, Evershed, & Eckardt, 2011; Evershed et al., 1994, 1997; H. R. Mottram et al., 1999; Reber & Evershed, 2004a; Salque et al., 2013).

Commodities	Lipid biomarkers	References
Terrestrial animal fats	Characteristic distribution of TAGs, diacylglycerols (hereafter DAGs), monoacylglycerols (hereafter MAGs) and free fatty acids. Particularly high abundance of C <sub>16</sub> :0 and C <sub>18</sub> :0 fatty acids.	Evershed et al. 2001
Marine animal fats	Isoprenoid fatty acids (4, 8, 12-trimethyltridecanoic acid and phytanic acid). Thermally produced $\omega$ -(o-alkylphenyl)alkanoic acids	Hansel et al. 2004, Copley et al. 2004, Craig et al. 2011
Plant waxes (e.g. brassica wax)	Long chain alcohols, ketones, n-alkanes, aldehydes and wax esters. Specific biomarkers of brassica wax (cabbage) nonacosane, nonacosan-15-ol, nonacosan-15-one.	Evershed et al. 1991
Beeswax	Characteristic distribution of odd number n-alkanes (C <sub>23</sub> -C <sub>33</sub> ), even numbered free fatty acids (C <sub>22</sub> -C <sub>30</sub> ), and long chain palmitic wax esters (C <sub>40</sub> -C <sub>52</sub> )	Evershed et al. 1997, Regert et al. 2003
Birch bark tar	Triterpenoids from lupane family, namely betulin, lupeol and lupenone	Charters et al. 1993
Palm fruit	High abundance of C <sub>12</sub> :0 and C <sub>14</sub> :0 saturated fatty acid	Copley et al. 2001

Table 4.2: Identification of fatty acid by using GC-MS (modified from Stear 2008)

## IDENTIFICATION OF LIPIDS

Different criteria can be used for the identification of lipid residues. For example, the presence of fatty acids can indicate a plant or animal origin through their relative abundance, while the TAG distribution and structure are also potentially useful indicators. However, caution must be exercised when using these criteria, for ratios between fatty acids may change over time and TAGs are often only present in very

low abundance or completely absent. In addition, because of the differential degradation and variable extraction rate of organic compounds, it is hard to tell exactly what types of food were processed in the pot only with the GC-MS analysis (cf. Reber & Evershed, 2004b). A more reliable method for the elucidation of the lipid origin is to determine the stable carbon isotope (hereafter  $\delta^{13}\text{C}$ ) value of individual C<sub>16</sub>:o and C<sub>18</sub>:o fatty acids.

In this thesis, I have conducted organic geochemical analyses on the absorbed lipids extracted from the potsherds. The analyses involve two different analytic methods: GC-MS and CSIA based on GC-C-IRMS. The former is used for separation and identification of organic compounds within a potsherd, and the latter can be employed for the further isotopic analysis of specific compounds. If fatty acids such as C<sub>16</sub>:o and C<sub>18</sub>:o are found in a range of different food products, the isotopic analysis can further distinguish between their origins. Most of the recent organic geochemical studies on potsherds successfully detected the presence of different food groups including animal fat, ruminant milk, marine resources (e.g. fish and mammals), fresh water resources, C<sub>3</sub>, and C<sub>4</sub> plants with those two methods combined (Oliver E. Craig et al., 2011; Cramp et al., 2011; Reber & Evershed, 2004a).

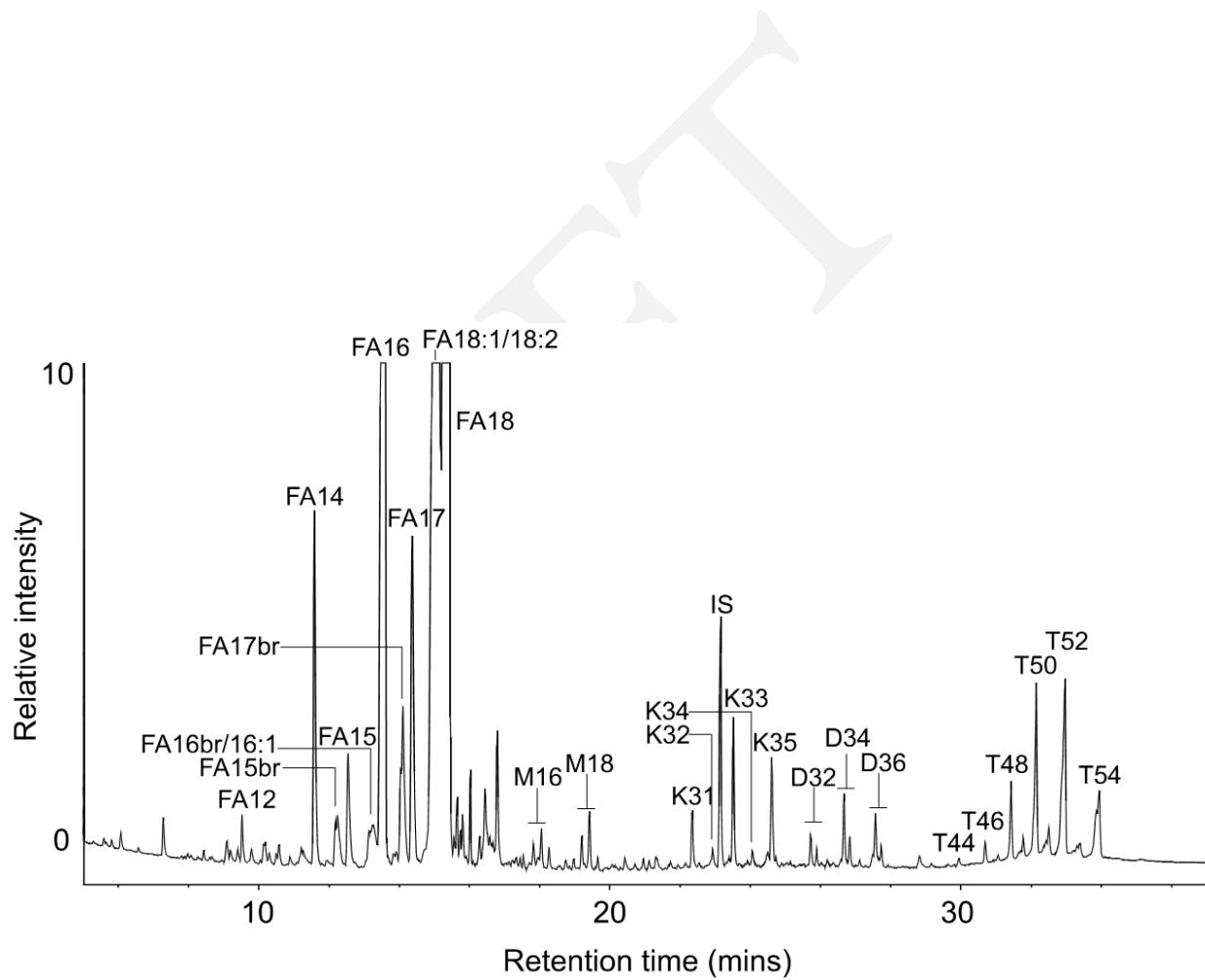


Figure 4.i: partial HTGC profile of the lipid extract from a Romano-British sherd from Stanwick, Northamptonshire (Evershed et al., 2002). Low abundances of intact TAGs are observed at retention times above 30 min. The majority of the was hydrolyzed during vessel use or burial, resulting in the formation of DAGs, MAGs, and free fatty acids. Key: IS = internal standard (n-tetratriacontane). IS was added to the sample at the extraction stage for quantification of lipid. The extracts are trimethylsilylated.

## GC-MS ANALYSIS

GC-MS enables the identification of even highly degraded commodities. A reliable classification of commodities processed in archaeological potteries can be made by comparing chemical structure of individual compounds with that of modern and archaeological references (A. J. Mukherjee, 2004). A knowledge of the degradative process occurring during vessel use and burial is essential in order to identify the lipid residues preserved within vessels. These analyses are enhanced by analyzing the results of laboratory and field experiments simulating use and degradation (cf. Dudd & Evershed, 1998; Dudd, Regert, & Evershed, 1998; Evershed, 2008a).

Figure 4.1 shows an example of degraded animal fat obtained by HTGC analysis of a Romano-British sherd from Stanwick, Northamptonshire. Low abundances of intact TAGs are observed at retention times above 30 min; however, the majority of the lipid was hydrolyzed either chemically or enzymatically during vessel use or burial, resulting in the formation of DAGs, MAGs, and free fatty acids. The fatty acids present, eluted between 10 and 20 min, comprise mainly the C<sub>16</sub>:0 and C<sub>18</sub>:0 components. The high abundance of C<sub>18</sub>:0 is indicative of animal fat.

Distributions of TAGs in ancient fats from pots can provide a reasonable evidence for the presence of animal fats and dairy products. For the detection of TAG ‘biomarkers’, GC-MS is used, which can help to make distinctions between different kinds of animal fats (Dudd & Evershed, 1998). For example, bovine adipose fats possess saturated TAGs of every carbon number between C<sub>44</sub> and C<sub>54</sub> and pig fats contain a narrow distribution of them (e.g. TAGs range from C<sub>46</sub> to C<sub>54</sub>) (cf. A. J. Mukherjee, 2004). On the other hand, milk fats are quite distinctive because of their relatively wide TAG distribution ranging from C<sub>40</sub> to C<sub>54</sub> (Dudd & Evershed, 1998; Evershed et al., 2003). Figure 4.3 shows TAG distributions of both fresh/degraded lipid residues gathered from the modern reference fats. Most importantly, however, it should be addressed that distributions of TAGs alone are not sufficient enough for the proper identification of lipid origin. Moreover, TAGs frequently do not survive in archaeological residues. Due to this vulnerable characteristic, sometimes TAGs may be misinterpreted. Figure 4.3d and e indicate fresh and degraded ruminant milk fat. Since the degradation processes during vessel use or burial make ruminant

milk TAG distributions (4.3e) similar to those of adipose fats (4.3a; b), a further decision has to be made based on a more robust stable isotopic criterion (Berstan 2002; Copley et al., 2003; Dudd & Evershed, 1998).

In this study, GC-MS was applied to identify the compounds which are only found in certain food groups (cf. Table 4.2). The biomarkers which these compounds constitute are present in different types of fats; for example, short chain fatty acids in dairy fat, unsaturated fatty acids in plant oil, cholesterol in animal fats and plant sterols (e.g. β-sitosterol) in plant oil. Especially, Phytanic acid (3,7,11,15-tetramethylhexadecanoic acid) and 4,8,12-TMTD (4,8,12-trimethyltridecanoic acid) are isoprenoid compounds that mostly found in particularly high concentrations in marine animals (Evershed, Copley, Dickson, & Hansel, 2008). Along with thermally produced long-chain O-(o-alkylphenyl)alkanoic acids, these compounds are indicators of aquatic/marine resources (Oliver E. Craig et al., 2011; Evershed et al., 2008). But, as I already indicated, they only occur in case of good preservation of food residues. One way to deal with this preservation issue, which I will employ in this study, is to use GC-MS in the selection monitoring (SIM) mode, where the analysis focuses on specific biomarkers, in order to try to get a better signal from the compounds which may be present in very low quantities, or which may be masked by more abundant compounds such as C16:0 and C18:0 fatty acids.

#### COMPOUND SPECIFIC ISOTOPE ANALYSIS

In most cases a pot is reused over time, and may be used to cook different kinds of food from one cooking episode to another. Researches with amino acids show that the first use of a pot essentially saturates it with them, and seals it from further amino acid contributions, that is, the amino acid residues trapped within a pot record only its first use (Fankhauser, 1997). On the other hand, fatty acids and other compounds tend to accumulate in the fabric of the pot wall. Therefore, the result of the analysis is, in this case, more likely to reflect the entire usages of the pot. Generally, the result is assumed to represent the type of food group that was most frequently processed in it. However, this does not mean we can just disregard the complication caused by its multiple usages. Besides, due to the differential degradation and variable extraction rate of the organic compounds, it is not easy to tell exactly what types of food were processed in

the pot only with GC-MS analysis (cf. Reber & Evershed, 2004b). On top of that, animal fats and plant oils offer great challenges, because the major components, unsaturated fatty acids in particular, rarely if ever survive, leaving mainly rather undiagnostic n-alkanoic acids such as C<sub>16</sub>:o and C<sub>18</sub>:o fatty acids (derived mainly through hydrolysis of triacylglycerols, Figure 4.2, Evershed, 2008b).

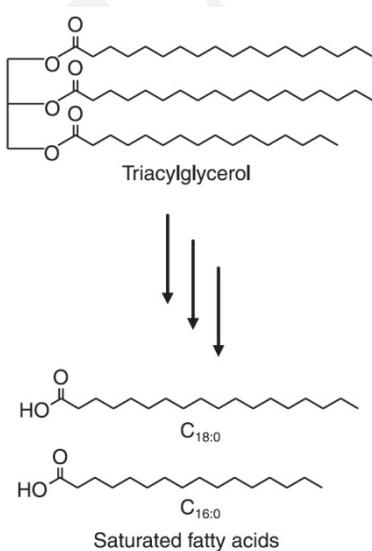


Figure 4.2: Undiagnostic C<sub>16</sub>:o and C<sub>18</sub>:o fatty acids generated through the hydrolysis of triacylglycerols due to the degradation of fat/oil during burial process. As biomarkers, C<sub>16</sub>:o and C<sub>18</sub>:o fatty acids have severely limited diagnostic value (Evershed, 2008b).

Luckily, we do have the last approach that can help us further clarify the origin of the organic compounds in a pot: compound specific stable carbon isotope analysis. Early works of stable isotope study in the archaeological field involved the bulk isotopic analysis (Haftorff & DeNiro, 1985; Morton & Schwarcz, 1988). However, the application of CSIA via GC-C-IRMS allows us to achieve a greater specificity, for the structure of diagnostic compounds in complex mixtures can be directly linked to their stable isotope value (Evershed et al., 1994). Thus, the compound specific stable isotope analysis avoids ambiguities arising from contamination by, e.g. plasticizers originating from plastic bags in which sherds are often stored. These ambiguities cannot be resolved in the bulk isotope analysis (A. J. Mukherjee, 2004). Most importantly, you do not need to have solid materials (e.g. bone) for the analysis.

Generally, different food groups tend to have different major fatty acids having different ranges of  $\delta^{13}\text{C}$  values (e.g. C<sub>16</sub>:o and C<sub>18</sub>:o). For example,  $\delta^{13}\text{C}$  values of ruminant (goat, sheep and cow/buffalo), chicken, equine, pig fats, ruminant milk, C<sub>3</sub> plant, C<sub>4</sub> plant, and aquatic resources (e.g. fish and mammals), have each their own range. Therefore,  $\delta^{13}\text{C}$  values of fatty acids provide the basis for distinguishing those food classes. Though these values were obtained from the modern fauna and flora, they have been employed as references for many archaeological studies (Oliver E. Craig et al., 2011; Cramp et al., 2011; Fraser, Insoll, Thompson, & Dongen, 2012; Reber & Evershed, 2004a, 2004b). In proceeding in this fashion, these studies assume that the  $\delta^{13}\text{C}$  values of modern samples are comparable to those of ancient members of the same species. Scholars were able to detect the presence of those types of food by measuring  $\delta^{13}\text{C}$  values of the two most common fatty acids in archaeological pots: palmitic acid (C<sub>16</sub>:o) and stearic acid (C<sub>18</sub>:o) with GC-C-IRMS, which provides a means to address some key questions concerning human subsistence in prehistory (2013; Oliver E. Craig et al., 2011; Evershed et al., 1994, 1997; H. R. Mottram et al., 1999; Salque et al., 2013).

In nature carbon exists as three isotopes, <sup>12</sup>C and <sup>13</sup>C, which are both stable, and <sup>14</sup>C, which is radioactive. Occurring as CO<sub>2</sub> (carbon dioxide), they are organizing respectively 98.89 %, 1.11 %, and  $1 \times 10^{-10}$  % of the global carbon pool. Being inorganic, carbon dioxide is incorporated into living organisms through the process of photosynthesis. Green plants transform carbon dioxide and water into oxygen and organic sugars. When incorporated into the plant tissue through photosynthesis, isotopic fractionation occurs and the ratio between <sup>13</sup>C to <sup>12</sup>C changes significantly, because plants use the carbon dioxide containing the lighter isotope, <sup>12</sup>CO<sub>2</sub>, more readily than that of the heavier isotope, <sup>13</sup>CO<sub>2</sub>. Plants are consumed by herbivores, and herbivores are consumed by carnivores. If one can measure the ratio between <sup>13</sup>C to <sup>12</sup>C in the remains of those organisms and compare with known reference isotope ratios, then it will be possible to trace their diet.

The stable carbon isotope ratio is measured by comparing the relative differences of <sup>13</sup>C to <sup>12</sup>C between the sample and the international standard, Pee Dee belemnite (PDB), a limestone from South Carolina (Malainey, 2010):

It is expressed using the delta ( $\delta$ ) notation:

$$\delta^{13}C = \left( \frac{R_{\text{sample}} - R_{\text{standard}}}{R_{\text{standard}}} \right) \times 1000$$

Where:

$R_{\text{sample}}$  = molar  $^{13}\text{C}/^{12}\text{C}$  ratio of the sample,

$R_{\text{standard}}$  = molar  $^{13}\text{C}/^{12}\text{C}$  ratio of the standard

The  $\delta^{13}\text{C}$  value is the difference between the  $^{13}\text{C}$  content of the sample and that of the standard, and is expressed relatively to the international standard. Differences between samples are very small, so values are counted per mil (‰), rather than percent (%). The standard contains less  $^{12}\text{C}$  and more  $^{13}\text{C}$  than most natural materials, so  $\delta^{13}\text{C}$  values of samples are usually negative, ranging between -37 and -8‰. The error range for compound specific  $\delta^{13}\text{C}$  values of fatty acids is  $\pm 0.3\%$ .

#### MODERN REFERENCE ANIMAL FATS AND PLANT OILS

Naturally, plants and animals of today cannot be directly compared to those of prehistoric times, due to the various environmental changes that have occurred over the last few hundred years. There are several factors of these changes including: (1) consuming fossil fuel since the industrial revolution which has caused changes in the isotopic composition of  $\text{CO}_2$  in the air (Friedli, Lütscher, Oeschger, Siegenthaler, & Stauffer, 1986); (2) commercial farming due to which animals have been fed with supplements to enhance their diets and to improve the nutritional quality of their meat and milk (cf. Chilliard, Ferlay, & Doreau, 2001; Lowe, Peachey, & Devine, 2002); and (3) selective breeding that has introduced changes in the composition of the fat and milk of domestic animals. There are also regional level factors. For example in Great Britain, since C<sub>4</sub> plants (e.g. millet) have been introduced and incorporated into animals' diet not long ago, it is hard to directly compare  $\delta^{13}\text{C}$  values of modern and prehistoric animals (Stear, 2008).

The identification of plant oils through the isotope analysis is possible, for the range of  $\delta^{13}\text{C}$  values is different in each group of plants that share the photosynthetic pathway. Terrestrial plants use three different photosynthetic pathways, namely C<sub>3</sub>, C<sub>4</sub> and CAM. The C<sub>3</sub> plants (e.g. wheat, rye, barley, legumes) are the most abundant, and are found mainly in moderate areas. They fix atmospheric  $\text{CO}_2$  using the Calvin

and Benson cycle (Calvin, Benson, & others, 1948).  $^{13}\text{CO}_2$  is discriminated by Ribulose-1,5-bisphosphate carboxylase/oxygenase (hereafter RuBisCO), resulting in relatively low  $\delta^{13}\text{C}$  values ranging from -32 to -20 ‰ (Boutton, 1991). C<sub>4</sub> plants (e.g. millet, maize, sugarcane, sorghum) fix CO<sub>2</sub> through the Hatch-Slack pathway (Hatch & Slack, 1966), and carbon fixation occurs near the surface of the leaf in mesophyll cells with phosphoenolpyruvate (hereafter PEP). The latter pathway gives relatively high  $\delta^{13}\text{C}$  values in the range of -17 to -12.5 ‰ (Malainey, 2010). Crassulacean acid metabolism (hereafter CAM) plants (e.g. pineapple, aloe vera, jade plant) can either assimilate CO<sub>2</sub> at night only or night and day. Carbon fixation at night occurs through PEP carboxylase as in C<sub>4</sub> plants. On the other hand, during the day time, CAM plants can switch their photosynthetic pathway and use RuBisCO to fix CO<sub>2</sub>. As a result, the range of  $^{13}\text{C}$  values for some CAM plants is quite broad (cf. Malainey, 2010).

For the identification of animal fats originated from archaeological pottery, they were compared with the carefully assembled data of modern fats (O. E. Craig et al., 2013; Copley et al. (2003); Dudd & Evershed, 1998; Evershed et al., 2003). The treatment of modern fats to create the reference database is slightly different from case to case. In Britain, only the animals that are being reared on known diets were sampled in order to form the database (e.g. C<sub>3</sub> plant diet in order to mimic the prehistoric condition, absence of C<sub>4</sub> plant), including adipose fats from cattle, sheep and pigs, and milk fat from cattle and sheep (Copley et al., 2003; Dudd & Evershed, 1998; Evershed et al., 2003). The  $\delta^{13}\text{C}$  values from these animals reflect their different diets and variations in their metabolism as well as physiology (Evershed et al., 1999; Stear, 2008). The ellipses shown in Figure 4.4a indicate the  $\delta^{13}\text{C}$  values obtained from the C<sub>16</sub>:o and C<sub>18</sub>:o fatty acids from each of the reference animal fats; sheep and cattle data are grouped together as ruminant fats. Dairy and adipose fats from ruminant animals can be distinguished, for the C<sub>18</sub>:o fatty acid in dairy fat is significantly more depleted in  $\delta^{13}\text{C}$  value (average 2.1 ‰, Copley et al., 2003). In Japan, to avoid the effect of commercial farming and selective breeding, modern reference samples were collected from authentic wild animals (Figure 4.4b). To facilitate comparison with archaeological data, the  $\delta^{13}\text{C}$  values obtained from all modern reference animals were adjusted by the addition of 1.2% considering post-Industrial Revolution effects of fossil fuel burning (Friedli et al., 1986).

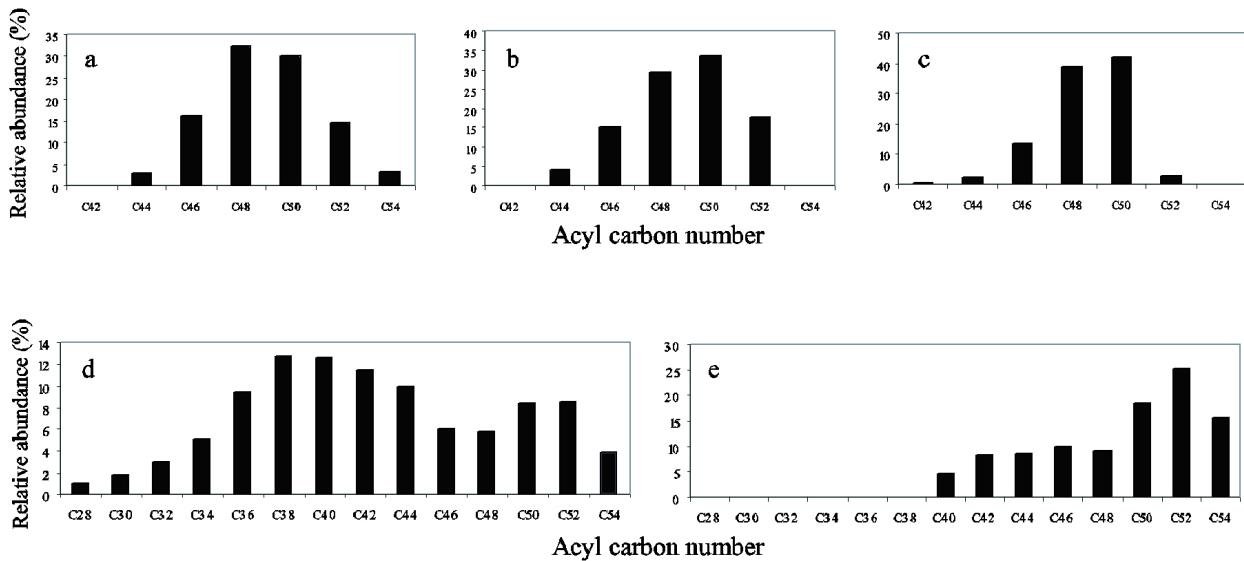


Figure 4.3: The distributions of TAGs in different kinds of animal fats (modified from A. J. Mukherjee, 2004: p. 20). (a): cow adipose fat (b): sheep adipose fat (c): pig adipose fat (d): fresh milk (e): milk degraded for 90 days

#### INTERPRETATION OF CSIA

For the interpretation of CSIA, the  $\delta^{13}\text{C}$  values acquired from the C16:0 and C18:0 fatty acids in archaeological potsherds are plotted in the figure of the reference animal fat ellipses (Figure 4.5a). When the  $\delta^{13}\text{C}$  values of fatty acids plotted within an ellipse, like the case of the pork (porcine) fat in Figure 4.5a, then the fat in question can be identified as pork fat. When the  $^{13}\text{C}$  values are plotted just outside the ellipse, then the fat can be identified 'predominantly' as pork fat. However, in most cases the  $\delta^{13}\text{C}$  values are located between the ellipses of the reference fats, which indicates the mixing of different classes of food stuffs within the vessel either at a moment or during all the time of its use.

To account for the mixing of different animal fats in varying proportions within a single vessel, a theoretical mixing model is used to calculate theoretical  $\delta^{13}\text{C}$  values following A. J. Mukherjee (2004; cf. Bull et al., 1999; Woodbury, Evershed, Rossell, Griffith, & Farnell, 1995):

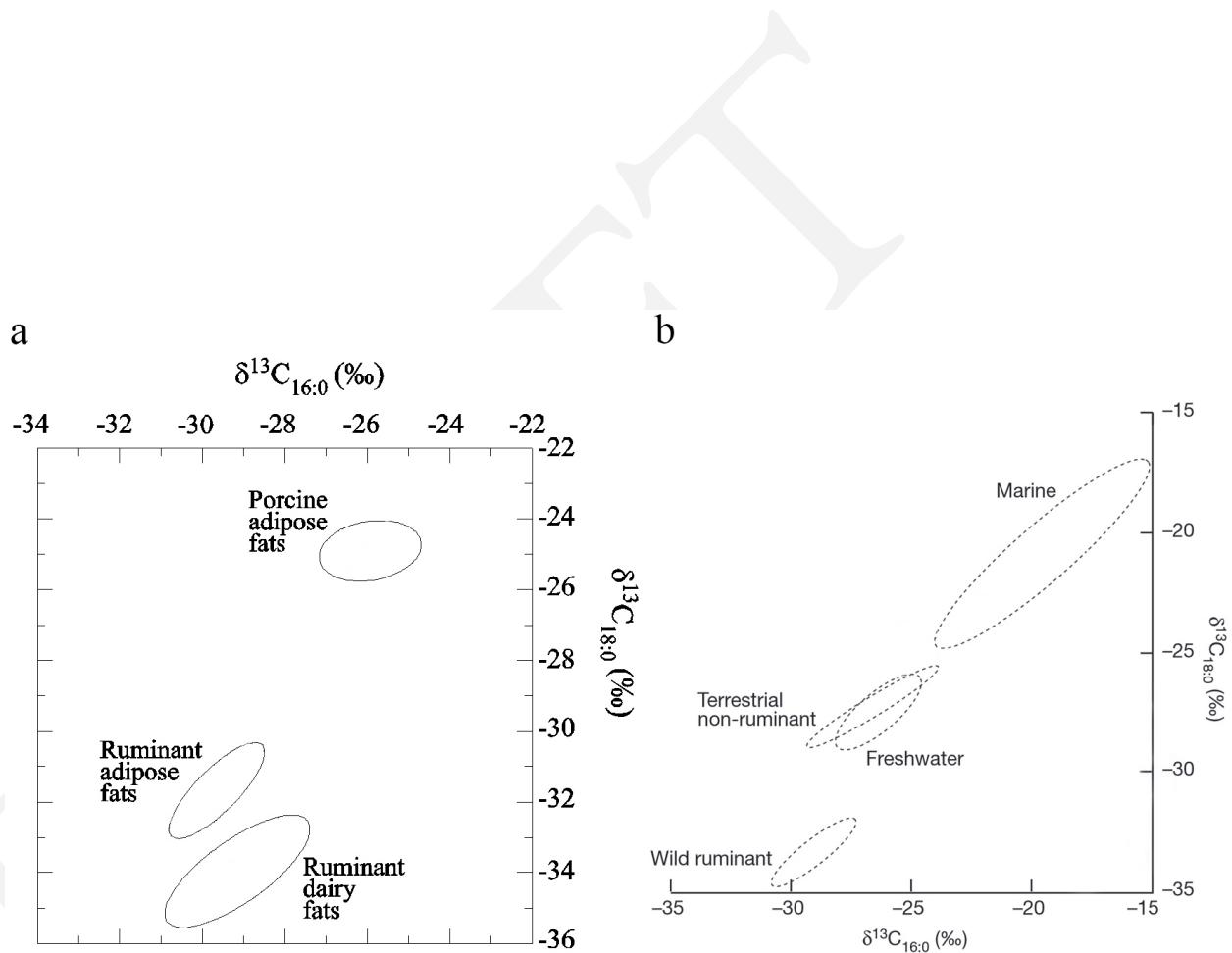


Figure 4.4: Reference database created based on modern fats for CSIA. (a): Only the animals having been reared on known diets were sampled (e.g. C<sub>3</sub> plant diet in order to mimic the prehistoric condition, absence of C<sub>4</sub> plants) (Copley et al., 2003; Dudd & Evershed, 1998). (b): The  $\delta^{13}\text{C}$  values obtained from all modern reference animals were adjusted by the addition of 1.2 permil, considering post-Industrial Revolution effects of fossil fuel burning (Friedli et al., 1986).

$$\delta^{13}C_{mix} = \delta^{13}C_{(A)} \left( \frac{(X \times A)}{(X \times A) + (Y \times B)} \right) + \delta^{13}C_{(B)} \left( \frac{(Y \times B)}{(X \times A) + (Y \times B)} \right)$$

Where:

$\delta^{13}C_{mix}$  = predicted  $\delta^{13}C$  value of the fatty acid with contributions from fats A and B

$\delta^{13}C_{(A)}$  =  $\delta^{13}C$  value of the individual fatty acid in fat A

$\delta^{13}C_{(B)}$  =  $\delta^{13}C$  value of the individual fatty acid in fat B

X = percentage of fat A present (%)

Y = percentage of fat B present (%)

A = percentage of the individual fatty acid in fat A (%)

B = percentage of the individual fatty acid in fat B (%)

Theoretical mixing curves between the porcine adipose fat, ruminant adipose fat and ruminant dairy fat are shown in Figure 4.5b. The ellipses which represent different food classes (ruminant adipose fat, ruminant dairy fat and porcine adipose fat) are connected by a theoretical mixing curve (Figure 4.5b).

