Part I

Overview: Kilns and kiln research in East Asia

1

Introduction

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Abstract: The purpose and content of the book are briefly introduced, covering the 18 chapters that are presented in four parts based on regions and chronology. The terminology and classification of kilns and firing techniques in East Asia are discussed in order to clarify choices for terminology in the various chapters (a unification of terms and names is provided in a glossary at the end of the book). In other words, the introduction summarizes the history of research on kiln classification in China, as well as in Korea and the Japanese archipelago, and presents a proposal to classify East Asian kilns according to a unified standard (without imposing this standard on the authors), as an attempt to create standard terminology over this wide region for future research.

Keywords: Kilns in East Asia, research history, regions, terminology, classification, overview

1.1. About this book

The beginning of ceramic industry by kiln firing in East Asia is often accompanied by pottery mass production, increasing social complexity, and social interaction over wide regions including the movement of potterer groups. While the globally known "flat kiln" construction is used in North China, another construction, well known as the "dragon kiln" from Chinese contexts, was later developed in South China and spread to its northern peripheries, Mongolia, the southern Russian Far East, the Korean peninsula and the Japanese archipelago including the Ryūkyū Islands, where it became the only known type of ceramics firing kiln.

This book will introduce early stages of the establishment of a kiln industry in East Asia and in particular in those regions that are peripheral to China and that experienced social and technological change of varying intensity during the spread of kiln-firing technology. Questions about "why", "how" and "where" will be answered on the one hand in smaller case studies, introducing excavations, technological studies, and on the other hand with some broader studies on historical, economic or social backgrounds as well as on the kiln technology itself. The combination of archaeological and scientific methods and the international cooperation of researchers combining ideas and methods of different research traditions are an important part of this research field, and we shall introduce some newer trends.

The 18 chapters of this book are collected in four parts, beginning with a presentation of some general ideas and methods used in East Asian kiln research in the first part, while the second part discusses the early advancement of kiln manufacture and trade in China. The third part deals with subsequent developments in the North and Northeastern continental periphery including the Korean peninsula, and the final part shows the expansion to the islands of the Japanese and Ryūkyū archipelago, closing the cycle almost two millennia after its beginning in South China (see front map).

In the general part, Tomoko Nagatomo (Chapter 2) discusses the diffusion of kiln technology from China to the Korean peninsula and further to the Japanese archipelago. These East Asian kilns, normally just vaguely described as spreading to peripheral regions, will be introduced as a genealogy of several traditions, being influenced from different times and appearing in differing types while spreading to different regions. Masa'aki Kidachi (Chapter 3) explains the importance of kilns ("flat kilns" and "climbing kilns" or *anagama* in his terminology) without ceiling construction in East Asia, their structure and its relation to the firing process. He introduces experiments and analogies from folklore studies. In an essay that sums up experiences from several interdisciplinary research projects and years of research coordination in the Nakadake Sanroku project introduced in Chapter 17, Maria Shinoto (Chapter 4) discusses different approaches to interdisciplinary research and introduces the concept of agility. This is an explicit approach to the frequent and flexible adaptation of research to new insights from the ongoing research process in order to gain better results and new perspectives in the course of a project rather than after its end. In the final chapter (Chapter 5) of this part, Johannes Sterba discusses another ubiquitous topic in kiln research: provenancing with scientific methods. He discusses several methods and introduces the common application and additional potential of a well-established combination of Neutron Activation Analysis and subsequent statistical analyses that has been developed particularly with the problems of pottery production in mind.

The second part starts the regional discussions with a focus on China and its immediate periphery: the climbing kiln developed from the latter half of second millennium BC in the Jiangnan region. It is important in the history of the Chinese ceramics industry, and although its structure looks "primitive" at first sight, it has a structure that is superior to even the most refined "flat kiln" that is built of tiles or similar material because the heat is better kept inside the kiln chamber. Therefore, excellent ceramics like stamped hard pottery and proto-porcelain continued to be produced in this kiln type, and finally celadon was produced in these kilns. Jianming Zheng (Chapter 6) argues, while reviewing the major kiln complexes in the Jiangnan region, that the Dongtiao River Basin centering on Deqing area was outstanding in antiquity, in the size of its kiln complexes, the high firing temperatures, and the quality of its products, and occupied a highly significant position in the history of Chinese ceramics. He also points out that the steady technical basis for the emergence and development of celadon in the Han dynasty was established in this area. Michèle Demandt (Chapter 7) interprets the development of proto-porcelain in this region and time as a deliberate replacement of bronze goods by ceramic skeuomorphs in the Yue state. While replacement of raw materials is often interpreted as a necessity caused by inaccessibility of the original raw materials – bronze in this case – the Yue case is different and leads to a better understanding of the social role of ceramics in Chinese society. This proto-porcelain had been increasingly exported during the Western Han period and is nowadays discovered in burials in the Shandong area and in elite burials in the Lelang commandery on the Korean peninsula.

On the other hand, the "flat kiln" is used in North China, and Yūsuke Mukai (Chapter 8) describes its development, discussing how craftspeople began to divide into groups working for pottery kilns and those working for roof-tile kilns. The firing chamber of flat kilns is easy to widen and enlarge, which is appropriate for firing goods used in architecture like tiles and roof tiles. As the kiln shape and structure that were perfected during the Han period continued to be used for centuries without major changes mainly in northern China, the influence of roof-tile production technology and kiln structure had widely spread to East Asia. He presents the important view of a history of kiln technology in China that differs from the history of porcelain- and celadon-producing kilns. Daisuke Nakamura (Chapter 9) finishes the second part with a paper on the use of kiln-fired pottery in long-distance trade around the Yellow Sea and the East China Sea during the period from the third century BC to the third century AD. He discusses a potential value change in pottery and concludes as follows: The first widespread distribution was of large containers for transport, produced in the Liaodong and Shandong peninsulas. However, after the development of proto-celadon in the Jiangnan region, medium-sized long-necked jars were exported to other regions from the Han Dynasty onwards. In short, the wide distribution of pottery changed from pottery for transport to high-quality ceramics as trade goods. In addition to the rising value of ceramic itself, it seems to have been highly valued for drinking and spread to the high strata of societies.

In the course of the following centuries, the flat kiln spread to the north and was used in the steppe. Introducing the few examples yet known, Isao Usuki (Chapter 10) covers North Asia, especially the kilns of the Xiongnu empire from the end of the Western Han to the beginning of the Eastern Han period. These kilns were presumed to have emerged under the influence of kilns in the northern rim of the Han Dynasty. Among them, the Khustyn Bulag site that Usuki shows is of particular significance as this is the location of the first kilns whose detailed structure is known north of the Han Dynasty territory. Irina Zhushchikhovskaya (Chapter 12) describes the situation in the Primor'e region further to the East from earliest firing devices in prehistoric times, potential relations to the Korean peninsula in the first half of the first millennium AD to fully developed kilns of the Bohai period and later, covering a period between the first millennium BC and the thirteenth century AD. Her investigations include archeometric studies and discuss firing conditions and temperatures in flat kilns as well as climbing kilns – which both appear in this region and show interesting potential for understanding the relation to neighboring regions. Katsuhiko Kiyama (Chapter 11) picks up the period of the latter stage of Zhushchikhovskaya's paper, and finishes the discussion of North Asia with a regionally broader overview of developed flat kilns of the Khitans, introducing studies on the structure of flat kilns and the pottery produced. Based on a detailed examination of the pottery, Kiyama shows that the pottery production at Chintolgoi Castle built by Khitans was an amalgamation of pottery traditions of different origins, such as those of the Bohai and Uyghur.

The next two chapters discuss the spread of kiln technology and complex developments on the Korean peninsula. Kiln technology was introduced to the Korean peninsula during the Chinese Han period. In contrast to North Asia, kilns were introduced in order to produce pottery rather than tiles and roof tiles. It is a characteristic of pottery fired in kilns on the Korean peninsula that there is a gradual increase of firing temperature over time. The production of kiln-fired pottery starts in the Proto-Three Kingdom period (P-TKP) and stabilizes at the beginning of the Korean Three Kingdom period (KTKP). Sungjoo Lee (Chapter 13) states that the technology of kiln and potter's wheel were introduced in the early P-TKP and replaced the former, long-term and continuous ceramic technology tradition, a process that differed in each regional part of South Korea. Unlike in the Han River basin, where kilns were introduced late and different types of pottery were produced by different organizations, in the Nakdong River basin integrated production of Wajil ware (grey-colored and kiln-fired earthenware) mainly for offering in burials, and Yeonjil ware (orange-colored and mostly open-fired earthenware) for daily use at an early stage can be observed. These aspects are the background to the regional differences in pottery production during the KTKP. Finally, Takafumi Yamamoto (Chapter 14) suggests, based on the political situation, that regional differences between the pottery styles and the borders of the kingdoms overlap each other, that the system of pottery production might have differed between these entities as well. Baekje adopted a dispersed production/urban accumulation system, while Silla adopted a centralized production/ regional distribution system. It can be concluded that this distinction between the two states originated from differences in their social characteristics, political systems and ritual customs, including burial practices.

Kiln technology came to the Japanese archipelago at the end of the fourth century via the Korean peninsula; the kilns are all of the tunnel/climbing kiln type, which originated in Southeast China and is typical for East Asia. Tomoko Nagatomo (Chapter 15) describes the process by which, at first, a single line from Mahan-Baekje, preceding the emergence of the tunnel kiln type, enters the archipelago. However, only when kiln technology from Gaya was introduced again did it become established in the archipelago. The kilns are administered under the central political power that would become the Japanese state and develop constantly, diffusing all over Japan. Masa'aki Kidachi (Chapter 16) examines the structure of tunnel kilns (long chamber kiln) introduced to the Japanese archipelago as follows: During the early period in the Japanese archipelago at the end of fourth century, these tunnel kilns can be divided into a sunken or underground kiln and a semi-sunken or semi-underground kiln. The choice of sunken or semi-sunken kilns depended on the topography and geology in which the kiln was constructed. Sunken kilns are not easy to heat up but have the advantage of keeping the heat well. On the other hand, semi-sunken kilns – like surface kilns – have the advantage of being more efficient at raising temperatures while being responsive to the heat supply, which means that the temperature in the firing chamber rises and falls considerably. In the second half of the seventh century, these tunnel kilns developed the capability to draw the fire deep into the kiln with the invention of the upright flue.

Parallel to the expansion of the Ancient Japanese state to the south, the southernmost Sue kiln site center in Japan was established as one of the latest of its kind around AD 800 in today's Kagoshima prefecture. This region is particularly interesting because of its remote location and unique prehistory and historical development, in which the establishment of a Sue kiln site is of interest because of its social and political implications and its relation to the southern islands of Ryūkyū. Recently, questions and methods new to traditional Japanese Sue research have been introduced and combined with traditional methods and ideas in a larger international project, which is introduced by Naoko Nakamura (Chapter 17). This study bridges time and region to the last kiln site cluster, which is introduced by Akito Shinzato (Chapter 18), the Kamuiyaki kiln site center on Tokunoshima in the Ryūkyū Islands, a National Historic Site in Japan. Chronologically, the kilns bridge ancient Japan and the Middle Ages, displaying relations to the Korean peninsula in the North and islands south of Okinawa in the midst of vibrant international seafaring and exchange in the Middle Ages.

1.2. Terminology and transliteration

The final part of this book is a glossary that aims to unify the names and terms used in this book in such a way that the various research traditions are respected but the meaning is clear and shows the relation between the same phenomena with different names in different languages and traditions. Also, emphasis is on correct transliteration and writings in the original writing system. For Korean, Revised Romanization from South Korea is used; for Chinese, Pinyin without tone indicators; while for Japanese, Revised Hepburn is implemented with consistent declaration of long vowels like ō or ū in terminology as well as place names and personal names. Russian and Mongolian are transliterated according to the suggestions of the authors in a consistent way.

In order not to impose certain terminology on the authors, we leave the choice to the authors in their chapters, but in the glossary each term may redirect to another term that we suggest as standard. Where necessary, this entry links to the alternative entries. The editors chose terminology according to the following principles:

1. Avoid misleading translations.
2. Favor English terminology that conveys the meaning in the original language or the constitutive characteristics.
3. Avoid the application of names borrowed from one language in another cultural context.

We hope that the glossary, though short, may serve as a means to standardize terminology and naming in East Asian kiln research. Kiln terminology in a narrower sense is a complex problem because classification and terminology depend on different traditions and principles. This book cannot offer standardized terminology in that respect, but the following overview of research history and classifications in different research traditions may provide some orientation for readers.

1.3. Overview of the history of kiln construction and kiln research

1.3.1. Research history and classification of kilns in China

A History of Chinese Ceramics shows the change in pottery, kilns and their distribution from the appearance of pottery to the Qin dynasty period, resulting from accumulated research on the history of ceramics (edited by the Chinese Society of Silicates 1991). According to this book, early kilns with holes dug in the ground shifted from side-hole (*ce kong shi*) to pit-type kilns (*tong xue shi*) (An & Zheng 1991: 5) (Fig. 1.1b), and later, the Mantou kiln (*mantou yao*), the circular kiln (*yuan yao*), and the dragon kiln (*long yao*) were developed.

Incidentally, around the 1920s Shinobu Komori was posted to China for work and investigated kilns all over China (Komori 1936). Komori classified Chinese kilns into two main categories, named in Japanese: the flat ground kiln (*hiragama*) in the north and the inclined kiln (*keishagama*) in the south. In addition, since the mixture of both types was seen in Jingdezhen (*Keitokokuchin*), it was defined as the Jingdezhen type. He changed the traditional name of Mantou kiln to the flat ground kiln (*hiragama*) and the climbing kiln in the southern area to the inclined kiln (*keishagama*), emphasizing the importance of the angle of the kiln floor. In addition, Komori argued that the southern kilns developed sequentially from the single-chamber tunnel kiln (*anagama*) to the large kiln (*ōgama*), the snake kilns (*jagama*), the double-chambered split bamboo kiln (*waritake-gama*) and the double-stokehole climbing kiln (*renbō-shiki noborigama*).

On the other hand, Zhenqun Liu focused on the flame flow in the kiln and categorized them according to a clear criterion (Liu 1982) into three categories: updraft kiln, with flame rising from the bottom to the top; semi-downdraft kiln, from the bottom to the ceiling and back to the smoke outlet near the floor; and flatdraft kiln, with flame flowing horizontally from the firebox to the firing chamber and down to the flue.

Haitang Xiong who is well versed in Japanese kilns, attempted to classify the kilns and investigate the diffusion of kilns in East Asia, including China, the Korean peninsula and the Japanese archipelago (Xiong 1995) (Fig. 1.1a). In particular, he focused on flatdraft kilns and presented a clear subdivision plan. It is important to note that this type of kiln, considered an advanced version of a flatdraft dragon kiln (type II), was classified as a semi-downdraft climbing kiln (type IV), which is different from a flatdraft kiln.

Masato Ozawa (1993) examined the updraft kiln, which Liu and Xiong did not subdivide. He focused on the passage (fire-way) length between the firebox and the firing chamber, in addition to the positional relationship between them. Ozawa divided the updraft kiln into three types (Fig. 1.1c) and introduced the semi-downdraft kiln to the four types as follows. Type A has a long fire-way that connects the firing chamber and the firebox. Type B has the firebox, dug deeply and distinguishable from the firing chamber and connected by multiple fire-ways. Type C has the firing chamber, which is located above the firebox, and the flame holes serve as the fire-ways. Type D has an integrated firebox and firing chamber and does not connect to a fire-way. After the transition from Type A to Type B and then to Type C, the emergence of Type D was shown to occur during the Western Zhou period.

Yoshiki Fukasawa attempted to classify kilns (Fukasawa 2011) from another perspective and focused on the presence or absence of an oven floor in the firing chamber that draws the flame from the firebox into the firing chamber. He categorized the updraft kiln as a kiln with oven floor. After dividing kilns with oven floor by the presence or absence of fire-way, the type with fire-way was divided by the shape of the fire-ways, and the type without fire-way was divided by the number and location of the supporting pillars for the oven floor. This classification clarified the structural problems with the oven floor. In other words, the larger the firing chamber for production of pottery and the larger the fire-way for providing heat, the more weakened the oven floor becomes. Another unique point of Fukasawa's classification is that it grouped the flatdraft dragon kiln and the semi-downdraft kiln as a kiln without oven floor, and furthermore, subdivided by the ratio of width to length: the broad-short kiln and the long-body kiln. It is quite different from division according to the flame flow (Liu 1982; Xiong 1995) or the slope of the firing chamber (Komori 1936; Ōkawa 1985). A broad-short kiln has a length equal to the width of the firing chamber, and a narrow-long kiln has a length of 2 to 16 times the width of the firing chamber. The latter was classified into two categories: round kilns that were almost flat with a firing chamber of round shape, and long-body kilns that were five or more times as long as the width of the firing chamber.

1.3.2. Classification of kilns on the Korean peninsula

The number of kilns excavated on the Korean peninsula has increased over the last few decades because of the increase in excavations associated with the development. Since the 2000s, the transition of kilns in the Baekje, Silla and Gaya regions has been studied in detail from various perspectives (e.g. Park 2001, Kim 2004, Kim 2007, Lee 2008, Zheng 2008, Choi 2010). However, while specific changes and differences between kilns of the same type within individual regions have been elucidated, because of the limiting focus on regions and time periods little attention has been paid to the differences between various regions, such as the difference between Silla and Baekje for example. Suggestions for a solution are discussed in the contributions of Chapters 13 and 14 in this book. Systematic classification of kilns covering a wide range of time and space in the Korean peninsula is scarce, and the Japanese classification of kilns has often been used, or categories based on the plan form have been proposed. Nevertheless, Lee Sungjoo has attempted to redefine the kilns of the Korean peninsula by using the Chinese classification based on the flame flow as described above (Lee 1991).

1.3.3. Classification of kilns in the Japanese islands

The terms "climbing kiln" (*noborigama*) and "flat kiln" (*hiragama*) have commonly been used for ancient kilns in the Japanese archipelago. However, Tsugio Mikami and

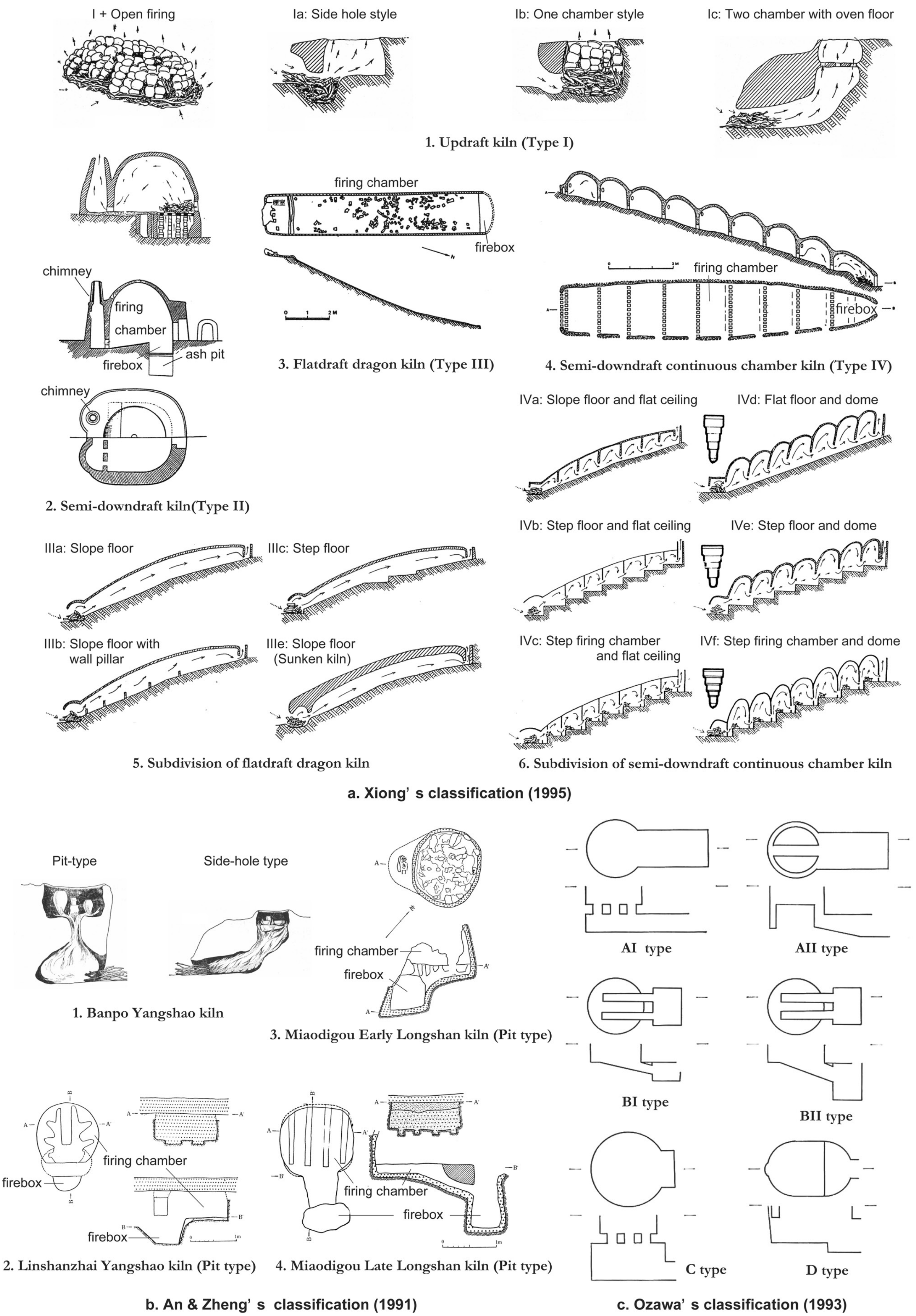

Figure 1.1. Kiln classification of previous studies.

Shōichirō Yoshida used the term "tunnel kiln" (*anagama*) instead of "climbing kiln" to avoid confusion since "climbing kiln" was used for a type of kiln with numerous connected firing chambers by ceramic researchers. Shinobu Komori, on the other hand, called a tunnel kiln one constructed underground. In addition, he included this kind of kiln as an inclined kiln (*keishagama*) which is constructed on the slope (Komori 1936).

Later, the Kiln Research Society collected information on Sue ware kilns and defined the term "tunnel kiln" (*anagama)* to distinguish them from the climbing kiln (Kiln Research Society 2004). This society supported Ōkawa's approach (Ōkawa 1985) and classified tunnel kilns into a type with wall and ceiling construction, also called "surface type" (*chijōshiki*), a type with only a ceiling construction, called "semi-sunken kiln" (*han-chikashiki*), and a type dug out completely without constructions, called "sunken kiln" (*chikashiki*). Furthermore, he divided them into several types according to the parts in their structure.

1.3.4. Classification of ancient kilns in East Asia

As described above, kilns have been classified according to the flame flow in China, and kilns in Japan have been classified according to the angle of the kiln floor and the kiln construction position (underground or surface). The differences in classification perspectives reflect the differences in kilns in each region, and neither of these classification standards is sufficient to cover all of East Asia. Therefore, the authors would like to propose classifying kilns based on the Fukasawa classification, considering the ancient kilns of China, Korea and the Japanese archipelago, using the unified criteria described below, based on an attempt offered by Nagatomo (2020) (Fig. 1.3, 1.4). After classification of kilns according to the presence or absence of the oven floor, kilns without oven floor are divided according to the definite but straightforward criteria of width and length of the firing chamber. Figure 3 shows the classification of ancient kilns in China, the Korean peninsula and Japan. Pit kilns and oven-floor kilns (updraft kiln) and kilns without oven floor

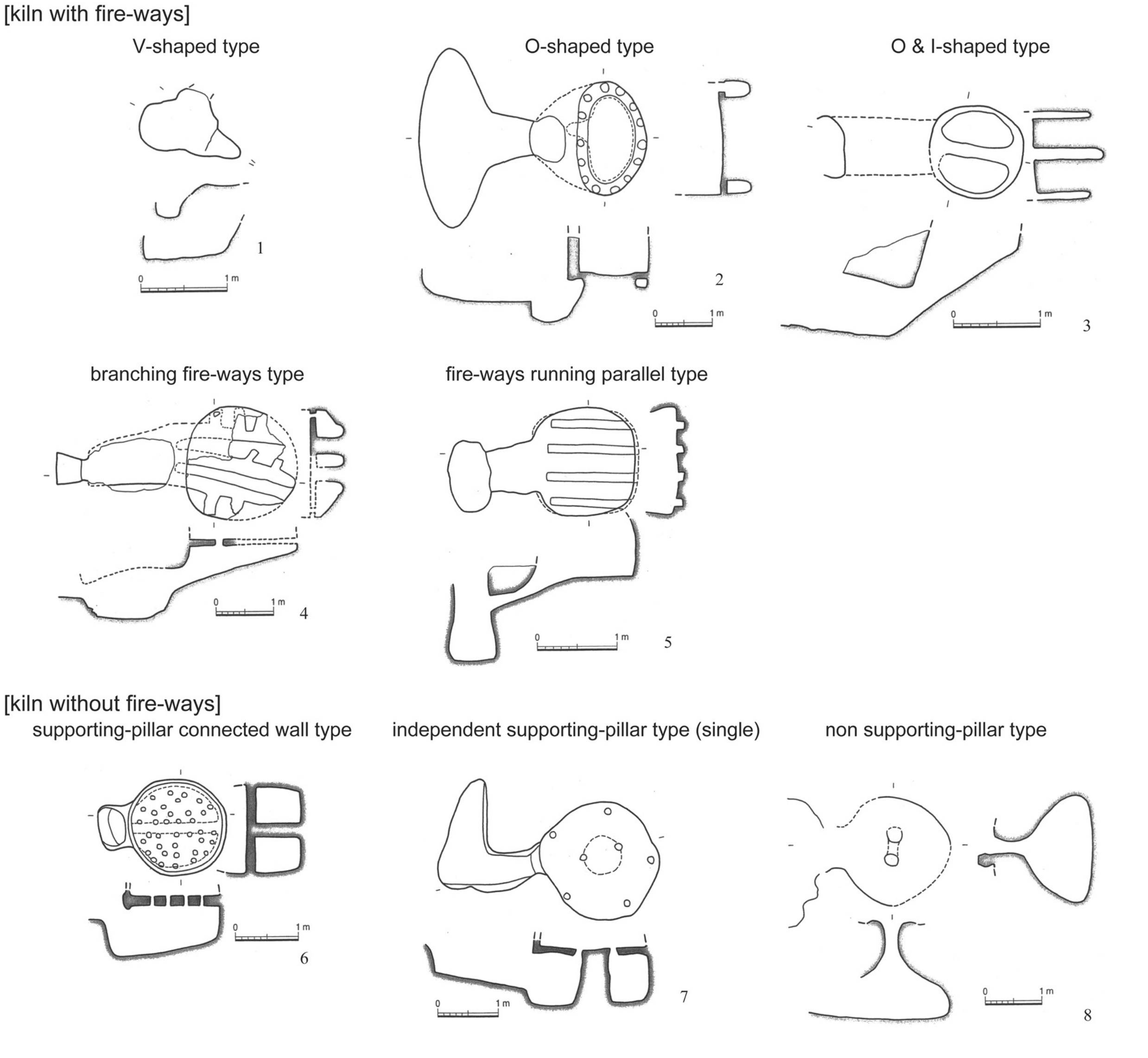

Figure 1.2. Examples of kiln with oven-floor types (after Fukasawa 2011).

