

**Asia Research Institute
Working Paper Series No. 126**

**Archaeological Report on the
Thnal Mrech Kiln Site (TMK 02),
Anlong Thom, Phnom Kulen, Cambodia**

John Miksic

Department of Southeast Asian Studies, National University of Singapore
seajnm@nus.edu.sg

Chhay Rachna

APSARA Authority, Cambodia

Heng Piphah

University of Hawaii at Manoa, USA

Chhay Visoth

APSARA Authority, Cambodia

November 2009



This paper was produced with the support of the APSARA Authority.

The **ARI Working Paper Series** is published electronically by the Asia Research Institute of the National University of Singapore.

© Copyright is held by the author or authors of each Working Paper.

ARI Working Papers cannot be republished, reprinted, or reproduced in any format without the permission of the paper's author or authors.

Note: The views expressed in each paper are those of the author or authors of the paper. They do not necessarily represent or reflect the views of the Asia Research Institute, its Editorial Committee or of the National University of Singapore.

Citations of this electronic publication should be made in the following manner: Author, "Title," ARI Working Paper, No. #, Date, www.nus.ari.edu.sg/pub/wps.htm. For instance, Smith, John, "Ethnic Relations in Singapore," ARI Working Paper, No. 1, June 2003, www.ari.nus.edu.sg/pub/wps.htm.

Asia Research Institute Editorial Committee

Maznah Binti Mohamad - Chair

Anjali Gera Roy

Gregory Clancey

Peter Wolfgang Marolt

Tim Bunnell

Venni Venkata Krishna

Zaide Joyce

Valerie Yeo

Asia Research Institute

National University of Singapore

469A Tower Block #10-01,

Bukit Timah Road,

Singapore 259770

Tel: (65) 6516 3810

Fax: (65) 6779 1428

Website: www.ari.nus.edu.sg

Email: arisec@nus.edu.sg

The Asia Research Institute (ARI) was established as a university-level institute in July 2001 as one of the strategic initiatives of the National University of Singapore (NUS). The mission of the Institute is to provide a world-class focus and resource for research on the Asian region, located at one of its communications hubs. ARI engages the social sciences broadly defined, and especially interdisciplinary frontiers between and beyond disciplines. Through frequent provision of short-term research appointments it seeks to be a place of encounters between the region and the world. Within NUS it works particularly with the Faculty of Arts and Social Sciences, Business, Law and Design, to support conferences, lectures, and graduate study at the highest level.

The following report summarizes recent mapping, excavations, and analyses of the pottery and kiln morphology at the Thnal Mrech Kiln site (TMK) in northern Cambodia. The site is located on Phnom Kulen, approximately 35 km northeast of Siem Reap in the famed Angkor region (the 9th-14th century capital of the predominantly Khmer-speaking people who lived in what is now Cambodia, northeast Thailand, and southern Laos). This report presents a preliminary analysis of the layout and structure of the Thnal Mrech site. Additionally, we provide assessments of the pottery assemblage and kiln structure. Functional, 'stylistic', economic, and environmental considerations are also important. Based on radiocarbon dating, we believe the kiln site was intensively used for an indeterminate period between the 11th and 13th centuries, during which changes were made to the kiln structure, engineering, and use. The site denoted TMK02 is one of many similar sites. Fortunately, this site is a good example and was excavated in accordance with normal archaeological practice. This study will benefit Cambodian kiln and pottery studies as well as provide a comparative example when studying kiln sites in the extended region and elsewhere.

The zone containing multiple kiln sites on Phnom Kulen is frequently known as Anlong Thom (approximately 'big river channel') due to its location near a village bearing this name. However, this term covers a fairly sizeable area. Specific kiln locations are known to locals as Sampov Thleay ('wrecked ship') or Thnal Mrech ('pepper road') in current terms and oral history. Local names should be adopted for purposes of clarity of identification, location, and interpretation. Therefore we use the local name Thnal Mrech Kiln Site or TMK rather than Anlong Thom for the excavated entity described in this report.

The name Thnal Mrech literally means 'road of pepper' (*Piper Nigrum Linn*). Phnom Kulen means 'mountain of lychee' (*Litchi chinensis Sonn. Nephelium litchi Cambess*) probably a reference to the abundance of such trees on the plateau. Sampov Thleay's place name suggests a Chinese origin for ceramic deposits there. Whether or not the kiln and pottery manufacture technology were influenced by Chinese or other groups is uncertain at this point in our inquiry. The toponym could be mere coincidence or a post hoc name, or may in fact reflect semi-diffused technology (although the level of diffused technology is not clear from past records).

According to thorough research by Jean Boulbet and Bruno Dagens (1973), Phnom Kulen is important in efforts to unveil the origins of the Angkor era. According to interpretations based on the eleventh-century Sdok Kak Thom inscription (K.235), historians believe that Phnom Kulen was known as Mahendraparvata in the past (Coedès 1968). Most sites on this plateau are generally thought to be associated with Jayavarman II, founder of Angkor. The Sdok Kak Thom inscription, composed in 1052 CE, suggests that Phnom Kulen was known in the 9th century as Mahendraparvata, and that was the capital of Jayavarman II after liberation from 'Java' (Coedès 1964). Along with temples and religious foundations, ceramic kilns were recognized during a survey of the area in 1883 (Aymer 1901).

Studies of Khmer ceramics began before the civil war in Cambodia started in 1970. B.P. Groslier wrote an essay on comparative dating of Phnom Kulen ceramics, which he referred to as Kulen Ware (Groslier 1981). Based on stratigraphic analysis from various excavations in the Angkor region, Groslier suggested that Kulen Ware might date back to the ninth century, contemporary with the reign of Indravarman, founder of the Bakong temple in the Roluos group, southeast of the larger Angkor complex. Other than comparative studies, no systematic research projects were conducted to understand kiln sites on Phnom Kulen until the early 21st century.

Improved accessibility to Phnom Kulen and awareness of looting at the kilns in the

1990s has attracted more research interest. It was not until 1995 that the APSARA authority in cooperation with Sophia University conducted the first research on Khmer kiln technology at the Tani kiln site, located approximately 19 km from TMK. In August 12, 1999 a short site reconnaissance was undertaken by APSARA, Nara National Cultural Properties Research Institute, and Sophia University (Nishimura 2000, Nara-APSARA 2000). Other than this investigation, however, most researchers and visitors from NGOs in Siem Reap were only interested in visiting and collecting wasters from these kilns and did not produce any reports or analysis. Since then, several researchers' and RUFA students' theses (Royal University of Fine Arts) have been dedicated to the study of ancient Khmer ceramics. One thesis, defended in 2002 by Chhay Visoth and Chap Sopheara, is dedicated to identification and classification of ceramics found *in situ* at TMK. Those samples are mainly wasters found in surface scatters, and remains from looting in early 1990s (Fig. 01).