When utilizing this theoretical mixing model for the interpretation of the contributions of different food-stuffs within mixture, we need to consider several important points. First of all, it is nearly impossible to quantify exactly how much mixing was occurred during each vessel use, and how often each vessel was subsequently re-used (A. J. Mukherjee, 2004). It is also difficult to estimate the exact relative amount of different food classes cooked in each pot over its lifetime usage, for the concentration of the fatty acids from different food classes varies significantly (Enser, 1991).

#### POSSIBILITIES OF VARIATION IN THE $\delta^{13}C$ VALUES OF FATTY ACIDS FROM ARCHAEOLOGICAL LIPID

##### C<sub>3</sub>, C<sub>4</sub> and marine plant contributions

Plants are consumed by herbivores and herbivores are consumed by carnivores. Since  $\delta^{13}C$  values in living organisms are influenced by their food, careful consideration is demanded, when the researcher tries to trace their identity based on  $\delta^{13}C$  values. For example, discriminating the contribution of C<sub>4</sub> plants to the diet of animals is not an easy task. This task might not be a problem in the areas where there are no native

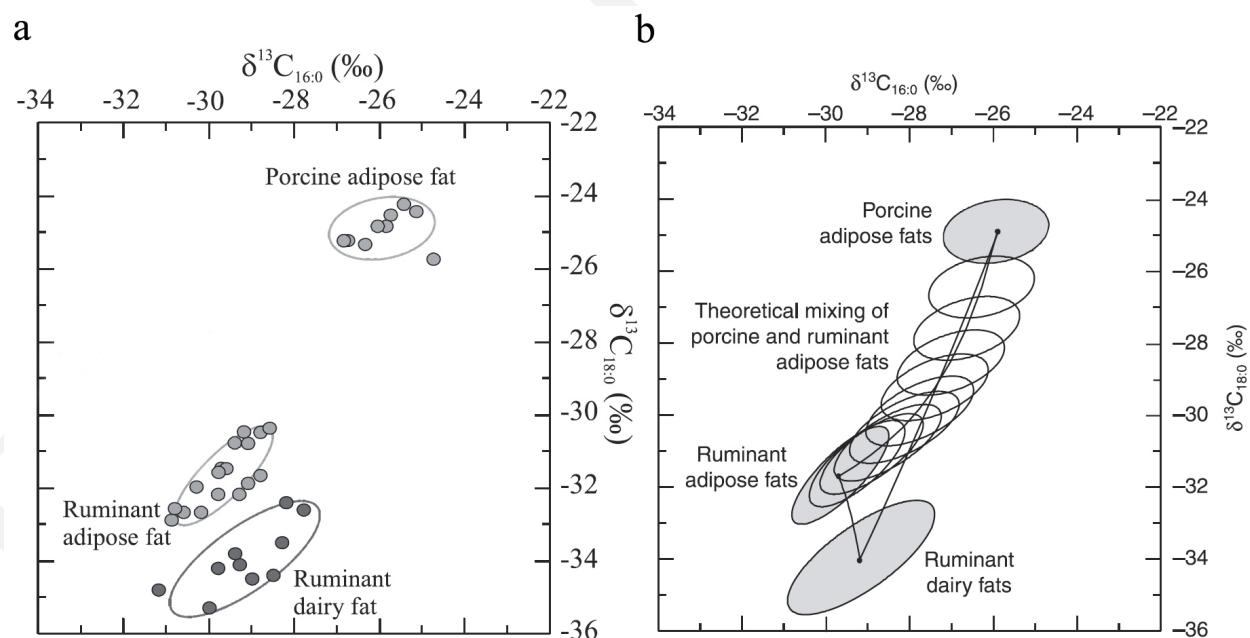


Figure 4.5: Interpretation of the results of CSIA (a):  $\delta^{13}\text{C}$  values acquired from the C<sub>16:0</sub> and C<sub>18:0</sub> fatty acids in archaeological potsherds are plotted along with the reference animal fat ellipses (R. P. Evershed, 2007) (b): Theoretical mixing curves between the porcine adipose fat, ruminant adipose fat and ruminant dairy fat are shown (Evershed, 2008b)

C<sub>4</sub> plants (e.g. the northern part of Europe or Britain), but must be taken into account when analyzing the lipids from more arid regions, where C<sub>4</sub> plants are quite ubiquitous. Table 4.3 shows the ranges of bulk  $\delta^{13}\text{C}$  values of the major ecosystem; it provides a guideline to the trends that might be observed in archaeological lipids (A. J. Mukherjee, 2004).

Material	Bulk $\delta^{13}\text{C}$ value (‰)
C <sub>3</sub> plant	-32 to -20
C <sub>4</sub> plant	-17 to -9
CAM plant	-20 to -10
Groundwater	-25 to -10
Atmospheric CO <sub>2</sub>	-8
Sea grasses	-15 to -3
Marine vertebrates	-17
Marine carbonates	0

Table 4.3: The ranges of bulk  $\delta^{13}\text{C}$  values of natural materials (modified from Mukherjee 2004)

In case of the archaeological lipid present in potsherds, the contribution of C<sub>4</sub> plants to an animal's diet would have caused more enriched  $\delta^{13}\text{C}$  values of the C<sub>16</sub>:o and C<sub>18</sub>:o fatty acids. So, if the reference animals used to compile the database are reared on C<sub>3</sub> diets, the  $\delta^{13}\text{C}$  values from archaeological lipids will show a deviation from those given by the database, when identifying animal fats with a possible C<sub>4</sub> diet contribution. This means, for example, it is quite possible that pure ruminant adipose fat can be misinterpreted as a mixture of ruminant and porcine adipose fats, or even pure pig fat (cf. Figure 4.5).

This can be overcome by comparing the difference between the  $\delta^{13}\text{C}$  values of the C<sub>16</sub>:o and C<sub>18</sub>:o fatty acids for the reference fats and that of archaeological fats ( $\Delta^{13}\text{C}$ ). The comparison will be expressed by following formula:

$$\Delta^{13}\text{C} = \delta^{13}\text{C}_{18:\text{o}} - \delta^{13}\text{C}_{16:\text{o}}$$

This can separate fats based on physiological differences between the animals (e.g. ruminant adipose, ruminant dairy, and non-ruminant adipose) regardless of differences of their diets or surrounding ecosystem (Figure 4.6, Copley et al. (2003); Evershed et al. (2008)).

At coastal sites such as shell middens, the contribution of marine plants needs to be considered. For example, the diet of sheep in North Ronaldsay, Great Britain is dominated by seaweed, only a small quantity of terrestrial grass being grazed by them seasonally. As a result, the bulk  $\delta^{13}\text{C}$  values acquired from their bone collagen measured around  $-13\text{\textperthousand}$ , a range of  $\delta^{13}\text{C}$  values which overlaps that of pure marine consumers (Ambers, 1990, 1994; cf. A. J. Mukherjee, 2004).

Most marine plants cannot absorb carbon dioxide directly from the atmosphere, but from dissolved gasses in the surrounding water. Though the  $\delta^{13}\text{C}$  value of marine  $\text{CO}_2$  is variable, and mainly depends on depth with other localized factors, it is usually in the region of  $0\text{\textperthousand}$ . Despite the difference in photosynthetic mechanism between marine and terrestrial plants, marine plants fractionate carbon approximately to the same extent as terrestrial  $\text{C}_3$  plants; and they have  $\delta^{13}\text{C}$  values in the range of  $-11$  to  $-19\text{\textperthousand}$  (Chisholm, Nelson, & Schwarcz, 1982). Foreshore plants that are not permanently submerged underwater may be more complicated, but still show a marine signature. Their  $\delta^{13}\text{C}$  values are distinguishable from  $-25\text{\textperthousand}$  of  $\text{C}_3$  plants (Ambers, 1990, 1994). Therefore, animals eating large amounts of marine and foreshore plants (e.g. seaweed), should be distinguished from those which eat predominantly terrestrial diets. However, if archaeological samples were collected from where both  $\text{C}_4$  plants and marine/foreshore ones are present, researchers need to carefully consider whether relatively enriched  $\delta^{13}\text{C}$  values in animal fats are from  $\text{C}_4$  plants or marine/foreshore ones.

#### Forest density and depletion of $^{13}\text{C}$

In the areas covered with dense forest we see a significant deviation of  $^{13}\text{C}$  distribution from the global average causing plants to be depleted of  $^{13}\text{C}$ . In these regions, a positive correlation between the forest density and the degree of depletion of  $^{13}\text{C}$  is observed. In addition, there is a gradual variation of  $\delta^{13}\text{C}$  values of tree leaves from the ground to the top of the tree; and it indicates that the most negative values occur near the ground (E. Medina & Minchin, 1980; Vogel, 1978). This is what we call the ‘canopy effect’ (E. Medina & Minchin, 1980). The average bulk  $\delta^{13}\text{C}$  value of  $\text{C}_3$  plants in open air areas is about  $-26\text{\textperthousand}$ . However, for the leaves in a subtropical monsoon forest, a  $\delta^{13}\text{C}$  value of  $-35\text{\textperthousand}$  was recorded, and a value as low as  $-37\text{\textperthousand}$  was observed in the Amazon forest (Ehleringer, Lin, Field, Sun, & Kuo, 1987; E. Medina, Klinge, Jordan, & Herrera, 1980).

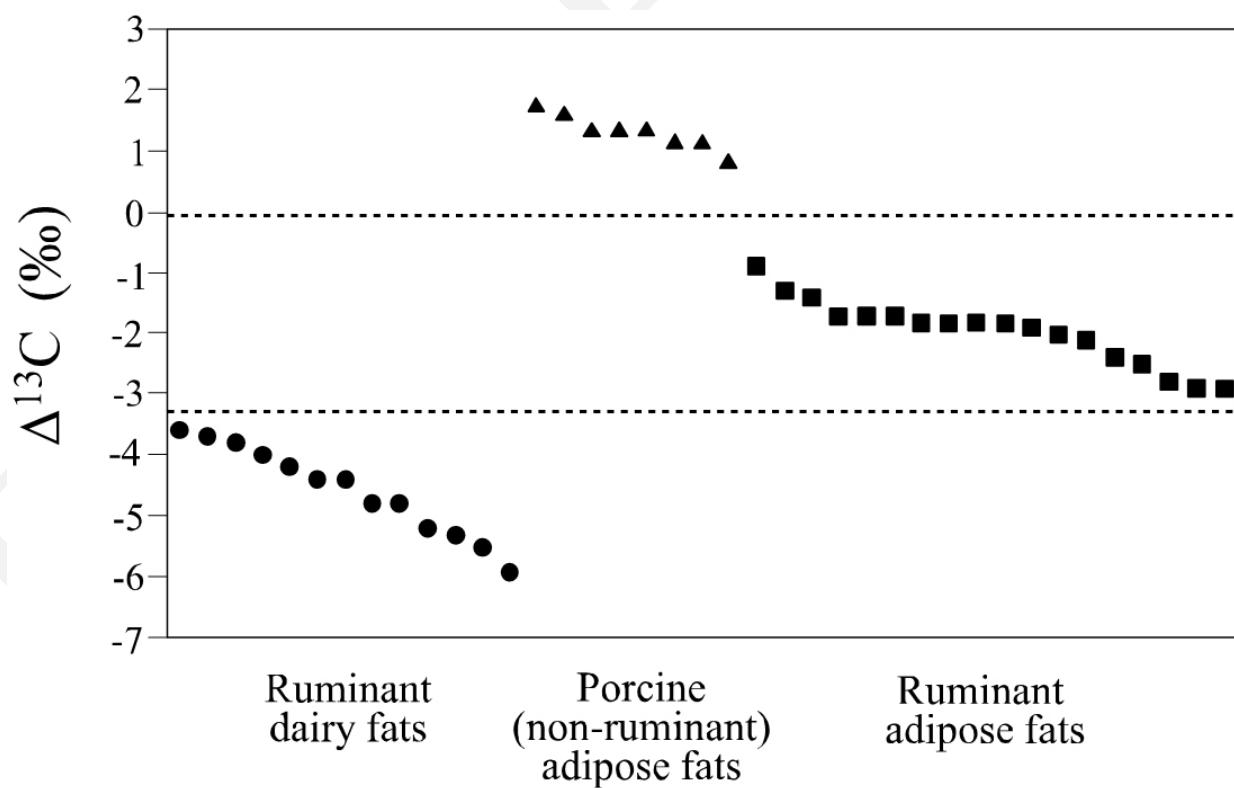


Figure 4.6: Plots showing the difference in the  $d^{13}\text{C}$  values of the C<sub>18:0</sub> and C<sub>16:0</sub> fatty acids ( $\Delta^{13}\text{C} = d^{13}\text{C}_{18:0} - d^{13}\text{C}_{16:0}$ ) obtained from the modern reference fats (Copley et al., 2003)

This phenomenon in dense forest areas will influence the  $\delta^{13}\text{C}$  values of fatty acids extracted from the local ruminant animals and pigs dwelling in forest (Van Der Merwe & Medina, 1989). Therefore, if the reference animals used for the study were not raised within forest environment, they may have more enriched  $\delta^{13}\text{C}$  values of fatty acid, compared with their ancient counterparts which dwelled in forest. That is, fatty acids from archaeological fats might indicate more negative  $\delta^{13}\text{C}$  values than those of their modern counterparts; and this must be carefully considered.

#### Variations in $\delta^{13}\text{C}$ values of $\text{CO}_2$

Things change over time. Any variation in the atmospheric  $\text{CO}_2$  which occurred over time as a result of climate change or environmental fluctuations, may have caused a deviation of  $\delta^{13}\text{C}$  values of archaeological animal fats from the reference values. The variation in the  $\delta^{13}\text{C}$  value of atmospheric  $\text{CO}_2$  from the multiplied tree-ring record obtained from oaks suggests it can vary up to 1.5 ‰ (Figure 4.7a), McCormac et al., 1994). Even within a relatively short term,  $\delta^{13}\text{C}$  value of atmospheric  $\text{CO}_2$  can vary quite dynamically (Figure 4.7b, Robertson et al., 1997). It is likely that other terrestrial plants will also show variation in a similar way, but its scale might differ between the species (A. J. Mukherjee, 2004). The differences in  $\delta^{13}\text{C}$  values between modern and ancient fats resulting from such temporal variation in atmospheric  $\text{CO}_2$  can be overcome by comparing  $\delta^{13}\text{C}$  values of modern reference and archaeological fats.

#### Sources of variation related to human activity

As I mentioned above, the theoretical mixing curve was calculated to consider mixing of different food products within a single vessel during its lifetime usage. However, in some cases, mixture with other uneatable natural products is often observed. For example, the beeswax contained in lipid extracts from potsherds appears often as a mixture with degraded fat from foodstuffs. Beeswax is characterized by a distribution of linear hydrocarbons of odd-numbered carbon ( $\text{C}_{21} - \text{C}_{23}$ ), free fatty acids of even-numbered carbon ( $\text{C}_{22} - \text{C}_{30}$ ), and/or long-chain wax esters with the carbon number range from  $\text{C}_{40}$  to  $\text{C}_{52}$  (Kolattukudy 1976; cf. A. J. Mukherjee, 2004). Though the exact reasons for the presence of beeswax in archaeological pottery vessels are yet unknown, it may have been used as a ‘slip’ due to its hydrophobic characteristic, or it might be a byproduct of the use of honey in cooking/flavoring. The abundant  $\text{C}_{16:0}$  fatty acid present in modern beeswax exhibits a  $\delta^{13}\text{C}$  value of around -26.4 ‰, while  $\text{C}_{18:0}$  fatty acid is

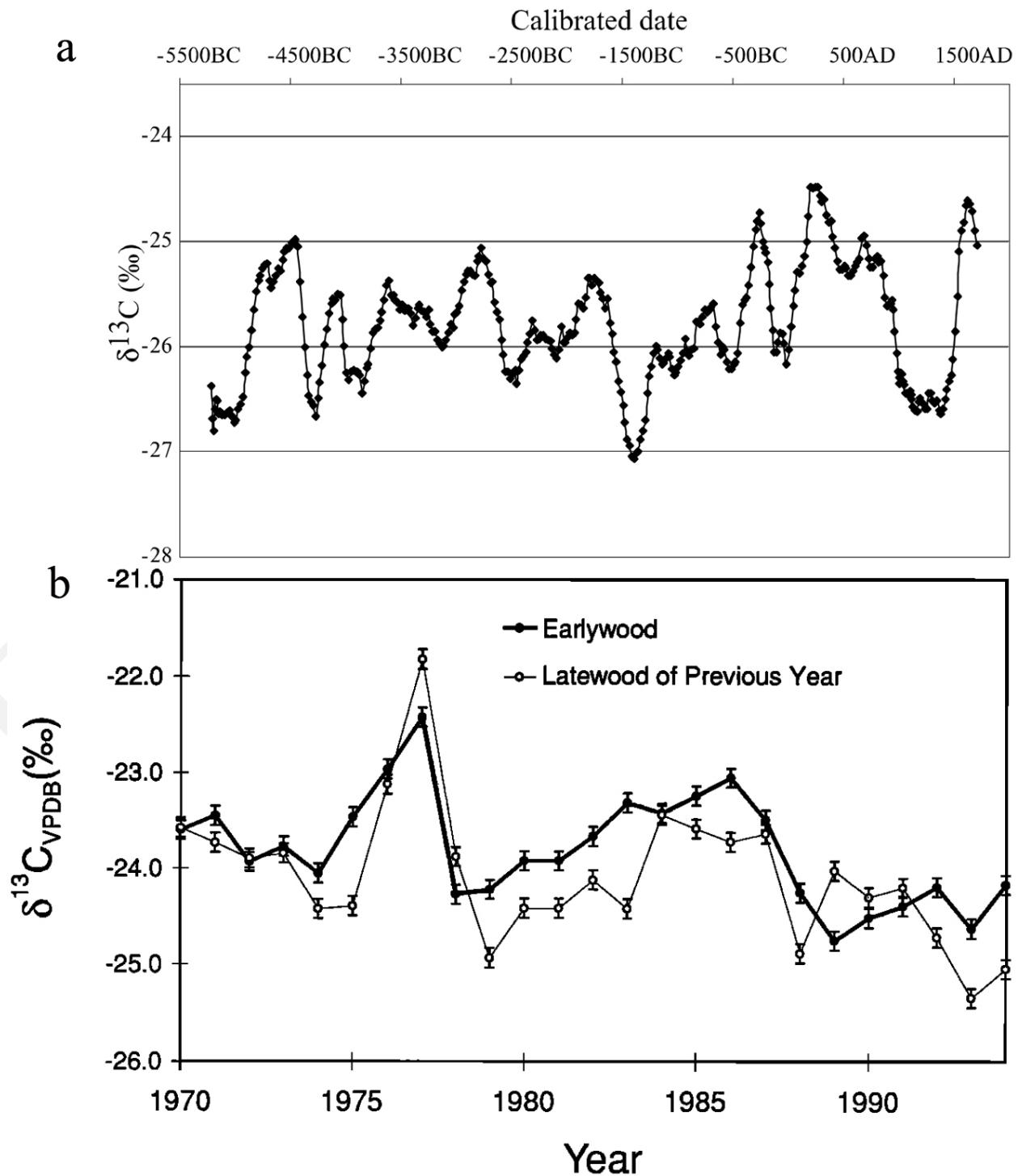


Figure 4.7:  $^{13}\text{C}$  values of cellulose from the oak tree-ring sequence (a): 11-yr running mean from ancient Irish oaks (data obtained from McCormac, Baillie, Pilcher, Brown, & Hoper, 1994; A. J. Mukherjee, 2004) (b): Yearly measurement from 1970 to 1995 of modern oaks in east England (Robertson et al., 1997)

present in low abundance (A. J. Mukherjee, 2004). In this situation it is important to assess whether there is a significant isotopic contribution from natural products like beeswax and how it may influence our interpretation of isotopic analyses.

#### RELATING LIPID RESIDUES TO FAUNAL ASSEMBLAGES

In most cases, animal domestication in prehistory has been assessed through the analysis of bone assemblages. In a dairy economy we may assume that an adult herd consists mostly of cows, with a small number of bulls for breeding and regularity in the group. It is also assumed that the majority of males were killed soon after their birth. In this perspective, it is quite probable that a bone assemblage from a dairy economy comprise generally calves and adult cows. On the other hand, in a meat-producing economy, animals were slaughtered just before they became adults (Legge, 1981; McCormick, 1992; S. Payne, 1973).

As I have mentioned just above, bone assemblages are often used to understand animal exploitation. However, there are some complications with interpretation. For example, (1) bone assemblages found at one place may not truly represent the actual fact, because animals may have been killed and processed at other places; (2) in acidic soils, juvenile or fragile bones are preferentially lost; (3) a bone assemblage may be incomplete due to the bones that have been discarded away from the site. Since it is possible to apply the recent progress of the analysis of lipid residues to understanding aspects of animal domestication, it is advisable to compare the interpretations based on fatty acid  $\delta^{13}\text{C}$  values and from bone assemblages.

When conducting CSIA, the best way to establish the reference database is to collect modern samples of fauna and flora from the same region where archaeological materials were collected. However, as I mentioned above, the modern day's commercial farming with supplements makes it impossible for us to directly compare  $\delta^{13}\text{C}$  values from archaeological materials with those from modern samples. To overcome this issue, scholars have been collecting samples from wild fauna and flora for creating the reference database. Unfortunately, in case of Korea, since wild terrestrial mammals are extremely rare, this type of approach is practically impossible.

In this thesis, as for the CSIA, the archaeological samples from the central part of the Korean peninsula were sent to the Stable Isotope facility at the University of California-Davis, and analyzed by Varian CP3800 GC coupled onto a Saturn 2200 ion trap MS/MS. Based on the results, the stable carbon isotope values of C<sub>16</sub>:0 and C<sub>18</sub>:0 fatty acids from the archaeological samples will be compared with the available modern references that were obtained from the modern fauna and flora that exist in either Japan, Northern Europe or North America (Copley et al., 2003; 2013; Oliver E. Craig et al., 2011; Cramp et al., 2011; Dudd & Evershed, 1998; Dudd, Evershed, & Gibson, 1999; Evershed et al., 1994, 1997; H. R. Mottram et al., 1999; Reber & Evershed, 2004a; Salque et al., 2013; V. J. Steele, Stern, & Stott, 2010) to detect the presence of the potentially cooked resources in the prehistoric Korean peninsula. Since the overall ecosystem of Japan, Northern Europe, and North America is similar to that of Korea and almost all the fauna and flora having produced the data for reference exist also in the Korean peninsula, this approach assumes that the  $\delta^{13}\text{C}$  values of available modern samples are comparable to archaeological ones from the Korean peninsula.

#### ANALYTICAL PROCEDURES

Lipids are medium-sized molecules that possess predominantly linear, branched or cyclic hydrocarbon skeletons making them soluble in organic solvents (Correa-Ascencio and Evershed 2014). For this reason, the most well-known way of the extraction of organic compounds is using a solvent mixture (e.g. chloroform-methanol 2 : 1 v/v) and the ultra-sonication of powdered potsherds. The main purpose of this approach is to extract free fatty acids and other organic compounds that are absorbed and trapped in the voids of clay matrixes. This way of extraction of lipids from archaeological ceramics by a solvent mixture has proven its effectiveness in different parts of the world. However, Craig and his colleagues (2004) showed that lipid recovery can be incomplete when extracting with a solvent mixture, and some portions of residues do remain non-extractable without the use of a stronger extractant (e.g. methanolic sodium hydroxide). As a response to that, Correa-Ascencio and Evershed (2014) recently developed a new extraction protocol that uses acidified methanol (2% sulfuric acid-methanol v/v). According to Correa-Ascencio and Evershed, this new “methanolic acid extraction” has several advantages over the

method of conventional solvent extraction:

- (1) The new method can recover both free and bound lipids from the ceramic matrix and therefore, is especially effective in increasing the recovery rate of lipid residues from archaeological pottery containing those of low concentration (Figure 4.9). In this regard, the application of this new method has the potential to expand the limits of the analysis of archaeological lipid residues when lipid preservation is limited.
- (2) The simultaneous extraction and derivatization of lipid residues shorten significantly the time and materials require for further isotopic analyses to one day of overall laboratory time instead of 4 to 5 days required when the chloroform : methanol extraction method is applied; and they shorten also the materials require.
- (3) The major disadvantage of the new method is the compositional information loss due to the hydrolysis of complex lipids (e.g. acylglycerols and wax esters) during the extraction process. However, the loss of these lipids is not problematic as they are the components that occur rarely, or in very low abundance, in most archaeological assemblages.

In this thesis, both methods were employed to test their suitability for the Korean peninsula. Figure 4.8 shows differences between the solvent and acid extractions.

#### GLASSWARE, SOLVENTS AND REAGENTS

All the solvents used for this research were HPLC (High-performance liquid chromatography) grade. The reusable glassware was washed with Decon 90 (Decon laboratories), rinsed with acetone, dried in the oven at first and heated in the furnace (450 BoC; 24 hours). In order to prevent contamination, combusted foil and tweezers were used to manipulate the samples. Analytical blanks were prepared with each batch of samples during each procedure of lipid extraction and derivatization to monitor any possible source of contamination. Analytical grade reagents (typically b %98% purity) were used throughout.

## SOLVENT EXTRACTION OF LIPIDS

Lipids were extracted following an established protocol outlined in Figure 4.8a. Approximately 5-10 g of each potsherd was sampled and the surface was cleaned using a drill (Dremel 3000) to remove any external contaminations, such as those originating from soil or fingers due to handling during the excavation/curation process. The cleaned sample was ground to fine powder in a glass mortar & pestle and accurately weighed to be put in a glass vial. Lipids were extracted using chloroform : methanol (2:1; 10 mL) and sonicated (20 min.  $\times$  2). The extract was then centrifuged (2500 rpm; 10 minutes.) and only the liquid portion containing the Total Lipid Extraction (hereafter TLE) was removed and transferred to a glass vial. The TLE was filtered through a silica column (1 g) to remove any particulate matter and accidental inclusions of solid materials. About a half portion of the TLE was derivatized to form Trimethylsilyl (hereafter TMS) ethers and esters prior to analysis by GC-MS. The other half was derivatized to fatty acid methyl esters (hereafter FAMEs) and analyzed by GC and GC-C-IRMS.

## PREPARATION OF TMS DERIVATIVES

One half of the TLE was treated with N<sub>o</sub>-bis(trimethylsilyl)trifluoroacetamide (hereafter BSTFA) containing 1 % trimethylchlorosilane (40  $\mu$ L; 70 BoC; 1 hour). Then, BSTFA was removed under gentle nitrogen gas and the derivatized TLE was dissolved in toluene (50  $\mu$ L) prior to GC-MS.