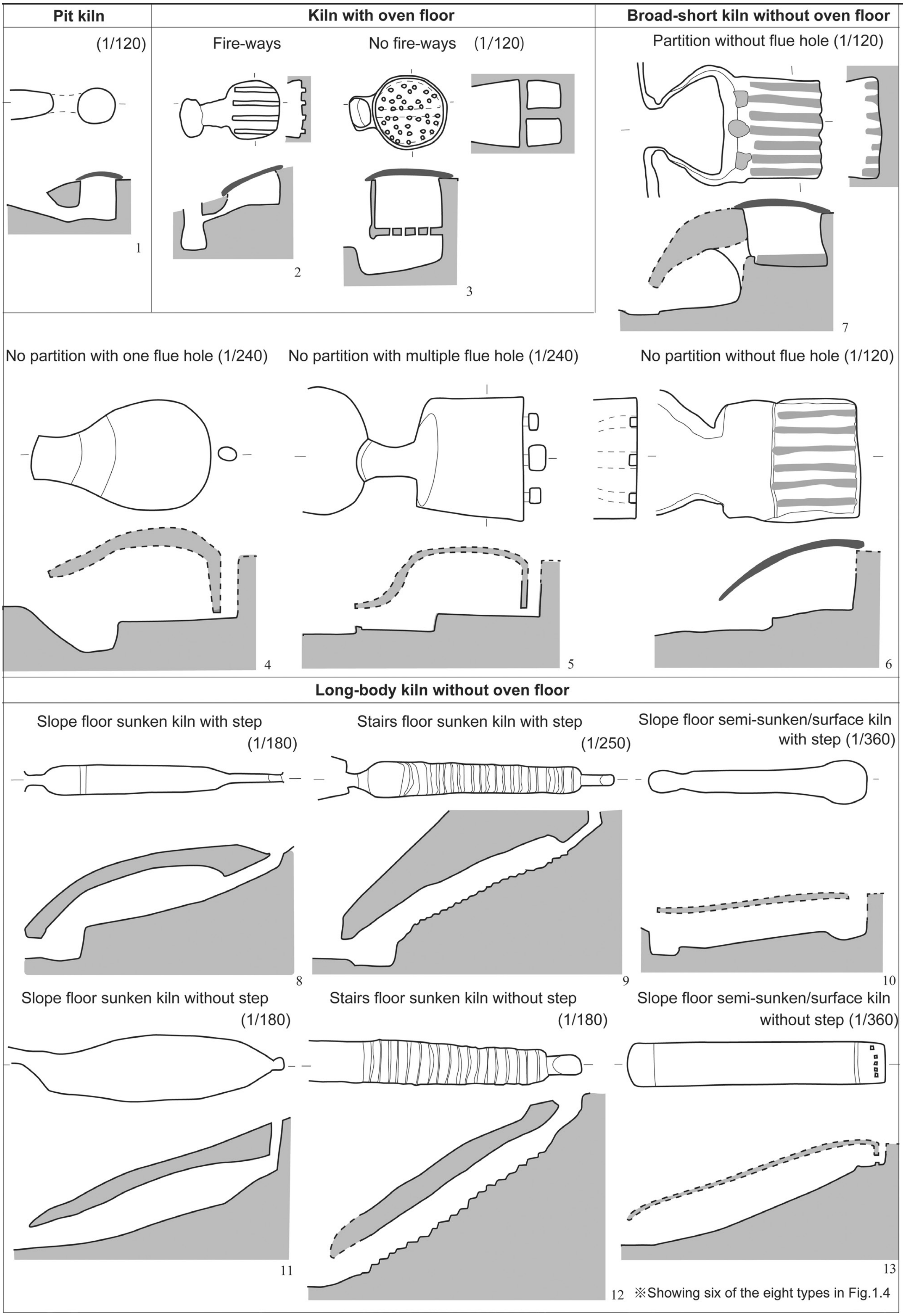

Figure 1.3. Classification of kilns (corresponds to Fig. 1.4) (Nagatomo 2020).

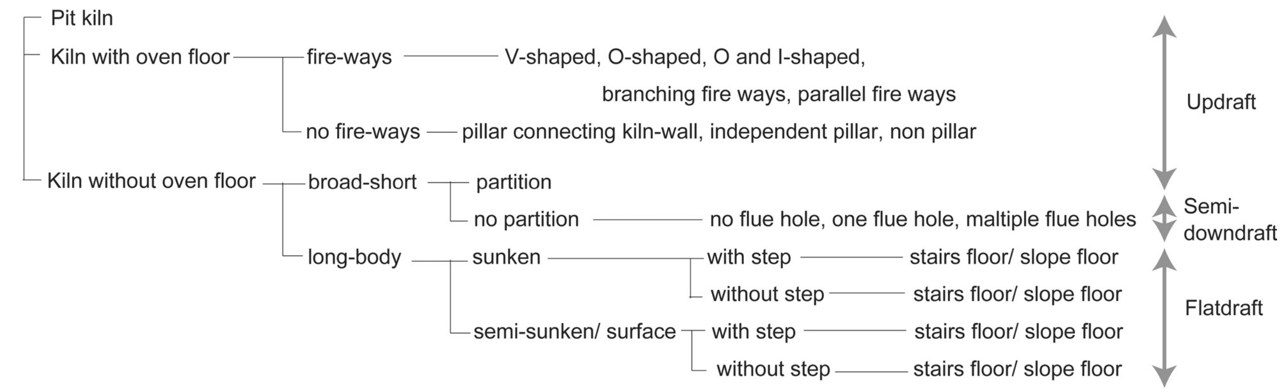

Figure 1.4. Classification of kilns in East Asia.

are broadly classified, and the kilns without oven floor are further subdivided into the broad-short kiln (flat kiln including semi-downdraft and updraft) and the long-body kiln (flatdraft dragon kiln).

Pit kiln

This type of kiln is constructed on a slope by digging a hole with an L-shaped cross-section (Fig. 1.3: 1). It is assumed that the lower horizontal hole is the stokehole and the vertical hole is the firing chamber. Fukasawa categorized this type as a round kiln among narrow-long kilns. Still, after examining the period of appearance and the structure in this paper, it has been independently categorized as a pit kiln.

Kiln with oven floor

This type corresponds to a typical updraft kiln without a fixed ceiling, which has an oven floor between the firebox and the firing chamber. Products are carried in and out of the kiln through the ceiling. The subdivisions follow Fukasawa's study (Fukasawa 2011). This type of kiln can be divided into two: a type with fire-ways (Fig. 1.3: 2) and a type without fire-ways (Fig. 1.3: 3). Furthermore, kilns with the fire-ways also are divided into three: two-way type (V-shaped, Fig. 1.2: 1) in which a single fire-way connects to a single firing chamber; ring type along with kiln-wall (O-shaped and O and I-shaped, Fig. 1.2: 2 and 3); multi-way type. Regarding the multi-way type, some have branching fire-ways (Fig. 1.2: 4), and others have fire-ways that run parallel to each other (Fig. 1.2: 5). Kilns without fire-ways are divided into the supporting-pillar connected wall type (Fig. 1.2: 6), the independent supporting-pillar type (Fig. 1.2g), and the non-supporting-pillar type (Fig. 1.2: 7). The independent supporting-pillar type has a single pillar or double pillar.

Broad-short kiln without oven floor

Basically, the space between a firing chamber and the firebox is one piece, and the length is up to twice the width of the firing chamber (Fig. 1.3). Most examples of this kind of kiln have a step between the firing chamber and the firebox. The kiln is divided into the sunken type and the semi-sunken/surface type. The latter can be subdivided according to the presence or absence of partition wall and flue (Fig. 1.3: 4–7). Those with partitions do not have a fixed ceiling (Fig. 1.3: 7), and those without partitions include kilns without a fixed ceiling (Fig. 1.3: 6). Therefore, some of the broad-short kilns without oven-floor show the flame flow from bottom to top, as in an updraft kiln. On the other hand, the flame flow in a broad-short kiln with a fixed ceiling is a semi-downdraft.

Long-body kiln without oven floor

This kind of kiln is flatdraft in flame flow (Fig. 1.3: 8–13). It is divided into the sunken type and the semi-sunken/surface type. The firing chamber and firebox are one unit, and the length is at least twice the width of the firing chamber. In addition, the presence or absence of a step between the firebox and the firing chamber can be observed, besides the presence or absence of a stairway on the floor of the firing chamber.

Although each chapter of this book uses a standard classification for the field, if the classification presented in the present chapter is kept in mind, this classification may help in understanding the structure and lineage of the kilns discussed in each case. The authors hope this will help in the reading of this book.

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2

Kilns in East Asia and Their Characteristics

Tomoko Nagatomo

Abstract: This essay discusses the introduction of kilns on the Korean peninsula and the Japanese archipelago, focusing on the differences in firing temperatures and distribution areas between 'flat' and 'tunnel' kilns. The flat kiln was first introduced in the Korean peninsula and originated from North China. Then, as the relationship between South China and the Korean Peninsula deepened, the tunnel kiln, a more advanced kiln that can fire higher, was introduced. There were three regions on the Korean peninsula at that time: the Midwest, the Southeast and the Southwest, and the differences of kiln style arose in these regions because of such differences as preceding societies and interaction with the state in South China. Furthermore, based on the examination results in the Korean peninsula, the earliest kilns in the Japanese archipelago were directly influenced by the kilns in the southwestern part of the Korean peninsula, but this did not form the basis of Japanese kilns. The kilns in the southeastern part of the Korean peninsula were introduced again and spread to Japan.

Keywords: flat kiln, tunnel kiln, firing temperature, southern China, northern China, Baekje and Mahan, Gaya and Silla, Korean peninsula, Japanese archipelago

Introduction

High-temperature firing in kilns was a highly advanced technology in the peripheral areas of China, and it was introduced into the Japanese archipelago from China via the Korean peninsula. In the regions where open-fired[1] pottery was used, the introduction of kilns enabled potters to make sophisticated tableware and storage equipment.

On the other hand, there is a wide variety of kilns in China, and the diffusion of kilns should be discussed in consideration of the diversity. In this paper, we will investigate the diffusion of kilns from China to the Korean peninsula and the Japanese archipelago, focusing on the kiln structure, after we comprehensively examined the kilns in China.

Incidentally, the first kiln-fired stoneware in Korea and Japan, which originated from China, was gray in color. Currently, gray stoneware has a unique name in each country, as follows: It is called *hui tao* in China, which simply means "gray stoneware". A layer of ash was applied to *hui tao* pottery, which was fired in high-temperature kilns of the Shang dynasty, resulting in a natural glazed gray finish. In Korea, gray pottery is called Wajil ware (low-fired stoneware) and Dojil ware (high-fired stoneware). Wajil ware appeared in the Proto-Three Kingdoms period (P-TK, first century BC to mid-third century), and Dojil ware appeared in the Korean Three Kingdoms period (KTK, late third century to seventh century). Japanese gray pottery is called Sue ware (stoneware), which appeared in the middle Kofun period (the end of the fourth century). Dojil ware and Sue ware sometimes bear a natural glaze.

2.1. Current issues

2.1.1. Sue ware and its kiln

Kilns were introduced into the Japanese archipelago at the end of the early Kofun period, the end of the fourth century. The Suemura kiln group (SKG) began to operate in this period; it was the largest long-term running kiln cluster from the Kofun to the Heian period. The study of Sue ware starts with the investigation of SKG, and has thus far shown great results.

At the beginning of Sue-ware studies, many researchers believed that the kiln-building technique spread from the SKG to the other local kilns (Tanabe 1971, 1981). However, when several early kilns were excavated in the Setouchi region and the coastal area of Osaka Bay, some researchers started to think that kilns were introduced and managed in various regions in the same early stage of SKG (Hashiguchi 1982, Saito 1983, Fujiwara 1992, Takesue 1993). And then, TG No. 232 kiln was discovered

[1] Open firing used in the absence of a permanent facility to fire pottery. There are various methods of open firing with different degrees of sealing in Southeast Asia. Some use a cover of rice straw; others use one of rice straw and mud. The latter can make more rigid pottery than normal open firing, but it is not a kiln.

in SKG, which is one of the oldest kilns in Japan (Okado eds. 1995, 1996). At present, the importance of SKG in the process of kiln development has resurfaced (Ueno 2002, Tanaka 2002, Hishida 2007, Nakatsuji 2013) due to the following facts: a) it contains some of the oldest kilns in Japan; b) it surpasses other kilns in scale and continuity; c) the presence of *futatsuki*, a small bowl with a lid that is the most common vessel type of Sue ware from the fifth century (Yamada 1998: 80).

There is no doubt that the Sue-ware kilns in Japan originated from the Korean peninsula. From comparing early Sue ware and Dojil wares, it is clear that the former was strongly influenced by the latter and the influence originated from the Gaya kingdom. However, there are some types of pots, such as wide-mouthed pots and wide-mouthed vessels with a small hole, among early Sue ware that compel some researchers to assume that early Sue ware was partly influenced by Baekje and Mahan ware (Sakai 1994, 2004). Regarding wide-mouthed vessels with a small hole, Nakakubo indicated that they were formed in Japan (Nakakubo 2017:108). However, there are few studies on the origin of the kiln itself. Among them, Ueno Kōzō presented the corpus of examples of the kiln in the Korean peninsula and insisted that the Deai kiln and TG 232 type kiln are similar to the ones in the Baekje and Mahan regions by emphasizing a planar form (Ueno 2017), but since the origin of early Sue ware was mainly in the Gaya region, the origin of Sue ware and that of the aforementioned kilns do not coincide.

2.1.2. Kilns in the Korean peninsula

In the P-TK period in Korea, the western region was known as Mahan, the eastern part as Jinhan, and the southeastern part as Byeonhan. Jinhan became Silla and Byeonhan became Gaya in the KTK period. The Mahan region is somewhat more complicated; Baekje formed in the present Seoul area and covered a peripheral area called Kyeongi. However, the southern part of Manhan did not become the territory of Baekje but continued to be called Mahan until the end of the sixth century.

New vessel shapes and techniques such as round bottoms and forming by paddle were introduced in the P-TK period. It was believed that Wajil ware in southeast Korea was formed by external influences from the stoneware of Lelang commandery (Shin 1982). In addition, the stoneware with a paddled pattern on the surface in central to southwest Korea was also formed in the second century with influence from Lelang stoneware (Park 1989). Furthermore, some researchers have presumed that Wajil ware was fired in a flat kiln (Yang 1984) and Dojil ware in a tunnel kiln because Dojil ware was fired at higher temperatures than Wajil ware (Takesue 1985, Shin 1986).

On the other hand, in the Baekje and Mahan regions, a large kiln group known as the Samryongri/Sansuri kilns, which began at the end of the P-TK period, has been excavated (Choi et al. 1986; Choi B. 1988). As a result, Choi Byeonghyeon estimated that kilns in the whole P-TK period were not flat kilns because Samryongri/Sansuri kilns have sloped floors (Choi 1992). Lee Seongju suggested that Wajil ware was influenced by the stoneware production technique of the Warring States period in China because the cord-paddling pattern was seen more often than the slanting lattice-paddling pattern[2] (Lee 1991). Also, he classified the kilns as dragon-shaped, round-shape, dome-shaped and rectangular-shape, and made them conform to Liu Zhenquin's classification (Liu 1982) based on the direction of the fire: updraft type, flatdraft type, semi-downdraft type, downdraft type. Lee Seongju argued that the kilns in the P-TK period resembled the round-shaped kiln of the flatdraft and semi-downdraft type in China. He concluded that it developed into a kiln in the Three Kingdoms period. He also believed that TK 73 of SKG in Japan succeeded the structure of the Samryongri/Sansuri kilns. As a result of Lee Seongju's study, it became a common view that the round-shaped kiln of the flatdraft and semi-downdraft type was introduced to the Korean peninsula and brought to the Japanese archipelago.

Research on kilns progressed in each region, such as Baekje and Mahan (Park 2001, Lee 2008, Jeong 2008, Choi 2010), Silla and Gaya (Kim 2004, Kim 2007). Five kilns per group appeared from the third to the fourth century in the Baekje and Mahan regions, but the number of grouped kilns increased from the end of the fifth century, especially in the southern area (Lee 2008). In addition, considering Oryangdong at Naju was the kiln site for firing jar-coffins (Choi et al. 2004, Yeon et al. 2011, Jeong 2012), peculiar developments in kiln-making were seen in Mahan region.

In the Silla region, a large and continuous kiln group consisting of more than 40 per group, such as Seongokdong, Hwasanri, Uksudong and Oksandong appeared in the latter half of the fourth century and reached their peak after the middle of the fifth century. As some of these were located around the royal capital of Silla (Ueno 2015), it is assumed that stoneware production was controlled by the regime (Yamamoto 2018). In contrast, no large kiln groups have been found in the Gaya region.

2.1.3. Issues with the regional diversity of kilns

Several issues can be identified from the above studies. First of all, the terms and contents of classification have still not been examined thoroughly enough. Secondly, an increase in kiln excavation shows the regional diversity of kilns in the Korean peninsula. However, when discussing

[2] The paddling technique to make round bottoms was new in the P-TK period. It was presumed that the technique was brought from the Lelang commandery, but there are several differences in the shape and type of stoneware. Therefore, Jeong Inseong explained that the short-necked jar fired by a kiln in the P-TK period originated from the Yan type stoneware in the early or middle Han dynasty. In short, he insisted that the short-necked jars were developed before the establishment of Lelang commandery (Jeong 2013). However, Takaku Kenji opposed to the idea judging from the parallel relationship between burials in Lelang commandery and those in South Korea (Takaku 2018). The beginning of the P-TK period seems not to date back many decades before the establishment of Lelang commandery.

the origin and development of kilns in the whole Korean peninsula, regional differences are not taken into account, and when discussing each region, comparisons with other regions are often not made. Kilns in the Japanese archipelago are said to have inherited the structure of Samryongri/Sansuri kilns in Baekje and Mahan but most early Sue ware came from the Gaya region. There is thus a contradiction in the origin of kilns and stoneware.

The number of excavation and research cases increased in China 37 years after the study of Liu Zhenqun (1982). Recently, Fukazawa Yoshiki compiled a corpus of Chinese kilns that used a slightly different classification system from Liu (Fukazawa 2011), emphasizing three-dimensional structures. The author and colleagues focused on the firing temperature of stoneware and are advancing research on the determination of the kiln type by this measure.

Therefore, in this article, the author will focus on the relationship between the kiln structure and firing temperature, while considering the lineages of kilns in the Korean peninsula and the Japanese archipelago and paying particular attention to regional differences in kilns on the Korean peninsula.

2.2. Kiln variety and firing temperature in China

2.2.1. Kiln structure

According to Fukazawa Yoshiki's (2011) study, kilns can be classified into two types by oven floor: the kiln with oven floor type (type I, chapter 1, section 1.3, Fig. 1.2) and the kiln without oven type (type II). Furthermore, type I is divided into two types: with fire-ways (type Ia, Fig. 1.2.1: 1) and without fire-ways (type Ib). Type II is also divided into two types by shape: a broad-short type[3] (type IIa, Fig. 1.2.1: 3) and a long-body kiln type (type IIb and IIc). The former's ratio of length to width is around 1:1, and the latter's ratio of these is from 2 to 16:1. In type IIa, as the end of a firing chamber is dug and changed into a firebox, usually, a step is seen. Type IIb is shaped round and its ratio of length to width is less than 5:1 (Fig.2.1: 2). Type IIc is shaped like a long oval and its ratio of length to width is 5 to 16:1 (Fig. 2.1: 4). Regarding the step of types IIb and IIc, there are two styles: with a step and without a step. In addition, there is a group that is a hybrid of the two previous types from the Spring and Autumn period to the Warring States period of north China; it shows the transition from type Ib to IIa in a particular region.

Firing chambers and firebox are vertically separated in kiln type I, while these are horizontally separated in kiln type II. In kiln type I, the firebox makes heated air that rises to the ceiling through the stoneware in the firing chamber. In kiln type II, heated air made in the firebox flows sideways to the flue on the opposite side of the firing chamber, through the pottery. Consequently, type II can make a stronger flow of fire and heat than type I.

[3] Beginning in the Western Zhou period, kilns started to have flues.

In the case of kiln type Ia, it is difficult to conduct the heat to the stoneware due to the narrow path of heat, but its kiln structure is solid. On the other hand, type Ib can easily conduct heat to the stoneware due to its wide path, but its structure is vulnerable. It turns out that there is a limit of quantity when firing stoneware in a type I kiln.

Kiln type II has a very small temperature gradient between the firebox and flue because of the short length of the firebox. In other words, it can fire stoneware at a uniform temperature. Kiln type IIa corresponds to the draft and round-shaped kilns of semi-downdraft type in previous studies. Kiln type IIc corresponds to the tunnel kiln. Since the strength of the flame depends on the difference in elevation between the firebox and the flue, in the case of the short firing chamber, we can observe the same degree of flame strength regardless of whether its bottom is flat or sloped. Regarding kiln type IIa, the slope of the firing chamber is related to the ease of stoneware placing but it can be said that it does not greatly affect the firing itself.

2.2.2. Period and distribution

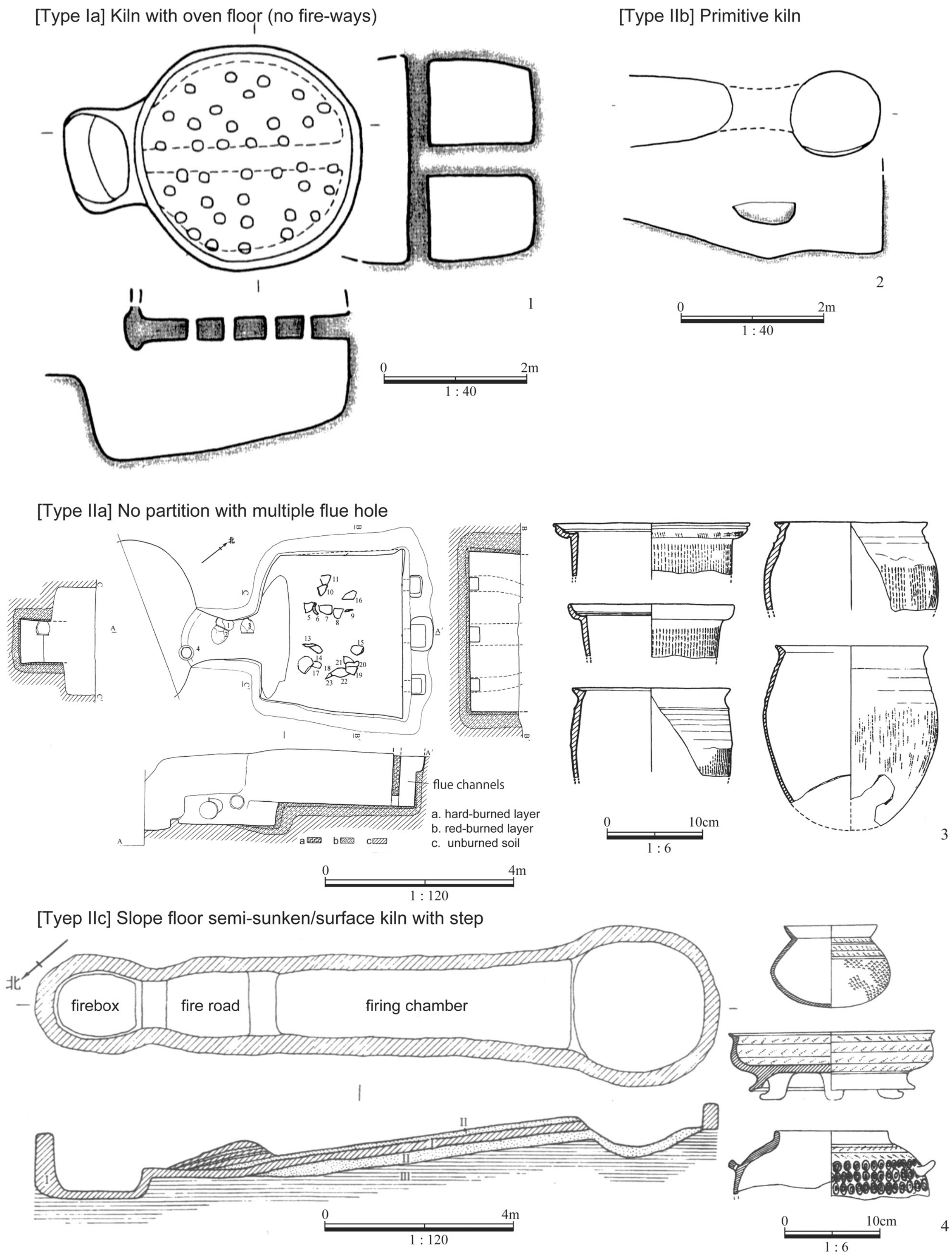
Kiln type I appeared in the middle Neolithic period and continued until around the Warring States period. Kiln type IIa appeared in the Western Zhou period and became more common when type I declined. Kiln types IIb and IIc appeared earlier than type IIa, and type IIb continued to be built from the Neolithic to the Bronze Age; type IIc was built from the Erlitou period until the Jin Dynasty (Fukazawa 2011).

Kiln type I was distributed in the upper and middle Yellow River basin. Kiln type IIa was mainly distributed in the middle Yellow River basin, but also distributed in the middle Yangtze River. Kiln type IIb was mostly seen in the middle Yellow River, and type IIc was distributed mainly in the lower Yangtze River and the coastal area of south China. Therefore, it is indisputable that type IIc kilns, with their long firing chambers, were developed only in the southern part of China. Fukazawa suggests that Sue-ware kilns in the Japanese archipelago originated from type IIc kilns in this area of China. Early kilns in China are very rare, and it is difficult to grasp the kiln structure at that time because most of the ones excavated had only the bottom and had lost their upper structure.

2.2.3. Correlation between firing temperature and kiln structure

When the firing temperature of kiln-fired stoneware was examined, the range was from about 800 up to nearly 1300 °C. There is a certain relationship between the structure of the kiln and the firing temperature[4] (Nagatomo 2017). Since the firing temperature can be analyzed from

[4] It is necessary to distinguish between experimental and actual high temperatures. In the case that a low-temperature operation is common in practice, there is the possibility that firing at a low temperature is preferred, to avoid the disadvantage of a high temperature, even if using higher temperatures is feasible.



1. Shanxi Yuanqu old city (after Archaeology Division of National Museum of Chinese History et al. 1997)
2. Hehan Xiawancun (after Fukazawa 2011) 3. Fangshan Nanzheng kiln No. 6 (after Cultural Relics Institute of Beijing 2008) ,
4. Guangdong Meihuacun Kiln (after Institute of Cultural Relics and Archaeology of Guangzhou 1998)

Figure 2.1. Kiln types in China.

stoneware, this method can compensate for the lack of preserved kilns from this period.

The author and research colleagues analyzed seven pieces of Yan state stoneware from the third century BC fired in a type IIa kiln (Fig. 2.1.3). Vitrification and amorphous clay minerals were observed with a polarizing microscope, but no minerals like mullite, which is formed over 1000 ℃, were found among them. This result showed this stoneware was fired at between 900 and 1000 ℃ (Table 2.1, Kanegae et al. 2017). Similar results were obtained for the firing temperature of Lelang stoneware excavated from the Korean peninsula and the Japanese archipelago (Cho 2006, Kanegae and Fukuda 2006). Additionally, although these are examples from the seventh to the tenth century in the Bohai period, examination with a polarizing microscope found that roof tiles were fired at between 800 and 900 ℃ or a slightly high temperature in a type II kiln at the Kraskino site in the Russian Far East (Zhushchikhovskaya and Nikitin 2017). These kilns were 12 in number and varied in size: about 1.0 to 1.7 m in width and 3.3 to 5.1 m in length, including firebox, firing chamber and flue.

Table 2.1. Firing temperature of pottery from the Pulandian Piziwo site

No.	period	form	FT
1	10th to 9th century BC	steamer	900-1000 ℃
2	10th to 9th century BC	steamer	900-1000 ℃
3	10th to 9th century BC	steamer	900-1000 ℃
4	4th to 3rd century BC	pot	900-1000 ℃
5	4th to 3rd century BC	pot	
6	4th to 3rd century BC	steamer	900-1000 ℃
7	4th to 3rd century BC	short-necked jar	900-1000 ℃
8	4th to 3rd century BC	short-necked jar	900-1000 ℃

On the other hand, in the lower Yangtze River, gray stoneware with natural glaze was fired at a high temperature in type IIc kilns. The natural glaze proves the use of the high temperature at which fuel-ash is melted. Ceramic was stably fired at a very high temperature, around 1200 ℃: 1160 to 1310 ℃ in the Later Han Dynasty, 1240 ℃ in the Three Kingdoms period, 1180 to 1300 ℃ in the Western Jin Dynasty, 1130 to 1270 ℃ in the Eastern Jin Dynasty, and 1190 ℃ in the Southern Dynasty (Table 2.2). The gray stoneware in the Meihuadun kiln from the late Spring and Autumn period (Fig. 2.2.) is estimated to have been fired at 1270 ℃, as was determined by the reheat thermal expansion coefficient measuring method (Institute of Cultural Relics and Archaeology of Guangzhou 1998), which shows that Type IIc kilns reached firing temperatures exceeding 1100 ℃ before the Warring States period.