In comparison to the number of Khmer kilns excavated in Buriram, Thailand (Kram Silapakorn 1989), fewer kilns have been studied in Cambodia. Cambodian kilns which have

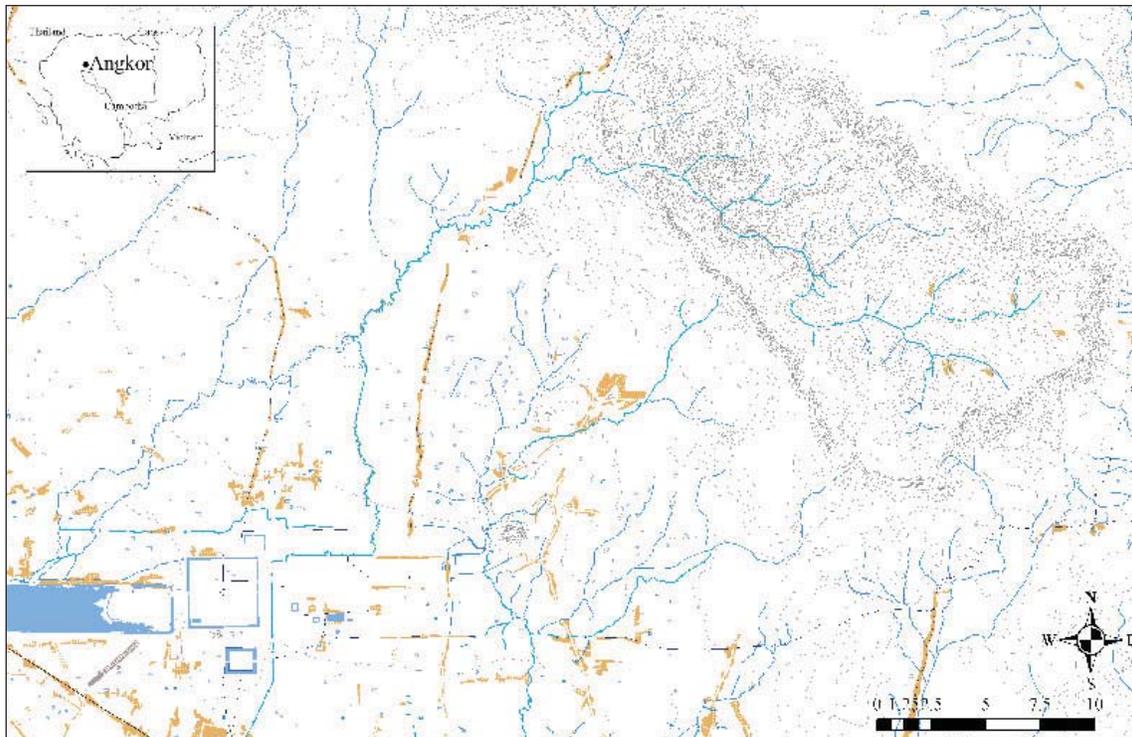


Figure 01. Central and northeast Angkor, showing the location of Angkor Wat and Thnal Mrech Kiln site. Spot heights and contours from Japan International Co-operation Agency.

been systematically investigated include Tani, Khnar Po, and Sarsei, all located near Phnom Kulen (Ear 2000, Nara 2000, Sophia 2000, Chhay and Chap 2002, Sok 2003, Em 2004).

In January 2007, the Department of Monuments and Archaeology 1 (DMA 1) of APSARA National Authority inaugurated a collaborative project with the National University of Singapore (NUS), with support from the Lee Foundation, to conduct an archaeological excavation of TMK sites. This excavation was designed to build a better understanding of Cambodian ceramic technology, particularly in the Angkor era when the so-called Kulen ware was developed. Another goal was to create a preliminary classification and typology of ceramics recovered from each kiln located at TMK. This classification, it is hoped, will provide a helpful resource for comparative studies of Khmer ceramics recovered in future excavations.

Future studies may focus on daily life, trade/exchange, cultural contact, technology, utility, ceremony, and many other aspects of past Cambodian culture, especially that of the potters and their communities who lived on Phnom Kulen. This will in turn enable scholars to deepen their knowledge of that segment of Cambodian history concerned with the formation, history, and decline of habitation and other activity on Phnom Kulen. Other topics, such as ceramic studies and compositional studies, etc., will also benefit from further attention.

Methodology

This project represents the first kiln excavation directed by Cambodian archaeologists. As a result, particular care was taken to ensure that the methodology and design of the project adhered to the standards required for long-term research. The planning process included excavation, post-excavation processing, and planning for future extensions of the project.

- Identification of the kiln structure: the excavation was based on a computer-generated contour map produced by the team in 2006. The results of this mapping survey caused the investigators to suspect that possible kiln structures are located on both sides of the dike which penetrates a peninsula-like area. Long trenches were excavated in one of these suspected kilns to identify kiln structure. This method is not fully accepted by Cambodian archaeologists due to its ineffective in obtaining precise stratigraphic data. It is however possible to remedy this deficiency by digging additional test pits to identify stratigraphic features and to test various hypotheses. One of these hypotheses concerns the relationship between the kiln and habitation areas. One possible hypothesis is that any occupation layer found at the site had accumulated after the kiln collapsed. According to an alternative hypothesis, the kiln area was located outside main habitation centre, so that excavations would only yield evidence of kiln activities. Possibly one of the reasons why the kilns were built on the reservoir embankment was to avoid impinging on the habitation zone.

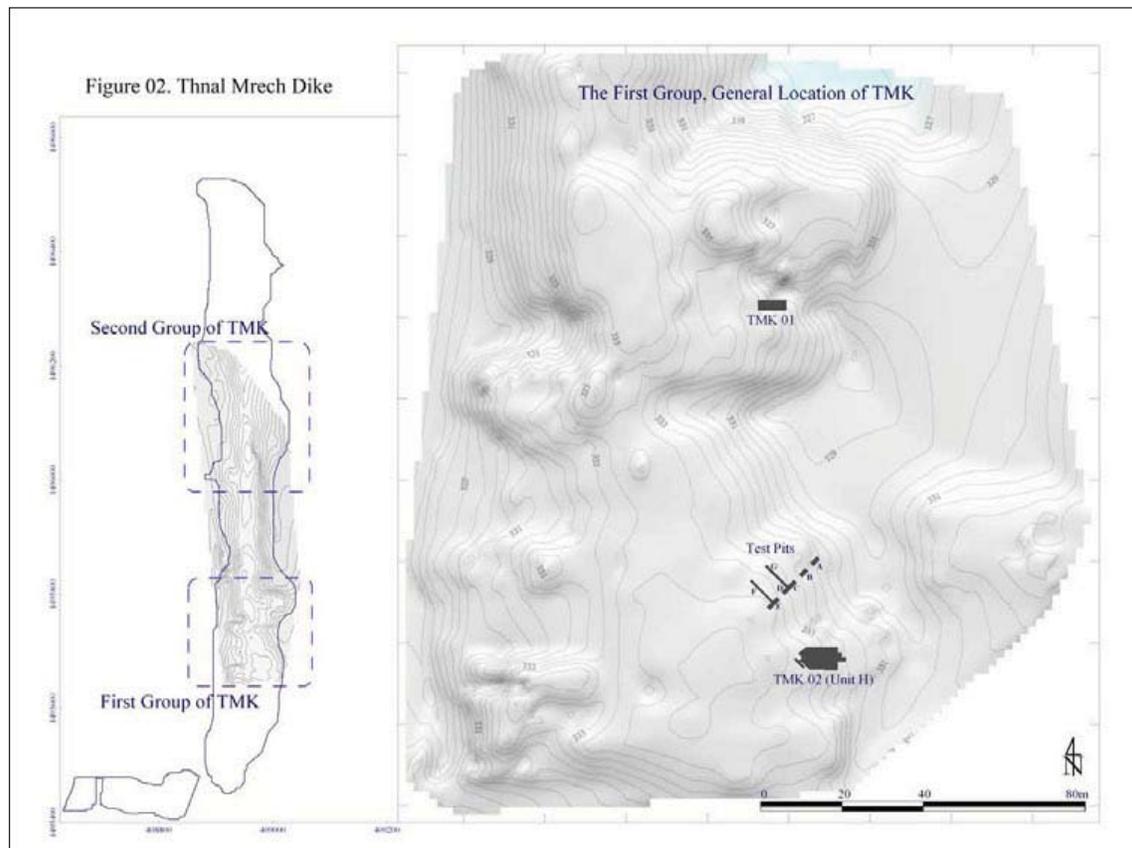
- Excavation of the kiln structure: the first excavation of a kiln in an unexplored area is inevitably difficult to plan, since the conditions archaeologists will encounter during the excavation are impossible to predict in advance. The excavators therefore planned several strategies for dealing with different possible scenarios in the excavation and post-excavation process. The main objective of excavating the kiln was to identify elements of its structure; these include its overall groundplan, the location and dimensions of such features as the walls, floor, roof, firebox, etc., and artifacts associated with each of these features. The excavations of Tani and Thnal Mrech 01 provided a preliminary idea of what the Thnal Mrech 02 kiln might look like.