## PREPARATION OF FAMEs

The FAME derivatives of the free fatty acids were prepared by heating them with BF<sub>3</sub>-methanol (14 % w/v; 100  $\mu$ L; 70 BoC; 1 hour). Nano-purified water was added (1 mL) and the FAME derivatives were extracted with chloroform (3  $\times$  2 mL) and the solvent was removed under nitrogen. The FAMEs were redissolved in hexane prior to the analysis by GC-MS and GC-C-IRMS.

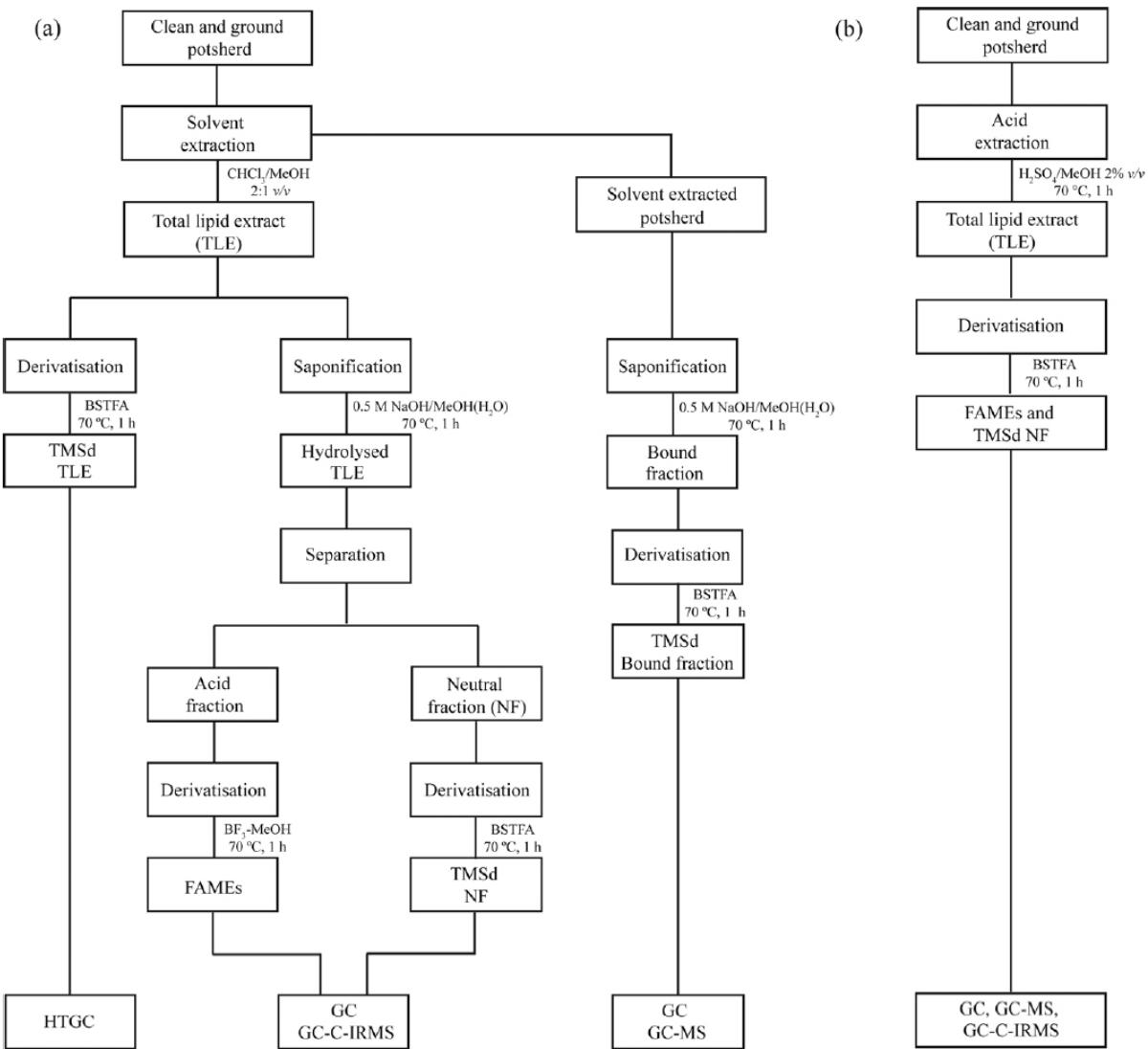


Figure 4.8: The comparison between (a) the solvent extraction protocol and (b) the acid extraction protocol (Correa-Ascencio & Evershed, 2014)

## METHANOLIC ACID EXTRACTION OF LIPIDS

Lipids were extracted following an established protocol outlined in Figure 4.8b. Approximately 5g of each potsherd was sampled and the surface was cleaned using a drill (Dremel 3000) to remove any external contaminations. The cleaned sample was ground to fine powder in a glass mortar & pestle and accurately weighed. The sample was transferred into a culture tube (I) and 5mL of H<sub>2</sub>SO<sub>4</sub> (sulfuric acid) : MeOH (methanol) were added to it; and the whole was heated (2% v/v, 70 BoC, 1 hour, vortex-mixing every 5 minutes). It is important to check the pH after extraction whether the sample is still acid, for carbonate-rich ceramic fabrics might neutralize acid. If the pH is below 3, then more H<sub>2</sub>SO<sub>4</sub> : MeOH should be added. The H<sub>2</sub>SO<sub>4</sub> : MeOH solution containing the extract was transferred to the test tube, and centrifuged for 10 minutes (2500 rpm). The clear solution was transferred to another clean culture tube (II) and 2mL of nano-purified water were added. Then, 4 mL of hexane were dropped in the culture tube (I), and vortex-mixed to recover any lipids that are not fully extracted by the methanol solution. The hexane portion was transferred in the culture tube (II) and vortex-mixed with the H<sub>2</sub>SO<sub>4</sub>:MeOH solution to extract the lipids. The washing of the culture tube (I) with hexane and vortex-mixing in the culture tube (II) was repeated twice. Then, the hexane portion was transferred to a clean vial. Following this, 2 mL of hexane were added directly to the H<sub>2</sub>SO<sub>4</sub> : MeOH solution in the culture tube (II), and vortex-mixed with it to extract the remaining lipid residues. The hexane extracts were gathered in a clean vial, and evaporated under a gentle nitrogen blow, and re-dissolved in 300  $\mu$ L of hexane for GC-MS and GC-C-IRMS.

## ANALYSIS WITH GC-MS AND GC-C-IRMS

### HIGH TEMPERATURE GC-MS

The trimethylsilylated TLEs and FAMEs were analyzed by 6890N Network GC system with a 5979 Mass selective Detector from Agilent Technologies at the Sachs laboratory, Department of Oceanography, University of Washington. The GC was equipped with a fused silica capillary column (J&W; DB5-MS; 60m x 0.32 mm; 0.25  $\mu$ m film thickness) and the interface was maintained at 110 BoC. The mass spectrometer was operated in the full scan mode. Helium was the carrier gas and the GC oven was programmed

as follows: 2 min isothermal at 50BoC are followed by an increase to 350BoC at a rate of 10BoC min<sup>-1</sup> and following this, the temperature is held at 350BoC for 10 min. The peaks are identified based on their mass spectral characteristics and GC retention times, and also by comparison with the NIST mass spectral library.

### GC-C-IRMS

The CSIA Analysis (measured ten times) was performed using a Thermo GC/C-IRMS system composed of a Trace GC Ultra gas chromatograph (Thermo Electron Corp., Milan, Italy) coupled onto a Delta V Advantage isotope ratio mass spectrometer through a GC/C-III interface (Thermo Electron Corp., Bremen, Germany). A compound identification support for the CSIA laboratory is provided by a Varian CP3800 gas chromatograph coupled onto a Saturn 2200 ion trap MS/MS (Varian, Inc., Walnut Creek, CA U.S.A.). The FAMEs dissolved in hexane were injected in the splitless mode, and separated on a Varian factor FOUR VF-5ms column (30m × 0.25mm ID, 0.25 micron film thickness). Once separated, the FAMEs are quantitatively converted to CO<sub>2</sub> in an oxidation reactor at 950BoC. Following water removal through a naftion dryer, CO<sub>2</sub> enters the IRMS.  $\delta^{13}\text{C}$  values were corrected using the working standards composed of several FAMEs calibrated against the NIST standard reference materials.

### SUMMARY

In this chapter, I have discussed about the methodological background, research design and analytical procedure of the organic geochemical analyses. I briefly outlined history of the organic geochemical analyses in the discipline of archaeology and elucidated the some of the main principles of the methods. I also listed the implications related to the analyses. Lastly, the details about the laboratory experimental processes were elucidated.

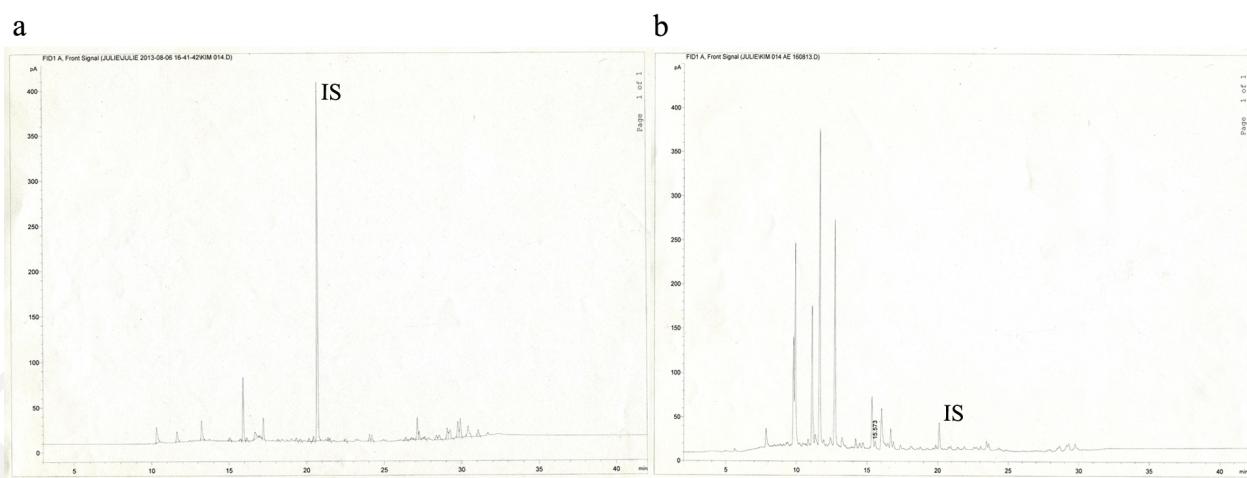


Figure 4.9: The GC chromatograms of the same archaeological sherd sample (KIMo14) showing different recovery rates. (a) chloroform : methanol solvent extraction (b): acidified methanol extraction (IS = Internal Standard). In both extractions, the same amount of internal standard was injected. The acidified extraction method showed a much higher recovery rate (more than 20 times) compared with the prevailing chloroform/methanol solvent extraction protocol.

A large, semi-transparent watermark is angled diagonally from the bottom-left towards the top-right. It contains the word "DRAFT" in a bold, serif font, with each letter stacked vertically.

# 5

## The Results

### INTRODUCTION

This chapter is dedicated to the results of the organic geochemical analyses and luminescence dating from four different habitation sites in the central part of the Korean peninsula. The overall archaeological phenomena of the four sites will be described in detail. Then, the sampling strategies, methods and the results of the organic geochemical analyses and luminescence dating for the each of the sites will be elucidated one by one.

## KIMPO-YANGCHON

The Kimpo-Yangchon site is located on the low hillocks around Guree-Ri, Yoohyeon-Ri, and Yangchon-Ri of Kimpo city, Gyeonggi province. The site is about 4 kilometers southwest of the Han River (Figure 1.1; 5.1). The research period was from October 30th, 2007 to February 25th, 2011. The site includes various archaeological phenomena such as house pits, mound burials, pit graves, stone-lined pit burials, and firing features which represent different time periods from the Chulmun period to the historical Joseon Dynasty (AD 1392 - 1897) (B. M. Kim, Kim, Kang, Chae, & Cho, 2013). The total area of the site is 863,992 square meters. Its main archaeological phenomena belong to the Mumun Period, and the analysis was focused on this time period.

Six house pits and two pit features were classified into the Chulmun period. The house pits are either round shaped or square shaped with rounded corners, and hold the interior features such as hearth, four post holes and ditch. Most of the potteries are pointed-bottomed deep bowls with various combinations of patterns including (short) slanted incising, herringbone, and lattice. The excavated house structures are assumed to belong to the late Middle - Late Chulmun Period.

As for the Mumun period, 126 house pits, pit features, and firing features were excavated. The house pits are classified into three types based on their shape: square, rectangular, and long house. Each of those houses normally has an array of multiple post holes which crosses the center of the pit; and some of them comprehend pit-hearths, storage pits, and ditches as interior features. Most of the potteries have the rim-punctuation or a combination of lip-scoring/rim-punctuation; and others a combination of double-rim/short slanted line incision (Figure 2.4). As for the ground stone tools, arrowheads, daggers, and axes were found. As for the farming tools, semi-lunar shaped stone knives (Figure 5.2; cf. Figure 2.6b) and mortar/pestle were found. The excavated features can be reclassified into two different lineages: (large) square/rectangular house pits with double-rim/short slanted line incision potteries and (small) rectangular house pits/(elongated) long houses with rim-punctuation potteries (Figure 2.4). These two lineages are considered to be an extension of the two Early Mumun pottery cultures (Garak-Dong style and Yeoksam-Dong style) which covers a large extent of Gyeonggi province (Figure 1.1). These Mumun features of the

site have a great value in understanding the overall aspect of the Mumun Period in the central west part of the Korean Peninsula. Considering the number of houses and artifacts (Figure 5.2), and their radiocarbon dating (Table 5.1), the period when the Kimpo-Yangchon site was occupied the most intensively is around 2,900 - 2,700 BP, the incipient/early stage of the Mumun period.

Location/house pit No.	Cultural historical period	C <sub>14</sub> date (uncalibrated years BP)	Calendar date
Area 2-I B/No.1	Mumun	2650±150	BC 815
Area 2-I B-1/No.1	Mumun	3010±150	BC 1255
Area 2-I B-1/No.2	Mumun	2540±140	BC 770
Area I-D /No.22	Mumun	2770±160	BC 910
Area I-D /No.23	Mumun	2850±40	BC 1005
Area 2-I F/No.1	Chulmun	4530±50	BC 3175
Area 2-I F/No.2	Chulmun	4550±50	BC 3175
Area I-G /No.4	Mumun	2700±40	BC 835
Area I-G /No.2	Mumun	2680±50	BC 830
Area I-H /No.5	Mumun	2380±40	BC 455
Area I-H /No.12	Mumun	2770±40	BC 935
Area 2-I B-1/No.3	Mumun	2950±50	BC 1175
Area 2-I J/No.1	Mumun	2670±40	BC 820
Area 2-I J/No.3	Mumun	2820±50	BC 975
Area 2-I J/No.4	Mumun	2740±50	BC 875
Area 2-I J/No.6	Mumun	2830±50	BC 980
Area 2-I J/No.9	Chulmun	4020±50	BC 2525
Area 2-I J/No.10	Mumun	2710±40	BC 860
Area 2-I J/No.12	Mumun	2900±50	BC 1100
Area 2-I J/No.13	Mumun	2650±50	BC 815
Area 2-I J/No.13	Mumun	2920±50	BC 1130
Area 2-I J/No.16	Mumun	2630±40	BC 808

Location/house pit No.	Cultural historical period	C <sub>14</sub> date (uncalibrated years BP)	Calendar date
Area 2-1 J/No.18	Mumun	2560±50	BC 775
Area 2-1 K/No.1	Mumun	2900±50	BC 1100
Area 2-1 K/No.2	Mumun	2630±40	BC 808
Area 1-K /No.3	Mumun	3020±50	BC 1300
Area 1-L /No.3	Mumun	2960±50	BC 1190
Area 1-L /No.5	Mumun	2750±50	BC 885
Area 1-L /No.6	Mumun	2550±40	BC 770
Area 1-L /No.10	Mumun	2820±50	BC 975
Area 1-L /No.11	Mumun	2910±50	BC 1105
Area 1-L /No.12	Mumun	2820±60	BC 975
Area 1-L /No.13	Mumun	2750±50	BC 885
Area 1-L /No.14	Mumun	2800±50	BC 955
Area 1-L /No.15	Mumun	3090±60	BC 1360
Area 1-L /No.16	Mumun	2990±50	BC 1215
Area 1-L /No.17	Mumun	2910±50	BC 1105
Area 1-L /No.19	Mumun	2720±50	BC 863
Area 1-L /No.20	Mumun	2550±50	BC 770
Area 2-3 Na /No.1	Mumun	2520±50	BC 595
Area 2-3 Na /No.3	Mumun	2660±60	BC 845
Area 2-3 Na /No.4	Mumun	2760±50	BC 885
Area 2-3 Na /No.6	Mumun	2680±56	BC 830
Area 2-3 Na /No.7	Mumun	2710±50	BC 858
Area 2-3 Na /No.8	Mumun	2920±50	BC 1130
Area 2-3 Na /No.15	Mumun	2850±50	BC 1010
Area 2-4 Ga /No. 2	Baekje Kingdom	1730±80	AD 320
Area 2-4 Ga /No. 11	Baekje Kingdom	1670±50	AD 375

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Location/house pit No.	Cultural historical period	C <sub>14</sub> date (uncalibrated years BP)	Calendar date
Area 2-4 Ga /No. 13	Baekje Kingdom	1670±60	AD 375
Area 2-4 Ga /No. 8	BaekJe Kingdom	1880±60	AD 145

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Table 5.1: The results of AMS radiocarbon dating of the Kimpo-Yangcho site (Kim 2013)

Sample No.	Location/house pit No.	Part	C <sub>14</sub> date (uncalibrated years BP)
KIMo30	Area 2-3 Na/No.3	Body	2660±150
KIMo31	Area 2-3 Na/No.3	Body	
KIMo32	Area 2-3 Na/No.7	Body	2710±150
KIMo33	Area 2-3 Na/No.7	Body	2710±150
KIMo34	Area 2-3 Na/No.7	Body	2760±150
KIMo35	Area 2-3 Na/No.8	Body	2920±150
KIMo36	Area 2-3 Na/No.8	Body	2920±150
KIMo37	Area 2-3 Na/No.8	Body	2920±150
KIMo38	Area 2-3 Na/No.11	Body	
KIMo39	Area 2-1 L/No.3	Body	2960±150
KIMo40	Area 2-1 L/No.3	Body	2960±150
KIMo41	Area 2-1 L/No.3	Body	2960±150
KIMo42	Area 2-1 L/No.10	Rim	2820±150
KIMo43	Area 2-1 L/No.10	Body	2820±150
KIMo44	Area 2-1 L/No.11	Body	2910±150
KIMo45	Area 2-1 L/No.11	Body	2910±150
KIMo46	Area 2-1 F/No.1	Body	4530±150 (Chulmun)
KIMo47	Area 2-1 F/No.1	Body	4530±150 (Chulmun)
KIMo48	Area 2-1 B-1/No.1	Body	
KIMo49	Area 2-1 D/No.14	Body	
KIMo50	Area 2-1 D/No.14	Body	
KIMo51	Area 2-1 D/No.8	Body	
KIMo52	Area 2-1 D/No.8	Body	
KIMo53	Area 2-1 D/No.9	Body	
KIMo54	Area 2-1 D/No.9	Body	
KIMo55	Area 2-1 D/No.15	Body	

Sample No.	Location/house pit No.	Part	C <sub>14</sub> date (uncalibrated years BP)
KIMo56	Area 2-1 D/No.15	Body	
KIMo57	Area 2-1 L/No.3	Body	
KIMo58	Area 2-1 D/No.10	Body	
KIMo59	Area 2-3 NA/No.5	Body	
KIMo60	Area 2-3 NA/No.5	Body	
KIMo61	Area 2-1 G/No.3	Body	
KIMo62	Area 2-1 G/No.3	Body	
KIMo63	Area 2-1 H/No.5	Body	2380±140
KIMo64	Area 2-1 H/No.5	Body	2380±140
KIMo65	Area 2-1 H/No.12	Body	2770±140
KIMo66	Area 2-1 H/No.12	Body	2770±140
KIMo67	Area 2-1 H/No.20	Body	
KIMo68	Area 2-1 H/No.20	Body	
KIMo69	Area 2-4 Ra/No.20	Body	
KIMo70	Area 2-3 Na/No.3	Body	
KIMo71	Area 2-1 B-1/No.3	Body	
KIMo72	Area 2-1 D/No.14	Body	
KIMo73	Area 2-1 G/No.5	Rim	
KIMo74	Area 2-1 G/No.5	Body	
KIMo75	Area 2-1 J/No.1	Body	
KIMo76	Area 2-1 L/No.1	Body	
KIMo77	Area 2-1 D/No.9	Body	
KIMo78	Area 2-1 L/No.9	Rim	

Table 5.2: The samples collected from the Kimpo-Yangchon site  
for organic geochemical analysis

## SAMPLING

### ORGANIC GEOCHEMICAL ANALYSES

At least two samples were collected from each of the houses, except those which did not yield pottery, and of which the date could not be estimated. If available, three samples were collected from one house. One sample was collected from some house pits which did not yield enough potsherds. Researches have showed that the potteries for ordinary day-to-day subsistence around this period tend to have rather monotonous characteristics in terms of shape and size (Bae, 2007; Shoda, 2008). Therefore, the shape and size of the potteries were relatively not critical issues for sampling. According to the experimental analysis of Evershed (Evershed, 2008a), the rim and upper body parts of pots are where organic residues are the most concentrated after cooking (cf. A. Barker et al., 2012; J. W. Eerkens, 2007). Ethnographic observations showed that generally, high-temperature boiling is regarded as a particularly effective cooking method in the preparation of faunal and floral resources in pots (Crown & Wills, 1995; Stahl, 1989; Wandsnider, 1997). During this process, convection currents of boiling water push extracted lipids from food stuffs to the pot wall. Since lipids float on water, they tend to accumulate and penetrate into the wall of the upper body and rim of the pot. Taking these facts as criteria, a total of 49 samples were collected (Table 5.2).

### LUMINESCENCE DATING

For the luminescence dating two samples were collected to see if there would be positive correlations between the luminescence dates and published AMS radiocarbon dates (Table 5.1, B. M. Kim et al., 2013). Both of the samples were collected from the house that has not been dated (Table 5.3).

### ORGANIC GEOCHEMICAL RESULTS

Before collecting 49 samples from the Kinpo-Yangchon site for the organic geochemical analysis in this thesis, 25 samples were collected for a preliminary analysis. They were all collected based on the same crite-



Figure 5.1: The location of the Kimpo-Yangchon site



Figure 5.2: Some of the artifacts uncovered during the excavation of the Kimpo-Yangchon site: semi-lunar shaped knife (upper-left), pots (rim-punctuation; upper-right), and arrowheads (down-left)

Sample No.	Location/house pit No.	Part	Depth (m)
U3045	Area 2-1 L/No.3	Body	0.3
U3046	Area 2-1 D/No.10	Body	0.3

Table 5.3: The samples collected from the Kimpo-Yangchon site for the luminescence dating in this thesis

ria that were mentioned in the “sampling” section. The purpose of the preliminary analysis is to ascertain the applicability of the organic geochemical analyses to examining the potteries from the central part of the Korean Peninsula. The samples were analyzed in accordance with the well-known standard solvent extraction protocol that demands the use of solvent mixture (chloroform-methanol 2 : 1 v/v; cf. chapter 4), at the organic geochemistry unit, University of Bristol, under the guidance of Dr. Richard P. Evershed. Unfortunately, since the lipid concentration of the samples were so low, I was not able to extract an analyzable amount of lipids from those 25 samples (cf. Figure 4.8a). Following Dr. Evershed’s suggestion, the direction of examination was changed to employ the methanolic acid extraction protocol (Correa-Ascencio & Evershed, 2014, cf. chapter 4). In this thesis, all the 49 samples from the Kimpo-Yangchon site were analyzed by the acid extraction protocol.

Table 5.4 and Figure 5.3, 5.4, and 5.5 show the results of the organic geochemical analyses. Among the 49 samples, I was able to analyze 20. 29 samples had to be omitted mainly due to contamination and low concentration of lipids. In spite of going through the cleaning process of samples using drill bits to minimize contamination, in accordance with the standard protocol (cf. Chapter 4), not all the sherds were suitable for the analyses. This is mainly because of poor handling of the pottery during the excavation and curation processes. Generally, the most frequently observed compounds in archaeological lipid residues are palmitic (C<sub>16</sub>:0) and stearic (C<sub>18</sub>:0) fatty acids (Evershed, 2008a). As expected, the organic compounds of all samples were dominated by those two saturated fatty acids. This means those organic compounds were highly degraded in soil during several thousand years of post-depositional processes (cf. Chapter 4). Nevertheless, with the results of GC-MS analysis, I was able to identify both major short- and long-chain (un)saturated fatty acids including C<sub>14</sub>:0, C<sub>15</sub>:0, C<sub>15</sub>:1, C<sub>17</sub>:0, C<sub>18</sub>:1, C<sub>20</sub>:0, C<sub>22</sub>:0, C<sub>22</sub>:2, and C<sub>24</sub>:0.

Sample No.	Compound detected	C16:o ( $\delta^{13}\text{C}$ )	C18:o ( $\delta^{13}\text{C}$ )	Interpretation via CSIA
KIMo38	C14:o, C15:o, C15:I, C16:o, C16:I, C17:o, C18:o, C18:I, C19:o, C20:o, C21:o, C22:o, C24:o	-29.6	-31.2	Ruminant adipose
KIMo42	C14:o, C16:o, C17:o, C18:o, C20:o, C20:I, C22:o, C24:o	-28.8	-27.3	Not identifiable
KIMo43	C16:o, C17:o, C18:o, C20:o, C22:o	-26.7	-25.4	Pork adipose
KIMo44	C14:o, C15:o, C16:o, C16:I, C17:o, C18:o, C20:o, C24:o	-25.6	-26.2	Aquatic resource and/or Pork adipose
KIMo49	C14:o, C15:o, C16:o, C17:o, C18:o, C24:o	-16.8	-17.2	Marine
KIMo51	C14:o, C15:o, C16:o, C16:I, C17:o, C18:o, C19:o, C20:o, C22:o, C23:o, C24:o	-27.8	-27.7	Pork adipose and/or C <sub>3</sub> plant oil
KIMo52	C16:o, C18:o, C22:2	-27.9	-29.3	Ruminant adipose and/or C <sub>3</sub> plant oil
KIMo57	C15:o, C16:o, C17:o, C18:o, C20:o, C20:I	-24.8	-22.5	Pork adipose
KIMo59	C14:o, C15:o, C16:o, C17:o, C18:o, C19:o, C20:o, C24:o	-27.3	-27.7	Not identifiable
KIMo60	C14:o, C15:o, C16:o, C17:o, C18:o, C18:I, C19:o, C20:o, C20:I, C22:o, C24:o	-26.7	-24.7	Pork adipose
KIMo61	C14:o, C16:o, C18:o, C20:o, phytanic acid	-23	-25.4	Marine

Sample No.	Compound detected	C16:o ( $\delta^{13}\text{C}$ )	C18:o ( $\delta^{13}\text{C}$ )	Interpretation via CSIA
KIMo62	C16:o, C18:o	-27.8	-26.9	Pork adipose and/or C <sub>3</sub> plant oil
KIMo69	C16:o, C17:o, C18:o, C20:o	-25.7	-26.6	Aquatic resource and/or Pork adipose
KIMo71	C16:o, C18:o	-28.7	-29.8	Ruminant adipose
KIMo72	C16:o, C18:o	-28.3	-29.7	Ruminant adipose and/or C <sub>3</sub> plant oil
KIMo73	C14:o, C16:o, C17:o, C18:o	-27.2	-27.8	Pork adipose and/or C <sub>3</sub> plant oil
KIMo75	C14:o, C15:o, C16:o, C17:o, C18:o, C20:o, C20:i	-24.1	-23.5	Marine and/or Pork adipose
KIMo76	C14:o, C16:o, C17:o, C18:o, C20:o	-26.5	-26.4	Pork adipose
KIMo77	C14:o, C16:o, C18:o	-27.3	-27.5	Not identifiable
KIMo78	C14:o, C16:o, C18:o, C20:o	-21.8	-24.7	Marine

Table 5.4: The results of the organic geochemical analysis by GC-MS and GC-C-IRMS of the samples from the Kimpo-Yangchon site, and their interpretations

There are compounds which are only found in certain food groups. Especially, phytanic acid (3,7,11,15-tetramethylhexadecanoic acid) and 4,8,12-TMTD (4,8,12-trimethyltridecanoic acid) are isoprenoid compounds which mostly are found in particularly high concentrations in marine animals [Evershed et al. (2008); cf. Chapter 4]. Along with thermally produced long-chain O-(o-alkylphenyl)alkanoic acids, these compounds are indicators of aquatic/marine resources (Oliver E. Craig et al., 2011; Evershed et al., 2008). Since the Kimpo-Yangchon site is only 4 kilometers apart from the Han river (Figure 5.1), it is essential to

know whether its dwellers relied on aquatic resources. Among those 20 samples, one samples showed the presence of phytanic acid (KIMo61), indicating the possibility that those pots were used for processing aquatic resources.