Based on the comparison of the firing temperature in each kiln type, we may conclude that type IIc kilns can reach a higher temperature than Type IIa kilns. As the distance from the firebox to the flue of kiln type IIa is

Table 2.2. Firing temperature of ceramics in Zhejiang Province (based on Ye et al. 2008)

area	site or artifact	form	period	FT	note
Shangyu	Xiaoxianyun kiln	Celadon no-necked jar with paddling patterns	Eastern Han	1160±20	
Shangyu	Xiaoxianyun kiln	Celadon no-necked jar with paddling patterns	Eastern Han	1310±20	
Shangyu	Xiaoxianyun kiln	Celadon shallow bowl	Eastern Han	1270±20	
Shangyu	Xiaoxianyun kiln	Celadon straight-necked pot	Eastern Han	1260±20	
Shangyu	Zhangzishan kiln	Black-glazed ceramic	Eastern Han	1220±20	
Shangyu	Zhangzishan kiln	Black-glazed ceramic	Eastern Han	1200±20	
Shangyu	Zhangzishan kiln	Black-glazed ceramic	Eastern Han	1240±20	
Shangyu	Zhangzishan kiln	Celadon bowl	Three Kingdoms	1240±20	
Shangyu	Longquan tang burial	Celadon	Western Jin	1300±20	made in Yue kiln
Shangyu	Longquan tang burial	Celadon	Western Jin	1180±20	made in Yue kiln
Shangyu	celadon	Celadon	Western Jin	1220±20	
Shaoxing	Western Jin burial	Celadon jar with four handles	Eastern Jin	1270±20	made in Yue kiln
Deqing	Dequin kiln	Black-glazed ceramic	Eastern Jin	1150±20	
Yuhang	Yuhang kiln	Black-glazed ceramic	Eastern Jin	1130±20	
Jinhua	Jinhua Wùzhōu kiln	Celadon	Eastern Jin	1180±20	
Shangyu	Zhangzishan kiln	Celadon small bowl	Souhern Dynasty	1190±20	

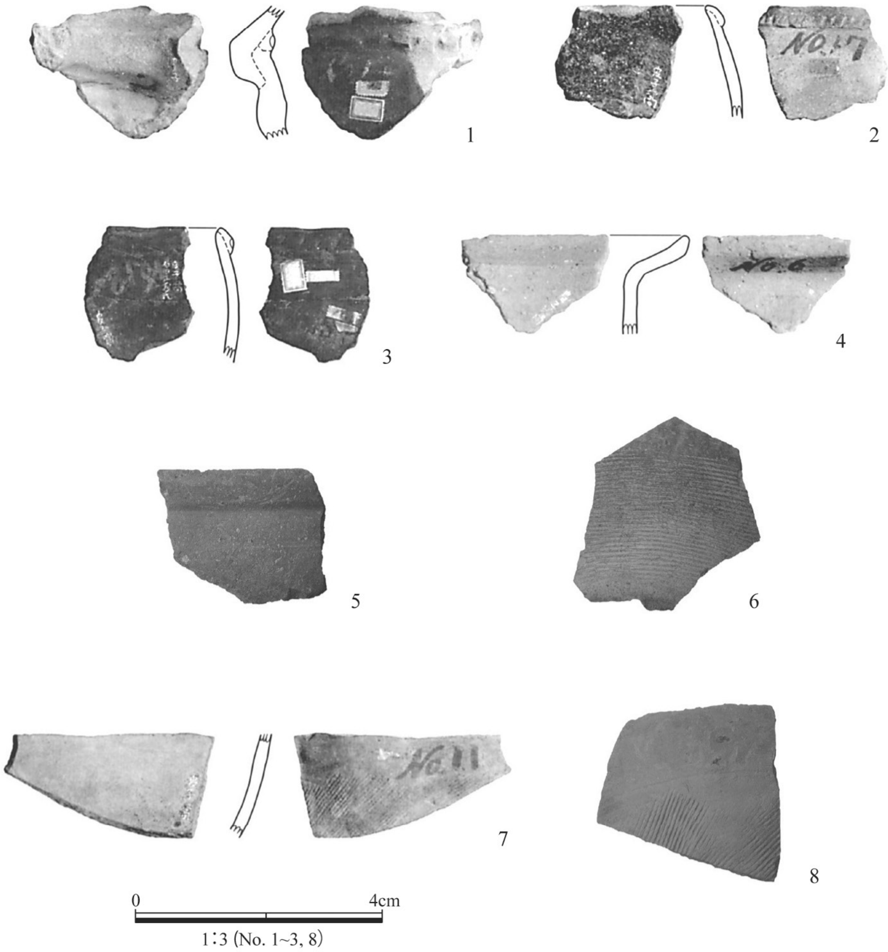


Figure 2.2. Analyzed pottery from the Pulandian Piziwo site (Kanegae et al. 2017).

short, the temperature gradient of these is not large. In other words, heat can easily escape from the kiln via the flue. In contrast, as type IIc kilns have longer firing chambers, the temperature gradient is larger. As a result, the flame and heat flow become strong, and the maximum firing temperature tends to increase in the firing chamber because heat can stay there for a long time.

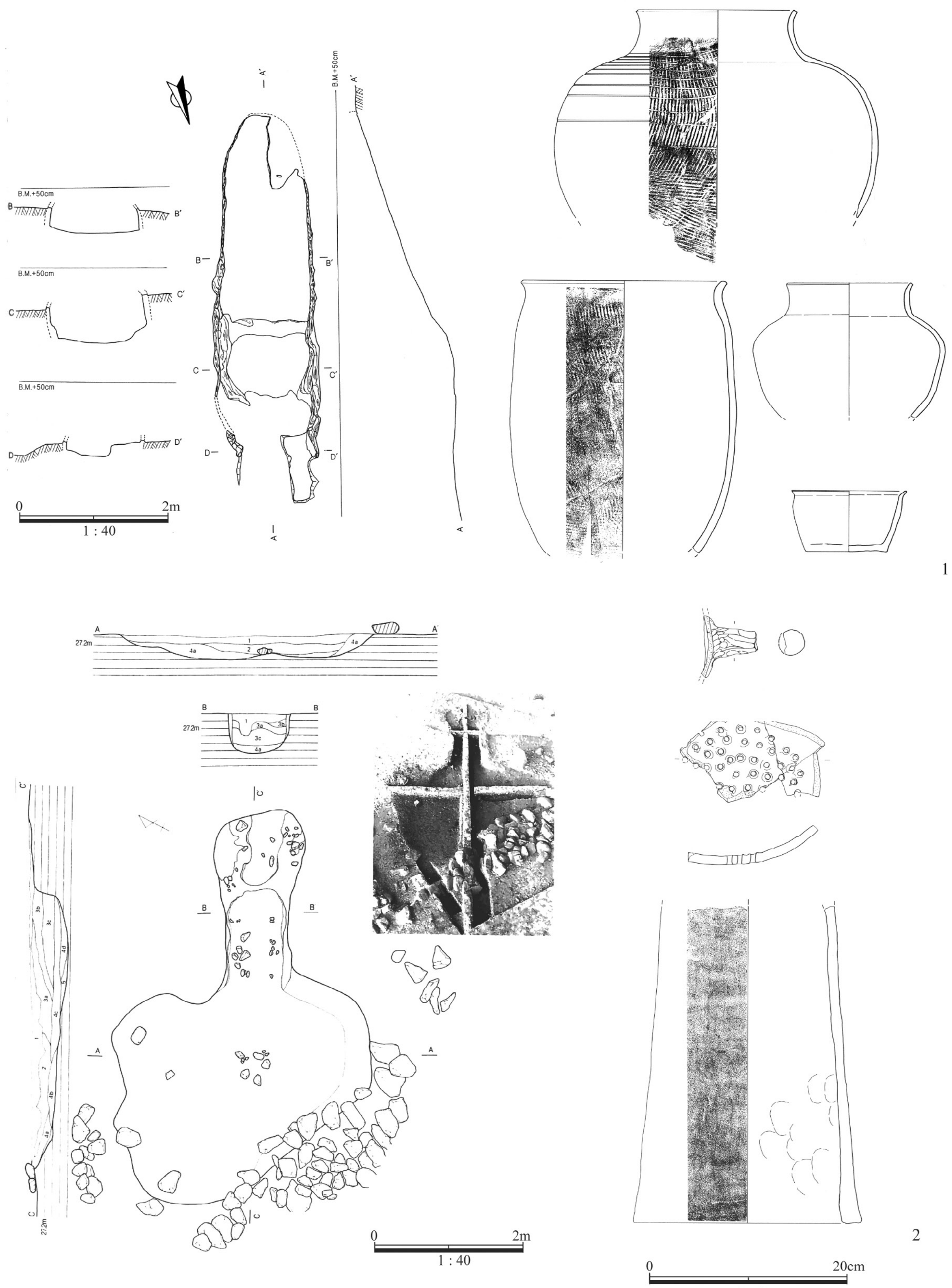
2.3. Kilns in South Korea

2.3.1. Early kiln and stoneware

Kiln-like remains have been found dating from the Bronze Age onward (Kang 2005). They are round or ditch-like, and their bottom face was often burnt, or a certain amount of stoneware sherds were found. However, it is difficult to regard these remains as kilns due to the lack of decisive evidence; the upper structures and burnt side walls have not survived, and stoneware found there does not have a rigid body. After all, it was not until the P-TK period that sure examples of kilns were found. Moreover, grouped kilns of more than ten per group have been found at the Samryongri/Sansuri kilns (Choi et al. 2006).

The Samsuri/Samryongri kilns continuously operated from the third to the fourth century, and they correspond to a transitional time from the P-TK to the KTK period in the Baekje and Mahan regions. These kilns are characterized by a deep firebox and have steps between the firing chamber and the firebox (Fig. 2.3: 1). The bottom of the firing chamber has a short slope. This conforms to the IIc type of kiln. Most of the stoneware found nearby was short-necked jars; the others were deep pots and steamers. According to the report on the Samryongri/Sansuri site kilns, the kilns were divided into five stages, and tray-shaped stoneware appeared starting in the fifth stage. However, there are no examples of pieces with sharp concave-sectioned lines and vessels with three legs, such as those found in Pungnap fortress. It is possible that the stoneware shapes found at the Samryongri/Sansuri site kilns were influenced by Baekje stoneware at the final stage, but these are typologically different from the examples from the Pungnap fortress and Mongchon fortress in central Baekje. The other characteristic of Samryongri/Sansuri site kilns is that they manufactured a blast tube for forging iron and provisioned the Seokjangri iron-making site (Nagatomo 2008).

Kilns were found in the Hwanseongdong site in the Gyeongju area of Jinhan region; this site was known as the iron production site (Fig. 2.3: 2). Although most of the firing chamber of the kilns did not remain, there are steps



1. Jincheon Samryong-ri kiln No. 88-1 (after Choi et al 2006)
2. Gyeongju Hwanseong-dong No. Na-13. (after Lee et al 2000)

Figure 2.3. Kilns in the Korean peninsula (1).

between it and the firebox. One of them was reported as a type IIa kiln: a draft kiln (Lee et al. 2000). Takesue Junichi insisted that this kiln was used for firing the clay core for casting ironware (Takesue 2002), but no clay core has been found at the kilns.

Made in the Jinhan and Byeonhan areas, Wajil ware has a variety of colors: light gray, light brown, white[5] (Society for

[5] The term "Wajil ware" was often used to refer to the stoneware with loosed reduction firing (Terai 2017); some researchers call the kiln-fired

Korean Archaeology 2013). Some unique types are seen, such as a jar with a pair of horn-shaped handles, jars with no necks, and short-necked jars with paddling pattern. In late stages of Wajil ware, the rate of types of pottery with short legs attached to round bottoms increased, such as small, wide-mouthed dishes with short legs and jars with short legs.

On the other hand, in the Baekje and Mahan regions, the findings consisted of rigid plane-stoneware, stoneware with paddling pattern, fired oxidation firing or reduction firing, and dark gray stoneware (Park Sunbal 2003). It is believed that the dark gray stoneware appeared under the influence of Lelang stoneware from the middle stage, which divided the P-TK period into three, besides stoneware with paddling pattern appeared at the same stage. Rigid plane-stoneware was composed of a deep pot, a cover and a bowl, which are characterized by a flat bottom and outward-opened rim. In addition, hand-strokes for smoothing the surface were observed on the lower body of this stoneware. Rigid plane-stoneware originated from a previous local culture. Stoneware with paddling patterns comprises a deep pot, a long oval-shaped pot, a steamer and a bowl. These have a round bottom or a flat bottom without hand-strokes on the lower body.

Stoneware in the P-TK period was diverse in each area, but an important point is that all the pieces have the common feature of a round bottom made by paddling. Judging from the observation of the paddling pattern on the round bottom, these were at one stage formed in a cylindrical shape. Next, the body was inflated by the paddling method, and then the bottom was reformed as round. By the paddling method, the walls of the stoneware are tightened and transformed at once. Therefore, the time required to make stoneware with the paddling pattern became shorter than for rigid plane-stoneware, which was made by piling up clay bands while adjusting the body shape to ensure there were no gaps. In short, the technique of making stoneware greatly changed in P-TK period (Nagatomo 2010). Since stoneware bodies became rigid, these were fired by kiln, even when the kilns themselves have not been found. It can be said that these new types of stoneware were accepted along with the introduction of kiln building technology.

2.3.2. Kilns of the Three Kingdoms period

Most of the kilns in the Baekje and Mahan regions are type IIc, with a step between the firing chamber and the firebox. The ratios of length to width of almost all the firing chambers is around 2:1, and the fireboxes are short. Some of the kilns are wider, more than 3 m. In the southern tip of the Mahan region, a kiln with part of its ceiling remaining was found at the Gunkok-ri site from the fourth century (Fig. 2.4: 1, Mokpo University Museum 1989). It is oval and short. The kiln has a slight step between the firing chamber and the firebox, and the bottom of the firing chamber has a gentle slope. Most of the other kilns in the Mahan region have a step and their firing chamber's length is two to three times their width. In the sixth century, kiln type IIa, with a nearly flat firing chamber and a high step between the firing chamber and the firebox, reappeared as a kiln for firing tiles. Since the Jeongamri site in the Baekje region has a new structure in which the fuel hole is made on the side and there are three flues, it is found that Kiln type IIa was introduced again as a new renewal style.

In the Gaya region, kilns of the fourth century were found, such as at the Myosari, Ugeori and Yeochori sites. They have a long, narrow shape with no step between the firing chamber and the firebox: a typical type IIc kiln. The firebox of the kiln is nearly horizontal and connects to the steeply sloping firing chamber in Yeochori section A (Fig. 2.4: 2). And then, the new shape of kiln appeared, in which both sides of the firing chamber are rounded and bulge out slightly, but the back wall rises vertically. However, these kilns consistently have no steps (Yamamoto 2018), and the maximum width of the firing chamber was 2 m or less. No wide-shaped kilns have been found.

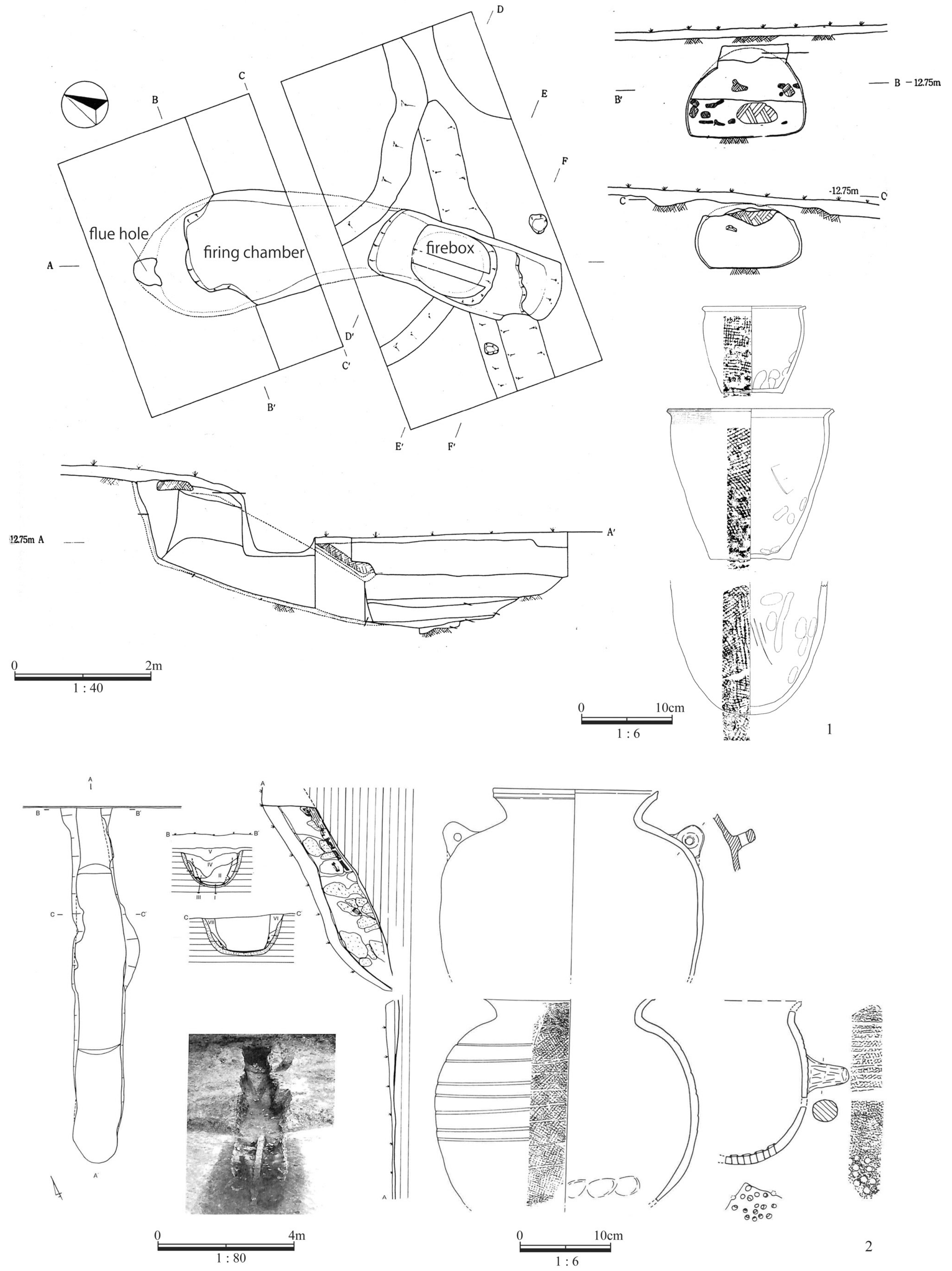
The proportion of tableware came to increase rapidly in Baekje, Silla and Gaya during the P-TK period. Shallow bowls and dish-like tableware appeared in Baekje. These vessels often had three legs attached, which is like the Chinese style. In addition, some patterns were drawn on the upper body of jars with short, straight necks and black jars with a polished surface from the KTK period. Baekje interacted with the Southern Dynasty of China and imported celadon jars with chicken-headed spout and large urns. The appearance of black jars with a polished surface reminds us of the relationship with porcelain in the Jiangnan area of central China. The rapid change in the composition of vessels from the P-TK period to the early Baekje period is closely related to the influence of Chinese stoneware.

On the other hand, the composition of Silla stoneware also changed significantly. The number of cups with a leg increased, and the ratio of tableware increased. Regional-style stoneware decorated using comb-shaped tools appeared, and large stands were also made. In Silla and Gaye, the custom of using a large amount of stoneware as burial goods began, which mainly consisted of tableware like cups with a leg. In contrast, the amount of stoneware used in graves is small in Baekje. It should be considered that the difference in demand for stoneware affected the improvement and enlargement of kilns involved in mass production.

2.3.3. Transition of firing temperature

The firing temperature of stoneware in the Baekje and Mahan area was analyzed by Cho Daeyeon (Cho 2006),

stoneware in the Baekje and Mahan regions "Wajil ware" (Kameda 2008, Terai 2017, Nakakubo 2017). However, in Korean archeology, it is common to use this term to refer only to stoneware in the Jinhan and Byeonhan regions in the P-TK period (Society for Korean Archaeology 2013). This paper will follow this usage.



1. Henam Gungokri Kiln (after Mokpo University Museum 1989), 2. Changnyeong Yeochori (after National Jinju Museum 1992)

Figure 2.4. Kilns in the Korean peninsula (2).

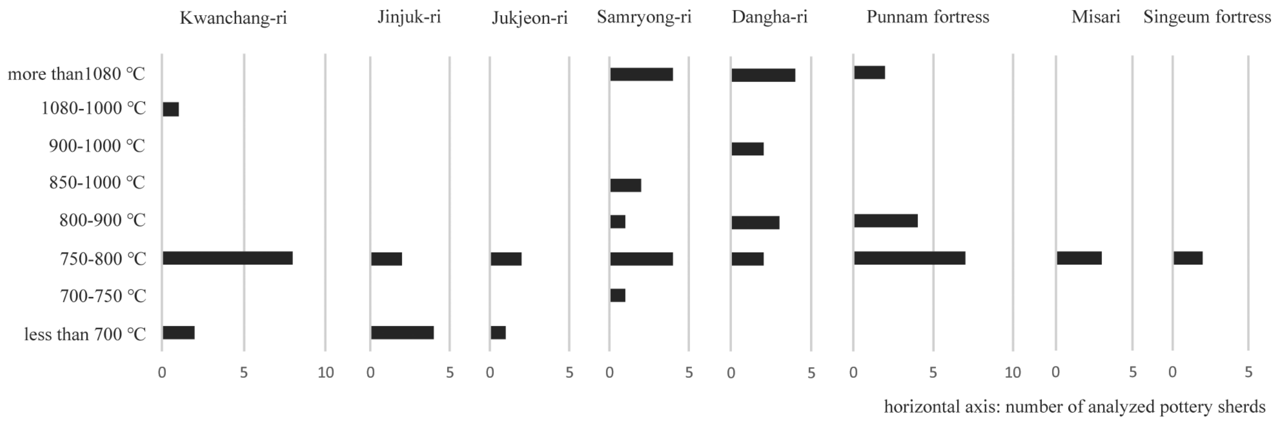


Figure 2.5. Results of the firing-temperature analysis for pottery in the Korean peninsula (based on Cho 2006).

and Fig. 2.5 shows the result. Regarding the stoneware of the Kwanchang-ri site in the Bronze Age, one sherd of stoneware was fired at around 1000 ℃ and two sherds were fired below 700 ℃. However, most of the stoneware was fired at the maximum firing temperature of 750 to 800 ℃. Examples from the Jinjuk-ri and Jukjeon-ri sites also showed the low firing temperature: below 800 ℃.

In the third to fourth centuries, a lot of stoneware was fired at high temperatures, over 1080 ℃, as in the Samryongri kiln. However, it should be noted that the frequency of stoneware fired at 800 to 1000 ℃ also increased, and a certain amount of stoneware was fired at 700 to 800 ℃. Also, in Pungnap fortress in central Baekje, there were examples fired at a high temperature of more than 1080 ℃, but the rate of stoneware fired at around 700 to 900 ℃ was high. Since Pungnap fortress is a residential area, it had a higher percentage of open-fired cooking stoneware than the Samryongri kiln site. Therefore, there was more stoneware fired at a low temperature in Pungnap fortress than in the Samryongri kiln. In the Misa-ri and Singeum fortresses, there were examples fired at around 700 to 800 ℃.

Based on the above, the stoneware was fired at a temperature of 800 ℃ or lower by the open firing in the Bronze Age. From the P-TK to the KTK period, stoneware fired at a temperature of over 1080 ℃ appeared. However, as most of the stoneware was fired at 700 to 1000 ℃ even after the introduction of kilns, it seems to have taken a long time to acquire the skill to fire in kilns at high temperatures.

Lee Seongju believes that the production of early Dojil ware starting in the middle of the third century parallels the late Wajil ware (Lee 2005). As mentioned above, he assumed that Wajil ware was fired in type IIc kilns. Although the firing temperature of Wajil ware sometimes went up to 1000 ℃, most of these were reduction-fired at a low temperature of 800 ℃ or lower. In contrast, the firing temperature of Dojil ware was around 1200 ℃. In the Silla and Gaya regions, the firing temperature increased gradually over time.

2.3.4. Change and development of kilns

In the P-TK period, kilns were built with a step between the firebox and the firing chamber across the regions. The kiln in Hwangsong-dong has such a step, although the firing chamber is as yet unrevealed; the Samryongri/Sansuri kilns have a deep firebox and a short firing chamber although they are type IIc kilns. It can be said that the former corresponds to kiln type IIa and the latter is kiln type IIc improved from kiln type IIa. This estimation agrees with the examination of stoneware firing temperature.

While the feature of a step between the firebox and the firing chamber was maintained even after the fourth century in the Baekje and Mahan regions, the type IIc kiln became the norm, considering that the firebox became slightly longer and the sloped bottom of the firing chamber appeared. Given the drastic change in the composition of stoneware including the vessel with three legs influenced by Chinese stoneware and the fact that a lot of celadon made in the Jiangnan area were acquired during this period, it is difficult to determine the change of kilns by internal changes. It is appropriate to consider the influence from the type II kilns in the Jiangnan area of Central China.

On the other hand, in kilns in the Gaya region from the fourth century onward, there was no step between the firebox and the firing chamber. At that time, the firing chamber changed from near horizontal to a strongly sloped shape to improve fire and heat flow. In other words, the bottoms of the firing chambers became bow-shaped (Ueno 2015). Moreover, kilns with a total length of more than 10 m appeared. Unlike kilns in Baekje, the complete style of the type IIc kiln was adopted in the Gaya region. It can be said that type IIc kilns in the Gaya region do not represent an improved kiln on the basis of the former one, type IIa.

From the early third century and later, 20 melting furnaces for casting iron were found at the Hwangsongdong site, and the refining of iron was also conducted there. With the prevalence of ironware, the presence of the Silla and Gaya region became larger in East Asia due to its rich iron resources. It has been found that opportunities of interaction with southern dynasties increased via intermediate areas. Incidentally, the rise of iron-making in the Silla and Gaya regions was reorganized at the end of the first century. From that period onward, a lot of potash glass made from India to southern China was brought to the southern part of the Korean peninsula (Nakamura 2015). There is a possibility that new kiln techniques were introduced from southern China after the end of the first century, but they have not been found. At present, as sure examples of type IIc kilns appeared from the latter half of the third century to the fourth century, this was brought about by the beginning of the interaction with the Southern dynasty at the time of the establishment of Baekje.

The step between the firebox and the firing chamber is the most notable difference between the Baekje-Mahan region and the Silla-Gaya region. Although there are type IIc kilns with a step in China, it would be easier to understand the influence of the former type IIa kilns rather than to assume different kiln types were introduced to Baekje and Silla-Gaya. Therefore, in the southern part of the Korean peninsula, after the kilns appeared at the time around the establishment of Lelang commandery, they were newly affected by the Jiangnan area in China. In short, under the influence of multiple kiln types in China, kilns in the Korean peninsula appeared and changed.

2.4. Origin and features of kilns in the Japanese archipelago

2.4.1. Earliest kilns

Many researchers consider the Deai kiln in the city Kobe, located at the western end of Kinki area, the earliest in Japan. Although the firing chamber is mostly lost, it was short and had a step between it and the deep firebox (Fig. 2.6: 1). The commonality with kilns in the Mahan region has been pointed out from the shape of the kiln (Kameda 1989, 2008). The clay of ceramics excavated from the Deai kiln is similar to that of the P-TK period, and the firing temperature is estimated to be not very high.

The ceramics comprise such kinds as a short-necked jar, a dish-like vessel and a steamer. As both tableware and the storage container were found at the Deai kiln, it is different from the early kilns of SKG, which mainly produced storage containers. In the studies of stoneware at the Deai kiln, the similarity of the stoneware of the Mahan region has been pointed out (Kameda 2008). Among these, Terai Makoto limited the origin to the region to the Hoseo area of the northern Mahan region based on the rim shape of the short-necked jar (Terai 2017). The steamer has a straight mouth and round holes in the flat bottom (Kameda 1989). Based on examination of the shape features, the origin of the steamer from the Deai kiln originated in the western area of the Gaya region to Mahan. However, the absence of cups with a high leg and the presence of dish-like vessels shows that the stoneware at the Deai kiln most likely originated from the Mahan region. Besides, the earliest kiln in Samryongri, kiln No. 88-1, is earlier than the Deai kiln, since the steamer of the former has a round bottom with smaller holes (Fig. 2.3).