- It was decided that the first step should be an extensive excavation of the layer of topsoil which had accumulated on top of the entire kiln, which made it possible to obtain a view of the kiln's collapsed roof structure. Once this was completed, it was decided to excavate half of the kiln (in a longitudinal direction, i.e. the longer dimension of the kiln) because: a) any errors by the archaeologists due to inexperience with the particular type of kiln found here would affect only half of the kiln structure, since the other half would remain undisturbed and could be checked by future archaeologists; b) kiln structures are often based on symmetrical designs that can be reconstructed by seeing only half of the structure; c) the undisturbed half would be useful for planning such future amenities as a site museum, in which visitors could see both aspects of the kiln: the excavated and the undisturbed state.

- Sampling methodology: artifacts were divided into two categories, those found inside and those found outside the kiln. Artifacts outside the kiln were collected according to natural stratigraphic layers. Stratigraphic layers around kilns are often complex, because they were formed by wasters thrown away during kiln usage. This formation process may cause thick deposits, some of which may be contemporary but nevertheless exhibit different characteristics. Charcoal samples were taken from each layer and inside the firebox. Carbon samples for dating purposes taken from the firebox might refer to the end of the site's use when the kiln collapsed, while samples from each layer might provide dates for chronological phases of kiln usage from the beginning till the end.

Excavation Process

The project was conducted in discrete stages, beginning with mapping of the general kiln zone, followed by excavation during which Khmer archaeology students received special training,



and concluding with analysis of excavated artifacts. Mapping was conducted in January and May 2006 and yielded a topographical contour map, analysis of which made it possible to divide the kiln structures located on Thnal Mrech into two groups, a first group in the south and a second group in the north (Fig. 02).

Test units were located inside the first kiln group in the south on two peninsular-shaped features located east of the dike. TMK 02 is south of TMK 01; both were located on mound-like structures extending sideways from the Thnal Mrech dike, and suspected before excavation to represent buried kiln structures. Informants reported that this area had been heavily looted during the 1990s. The current condition of the site consists of dozens of looters' pits with kiln

structure fragments and many ceramic fragments (pieces of wasters) present on the surface. However one of the projecting mounds remain in good condition without any looters' pit, suggesting that one or more undisturbed kilns might be located there.

A first test pit was opened in one of the looters' pits located at the edge of the slope to gather information on the composition of the soil strata. A trench 1 metre wide and 17.5 metres long was laid out along the slope of one of the "peninsulas" oriented approximately 45 degrees east of magnetic north (northeast). This trench was divided into four smaller trenches separated by 2m baulks. From the top to the bottom of the slope (southwest), these were designated as Unit E (3.5m x 1m), CD (4m x 1m), B (2m x 1m), and A (2m x 1m). Two other trenches (7m x 0.5m) extended from units D and E to the northwest (Fig. 02).

These units provide good information concerning a concentration of wasters, which were mostly found at the end of the slope in trenches A, B, and C. Stratigraphy consisted of two thick soil layers on top of the original dike surface. This helps to reconstruct the condition of the kiln when it was built and in use. Data also demonstrate that kilns are not generally located on peninsulas protruding from the dike.

A small T-shaped unit (2m x 0.5m lying SE and 2m x 0.5m lying NE) was laid out on another protruding area south of the previous one. Some sherds were uncovered from the SE unit. In the NE unit, part of the collapsed kiln roof was uncovered 20cm below the surface. A broad trench (E-W 9m x N-S 5.6m) was laid out to reveal the complete kiln structure. The entire overburden of topsoil was removed to reveal the collapsed roof structure. The east side of this unit contained soil of a different texture: soft and powdery. This is the front end of the kiln, where the firebox was located. The roof structure at this stage was composed of chunks of burned clay mixed with soft dirt, forming a flattened layer of burned clay all over the unit. Although the roof structure was discernible, no trace of chimney was present (Pl. 01-02).

After documenting this stage of excavation (drawing and photographing), part of the roof was removed to reveal the outline of the kiln. Due to its irregular shape, i.e. the intersecting orientation of the firebox and the upper wall, chunks of brick were removed from around the



Plate 01. General view of the collapsed roof of kiln structure from East to West, Thnal Mrech Kiln, Phnom Kulen.



Plate 02. General view of the collapsed roof of kiln structure from West to East, Thnal Mrech Kiln, Phnom Kulen.

kiln in an attempt to clarify its overall shape. However only the upper part of the west wall outline was removed. Following this outline an estimated central east-west axis was laid out, after which the northern half was excavated to reveal the floor and inner kiln section. Two modified kiln structures and a floor with multiple steps including a firebox were uncovered. The upper part of the kiln turned out to be the remains of an early kiln structure (TMK 02a) which was later modified/enlarged (TMK 02b). Both of these kilns form a strange irregular shape which differs from TMK 01, Tani, Sarsei, and Buriram. These two stages of TMK 02 do not exhibit the expected elongated oval shape; instead they describe a combination of oval and rectangular shapes. To clarify matters, each kiln will be described separately.

TMK 02a

This section is 2.90 m wide, while its remaining length (from the upper end until it is interrupted by TMK 02b) is 2.5m. A foundation of a clay pillar, possibly supporting the roof, is seen in the middle with a diameter measuring 35cm to 40cm from base to body. The shape of this surviving portion of the kiln suggests that it was oval with an extended square body. The surface of the interior of this kiln is the original floor structure with possibly two modified floor layers. The original floor structure inclines at an angle of approximately 25°, while the second-stage floor layer is flat and level with the broken part of the western wall of TMK 02b. This structure suggests the usage of crossdraft technology (Pl. 03).

TMK 02b

This kiln has an outline measuring 5.70m x 3.60m divided into the ware chamber, 3.70m x 3.10m, and a firebox 0.90m x 2.10 m which is 1.10m below the ware chamber. Four pillars are found in the middle and near the northern wall with diameters between 25cm to 30cm. The shape of this structure is irregular, but exhibits an elongated oval shape with a right angle corner at the southwest. The northeast corner is unidentifiable but possibly displayed the same angle. Northern and western walls are almost perfectly aligned north-south and east-west. The southern wall of the firebox, however, runs off at an angle (160°) from the southern wall, forming a semi-oval firebox. The thickness of these walls varies from 20cm to 30cm (Pl. 03).