The result of isotope analysis (Figure 5.3; 5.4; 5.5) effected on palmitic (C16:o) and stearic (C18:o) fatty acids on the samples show more interesting characteristics of these ancient farmers' diet. They indicate that they consumed various food stuffs including pork, C<sub>3</sub> plants, ruminants, and aquatic resources (Fresh water and Marine). Many samples indicate that the pots from which they came were used for processing multiple foodstuffs. The dominant food classes were pork and aquatic resources, which occupied respectively nine and six samples, that is, about 45 and 30 percent of all the samples.

The result of CSIA on KIMo61 agreed with that of GC-MS analysis, indicating the pot was used for processing marine resources. 25 percent (five samples) shows presence of C<sub>3</sub> plant oils. However, it has to be carefully considered whether this means rice occupied about one-fourth of those farmers' diet. Firstly, C<sub>3</sub> plants include not only rice, but also legumes and barley. As G. Lee (2011) mentioned, we have pollen data from 5,500 BP to 2,600 BP showing the ancient farmers of the Korean peninsula utilized soybean (*Glycine max*) and azuki (*Vigna angularis*) as subsistence resources. Therefore, it is impetuous to argue that the detected C<sub>3</sub> plant oils are from rice alone. Secondly, since the area of C<sub>3</sub> plant oils in Figure 5.3 could indicate the mixture of pork and ruminant adipose (cf. Chapter 4), we do not have any assurance that the C<sub>3</sub> plant oils of which the presence is indicated by those five samples are actually plant oil. Lastly, all of the samples identified as revealing C<sub>3</sub> plant oils are also interpreted as containing pork and ruminant adipose, for the ellipses of C<sub>3</sub> plant oils and pork adipose overlap each other (Figure 5.3 and 5.4). Therefore, under this circumstance, what we can draw from the given data is that 'at most', rice occupied about one-fourth of the diet of the ancient farmers at the Kimpo-Yangchon site.

#### LUMINESCENCE DATING RESULTS

The samples were dated using TL, OSL, and IRSL at the luminescence dating lab, University of Washington. Due to the absence of the associated sediments, the dose rate (alpha, beta, and gamma) was measured using the samples themselves.

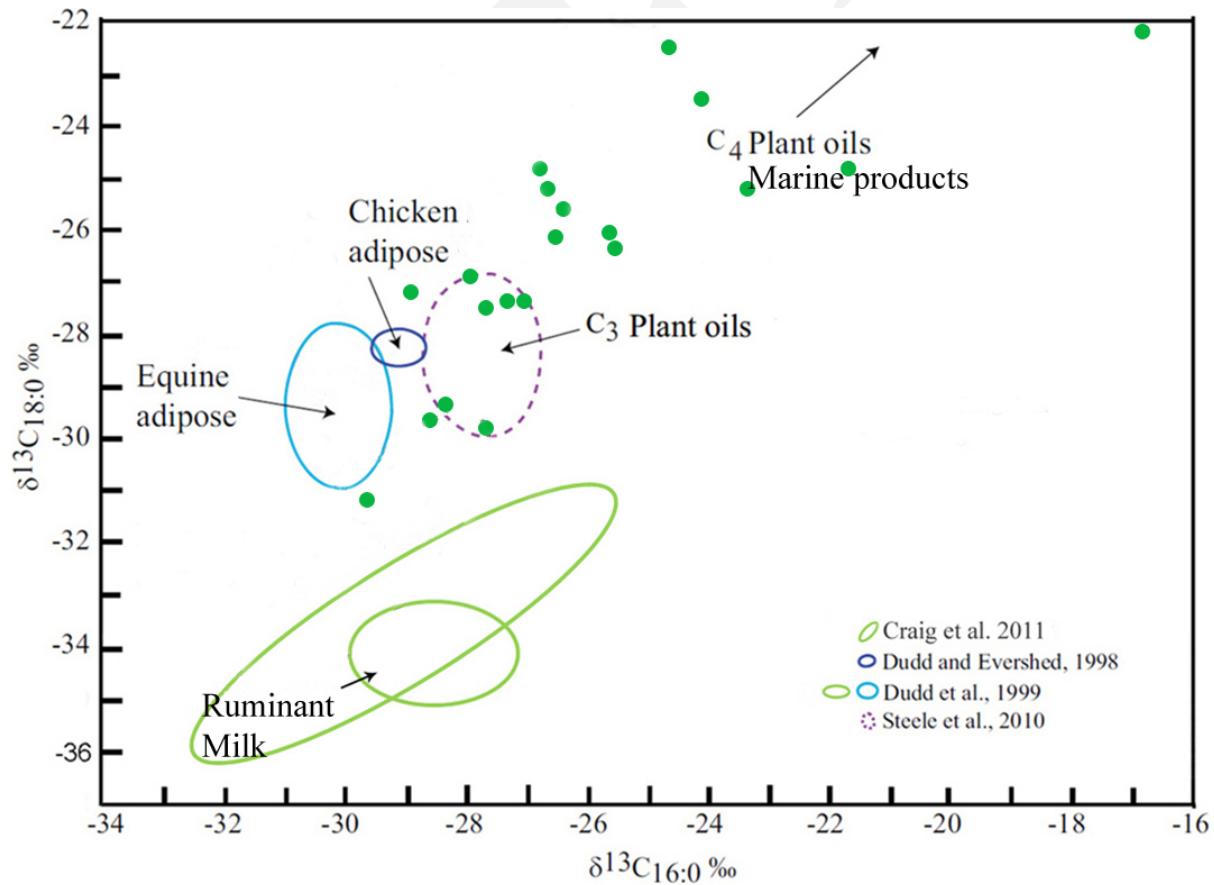


Figure 5.3: The results of CSIA by GC-C-IRMS of the samples from the Kimpo-Yangchon site

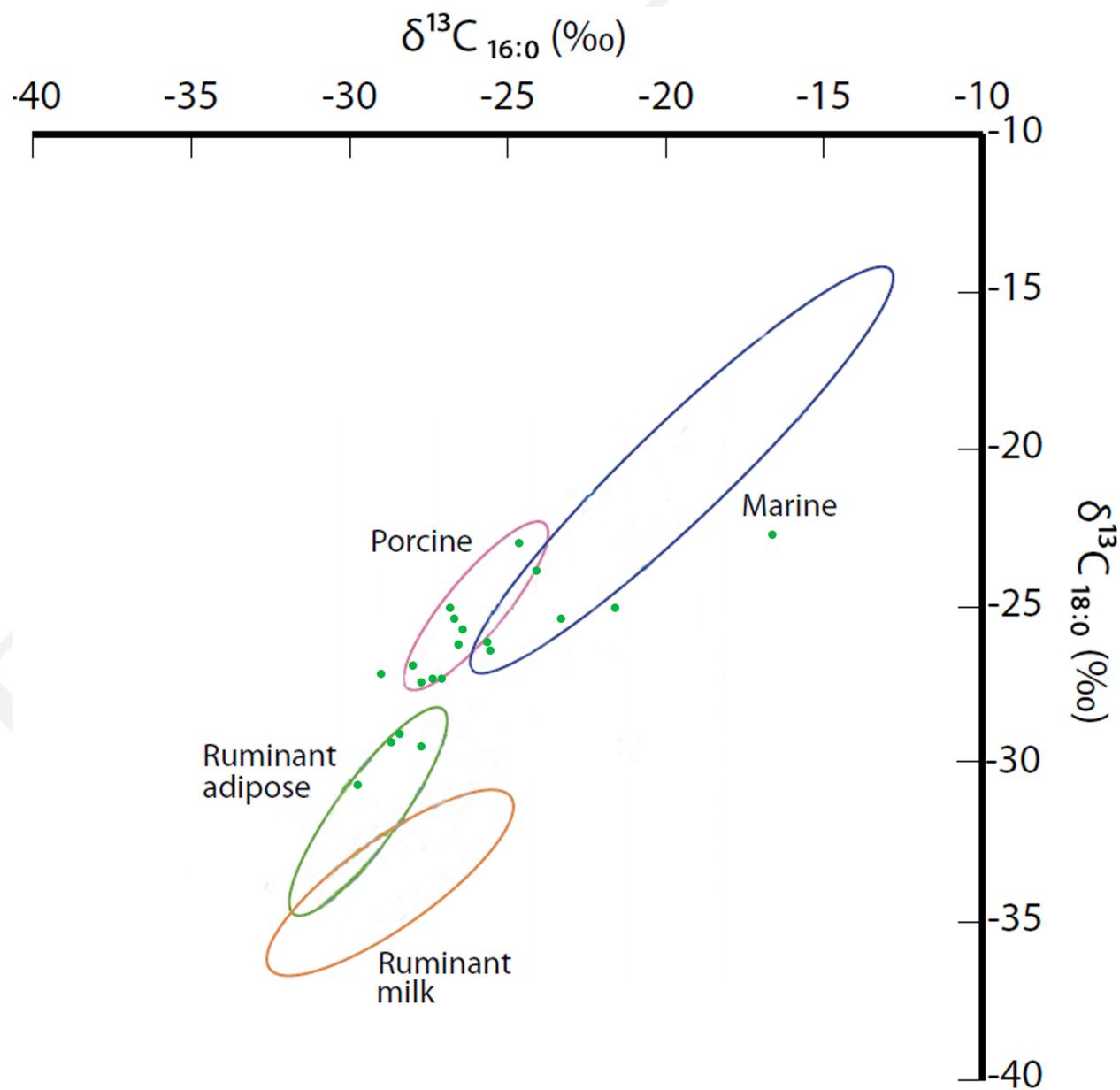


Figure 5.4: The results of CSIA by GC-C-IRMS of the samples from the Kimpo-Yangchon site using the reference from Oliver E. Craig et al. (2011)

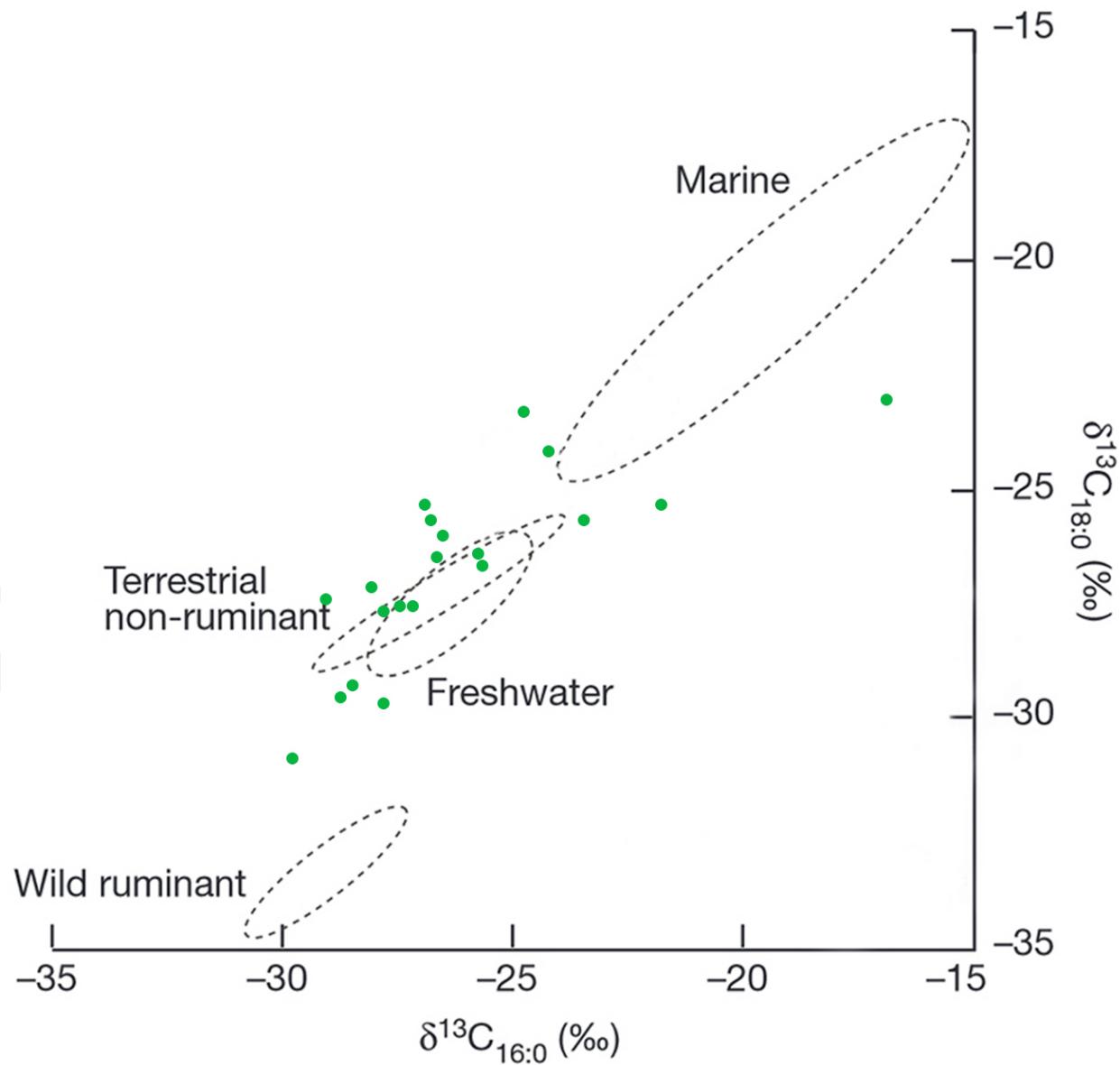


Figure 5.5: The results of CSIA by GC-C-IRMS of the samples from the Kimpo-Yangchon site using the reference from O. E. Craig et al. (2013)

Table 5.5 shows the results of the luminescence dating. Though the dates were slightly outside the main occupation period (2,800 - 2,700 BP) of the Kimpo-Yangchon site estimated by the radiocarbon dates, they corresponded overall with the published dates.

Lab. No	Depth (m)	Water Content (%)	Dose rate* (Gy/ka)	TL (De)	OSL (De)	IRSL (De)	Age (BC)
U3045	0.3	10.7	5.227±0.486	13.625±3.55	12.819±0.296	11.141±0.429	658±150
U3046	0.3	15.1	6.880±0.579	10.792±2.031	11.775±0.389	10.16±0.445	495±185 (OSL)

Table 5.5: The results of the luminescence dating of the potsherd samples from the Kimpo-Yangchon site. Note that the age of U3046 was calculated solely based on the OSL signal due to an abnormally large error term of the TL date (11538 yr)

## SOSA-DONG

The Sosa-Dong site is located on the low hill of Sosa-Dong, Pyeongtaek city, Gyeonggi province. The site is about 2.5 kilometers north of the Anseong stream (Figure 1.1; 5.1). The excavation was conducted by Korea institute of Heritage, from September 2004 to September 2006 (B. M. Kim et al., 2008). The site comprehends various archaeological phenomena such as house pits, mound burials, pit graves, pit features and ditches which belong to different time periods from the Mumun period to the historical Joseon Dynasty (AD 1392 - 1897).

A total of 81 Mumun period house pits were found. Based on the results of the radiocarbon dating of charcoal from the house pits (Table 5.6), it is inferred that the site goes back to the times as early as the incipient/early stage of the Mumun period, or as late as the middle/late Mumun period. The house pits are classified into four types based on their shape: square, circular, rectangular, and longhouse. The rectangular and longhouse pits were built around the early stage of the Mumun period (2900 - 2700 BP); and the square and circular pits near the late Mumun period (2500 - 2300 BP). The site has a chronological void from 2700 BP to 2500 BP. Some of these houses incorporate hearths, storage pits and ditches as

interior features. Most of the potteries have the rim-punctuation or a combination of lip-scoring/rim-punctuation; and others a combination of double-rim/short slanted incision or rim-punctuation/short slanted incision (figure 5.6). As for the ground stone tools, arrowheads, daggers, chisels and axes were found (Figure 5.6). As for the farming tools, semi-lunar shaped stone knives (Figure 2.6b) and mortars/pestles were found. Especially, carbonized 46 rice (*Oryza sativa*; Figure 5.7a) and 31 possible barley (*Hodeum vulgare L.*; Figure 5.7b) grains were found inside of one house pit, near the hearth (Area “Ga”/No. 10).

The overall archaeological phenomena of the Sosa-Dong site are quite similar to those of the Kimpo-Yangchon site. The composition of different types of house pits, potteries and stone artifacts clearly indicate the resemblance between the two sites. Probably one of the most interesting features of the Sosa-Dong site compared with the Kimpo-Yangchon site is carbonized rice and possible barley grains. Considering their ‘burnt’ condition, it is beyond all doubt that rice and barley were cooked for consumption.

Location/house pit No.	Cultural historical period	C14 date (uncalibrated years BP)	Calendar date
Area La/No. 20	Mumun	3010±60	BC 1240
Area Da/No. 5	Mumun	2990±50	BC 1220
Area Da/No. 6	Mumun	2990±50	BC 1220
Area Ga/No. 17	Mumun	2950±50	BC 1160
Area Ga/No. 7	Mumun	2930±60	BC 1150
Area Da/No. 7	Mumun	2930±50	BC 1150
Area La/No. 10	Mumun	2900±50	BC 1120
Area Ga/No. 2	Mumun	2850±60	BC 1060
Area Ga/No. 10	Mumun	2840±50	BC 1050
Area Ga/No. 14	Mumun	2850±50	BC 1050
Area Ga/No. 16	Mumun	2840±50	BC 1050
Area Ga/No. 18	Mumun	2840±50	BC 1050
Area Ga/No. 28	Mumun	2850±50	BC 1050
Area Da/No. 4	Mumun	2810±50	BC 980

Location/house pit No.	Cultural historical period	$\text{C}^{14}$ date (uncalibrated years BP)	Calendar date
Area Ga/No. 20	Mumun	$2750 \pm 50$	BC 910
Area La/No. 4	Mumun	$2740 \pm 50$	BC 900
Chronological void			
Area Ga/No. 13	Mumun	$2550 \pm 50$	BC 670
Area La/No. 7	Mumun	$2470 \pm 80$	BC 600
Area Ga/No. 15	Mumun	$2470 \pm 60$	BC 590
Area Ga/No. 4	Mumun	$2300 \pm 50$	BC 310

Table 5.6: The results of AMS radiocarbon dating of the Sosa-Dong site

## SAMPLING

### ORGANIC GEOCHEMICAL ANALYSES

The general sampling strategy for the organic geochemical analyses on the Sosa-Dong site is quite similar to that on the Kimpo-Yangchon site. At least two samples were collected from each of the houses, except those which did not yield pottery, and whose date could not be estimate. If available, three samples were collected from one house. One sample was collected from some house pits that did not yield enough potsherds. The shape and size of the pots were not considered, for the potteries for ordinary day-to-day subsistence around this period tend to have rather monotonous characteristics in terms of shape and size (Bae, 2007; Shoda, 2008). Following the criteria of Evershed (2008a, Figure 5.8), the rim and upper body parts were chosen and a total of 37 samples were collected (Table 5.7).



Figure 5.6: Some of the artifacts uncovered during the excavation of the Sosa-Dong site including potsherd, arrowheads and stone chisel. The potsherd in the picture has the rim-punctuation/short slanted incision

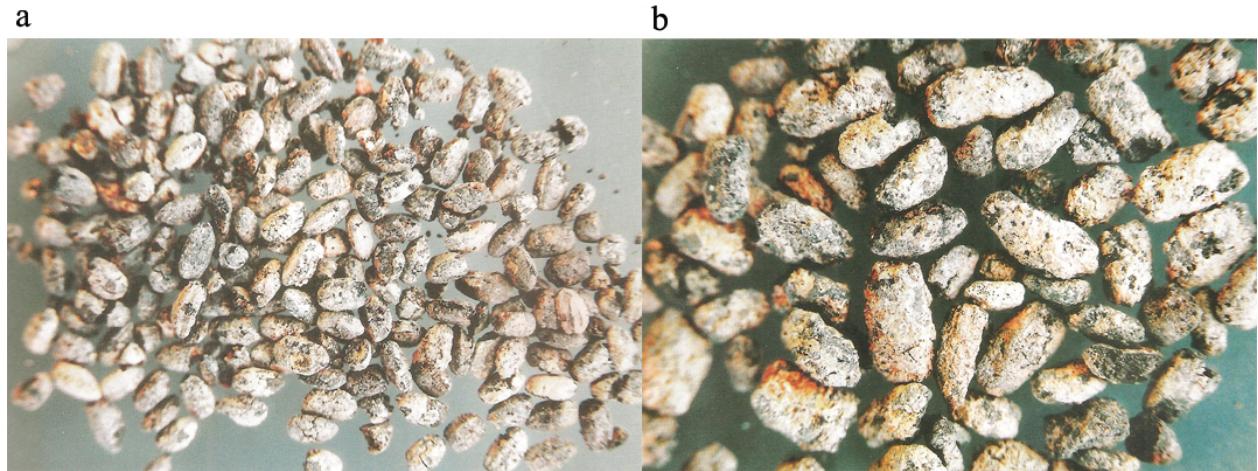


Figure 5.7: (a): The carbonized rice grains (*Oryza sativa*) and (b): possible barley (*Hordeum vulgare L.*) grains excavated in the Area “Ga” house pit No. 10

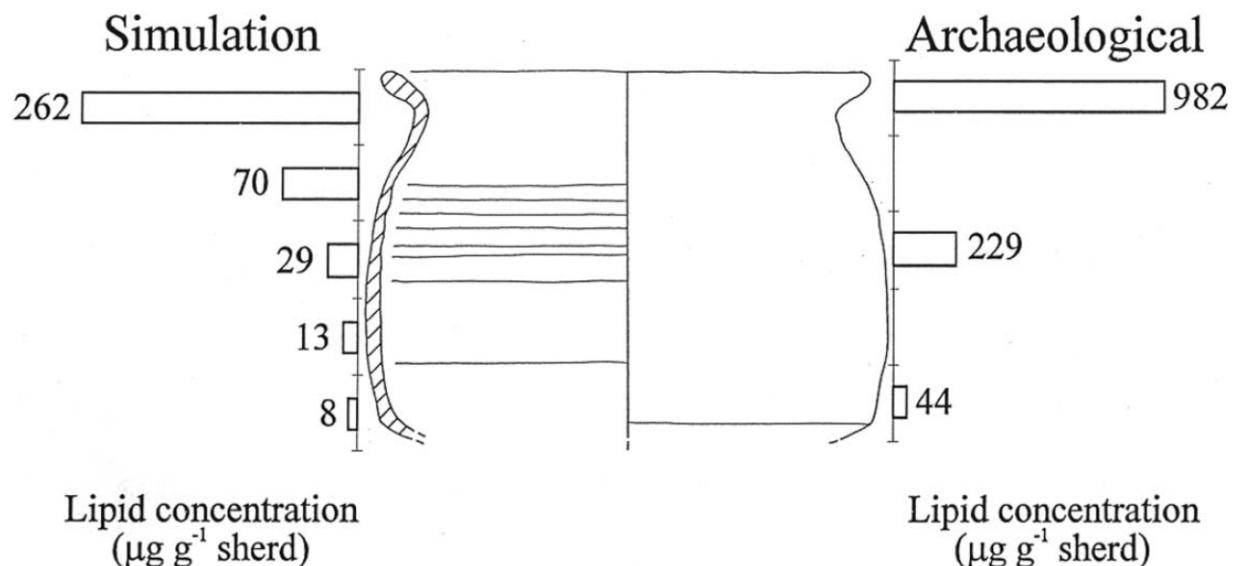


Figure 5.8: Diagram showing the lipid concentration of each body part from the both experimental and archaeological sherd samples (adapted from 2008a)

Sample No.	Location/house pit No.	Part	C <sub>14</sub> date (uncalibrated years BP)
SOSo30	Area La/No. 14	Body	
SOSo31	Area La/No. 4	Body	
SOSo32	Area La/No. 4	Rim	
SOSo33	Area La/No. 4	Rim	
SOSo34	Area Ga/No. 7	Body	2930±60
SOSo35	Area Ga/No. 10	Body	2840±50
SOSo36	Area Ga/No. 10	Body	2840±50
SOSo37	Area Ga/No. 14	Body	2850±50
SOSo38	Area Ga/No. 14	Body	2850±50
SOSo39	Area La/No. 11	Rim	
SOSo40	Area La/No. 11	Body	
SOSo41	Area La/No. 11	Body	
SOSo42	Area Ga/No. 23	Body	
SOSo43	Area Ga/No. 23	Body	
SOSo44	Area Ga/No. 24	Body	
SOSo45	Area Ga/No. 24	Body	
SOSo46	Area Ga/No. 25	Body	
SOSo47	Area Ga/No. 25	Body	
SOSo48	Area La/No. 15	Rim	
SOSo49	Area La/No. 15	Rim	
SOSo50	Area La/No. 15	Rim	
SOSo51	Area La/No. 2	Body	
SOSo52	Area La/No. 2	Body	
SOSo53	Area La/No. 5	Body	
SOSo54	Area La/No. 5	Body	
SOSo55	Area La/No. 10	Body	2900±50

Sample No.	Location/house pit No.	Part	C <sub>14</sub> date (uncalibrated years BP)
SOSo56	Area La/No. 10	Rim	2900±50
SOSo57	Area La/No. 19	Body	
SOSo58	Area La/No. 19	Body	
SOSo59	Area La/No. 18	Body	
SOSo60	Area La/No. 18	Body	
SOSo61	Area La/No. 31	Body	
SOSo62	Area La/No. 31	Body	
SOSo63	Area La/No. 31	Body	
SOSo64	Area La/No. 32	Body	
SOSo65	Area La/No. 32	Body	
SOSo66	Area La/No. 36	Body	

Table 5.7: The samples collected from the Sosa-Dong site for organic geochemical analysis

#### LUMINESCENCE DATING

As at the Kimpo-Yangchon site, two samples were collected for the luminescence dating to see if there would be positive correlations between its results and the published AMS radiocarbon dates (B. M. Kim et al., 2008, Table 5.6). One of the two samples was collected from a house which had been dated by the radiocarbon dating, and the other from another which has not been (Table 5.8).

Sample No.	Location/house pit No.	Part	Depth (m)
U3042	Area La/No.4	Body	0.3
U3043	Area La/No.14	Body	0.3

Table 5.8: The samples collected from the Sosa-Dong site for the luminescence dating in this thesis

## ORGANIC GEOCHEMICAL RESULTS

As at the Kimpo-Yangchon site, before collecting 37 samples, 21 samples were collected for a preliminary analysis to ensure the analytical protocol. The samples were collected based on the same sampling strategy in this thesis and analyzed by the standard solvent extraction protocol (chloroform-methanol 2 : 1 v/v; cf. chapter 4) at the organic geochemistry unit, University of Bristol. However, it was nearly impossible to extract the lipids from those samples, due to their low concentration (cf. Figure 4.8a). Under this circumstance, the direction of examination was changed to employ the methanolic acid extraction protocol (Correa-Ascencio & Evershed, 2014, cf. chapter 4). In this thesis, all the 37 samples from the Sosa-Dong site were analyzed by the acid extraction protocol.

Table 5.9, Figure 5.9, 5.10, and 5.11 show the results of the organic geochemical analyses. Among the 37 samples, 28 were analyzable. Nine samples had to be omitted mainly due to contamination and low concentration of the lipids. Compared with that of the Kimpo-Yangchon site (20 analyzable samples among 49), this recovery rate is quite high. Considering that there are spatio-temporal similarities between the two sites, their difference in recovery rate of samples probably means the potsherds were more carefully treated during the excavation and curation processes in case of the Sosa-Dong site.

As I mentioned above, the most frequently observed compounds in archaeological lipid residues are palmitic (C<sub>16</sub>:0) and stearic (C<sub>18</sub>:0) fatty acids (Evershed, 2008a). The Sosa-Dong site was not an exception, and the organic compounds of all samples were dominated by those two saturated fatty acids, due to the degradation in soil during several thousand years of post-depositional processes. Along with the C<sub>16</sub>:0 and C<sub>18</sub>:0 fatty acids, I was able to identify both major short- and long-chain (un)saturated fatty acids including C<sub>13</sub>:0, C<sub>14</sub>:0, C<sub>15</sub>:0, C<sub>15</sub>:1, C<sub>16</sub>:1, C<sub>17</sub>:0, C<sub>18</sub>:1, C<sub>18</sub>:2, C<sub>20</sub>:0, C<sub>22</sub>:0, C<sub>22</sub>:1, C<sub>23</sub>:0, C<sub>24</sub>:0, and C<sub>24</sub>:1.