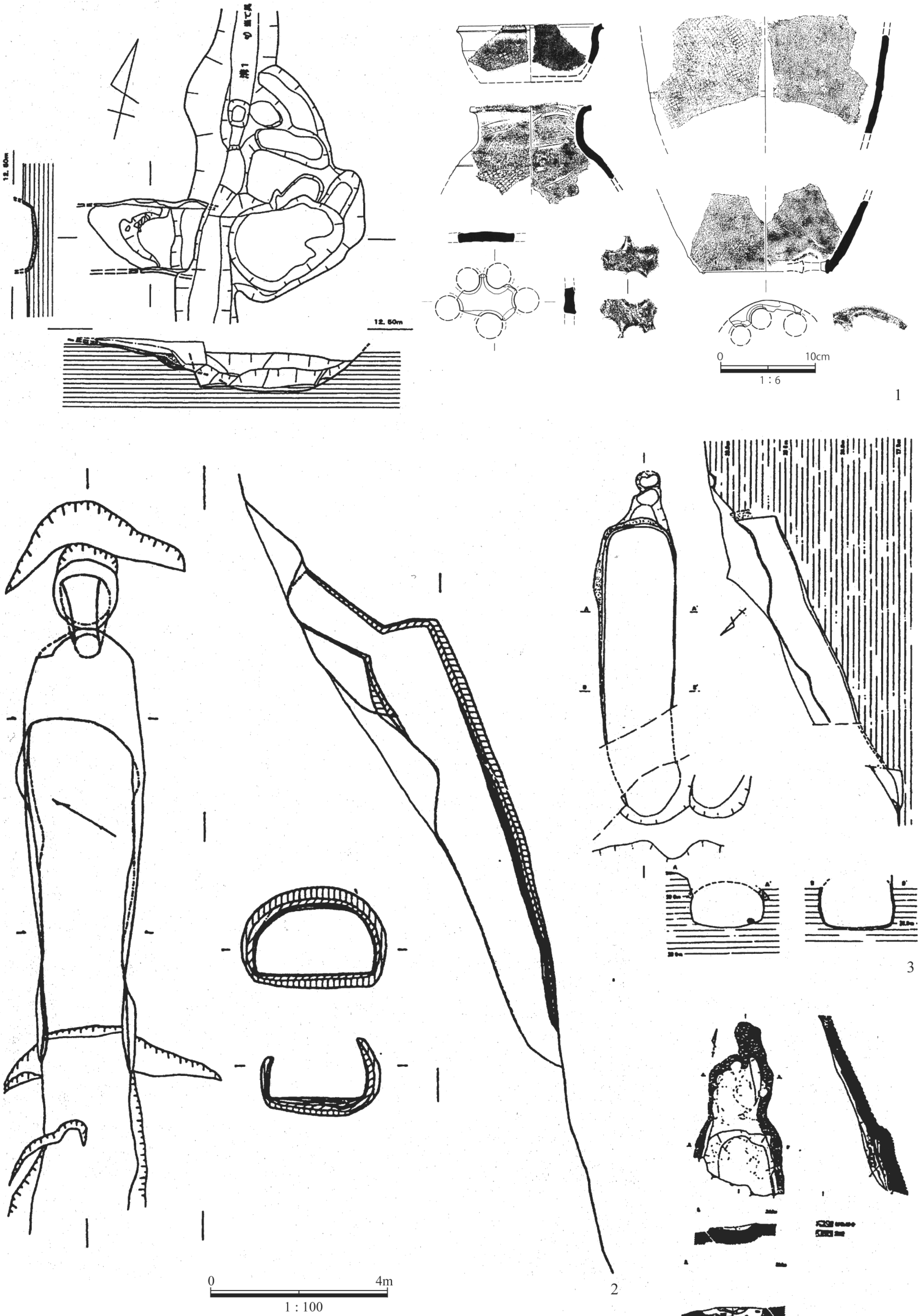
2.4.2. Early kilns and SKG

The confirmation of a certain number of kilns started during the period of TG 232 in SKG with such kilns as the Asakura kiln and Iyashiki kiln in the Kyushu area, West Bank kiln of Mitani-Saburoike in the Shikoku area, Okugatani kiln in the Setouchi area, and SKG, Suita No. 32 Kiln, Ichisuka No. 2 Kiln in Kinki area. In addition, the presence of kilns is assumed in the southern and western end of the Kinki area because of the distribution of the characteristic early Sue ware (Nakatsuji 2013). The distribution of kilns shows that kilns were introduced along the inner sea corridor from northern Kyushu to Osaka Bay.

As briefly mentioned in section 2.2, Ueno Kozo considered the southern Mahan area a possible origin place of Japanese kilns. He emphasized that early kilns in Japan have a small and linear planar shape, despite the difference in the presence or absence of a step between the firebox and the firing chamber (Ueno 2010, 2017). Fujiwara Manabu compared the kilns in the southern Korean peninsula from the late fourth to early fifth century with those in the Japanese archipelago (Fujiwara 1992). In consideration of the shape and size of the Samryongri/Sansuri site kilns, he found kilns in the southern Korean peninsula to be 4 to 15 m in length, 1.3 to 3.0 m in depth, and 10° to 30° in incline. Also, the vertical location of kiln-building was classified as underground, semi-underground and aboveground. Furthermore, Fujiwara determined that kilns were introduced to the Japanese archipelago when a huge, narrow kiln was formed in the Korean peninsula. Referring to these studies, let us begin our examination of the early kilns in Japan based on the previous analysis in this chapter.

The possibility of a step between the firing chamber and the firebox in the Iyashiki Kiln has been pointed out (Fujiwara 1992), but other than that the early kilns in the Japanese archipelago have no step. The firing chamber remained in Suita No. 32 kiln and Ichisuka No. 2 kiln. They are type IIc kilns, which have a slightly long firebox and a round flue (Figs. 2.6: 2–5). Besides these examples, most of the kilns in the period of TG 232 in SKG do not have a step. This fact shows that the early kilns in Japan were not descended from the kilns in Mahan and Baekje but were descended from kilns in the Gaya region. It was pointed out that the early Sue ware is similar to the stoneware of the Gaya region, such as that of the Haman, Changwon, Gimhae area. Since the early Sue ware has the quality and color of the body fired at high temperature in a reducing atmosphere, it can be understood that it was fired by a consummated type IIc kiln from the beginning of the introduction.

Incidentally, the amount of stoneware fired by oxidation firing that was distributed in the Korean peninsula,



1. Deai Kiln (after Kameda 2008) 2. Ichisuka kiln No. 2 (after Ueno 2017)
3. Iyashiki Kiln (after Ueno 2017) 4. Okugatani Kiln (after Ueno 2017)

Figure 2.6. Early kilns in the Japanese archipelago.

including cooking utensils such as a steamer and a deep pot, increased in settlements without kilns such as the Nagahara and Shitomiyakita sites in the Kinki area starting in the fifth century. Based on the characteristics of the steamer, it is obviously related to the Baekje and Mahan regions (Terai 2016). It seems that specialists from the Baekje and Mahan regions introduced other new technologies, along with kilns, to the Japanese islands.

2.5. Conclusion: Spread of kilns in East Asia

As the author examined above, the diversity in the peripheral areas around China is closely related to the regional differences of kiln types in China, which can be roughly divided into north China along the Yellow River and central

China along the Yangtze River. In north China, updraft kilns appeared first, and then flat kilns (type Iia) appeared in the Warring States period. In central China, tunnel kilns (type Iic) appeared around the Erlitou period and continued for a long time through the Qin and Han dynasties.

Kilns appeared earlier in Northern China, but were difficult to fire stably at high temperatures (more than 1000 °C), judging from the firing quality of the stoneware and structure of the kiln. Low-temperature kiln firing was adopted instead of open-field firing in order to adapt to the cold climate, in which firing temperatures do not rise easily, and the limited forest resources. On the other hand, central China is warm and humid. People could fire stoneware by open firing with a stable temperature from 800 to 900°C, but kilns started to be used for high-temperature firing in order to obtain more rigid stoneware. As a result, celadon was created there.

In the Qin and Han dynasties, a flat kiln of short-wide style (type Iia) was widely used in the Yan state area, which is adjacent to the Korean peninsula, just before the kiln and its technology were introduced to the Korean peninsula. Considering that Wajil ware was fired at a low temperature

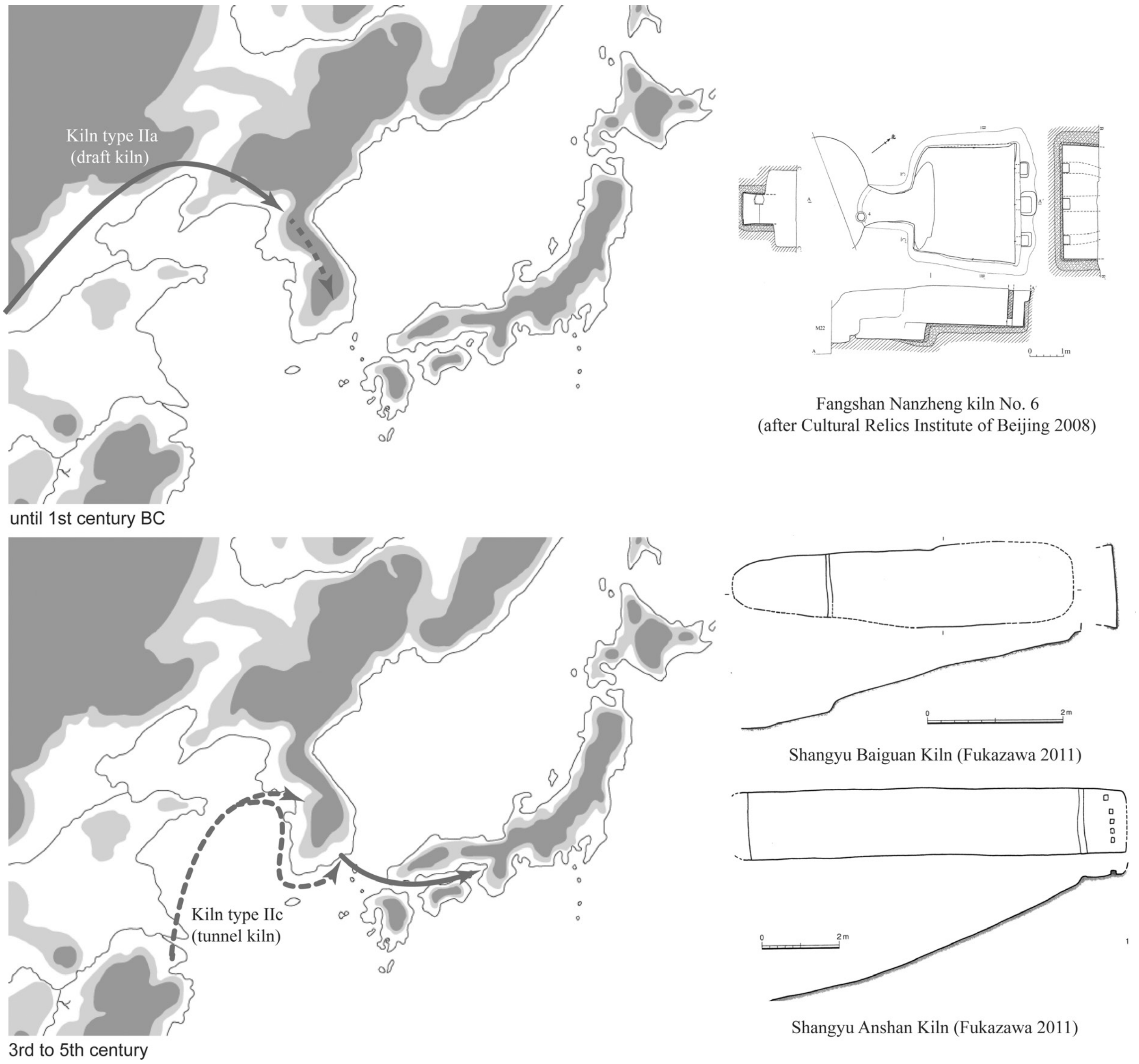


Figure 2.7. Spread of the two types of kiln.

(under 1000 °C) according to the analysis of the clay (Kanegae and Fukuda 2006), there is a high possibility that the flat kiln was introduced to the Korean peninsula from the neighboring area.

With the arrival of the technique and structure of the tunnel kiln of long-body type Iic in the KTK period, people who were already using kilns of the former style succeeded in improving them or accepting the new style. Kilns were built on the slope and had a long firing chamber to improve flame flow. As a result, the maximum temperature of firing became higher than 1000 °C and stoneware came to have a more rigid body. However, the structure of kilns was not uniform and had great regional differences. The broad-short style with a step between firing chamber and firebox was maintained in the Baekje and Mahan regions, while kilns were changed to tunnel types without a step in the Gaya and Silla regions. It is significant that kilns were introduced to the Korean peninsula twice, in different periods (Figs. 2.7).

The Deai kiln, which was the earliest kiln in the Japanese archipelago, was influenced by kilns in the Baekje and Mahan region, but it was short-lived. In the period of the TG 232 kiln of SKG, the kiln and its technology were introduced in the range from the northern Kyushu area to Osaka Bay by sea again. The style of kilns was strongly influenced by kilns in the Gaya region, which is a narrow-long tunnel kiln.

The introduction of kilns and their attendant techniques is always related to political interaction in East Asia. The first spread was the spread of flat kilns through technological diffusion at the time of the establishment of the Lepang commandery. In the second spread, of tunnel kilns, Baekje began to build a stronger relationship with the state of the Southern dynasty in China against a northern rival, Goguryo. Also, in the case of the Japanese archipelago, there were conflicts among Japan, Silla, Gaya and Goguryo, which was pushing southward. It can be said that the introduction and development of kilns was complicated in combination with the activation of interaction, the change of trade networks, and international competition.

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3

The Basic Concept and Appearance of Tunnel Kilns: Ethnoarchaeology and Sue-Ware Kilns from the Point of View of Experimental Archaeology

Masaaki Kidachi

Translation from Japanese into English: Robert Sträter

Abstract: The author describes the principle of the kiln drawing flames from the basic design of the kiln, the inclination angle of the floor, the relationship between the volume of the firing section and the opening area of the firing and smoke outlet, and the temperature of the room. Furthermore, the points to be noted when excavating a kiln are described separately for the firing port, the combustion and firing sections, and the ceiling of the firing section. In addition, from the results of experiments on Sue-ware *anagama* kilns, the color tone and temperature difference, stress on the kiln itself, refractoriness of the soil and fuel consumption are explained.

Keywords: Structure of kiln, tunnel kilns, flame ignition, inclination angle, temperature difference, color tone, stress of Sue-ware kilns

3.1. Firing principle of tunnel kilns: about "pulling the flame"

Climbing kilns are made and built on slopes. However, depending on the construction of the kiln type, the choosing of a site changes significantly. Construction and site conditions of a kiln are in a symbiotic relationship.

*3.1.1. The ignition and extinguishing of embers (*oki*)*

When modern potters fire with tunnel kilns or multi-chambered climbing kilns (*Renbō-shiki Noborigama*, Fig. 3.1), they pay attention to the intensity of the flame. They may notice a stagnation of temperature during the firing, perhaps because the fire does not burn well even though plenty of fuel has been added. Potters describe this state as "pulling the flame." To ensure the correct temperature, different measures must be applied. For instance, by mixing and piling up the accumulated charcoal in the firebox and supplying oxygen to the smoldering charcoal, the firing is accelerated. Other measures include shifting the thrown-in burning material, exchanging large pieces of firewood with fast-burning scantlings, or closing and opening the flue.

If the fuel burns well, the firewood ignites, and after heat emission, it turns to embers. The embers cover the entire floor of the firebox and keep the interior of the kiln warm. Nevertheless, if too many embers accumulate, adding the next batch of firewood makes the space smaller, which causes a hard burning of the firewood so that the embers are scratched out from the firebox. Regarding the color of the embers, some potters differentiate between "bad embers" (extinguished embers) and "good embers." "Bad embers" are dark and never burn out well. "Good embers" are bright, burn down smoothly, become ash, and the speed at which the next firewood is replaced by new embers is fast. We can say that the renewal of firewood and embers is the decisive factor for the temperature rise in the kiln. On the other hand, if the embers, which kept the kiln warm, are scratched out, the temperature of the interior of the kiln will fall suddenly. This does not mean that it returns to zero, because the entire kiln has already accumulated heat, but it wastes time and fuel.

According to modern potters, the ignition of embers can be good or bad. The reason is not only the kiln's construction; some other causes like changes in the environment or the kiln firing may be assumed. Not all causes can be made clear, but first, the basic concept of kiln firing should be explained.

3.1.2. The principle of the flame's ignition

If the supply of oxygen and carbon dioxide is optimal, even when the space is closed, the burning will be accelerated. A tunnel kiln was dug like a tunnel in a slope, and air flows one way from the stokehole to the flue hole. This flow becomes proportionally faster if there is a significant difference in height between the stokehole and the flue hole. If the stokehole's outlet area and the flue hole are large, it becomes proportionally faster.

Inclination angle of the floor and basic design of kilns. Takuma Yogo points out the importance of the ratio of the

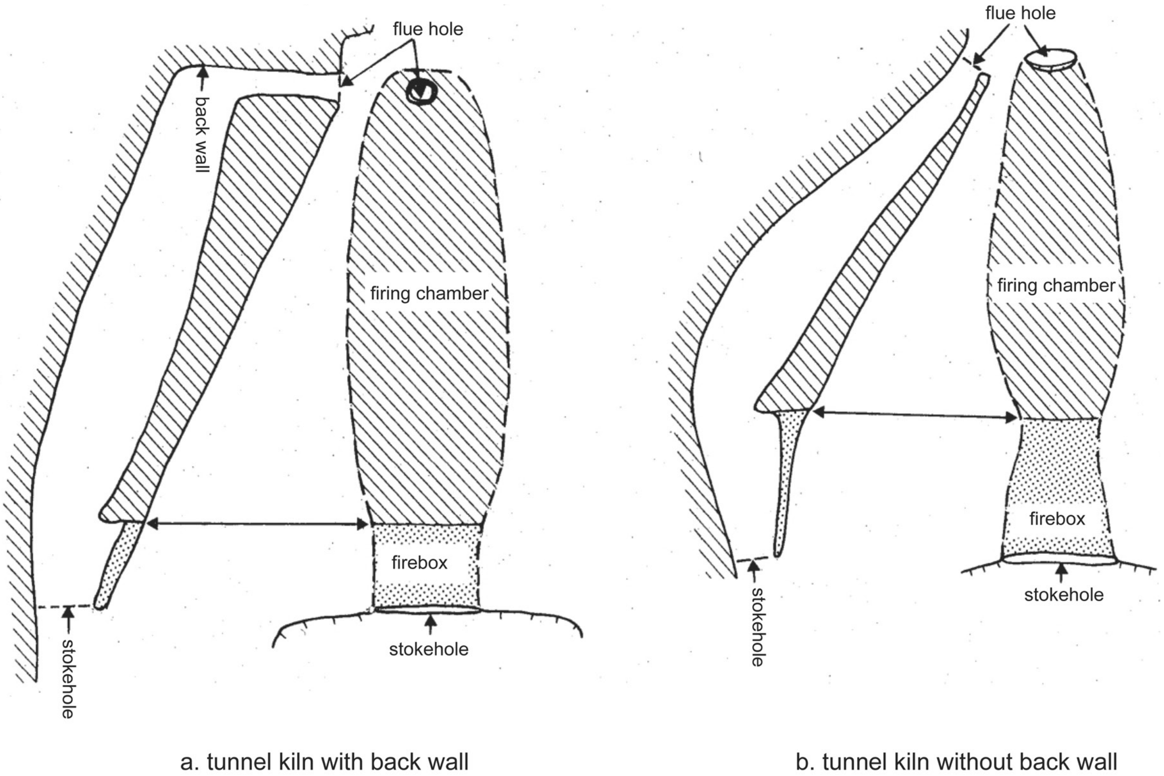

Figure 3.1. Terms for parts of a tunnel kiln (Kiln Research Society 2010).

difference in height between the stokehole and the flue hole, and their horizontal distance (Yogo 2010: 102). The decisive point of the kiln's construction is not the floor's inclination angle, but the difference in the height of the stokehole and the flue hole, and the horizontal distance is interrelated.

If this is the case, then the supposed angle, which is a connected line between the floor of the stokehole and the back side of the flue, influences the power of the flame. Let it be called the "S-F angle" provisionally (Fig. 3.2). Because there are some cases where the flue remains, it is possible to compare and examine the flame's ignition by the difference between the elevation near the stokehole and the elevation of the flue, and their horizontal distance (Kidachi 2019: 34–35).

Today's potters increase the flame's ignition through the height of the chimney, but the products are in the kiln, and because of this, they make the floor of the firebox as horizontal as possible, and so it is necessary to increase the S-F angle via the chimney. There are no verifications of chimneys through Sue-ware (Japanese stoneware) kiln excavations. The slope of Sue-ware tunnel kiln floors are steeper than today's tunnel kilns. There is a big difference in height between the stokehole and the flue hole of the kiln. The kiln itself is considered to have played the role of the chimney.

Capacity of the firebox and aperture size of the stokehole and flue hole. The essential factor determining the surface area of the firebox's aperture and the flue is the capacity of the firebox (Furutani 1994: 38–39). Because a tunnel kiln is a room where the firebox and firing chamber are located next to each other, distinguishing the boundary is not easy. Nevertheless, by detailed observation of the burning state of the walls and floor and the charcoal and ashes from excavations, it is possible to confirm the combustion's extent. However, when more than half the ceiling has collapsed, it is challenging to figure out an exact calculation of the firebox's volume. Besides, it is arduous to explain the surface area of the apertures of the firebox and the flue through excavations. In particular, it is complicated to determine the opening area at the time of firing because the firing mouth is repeatedly created and destroyed each time it is operated. It may be possible to estimate the size of the opening from the area of the burned part.

As above, due to the S-F angle of a tunnel kiln, the flame's ignition is strong. Furthermore, depending on the increase and decrease of the firebox's surface area and flue hole's aperture, the degree of this strength can be controlled. Modern tunnel kilns use this concept, and all is planned according to the clay, the form of the product, the amount of available fuel, and feeding time. The balance is determined by various factors such as the firebox's size, the fuel's opening surface area, or the chimney's length. However, because of weather and atmospheric pressure, conditions are rarely, if ever, identical. When the balance between natural conditions and kiln firing crumbles, a stagnation of temperature rise can be assumed.

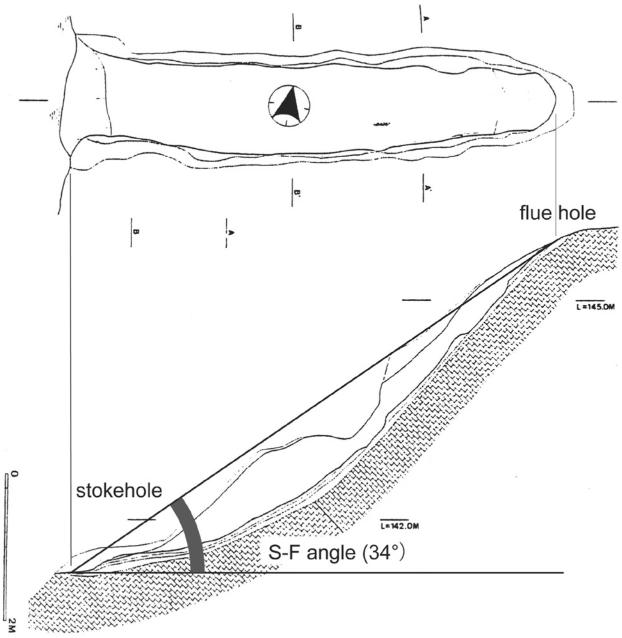

Figure 3.2. Measuring method of S-F angle (Koyanagi No.1 kiln in Kyoto Prefecture) (adapted from Kiln Research Society 2004).

3.1.3. Temperature differences in the kiln

The flame in the firebox stretches out widely, but it cannot heat the whole firing chamber, which is several meters long. There are high temperatures in parts, which face the firebox (in front of the fire). However, the temperature falls rapidly in parts near the flue. Because the fire rises to the ceiling, the floor's temperature is low, and that of the ceiling area becomes high.

We can say that the tunnel kiln has a structure whose primary purpose is to raise the kiln's temperature rather than homogenize the temperature. The temperature difference inside the kiln cannot be avoided in the upper construction. Nevertheless, by taking enough time for the roasting step and continuing the heating, the temperature difference can be reduced. Once the temperature is raised, the temperature difference cannot be reduced (Furutani 1994: 129).

3.1.4. A flame that requires heat

If there is a temperature difference in the kiln, the flame flows to the warm part, avoiding the cool part. Once the flame's flow has started, it cannot be easily changed. To heat the inside of the kiln without any temperature difference, consideration must be given to the fuel input location and the air passages.

If the difference in height between the entrance and exit is large, the flame's pulling will be intense. If a chimney is constructed during firing, the S-F angle increases noticeably. However, the cooled chimney does not show the expected effect. If the chimney is installed from the beginning, because the kiln firing warms the chimney at the same time, the original effect is maintained (Furutani 1994: 39).

A temperature difference inside the kiln is unavoidable in the upper construction of a tunnel kiln, but by a moderate rise in the temperature of the whole kiln, the difference in temperature can be reduced. That is why the beginning of kiln firing is particularly important. At first, a small fire is lighted outside the stokehole, and when the outer wall heats up, the flame will get progressively closer to the inside of the stokehole. If the warmed firewood burns directly inside the firebox, the high temperature inside the kiln rises immediately, and stonewares may be damaged. If the firing part of the kiln takes time, it can be heated later, but if the entrance is not heated at first, it will not be sufficient. Furthermore, if the stokehole's outer wall is not heated at first, it will be difficult to warm the kiln's back. If the first roasting is incomplete, the required temperature will not be reached. Modern potters say that it is essential to slowly warm the temperature in order from the entrance to the flue hole by roasting for a long time, to eliminate temperature irregularities inside the kiln and unevenness of the flame (Furutani 1994: 126–29).

3.1.5. Eructation of the kiln

In modern kilns, flames may spout out from the firebox. Some potters call this phenomenon "eructation," which is a bad sign for the flame's pulling. This phenomenon is produced because the flame's flow, which should face towards the flue, does not grow favorably. When the rising of temperature is not going well, or when the firewood is thrown in too fast, the phenomenon will be excited. In modern tunnel kilns, there are numerous cases in which soot sticks to the firebox's surroundings. It is not a "burp," but happens because the flame often leaks to the outside of the stokehole.

3.2. Evidence of kiln sites

3.2.1. Stokehole

The stokehole is the entrance of the kiln, where the firewood is added during the firing stage. In ethnological examples, the stokehole is built after the kiln is filled, and at the moment of taking everything out, it will be destroyed. Therefore, it is difficult to confirm a stokehole at the site unless the conditions are excellent. The detected "stokehole" is likely to be only a trace of a broken stokehole (Kidachi 2010: 126–27).

The beginning of kiln firing from the ethnological perspective. In ethnological examples of Japan, it was necessary to remove humidity from products and the kiln, so at the beginning of kiln firing, a large amount of firewood was thrown in to let the humidity volatilize gradually. Today's potters call firing by kiln "kiln burning." It is a fact that the kiln is burnt to bake the products but, if the kiln is not burnt, products cannot be burnt. In order to fire a product, the temperature of the whole kiln should be raised, and the radiant heat should be used to fire the product. The temperature is increased from the outside to the inside of the firebox, and then to the firing section.

The unique entrance of the kiln: the entrance of the chevron shape. At the kiln site in Hyogo prefecture, the kiln entrances are in the shape of a chevron, which is often burnt red. No similar fireboxes can be seen in other ethnological cases. Some assumptions about the firing of an empty vessel at the beginning at the kiln's construction were made, whether the surroundings of the kiln's entrance were widely burnt or the roasting opened a large aperture, and the stokehole narrowed successively. It is supposed that the stokehole narrowed. Generally, it is believed that the stokehole did not change from the beginning to the end of firing. However, the possibility should be considered that the shape of the "stokehole" and the firing section's position have changed. By this token, the chevron-shaped entrance could not entirely be a unique case.

The process of detecting a stokehole. It is necessary to comprehensively investigate the preservation of the remains which are recognized as a stokehole at the excavation site, from detailed observation and the distribution of the collapsed kiln wall and black coal layers. As one indicator for identifying the stokehole, there is a method that verifies the distribution area of the charcoal layer. However, it is necessary to note the next point. During firing, a large amount of embers may be scraped out to extinguish the fire if necessary, as they may have accumulated as charcoal. Moreover, immediately after emptying the kiln, a large amount of charcoal produced by reduction cooling of the kiln-fired burning material should be left, but the product cannot be taken out without removing the charcoal. It is assumed that large charcoal pieces were reused as fuel. Hence, a loss of information is possible after the charcoal was scratched out because it is left spread out on the floor. The charcoal would have been trampled into fine fragments and dust by the kiln removal work.