The firebox's southern wall was intentionally made into a zig-zag shape with two superimposed windows at the eastern part. These windows were most probably designed to facilitate airflow and the addition of fuel during the firing process. The bottom window, located at the same level as the firebox floor, was blocked with fragments of burned clay and plastered with clay. This implies modification of the level during usage of the kiln (Fig. 05). Floor recovered in this kiln suggests two floor types of at least two distinctive phases. During its final usage, the kiln floor was modified into twelve steps of irregular height and width. These steps are made of recycled firing supports and plastered with clay bands to form level platforms. The early stage of the floor could be seen at the top part as one or two sloped floors with inclination approximately 27°. This floor structure suggests a crossdraft design for the kiln.

The kiln almost certainly had a chimney, but no trace of it was identified during the excavation. This is possibly due to the fact that when the kiln collapsed, most of the upper structure slid downward into the firebox.

TMK 02 is one of the biggest kilns yet found in the Angkor region. It is assumed that potters exploited the slope of a pre-existing dike, Thnal Mrech, to build a crossdraft structure. The slope was modified to create fundamental structural kiln elements including floor, firebox, and base of the kiln wall. Modification of the slope resulted in an oval pit. This process enabled the potters to plaster clay against the flat slope and pit walls to produce a hard floor and wall base



Plate 03. General view of the Thnal Mrech Kiln 02 (TMK 02a and TMK 02b), Phnom Kulen.

after the firing process. This technique produced a strong and stable structure. The collapsed upper kiln structure could have destroyed one of these wall-bases. This may have resulted in the wall extension at the southern wall of TMK 02 which may have witnessed three major modifications.

Stratigraphy

Geological layers were defined during the excavation (Figures 07-11). Detailed description is attached in Appendix A. These layers were mainly formed by two physical processes. The first process occurred during usage, when wasters were thrown away after the firing process forming different piles, which manifested themselves stratigraphically. The second process occurred after the kiln collapsed, so that most artifacts recovered in these layers come from different kilns. These layers are seen on top of and in front of the kiln, e.g., layers 1, 2, 3, and 5.

These piles are quite close to the kiln, e.g., layer 4 (a, b, c, d) and 6 (a, b). More wasters are recovered from the southern part compared to the northern part of the kiln. This implies that the potters had a habit of throwing wasters near the kiln rather than storing them at a common dumpsite. This also implies that the kiln was situated in a very narrow space, and the workshop was distant from it, possibly to make it more comfortable. Archaeological test units have not yet found any workshops.

Charcoal samples collected from multiple layers in front of the kiln produced a series of consistent dates ranking from BP 970 (± 30) to 905 (± 30). Highest probabilities of these dates rank from:

- AD 1016-1157 (96.5%): sample recovered from layer 4c.
- AD 1022-1166 (97.2%): sample recovered from layer 4c.
- AD 1025-1208 (98.7%): recovered from layer 6b in the extension unit.
- AD 1027-1211 (99.2%): recovered from layer 3a

-AD 1031-1215 (99%): recovered from layer 5.

These absolute dates suggest that TMK02 was in use during a period of approximately fifty years, in early eleventh century CE. Details of original AMS C14 calibrated dates are attached in Appendix B.

Artifacts and Classification

Artifacts recovered from this excavation can be divided into various classes depending on the research questions and cultural norms of identification, style and use. Style and function will always be debatable. We attempted to discriminate between kiln products and habitation remains, but the second category represents ~0% of the assemblage. Only one piece of Chinese qingbai, most probably associated with habitation, was recovered on top of the collapsed kiln roof (Pl. 04).

Kiln products can be divided into many categories including supports for stacked firing, roof tiles, restricted-neck jars, small restricted-neck ‘jarlets’, and covered containers. Some of the covers fit within the body using an inverted rim and others overlap the external body rim.



Plate 04. Chinese ware, qingbai.

The above example is part of an effort to compose a standardized classification system for artifacts recovered from the Kulen kilns. Classification of Khmer ceramics generally follows the general concept of morphological types; i.e., rim, body, base, jar, vessel, pot, etc. This is due to the unavailability of archaic terms used to identify each type. Our typology is used to answer current questions and also to help to illuminate possible past categories, functions, etc.

In the case of TMK 02 most of the morphologies of recovered artifacts are still known by locals and words for them can be found in the Khmer dictionary (Chuong 1967). This enables us to produce a trial classification scheme for Kulen wares based on Khmer terms. Classification of artifacts in this article will be based on the classification in Chhay and Chap (2002). Other sources will be utilized as well (Ear 2000, Sok 20003, Em 2004). Morphology is important for our typology and potential evolutionary changes, including the ratio of different kinds of vessels that were produced (e.g., basic seriation).

The concept of evolution is partly grounded on a general concept of stylistic and functional change in art-historic theory. A form often evolves from simple to complex, although industrial production may revert to standardized forms and artistic license may be common.

Each shape is coded alpha-numerically. The first letter defines the main family. Small letters behind this code indicate subgroups. Additional alphabetic codes indicate further sub-subgroups, which define shape varieties within the subgroup category. A final numeric code defines specific morphology and style varieties. Codes from main families throughout are separated by hyphens except the final numeric code, e.g., A-a-a2. Khmer language publications will follow Khmer alpha-numerical order. We designed a flexible paradigmatic classification

system for additional shapes found in other excavations and within the current assemblage.

We can easily add categories/classes such as decorative elements that follow a paradigmatic classification system. Categories that relate to social issues, such as male/female distinctions of parts, usage, production and so on can be added to our system as well. For example, the *danlap*—in modern context—is a small vessel used to store bees’ wax which is believed to have magical powers (a shaman or doctor of magic puts a spell on the wax and container contiguously through an incantation). Only men can touch it. Females might be harmed or driven mad if they touch the vessel. They can safely use the contents of their own vessel, but the practice and mythology are largely restricted to male use.

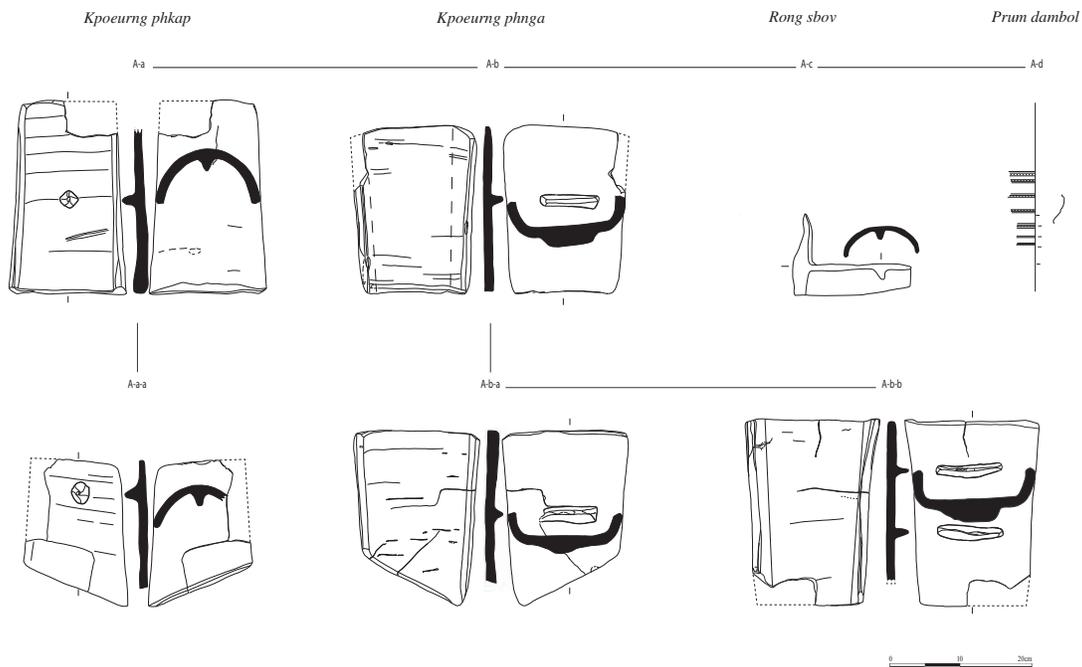
Our classification system is demonstrated through the examples below. Cambodian terms for ceramics demonstrate both shape and function.