Table 5.9. The results of the organic geochemical analysis by GC-MS and GC-C-IRMS of the samples from the Sosa-Dong site, and their interpretations

Sample No.	Compound detected	C16:o ( $\delta^{13}\text{C}$ )	C18:o ( $\delta^{13}\text{C}$ )	Interpretation via CSIA
SOSo30	C16:o, C18:o	-25.7	-27.3	Fresh water and/or Marine
SOSo31	C16:o, C17:o, C18:o	-26	-27.9	Fresh water and/or Marine
SOSo32	C14:o, C15:o, C16:o, C16:i, C17:o, C18:o, C18:2, C22:o, C24:o, C24:i	-23.8	-25.7	Marine
SOSo33	C14:o, C15:o, C15:i, C16:o, C16:i, C17:o, C18:o, C18:2, C22:o, C24:o, C24:i	-22.8	-31.1	Not identifiable
SOSo35	C14:o, C16:o, C18:o, C18:2, C22:i, C24:i	-29.5	-27.2	Not identifiable
SOSo36	C14:o, C16:o, C17:o, C18:o, C18:2, C20:o, C22:o, C22:i, C24:i	-22.8	-24.5	Marine
SOSo37	C14:o, C16:o, C16:i, C17:o, C18:o, C18:i, C20:o, C22:i, C24:o, C24:i	-28.8	-28.5	C <sub>3</sub> plant oil
SOSo38	C14:o, C14:i, C16:o, C16:i, C17:o, C18:o, C18:2, C19:i, C20:o, C22:o, C22:i, C24:i	-26.5	-24.3	Pork adipose
SOSo39	C14:o, C15:o, C16:o, C17:o, C18:o, C19:o, C20:o, C22:o, C22:i, C24:i	-30.7	-28.1	Equine adipose

Sample No.	Compound detected	C16:o ( $\delta^{13}\text{C}$ )	C18:o ( $\delta^{13}\text{C}$ )	Interpretation via CSIA
SOSo40	C14:o, C16:o, C16:i, C17:o, C18:o, C18:2, C20:o, C22:o, C22:i, C24:o, C24:i	-26.2	-23.5	Pork adipose
SOSo41	C14:o, C16:o, C18:o, C20:o, C22:o, C22:i, C24:o, C24:i	-26	-23.6	Pork adipose
SOSo42	C14:o, C14:i, C16:o, C16:i, C17:o, C18:o, C18:2, C20:o, C22:o, C22:i, C23:o, C24:o, C24:i	-23.2	-23.9	Marine
SOSo43	C14:o, C16:o, C16:i, C18:o, C18:i, C18:2, C19:i, C22:o, C22:i, C23:o, C24:i	-26.8	-26.3	Pork adipose
SOSo45	C14:o, C16:o, C18:o, C18:2, C22:i, C24:i	-28.6	-27.7	C <sub>3</sub> plant oil
SOSo47	C14:o, C16:o, C18:o, C18:2, C22:i, C24:i	-29	-27.5	C <sub>3</sub> plant oil
SOSo48	C14:o, C16:o, C16:i, C17:o, C18:o, C18:i, C18:2, C22:o, C22:i, C24:i	-26.1	-23.9	Pork adipose
SOSo49	C16:o, C18:o, C19:o, C20:o, C22:o, C24:o, C24:i, phytanic acid	-27.4	-24.3	Pork adipose and aquatic resources
SOSo50	C14:o, C16:o, C16:i, C17:o, C18:o, C18:2, C20:o, C22:o, C22:i, C23:o, C24:o, C24:i	-27.9	-23.6	Not identifiable

Sample No.	Compound detected	C16:o ( $\delta^{13}\text{C}$ )	C18:o ( $\delta^{13}\text{C}$ )	Interpretation via CSIA
SOSo51	C14:o, C16:o, C16:i, C17:o, C18:o, C18:i, C18:2, C19:o, C22:o, C22:i, C24:i	-22.3	-21.4	Marine
SOSo54	C14:o, C16:o, C16:i, C17:o, C18:o, C18:2, C22:o, C22:i, C24:i	-25.2	-25.7	Fresh water and/or Marine
SOSo55	C14:o, C16:o, C16:i, C18:o, C18:i, C22:i, C24:i	-27.4	-27.4	C <sub>3</sub> plant oil and/or Pork adipose
SOSo56	C14:o, C16:o, C17:o, C18:o, C18:2, C19:o, C19:i, C20:o, C20:2, C21:o, C22:o, C22:i, C23:o, C24:o, C24:i, phytanic acid	-24.6	-22.3	Pork adipose and aquatic resources
SOSo57	C14:o, C16:o, C18:o, C18:2, C20:o, C22:o, C22:i, C24:o, C24:i	-25.4	-23	Pork adipose
SOSo58	C14:o, C16:o, C17:o, C18:o, C18:2, C19:o, C20:o, C22:o, C22:i, C24:o, C24:i	-29	-25	Not identifiable
SOSo60	C14:o, C16:o, C18:o, C18:2, C22:i, C24:i	-25.8	-24.2	Pork adipose
SOSo62	C14:o, C16:o, C17:o, C18:o, C18:2, C19:o, C20:o, C22:o, C22:i, C24:o, C24:i	-25.9	-23.5	Pork adipose

Sample No.	Compound detected	C16:o ( $\delta^{13}\text{C}$ )	C18:o ( $\delta^{13}\text{C}$ )	Interpretation via CSIA
SOSo63	C13:o, C14:o, C14:i, C15:o, C15:i, C16:o, C16:i, C17:o, C18:o, C18:2, C19:o, C19:i, C20:o, C20:2, C21:o, C22:o, C22:i, C23:o, C24:o, C24:i	-25.3	-23.1	Pork adipose
SOSo64	C14:o, C16:o, C16:i, C17:o, C18:o, C18:i, C18:2, C22:i, C24:i	-25.2	-26.3	Fresh water and/or Marine

Table 5.9: The results of the organic geochemical analysis by GC-MS and GC-C-IRMS of the samples from the Sosa-Dong site, and their interpretations

The geographic location of the Sosa-Dong site is quite similarly to that of the Kimpo-Yangchon site. The site is only 2.5 kilometers apart from the Anseong stream, and also close to the Yellow Sea (Figure 5.1). This means it is quite possible that the farmers of the Sosa-Dong site performed fishing also. During the excavation of the Sosa-Dong site, a total of 17 net sinkers were found. In this regard, it is essential to know whether the dwellers of the Sosa-Dong site relied on aquatic resources. According to Evershed et al. (2008), phytanic acid (3,7,11,15-tetramethylhexadecanoic acid), 4,8,12-TMTD (4,8,12-trimethyltridecanoic acid) and thermally produced long-chain O -(o-alkylphenyl)alkanoic acids are the indicators of aquatic/marine resources (cf. Oliver E. Craig et al., 2011). Among those 28 samples, two samples showed the presence of phytanic acid (SOS o49, SOSo56), indicating the possibility that those pots were used for processing aquatic resources.

The results of the isotope analysis effected on palmitic (C16:o) and stearic (C18:o) fatty acids on the samples show a varied diet of these ancient farmers. The result (Figure 5.9; 5.10; 5.11) indicate that they consumed several food stuffs including pork, aquatic resources, and C<sub>3</sub> plants. The diet of the ancient dwellers of the Sosa-Dong site was dominated by pork and aquatic (freshwater and marine) resources. About 40

percent of the samples shows the presence of Pork adipose. At most only 14 percent (4 samples) shows the presence of C<sub>3</sub> plant oil. Considering that 17 net sinkers were found at the site, it is not surprising that about 30 percent (8 samples) indicates the presence of aquatic resources. As a whole, the diet pattern of the Sosa-Dong site is somewhat similar to that of the Kimpo-Yangchon site.

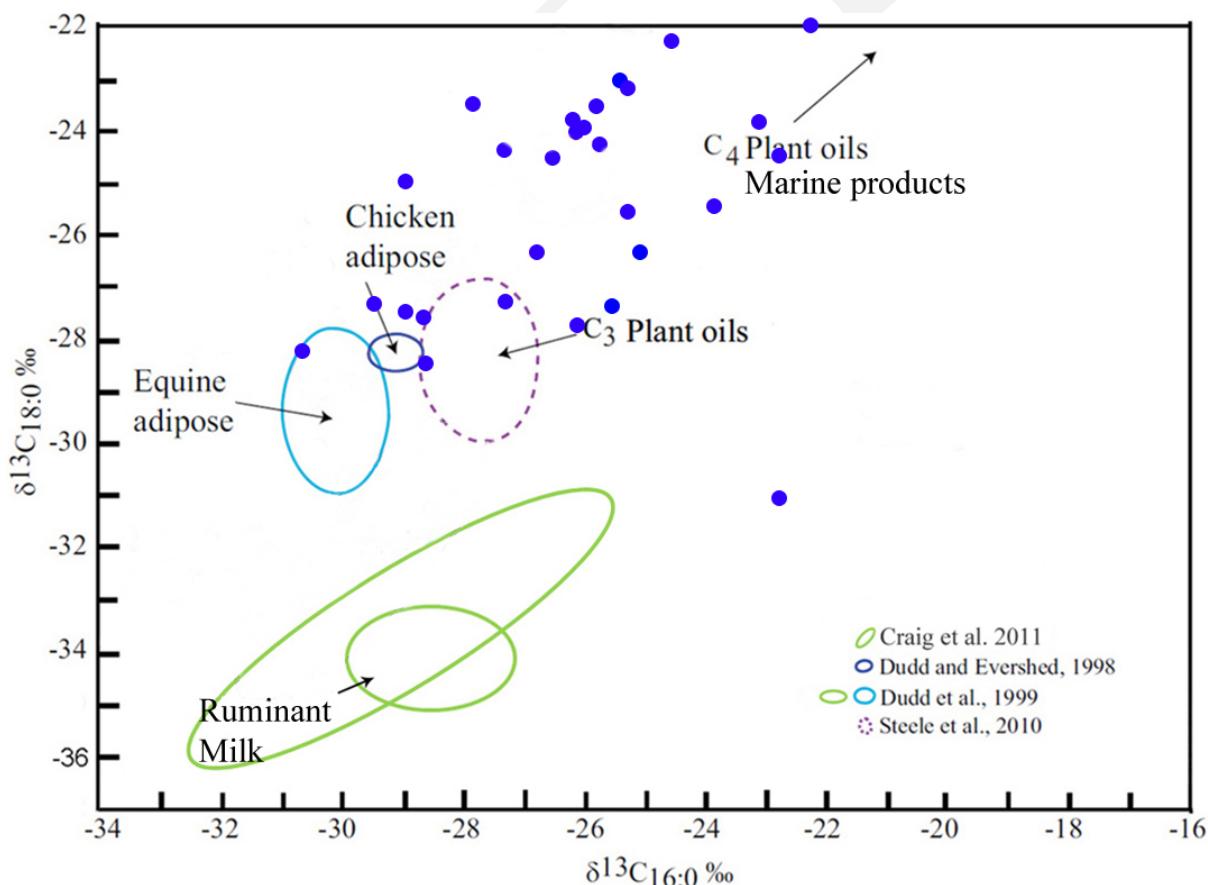


Figure 5.9: The results of CSIA by GC-C-IRMS of the samples from the Sosa-Dong site

#### LUMINESCENCE DATING RESULTS

The samples were dated using TL, OSL, and IRSL at the luminescence dating lab, University of Washington. Unfortunately, due to the absence of the associated sediments, the dose rate (alpha, beta, and gamma) was measured using the samples themselves.

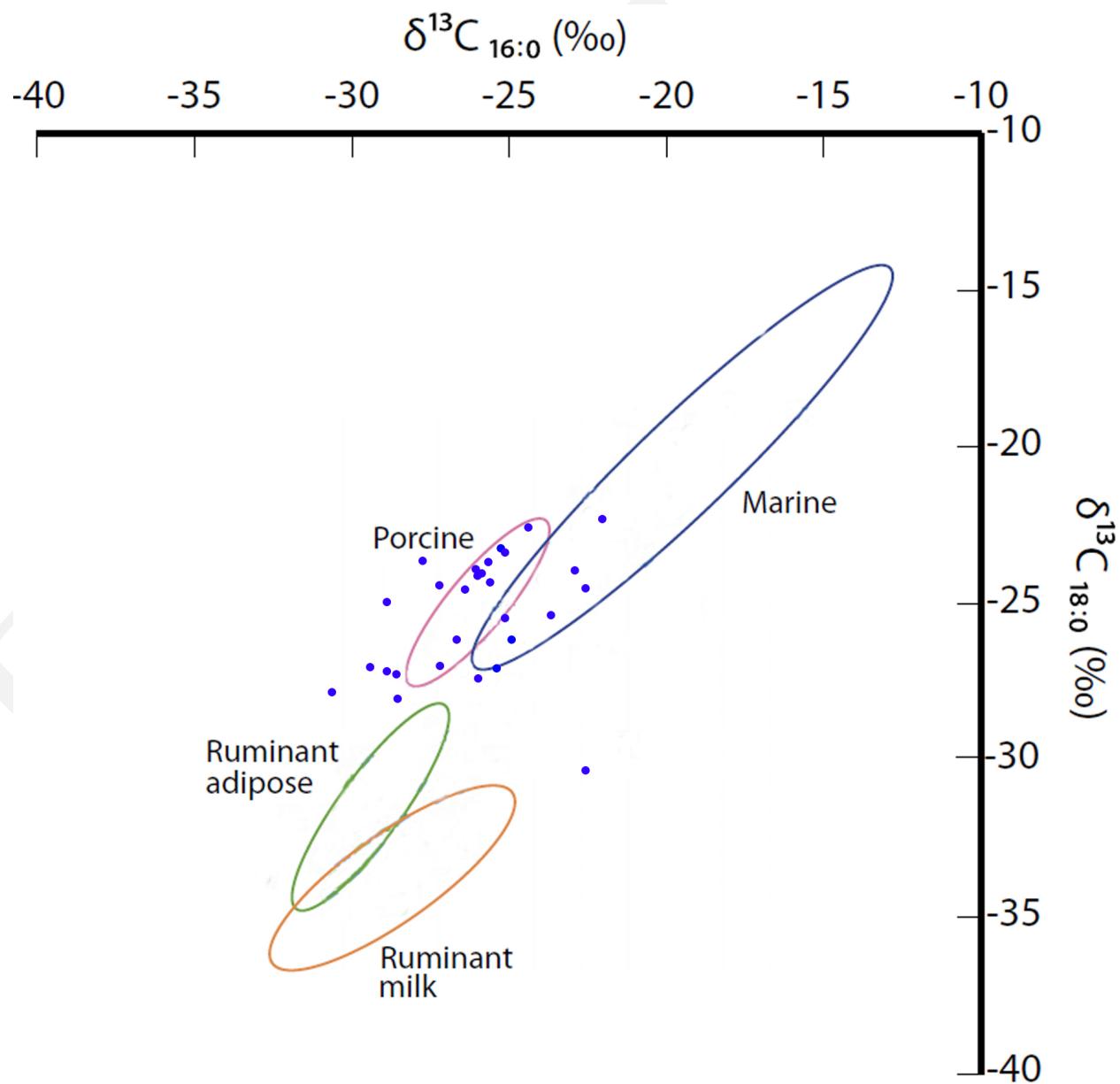


Figure 5.10: The results of CSIA by GC-C-IRMS of the samples from the Sosa-Dong site using the reference from Oliver E. Craig et al. (2011)

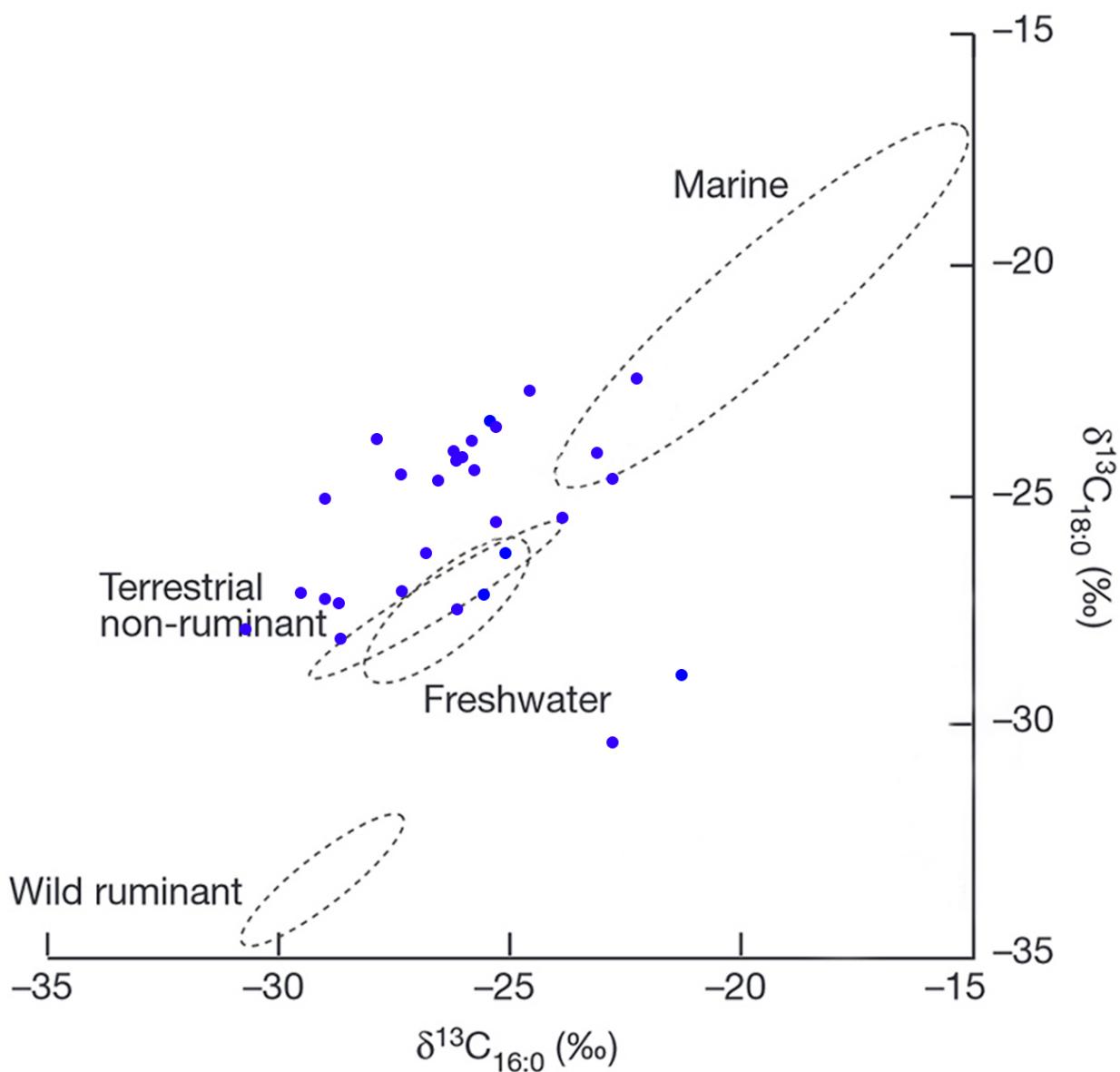


Figure 5.II: The results of CSIA by GC-C-IRMS of the samples from the Sosa-Dong site using the reference from O. E. Craig et al. (2013)

Table 5.10 shows the results of the luminescence dating. Overall, the dates match with the main occupation period of the Sosa-Dong site estimated by the radiocarbon dates.

Lab. No	Depth (m)	Water Content (%)	Dose rate* (Gy/ka)	TL (De)	OSL (De)	IRSL (De)	Age (BC)
U3042	0.3	18.4	7.872±0.475	20.97±1.59	14.487±0.43	13.194±0.307	882±209
U3043	0.3	19.7	6.664±0.40	13.999±1.469	11.958±0.229	14.18±0.591	995±127

Table 5.10: The results of the luminescence dating of the potsherd samples from the Sosa-Dong site

## SONGGUK-RI

Among the thousands of prehistoric archaeological phenomena in the Korean peninsula, probably one of the most well-known and thoroughly studied sites is the Songguk-Ri site. Located in Buyeo city, Chungnam province, South Korea, it belongs to the Middle and Late Mumun period (Figure 1.1; 5.1). The initial excavation was conducted in 1975; and Songguk-Ri became the first archaeological site in Korea, which yielded bronze artifacts, tubular greenstone (jade) beads, typical un-patterned pottery and rounded pit-houses with two post holes (Figure 5.12). These characteristic rounded pit houses were also found at other archaeological sites of later excavation, along with similar assemblages. It is why archaeologists recognized Songguk-Ri as a certain archaeological type of the Middle Mumun period, and designated both the formers and the latters ‘the Songguk-ri Style’. Until now, the site has been excavated 14 times by different branches of the National Museum of Korea and the Korean National University of Cultural heritage (Buyeo National Museum, 2000; G. T. Kim, Seo, Jeong, & Joo, 2011, 2013; National Museum of Korea, 1979, 1986, 1987).

Groups of pit-houses are found in various spots in an area of almost several square kilometers. The un-patterned potteries excavated from the site were named ‘the Songguk-Ri style pottery’; and potteries of this style were found at many other sites in the central part of the Korean peninsula with typical assemblages. The evidence of a wooden fence around the residential area indicates conflict and competition

between the local Mumun societies (National Research Institute of Cultural Heritage, 2002). A number of smaller settlements presumed to be formed about the same period were found within the radius of several kilometers from Songguk-Ri. The site also comprehends stone-cist burials with a Liaoning-style bronze dagger, large tubular-shaped greenstone ornaments and a ground stone dagger (Figure 5.12). The high status materials (e.g. bronze dagger, green stone beads) in stone cist burials at the site and a number of small settlements around it led archaeologists to assume that in Songguk-Ri and its vicinity appeared the earliest form of social hierarchy in the ancient Korean Peninsula. With the importance of the site, it is registered as “Historical Site No. 249 (Cultural heritage Administration of Korea)”.

The latest excavation of the Songguk-Ri site was conducted by the Korean National University of Cultural Heritage. The 12th to 14th excavations were held from April of 2008 to September of 2011 (G. T. Kim et al., 2011, 2013). As for the Mumun period, 47 house pits and 34 pit features were found. Based on the results of the radiocarbon dating of charcoal from the house pits and pit features (Table 5.11), the site was classified into the middle/late Mumun period. The house pits are classified into four types by their shape: circular, square, rectangular. No longhouse was found, for this type existed only during the incipient/early stage of the Mumun period. As for the ground stone tools, arrowheads, semi-lunar shaped stone knives, spindle whorl, and pieces of green stone beads were excavated.

During the 14th excavation, several kinds of carbonized grains were found at 11 different features including house pits and pit features. The confirmed kinds were rice (*Oryza sativa*), foxtail millet (*Setaria italica*), broomcorn millet (*Panicum Millaceum*), soybean (*Glycine max*) and azuki (*Vigna angularis*). The two dominant grains were foxtail millet and rice, which occupied respectively about 65 and 32 percent of the identified ones, (their respective number: 5798 and 2892).

## SAMPLING

### ORGANIC GEOCHEMICAL ANALYSES

The samples for the organic geochemical analyses were collected during the 14th excavation of the Songguk-Ri site. The general sampling strategy for the site was somewhat different from that of the

house pit No.	Cultural historical period	C14 date (uncalibrated years BP)	Calendar date
No. 2	Mumun	2430±50	BC 475
No. 23	Mumun	2540±50	BC 660
No. 23	Mumun	2450±40	BC 580
No. 26	Mumun	2350±60	BC 450
No. 26	Mumun	2360±50	BC 450
No. 38	Mumun	2500±60	BC 655
No. 39	Mumun	2590±50	BC 785
No. 43	Mumun	2220±60	BC 260
No. 48	Mumun	2520±50	BC 595
No. 51	Mumun	2410±40	BC 470
No. 51	Mumun	2520±40	BC 650
No. 52	Mumun	2560±40	BC 680
No. 52	Mumun	2460±40	BC 580
No. 67	Mumun	2420±40	BC 470
No. 67	Mumun	2490±50	BC 650
No. 68	Mumun	2440±40	BC 580
No. 70	Mumun	2410±40	BC 470
No. 70	Mumun	2430±50	BC 580

Table 5.II: The results of the AMS radiocarbon dating of the Songguk-Ri site Kim 2011; 2013a

Kimpo-Yangchon and Sosa-Dong sites. Since the potsherds from the Songguk-Ri site were quite scarce, all the available ones which were conceded by the institution were sampled for the analysis. Under these circumstances, I have collected a total of 27 samples from 16 house pits and 2 pit features (Table 5.II). Unfortunately, no rim and upper body parts were selectively collected, for none of the available potsherds came from the rim portion.

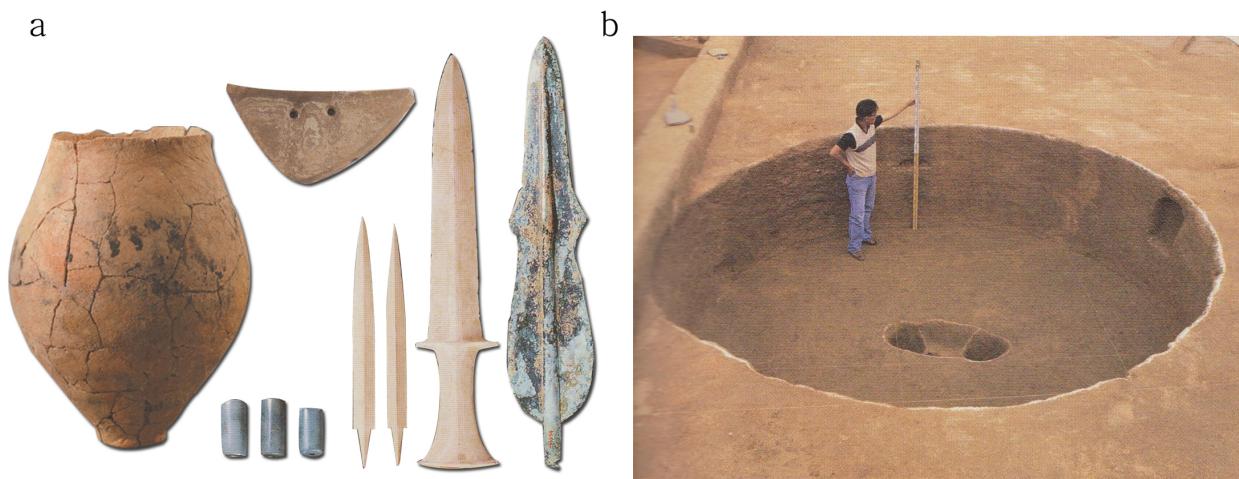


Figure 5.12: (a): some of the artifacts uncovered during the excavation of the Songguk-Ri site: pot, large tubular-shaped greenstone ornaments, semi-lunar shaped stone knife, arrowheads, ground stone dagger, and Liaoning-style bronze dagger (G.-A. Lee, 2003; Yoon & Bae, 2010) (b): the “Songguk-Ri style” rounded pit-houses with two post holes (Yoon & Bae, 2010)

Sample No.	Location/house pit No.	Part	C <sub>14</sub> date (uncalibrated years BP)
SONo01	No. 52	Body	2560±40, 2460±40
SONo02	No. 53	Body	
SONo03	No. 54	Body	
SONo04	No. 60	Body	
SONo05	No. 70	Body	
SONo06	No. 73	Body	
SONo07	No. 77	Body	
SONo08	No. 54 (pit feature)	Body	
SONo09	No. 59 (pit feature)	Body	
SONo10	No. 51	Body	2410±40, 2520±40
SONo11	No. 51	Body	2410±40, 2520±40
SONo12	No. 60	Body	
SONo13	No. 60	Body	

Sample No.	Location/house pit No.	Part	C <sub>14</sub> date (uncalibrated years BP)
SONo14	No. 61	Body	
SONo15	No. 72	Body	
SONo16	No. 72	Body	
SONo17	No. 74	Body	
SONo18	No. 74	Body	
SONo19	No. 52	Body	2560±40, 2460±40
SONo20	No. 53	Body	
SONo21	No. 58	Body	
SONo22	No. 58	Body	
SONo23	No. 59	Body	
SONo24	No. 59	Body	
SONo25	No. 62	Body	
SONo26	No. 63	Body	
SONo27	No. 69	Body	

Table 5.12: The samples collected from the Songguk-Ri site for the organic geochemical analyses in this thesis

#### LUMINESCENCE DATING

Unfortunately, no sample was collected for the Luminescence dating. This is due to the scarcity of potsherds unearthed during the 14th excavation.

#### ORGANIC GEOCHEMICAL RESULTS

Table 5.13, Figure 5.13, 5.14, and 5.15 show the results of the organic geochemical analyses. Among the 27 samples, 18 were analyzable. Nine samples were omitted due to the contamination and low concentration

of lipids.