An even more effective indication for determining the location of the stokehole is the distribution area of the red burned soil, which was detected in the charcoal's lower layer. It is presumed that the area of red burned soil developed when the flame spread into the kiln after the beginning of firing and roasting outside the firebox. If we verify the movement's extent, we can probably conclude the place of the first firing. Nevertheless, if the firebox is destroyed at the time of the kiln's discharge, these fragments will accumulate as red burned soil. It is necessary to distinguish between red burned soil burned *in situ* and red burned soil of secondary deposition.

Furthermore, it is possible that the ceiling construction of the firebox area collapsed and accumulated on the floor – that the collapsed ceiling of the firebox part slipped down the sloped floor. There are many examples in which collapsed kiln wall fragments have tumbled down and accumulated because the firebox parts are almost flat. For that reason, although we have excavated around the firebox area, it is difficult to identify which part is the collapsed kiln wall fragment, and observing the ceiling wall fragment's burning state will ensure accuracy. In the firebox area, the temperature increases even more, and there are many confirmed cases with glaze. It is expected that the temperature becomes gradually lower at the kiln's back than in the firebox part. Through conditional comparisons, we can reconstruct the original location.

The ceiling of the firebox area's entrance. The sunken kiln was a dug-out ceiling; however, entire parts of those are not dug out, and most of the stokehole is constructed on the ground. The carved ceiling is that of the firing chamber. The sunken kiln type's firebox at the Karimata site in Ogōri in Fukuoka prefecture has a constructed ceiling. At the time of excavation, the whole ceiling was collapsed, but by detailed observation of the side walls, a provisional ceiling construction has been confirmed (Mochizuki 2010: 41–42). The ceiling construction of the firebox section may be closely related to the shape of the stokehole. In this way, based on the stokehole, it is assumed that the firebox part would collapse on to other parts and be destroyed at the moment of the kiln's discharging. Hence, it is difficult for it to remain. Nevertheless, there are examples that confirm those collapsed remains directly above the floor. Sometimes there are traces left on side walls as changes in the burn color. At excavation sites, detailed observation and documentation are necessary.

The precise observation of detectable remains like side walls and the floor allow us to set a certain standard. However, if the verification of the collapsed ceiling fragment's preservation state moves forward, it will help in understanding the remains of the firebox's provisional ceiling and the stokehole.

The situation of the stokehole's front area. At sunken kilns, the soil is thrown outside the stokehole to construct a flat surface in front of it. On the other hand, temporary storage for production use should be considered. In the case of a sunken kiln, a large amount of dug-out soil is discharged, but at the beginning of digging, it is assumed that a vertical precipice was scraped out. Perhaps a horizontal hole was dug into the near-vertical wall. Independent from the scratching out of the wall, some flat areas are formed. In the case of a steep slope, the discharged soil slips down the slope and forms no flat surface. If there were no steep slopes, the discharged soil would form a flat surface. The flat surface would have been made lower than the kiln so as to improve efficiency and keep out rainwater. It is necessary to pay attention to the topographical modifications nearby and around the time of the kiln's construction.

In case of a semi-sunken kiln, the amount of dug-out soil is small, and the discharged soil would be used to form a ceiling. Thus, it is assumed that the amount of discharged soil was scarce. It is possible to dig down the kiln's surroundings and float its body, but the topography's modification in front of the firebox area is not apparent.

Besides, many semi-sunken kilns at the Ushikubi kiln site in Fukuoka prefecture were constructed on steep slopes, and the front parts were carved out. An embankment cannot be confirmed. In this case, dug-out soil as well as the failed products and the charcoal were thrown away below the slope. There are many cases in which such sloped topography is used in the sunken kilns, but even in the case of semi-sunken kilns, there are some confirmed and selected examples.

3.2.2. The firebox and firing chamber

In the case of a tunnel kiln, the firebox and the firing chamber follow one after another, and it is often difficult to differentiate between them. In the case of a tile kiln, there are prepared steps (Ōkawa 1985: 30), and examples can be confirmed in which the firebox and firing chamber are divided. However, in the case of a Sue-ware kiln, it cannot be divided in general. When some of the fuel is left as charcoal or ash, it is assumed that its distribution area reflects the firebox's size, but attention should be paid to the fact that the distribution extent of charcoal and ash changes with each firing. It is possible that the range of the firebox section moved with each firing, just as the stokehole might have moved during firing. In that way, The size of the stokeholes identified in the excavations would then be the overlap of the burning areas experienced in multiple kiln firings.

The firebox's ceiling. The ceiling of the firebox part is where, in general, the temperature becomes higher inside the kiln. Air enters the stokehole, the flame of the firebox part rises diagonally to the firing chamber's ceiling, and the part which is in the combustion zone but quite near the firing chamber becomes hottest. Hence, this part of the ceiling inside the kiln was the easiest to damage, and it may have had to be repaired after each firing.

When temperatures become high, as in ash-glazed stoneware kilns, the ceiling cannot withstand the temperature, so columns, called pillars, are erected to prevent it from collapsing. It was thought that they were installed to divide the flame evenly. However, to achieve that, it would be enough to arrange the position of large products during the kiln filling. According to a thermal simulation conducted by the Japan Atomic Energy Agency, "Technical Exchange Meeting on Echizenyaki Stonewares," the ceiling temperature of that portion is the highest when there is no pillar. Conversely, when a pillar is set up, the pillar takes away the heat of the kiln (Technical Exchange Meeting on Echizen Ware 1998; Kidachi 2010: 122). It cannot be said that it played no role in "dividing the flame," but it cannot be thought that it had no role except to support the ceiling.

In conventional excavation research, sufficient attention has not been paid to the restoration condition of the burning stability of the firebox's ceiling. If a collapsed ceiling remained on the floor, these fragments would become a crucial factor in knowing how to repair and burn. Usually, we try to verify repair traces of tunnel kilns by cutting open the side walls and the floor, but in this part of the kiln's inside the temperature is low, and it is a part that does not need so many repairs. The part that is indispensable for knowing the firing temperature is the fragments, and observation of these is essential. This is a principle that is not only limited to tunnel kilns.

3.2.3. The flue hole and the accompanying facilities in the kiln's and chimney's surroundings

The flue hole and the chimney. For controlling the flame's ignition in modern kiln firing, the flue hole is opened and closed during the firing. It is possible that such work was also performed on Sue-ware kilns, but because a cooling reduction was conducted at Sue-ware kilns, it was necessary to seal the flue hole and stokehole completely airtight after the kiln firing was finished. If there is a flat surface in the flue hole's surroundings, it is assumed that an opening and closing were used. Because it is impossible to look through the stokehole to the end of the kiln during a firing test, the firing situation is often observed at the flue hole during firing. Since the firing mouth is narrowed down, the closer to the final stage, the worse the kiln's visibility from the firing mouth. By observing both the flue hole and the stokehole, the firing situation of the kiln's inside can be estimated.

In the case of a Sue-ware kiln, in order to avoid the accumulation of water at the flue hole, which runs on the surface, there is sometimes a drainage ditch that encloses the flue hole. It is assumed that the flat surface around the flue hole was not just a work surface, but also functioned as just such a water barrier. There is a sunken kiln with a groove in the smoke exhaust part, which is part of the Sue-ware kiln. It is presumed that the flame's flow blown out can be estimated by the firing state and the construction of the fuel to accelerate or suppress the smoke emission. The idea that different works like accelerating or suppressing the smoke can be conducted around the flue hole is fascinating. For this reason, detailed observation at excavation research sites is necessary (Mochizuki 2010: 60–61).

That the height difference between flue hole and stokehole is important for the flame's ignition has already been mentioned above. However, due to the ditch, which is fixed at the flue hole, the height difference between stokehole and flue hole would be smaller than the height difference of the original ground surface and would have suppressed the flame's lighting.

Because a kiln with a ditch has a hollowed-out form, the difference in height must be enormous. Besides, the temperature on the floor is reduced, and the fuel consumption increases. Various measures are required, such as narrowing the opening area of the flue hole and the stokehole to prevent fuel consumption and heat loss due to smoke exhaust. It also depends on the location's condition, like terrain, but it is assumed that the main reason for installing the ditch at the flue zone is the idea of reducing the efficiency degree, even though it is a sunken kiln type.

The accompanying features of the kiln's surroundings. In the case of a semi-sunken kiln, many cases can confirm extensive changes in the environment of the kiln. Remarkably, a continuous pit was laid around the ditch to allow rainwater to escape the surroundings while protecting the exposed kiln ceiling. This not only let the rainwater flow off, but also became a stairway or a passage for applying the flue hole, and it is possible that it was used during the repair of the exposed ceiling. If a crack forms in the ceiling zone, air can leak out from it. As reduction cooling would lead to oxidation, modern Daruma kilns were cooled after firing by adding muddy water to the entire kiln, filling in the cracks. Similar work was necessary. Furthermore, there are also cases where the slopes around the kiln have been modified like terraced fields to provide flat surfaces. This area may have been used as a fireplace or a simple workshop. Ethnoarchaeological studies of people who lived in the mountains are indispensable in clarifying the supply lines of the potters at that time, such as the passage to the kiln and the locations of the mountain paths. Ethnological examples of modern charcoal kilns should be consulted (Fujiwara 2020).

Near the kiln, the workshop or the pit for clay mining can be detected, and there are also good examples for reconstructing the supply ways. However, from a multitude of Sue-ware kilns in western Japan, there are many cases in which only the kilns can be detected in the mountainous regions, and in contrast, it is highly possible that the workshops were built in the plain's settlements. In the east of Japan, both kilns and workshops were generally built in mountainous regions. It is becoming clear that there were significant regional differences, but it is assumed that these differences indicate whether the Sue-ware production system was relatively independent of the local community. Even if the kilns are similar, the facilities around them may differ depending on the difference in the social systems that supported them.

3.3. Firing experiment with Sue-ware tunnel kilns

3.3.1. An experiment with temperature difference and color tone

The atmosphere that determines the color of Sue ware: experiment with cooling and firing. Because the soil's components decide the color of the finished product, the firing and the cooling, the color tone of stonewares is diverse. Experiments have revealed that Sue ware has a blue-gray color and is cool and reduced (Sasaki & Yogo 2004, Yogo 2010).

Therefore, I would like to introduce the experiment with the firing and construction of a Sue kiln conducted by the Kiln Research Society (Kidachi 2010). By observing the fired products from the experiment, it was found that many of the pieces placed in contact with the firebox were bluish-grey and firmly baked, and the natural glaze was melted. The black color of the stonewares which were arranged near kiln's back wall had faded, and although ash fall is confirmed, it does not melt. Ash falls down on the whole firing zone, but there is only a small part in front of the fire that melts. It can be said that the firing temperature was high enough to melt the ash only in the limited part in front of the fire. Ashes move from the front of the fire to the kiln's back and gradually change their appearance due to the temperature difference, thus: "melting (vitrification) → solidifying and adhering (welding) → mere powder ash." Depending on the kiln firing, the atmosphere inside the kiln changes precipitously. During the stage of removing the moisture from the kiln by roasting and gradually raising the kiln's temperature, an oxidizing atmosphere is maintained in the kiln. After reaching a specific temperature, we finally enter the "offensive fire" stage.

The firewood will suddenly remove the temperature of the firebox zone if put in the high-temperature firebox part. The firewood, which absorbs the kiln's heat, will begin to burn rapidly. At first, it produces a situation of oxygen deficiency, then dark black smoke rises, and the kiln's inside part turns into an airtight atmosphere. Due to the oxygen deficiency, the goods in front of the fire will be directly covered with dark black smoke, i.e. the warm air of a reduced atmosphere. By throwing in the next load of firewood without changing the state of reduction, this state can be kept, but the kiln's inside temperature will not rise. If the reduced state declines, it turns into an oxidative atmosphere, black smoke turns into flames, and high temperatures result. The burning of firewood is accelerated, and depending on the oxidative flame, the temperature of the inner kiln rises. After a while, the view into the flame-filled kiln widens and the products glowing from the heat become visible in white. The oxidative atmosphere stage is the moment of the highest firing temperature. If this moment is passed by, the kiln's inner temperature will begin to fall. Burned firewood turns into embers because a large amount of heat will no longer be generated. These embers take on the role of the firebox's heat insulation, but they do not raise the temperature of the firing chamber. This is because the embers do not generate long-stretching flames.

Just before the temperature inside the kiln begins to drop gradually, one adds new firewood. In this way, through a change in reduction and oxidation, the temperature rises, and offensive firing is conducted by balancing the timing when firewood is thrown into the kiln and the amount, the oxidative atmosphere; in the other way, the reduction atmosphere can be prolonged.

When the desired temperature is finally reached, a large amount of firewood is thrown in, and the kiln is sealed entirely airtight. The firewood tries to burn in the high temperature, but since the air inlet and outlet are completely closed, this deprives the kiln of oxygen. From the kiln wall to the products, it burns by consuming all of the oxygen, but it cannot burn out and turns into charcoal. A high temperature produces a strongly reduced atmosphere, and while maintaining this atmosphere, it successively cools down the kiln, so that the Sue ware shows its reduction color. It is not only the product but also the inner walls of the kilns, the ceiling, the floor, and all turn to that reduction color.

After the kiln is closed, the walls shrink, causing fissures. Therefore, to avoid air leaks, mud and muddy water are put on the whole kiln to cover the crevices. Directly after occlusion, the kiln's inside spits out a large amount of smoke caused by the burned firewood, and because the pressure becomes higher, smoke is emitted from the kiln walls, the stokehole and the flue hole. The work of putting mud and muddy water on parts where smoke is rising and covering crevices must be done repeatedly. If the work eases off and the pressure is low, oxygen enters the inner kiln through the crevices, and it turns to an oxidative atmosphere so that the color tone becomes red. This post-occlusion treatment is thus essential for producing a blue-gray tone.

The formation of the ash pile. In the experiment, reduction cooling could not be performed successfully. Due to the foundation, there is a limit in the kiln's fire resistance, and at the moment of the kiln's closing, a large amount of firewood could not be thrown in. Hence, at the moment of the kiln's cleaning, a large quantity of the added firewood burned out to ash in the firebox, and there was very little charcoal left. Despite the firing experiment having been performed for ten years, this did not form a disposal area of ashes and burnt-out charcoals (*haibara*) like at the Sue kiln excavated around the experimental kiln. The excavated ash pile sometimes exceeds 1 m. It contains charcoal, but most of it is a powdery, black soil. The actual composition of the ash pile is an accumulation of charcoal powder and black charcoal.

Of course, charcoal can accumulate if the act of scratching out the embers is repeated often during firing. However, it is possible to reduce such loss by devising a method for heating sufficiently, and it is not clear why this work was done in the Sue kiln or why a thick coal accumulation layer was formed. It becomes clear that the ash pile is an important source that indicates the conditions of the firing method, but at the same time, it also becomes apparent that its formation mechanism is unclear.

Reducing flame firing. As described above, although the reduction cooling has not been sufficiently successful, in the firing experiment, it was possible to fire the reduced color *sueki*. Through observation of the firing stage, it turned out that only the part exposed to the intense flame was discolored.

After the added firewood starts to burn, a large amount of black smoke is spat out, but its temperature is still low. It gradually oxidizes and turns into flames, but during this transitional stage, the goods may turn into a reductive state. Once it was fired at high temperature, even if an oxidative state was reached at a lower temperature, it would not return to the oxidized color. Nevertheless, it is difficult to obtain a perfect reductive color. Furthermore, in order to observe the product's burning state, a photograph was taken during the firing process. When around 1000° is surpassed, and the oxidation progresses, the flame inside the kiln turns transparent, and a white glimmer can be easily seen on the products. At that moment, the hot part of the product shines brightly on the protruding parts, and the slightly dented parts become darker. When it was left as it was and the temperature inside the kiln began to drop, the protruding parts on the contrary changed to a dark color tone and the slightly dented parts began to shine white. Because cold air enters from the stokehole, the protruding parts would directly hit the cold air. Since the cold air cannot directly hit the hollow portion, it seems that the heat was still stored, and the temperature seemed to rise relatively. After that and because firewood was thrown in, it became impossible to observe the kiln inside. The air directly hits the protruding parts in front of the fire, slightly reducing the high temperature, then the cold air has a slightly oxidizing effect. It is assumed that the differences in temperature and atmosphere strongly influence the product's firing condition and also its color tone.

It is presumed that the color tone of Sue ware is determined by reducing the cooling stage's atmosphere and the influence of the reducing flame. In addition, many of the early examples of Sue ware have a sepia-colored cross-section and are fired firmly. It is the coloring by high-temperature firing in an oxidative atmosphere that turns the cross-section sepia-colored. It is assumed that the product was fired at a high temperature while maintaining the oxidation state, and the reduction cooling was performed after the temperature decreased in the final stage. Since the reduction cooling temperature is low, it is assumed that the reducing atmosphere was not able to break into the cross-section that had been fired at high temperature. In many cases, only the surface is reduced and cooled, with a dark bluish color. Therefore, in the early stage of the kiln introduction, it is possible that the offensive firing maintained an oxidizing atmosphere, and that the reducing atmosphere used in the experimental kiln did not occur.

Baking of products and the kiln-filling position – the actual state of temperature difference. When fired in an experimental kiln with a total length of about 7 m (no refractory bricks used), the kiln's chimney's temperature was about 200° lower than that of the firebox. Even in the Sue-ware experimental kiln (made of refractory brick) at the Ogōri City Archaeological Center in Fukuoka prefecture, a temperature difference of about 200° was confirmed even though it was a small kiln of about 4 m. In these experiments, the temperature near the ceiling was measured using a 50 cm thermocouple, but similar temperature differences were confirmed in the experiments measured with a 1 m long thermocouple. This is the case not only in front of and behind the fire of the firing chamber; it has also been confirmed that similar large temperature differences in the kiln's inside near the ceiling and the floor occur (Technology Exchange Meeting of Echizen Stoneware 1998). It was also confirmed that in the case of large goods, the hot wind of the high temperature near the ceiling hits the products' rims and blows into the inside of the product. Because the hot wind's temperature near the floor is lower than near the ceiling, a huge temperature difference between the product's inside and outside occurs. Inside large ancient Sue-ware pots, even though firing near the rim is well done, there are many cases where the bottom's outer surface is poorly fired and is whitish gray and soft. Observations of the inside and outside surfaces of large goods are rarely done, but it would be important to understand the form and height of the ceiling of course, depending on the kiln-filling position and the shapes of the rim and body portion of a massive product, both when hot air is easily blown and when hot air is not blown.

Since it is a fact that a temperature difference occurs inside a kiln, it is necessary to reduce the difference a bit by devising a firing method, such as prolonging the firing time or performing "intermittent firing." The temperature difference between the areas in front of and behind the fire will spread widely if the firewood is rushed. The floor surface is where it is particularly difficult to store heat. The flame inevitably rises, and the temperature near the ceiling rises.

After the firing experiment was continued for over ten years, the kiln was fired continuously for three days and nights. It was changed to "stop the fire" that interrupts the kiln at night. The advancing age of the participants made it difficult to work continuously for an extended time, but as a result of this experiment, it seems that the entire kiln will accumulate heat due to the leftover embers, and the temperature difference will decrease, and the flame of the kiln will crawl on the floor. Although the number of days of firing increases and the loss of firewood fuel is unavoidable to a certain extent due to stopping the burning, it is an effective means of reducing the temperature difference. However, it is not possible to confirm by excavation research whether this procedure was conducted.

The form and temperature difference of the kiln's rear. In the firing experiment kiln, it is assumed that the firing of the products, which are packed in the rear area, was relatively weak, and the firing temperature was low. The construction of kilns in which only the rear of the kiln is sharply narrowed, and the slope is strengthened, is due to the fact that the heat was concentrated to make the kiln's temperature uniform. Nevertheless, the positioning of goods in the kiln's rear area on a steep slope is difficult.

If a temperature difference of about 200° between the part in front of the fire in the firing chamber and behind the fire at the kiln's rear area is supposed, and the temperature in the rear zone was raised (or it was attempted to raise it) to 1150°, then the firing temperature of the foremost part of the firing chamber must have risen to 1350°. In that case, the temperature in the ceiling's vicinity should have become higher than in the vicinity of the floor on which the products were placed. This high temperature requires a considerable amount of fuel, and the ceiling can collapse. Furthermore, from the experiences of the firing experiments, it is assumed that the temperature rising to 1350° would exceed the limits of the kiln's fire resistance and stamina, and a temperature rising to this extent was problematic. It is assumed that the kiln was fired while maintaining the temperature balance between the kiln firing section and the kiln rear.

In modern kiln-packing, products that are to be fired at a high temperature are placed in the front of the firing section. The medieval (Kamakura and Muromachi period in Japan; 1199–1573) stoneware kilns were constructed in the same way, and even in the early modern (Azuchi-Momoyama and Edo period in Japan; 1573–1868) multi-chambered climbing kilns, the temperature difference inside the room was unavoidable, so the products and glaze were changed depending on the kiln filling position and height (Kinkodō Kamesuke 1830). It is assumed that even at the Sue-ware kilns, vessels for liquid storage like jars, bowls and narrow-necked jars, which are sorts that must not leak due to firing failures or cracks, were placed in front of the fire and tableware that does not need high firing temperatures was placed near the kiln's rear.

3.3.2. The stress of Sue-ware kilns

Stress concerning the temperature difference. Due to the location conditions of the kiln's construction, geological features like terrain and water become essential. When the bedrock is stable, a sunken kiln cannot be built, and if it is too fragile, there is the danger of cave-ins. Fire resistance is also important. Notably, the ceiling part of the firing chamber is where the temperature rises the most, and if it cannot endure the high temperature, the ceiling collapses. If the ceiling temperature is more than 200° higher than the floor surface, and someone wants to bake the product at 1150°, the combustion ceiling will be as hot as 1350°. Not much base soil can withstand such high temperatures.

Contraction stress concerning the sintering. Clay is said to shrink by 10 per cent when dried and by 10 per cent more when sintered at 1100° or higher. If the ground is good, the ratio will decrease, but the shrinkage due to drying and firing will be 10 per cent. If the wall surfaces of the kiln have the same clay, a 5 m long tunnel kiln will shrink about 50 cm and a 10 m long kiln about 1 m. Since it touches the ground, a gap is created between it and the ground, and it does not shrink so much due to cracking, but the kiln itself also receives immense shrinkage stress due to firing. Products are not fired several times, but kilns are heated over and over again. Therefore, the already-fired material is added and kneaded into clay to suppress the shrinkage as much as possible to build the kiln wall's surfaces.

Fuel consumption and the soil's fire resistance. Even in modern brick kilns, old bricks that have already been baked are preferred. In the case of new materials such as firebricks, the fire resistance is high, but since a large amount of heat is required to burn the bricks, older firebricks that have been baked are most effective (Furutani 1994: 49). Even modern potters reuse materials from old multi-chambered climbing kilns instead of firebricks to economize fuel. The fire resistance of modern firebricks is high, and a large amount of fuel is necessary to heat them, but traditional clay bricks are already baked, so they warm up quickly and save on fuel (Furutani 1981: 105). If such information is applied to the Sue kiln, it is not always necessary to select a ground with extremely high fire resistance. Although it is necessary to have a degree of fire resistance and stability that can prevent a ceiling collapse, if the degree of fire resistance is too high, fuel consumption will increase. It is better to choose the right ground. There is also the opinion that kilns made of soil of the same clay quality as potter's clay are suitable (Ōgami 1981: 26).

In the Sue-ware tunnel kiln, it was common to mix chopped straw with a length of 3 to 5 cm into the ceiling frame. A similar mixture of clay and susa (straw) is used for the clay walls of modern Japanese architecture. In modern earth walls, it is sometimes explained that the *susa* fibers play the role of connecting clay. However, in Sue kilns, the effect is only temporary because the plant fibers are burned out by the fire. As a result of measuring the shrinkage rate of clay mixed with straw, it can be confirmed that the clay that the shrinkage by about 20 per cent depending on drying and firing is reduced by 10 per cent (Kidachi 2010: 113). Because there are few experimental cases, it is necessary to confirm the effect with a large amount of soil.

3.4. The whole life of a kiln: the reuse of a "tunnel kiln"

3.4.1. The diversion of kiln walls

There are examples of kiln sites where the floor of the kiln has been planed. Moriuchi Shuzo thought that the burnt floor might have been planed off to be used as a material for the kiln walls. (Moriuchi 2002). General excavations focus on the construction and operation of kilns but have not fully considered the post-abolition phase. The remaining evidence is not only from the construction to the abolition, but also contains all from the abolition to the present, so the life history of a kiln should be investigated and considered an important point. According to Tsunejiro Ito, who has traditional skills in charcoal-making and slash-and-burn cultivation, charcoal-making craftsmen excavated the old Sue-ware kiln site, collected the kiln walls, and crushed and mixed them into the new charcoal-made kiln wall soil. The sand-like "fired powder" from the kiln wall had already been burned and contracted. If this were included, the kiln would become solid, and the shrinkage rate of the kiln walls would be minimized. For charcoal-making craftsmen, Sue-ware kiln sites become valuable sources of knowledge (Kidachi 2012: 26–27).

Such conversion was probably not only limited to present-day charcoal kilns. From cases where the floor of Sue-ware kiln sites was scratched off, it is supposed that collapsed ceilings and side walls were brought out from where they belonged. It is necessary to check not only the floor leveling but also the preservation of the kiln wall pieces buried in the soil. Although it is challenging to specify when the material was taken out, it should be considered whether it was immediately after the kiln was abolished or after some time had passed.

3.4.2. Analysis to exclude mixed objects

The more detailed the examination, the more the possibility that the ceiling has been taken away for reuse, as described above, becomes clear, but it is limited to the sunken kiln type. Most of the ceiling frame constructions left little room for investigation because the ceiling collapsed quickly. Excavation location information is no longer sufficient for analysis in the kiln. It is possible that some of the artefacts on the floor are newer than when the kiln was in operation, and detailed observation of the stratigraphic deposits and accompanying artefacts is essential. However, there have been few attempts to reconstruct various activities from the kilns' buried condition. There are even cases where the soil layer pattern in the kiln is not available, and even if it were, there are many cases where no consideration has been given to its meaning. Even when the excavated material from the floor is reported, it is necessary to think about various situations that may have arisen after the abolition of the kiln.

Even if it was confirmed that there was no prospective mixing, and in the case that the old stoneware fragments were used as a fired pillar at the time of the final kiln firing, the concept of reliable floor material would collapse. It is important to note that kiln artifacts may have been relocated, whether they are in the ash pile or inside the kiln.

The "mixed products" themselves are evidence of reuse of the kiln, which is also historically accurate. A detailed examination should consider the time of reuse and the method of the investigation itself. The life history of the kiln cannot be analyzed only through the perception that it was disturbed.

3.4.3. The kiln's life history

In traditional Japanese archeology, the reliable extraction of artifacts at the beginning of the operation without prospective mixing was an essential viewpoint for investigation. However, the actual condition cannot be approached unless the life of the kiln is investigated. Why was a kiln built there? Who and where did they get the bases for placing the pottery in the kiln? Where was the clay collected, and where was the workshop? How can the flow lines related to kiln firing be restored? What was the nature of the surrounding environment before, during and after the kiln operation? After the kiln was shut down, was it left alone, or was it reused? In the future, it will be necessary not only to discard artifacts of different ages from the kiln as mixed products but also to ask why they were mixed.

We have turned away from that analysis and focused only on the time the kiln was operating. From now on, we need to look a little further. It is possible that the state that we had assumed for the appearance of the kiln at the time of operation was the result of reuse after its abolition. If we do not pay attention to the kiln's whole life, including the time after abolition, we cannot reconstruct the appearance at the time of operation.

The tunnel kiln is a simple construction, but various types of knowledge and information are used in making it. The excavated Sue kilns on the Japanese archipelago are numerous (Kiln Research Society 2010). To investigate the actual situation in detail, it is necessary to carry out firing experiments and detailed observation of the remains while keeping in mind the basic principles of the kiln described above. If we do not have the technology to fire a kiln, we cannot clarify the meaning of the kiln structure. We have been forced to experience it by repeating firing experiments (Kidachi et al. 2010).This is only an interim report on the research, but we hope it will help to observe the remains of the kilns and consider their function.