- *Kpoeurng*: roof tile. This term represents the whole architectural ware family coded as A (Fig. 03).

- *Kpoeurng phkap*: round tile or cover tile. Coded as A-a.
- *Kpoeurng phnga*: flat tile or canal tile. Coded as A-b.
- *Rong sbov*: literally means ‘thatch barrier’. In modern understanding it refers to a plank of wood placed at the end of the roof. In some historic buildings such as the National Museum this plank is carved with lotus designs similar to ancient temples. Historically, this type of roof tile was used at the distal end of roof ‘eave tiles’. This particular shape generally bears designs such as the lotus petal, rishi in meditation, floral designs, etc. (e.g., coded as A-c-??)
- *Prum dambol*: the finial tile is another type of roof tile with a pointed baluster on top used to cover the triangle joint of the roof. Coded as A-d-??

- *Danlap*: this term is preserved in daily usage. It identifies small globular covered boxes used to store bees’ wax (generally associated with black magic). Angkorian

Figure 03. Roof Tile Family (A)



inscriptional evidence of this term ‘tanlap’ mostly refers to metallic forms including gold and silver (Coedès 1951 and 1954). K391 ‘...vrah gandha tanlap mvay...’. This indicates that *danlap* could have been used as perfume containers. Unit H also yielded large covered containers in the same shape. Thus, this term can be applied to both large and small covered boxes. Their use in antiquity is unknown, but the same forms and concepts adhere to modern contexts. This shape is coded as B (Fig. 05).

- *Kotth*: literally ‘urn used to store cremated ash’. Groslier reported finding identical containers with human remains at his Srah Srang excavation (Dumarçay and Courbin 1988, Brown 1988). That usage of these containers was restricted only to burial cannot be confirmed. In modern burial practice, human relics can be stored in any type of container including bowls, teapots, metal urns, etc. Bas-reliefs on the Bayon Temple seem to show items of this shape serving as containers for food rather than human relics. This shape is reminiscent of the *danlap* with the exception of its half-conical or cylindrical form (Pl. 05). This shape is identified by code C (Fig. 05).

•Both *danlap* and *kotth* bear different varieties of lids (*kumrop*). It is difficult to determine whether and which type of lid might have been used for *danlap* and *kotth*. However, bas-reliefs on the Bayon depict utilitarian wares similar



Plate 05. Bayon, outer gallery bas-relief, late 12th -early 13th centuries.

to *danlap* and *kotth* with pointed-finial or conical lids. This problem requires formation of another supplementary group of lids *danlap* and *kotth*, coded as BC. Conical lids are often believed to be for *krala*. Thus they are coded as BCE (Fig. 04).

- *Khuoch*: generally translated as ‘bottle’. ‘Small, globular vessel with restricted neck and everted rim’ is a more accurate description than bottle. This shape suggests that it was used as a liquid container. Locals currently define it as oil (perfume) container. It is coded as D (Fig. 05).

- *Krala*: they resemble ovoid-shaped jars from a lateral perspective. They can be big or small. They were likely used for storage. The very large ones are frequently used for water. Many are used for fish-paste storage as well. They are coded as E (Fig. 06).

Figure 04. Lid Family (BC and BCE)

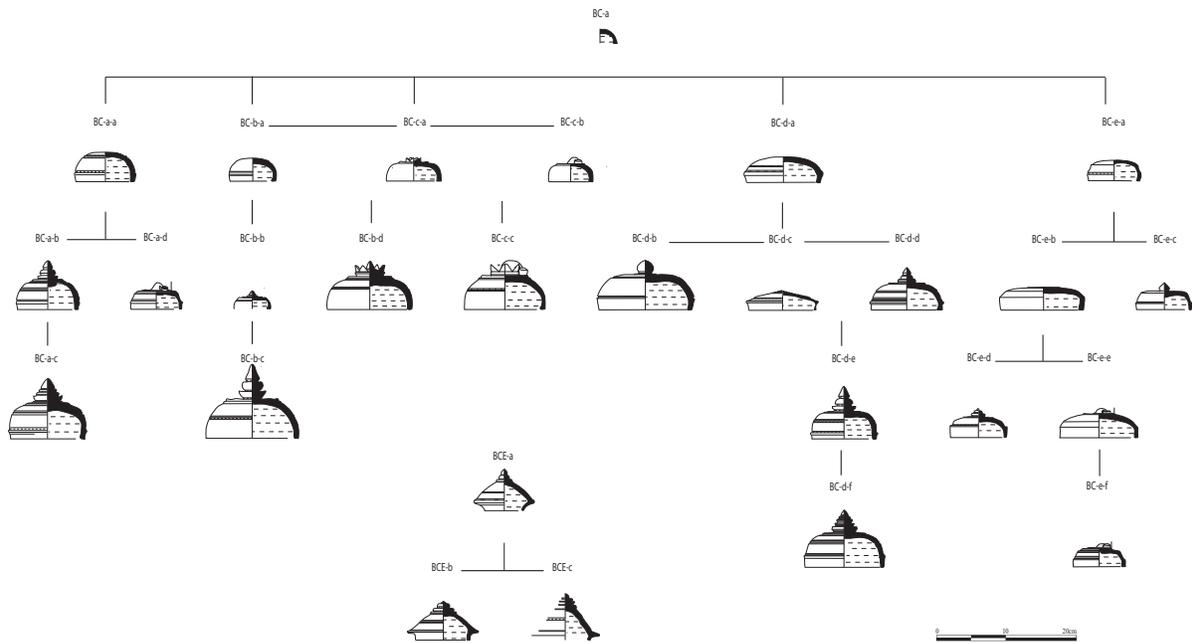
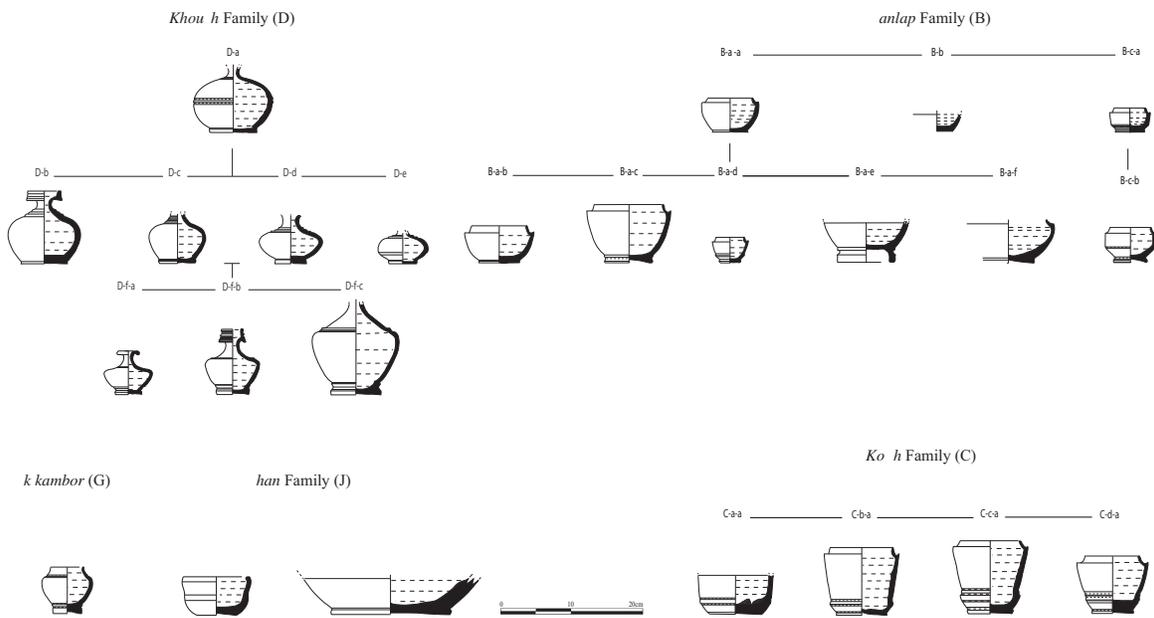