Generally, the most frequently observed compounds in archaeological lipid residues are palmitic (C<sub>16</sub>:0) and stearic (C<sub>18</sub>:0) fatty acids (Evershed 2008a). The Songguk-Ri site was not an exception; and C<sub>16</sub>:0 and C<sub>18</sub>:0 fatty acids were the only organic compounds that were detected from all the analyzable 18 samples. Along with C<sub>16</sub>:0 and C<sub>18</sub>:0 fatty acids, I was able to identify both major short- and long-chain (un)saturated fatty acids including C<sub>13</sub>:0, C<sub>14</sub>:0, C<sub>15</sub>:0, C<sub>15</sub>:1, C<sub>16</sub>:1, C<sub>17</sub>:0, C<sub>18</sub>:1, C<sub>18</sub>:2, C<sub>19</sub>C<sub>20</sub>:0, C<sub>22</sub>:0, C<sub>22</sub>:1, C<sub>23</sub>:0, C<sub>24</sub>:0, and C<sub>24</sub>:1.

Sample No.	Compound detected	C16:o ( $\delta^{13}\text{C}$ )	C18:o ( $\delta^{13}\text{C}$ )	Interpretation via CSIA
SONoo1	C13:o, C14:o, C14:i, C15:o, C15:i, C16:o, C16:i, C17:o, C18:o, C18:i, C18:2, C19:o, C20:o, C20:i, C21:o, C22:o, C22:i, C23:o, C24:o	-28.1	-24.9	Possibly Pork adipose
SONoo2	C13:o, C14:o, C14:i, C15:o, C15:i, C16:o, C16:i, C18:o, C18:i, C19:o, C20:o, C20:i, C21:o, C22:o, C22:i, C23:o, C24:o	-27.1	-25.7	Pork adipose
SONoo3	C13:o, C14:o, C14:i, C15:o, C15:i, C16:o, C16:i, C17:o, C18:o, C18:i, C19:o, C19:i, C20:o, C20:i, C20:2, C21:o, C22:o, C22:i, C23:o, C24:o, C24:i	-27.1	-27.6	Fresh water and/or C <sub>3</sub> plant oil
SONoo4	C13:o, C14:o, C14:i, C15:o, C15:i, C16:o, C16:i, C17:o, C18:o, C18:i, C19:o, C19:i, C20:o, C20:i, C20:2, C21:o, C22:o, C22:i, C23:o, C24:o, C24:i	-26.6	-25.9	Pork adipose
SONoo5	C13:o, C14:o, C14:i, C15:o, C15:i, C16:o, C16:i, C17:o, C18:o, C18:i, C19:o, C19:i, C20:o, C20:i, C21:o, C22:o, C22:i, C23:o, C24:o, C24:i	-28.7	-31.6	Ruminant adipose

Sample No.	Compound detected	C16:o ( $\delta^{13}\text{C}$ )	C18:o ( $\delta^{13}\text{C}$ )	Interpretation via CSIA
SONo06	C13:o, C14:o, C14:i, C15:o, C15:i, C16:o, C16:i, C18:o, C18:i, C18:2, C19:o, C20:o, C20:i, C21:o, C22:o, C22:i, C23:o, C24:o, C24:i	-27.6	-26.9	Pork adipose
SONo12	C14:o, C14:i, C16:o, C16:i, C17:o, C18:o, C18:i, C18:2, C20:o, C20:i, C21:o, C22:o, C22:i, C24:o, C24:i	-28.1	-27.7	C <sub>3</sub> plant oil
SONo13	C14:o, C14:i, C15:o, C16:o, C16:i, C17:o, C18:o, C18:i, C18:2, C19:o, C19:i, C20:o, C20:i, C20:2, C21:o, C22:o, C22:i, C23:o, C24:o, C24:i	-26.7	-26.4	Pork adipose
SONo14	C13:o, C14:o, C14:i, C15:o, C16:o, C16:i, C17:o, C18:o, C18:2, C22:i, C24:i	-27.9	-29	Ruminant adipose and/or C <sub>3</sub> plant oil
SONo16	C14:o, C14:i, C15:o, C16:o, C16:i, C17:o, C18:o, C18:2, C20:o, C22:i, C24:i	-27.7	-24.7	Possibly Pork adipose
SONo17	C14:o, C14:i, C15:o, C16:o, C16:i, C17:o, C18:o, C18:2, C22:o, C22:i, C24:o, C24:i	-27.3	-28.4	Fresh water and/or C <sub>3</sub> plant oil

Sample No.	Compound detected	C16:o ( $\delta^{13}\text{C}$ )	C18:o ( $\delta^{13}\text{C}$ )	Interpretation via CSIA
SONo18	C14:o, C14:i, C15:o, C15:i, C16:o, C16:i, C17:o, C18:o, C18:2, C22:o, C22:i, C24:o, C24:i	-23.2	-23.9	Marine
SONo20	C14:o, C14:i, C15:o, C15:i, C16:o, C16:i, C17:o, C18:o, C18:i, C18:2, C19:o, C19:i, C20:o, C20:i, C20:2, C21:o, C22:o, C22:i, C23:o, C24:o, C24:i	-27.3	-28.6	Fresh water and/or C <sub>3</sub> plant oil
SONo22	C14:o, C14:i, C16:o, C16:i, C18:o, C18:2, C20:o, C22:i, C24:i	-28.9	-29.3	Ruminant adipose
SONo24	C14:o, C14:i, C16:o, C16:i, C17:o, C18:o, C18:2, C19:o, C20:o, C22:o, C22:i, C23:o, C24:o, C24:i, phytanic acid	-27.5	-28	Fresh water and/or C <sub>3</sub> plant oil
SONo25	C14:o, C14:i, C16:o, C16:i, C17:o, C18:o, C18:2, C20:2, C21:o, C22:o, C22:i, C24:i	-30.1	-28.4	Equine adipose
SONo26	C14:o, C14:i, C15:o, C16:o, C16:i, C17:o, C18:o, C18:i, C18:2, C22:o, C22:i, C24:i	-30	-28.9	Equine adipose
SONo27	C14:o, C16:o, C16:i, C18:o, C18:2, C22:i, C24:i	-28.5	-28.1	Terrestrial non-ruminant and/or C <sub>3</sub> plant oil

Sample No.	Compound detected	C16:o ( $\delta^{13}\text{C}$ )	C18:o ( $\delta^{13}\text{C}$ )	Interpretation via CSIA
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Table 5.13: The results of the organic geochemical analysis by GC-MS and GC-C-IRMS of the samples from the Songguk-Ri site, and their interpretations

The geographical conditions of the Songguk-Ri site are not drastically different from the Kimpo-Yangchon and Sosa-Dong sites. Not too far away from the Songguk-Ri site is the Geum River, which is about 7 kilometers southwest of it. Therefore, aquatic resources might have chances of having contributed to the diet of its dwellers. In order to fully understand whether these ancient farmers relied on aquatic resources, it is important to examine carefully the presence of aquatic biomarkers such as phytanic acid (3,7,11,15-tetramethylhexadecanoic acid), 4,8,12-TMTD (4,8,12-trimethyltridecanoic acid) and thermally produced long-chain O -(o-alkylphenyl) (cf. Oliver E. Craig et al., 2011; Evershed et al., 2008). Beside detecting phytanic acid from one sample (SONo24), no other aquatic biomarkers were identified.

The results of the isotope analysis of C16:o and C18:o fatty acids show their characteristic diet. In Songguk-Ri site, the story is a bit different from the former two cases. The results (Figure 5.13; 5.14; 5.15) indicate that they consumed several food stuffs including pork, C<sub>3</sub> plants, aquatic resources (mostly fresh water) and ruminants. The most interesting result is that almost none of the samples indicated the presence of marine resources. This is probably because the distance between the site and the shore nearest to it is much farther than in case of the Kimpo-Yangchon and the Sosa-Dong sites (Figure 5.1). Therefore, people relied much more on freshwater resources than on the marine ones (Figure 5.15). Also, the result of CSIA on SONo24 agreed with that of GC-MS analysis, indicating the pot was used for processing freshwater resources. Pork was still quite a popular foodstuff. Two samples indicated the presence of equine adipose. In Korea, the earliest confirmed evidence of domesticated horse came from several Late Mumun sites dated as early as 2300 BP (G.-A. Lee, 2011; J. J. Lee, 2009). Considering that the Songguk-Ri site is classified into the Middle/Late Mumun period, it is quite possible that domesticated/wild horses

would have contributed to its dwellers' diet. As stated above, during the 14th excavation of the Songguk-Ri site, over several thousands of carbonized grains were found. The dominant grains were foxtail millet and rice. Though I was able to show the presence of the C<sub>3</sub> plant oil which could have originated from rice, none of the samples indicated the presence of millet (C<sub>4</sub> plant oil: <sup>13</sup>C values in the range of -17 to -12.5 ‰; cf. Chapter 4).

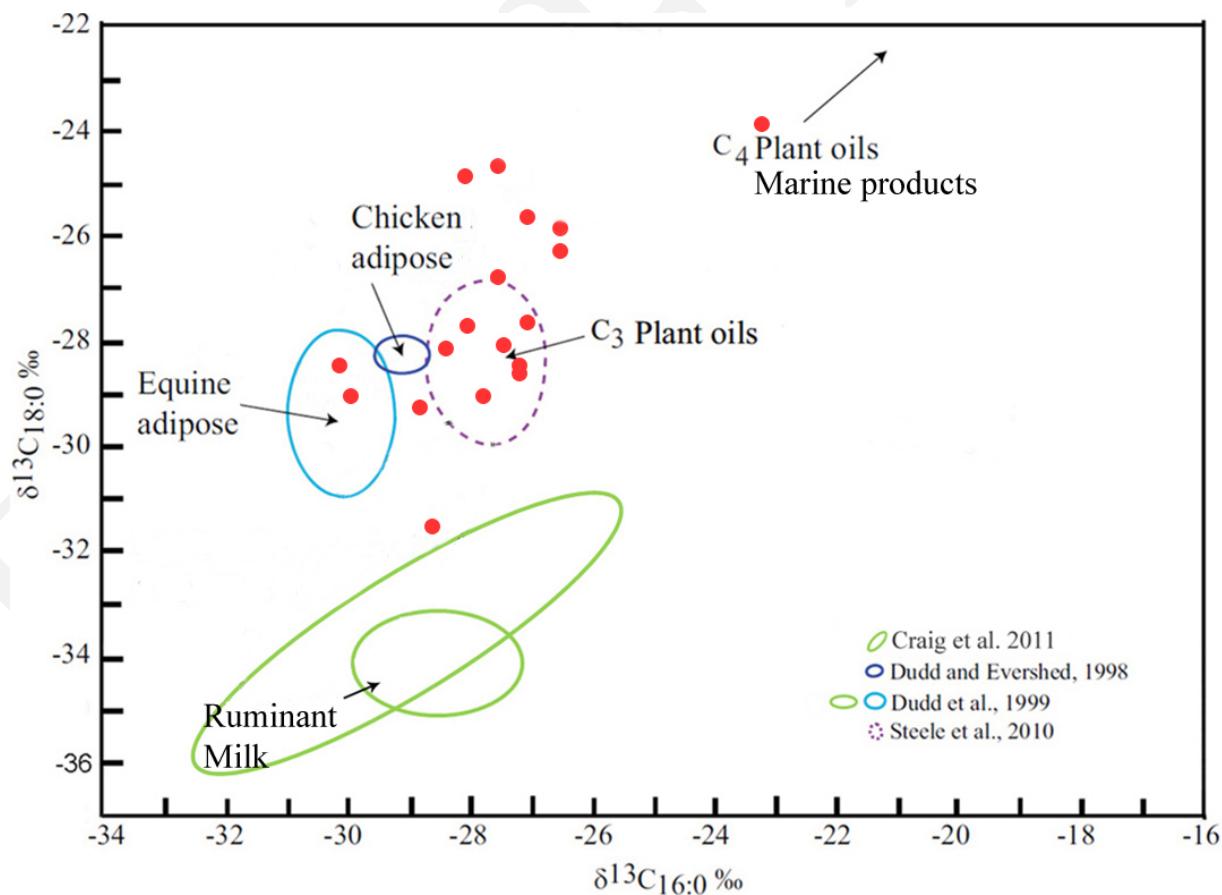


Figure 5.13: The results of CSIA by GC-C-IRMS of the samples from the Songguk-Ri site

#### EUPHA-Ri

Eupha-Ri is an Iron Age archaeological site in Huengseong city, Gangwon province, South Korea (Figure 5.1). The Huengseong city council had had a plan to build a cultural/athletic park; and the archaeological

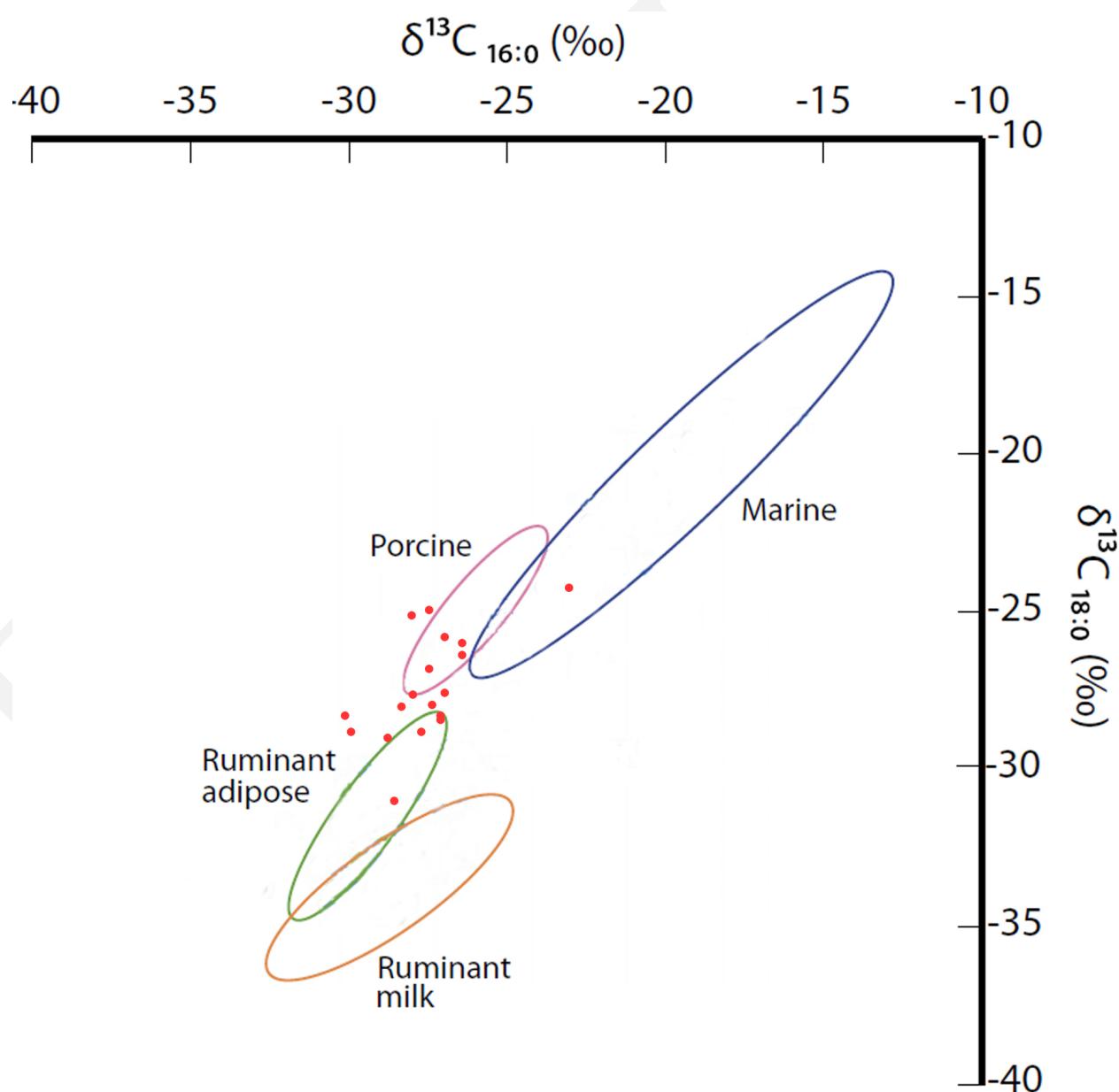


Figure 5.14: The results of CSIA by GC-C-IRMS of the samples from the Songguk-Ri site using the reference from Oliver E. Craig et al. (2011)

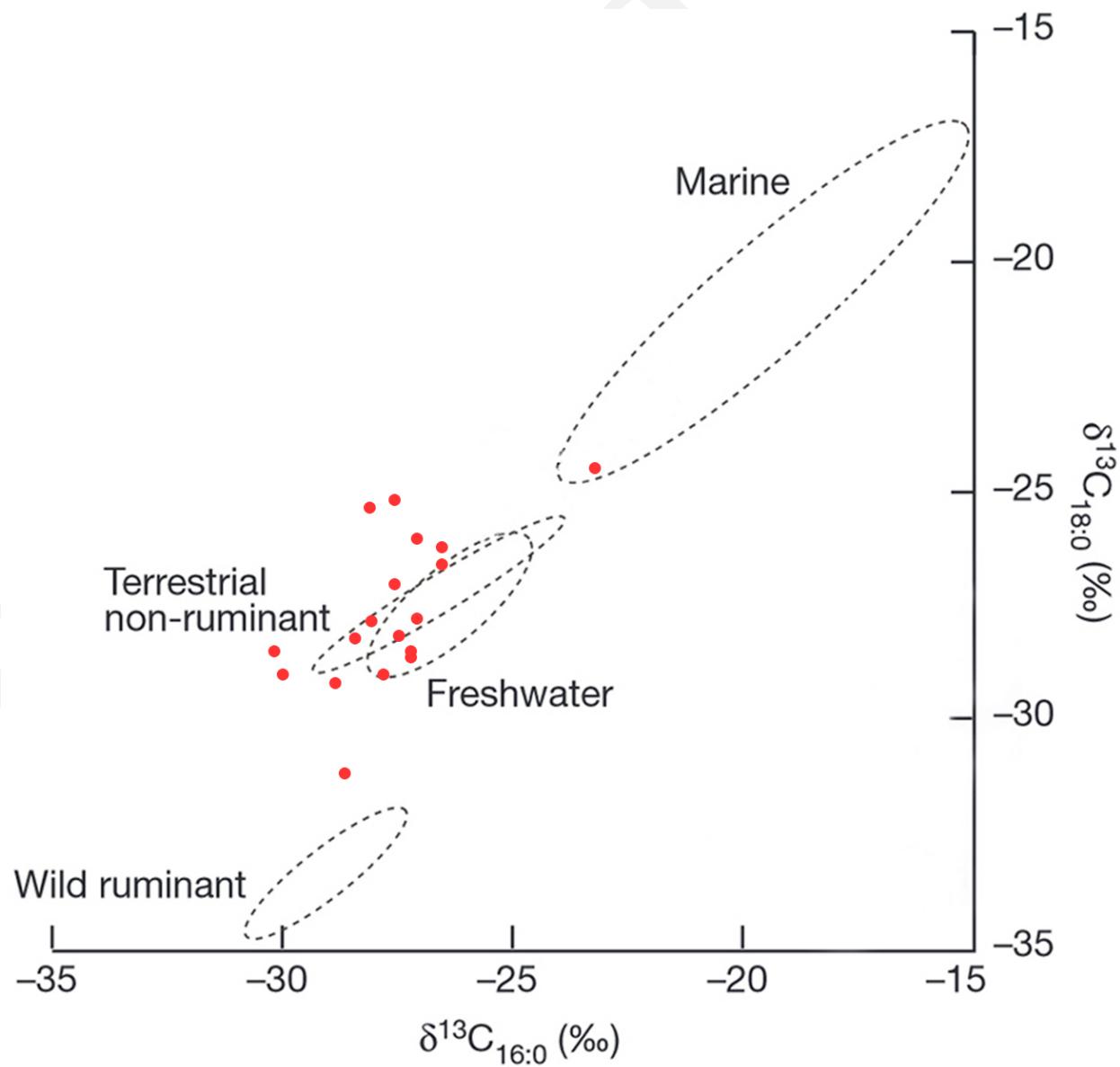


Figure 5.15: The results of CSIA by GC-C-IRMS of the samples from the Songguk-Ri site using the reference from O. E. Craig et al. (2013)

investigation had been performed beforehand by the Yonsei University Wonju Museum (H. J. Wang et al., 2013). The excavation was held from May 15th, 2009 to December 11th, 2011. The site comprehends various archaeological phenomena such as house pits, pit features and jar burials which represent different time periods from the Iron Age to the historical Joseon Dynasty (AD 1392 - 1897). The total site area is 23,840 square meters. Its main archaeological features belong to the Iron Age; and this thesis is focusing on this time period.

36 house pits, 24 pit features, and four jar burials were excavated and classified into the Iron Age. Based on the AMS radio carbon dating applied to the four charcoal samples collected from the house pits, the main occupation period was assumed to be around 1,850 - 1,640 BP (Table 5.14). The house pits are either “Lü” or “Tü” shape with rounded corners, and comprehend interior features such as hearth and post holes (Figure 5.16). This description of their shape is based on the Chinese characters. The Iron age style hardened un-patterned pottery and that which was made by the beating method were excavated. Other ceramic artifacts were also found, including a mold for iron casting, a net sinker and spindle whorls (Figure 5.17b). As for Iron ware, axes, daggers and arrowheads were found (Figure 5.17b).

Overall, the Eupha-Ri site shows the typical characteristics of the Iron Age sites in the central part of the Korean Peninsula.

House pit No.	Cultural historical period	C <sub>14</sub> date (uncalibrated years BP)	Calendar date
No. 1	Iron Age	1850±20	AD 188
No. 15	Iron Age	1780±20	AD 228
No. 15	Iron Age	1780±20	AD 217
No. 29	Iron Age	1640±20	AD 336

Table 5.14: The results of the AMS radiocarbon dating of the Eupha-Ri site (Wang 2013)

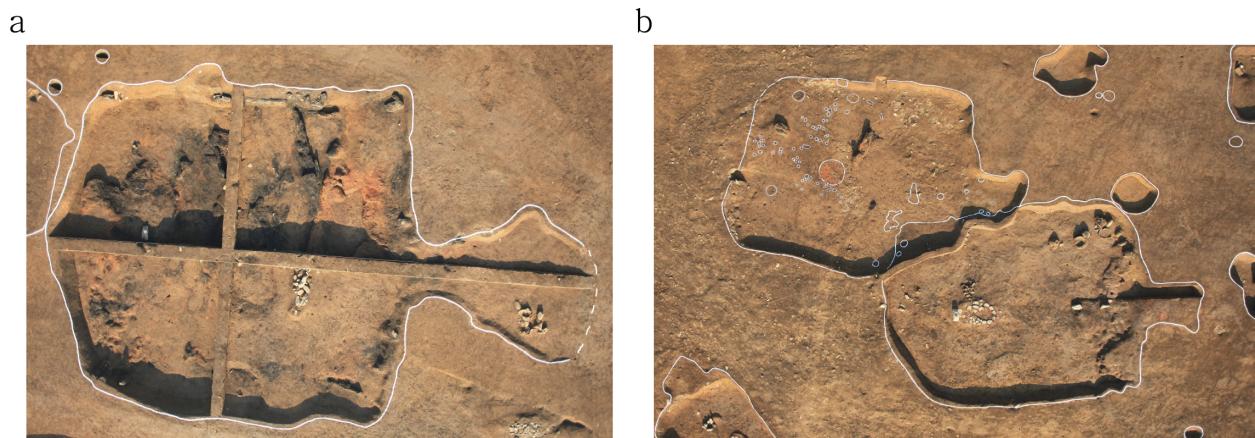


Figure 5.16: (a): “*Lü*” shape and (b): “*Tü*” shape house pits excavated from the Eupha-Ri site.

## SAMPLING

### ORGANIC GEOCHEMICAL ANALYSES

Though numerous complete pots were excavated (Figure 5.17a), not many ‘potsherds’ were found. Since in archaeological investigation, the priority is given to preserving pots in their original form and since it is not common to find lots of complete ones, I was not allowed to take parts from complete ones for the analyses. Under these limited conditions, the samples were collected among the available potsherds found at house pits.

Thus, a total of 25 samples were collected from eight house pits (Table 5.15). Though I tried to collect as many samples as I could in the given situation, I have to confess that the eight house pits might not fully represent the entire aspect of the site.

### LUMINESCENCE DATING

For the luminescence dating three samples were collected to see if there would be positive correlations between the luminescence dates and published AMS radiocarbon dates (H. J. Wang et al., 2013, Table 5.14). Among the three samples, one was collected from the house pit that had been dated by the radiocarbon

Sample No.	House pit No.	Part	C <sub>14</sub> date (uncalibrated years BP)
EUPo01	No. 15	Rim	1780±20
EUPo02	No. 15	Rim	1780±20
EUPo03	No. 15	Rim	1780±20
EUPo04	No. 15	Rim	1780±20
EUPo05	No. 15	Rim	1780±20
EUPo06	No. 15	Rim	1780±20
EUPo07	No. 15	Rim	1780±20
EUPo08	No. 15	Bottom	1780±20
EUPo09	No. 15	Bottom	1780±20
EUPo10	No. 15	Bottom	1780±20
EUPo11	No. 15	Bottom	1780±20
EUPo12	No. 33	Rim	
EUPo13	No. 32	Body	
EUPo14	No. 32	Body	
EUPo15	No. 32	Body	
EUPo16	No. 29	Body (beating method)	1640±20
EUPo17	No. 15	Body	1780±20
EUPo18	No. 15	Rim	1780±20
EUPo19	No. 7.8.9 disturbed	Rim	
EUPo20	No. 7.8.9 disturbed	Rim	
EUPo21	No. 12	Rim (beating method)	
EUPo22	No. 7.8.9 disturbed	Rim (beating method)	
EUPo30	No. 33	Body	
EUPo31	No. 32	Body	
EUPo32	No. 29	Body	1640±20

Table 5.15: The samples collected from the Eupha-Ri site for the organic geochemical analyses in this thesis



Figure 5.17: Some of the artifacts uncovered during the excavation of the Eupha-Ri site (a): Iron Age style hardened un-patterned pottery, a pot made by the beating method (center, second row) (b): mold for iron casting, net sinker, spindle whorls, iron axes and arrowheads

dating, and the other two from those which had not been (Table 5.16).

Sample No.	Location/house pit No.	Part	Depth (m)
U3039	No. 33	Body	0.3
U3040	No. 32	Body	0.3
U3041	No. 29	Body	0.3

Table 5.16: The samples collected from the Eupha-Ri site for the luminescence dating in this thesis

#### ORGANIC GEOCHEMICAL RESULTS

Table 5.17, Figure 5.18, 5.19 and, 5.20 show the results of the organic geochemical analyses. Among the 25 samples, only eight were analyzable. 17 samples were omitted mostly due to the low concentration of the lipids. Like the results in case of the former three sites, palmitic (C16:0) and stearic (C18:0) fatty acids were detected from all the analyzed eight samples. Along with C16:0 and C18:0 fatty acids, I was able

to identify both major short- and long-chain (un)saturated fatty acids such as C<sub>14</sub>:0, C<sub>15</sub>:0, C<sub>16</sub>:1, C<sub>17</sub>:0, C<sub>18</sub>:2, C<sub>19</sub>, C<sub>20</sub>:0, C<sub>21</sub>:0, C<sub>22</sub>:0, C<sub>22</sub>:1, C<sub>23</sub>:0 and C<sub>24</sub>:0. The overall lipid concentration of the samples from the Eupha-Ri site was quite low; and the number of the identified fatty acids was much smaller than those at the former three sites.

This was quite striking, because the Eupha-Ri site is almost 1000 years younger than the other sites (such as Kimpo-Yangchon or Sosa-Dong), and I thought lipids in younger sites had more chances to survive against the post-depositional process than in older ones. The overall low concentration of lipids at the Eupha-Ri site is probably due to the hard fabric of the Iron Age potteries. The surface treatments and a high firing temperature brought into play in manufacturing the Iron Age ceramic vessels would have generated smaller pores, which would have limited the concentration of lipids (cf. Correa-Ascencio & Evershed, 2014). Otherwise, more lipids could have been absorbed into the vessels. Though Correa-Ascencio and Evershed (2014) showed the effectiveness of the methanolic acid extraction on hard and burnished pots, the lipid concentration of the Eupha-Ri site's potsherds was still low, compared with that which had been observed at more porous Mumun potteries.