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4

An Essay on Interdisciplinary Kiln Research and Agile Research Design

Maria Shinoto

Abstract: Archaeological research on kiln sites involves a wide range of additional disciplines in order to answer questions that archaeologists pose on their material and findings. Since kiln research typically poses questions on material used and processed, on the construction of kilns and firing technology which can only be solved with methods from natural science and engineering, kiln research is interdisciplinary in the first place. This essay summarizes the experiences of a decade of decidedly interdisciplinary research at the Nakadake Sanroku Kiln Site Center and other projects, tries to categorize the various patterns of collaboration and emphasizes the importance of an "agile" approach, which turned out to improve the results significantly as compared to traditional interdisciplinary research patterns.

Keywords: Agile Research, Interdisciplinarity, Archaeometry, Natural Sciences, Engineering, Research Process, Communication

4.1. Kiln research and interdisciplinarity

Archaeology benefits greatly from methods, theories and tools borrowed from other disciplines. Our sources are material remains of human life uncovered from the soil. Our method is excavating and documenting with words, drawings, photography, structured data and 3D data. The technology for excavating and documenting is getting increasingly sophisticated in the course of technological evolution in other disciplines, and recent developments are breathtaking. But excavation and documentation alone does not create a sensible narrative for understanding the past, the society, or whatever we are looking for to understand. Archaeologists need knowledge, ideas, methods, and tools from other sciences in order to make sense of their sources.

Kiln research is one of those fields of archaeological studies that are particularly dependent on interdisciplinary work. The construction and material of a kiln, the firing process and the firing material have to be understood from the point of view of an engineer as well as a potterer, excavated materials have to be handed over to mineralogists and other specialists in material sciences in order to understand the heat stress on the material and draw conclusion about temperatures and firing duration. Geologists can help finding sources of raw materials and, together with mineralogists, can offer hypotheses about the processing of the raw materials into an intermediate product that is then fired in the kiln. Of course, experiments under strict scientific observation and in cooperation with potterers and other practitioners – whose expertise from another non-scholarly angle is highly valued – can help solving this problem from an additional angle. This is in contrast to a more archaeocentric and discipline oriented understanding, an understanding that is more focussed on problems, and which adds methods from various disciplines and even non-scientific knowledge to a project when needed. Thus, the constellation of disciplines involved in a problem may change in the course of the ongoing research due to new insights. However, the archaeologist stays in the center since research on kiln sites as such almost always starts with the finds and findings – the typical matter of archaeological study.

The interdisciplinary aspect in kiln research is not limited to questions of materials and technology: The social and political organisation of the craftsmen, accessibility of material and distribution of products as well as their role in the historical development of the region are another important aspect. In these cases kiln research is more leaning towards the humanities and collaboration with historians, sociologists, economists – to mention only the most obvious relations. This book introduces studies that deal with parts of all of these aspects in different regions and times, but this essay shall concentrate on cooperation regarding the technological and material aspects rather than on cooperation with researchers from other disciplines in the humanities. Cooperations between archaeologists and researchers from the natural sciences or engineering departments can pose problems on a research project because of the different "cultures" or traditions in these departments as compared to the humanities.

This essay is mainly based on the authors‘s experience of coordinating research and continuous discussion and exchange between researchers from various disciplines and nations in the Nakadake Sanroku kiln site center in South Japan (Shinoto et al. 2015, see also chapter 17 in this volume) among several others. Intermediate reflections on these experiences were presented at International Conferences. A first talk during the WAC8 conference in Kyōto (Shinoto 2016) stressed the roles of attitudes like curiosity, incomprehension, indifference, while the second talk on the SEAA8 in Nanjing (Shinoto 2018) discussed advantages and dangers of agile research design.

Rather than introducing the content of interdisplinary research, this essay shall focus on the why and how.

4.2. Types of interdisciplinary research

Typically, an interdisciplinary research project is understood as successful when all contributions are integrated in the result and form a vital part in the final discussions. However, the integration of all contributions and vital participation of all researchers in the course of the whole project from its outset to the final stages leads to more, deeper, and even unexpected insights as compared to an approach where the archaeologist poses certain research problems to a research group and waits for the results to be presented at the end of the project.

The intensity of mutual exchange or the integration of different disciplines may differ significantly in different research projects, and it is important to keep in mind that the circumstances for kiln research vary as they do in every archaeological project: There are rescue excavations that leave no time for discussion but require the excavators to save information for later that is at danger to be lost and therefore just organize separate scientific investigations. A short term project may be focussed on a limited question with a small group of researchers that does not need any formal discussions and exchange. Finally, long term projects with a wider range of research questions and larger groups of researchers from various disciplines may need some consideration of how research should be organized in order to gain really new, unexpected insights. The following classification keeps this variety of circumstances in mind but is most closely related to the latter scenario, the long term project which is predominant in kiln research as soon as production centers are concerned.

Looking at how research is done in the real world, a classification with four levels of integration seems applicable. Each level has its merits and demerits that have to be discussed and understood when designing research on a kiln site or a kiln site cluster.

4.2.1. Multidisciplinary or parallel research

Multidisciplinary research describes a rather parallel kind of working, with no real exchange between the fields. One may think of a project with several unrelated subprojects: Dating of features or layers with radiocarbon dating in one group and thermoluminiscence dating in another group, creating a geological map for material research in a geological sub project, while doing research on chemical and mineralogical characteristics of the products in another subproject and mapping archaeological prospections by archaeologists, to name some examples.

In most cases, each of these subprojects finishes with a report that may be published separately as a journal article or as a chapter in a final, comprehensive report on the larger project. Nobody from the different subprojects or disciplines will understand what happens or what could be learned from each other before the final publication. In some cases, all results will be integrated in an overview by a project leader in the final stage of a project as another chapter in the report, in other cases, the reports from the respective disciplines stand only for themselves without further integration.

This kind of research design can often be found in excavation reports, where scientific studies like biological determination of species from wood or bone remains, or results of material analyses or scientific dating is added as a separate report of data without further discussion. Such parallel research is good practice as long as excavations or investigations into cultural heritage are to be documented urgently and left for later, advanced and integrated research. Each of the disciplines – archaeology included – offers information and data from its own research for further usage without offering overall “sense”.

The relation between the disciplines may be characterized by the terms “indifference” or “ignorance”, and while each subproject seems to be autonomous, the overall concept is hierarchical: Every discipline serves one central person or institution that will later use the data for whatever purpose – without discussing with those who provided the data. While this is inevitably part of research reality, these characteristics seem to be the root of problems in interdisciplinary research that can be observed frequently. These are (a) missing out of synergy effects and new learning as well as (b) lack of satisfaction or enthusiasm for the overall research.

(a) Synergy effects and learning: To start with an example from kiln site research, it is obvious that a geological map integrated with a historical map and distribution maps from archaeological prospection will inevitably lead to new insights and better options for the interpretation of findings in each of those maps. Exchange between geologists working on the geological map with mineralogists who analyse the material of kilns or ceramics is clearly necessary in order to understand the interaction of landscape and people. In a parallel research design, everybody keeps his or her own results separate, and a distribution map of archaeological finds alone for example will not help understand how geology contributed to a certain distribution pattern as long as the geological map is created, presented and discussed sepatarely, without informing the archaeologists creating their distribution map from surveys.

Deeper understanding is not always the aim of a project, however, academical research should aim at overall understanding, new insights, and relations that were unknown in the past.

(b) Satisfaction: As long as each researcher is just treated as a provider for data that are generated with well established methods in his or her discipline, this research will be considered more a kind of service rather than research on its own by either side: researcher and project leader. The reality in archaeological research is that archaeologists often seek for additional, scientific data to back up their own findings. For example, dates derived from typology, cross dating or stratigraphy shall be backed up with scientific dating, or pottery that seems to stem from a certain site judged by archaeological typology needs to be provenanced with chemical data – to name the two most common cases.

Aside from institutions that offer these analyses as a paid service, there is not much academic attraction in performing such a role – a role that in archaeological projects is often given to researchers based in disciplines from the natural sciences. On the other hand, as long as the scientist does not have any interest in the specific archaeological problem or cannot expect scientifically interesting developments or results for his or her own field of study, cooperation in archaeological projects of this kind is of little interest for the scientist.

Although "satisfaction" is a term that does not necessarily relate to the academic work, experience from several interdisciplinary projects shows that satisfaction of researchers with their contribution to an interdisciplinary project and the acceptance of these contributions by the other partners in the project is one of the most important factors for excellent research process and results. It may even become difficult to find a scientist willing to contribute to an archaeological project without mutual interest and comprehension and satisfaction.

Kiln research in particular depends on the contributions from natural sciences, thus, it is imperative to replace – on both sides – *indifference* and *ignorance* with *interest* and and a certain *comprehension* of the expertise of the other discipline in order to start a fruitful discussion.

4.2.2. Phased exchange

A slightly more integrated approach is what may be called "phased exchange": While in parallel research, the results are presented to colleagues and the public simultaneously at the end of a project and influence research only afterwards, with phased exchange, intermediate results are presented to colleagues in the course of a project, often provided with intermediate reports in workshops on an annual basis, after "half time" or towards the end of the project.

These workshops may become an inspiring platform for exchange, adjustments and progress. On the other hand experience shows that due to time constraints these workshops often turn out to be a mere exchange of results in order to confirm that everybody is "on track". It is more important to get the own presentation done and well rather than incorporating ideas and results from other work. In order to escape this trap, a good organisation that encourages discussions and adaptation to new insights in the next phase is necessary. This is the responsibility of the project leaders, but more than that, researchers participating from different disciplines need a certain amount of *curiosity* towards and *understanding* of the other disciplines as well as an *interest in the overall project* and its aims in order to react flexibly on research going on in various sub projects.

Although "phased exchange" in interdisciplinary research does still allow for mutual incomprehension between the disciplines, in order to really stand out from "parallel research", on the side of the participants it needs to overcome indifference toward the other disciplines involved and to the overall project aim. Not at last, it demands a certain understanding of all disciplines from the side of the project leader in order to monitor the exchange during workshops and other phased events. Since the organisation depends on these qualities of the project leader, interdisciplinarity with phased exchange may still be characterized as hierarchical. It should be obvious though, that phased exchange if done well may encourage a certain progress in the course of the project and will prevent the lack of satisfaction mentioned in relation to parallel research.

4.2.3. Continuous integration

Continuous integration or cooperation may be the most fruitful form of research, where specialists from each field do not only exchange their final results but almost continually exchange and discuss intermediate insights and problems arising during the course of the whole project. In this case, research design evolves on common grounds, based on a comprehensive understanding of new results from various disciplines. In the continuous process of exchange, research design may be altered, new questions may turn up while other questions may be abandoned – because they are valued as "solved" or due to new insights from the ongoing research process which show that these old questions are not relevant. New interdisciplinary cooperations between researchers or groups may form according to these changes. This is where agile research design comes into play, which will be discussed below.

Figure 4.1. On a tour guided by archaeologists in the forests of the Nakadake Sanroku Kiln Site Center; a geologist and a potterer take the lead and discuss potential raw materials and their change in quality during natural or artificial processing. (Foto M. Shinoto 2016).

To expand on the example from above: Geologists may map an area with a certain soil quality that is not suitable for building kilns and report this to the archaeologists who could then shift their prospections and search for distribution of kilns to a more suitable area; the archaeologist in this case is not a hierarchically higher person that needs to be reported to, but rather a partner for solving a thematic problem who needs this information in order to adjust the activities. In the same project, researchers creating a historical map may better understand certain patterns thanks to insights on soil quality and hypothetical kiln distribution that they receive as soon as possible from their partners in the departments of geology or archaeological prospection. In other cases, a historical map may reveal historical activities that have destroyed areas in the kiln site cluster, and together with geologists and 3D surface data, the whole group of researchers working on different maps may attempt to set up hypothetical models about the original distribution of kiln sites in the region.

In an ideal world, all participants discuss on equal ground, but experience from the Nakadake Sanroku project shows that a *managing part* is often necessary in order to keep the discussion going and to give all researchers a voice. Language, research tradition, personal preferences, or character form barriers that cannot be overestimated. The *managing part* can understand its own role hierarchichally, but rather than transferring well defined research problems to subprojects or collecting results from a higher position like in phased exchange, the managing part should facilitate discussions and encourage mutual development of ideas and common research problems among the researchers from various fields. These researchers may ideally form independent ad-hoc groups if an opportunity for exchange arises.

This stage of continuous integration will encourage identification of each researcher with the project as a whole, the ongoing process will lead to a certain degree of mutual understanding, and an ideal outcome can be described as follows: (1) Research problems and processes that could not be envisioned at the start of the project will turn up in the course of a project and thus significantly promote knowledge and understanding. (2) Like in the saying “the whole is more than the sum of its parts”, final results reflect a knowledge that exceeds the capabilities of separate “sub projects” and of a single project leader; they lead to a new and comprehensive understanding.

There is another side of the coin, and this is the danger of working with immature, intermediate research results. Before a whole project abandones certain questions or focusses on a new perspective, it is important to assure that the intermediate results are valid to state a new hypothesis. A gradual adaptation, starting with some temptative collaboration among a small group of researchers is a good starter for such adaptations; and the continuous exchange about the chosen paths with the managing part is imperative.

4.2.4. Incorporation

Incorporation is the most integrated form of interdisciplinary research. In this case, one person covers several disciplines and acts as an archaeologist and as a scientist of one or more disciplines at the same time. Archaeologists may perform chemical analyses with pXRF on site, they may specialize on the use of a microscope for mineralogical analyses, others may specialize on wood as the object of their research. These kinds of incoorporation of several roles in one person can be fruitful and dangerous at the same time.

Archaeologists have incorporated new technologies since the early stages of the discipline; the documentation of findings with photography may be one example. In the beginning, and in some cases even until today, photographical documentation was the job of specialists, but in the course of the decades, the technology became easier to use and archaeologists, though not specialized on photography, are now in the position to incorporate this technology into their own workflow. A similar trend can be seen with 3D documentation. Ultimately, incorporation of the technique by the archaeologist can be helpful in these cases, since the archaeologist sees what has to be documented, and rather than discussing this with a specialist, it may be easier to execute the task oneself. On the other hand, the fruitful discussion between experts with different backgrounds gets lost in this case.

While these are examples of possibly successful incorporation, others which are closely related to kiln research may illustrate negative side effects. In recent years, chemical analysis of pottery with portable XRF performed by the archaeologist is increasingly popular, but a chemical analysis is more than just looking at numbers produced by a random machine. An understanding of the weaknesses and limits of the technology and the applicability of the outcome to a certain research problem have to be understood as well as the meaning of certain elements in the mineralogy and the ceramic system.

After all, the incorporation of foreign methods, technology, and research topics like chemistry by the archaeologist is an extension of archaeological tools, but it is imperative that the archaeologist has sufficient knowledge about (1) the nature of the measured object and (2) the limitation of the method used in comparison to alternative methods.

Finally, recent decades show a trend of archaeologists being trained as experts in certain fields or technologies like pollen analysis, analysis of wooden artefacts, scientific pottery analysis to name just a few. Certainly, the expertise of two disciplines unified in one person, the accumulation of knowledge about archaeological research on wood only e.g. has great potential. As long as the researcher is not just “trained to use a machine” but has an equal expertise in archaeology as well as the other field and is able to follow the research development in the related disciplines, this approach is most promising and as such also valuable in a project oriented at “continuous integration”.

4.3. Agile research

When it comes to continuous cooperation like in the third stage of interdisciplinary integration, an agile research process is most appropriate. The following sections will discuss what this means, why it is appropriate, discuss its strengths and pitfalls, and not at least, share some ideas on the process and tools in an international academic environment, where people from different cultures, with different languages and from different time zones cooperate on a common goal with different methods.

Since 2013, a group of nearly twenty researchers from various disciplines and countries work in a cooperation in Japan’s southernmost Sue kiln site center, Nakadake Sanroku in Kagoshima prefecture (see chapter 17). The planning phase started on a smaller scale in 2012, and while it was the intention from the outset to design the whole research process as an integrated process according to Stage 3 as described above, the growing number of researchers and disciplines involved posed some serious challenges to the organization. Such organization was the task of the author who is also involved in digital applications and developments, therefore choosing the agile concept was an option that suggested itself. This chapter will introduce incentives for choosing an agile approach, the research design and tools as well as the conclusions the author draws from experiences in several interdisciplinary projects. After all, the strength of this approach – the speed and dimension with which knowledge increases and new perspectives arise – is significant. But there are pitfalls to be aware of, which might be balanced with a well thought-out set of rules and tools.

4.3.1. The concept

The idea of “agile” was first introduced by software developers in 2001 in the “Manifesto for Agile Software Development” (“Manifesto...” 2001) with a set of values and twelve related principles. Although it can be assumed that the ideas have been practiced naturally earlier in a less formalized way and in a variety of businesses, the manifesto made the idea explicit and paved the way for a more fundamental and standardized implementation. The idea spread from software development to other business fields, and a whole industry of consultants dealing with “agile” and related approaches like “kanban”

Table 4.1. Values and principles in the Agile Manifesto

Values in the Agile Manifesto	Contrasted traditional values	Keywords to corresponding principles
Individuals, interactions	Processes, tools	Continuity, collaboration, motivation, simplicity, self-organisation (1, 4, 5, 10, 11)
Working software	Comprehensive documentation	Results, sustainability (7, 8)
Customer collaboration	Contract negotiation	Collaboration, motivation, face-to-face conversation (4, 5, 6)
Responding to change	Following a plan	Flexibility according to changing circumstances, frequent delivery, sustainability, adjustments at regular intervals (2, 3, 8, 12)

and "scrum" has developed since, creating a sometimes rigid formalization. Not at least because of this over-formalization, "agile" has become heavily criticized and is even considered "dead" at times. Some of the first and best known statements in that regard were made by Dave Thomas in 2015 (Thomas 2015).

Such a reaction of insiders in the software industry should be of no concern in the context of interdisciplinary research. First of all, as mentioned earlier, "agile" is the explicit formalization of natural ways of interaction in collaboration that had previously existed, and thus can be expected to be a durable concept in the future as well. Secondly, as long as the formalization process is not overdone for the sake of itself, it is worth considering and drawing conclusions about the process of interaction in interdisciplinary academic collaboration. A look back to 2001 when everything started with enthusiasm may help to get some ideas. The values and principles of the original manifesto are summarized in table 1.

Obviously, the focus in the Agile Manifesto is on software development and customer relationships. In kiln research, these may be replaced with *research* on the one side and *internal interdisciplinary collaboration and public communication* on the other – which may become more obvious below.

Not all of the principles mentioned in the manifesto are of interest for research teams, but mainly *continous exchange among individuals* as well as *highly motivated individuals* that *continuously communicate about their results* and *demand results from others* seem to be responsible for unexpected progress in unforeseen directions. Also, the more motivated an individual is the more he or she is willing to self-organize smaller groups and exchange ideas directly with other researchers.

Starting with the last pair of contrasting values in table 1 – either *responding to change* or *following a plan* – the parallels to interdisciplinary research are obvious. Projects are mostly planned out in the outset, funding is closely linked to certain institutions and selected research partners from beginning to the end of the project, and they are supposed to work on a fixed range of research problems and material that is estimated at the beginning of the project. The project will follow this plan if it is designed with an interdisciplinary integration of level 1 (parallel research) or level 2 (staged exchange) in mind. In certain cases, a researcher or a single research group may change the course of a certain analysis or method applied just in their realm of methods – mostly in case of unexpected problems and in order to keep up with the original plan and adapt the procedure to achieve the original goals. Obviously, continuous *interaction between individuals* is the easiest way of information exchange and for adaptation of goals and research design. However, conversation in larger groups needs rules and some form of formalization as well as standardized tools; these will be discussed below.

The second value pair of *working software* in contrast to *comprehensive documentation* cannot easily be converted to the world of research. Although "working software" may stand for "meaningful research" or "acceleration and broadening/deepening of research", thorough documentation is certainly demanded and thus in no contrast in the case of research.

The third constrasting pair of values – *customer collaboration* versus *contract negotiation* is less obvious in their relation to research design. Although contract negotiation has its counter part in project applications, it is difficult to decide whether the customers are the foundations or institutions that donate to research, or whether the academic and non-academic public that finally receives the research results should be considered the customers. The important point is to ensure that applications do not lead to fixed workflows that cannot be adapted to new insights; and where possible, sporadic exchange about the course of the project with the donating institutions may help in changing directions and re-direct funds.

The 12 principles published on the website of the agile manifesto give some more detailed ideas of how the values may be implemented and summarized.

- Indiduals are motivated and able to continuously collaborate and spontaneously self-organise and to adapting a complex research problem to changing circumstances and new insights.
- Frequent delivery and exchange of intermediate results for discussion, and in order to receive ideas from those with a different expertise, face-to-face communication and adjustment of plans in regular intervals is key to achieving the utmost goal: insights. This relates to insights that were envisaged in the planning stage of the project, but also those that come to the surface unexpectedly.

4.3.2. Advantages

Advantages of agile research management are similar to those in software development: New insights in one area or by a group of related researchers are immediately accessible to the project, which can in turn react upon the insights accordingly. Developments adapt to research results in a signicantly shorter period of time, particularly, adaptations occur in the course of the project rather than after the submission of all isolated results after the project is closed.

4.3.3. Constraints and problems

The agile idea of teamwork was based on the reality in office work in 2001: Sharing the same office and having face-to-face communications on a day to day basis. But not only in software development this is not the reality any more in 2021, and it was never true in interdisciplinary research. It is well known that the earliest developments in asynchronous communication over the internet were implemented by researchers at the CERN, and the overlap between research and software development has continued ever since. Teams can form with members on a global scale, both in the software industry and business as well as in research. Technical problems can be overcome.

However, there is a decisive difference that separates teamwork in research from teamwork in business: The human factor has a larger impact because researchers with special expertise are rare, only few individuals or institutions can replace each other, while software engineers with similar backgrounds are distributed in almost all regions of the world. Therefore in research, it may be necessary to bend the principles of agile to time zones and the personalities involved – rather than expecting personalities with experience and well established routines to adapt to the principles of agile. Worldwide distribution of researchers, traditional biases towards other disciplines, different background as regards culture, society, language, and personality of a researcher may hamper continuous exchange on equal grounds.

Another pitfall of agile research design may be immature reasoning and decision making in cases where new findings are adopted without sufficient critical examination.

The worldwide distribution of researchers is a problem that can be solved with a mixture of focussed meetings and the use of the internet, as will be explained below. However, biases between disciplines or methods do exist, and it is sometimes impossible to encourage the conversation between members of opposing camps. Of course, choosing the appropriate research partners from the start is one solution to the problem, but not always possible.

Furthermore, an interdisciplinary project brings together people of different native language, cultural and social behaviour, academic traditions and the different thinking and behaviour common in their respective disciplines. All these factors are even obstacles to the implementation of a smooth conversation whenever people with these backgrounds meet somewhere face to face. However, they become more serious whenever a conversation has to be kept alive over the long period of a project and over several continents and time zones without personal meetings.

English is the *lingua franca* in nowadays academia, but still not felt as a natural means of conversation or discussion in certain academic communities. Language can keep people away from the discussion, and it is particularly difficult for persons of a more introvert character to actively take part.

Finally, in a larger project some research progresses quickly for whatever reason while other research needs longer to produce results that will be useful for the whole group. It needs mutual understanding and trust to keep all members actively contributing to the community and waiting for those who need more time.

4.4. Implementation of continuous integration and agility

Continuous integration can be the most fruitful approach to interdisciplinary research, and an agile research design with clear communication of rules, duties, and rights is the appropriate way to reach or get beyond original research goals and to create a project that is driven by common excitement about the subject and its development. Such success does not come naturally, and the following paragraphs discuss experience with some tools for communication and organization. Unfortunately, there is not yet a comprehensive solution that fits to all potential scenarios.

The recent years are characterized by an overwhelming dynamic in the development of communication tools in and outside research, but also – in the realm of scientific research – by the development of new value systems as regards open and fair data in the European Union (2016) and elsewhere (e.g. “Forschungdaten.info” 2021), as well as the increasing demand for transparency of the whole research process – even in the documentation of archaeological excavations (e.g. Boyd et al. 2021). Additionally, formal contracts between researchers or research groups are increasingly enforced by universities in interdisciplinary research.

Both phenomena will be important factors for the successful implementation of agile research processes in the future for two reasons. Firstly, with open and fair data becoming the norm in thinking about research data, the wide spread understanding that data are the property of the researcher who produced them, is becoming a minority‘s view which can be excluded from agile research processes in the outset while the majority will accept sharing data and insights during the research process as a natural concept. Secondly, with explicit contracts being the norm, writing down clear rules and potential sanctions is becoming just another natural step at the beginning of a research project rather than a sign of "lack of trust" as it might have been interpreted earlier. On the other hand, this change in research culture and common sense still seems limited to some regions or disciplines, and is has to be seen how and with which pace archaeological research in East Asia will evolve.

With these developments in mind, the following ideas about cooperation, based on technology available at the time of this writing, may give some ideas of how to – or how not to – organize kiln research or other interdisciplinary projects with agility in mind.

4.4.1. An organizing hub

In a small project, the project leader will have an overview over all research questions, methods, and researchers involved. But in projects with a wide range of research questions and methods, assistants serving as a fascilitator may become necessary. They need a certain understanding of the whole project and of the methods or disciplines involved, and should be able to draw new links between research questions and results, methods and researchers – in order to create cooperations that overcome the limitations of isolated work on a certain problem. Furthermore, a certain command of the language of the counterparts is helpful, as well as personal acquaintance of the researchers – which is not always possible.

The workload of a fasciliator cannot be overestimated, and there is an aspect of self sacrifice. On the one hand it is inspiring to think across the borders, implement new ideas and encourage the specialists to give new ideas and cooperations a try. On the other hand, fact is, the results are presented by others, and the scholarly value of the contribution of a facilitator or organizer may be disputed. While this is finally a question of mutual respect as regards the contribution of the rôle of each participant, it is always a good idea to discuss expectations and commitments clearly at the beginning of the project.

4.4.2. Formal implementation of conversations

The best conversation happens naturally and in personal. At least annual meetings seem to be necessary to keep up the dynamics among the group members, but they are not easy to implement due to financial or time constraints. Meetings at the start of a project and before summarizing the results at the end seem to be a good compromise that should be part of the project finance plan; in longer projects intermediate meetings are desirable. But how to keep the conversation going between these highlights?

Video conferences have become a replacement of personal meetings in many cases in the course of the pandemic that started in 2020. It already has become obvious beyond doubt that video conferences will help greatly in further implementations of agile research design. In the Nakadake Sanroku project, they are now covering a large amount of the interdisciplinary discussions between the continents. Not at least the option to chat in the course of the verbal discussion helps with language problems. Together with a rigid track of the contents of discussions in written protocols, video conferences have largely improved the agile workflow.

Email being spontaneous, direct, and asynchronous, is convenient and the most popular means of communication – at least, we all know it very well and use it daily. Unfortunately, it is a mess when it comes to get organized, since with emails it is almost impossible to track who was part of which conversation and what the final decision was in a certain case. Except for short term consultations on a particular, preferably non scientific topic between two persons where email is still the most convenient tool, email should be replaced by other tools for serious discussions.

A modern **conversation plattform** like SLACK demands constant access to the software, in many cases immediate reaction in order not to fall behind in a group, and due to the noise that comes with it, is not as transparent as needed. The author has been part of several attempts from several sides on various occasions to introduce such a platform to an academic conversation, but it never lasted. Not at least, most conversation plattform software is proprietary with all its demerits and should be avoided for this reason alone. In the future, better organized OpenSource tools may replace these solutions which then may also replace the next suggestion: a forum.

Forum software is not only OpenSource, easy to implement and transparent to all members. It offers (1) sub forums on sub topics or temporal topics for a more closed conversation between members of varying access rights, it serves as a (2) self-documenting system without need for protocols, and not at least, it offers (3) asynchronous participation with all its merits like in email. The author is an avid supporter of the forum solution, but unfortunately, at least in the Nakadake Sanroku project, this approach was equally unpopular as the modern conversation platforms mentioned above. Reasons may be as follows: (a) The necessity to open a browser and log in as well as doing this regularly in order to actively participate in the conversations seems to be too much of a barrier for most of the researchers. A forum thread needs serious thinking and writing because it is semi-public and stays open to the forum members, while an email can be written more leisurely.

A **wiki** is a solution similar to a forum, it has the advantages of being OpenSource and offering various access rights for users as well, but the focus of a wiki *per se* is less on the ongoing conversation but rather on presenting results of a conversation. So despite being a solution to create a final report, it is not suited for ongoing conversations.