Figure 05. Main Container Families



- *Phoeng* and *peang*: cylindrical vessels in cross-section appearing square, rectangular, or trapezoidal. The terms refer to items like flowerpots. They are generally big vessels and have abrupt everted rims. Large ones may be referred to as *peang* depending on use. They are classified as F (Fig. 06).

- Additional terms for *krala* and *phoeng* are also used depending on function as stated above. *Peang* sometimes refers to *krala* when storing fish-paste ‘*krala prahok* or *pieng prahok*’. *Aotin* is also used instead of *krala* to define a rice wine or fish sauce container. However, *peang* can also be used in place of *aotin*. Due to confusion of the term *peang*, its identification will fall into both categories E and F.

- *Akkambor*: literally a type of bird (*Ichthyophaga ichthyaetus*) and lime, possibly related to betel nut chewing and lime containers. The term refers to zoomorphic pottery in bird form. Their ancient function is unknown, but locals now use the term to refer to similarly formed vessels for lime storage. These are more like bottles with semi-restricted necks and small openings with no rims. They are classified as G (Fig. 05).

- *Ka-am*: globular vessels with long restricted necks and everted rims of varying sizes. They are used as water carrying and containing vessels. Their code is H (Fig. 06).

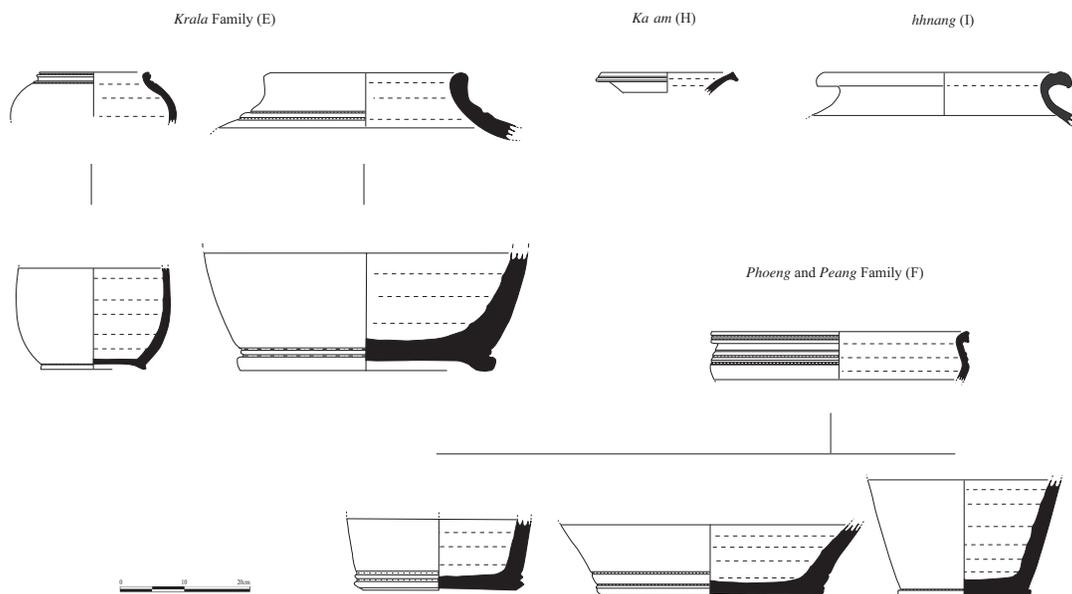
- *Chhnang*: cooking pots. These are used for rice, soup and herbal medicine. The main function involves cooking. Most are bowl-shaped, have lids and range in size from small to large. A modern form similar to a cooking pot depicted on the bas-relief of the Bayon suggests that it has been almost unchanged for at least 700 years. These are classified as I (Fig. 11 and Pl. 06-07).

- *Chan*: bowl or plate. The code is J (Fig. 10).

- Unidentifiable pieces are categorized as U followed by ‘large’ and ‘small’ to indicate big and small pieces.

Numerous firing supports were found during the excavation. It is extremely difficult to produce a typological code for them due to their distinctive characteristic. Firing supports

Figure 06. Container Families



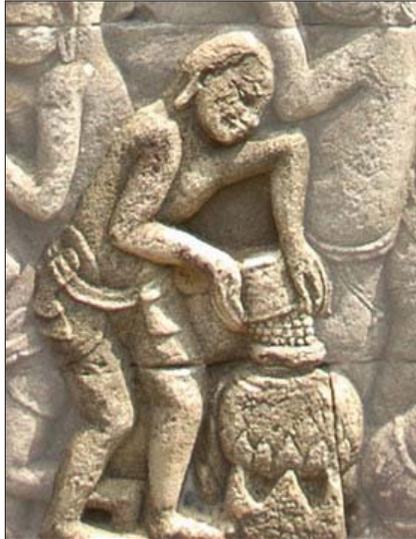


Plate 06. Bayon, outer gallery bas-relief, chhnang, cooking pot, late 12th -early 13th centuries.

Plate 07. Cambodia, Kompong Chhnang province, chhnang, cooking pot, modern form.



can be divided roughly into three main types. The first type describes the majority of all firing supports. These were made by hand rolling a piece of wet clay to produce a sausage-like shape. This type was possibly used to stabilize ceramics by holding and separating lids knot-to-knot or shoulder-to-shoulder noticeably that of codes B, BC, and C. The second type is a semi-cylindrical brick-shaped support that was used to stand on the inclining floor. One can be seen on the upper floor of TMK 02b. The third type is a piece of clay applied to the interiors of pottery of codes A, B, and C to stack smaller ceramics inside bigger ones. There are many variations of this type, sometimes consisting of just one piece of clay put at the inner bottom of the pot, but at other times consisting of two, three, or four arranged at different angles (Pl. 08-09).

Following the above terminology ceramics uncovered from unit H can be divided into two main species: utilitarian ware and architectural ware. Architectural ware mainly comprises roof tile. Utilitarian ware includes kiln products and habitation remains. Kiln products comprise *danlap* 'B', *kothh* 'C', and *khuoch* 'D'. Wares used in habitation activities include both earthenware and stoneware, some of which bear smudging resulting from the cooking process.

Most of the artifacts recovered can be separated into combinations of large and small



Plate 08. Firing supports, semi-cylindrical brick-shaped, sausage-shaped, and pieces of clay. TMK 02, Thnal Mrech Kiln, Phnom Kulen.