Sample No.	Compound detected	C16:o ( $\delta^{13}\text{C}$ )	C18:o ( $\delta^{13}\text{C}$ )	Interpretation via CSIA
EUPo05	C14:o, C15:o, C16:o, C16:i, C17:o, C18:o, C18:2, C19:o, C20:o, C21:o, C22:o, C22:i, C23:o, C24:o, phytanic acid	-26.2	-29.4	Aquatic resources
EUPo19	C16:o, C18:o, C20:o, C22:o, C22:i, C24:o	-29.2	-30.1	Ruminant adipose
EUPo20	C16:o, C18:o, C18:2	-32.4	-31.4	Not identifiable
EUPo21	C16:o, C18:o, C18:2	-30.1	-30.4	Ruminant adipose and/or Equine adipose
EUPo22	C16:o, C18:o	-32.7	-30.5	Not identifiable
EUPo30	C14:o, C16:o, C16:i, C18:o, C18:2	-27.3	-29.7	Ruminant adipose and/or C <sub>3</sub> plant oil
EUPo31	C16:o, C17:o, C18:o, C20:o, C22:o	-26.8	-26.6	Pork adipose and/or Fresh water resource
EUPo32	C14:o, C15:o, C16:o, C16:i, C18:o, C18:2	-27	-28.2	Ruminant adipose and/or Fresh water resource and/or C <sub>3</sub> plant oil

Sample No.	Compound detected	C16:o ( $\delta^{13}\text{C}$ )	C18:o ( $\delta^{13}\text{C}$ )	Interpretation via CSIA
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Table 5.17: The results of the organic geochemical analyses by GC-MS and GC-C-IRMS of the samples from the Eupha-Ri site, and their interpretations

Geographically, the Eupha-Ri site is just near the Seom River. Therefore, aquatic resources, especially fresh water ones, might have chances of having contributed to its dwellers' diet. In order to fully understand whether they relied heavily on aquatic resources or not, it is important to carefully examine the presence of aquatic biomarkers such as phytanic acid (3,7,11,15-tetramethylhexadecanoic acid), 4,8,12-TMTD (4,8,12-trimethyltridecanoic acid), and thermally produced long-chain O -(o-alkylphenyl) (cf. Oliver E. Craig et al., 2011; Evershed et al., 2008). Among the eight samples, one samples showed the presence of phytanic acid (EUPo05), indicating the possibility that those pots were used for processing aquatic resources.

In the Eupha-Ri site, the diet pattern is quite different from that of the former three cases. The isotope analysis of C16:o and C18:o fatty acids shows its interesting aspect. The results of the analysis (Figure 5.18; 5.19; 5.20) indicate that the site's ancient dwellers mainly consumed several food stuffs such as ruminants, C<sub>3</sub> plants and aquatic resources (fresh water). The most interesting result is that only one sample indicated the presence of pork adipose. Also, almost all samples except two 'not identifiable' ones showed the presence of ruminant adipose. This diet pattern focused on ruminants in the Iron Age is quite different from that of the Mumun period in which the pork is dominant. Also, one sample showed the possibility of the presence of equine adipose. During the excavation of the Eupha-Ri site, two molars that belong to horse and cattle were found. In this regards, it is quite possible that people consumed these animals. Two samples showed the possibility of the presence of C<sub>3</sub> plant oil.

#### LUMINESCENCE DATING RESULTS

The samples were dated using TL, OSL and IRSL at the luminescence dating lab, University of Washington. Unfortunately, due to the absence of the associated sediments, the dose rate (alpha, beta and gamma)

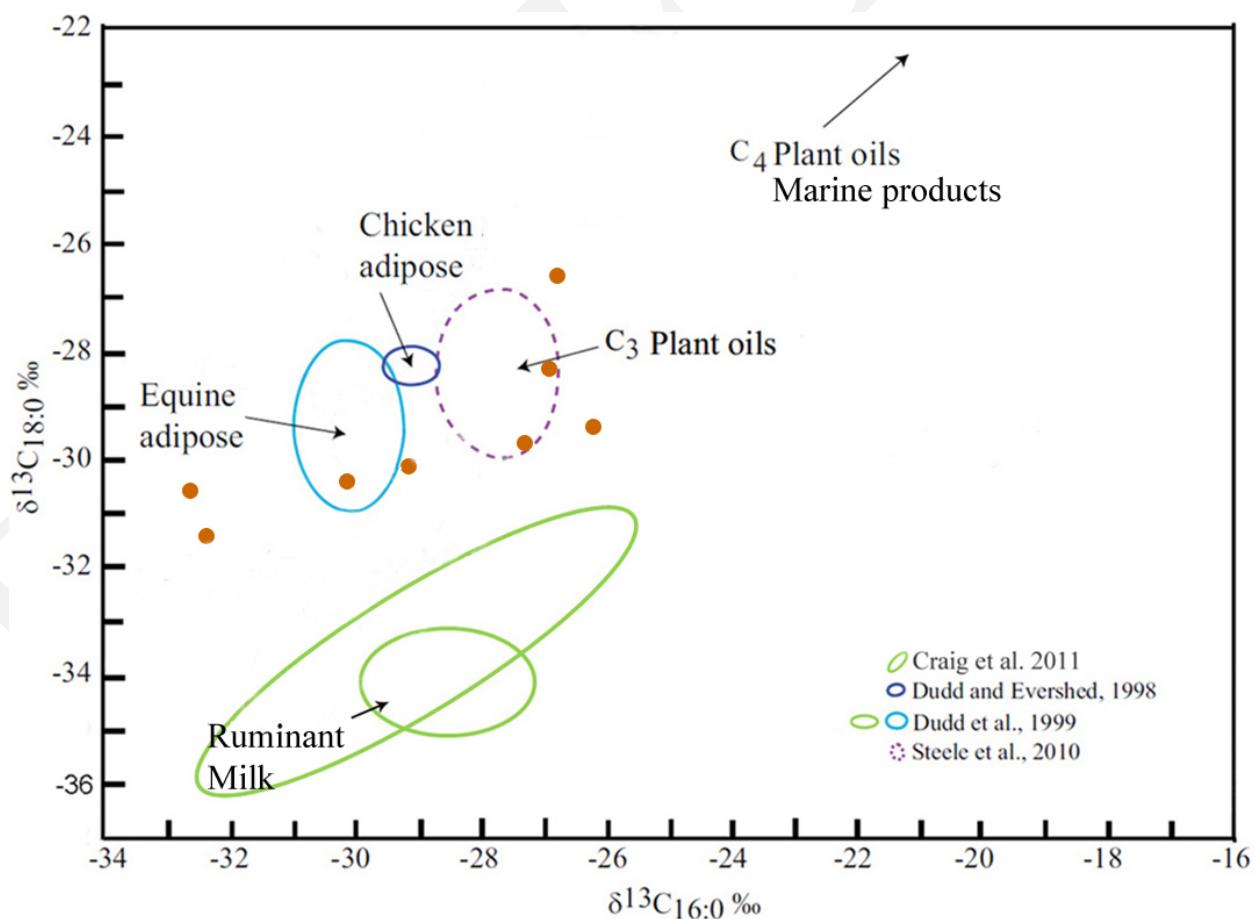


Figure 5.18: The results of CSIA by GC-C-IRMS of the samples from the Eupha-Ri site

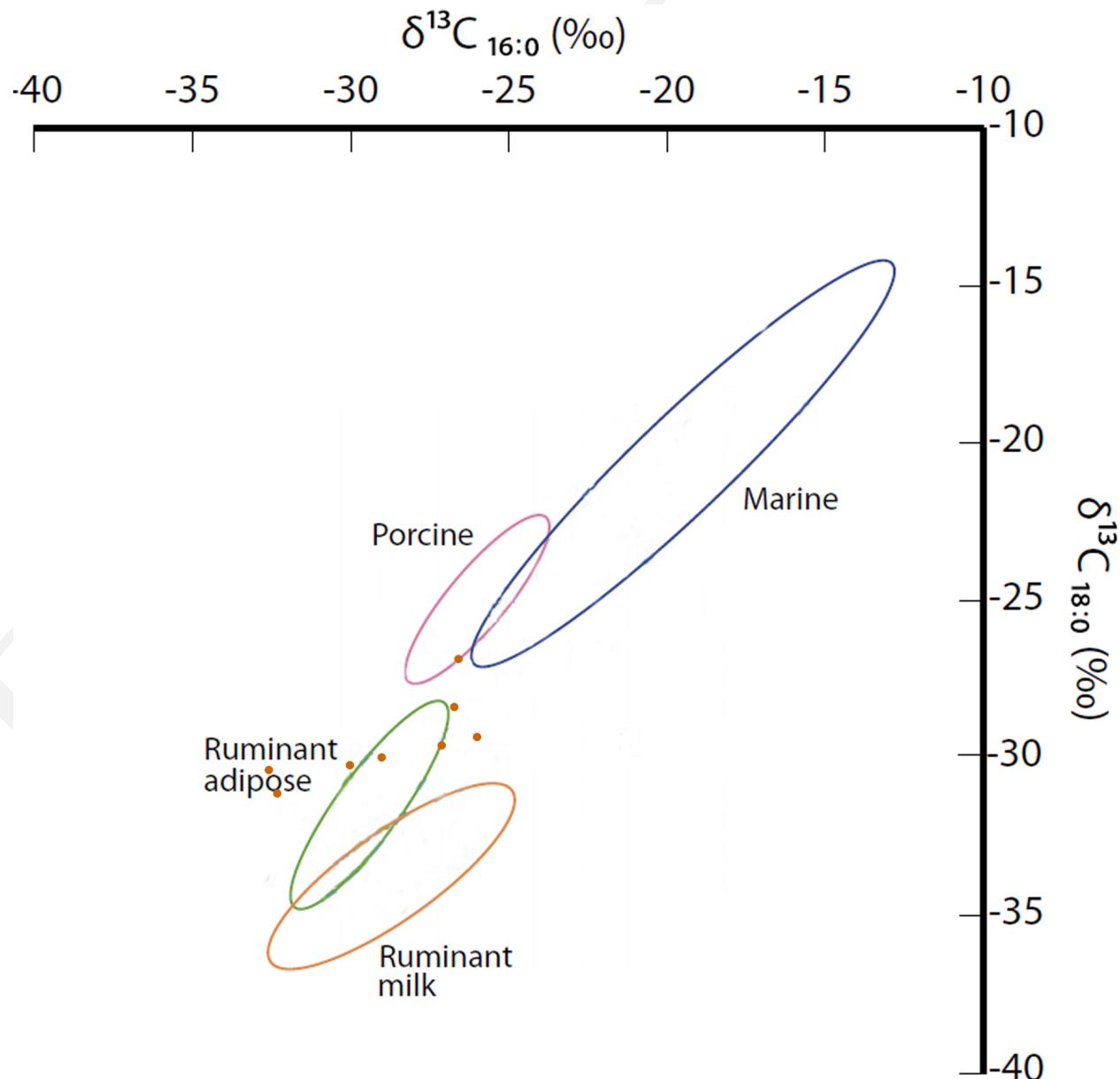


Figure 5.19: The results of CSIA by GC-C-IRMS of the samples from the Eupha-Ri site using the reference from Oliver E. Craig et al. (2011)

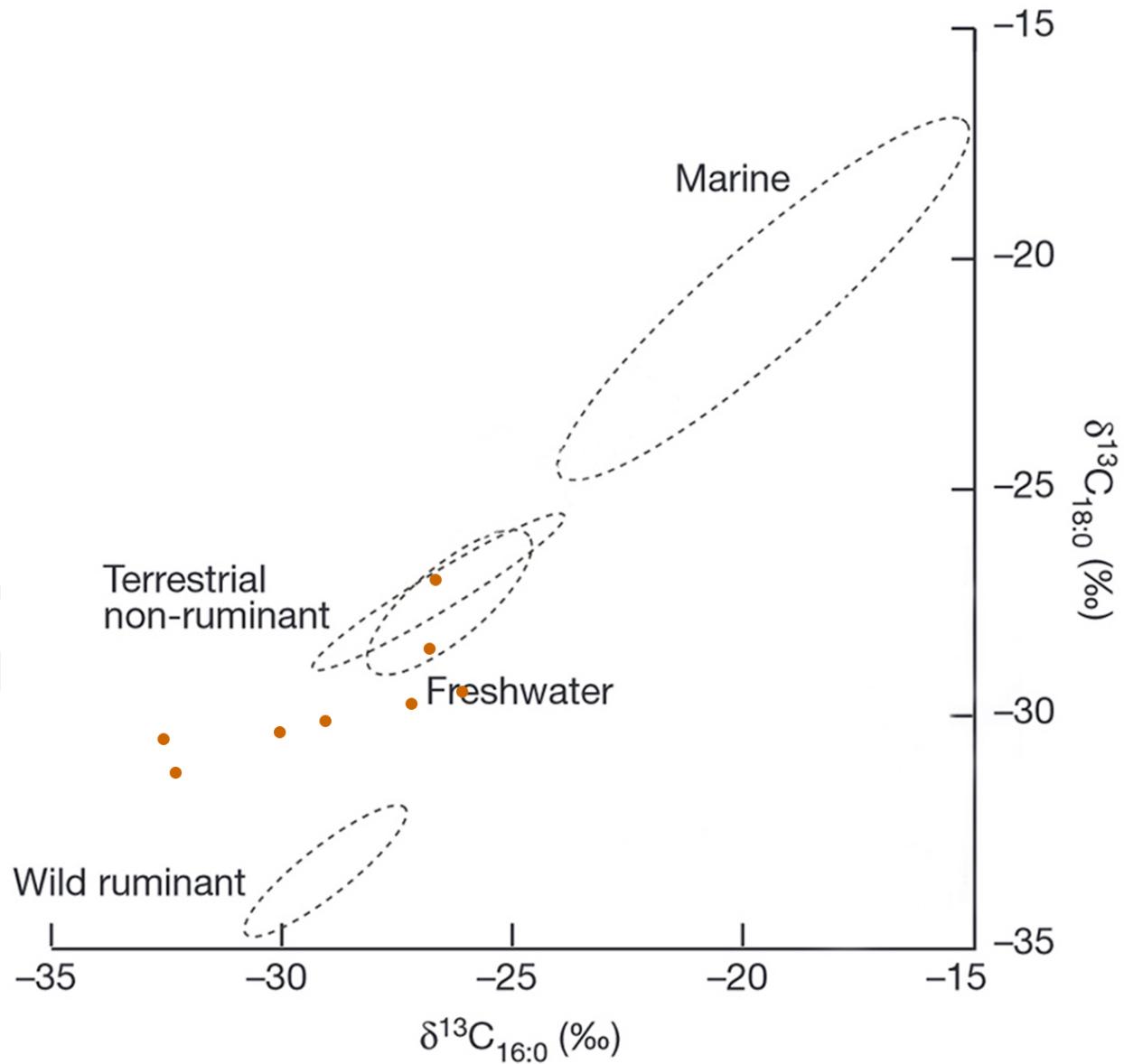


Figure 5.20: The results of CSIA by GC-C-IRMS of the samples from the Eupha-Ri site using the reference from O. E. Craig et al. (2013)

was measured using the samples themselves.

Table 5.18 shows the results of the luminescence dating. U<sub>3039</sub> and U<sub>3041</sub> corresponded to the published four AMS radiocarbon dates (Table 5.14). The date presumed by U<sub>3041</sub> indicates that the site was occupied by the Iron Age people slightly longer than the radiocarbon dates suggest. The result of U<sub>3040</sub> did not match with both archaeological features of the site and the radiocarbon dates.

Lab. No	Depth (m)	Water Content (%)	Dose rate* (Gy/ka)	TL (De)	OSL (De)	IRSL (De)	Age
U <sub>3039</sub>	0.3	14	6.378±0.429	14.67±1.07	8.13±0.264	14.652±2.537	162±114 AD (OSL)
U <sub>3040</sub>	0.3	13.4	5.336±0.562	12.3±3.1	8.974±0.16	10.04±0.214	251±122 BC
U <sub>3041</sub>	0.3	12.6	6.596±0.300	7.916±0.598	8.578±0.186	8.534±0.326	517±77 AD

Table 5.18: The results of the luminescence dating of the potsherd samples from the Eupha-Ri site. The overall low water content of the samples shows the less porous nature of the Iron Age pottery.

## SUMMARY

In this chapter, the focus was given to the results of the organic geochemical analyses and luminescence dating from four different habitation sites in the central part of the Korean peninsula. Firstly, the overall archaeological phenomena of the four sites were described in detail. Then, I elucidated the sampling strategies, methods and the results of the organic geochemical analyses and luminescence dating for the each of the sites one by one.

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## COLOPHON

This document was typeset using the  $\text{\LaTeX}$  typesetting system originally created by the Jonathan Kew, and the `uwthesis` class created by Jim Fox. Other elements of the document formatting source code have been taken from the `Latex`, `Knitr`, and `RMarkdown` templates for UC Berkeley's graduate thesis, and `Dissertate: a \LaTeX dissertation template to support the production and typesetting of a PhD dissertation at Harvard, Princeton, and NYU`

The body text is set at `11pt` with `EBGaramond(3)`. The thesis was written as `R markdown` and  $\text{\LaTeX}$ formatted documents, which was converted to PDF using `pandoc` using `knitr` with a custom R package.

This PDF was generated on `2015-06-01 05:41:48` in the following computational environment:

```
## R version 3.2.0 (2015-04-16)
## Platform: x86_64-pc-linux-gnu (64-bit)
## Running under: Ubuntu 14.04.2 LTS
##
## locale:
##   [1] LC_CTYPE=en_US.UTF-8          LC_NUMERIC=C
##   [3] LC_TIME=en_US.UTF-8          LC_COLLATE=en_US.UTF-8
##   [5] LC_MONETARY=en_US.UTF-8       LC_MESSAGES=en_US.UTF-8
##   [7] LC_PAPER=en_US.UTF-8          LC_NAME=C
##   [9] LC_ADDRESS=C                  LC_TELEPHONE=C
##  [11] LC_MEASUREMENT=en_US.UTF-8    LC_IDENTIFICATION=C
##
## attached base packages:
## [1] stats      graphics   grDevices utils      datasets  methods   base
##
## other attached packages:
```

```
## [1] git2r_0.10.1    xtable_1.7-4    kwakthesis_1.0
##
## loaded via a namespace (and not attached):
## [1] magrittr_1.5      formatR_1.2      tools_3.2.0
## [4] rstudioapi_0.3.1  dependencies_0.0-1 rstudio_0.98.1103
## [7] stringi_0.4-1     knitr_1.10.5     jsonlite_0.9.16
## [10] stringr_1.0.0     evaluate_0.7
```

The following dependencies external to R are required:

```
## [1] "zlib headers and library. OpenSSL (non-Windows)\nheaders and library. Optional LibSS
## [2] "ICU4C (>= 50.0)"
```

The current git commit of this file is 4c3b50337fd79935978f7cfbodob51f372dbecce, which is on the master branch and was made by Seung@AWS on 2015-05-30 22:57:21. The current commit message is “chapter 4 and 5 reference and table orientation”.

- Ahn, J. H. (2000). Organization of korean agricultural society. *Journal of Korean Archaeological Society*, 45.
- Ambers, J. C. (1990). Identification of the use of marine plant material as animal fodder by stable isotope ratios. In *PaC7* (pp. 251–258). Retrieved from <http://cat.inist.fr/?aModele=afficheN&cpsidt=6561461>
- Ambers, J. C. (1994). Stable carbon isotope values from tofts ness. In *Whither environmental archaeology*. Oxford: Oxbow books.
- Bae, J. S. (2007). *The establishment of mumun pottery period and complex society*. Seoul: Seokyeong Press.
- Bar-Yosef, O. (2011). Climatic fluctuations and early farming in west and east asia. *Current Anthropology*, 52(S4), S175–S193. Retrieved from <http://www.jstor.org/stable/10.1086/659784>
- Barker, A., Venables, B., Stevens Jr, S. M., Seeley, K. W., Wang, P., & Wolverton, S. (2012). An optimized approach for protein residue extraction and identification from ceramics after cooking. *Journal of Archaeological Method and Theory*, 19(3), 407–439. Retrieved from <http://link.springer.com/article/10.1007/s10816-011-9120-5>
- Barton, L., Newsome, S. D., Chen, F.-H., Wang, H., Guilderson, T. P., & Bettinger, R. L. (2009). Agricultural origins and the isotopic identity of domestication in northern china. *Proceedings of the National Academy of Sciences*, 106(14), 5523–5528. Retrieved from <http://www.pnas.org/content/106/14/5523.short>
- Belfer-Cohen, A., & Goring-Morris, A. N. (2011). Becoming farmers. *Current Anthropology*, 52(S4), S209–S220. Retrieved from <http://www.jstor.org/stable/10.1086/658861>
- Bentley, R. A., Tayles, N., Higham, C., Macpherson, C., & Atkinson, T. C. (2007). Shifting gender relations at khok phanom di, thailand. *Current Anthropology*, 48(2), 301–314. Retrieved from <http://www.jstor.org/stable/10.1086/512987>
- Berstan, R., Dudd, S. N., Copley, M. S., Morgan, E. D., Quye, A., & Evershed, R. P. (2004). Characteri-

- sation of ‘bog butter’ using a combination of molecular and isotopic techniques. *Analyt*, 129(3), 270–275. Retrieved from <http://pubs.rsc.org/en/content/articlehtml/2004/an/b313436a>
- Bethell, P. H., Goad, L. J., Evershed, R. P., & Ottaway, J. (1994). The study of molecular markers of human activity: The use of coprostanol in the soil as an indicator of human faecal material. *Journal of Archaeological Science*, 21(5), 619–632. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0305440384710612>
- Binford, L. R. (1968). Post-pleistocene adaptations. in new perspectives in archeology. Retrieved from <http://core.tdar.org/document/176969>
- Bleed, P., & Matsui, A. (2010). Why didn’t agriculture develop in japan? A consideration of jomon ecological style, niche construction, and the origins of domestication. *Journal of Archaeological Method and Theory*, 17(4), 356–370. Retrieved from <http://link.springer.com/article/10.1007/s10816-010-9094-8>
- Boland, J. M. (1990). Leapfrog migration in north american shorebirds: Intra-and interspecific examples. *Condor*, 284–290. Retrieved from <http://www.jstor.org/stable/1368226>
- Boone, J. L., & Smith, E. A. (1998). Is it evolution yet? A critique of evolutionary archaeology I. *Current Anthropology*, 39(S1), S141–S174. Retrieved from <http://www.jstor.org/stable/10.1086/204693>
- Boutton, T. W. (1991). Stable carbon isotope ratios of natural materials: II. atmospheric, terrestrial, marine, and freshwater environments. *Carbon Isotope Techniques*, 173–185. Retrieved from [https://books.google.com/books?hl=en/&lr=/&id=op7qsMF\\_h8cC/&oi=fnd/&pg=PA173/&dq=Stable+carbon+isotope+ratios+of+natural+materials+II:+atmospheric+,+terrestrial,+marine+and+freshwater+environments/&ots=nuJNsuqVAR/&sig=yMEZGDI2M1mYsUeOUzaZY5nRJaA](https://books.google.com/books?hl=en/&lr=/&id=op7qsMF_h8cC/&oi=fnd/&pg=PA173/&dq=Stable+carbon+isotope+ratios+of+natural+materials+II:+atmospheric+,+terrestrial,+marine+and+freshwater+environments/&ots=nuJNsuqVAR/&sig=yMEZGDI2M1mYsUeOUzaZY5nRJaA)
- Bramanti, B., Thomas, M. G., Haak, W., Unterlaender, M., Jores, P., Tambets, K., ... others. (2009). Genetic discontinuity between local hunter-gatherers and central europe’s first farmers. *Science*, 326(5949), 137–140. Retrieved from <http://www.sciencemag.org/content/326/5949/137.short>
- Bull, I. D., Bergen, P. F. van, Bol, R., Brown, S., Gledhill, A. R., Gray, A. J., ... Evershed, R. P. (1999).

Estimating the contribution of spartina anglica biomass to salt-marsh sediments using compound specific stable carbon isotope measurements. *Organic Geochemistry*, 30(7), 477–483. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0146638099000224>

Buyeo National Museum. (2000). *Songguk-ri VI*. Buyeo: Buyeo National Museum.

Calvin, M., Benson, A. A., & others. (1948). *The path of carbon in photosynthesis*. US Atomic Energy Commission, Technical Information Division. Retrieved from <http://www.biology.lsu.edu/introbio/fall/Fall/%202007/1201/004/Papers/Calvin.pdf>

Cannon, M. D., & Broughton, J. M. (2010). Evolutionary ecology and archaeology: An introduction. *Evolutionary Ecology and Archaeology: Applications to Problems in Human Evolution and Prehistory*, 1–12. Retrieved from [http://www.anthro.utah.edu/PDFs/cannon\\_and\\_broughton.pdf](http://www.anthro.utah.edu/PDFs/cannon_and_broughton.pdf)

Cauvin, J. (1994). *Naissance des divinités, naissance de l'agriculture: La révolution des symboles au néolithique*. Paris: CNRS.

Cavalli-Sforza, L. L., Menozzi, P., & Piazza, A. (1994). *The history and geography of human genes*. Princeton university press. Retrieved from <http://books.google.com/books?hl=en/&lr=/&id=FrwNcwKaUKoC/&oi=fnd/&pg=PP17/&dq=The+history+and+geography+of+human+genes/&ots=Hm4WRjGA79/&sig=XPSjRtjukErxE6aP0i1F5UeNgsc>

Charters, S., Evershed, R. P., Goad, L. J., Leyden, A., Blinkhorn, P. W., & Denham, V. (1993). Quantification and distribution of lipid in archaeological ceramics: Implications for sampling potsherds for organic residue analysis and the classification of vessel use. *Archaeometry*, 35(2), 211–223. Retrieved from <http://onlinelibrary.wiley.com/doi/10.1111/j.1475-4754.1993.tb01036.x/full>

Childe, V. G. (1951). Man makes himself. Retrieved from <http://agris.fao.org/agris-search/search.do?recordID=US201300597046>

Chilliard, Y., Ferlay, A., & Doreau, M. (2001). Effect of different types of forages, animal fat or marine oils in cow's diet on milk fat secretion and composition, especially conjugated linoleic acid (CLA) and polyunsaturated fatty acids. *Livestock Production Science*, 70(1), 31–48. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0301622601001968>

Chisholm, B. S., Nelson, D. E., & Schwarcz, H. P. (1982). Stable-carbon isotope ratios as a measure of marine versus terrestrial protein in ancient diets. *Science (New York, NY)*, 216(4550), 1131. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/17808502>

Cohen, D. J. (2003). Microblades, pottery, and the nature and chronology of the palaeolithic-neolithic transition in china. *The Review of Archaeology*, 24(2), 21–36.

Cohen, D. J. (2011). The beginnings of agriculture in china. *Current Anthropology*, 52(S4), S273–S293. Retrieved from <http://www.jstor.org/stable/10.1086/659965>

Cohen, M. N. (1977). The food crisis in prehistory. overpopulation and the origins of agriculture. Retrieved from <http://agris.fao.org/agris-search/search.do?recordID=US19780243901>

Cohen, M. N. (2009). Introduction: Rethinking the origins of agriculture. *Current Anthropology*, 50(5), 591–595. Retrieved from <http://www.jstor.org/stable/10.1086/603548>

Condamin, J., Formenti, F., Metais, M. O., Michel, M., & Blond, P. (1976). The application of gas chromatography to the tracing of oil in ancient amphorae. *Archaeometry*, 18(2), 195–201. Retrieved from <http://onlinelibrary.wiley.com/doi/10.1111/j.1475-4754.1976.tb00160.x/abstract>

Copley, M. S., Berstan, R., Dudd, S. N., Docherty, G., Mukherjee, A. J., Straker, V., ... Evershed, R. P. (2003). Direct chemical evidence for widespread dairying in prehistoric britain. *Proceedings of the National Academy of Sciences*, 100(4), 1524–1529. Retrieved from <http://www.pnas.org/content/100/4/1524.short>

Copley, M. S., Berstan, R., Dudd, S. N., Straker, V., Payne, S., & Evershed, R. P. (2005a). Dairying in antiquity. i. evidence from absorbed lipid residues dating to the british iron age. *Journal of Archaeological Science*, 32(4), 485–503. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0305440304001190>

Copley, M. S., Berstan, R., Mukherjee, A. J., Dudd, S. N., Straker, V., Payne, S., & Evershed, R. P. (2005b). Dairying in antiquity. III. evidence from absorbed lipid residues dating to the british neolithic. *Journal of Archaeological Science*, 32(4), 523–546. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0305440304001189>

- Copley, M. S., Rose, P. J., Clapham, A., Edwards, D. N., Horton, M. C., & Evershed, R. P. (2001). Detection of palm fruit lipids in archaeological pottery from qasr ibrim, egyptian nubia. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 268(1467), 593–597. Retrieved from <http://classic.rspb.royalsocietypublishing.org/content/268/1467/593.short>
- Corr, L. T., Richards, M. P., Jim, S., Ambrose, S. H., Mackie, A., Beattie, O., & Evershed, R. P. (2008). Probing dietary change of the kwädäy dän ts' inchi individual, an ancient glacier body from british columbia: I. complementary use of marine lipid biomarker and carbon isotope signatures as novel indicators of a marine diet. *Journal of Archaeological Science*, 35(8), 2102–2110. Retrieved from <http://www.sciencedirect.com/science/article/pii/S030544030800023X>
- Correa-Ascencio, M., & Evershed, R. P. (2014). High throughput screening of organic residues in archaeological potsherds using direct acidified methanol extraction. *Analytical Methods*, 6(5), 1330–1340. Retrieved from <http://pubs.rsc.org/en/content/articlehtml/2013/ay/c3ay41678j>
- Craig, O. E., Love, G. D., Isaksson, S., Taylor, G., & Snape, C. E. (2004). Stable carbon isotopic characterisation of free and bound lipid constituents of archaeological ceramic vessels released by solvent extraction, alkaline hydrolysis and catalytic hydrolysis. *Journal of Analytical and Applied Pyrolysis*, 71(2), 613–634. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0165237003001530>
- Craig, O. E., Saul, H., Lucquin, A., Nishida, Y., Taché, K., Clarke, L., ... others. (2013). Earliest evidence for the use of pottery. *Nature*, 496(7445), 351–354. Retrieved from <http://www.nature.com/articles/nature12109>
- Craig, O. E., Steele, V. J., Fischer, A., Hartz, S., Andersen, S. H., Donohoe, P., ... others. (2011). Ancient lipids reveal continuity in culinary practices across the transition to agriculture in northern europe. *Proceedings of the National Academy of Sciences*, 108(44), 17910–17915. Retrieved from <http://www.pnas.org/content/108/44/17910.short>
- Cramp, L. J., Evershed, R. P., & Eckardt, H. (2011). What was a mortarium used for? Organic residues and cultural change in iron age and roman britain. *Antiquity*, 85(330), 1339–1352. Retrieved from <http://>

[http://research-information.bris.ac.uk/files/8386343/Cramp\\_etal\\_2011.pdf](http://research-information.bris.ac.uk/files/8386343/Cramp_etal_2011.pdf)

Crawford, G. W. (2011). Advances in understanding early agriculture in japan. *Current Anthropology*, 52(S4), S331–S345. Retrieved from <http://www.jstor.org/stable/10.1086/658369>

Crown, P. L., & Wills, W. H. (1995). The origins of southwestern ceramic containers: Women's time allocation and economic intensification. *Journal of Anthropological Research*, 173–186. Retrieved from <http://www.jstor.org/stable/3630253>

Dudd, S. N., & Evershed, R. P. (1998). Direct demonstration of milk as an element of archaeological economies. *Science*, 282(5393), 1478–1481. Retrieved from <http://www.sciencemag.org/content/282/5393/1478.short>

Dudd, S. N., Evershed, R. P., & Gibson, A. M. (1999). Evidence for varying patterns of exploitation of animal products in different prehistoric pottery traditions based on lipids preserved in surface and absorbed residues. *Journal of Archaeological Science*, 26(12), 1473–1482. Retrieved from <http://www.sciencedirect.com/science/article/pii/S030544039804344>

Dudd, S. N., Regert, M., & Evershed, R. P. (1998). Assessing microbial lipid contributions during laboratory degradations of fats and oils and pure triacylglycerols absorbed in ceramic potsherds. *Organic Geochemistry*, 29(5), 1345–1354. Retrieved from <http://www.sciencedirect.com/science/article/pii/S014663809800093X>

Earle, T. K. (2002). *Bronze age economics: The beginnings of political economies*. Westview Pr.