A **distributed version control system** like git with options like **GitLab** or **GitHub** and **Bitbucket** should not be ruled out as a tool of communication in such a research project. They offer a range of tools for conversation and problem solving; and of course, since git was introduced to create software, it combines well with agile project management. But a distributed version control system with its fixed rules and technical aspects may be too much for most members of a project from the humanities department. In the experience of the author during the last years, distributed version control can only be implemented in an interdisciplinary workflow with smaller groups of researchers with experience in programming at this point in time but serves the purpose well where it is chosen.

After all, in order to include the technically less inclined, the author suggests the combination of a forum and video conferences for the project or sub projects in combination with sporadic email exchange between two or three persons on matters of no public or scientific interest as a means to compensate the lack of personal meetings on a frequent basis. An explicit agreement on the conversation style between all participants at the beginning of the project may help getting over the first time where this approach is not yet familiar.

4.4.3. Integration of members and formal agreements

As mentioned above, integration of all researchers into the discussion can be a problem due to a variety of reasons. It is the job of the project leader or fascilitator to keep the discussion going and guarantee fair usage of research data. An agreement on the form of conversations and on the frequency of the conversations may be an additional means, but it is difficult to enforce a discussion with rules. However, rules may be a means to raise awareness regarding conversation in the beginning.

4.5. Conclusion

Archaeological kiln site research requires the integration of methods and knowledge from a variety of discplines based in the humanities, in engineering, and in natural sciences; not at least it requires knowledge and experience from practicioners.

The most fruitful research is done when all members of a project are in constant exchange regarding ideas, newly arising problems, and upcoming results on equal terms, thus offering precious insights to other members and influencing the course of the whole project before final reports are written. Such vivid exchange is a chance, but it inevitably consumes more time and effort than isolated research on a fixed problem. Furthermore, it bears the problem of unbalanced contribution of the participating researchers due to a variety of factors.

Each of these potential problems has to be considered when setting up clear rules and agreements at the start of the project and whenever another researcher joins in the course of a project. A central figure needs to monitor the behaviour of the participants; this central figure will in most cases be the project leader or a researcher in charge of organizing the interdisciplinary part, never being above but always being a partner of the researchers. An important responsibility of such a central figure is to keep the conversation between the research groups going, to be aware of chances, new topics arising and to stimulate new cooperations in the project. A certain command of the languages of the researchers involved, some knowledge of the various methods and materials is essential for this role, while active participation of each researcher with as little interference as possible by organizers is most desirable.

After all, broader and deeper insights, even unpredictable insights can be expected from a project that is driven by enthusiasm and cooperation of all participants and which benefits from an agile approach.

Acknowledgements

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5

Provenance Studies and Beyond

Johannes H. Sterba

Abstract: Provenancing of ceramics, i.e. the establishment of a ceramics physical origin, greatly enhances our understanding of ancient civilizations, their cultural development, exchange and movement patterns. Basing provenance studies on objectively measureable and reproducible data like the chemical composition of the material offers important insights in this respect. Various multivariate statistical methods are in use to analyse the large datasets produced by analytical methods like Neutron Activation Analysis (NAA). Of those statistical methods, a well established method using a modified Mahalanobis Distance that takes measurement errors as well as dilution effects (best relative fit factors) into account has repeatedly proven its usefulness specifically for the provenancing of ancient ceramics. Three examples from recent studies, two from East Asia and one from Northeast Africa show what the combination of NAA and this statistical approach can provide beyond simple establishment of a ceramic sample's origin.

Keywords: Neutron Activation Analysis; Best relative fit; Provenancing; Ancient ceramics; Statistical analysis

5.1. Introduction

Provenancing of ceramics is important for understanding ancient civilizations, their cultural development and their exchange and movement patterns. Provenancing by archeological means alone presents difficulties because typologies, changes in form or pattern, and even production techniques can be exchanged between sites. Basic raw materials like clay, however, are very rarely exchanged over significant distances. Objectively measurable and reproducible data, like the chemical composition of the material, provide additional information on the raw materials used in production which can lead to a much clearer understanding of provenance and cultural exchange (e.g. Jones 1986).

Provenancing, i.e. the assignment of a sherd to its production site based on chemical composition, relies on three basic premises:

1. The object under investigation is chemically homogeneous.
2. All objects within one group or provenance preserve and share their chemical composition.
3. Objects from a different origin have a clearly distinguishable chemical composition.

Reliance on those three premises is a challenge and provides an opportunity to go beyond the mere localization of ceramics. An important part of the first premise, the homogeneity within one sample, is that the sample size under investigation needs to be large enough to be representative of the sample as a whole and represent the bulk chemistry while ignoring surface contaminations. The second premise refers to the fact that different production techniques, or recipes that require e.g. mixtures or cleaning of raw materials, can potentially lead to different chemical compositions, allowing for more than one group or chemical fingerprint within a single production site.

Differentiation of changes to the chemical fingerprint due to changes in production techniques are usually small but systematic (e.g. Garcea et al. 2020; D'Ercole et al. 2017). Thus, recognizing such changes and correctly assigning analyzed ceramics not only to a production site, but to a specific production technique or period within the production site, requires statistical analysis of the compositional data specifically suited to detecting those minute changes. A ceramic-specific multivariate statistical filter that is able to reduce the variation introduced into the dataset by inconsistencies in the paste production was developed in Bonn in the 1980s (Mommsen, Kreuser, and Weber 1988; Beier and Mommsen 1994). Provenancing based on chemical composition as described above puts several restrictions on an appropriate analytical method to measure the chemical composition. The method needs to be able to measure a multitude of elements, especially many of the minor and trace elements, to be able to "see" such minute changes in the composition as would be expected from e.g. differing mixtures or the introduction of a coloring agent.

Furthermore, the precision and reproducibility of the measurement itself needs to be high. This is due to the fact that the comparison of measurement values needs to take measurement errors into account. It is obvious that two values of 4 ± 1 and 5 ± 1 are indistinguishable, whereas 4 ± 0.1 and 5 ± 0.1 are very clearly different.

Finally, the analytical method needs to be able to report bulk chemical composition, i.e. penetrate beyond the surface of the object and be relatively insensitive to minimal inhomogeneities.

All of the requirements on the analytical method mentioned above are easily fulfilled by Neutron Activation Analysis (NAA) (Greenberg, Bode, and De Nadai Fernandes 2011).

5.2. Materials and methods

5.2.1. Neutron activation analysis

Neutron Activation Analysis (NAA) is a radiochemical method for elemental analysis. To perform NAA, the sample under investigation is irradiated with neutrons, thereby producing radioisotopes from stable isotopes contained in the sample (activation). After activation, the radioactivity of the sample is measured by gamma spectroscopy. Interpretation of this gamma spectrum leads to the identification of the radioisotopes produced in the sample by activation as well as to the determination of their abundance (activity). Since the radioisotopes can, in most cases, only be produced from a specific stable isotope, their existence is indicative of the stable isotope being contained in the sample. The abundance or activity of the radioisotope is directly related to the abundance of the stable isotope before activation. By irradiation and measurement of reference samples of known composition, comparison of the activities measured leads directly to the elemental concentrations in the sample.

Due to the nature of neutrons and their interaction with atomic nuclei, no information on the oxidation state of the elements measured can be obtained. However, since the penetration depth of neutrons in regular matter is on the order of several centimeters, the elemental concentration values obtained represent the bulk chemistry of the sample. Main elements like Hydrogen (H), Oxygen (O), Nitrogen (N), Carbon (C) and Silicon (Si) are hardly activated or don't produce an easily measurable radioisotope, thus those elements could be described as being "invisible" to the method. In the case of the analysis of biological and geological material, this is an asset since the matrix (i.e. SiO_2 in the case of geological material) does not interfere with the measurement. Other elements, specifically many of the rare-earth elements that are usually only contained in minute traces, activate quite easily, resulting in very low detection limits for those elements on the order of ng/g. This is another asset for the application of NAA to provenancing, since the trace elements contained in a sample are especially highly characteristic of its composition.

As described above, NAA directly relates elemental concentrations in a sample to a measurement of radioactivity. Since even low amounts of radioactivity can easily be measured, the total sample mass needed for this type of analysis is usually on the order of 50–150 mg. However, during sampling, great care has to be taken that the sample is representative of the full object under investigation, which can make it necessary to take larger sample amounts of up to 500 mg.

In summary, to perform NAA on a ceramic object, a small sample of 50–500 mg needs to be taken off the object. This sample is then irradiated in the neutron flux of a reactor and subsequently measured on a gamma spectrometer. Usually, at least two subsequent measurements are done to be able to gain precise data on short- and long-lived radioisotopes. This results in a total time requirement of three to five weeks from irradiation to results. For this reason, NAA is usually performed in batches of 30–100 samples. The elemental concentrations measurable are Na, Mg, Al, Cl, K, Ca, Sc, Ti, Cr, Mn, Fe, Co, Ni, Zn, As, Rb, Sr, Zr, Sb, Cs, Ba, La, Ce, Nd, Sm, Eu, Tb, Dy, Yb, Lu, Hf, Ta, W, Th and U. Not all of those elements are of equal importance for provenancing, so usually a smaller selection of about 25–28 elements is chosen for analysis. For detailed descriptions and more information see e.g. (Minc and Sterba 2017; Sterba 2018).

5.2.2. Statistical analysis

Once the chemical composition of a sample, often called its chemical fingerprint, has been established, it is necessary to compare the sample's fingerprint to other chemical fingerprints, either of other unknown samples or of already established groups. To compare two chemical fingerprints, all elemental concentration values are compared to each other, ideally taking the associated measurement error into consideration. If all elemental concentrations of two samples are sufficiently similar, the two samples are considered to be made from the same material, and thus from the same origin or provenance.

Since the number of measured samples as well as the number of potential candidates for comparison is usually very large, a comparison by hand is, if not impossible, at least extremely inefficient. Thus, different multivariate statistical methods are usually applied to process a large number of samples more quickly.

Bivariate plots

A very simple exploratory method is to use bivariate plots of datasets. In this method, two to four (if using ratios) elements are selected from the dataset and each sample is plotted onto an area spanned by those elements (see Fig. 5.1). Careful selection of the elements (or ratios) used can lead to visible grouping of the points representing samples.

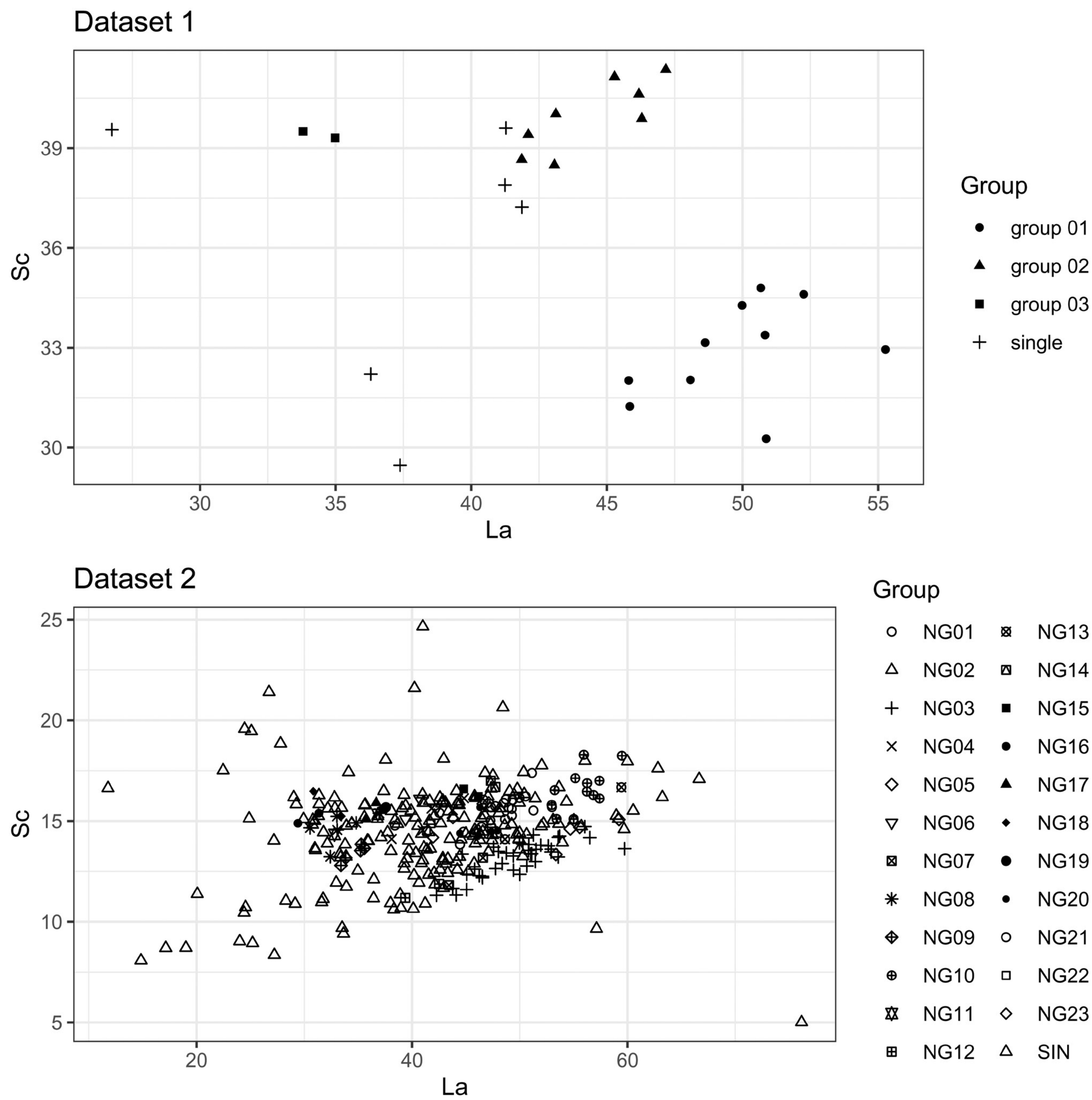

Figure 5.1. Comparison of bivariate plots of two datasets of ceramics, previously grouped by NAA and subsequently by statistical analysis. Lacking this analysis, no grouping information would be available. While, in the top figure, a visible separation into three groups occurs, the same set of elements leads to no visible groups in the second plot.

While this strategy is sometimes useful for specific datasets and sets of elements, it lacks several important features:

1. It uses only a small subset of the information available (i.e. at most four elements out of a total of more than 20).
2. It ignores measurement errors, potentially showing stronger separations than the data allows.
3. It is usually possible to find some combination of elements to plot that show some grouping, sometimes finding several groupings that cannot be correlated with each other.
4. It is an exploratory method only; decisions on the exclusion or inclusion of samples at the border of visible groups can hardly be founded on statistical measures.

Principal component analysis

A method related to bivariate plots is Principal Component Analysis (PCA), a statistical method that finds the linear components in a dataset that express the most variation, resulting in a reduction of variables necessary to describe the dataset. After PCA calculation is done, the first few principal components are then used to produce similar plots

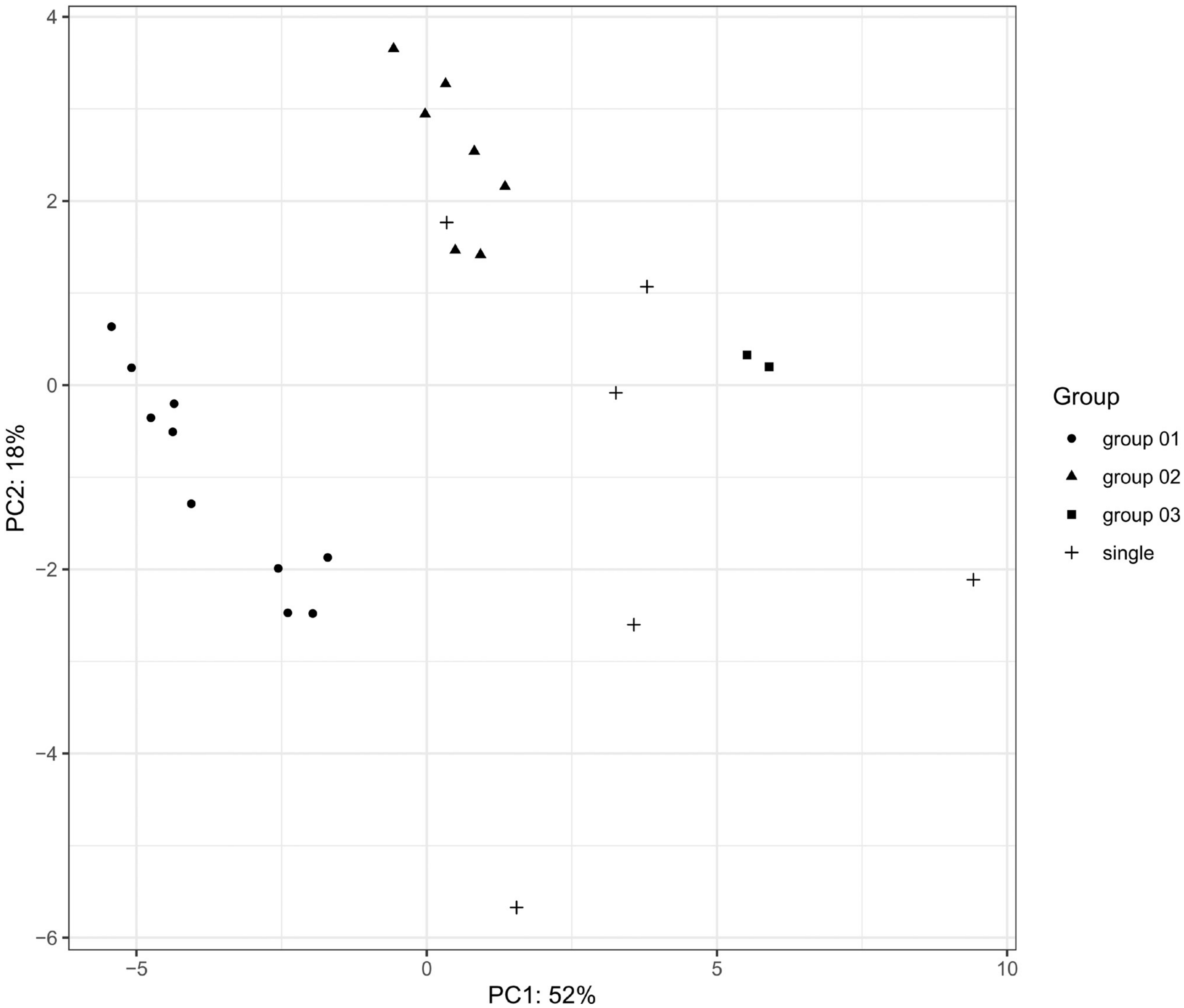

Figure 5.2. Principal Component Analysis (PCA) of the same dataset as in Fig. 5.1 (top part). The grouping is visible, however, especially along the borders of the groups, it is not clear if samples belong to a group or not.

to bivariate plots, again sometimes showing groupings. Fig. 5.2 shows a PCA of the dataset also used in Fig. 5.1 (top plot). The grouping that was apparent in the bivariate plot is still clearly visible. However, it is not obvious how the singles should be handled (specifically the one single "inside" of group 02), and there seems to be a separation between the samples belonging to group 01. Without the different shapes of the data points in the figure, it would not be clear how to group them.

Depending on the dataset and the number of outliers or singles therein, a PCA can lead to usable groupings. However, similarly to bivariate plots, no information about measurement errors is used. Furthermore, PCA is again an exploratory method; handling of samples along the borders of visible groups is not straightforward.

Cluster analysis

Cluster analysis is a statistical method that uses distance measures (e.g. the euclidian distance) to calculate closeness or similarity between samples. In an iterative algorithm, the samples are then grouped by their respective distances. This leads to a visualization that is called a dendrogram, where the dataset is represented in a tree-like structure. The samples forming the leaves and their closeness along the stem represent their distance (Fig. 5.3).

To use a dendrogram for grouping, a cut-off distance is defined and all samples linked below that distance are grouped together. In the example of Fig. 5.3, a cut-off distance of 15,000 leads to two large groups and one single sample, whereas a cut-off distance of 5000 results in five groups and several singles. Thus, the grouping produced by cluster analysis relies on the distance measure, the linking method used to connect samples, and the cut-off distance applied. While there are some general best practices on how to select those three components, no definitive rules exist. This makes it possible to reach different groupings by trial and error. Furthermore, as in both methods mentioned above, no information on the measurement error is included in cluster analysis.

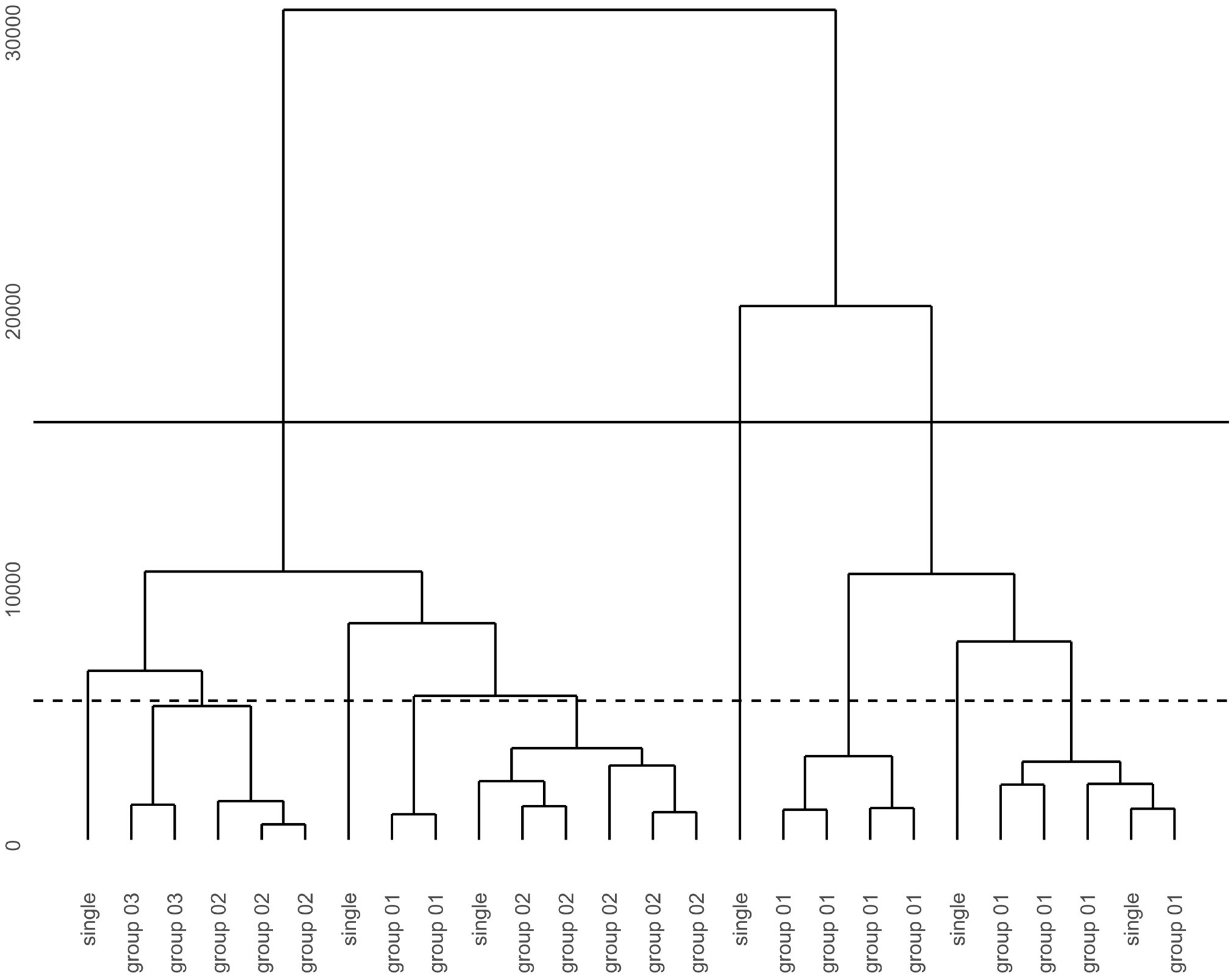

Figure 5.3. Cluster analysis and subsequent dendrogram of the dataset used in Fig. 5.2 and Fig. 5.1. Distances are calculated as euclidian distances, and clustering is done by the complete linkage method. Instead of sample names, group names are used to make comparison of the grouping methods more visible. The grouping done by NAA and statistical analysis (group01, group02 and group03) agrees with the archeological grouping of this dataset; the grouping that would follow from the dendrogram cannot be related to archeological groups.

A ceramic-specific approach

From the examples above it is clear that it would be preferable to have a statistically valid method for grouping ceramics with respect to their chemical composition, potentially allowing statistical testing or prediction. This method needs to 1) include measurement errors in the analysis, and 2) find a way to overcome additional spread introduced into the dataset because of dilution effects during paste production (Mommsen and Sjöberg 2007).

Dilution in this case means that some component is added to (or removed from) the raw clay that does not contribute to the elemental composition. For example, the addition of quartz sand during tempering would increase the total mass of the sample; however, since both silicon and oxygen (Si and O) are usually not measured, the relative concentration values of all other elements wouldn't change. Similarly, the use of an organic compound would only result in a dilution. Such a dilution results in additional spread that is introduced into the dataset, for the simple reason that between batches of paste produced by the potters, slight differences are highly likely. Fortunately, such a dilution can be easily corrected for by introducing a "dilution factor," i.e. a single number by which all elemental concentration values of one sample are multiplied, to reduce the apparent difference to another sample.

To illustrate this process, Fig. 5.4 shows the comparison of a dataset before (left) and after (right) dilution correction. It is the same dataset used in Fig. 5.1. As can be seen, just by correcting for the dilution factor, the group members come much closer to each other. Samples classified as "single" don't change their position, because dilution correction can only be applied against another sample or group mean. In Fig. 5.4, dilution correction is done for all samples belonging to one group against their common mean.

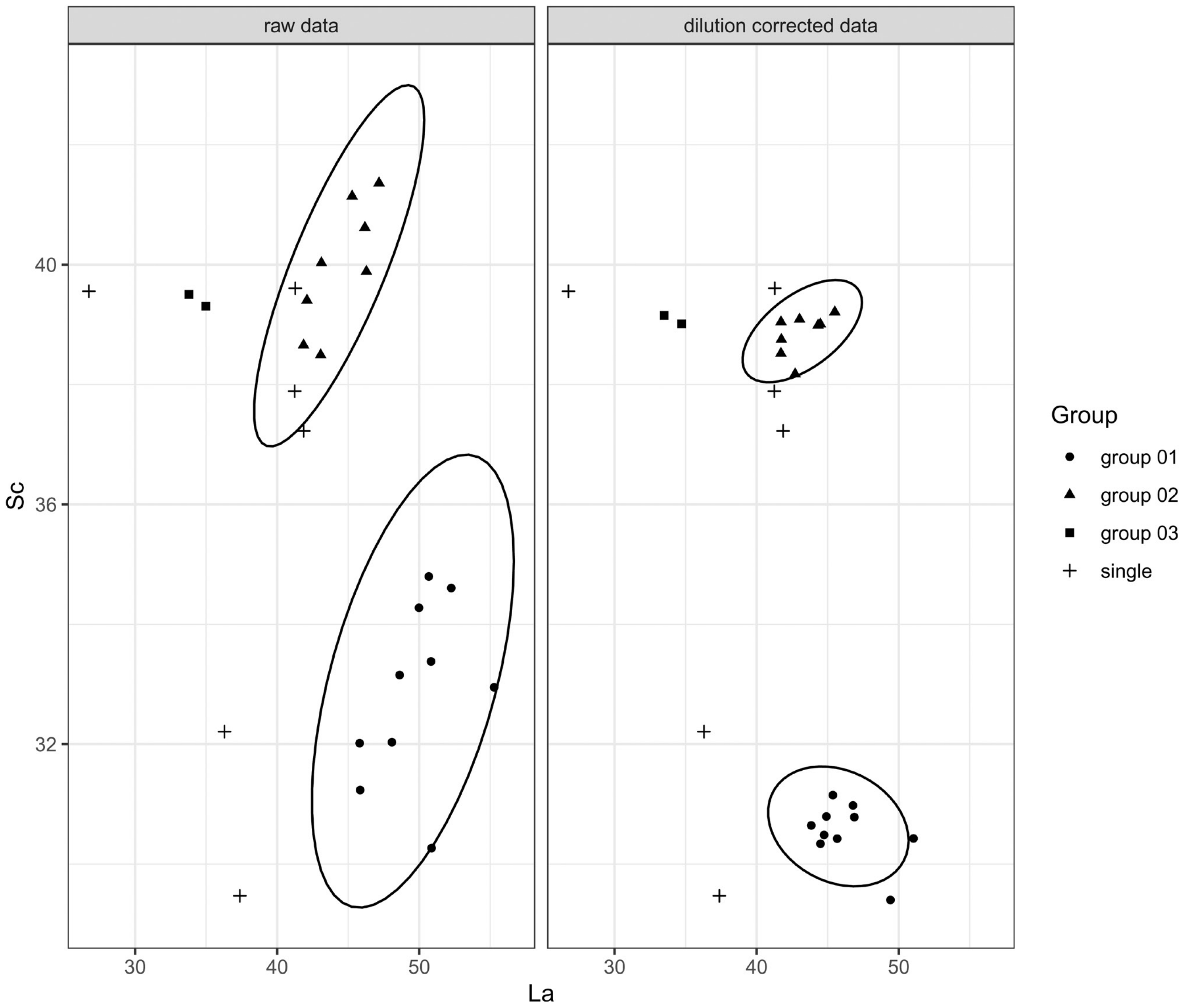

Figure 5.4. Comparison of a dilution corrected dataset before and after correction.