Plate 09. The remains of firing supports, pieces of clay applied to the interiors of pots, and the sausage shapes on the lids of the covered boxes. TMK 02, Thnal Mrech Kiln, Phnom Kulen.

sherds. Small sherds are difficult to identify and are mainly body sherds from all shapes. Thus all of these small fragments are placed in the ‘unidentified’ category. Identified materials such as rims, bases, and lids will be categorized into the the main groups. Stratigraphy is used as ‘unit’—SU—to group each typology to produce a chronology and percentage of artifacts found in each layer.

Type	Total Quantity	Numerical Percentage	Total Weight/g	Weight Percentage
A	2599	26%	145331	38%
B	853	9%	24675.88	6%
BC	2353	24%	98783.83	25%
C	2433	24%	65513.2	17%
D	447	4%	17596.7	5%
E	25	0%	3642	1%
F	11	0%	2990	1%
G	6	0%	162	0%
H	6	0%	298	0%
I	4	0%	92	0%
J	15	0%	1620	0%
U	1257	13%	28129	7%
Total	10009	100%	388833.66	100%

Table 1: Quantity, weight, and percentage of each type in the total assemblage

Artifacts recovered from this excavation are not necessarily associated with TMK 02. After TMK 02 collapsed, wasters from other kilns—particularly kilns located on top of the dike—were thrown and deposited on top and in front of it. This is indicated by stratigraphy on the east wall. Artifacts found from SU 4 and 6 are closely related to TMK 02.

Type	SU 1	SU 2	SU 3	SU 4	SU 5	SU 6
A	1336	449	308	120	15	371
B	231	295	116	101	17	93
BC	728	740	307	269	93	216
C	817	711	258	324	101	222
D	94	141	36	137	11	28
E	1	19	0	2	3	0
F	1	7	0	0	3	0
G	0	4	2	0	0	0
H	0	2	0	0	4	0
I	0	1	1	1	1	0
J	2	9	0	4	0	0
U	497	298	107	292	30	33
Total	3707	2676	1135	1250	278	963

Table 2: Quantitative variation of each type by stratigraphic unit by number of sherds

Type	SU 1	SU 2	SU 3	SU 4	SU 5	SU 6
A	46000	32097.40	20150	10880	9272	26931.60
B	4439	8527.59	3301	2836.29	1732	3840
BC	15176	38399.54	15928.29	6360	10943	11977
C	10870	24473	7329	6364.25	7278	9199
D	2061	6539.7	1858	4316	1428	1394
E	220	2162	0	400	860	0
F	180	1660	0	0	1150	0
G	0	32	130	0	0	0
H	0	110	0	0	188	0
I	0	30	40	20	2	0
J	52	1510	0	58	0	0
U	4297	12592	5611	2975	1657	997
Total	83295	128133.23	54347.29	34209.54	34510	54338.60

Table 3: Quantitative variation of each type by stratigraphy unit by weight in grams

Data presented in the above tables suggest that most ceramic concentrations belong to codes A, B, BC, C, and D. This implies that the concentrations comprise the main products of TMK02 and other kilns near it. Other codes represent less than ten percent of the total assemblage.

Technique in Clay and Glaze

Ceramics obtained from the excavation contain both glazed and unglazed stoneware and earthenware. Glazed wares represent the highest concentration of the total assemblage. Earthenware comprises mostly cooking pots and large containers. Most of the stoneware was possibly fired between 900 to 1200 degrees Celsius.

Traces on ceramic walls suggest three techniques were used in making pottery at Thnal Mrech. The wheel was commonly used to make small-sized pottery such as codes B, C, D, G, and J. Coiling is mostly observed on the larger ones including codes A, E, F, H, and I. Another technique, paddle and anvil, was possibly applied to code I as seen on a few pieces recovered from unit H.

The paste of most pottery of codes B, C, D, E, G, and J is a fine white clay that sometimes contains tiny pores. Temper is seen in the paste of codes A, E, F, H, and I, and some dark clay is used for the paste of codes BC and J. Temper was used to strengthen pottery, improve drying and to produce uniform density, and possibly to change the glaze appearance by making it darker.

Firing supports found in the excavation were made of white clay similar to that used for pottery. The inner paste indicates that potters might apply silt from decomposed sandstone as temper to reduce clay stickiness. Silt temper may produce numerous pores that reduce the weight of firing supports.

In general, glaze observed on ceramics taken from unit H comes in four varieties: common Kulen green, hay yellow, milky white, and light brown. A few ceramics, however, contain a mixture of both green and light brown glazes. Very few pieces were slipped dark reddish brown resulting from iron-rich clay. Green glaze is the majority colour. The glaze was probably applied by dipping the ceramics in liquid glaze. On parts, particularly bases and rims, where glaze was not desired, it was wiped away with cloth. The interiors were glazed by swirling a small amount of liquid glaze leaving swirl-marks. Unglazed wasters imply that potters employed two firing process, i.e., pre-firing before glazing and final firing after glazing.

Glaze variation possibly resulted from temperature differences and clay mineral contents. Varieties of glaze coincide with different clay textures, i.e., green glaze is seen on the pure white clay while brown glaze was applied on dark brown clay that sometimes contains much temper. This evidence indicates that potters chose to match glaze colour with different clay sources. This implies that glaze technique was already developed by the time of TMK 02. This could result from long-term observation or merely coincidence (Chhay, Chap 2002).

During a lecture by Bonnie Baskin at the Conservation d'Angkor to archaeologists from various NGOs in the Angkor region in 2003, potters from the Yuko kiln reported that replicas of *kothh* code C using white clay, taken from Anlong Thom on Phnom Kulen, resulted in a glaze highly comparable to Kulen Wares. Use of dark or red clay yielded brown-glazed wares similar to ancient ones.

Hypotheses and Discussion

Kilns on Thnal Mrech are mostly built on an artificial embankment, thereby exploiting its slope. Other kiln sites found in Angkor are also built on embankments, such as at Sarsei, Khnar Po, and Tani. Conversely, Bang Kong and one of the Sarsei kiln group were built on mounds in flat areas near river channels and ponds. Tani kiln B1 shows a similar crossdraft structure to TMK 02 (Aoyagi et al 2000). The structure of TMK 02 is considerably different from that of kilns in Buriram. Influence of the dragon kiln from China on the structure of TMK cannot be verified due to limited research. The structure could be merely the result of internal evolution from previous periods, external influence, or a combination of both; this is the same concept as represented by Khmer temple construction.

It is reasonable to speculate that kiln location was based on proximity to the nearest clay source. Clay could be found in various streams sources or *chup*, Khmer for spring of water. In case of the Thnal Mrech embankment, it is extremely easy to collect clay and water because the

embankment is connected to the surrounding mountains, forming a huge reservoir which could have served to collect water from rain and natural water (see Hansen 1969 for further details on water management).

TMK 02 refutes the presumption that kiln form was often based on a symmetrical axis and elongated oval shape. It also suggests that different skills and methods were used by potters to build and modify kilns. Floor modification is likely indicative of separate firing processes for ceramics of different sizes on different steps due to spatial limitations. Small ceramics were placed on multiple steps while larger ones stood on pedestal firing supports stacked on the sloping floor. Spatial congestion may result in major ceramic deformation during the firing process. This is possibly one of the reasons for the fact that wasters represent most of the total artifact assemblage. Some wasters may have been utilizable, but the potters might have had a concept of completeness or beauty in their products and so did not make use of them. The orientation of the firebox toward the northeast suggests that potters might have exploited the wind direction during the dry season particularly winter (December and January) when the wind blows from the northeast.