Edwards, C. J., MacHugh, D. E., Dobney, K. M., Martin, L., Russell, N., Horwitz, L. K., ... others. (2004). Ancient DNA analysis of 101 cattle remains: Limits and prospects. *Journal of Archaeological Science*, 31(6), 695–710. Retrieved from <http://www.sciencedirect.com/science/article/pii/S030544030300181X>

Eerkens, J. (2002). The preservation and identification of piñon resins by GC-MS in pottery from the western great basin. *Archaeometry*, 44(1), 95–105. Retrieved from <http://onlinelibrary.wiley.com/doi/10.1111/1475-4754.00045/full>

Eerkens, J. W. (2001). *The origins of pottery among late prehistoric hunter-gatherers in California and the*

*western great basin* (PhD thesis). UNIVERSITY OF CALIFORNIA Santa Barbara. Retrieved from <http://anthropology.ucdavis.edu/people/jweerken/pdfs/Eerkens/%202001/%20-%20Dissertation.pdf>

Eerkens, J. W. (2005). GC-MS analysis and fatty acid ratios of archaeological potsherds from the western great basin of north america\*. *Archaeometry*, 47(1), 83–102. Retrieved from <http://onlinelibrary.wiley.com/doi/10.1111/j.1475-4754.2005.00189.x/full>

Eerkens, J. W. (2007). Organic residue analysis and the decomposition of fatty acids in ancient potsherds. *BAR INTERNATIONAL SERIES*, 1650, 90. Retrieved from [http://www.archbase.org/residue/samples/Sample\\_Chapter08.pdf](http://www.archbase.org/residue/samples/Sample_Chapter08.pdf)

Ehleringer, J. R., Lin, Z. F., Field, C. B., Sun, G. C., & Kuo, C. Y. (1987). Leaf carbon isotope ratios of plants from a subtropical monsoon forest. *Oecologia*, 72(1), 109–114. Retrieved from <http://link.springer.com/article/10.1007/BF00385053>

Enser, M. (1991). Animal carcass fats and fish oils. *Analysis of Oilseeds, Fats and Fatty Foods*, 329–394.

Evershed, R. P. (1993). Biomolecular archaeology and lipids. *World Archaeology*, 25(1), 74–93. Retrieved from <http://www.tandfonline.com/doi/abs/10.1080/00438243.1993.9980229>

Evershed, R. P. (2007). Exploiting molecular and isotopic signals at the mesolithic-neolithic transition. In *PROCEEDINGS-BRITISH ACADEMY* (Vol. 144, p. 141). OXFORD UNIVERSITY PRESS INC.

Evershed, R. P. (2008a). Experimental approaches to the interpretation of absorbed organic residues in archaeological ceramics. *World Archaeology*, 40(1), 26–47. Retrieved from <http://www.tandfonline.com/doi/abs/10.1080/00438240801889373>

Evershed, R. P. (2008b). ORGANIC RESIDUE ANALYSIS IN ARCHAEOLOGY: THE ARCHAEOLOGICAL BIOMARKER REVOLUTION\*. *Archaeometry*, 50(6), 895–924. Retrieved from <http://onlinelibrary.wiley.com/doi/10.1111/j.1475-4754.2008.00446.x/full>

Evershed, R. P., Arnot, K. I., Collister, J., Eglinton, G., & Charters, S. (1994). Application of isotope ratio monitoring gas chromatography-mass spectrometry to the analysis of organic residues of archae-

ological origin. *Analyst*, 119(5), 909–914. Retrieved from <http://pubs.rsc.org/en/content/articlehtml/1994/an/an9941900909>

Evershed, R. P., Bethell, P. H., Reynolds, P. J., & Walsh, N. J. (1997).  $\Sigma\beta$ -Stigmastanol and related  $\Sigma\beta$ -stanols as biomarkers of manuring: Analysis of modern experimental material and assessment of the archaeological potential. *Journal of Archaeological Science*, 24(6), 485–495. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0305440396901326>

Evershed, R. P., Copley, M. S., Dickson, L., & Hansel, F. A. (2008). EXPERIMENTAL EVIDENCE FOR THE PROCESSING OF MARINE ANIMAL PRODUCTS AND OTHER COMMODITIES CONTAINING POLYUNSATURATED FATTY ACIDS IN POTTERY VESSELS\*. *Archaeometry*, 50(1), 101–113. Retrieved from <http://onlinelibrary.wiley.com/doi/10.1111/j.1475-4754.2007.00368.x/full>

Evershed, R. P., Dudd, S. N., Anderson-Stojanovic, V. R., & Gebhard, E. R. (2003). New chemical evidence for the use of combed ware pottery vessels as beehives in ancient greece. *Journal of Archaeological Science*, 30(1), 1–12. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0305440301908271>

Evershed, R. P., Dudd, S. N., Charters, S., Mottram, H., Stott, A. W., Raven, A., ... Bland, H. A. (1999). Lipids as carriers of anthropogenic signals from prehistory. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 354(1379), 19–31. Retrieved from <http://rstb.royalsocietypublishing.org/content/354/1379/19.short>

Evershed, R. P., Dudd, S. N., Copley, M. S., Berstan, R., Stott, A. W., Mottram, H., ... Crossman, Z. (2002). Chemistry of archaeological animal fats. *Accounts of Chemical Research*, 35(8), 660–668. Retrieved from <http://pubs.acs.org/doi/abs/10.1021/ar000200f>

Evershed, R. P., Dudd, S. N., Lockheart, M. J., & Jim, S. (2001). Lipids in archaeology. *Handbook of Archaeological Sciences*, 331–49.

Evershed, R. P., Heron, C., & John Goad, L. (1990). Analysis of organic residues of archaeological origin by high-temperature gas chromatography and gas chromatography-mass spectrometry. *Analyst*,

115(10), 1339–1342. Retrieved from <http://pubs.rsc.org/en/content/articlehtml/1990/an/an9901501339>

Fankhauser, B. (1997). Amino acid analysis of food residues in pottery: A field and laboratory study. *Archaeology in Oceania*, 32(1), 131–140. Retrieved from <http://onlinelibrary.wiley.com/doi/10.1002/j.1834-4453.1997.tb00379.x/abstract>

Flannery, K. V. (1972). The cultural evolution of civilizations. *Annual Review of Ecology and Systematics*, 399–426. Retrieved from <http://www.jstor.org/stable/2096853>

Flannery, K. V. (1976). The early mesoamerican village. *AcademicPress, Orlando, Florida.*

Fraser, S. E., Insoll, T., Thompson, A., & Dongen, B. E. van. (2012). Organic geochemical analysis of archaeological medicine pots from northern ghana. the multi-functionality of pottery. *Journal of Archaeological Science*, 39(7), 2506–2514. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0305440312001161>

Friedli, H., Lötscher, H., Oeschger, H., Siegenthaler, U., & Stauffer, B. (1986). Ice core record of the  $^{13}\text{C}/^{12}\text{C}$  ratio of atmospheric CO<sub>2</sub> in the past two centuries. *Nature*, 324(6094), 237–238. Retrieved from <http://www.nature.com/nature/journal/v324/n6094/abs/324237ao.html>

Gremillion, K. J., & Piperno, D. R. (2009). Human behavioral ecology, phenotypic (developmental) plasticity, and agricultural origins. *Current Anthropology*, 50(5), 615–619. Retrieved from <http://www.jstor.org/stable/10.1086/605360>

Hansel, F. A., Copley, M. S., Madureira, L. A., & Evershed, R. P. (2004). Thermally produced  $\omega$ -alkylphenyl alkanoic acids provide evidence for the processing of marine products in archaeological pottery vessels. *Tetrahedron Letters*, 45(14), 2999–3002. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0040403904002072>

Haßtorf, C. A., & DeNiro, M. J. (1985). Reconstruction of prehistoric plant production and cooking practices by a new isotopic method. Retrieved from <http://www.nature.com/articles/315489ao>

Hatch, M. D., & Slack, C. R. (1966). Photosynthesis by sugar cane leaves: A new carboxylation reaction and the pathway their location in chloroplasts. *Biochemistry and Biophysical Research Communications*,

34, 589–593.

Heron, C., & Evershed, R. P. (1993). The analysis of organic residues and the study of pottery use. *Archaeological Method and Theory*, 247–284. Retrieved from <http://www.jstor.org/stable/20170233>

Heron, C., Evershed, R. P., & Goad, L. J. (1991). Effects of migration of soil lipids on organic residues associated with buried potsherds. *Journal of Archaeological Science*, 18(6), 641–659. Retrieved from <http://www.sciencedirect.com/science/article/pii/030544039190027M>

Ho, S. Y., Larson, G., Edwards, C. J., Heupink, T. H., Lakin, K. E., Holland, P. W., & Shapiro, B. (2008). Correlating bayesian date estimates with climatic events and domestication using a bovine case study. *Biology Letters*, 4(4), 370–374. Retrieved from <http://classic.rsbl.royalsocietypublishing.org/content/4/4/370.short>

Jansen, T., Forster, P., Levine, M. A., Oelke, H., Hurles, M., Renfrew, C., ... Olek, K. (2002). Mitochondrial DNA and the origins of the domestic horse. *Proceedings of the National Academy of Sciences*, 99(16), 10905–10910. Retrieved from <http://www.pnas.org/content/99/16/10905.short>

Kim, B. (2006). Political economy of wet rice cultivation in the bronze period in central western korea. *Journal of the Korean Archaeological Society*, 58, 40–65.

Kim, B. M., Kim, A. G., Kang, B. H., Chae, A. R., Cho, U. J., Oh, K. T., & Park, S. N. (2008). *Sosa-dong i*. Seoul: The Korea Institute of Heritage.

Kim, B. M., Kim, A. G., Kang, T. H., Chae, A. R., & Cho, U. J. (2013). *Kimpo-yangchon*. Hanam: The Korea Institute of Heritage.

Kim, G. T., Seo, H. J., Jeong, C. Y., & Joo, H. M. (2011). *Songguk-ri XII, XIII*. Buyeo: The Korean National University of Cultural Heritage.

Kim, G. T., Seo, H. J., Jeong, C. Y., & Joo, H. M. (2013). *Songguk-ri XIV*. Buyeo: The Korean National University of Cultural Heritage.

Kim, J. (2003). Land-use conflict and the rate of the transition to agricultural economy: A comparative study of southern scandinavia and central-western korea. *Journal of Archaeological Method and Theory*,

- 10(3), 277–321. Retrieved from <http://link.springer.com/article/10.1023/A:1026087723164>
- Kim, J. (2006). Resource patch sharing among foragers: Lack of territoriality or strategic choice. *Beyond Affluent Foragers: Rethinking Hunter-Gatherer Complexity*. Oxford: Oxbow. P, 168–91.
- Kim, J. C., Duller, G. A., Roberts, H. M., Wintle, A. G., Lee, Y. I., & Yi, S. B. (2010). Re-evaluation of the chronology of the palaeolithic site at jeongokri, korea, using OSL and TT-OSL signals from quartz. *Quaternary Geochronology*, 5(2), 365–370. Retrieved from <http://www.sciencedirect.com/science/article/pii/S1871101409000272>
- Lee, G.-A. (2003). *Changes in subsistence patterns from the chulmun to mumun periods: Archaeobotanical investigation* (PhD thesis). University of Toronto.
- Lee, G.-A. (2011). The transition from foraging to farming in prehistoric korea. *Current Anthropology*, 52(S4), S307–S329. Retrieved from <http://www.jstor.org/stable/10.1086/658488>
- Lee, J. J. (2009). Archaeological approaches to documenting animals in the korean peninsula. In *New approaches to prehistoric agriculture* (pp. 252–269). Seoul: Sahoi Pyoungnon.
- Lee, J. J. (2011). Intensification of millet and rice agriculture in korea –evidence from stable isotopes–. *Journal of the Korean Ancient Historical Society*, 73, 31–66.
- Legge, A. J. (1981). Aspects of cattle husbandry. In *Farming practice in british prehistory*. Edinburgh University Press.
- Lowe, T. E., Peachey, B. M., & Devine, C. E. (2002). The effect of nutritional supplements on growth rate, stress responsiveness, muscle glycogen and meat tenderness in pastoral lambs. *Meat Science*, 62(4), 391–397. Retrieved from <http://www.sciencedirect.com/science/article/pii/S030917400200027X>
- Malainey, M. E. (2010). *A consumer's guide to archaeological science: Analytical techniques*. Springer Science & Business Media. Retrieved from [https://books.google.com/books?hl=en/&lr=/&id=GULunY0dWvAC/&oi=fnd/&pg=PR5/&dq=A+consumer/%27s+Guide+to+Archaeological+Science/&ots=P\\_Grbik9hC/&sig=lt4PwGYIteQ74ps2wYtlmEB2QFg](https://books.google.com/books?hl=en/&lr=/&id=GULunY0dWvAC/&oi=fnd/&pg=PR5/&dq=A+consumer/%27s+Guide+to+Archaeological+Science/&ots=P_Grbik9hC/&sig=lt4PwGYIteQ74ps2wYtlmEB2QFg)

- Malhi, R. S., Kemp, B. M., Eshleman, J. A., Cybulski, J., Smith, D. G., Cousins, S., & Harry, H. (2007). Mitochondrial haplogroup m discovered in prehistoric north americans. *Journal of Archaeological Science*, 34(4), 642–648. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0305440306001488>
- Malmström, H., Gilbert, M. T. P., Thomas, M. G., Brandström, M., Storå a, J., Molnar, P., ... others. (2009). Ancient DNA reveals lack of continuity between neolithic hunter-gatherers and contemporary scandinavians. *Current Biology*, 19(20), 1758–1762. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0960982209016947>
- McCormac, F. G., Baillie, M. G. L., Pilcher, J. R., Brown, D. M., & Hoper, S. T. (1994).  $\Delta^{13}\text{C}$  measurements from the irish oak chronology. *Radiocarbon*, 36(1), 27–35. Retrieved from <http://cat.inist.fr/?aModele=afficheN&cpsidt=3729657>
- McCormick, F. (1992). Early faunal evidence for dairying. *Oxford Journal of Archaeology*, 11(2), 201–210. Retrieved from <http://onlinelibrary.wiley.com/doi/10.1111/j.1468-0092.1992.tb00264.x/abstract>
- Medina, E., & Minchin, P. (1980). Stratification of  $\delta^{13}\text{C}$  values of leaves in amazonian rain forests. *Oecologia*, 45(3), 377–378. Retrieved from <http://link.springer.com/article/10.1007/BF00540209>
- Medina, E., Klinge, H., Jordan, C., & Herrera, R. (1980). Soil respiration in amazonian rain forests in the rio-negro-basin. *Flora*, 170(3), 240–250.
- Mirabaud, S., Rolando, C., & Regert, M. (2007). Molecular criteria for discriminating adipose fat and milk from different species by nanoESI MS and MS/MS of their triacylglycerols: Application to archaeological remains. *Analytical Chemistry*, 79(16), 6182–6192. Retrieved from <http://pubs.acs.org/doi/abs/10.1021/ac070594p>
- Morton, J. D., & Schwarcz, H. P. (1988). Stable isotope analysis of food residue from ontario ceramics. In *Proceedings of the 26th international archaeometry symposium: Held at university of toronto, toronto, canada, may 16th to may 20th, 1988* (pp. 89–93). University of Toronto. Archaeometry Laboratory. Retrieved from <http://www.bcin.ca/Interface/openbcin.cgi?submit=submit/&Chinkey=>

10527

Mottram, H. R., Dudd, S. N., Lawrence, G. J., Stott, A. W., & Evershed, R. P. (1999). New chromatographic, mass spectrometric and stable isotope approaches to the classification of degraded animal fats preserved in archaeological pottery. *Journal of Chromatography A*, 833(2), 209–221. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0021967398010413>

Mukherjee, A. J. (2004). *The importance of pigs in the later british neolithic: Integrating stable isotope evidence from lipid residues in archaeological potsherds, animal bone, and modern animal tissues* (PhD thesis). University of Bristol. Retrieved from <http://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.416805>

National Museum of Korea. (1979). *Songguk-ri i*. Seoul: National Museum of Korea.

National Museum of Korea. (1986). *Songguk-ri II*. Seoul: National Museum of Korea.

National Museum of Korea. (1987). *Songguk-ri III*. Seoul: National Museum of Korea.

National Research Institute of Cultural Heritage. (2002). *Dictionary of korean archaeology*. Daejeon: National Research Institute of Cultural Heritage.

Norton, C. J. (2000). Subsistence change at konam-ri: Implications for the advent of rice agriculture in korea. *Journal of Anthropological Research*, 325–348. Retrieved from <http://www.jstor.org/stable/3631087>

Norton, C. J. (2007). Sedentism, territorial circumscription, and the increased use of plant domesticates across neolithic–Bronze age korea. *Asian Perspectives*, 46(1), 133–165. Retrieved from <http://muse.jhu.edu/journals/asi/summary/v046/46.inorton.html>

Payne, S. (1973). Kill-off patterns in sheep and goats: The mandibles from aşvan kale. *Anatolian Studies*, 23, 281–303. Retrieved from [http://journals.cambridge.org/abstract\\_S0066154600003744](http://journals.cambridge.org/abstract_S0066154600003744)

Price, T. D. (1995). Social inequality at the origins of agriculture. In *Foundations of social inequality* (pp. 129–151). Springer. Retrieved from [http://link.springer.com/chapter/10.1007/978-1-4613-2899-1\\_5](http://link.springer.com/chapter/10.1007/978-1-4613-2899-1_5)

- Price, T. D., & Gebauer, A. B. (1995). *Last hunters, first farmers: New perspectives on the prehistoric transition to agriculture*. School for Advanced Research on the.
- Reber, E. A., & Evershed, R. P. (2004a). How did mississippians prepare maize? The application of compound-specific carbon isotope analysis to absorbed pottery residues from several mississippi valley sites. *Archaeometry*, 46(1), 19–33. Retrieved from <http://onlinelibrary.wiley.com/doi/10.1111/j.1475-4754.2004.00141.x/full>
- Reber, E. A., & Evershed, R. P. (2004b). Identification of maize in absorbed organic residues: A cautionary tale. *Journal of Archaeological Science*, 31(4), 399–410. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0305440303001390>
- Redman, C. L. (1978). *The rise of civilization: From early farmers to urban society in the ancient near east*. WH Freeman San Francisco. Retrieved from <http://library.wur.nl/WebQuery/clc/107917>
- Regert, M., Vacher, S., Moulherat, C., & Decavallas, O. (2003). Adhesive production and pottery function during the iron age at the site of grand aunay (sarthe, france)\*. *Archaeometry*, 45(1), 101–120. Retrieved from <http://onlinelibrary.wiley.com/doi/10.1111/j.1475-4754.00098.x/full>
- Reynard, L. M., & Hedges, R. E. M. (2008). Stable hydrogen isotopes of bone collagen in palaeodietary and palaeoenvironmental reconstruction. *Journal of Archaeological Science*, 35(7), 1934–1942. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0305440307002488>
- Richards, M. (2005). The archaeological transition in europe: Archaeological models and genetic evidence. *Documenta Praehistorica*, 30, 159–167.
- Richards, M. P., Pearson, J. A., Molleson, T. I., Russell, N., & Martin, L. (2003). Stable isotope evidence of diet at neolithic çatalhöyük, turkey. *Journal of Archaeological Science*, 30(1), 67–76. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0305440301908258>
- Robb, J. (2013). Material culture, landscapes of action, and emergent causation: A new model for the origins of the european neolithic. *Current Anthropology*, 54(6), 657–683. doi:[10.1086/673859](https://doi.org/10.1086/673859)
- Robertson, I., Switsur, V. R., Carter, A. H. C., Barker, A. C., Waterhouse, J. S., Briffa, K. R., & Jones, P. D. (1997). Signal strength and climate relationships in  $^{13}\text{C}/^{12}\text{C}$  ratios of tree ring cellulose from oak in east

england. *Journal of Geophysical Research: Atmospheres* (1984–2012), 102(D16), 19507–19516. Retrieved from <http://onlinelibrary.wiley.com/doi/10.1029/97JD01226/full>

Rowley-Conwy, P. (2009). Human prehistory: Hunting for the earliest farmers. *Current Biology*, 19(20), R948–R949. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0960982209017679>

Salque, M., Bogucki, P. I., Pyzel, J., Sobkowiak-Tabaka, I., Grygiel, R., Szmyt, M., & Evershed, R. P. (2013). Earliest evidence for cheese making in the sixth millennium BC in northern europe. *Nature*, 493(7433), 522–525. Retrieved from <http://www.nature.com/articles/nature11698>

Shoda, S. (2008). The traces of cooking on bronze age potteries. In *The archaeology of cooking* (pp. 37–45). Seoul: Seokyeong Press.

Smith, B. D. (1989). Origins of agriculture in eastern north america. In. American Association for the Advancement of Science. Retrieved from <http://faculty.bennington.edu/~kwoods/classes/enviro-hist/easter/%20zona/%20agr/%20origin.pdf>

Stahl, A. B. (1989). Plant-food processing: Implications for dietary quality. *Foraging and Farming: The Evolution of Plant Exploitation*, 171–94.

Stear, N. A. (2008). *Changing patterns of animal exploitation in the prehistoric eurasian steppe: An integrated molecular, stable isotopic and archaeological approach* (PhD thesis). University of Bristol. Retrieved from <http://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.495815>

Steele, V. J., Stern, B., & Stott, A. W. (2010). Olive oil or lard?: Distinguishing plant oils from animal fats in the archeological record of the eastern mediterranean using gas chromatography/combustion/isotope ratio mass spectrometry. *Rapid Communications in Mass Spectrometry*, 24(23), 3478–3484. Retrieved from <http://onlinelibrary.wiley.com/doi/10.1002/rcm.4790/full>

Steward, J. H. (1972). *Theory of culture change: The methodology of multilinear evolution*. University of Illinois Press. Retrieved from [http://books.google.com/books?hl=en/&lr=/&id=VF4FE9SeQwAC/&oi=fnd/&pg=PP111/&dq=Theory+of+Culture+Change:+The+Methodology+of+Multilinear+Evolution/&ots=f\\_tmtIkZaw/&sig=q2iVXhaqR3wE4-M6nj67TK7tEBg](http://books.google.com/books?hl=en/&lr=/&id=VF4FE9SeQwAC/&oi=fnd/&pg=PP111/&dq=Theory+of+Culture+Change:+The+Methodology+of+Multilinear+Evolution/&ots=f_tmtIkZaw/&sig=q2iVXhaqR3wE4-M6nj67TK7tEBg)

- Thompson, A. H., Chaix, L., & Richards, M. P. (2008). Stable isotopes and diet at ancient kerma, upper nubia (sudan). *Journal of Archaeological Science*, 35(2), 376–387. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0305440307000829>
- Van Der Merwe, N. J., & Medina, E. (1989). Photosynthesis and  $^{13}\text{C}$ / $^{12}\text{C}$  ratios in amazonian rain forests. *Geochimica et Cosmochimica Acta*, 53(5), 1091–1094. Retrieved from <http://www.sciencedirect.com/science/article/pii/0016703789902135>
- Vilà, C., Leonard, J. A., Götherström, A., Marklund, S., Sandberg, K., Lidén, K., ... Ellegren, H. (2001). Widespread origins of domestic horse lineages. *Science*, 291(5503), 474–477. Retrieved from <http://www.sciencemag.org/content/291/5503/474.short>
- Vogel, J. C. (1978). Recycling of CO<sub>2</sub> in a forest environment. *Oecologia Plantarum*, 13, 89–94.
- Wandsnider, L. (1997). The roasted and the boiled: Food composition and heat treatment with special emphasis on pit-hearth cooking. *Journal of Anthropological Archaeology*, 16(1), 1–48. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0278416597903032>
- Wang, H. J., Gong, S. J., Choi, T. S., Kim, I. G., Seo, S. D., & Kim, H. R. (2013). *Excavation report of the potential hoengseong leisure park ground plot*. Wonju: Yonsei University Wonju museum.
- Welch, P. D., & Scarry, C. M. (1995). Status-related variation in foodways in the moundville chiefdom. *American Antiquity*, 397–419. Retrieved from <http://www.jstor.org/stable/282257>
- Whittle, A., & Cummings, V. (2007). *Going over: The mesolithic-neolithic transition in north west europe*. Oxford University Press.
- Winterhalder, B., & Kennett, D. J. (2006). Behavioral ecology and the transition from hunting and gathering to agriculture. *Behavioral Ecology and the Transition to Agriculture*, 1–21. Retrieved from [http://books.google.com/books?hl=en/&lr=/&id=wdGmoBFqtMC/&oi=fnd/&pg=PA1&dq=Behavioral+ecology+and+the+transition+from+hunting+and+gathering+to+agriculture/&ots=-l2zUw5ZnN/&sig=JtxWSfNHe\\_76Dqpl4sCRosQNgV8](http://books.google.com/books?hl=en/&lr=/&id=wdGmoBFqtMC/&oi=fnd/&pg=PA1&dq=Behavioral+ecology+and+the+transition+from+hunting+and+gathering+to+agriculture/&ots=-l2zUw5ZnN/&sig=JtxWSfNHe_76Dqpl4sCRosQNgV8)
- Winterhalder, B., & Kennett, D. J. (2009). Four neglected concepts with a role to play in explaining the origins of agriculture. *Current Anthropology*, 50(5), 645–648. Retrieved from <http://www.jstor.org/stable/282257>

[org/stable/10.1086/605355](http://www.jstor.org/stable/10.1086/605355)

Winterhalder, B., & Smith, E. A. (1992). Evolutionary ecology and the social sciences. *Evolutionary Ecology and Human Behavior*, 3–23.

Woo, J. (2012). Seoul food: Treating your idol to lunch is the true test of fandom. *Wall Street Journal: Life and Style*. Retrieved from <http://online.wsj.com/articles/SB10001424052970204136404577211072079207422>

Woodbury, S. E., Evershed, R. P., Rossell, J. B., Griffith, R. E., & Farnell, P. (1995). Detection of vegetable oil adulteration using gas chromatography combustion/isotope ratio mass spectrometry. *Analytical Chemistry*, 67(15), 2685–2690. Retrieved from <http://pubs.acs.org/doi/abs/10.1021/aco00111a029>

Yoon, T. Y., & Bae, J. S. (2010). *Agrarian society and the leader*. Seoul: National museum of Korea.