Interestingly, such a correction of the raw data can easily be done mathematically and, from a statistical point of view, leads only to the reduction of the number of degrees of freedom by one. This means that the corrected data can still be analyzed by all multivariate statistical methods, as long as the number of degrees of freedom is reduced by one.

However, it would be preferable if the similarity between two samples could be described numerically. Ideally, this numerical value would take into consideration the dilution factor mentioned above as well as the measurement errors. Such a measure was developed in the 1980s in Bonn (Mommsen, Kreuser, and Weber 1988; Beier and Mommsen 1994; Sterba et al. 2009). It used a modified version of the so-called Mahalanobis distance, which in its original form could be described as calculating the distance between two vectors in units of their standard deviation. By replacing the standard deviations with the measurement errors and minimizing the distance with respect to the dilution factor, this modified Mahalanobis distance provides a statistically valid means of defining the similarity of two chemical fingerprints.

With the calculation of the modified Mahalanobis distance between each possible pair of samples in a given dataset, it is possible to reach a first grouping of a subset of samples with small distances. From this, a group mean can be calculated as well as the modified Mahalanobis distance from all samples in the dataset to this group mean. From this calculation, more samples can be added to the group, if they are sufficiently close to the mean, leading to a modified group and a modified group mean. By iteratively repeating this process until no more samples come close to the group mean, groups can be formed.

Fig. 5.5 shows the modified Mahalanobis distances between the group means and all samples in the dataset already used repeatedly. It is clear to see that between the last sample belonging to a group and the first sample not belonging, a gap exists. This is usually a good indication of a complete group.

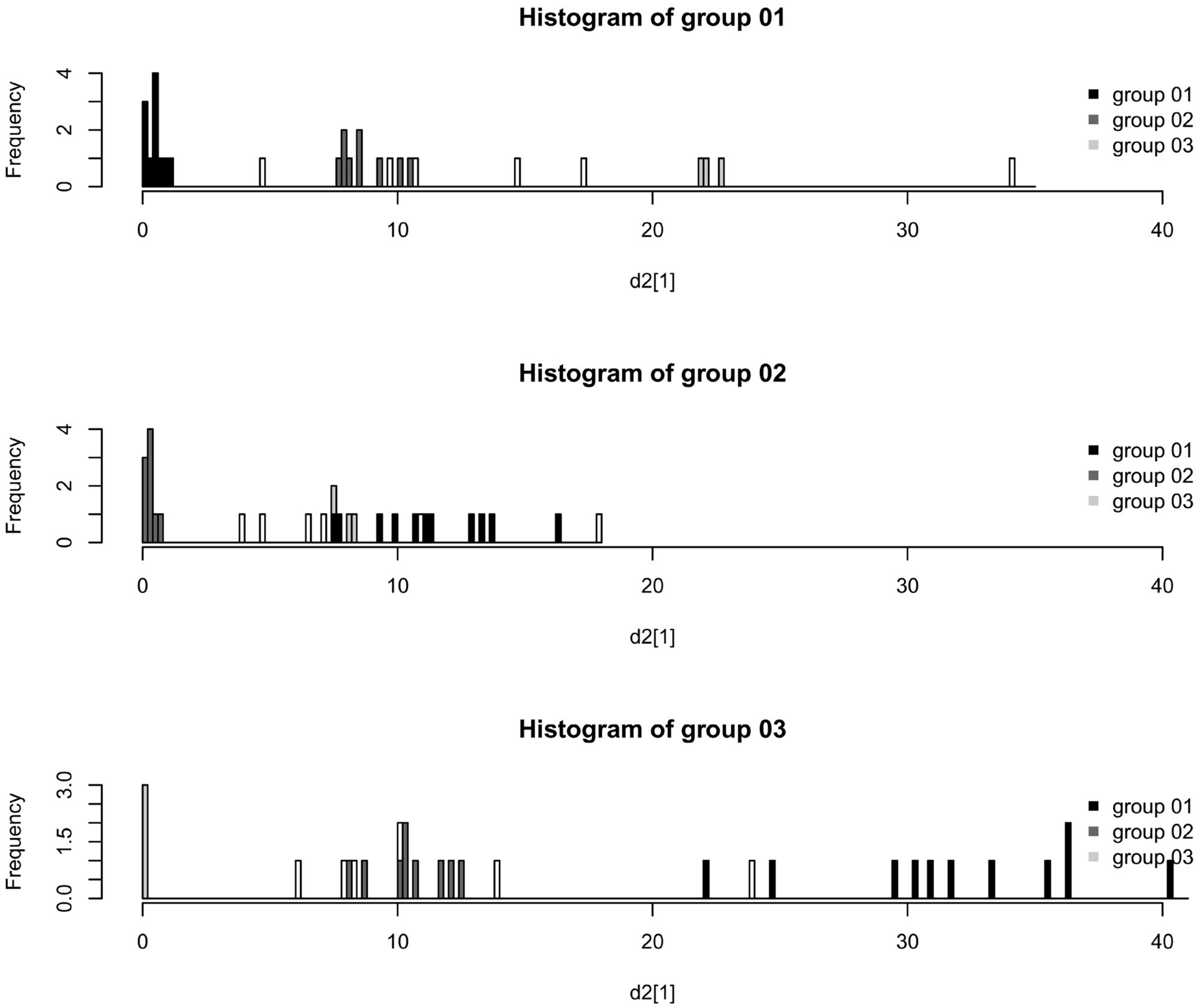

Figure 5.5. Histograms of the modified Mahalanobis distances between the group mean and all other samples for three groups in the dataset. It is important to note that only the distance from 0 is relevant; interpretation of the distances between samples marked in the histogram ignore the multidimensional nature of the Mahalanobis distance.

It is important to note two properties of this grouping process: Firstly, once a group is defined in the way described above, new samples can always be compared to this group and, if suitable, added, changing the group mean. Once a group reaches a large enough size (several tens of samples), the group mean stabilizes. Secondly, because of the properties of the Mahalanobis distance, the modified Mahalanobis distances are distributed according to the X^2-distribution (if the reduction in numbers of degrees of freedom is taken into account), making predictions or statistical tests possible.

5.2.3. Beyond provenancing

The process described above, i.e. the combination of NAA and a ceramic-specific statistical approach to grouping, offers a reproducible and statistically sound way of comparing and grouping ceramic material. Due to the dilution factor, a large component of the spread usually visible in such datasets is removed, allowing an unobstructed view of the similarities and dissimilarities of the samples. With this, it becomes possible to associate samples not only with a region of origin but with a specific recipe in use in a spatially and temporarily delimited region. This takes the usual approach of provenancing beyond its traditional borders by providing information on temporal shifts in recipes or transport routes, as well as on changes in the recipe connected to technological or cultural choices.

5.3. Case studies

The potential of the approach to provenancing described in the previous section is best demonstrated in case studies. Three significantly different outcomes from systematic research based on NAA are introduced, and while two of these case studies from East Asia are presented in this volume as well – the Nakadake Sanroku kiln site center and the Kamuiyaki kiln site center, the third, complementary case study is taken from Northeast Africa.

5.3.1. Kamuiyaki Kiln Site Cluster

The Japanese National Historical Site "Kamuiyaki kiln site center" is located in the south of Tokunoshima Island and is understood to have been the production center of a specific pottery type that resembles traditional Sue ware. Its discovery (Hirose 1933) has been dated to the Gusuku period of the Ryūkyū islands, mostly equivalent to the Japanese Middle Ages (National Museum of Japanese History 1997). Pottery from the Kamuiyaki kiln site center is widely distributed throughout the Ryūkyū islands. Within the site, two chronologically significant typological groups can be distinguished (Satō 1970, Shinzato 2018).

In a preliminary study (Sterba et al. 2020), 20 vessels from a specific context were selected for NAA and subsequent data analysis. Of the 20 samples, 10 vessels each were selected from the aforementioned typological groups A (older) and B (younger). All vessels but one were found within one ash heap associated with several kilns, the two groups found in two different layers with a distinct separation layer without any finds. Typological and stratigraphical assessments agree.

NAA was performed on the 20 samples at the TRIGA Center Atominstitut of TU Wien, applying standard procedures (Sterba 2018) and subsequent statistical data analysis. Application of dilution correction and grouping of the samples with respect to their chemical fingerprint resulted in two groups of ten and eight samples, respectively, as well as two singles. The two groups could clearly be separated according to their chemical differences, mainly in the metals and metalloids Sc, Cr, Fe, Co, As and Sb. Furthermore, the two groups clearly correlate to the two chronological/typological groups already established, even though no *a priori* information was used in the chemical grouping. Every vessel from the older group A was chemically grouped into one group, whereas all eight samples from the second chemical group belong to the younger typological group B. The two singles (samples that cannot be chemically assigned to a group) also belong to the older group.

The most obvious conclusion from this result is that the typological and chronological grouping can be confirmed by chemical analysis. Thus, future finds of pottery fragments that have no clear stratigraphy or that show no distinguishable typological features can still be assigned to one of the two groups by chemical analysis. With this, NAA and statistical analysis not only yield information on provenance but also chronological information within the production site.

More importantly, however, this result indicates that the two periods of production at this subcluster of the Kamuiyaki kiln site center applied different recipes to the production, either by selection of different raw materials or through different preparation of the paste. Further investigations of other subclusters could potentially yield either a better definition of the two chemical fingerprints or additional chemical fingerprints corresponding to more recipes.

5.3.2. Nakadake Sanroku – a complex kiln cluster

The kiln cluster at Nakadake Sanroku, close to Minamisatsuma City in Kagoshima Prefecture, southern Japan, was a production center for Sue ware during the ninth and tenth centuries AD. It contains more than 50 Sue kilns and covers an area of over 6 km² (Nakamura and Shinoto 2015; Shinoto and Nakamura 2016).

Sue ware was widely distributed throughout Japan, including the southern islands. Hence, more than 200 samples of Sue ware found at the kiln cluster were analyzed by NAA with the prospect of defining a chemical fingerprint for the production center (Sterba 2015). The samples were collected from several different contexts; more than 60 samples are clearly from kilns or associated wasters (haibaras), while most of the remaining sherds were collected along the brooks within the kiln cluster. The kilns are distributed along the side of Mt. Nakadake on steep slopes. In ongoing studies, the find locations of the samples are tentatively associated with three major drainage basins, denoted A, B and C. Within the basins, geographical sublocations along watersheds can be defined, resulting in sublocations Ap02, Bp01 etc.

Statistical analysis of the chemical fingerprints of the samples yielded 23 chemical groups, which are often chemically similar but clearly distinct, as well as a large number of chemical singles that probably indicate numerous other small groups where only a single sample was found.

Considering the geographical situation of the kiln cluster, associations of the chemical groups with the sublocations or at least with the main drainage basins would be expected. However, a comparison of the find locations and the chemical groups, as can be seen in Fig. 5.6, show a much more complex situation.

As can be seen in Fig. 5.6, the two chemical groups NG03 and NG10 cover almost all geographical sublocations, while chemical groups NG16, NG17 and NG18 can only be found in the sublocation Bp03. Some sublocations yield only one or two chemical groups (i.e. Cp01, Cp02 and Bp01), while others contain a multitude of chemical groups (i.e. Bp03 or Bp08).

Compared to the situation described above (Kamuiyaki kiln site center), a clear assignment of external samples to Nakadake Sanroku seems much more complicated or even impossible. However, it is important to note that for two of the chemical groups (NG03 and NG06), corresponding samples were found on the islands Tanegashima and Kikaijima, both to the south of Nakadake Sanroku (Sterba 2015). On Tanegashima, the much closer island, only samples from the chemical group NG06 were found; on Kikaijima, only samples from the chemical group NG03

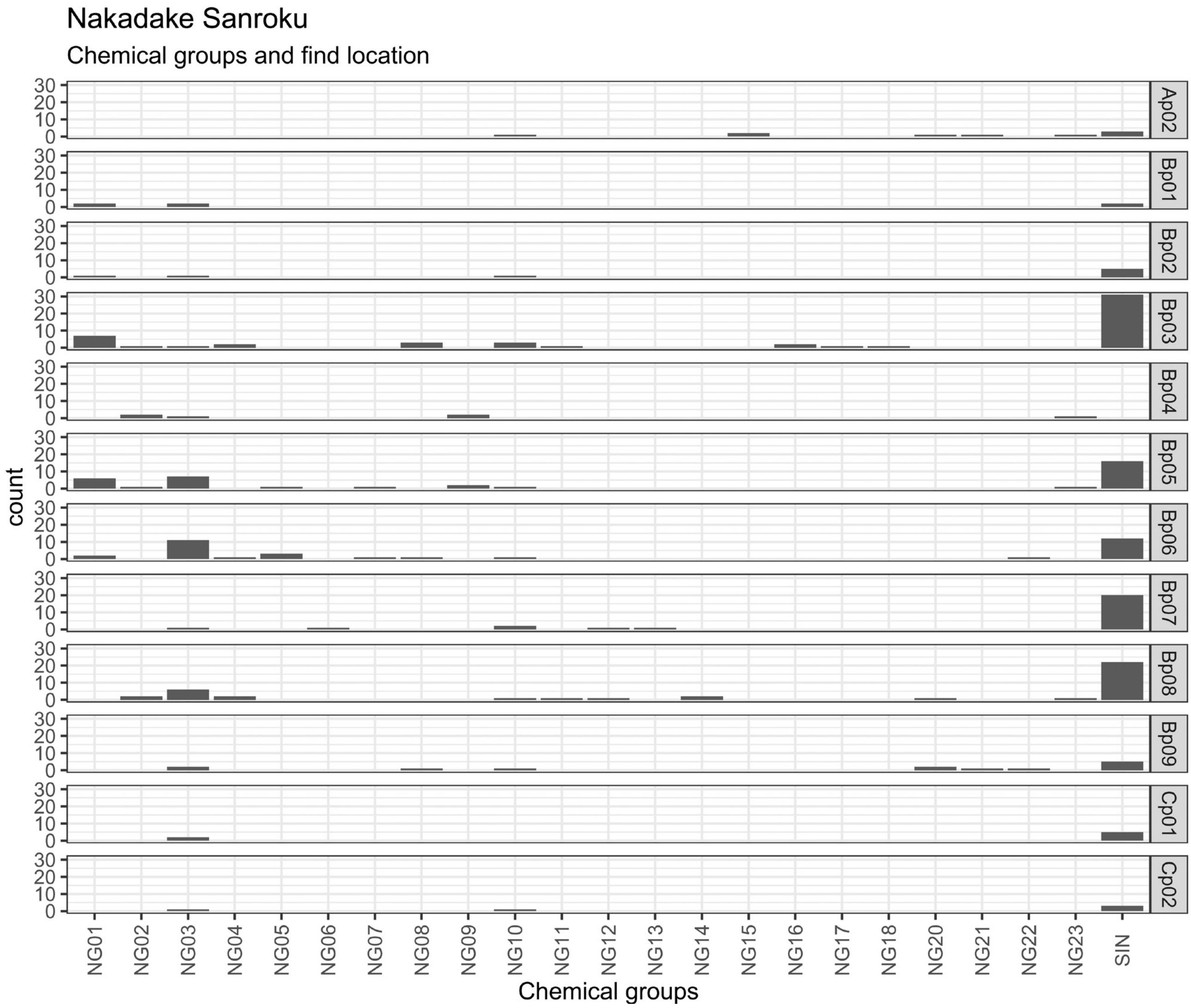

Figure 5.6. Comparison of the chemical groups found in the *Sue*-ware corpus of Nakadake Sanroku with the geographical find locations, based on watershed divides. A, B and C denote the major drainage basins with sublocations along minor watersheds.

were found. Chemical group NG06 only has representative samples in sublocation Bp07 at Nakadake Sanroku, whereas samples from chemical group NG03 can be found in most sublocations.

While the total sample number in this specific case is very small (only two samples each on the two islands), the distribution might hint at complex distribution patterns of the products from Nakadake Sanroku. It is also important to note that, due to the archeological context, the chronological development and typology in Nakadake Sanroku is mostly unclear. This means that the distribution of the samples over the different geographical locations lacks the chronological information that could help to explain the distribution of the visible chemical groups.

5.3.3. The cooking pots of Nile clay

In the course of the European Research Council Across-Borders project (Budka and Auenmüller 2018), over 300 ceramic samples from Sai Island in northern Sudan were investigated by Neutron Activation Analysis (NAA) (D'Ercole and Sterba 2018). Sai Island, a border settlement between Upper Nubia and Egypt, was repeatedly under different political influence, which included the establishment of an Egyptian town during the New Kingdom (ca. 1539–1077 BC). Preliminary investigation of the chemical composition of the ceramic samples quickly resulted in a large group (more than 100 pieces) of ceramics made from Nile clay. Since Nile clay as a raw material is chemically very homogeneous, and thus is not necessarily local to Sai Island but could be from any point along the Nile River, additional and more careful statistical analysis of the compositional group was performed. Typologically, this group could be separated into "Egyptian-Local," "Nubian-Local" and "Egyptian-Import" wares, i.e. ceramics made in Egyptian style but most probably locally made, ceramics made in Nubian styles but most probably locally made, and material in Egyptian style but most probably not produced locally.

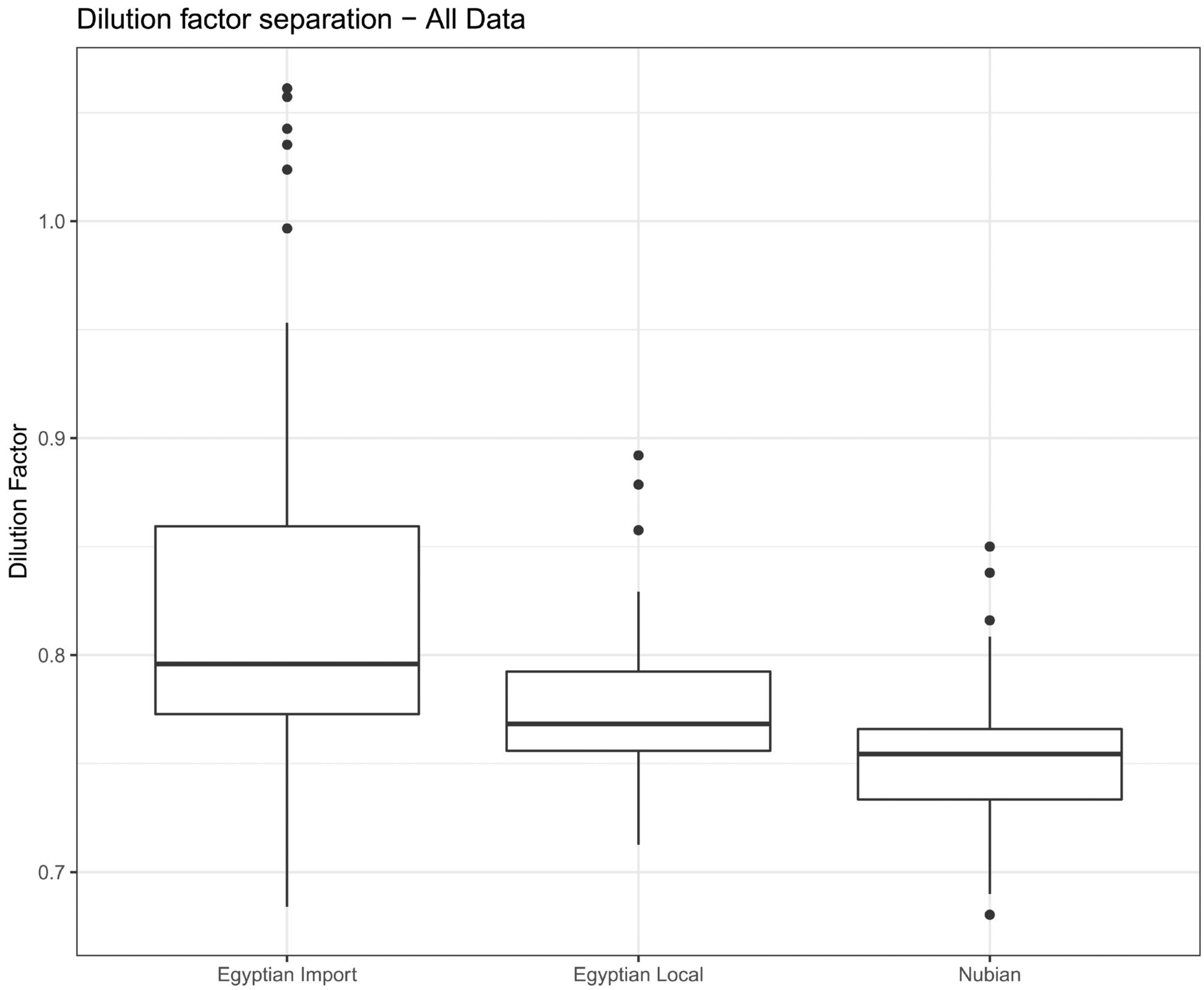

Figure 5.7. Boxplot of the dilution factors for the three different typological categories found within the ceramics made from Nile clay. While the distribution of the imported samples has a large range of dilution factors, the range for the other two typologies is much smaller, indicating a more standardized production.

A comparison of the dilution factors of the three different typological categories (Fig. 5.7) yielded some interesting information: The distribution of the dilution factors within the three groups is different. While in the two groups that were most probably locally made from Nile clay found close to or on Sai Island, the dilution factors vary only in a small range, in the samples most probably from somewhere else along the Nile, the dilution factor distribution covers a much larger range. This can be explained by the locally produced ceramics having a much smaller range of different amounts of additives (organic material or sand) because they all were made within a community and within a fairly small area. The ceramics produced elsewhere show a much larger range of amounts of additives used, since they came from many different workshops along the Nile.

Taking this approach one step further, a closer look at the dilution factors of samples typologically categorized as Egyptian Imports is shown in Fig. 5.8: Some of the samples could easily be recognized as cooking pots. Their dilution factors are, in general, larger (closer to 1) while the dilution factors of all other samples are much smaller (around 0.8). This indicates a difference in the amount of temper, be it sand or organic matter, that was added to the two groups, although both used the same raw materials. Considering the technological demands on cooking pots, this is a clear indication of a conscious decision of the potters to use different mixtures of the same raw materials to achieve different technological properties.

5.4. Conclusion

Moving from purely archeological provenancing to archeometric analysis to support typological data with measurable chemical data allows the application of statistical methods, and thus leads to a more reproducible approach to the establishment of the provenance of ceramic material. Applying chemical analysis, specifically Neutron Activation Analysis (NAA) to provenancing

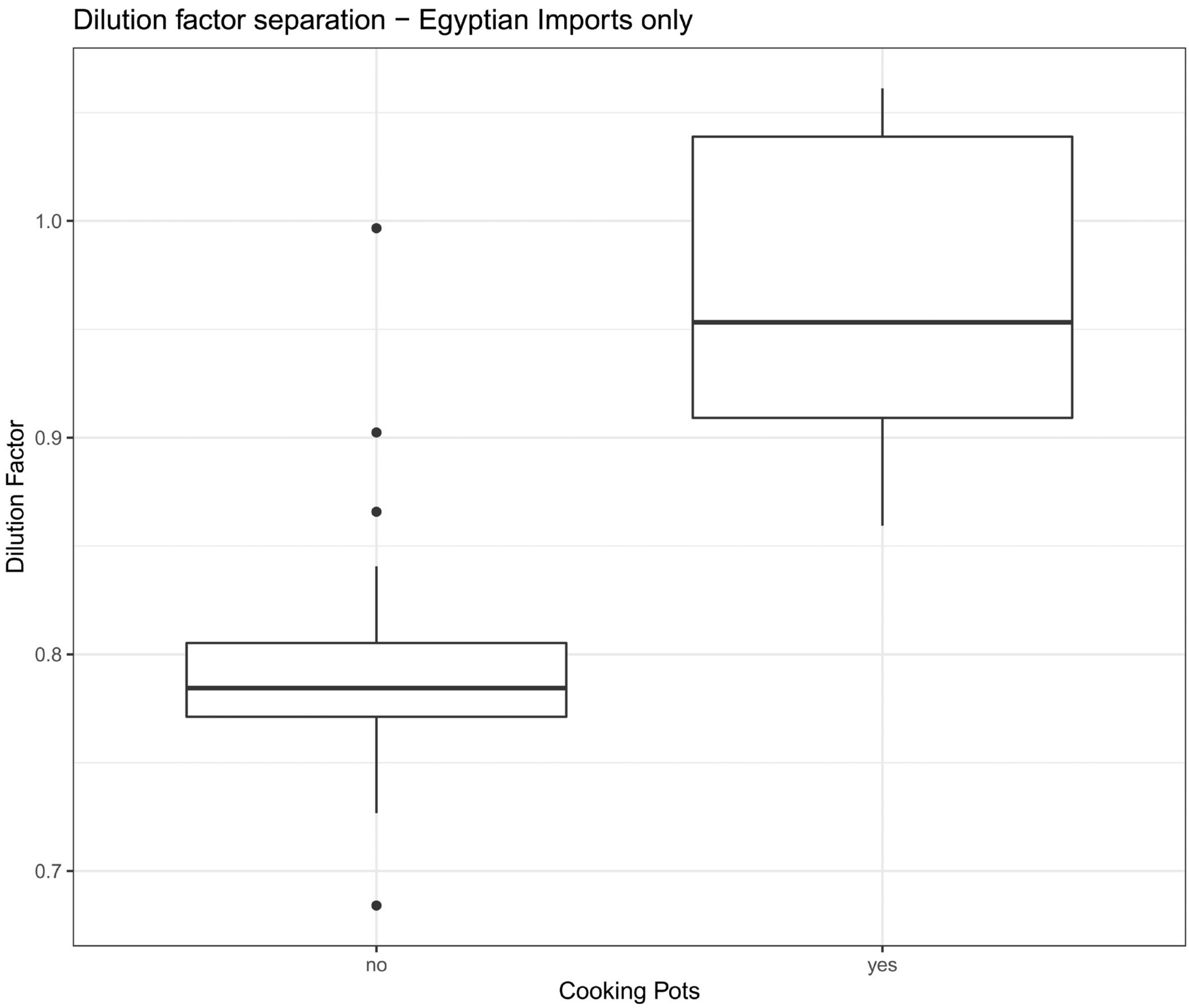

Figure 5.8. Boxplot of the dilution factors for the samples made from Nile clay and classified as Egyptian Imports. The samples that could clearly be identified as cooking pots are shown separately, showing a significantly different average dilution factor from all other samples. This strongly indicates a conscious choice to reach necessary technological properties.

of ceramics is well established and has been producing meaningful results and support for archeology since the 1970s (Perlman and Asaro 1969; Yellin et al. 1977; Jones 1986; Mommsen et al. 1995; Hein, Mommsen, and Maran 1999; Mommsen and Maran 2001; Sterba et al. 2009; Zuckerman et al. 2010; Moreno Megías et al. 2020).

Taking into consideration the case studies provided above, it can be seen that, with careful statistical analysis of the chemical data and in combination with archeological information, traditional provenancing can be pushed beyond the establishment of a single source of production. It becomes possible to establish different recipes employed within a single production center. In cases where reliable dating information is available, not only can the physical location of origin be established, but the time frame or sequence of production also comes within the method's reach. Changes in recipes become visible and provide information on changes in production techniques or use of raw materials.

In comparison to the macroscopic viewpoint provided by traditional methods of provenancing, NAA and subsequent statistical analysis offer a microscopic scale on which to interpret and contextualize archeological findings.

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Part II

Advances of Kiln Manufacture in China