Artifacts uncovered from unit H provide a concrete typology of products that might have been made for distribution to various places during the Angkor era. The majority of green-glazed wares and codes A, B, BC, C, and D fall into the typology of ceramics produced by TMK 02. Kulen wares have been found almost in every Angkorian site. This enables archaeologists/researchers to base their hypotheses on Kulen wares found during excavations.

The ultimate form and function of each type are still debatable due to cessation of production in the post-Angkor period. Although ceramic production was industrialized during the Angkor period, written evidence does not describe the physical appearance of the products. Most containers and other possible ceramic shapes mentioned in written sources from the pre-Angkor and Angkor periods have been identified as metal rather than clay artifacts. Groslier (1981) points out a reasonable explanation for this phenomenon, i.e. that the Khmer were so familiar with metal work that they did not improve their ceramic craftsmanship. However modern evidence for the appearance of certain shapes can be found among both metalware, particularly silver, and wooden utilitarian objects.

Similar types of ceramics have been uncovered from other kiln groups in Angkor. However, the products of other kilns are usually large vessels of codes E, F, and H, and roof tiles (code A). It is not yet possible to compare the quality of TMK 02 ceramics to the products of other kiln groups, because systematic studies of ceramics from other kiln groups, besides Tani, are yet to be conducted. Collections from unit H are mostly wasters, thus it is difficult to infer the quality of TMK based on these examples. However preliminary speculation can be advanced based on the apparently poor quality of TMK 02. Some green-glazed sherds collected from the Bang Kong kiln group yielded higher quality clay, glaze, and firing technique than ceramics from TMK 02. On the other hand ceramics uncovered from Tani, Sarsey, and Khnar Po are of inferior quality to TMK ceramics (Sophia 2000, Sok 2003, Em 2004).

The appearance of light brown-glazed ware in layer 1 indicates that there was also a later phase of kiln production at the TMK group, i.e., post TMK 02. It is plausible that the TMK group started to produce light brown-glazed wares after BP905. This conclusion supports the hypothesis that brown-glazed ware appeared during the eleventh century (Groslier 1981). This evidence implies that there should be another source of brown-glazed ware beyond the Buriram kilns, as suggested by Roxana Brown (1988).

AMS C14 dates of the early to mid-eleventh century do not confirm previous suggestions that Kulen ware dates back to the ninth century. However, TMK 02 is only one example among

many other kilns in the group. It is possible that other kilns may predate TMK 02 such as TMK 01. A charcoal sample from TMK01 produced an AMS C14 date of 1070 BP (± 30) (Yukitsugu, Chhay 2007). This indicates that the TMK group may have been involved in long-term ceramic production throughout the Angkor period. Lotus designs on various eave tiles found at Thnal Mrech bear similarity to those of eave tile designs on sandstone temples in the twelfth and thirteenth centuries.

Further studies will include chronology of the TMK site, comparative studies of kiln structure with different localities, both inside and outside Cambodia, comparative studies of ceramics found at various Khmer kilns, and an assessment of Kulen-type ceramics found at other archaeological sites. A database will also be produced, incorporating all artifacts found during excavation. We hope that this report will contribute to a better understanding of Khmer ceramic technology.

Acknowledgments

The excavation would not have been accomplished without support from H.E Bun Narith Director of APSARA authority, H.E Ros Borath Vice Director of APSARA authority, Mrs. Mao Lao Head of Department of Monuments and Archaeology 1, Mr. Im Sokrithy, Mr. Ea Darith, Mr. Lam Sopheak and the National University of Singapore. We extend our gratitude to the following individuals: archaeologists: Tep Sokha, Chap Sopheara, San Kosal, Sok Hunly; graduate students: Kang Samoeurn, and Neak Sophirath; undergraduate students: Lanh Udomreangsei, Em Kimsreang, Sakhoeurn Sakda, Chhun Sambor, Ieng Khantei, Chhun Chandy, Keo Chany, and Chan Ra; foreign researchers: Sharon Wong Wee Yee, and Edna Wong for their assistance during the excavation; locals living on Phnom Kulen for their generous participation and support. Lun Votey, Tuy Lyda, Men Chandarareasmei, Ly Chariya, and Em Socheata deserved great thanks for their contribution with laboratory work and artifacts analysis. We thank G.Y. Goh of NTU for the final layout of this report. We thank both Cambodian and foreign researchers for their insight and critique which help motivate us to achieve goals.

Abbreviations

AMS: Accelerator Mass Spectrometry
 EFEO: École Française d'Extrême-Orient
 SU: Stratigraphy Unit
 TMK: Thnal Mrech Kiln

References Cited

- Aoyagi, Yoji et al
 2000. "Excavation of a Khmer Ceramic Kiln Site: Report of the Investigation of Kiln B1, Tani Kiln Complex", *Udaya*, Vol 1: 235-253. Phnom Penh.
- Aymonier, Étienne
 1901. *Le Cambodge: Les Provinces Siamoises. Vol II*. Paris: Ernest Leroux.
- Boulbet, Jean and Dagens, Bruno
 1973. "Les Sites Archéologiques de la région du Bhnam Gulen (Phnom Kulen)", *Arts Asiatiques*, Vol 27. (n° special).

- Brown, Roxana
1988. *The Ceramic of Southeast Asia Their Dating and Identification*. Second edition. Singapore: Oxford University Press.
- Chuon Nath
1967. *Khmer Dictionary*. Phnom Penh: Buddhist Institute.
- Chhay Visoth, Chap Sopheara
2002. *Ceramics from Anlong Thom* (in Khmer). B.A Thesis, Department of Archaeology, Royal University of Fine Art, Phnom Penh.
- Coedès, George
1951. *Inscriptions du Cambodge, Vol III*. Paris: EFEO.
1954. *Inscriptions du Cambodge, Vol VI*. Paris: EFEO.
1968. *The Indianized States of Southeast Asia*. Edited by Walter F. Vella; translated by Sue Brown Cowing. Honolulu: University of Hawaii Press.
- Dumarçay, Jaques and Courbin, Paul
1988. *Le Fouille de Srah Srang, in Documents Graphiques de la Conservation d'Angkor 1963-1971*. Paris: EFEO.
- Ear, Darith
2000. "Summary of new light on Khmer Ceramic" (in Khmer), *Udaya*, Vol. 1: 37-47, Phnom Penh.
- Em, Socheata
2004. *Ceramics from Khnar Po Kilns* (in Khmer), B.A Thesis, Department of Archaeology, Royal University of Fine Art, Phnom Penh.
- Groslier, Bernard Philippe
1981. "Introduction to the Ceramic Wares of Angkor", *Khmer Ceramics 9th-14th Century*. Singapore: Southeast Asian Ceramic Society.
- Hansen, Erik
1969. *Cambodge: Aménagement du Phnom Kulen*. UNESCO Rapport dactylographié.
- Nishimura
2000. "Report of the Kulen Kiln Site Inspection", *Report on the Cooperative Research of Asian Cultural Heritage Protection* (in Japanese).
- Rooney, Dawn
2000. "Khmer Ceramics: Their Role in Angkorian Society", *Udaya*, Vol I: 129-145. Phnom Penh.
- Kram Silapakorn
1989. *Ancient Kiln Sites in Buriram Province*. Bangkok: Silapakorn.

Sok, Keosovannara

2003. *Ceramics from Sarsei Kilns* (in Khmer), B.A Thesis, Department of Archaeology, Royal University of Fine Art, Phnom Penh.

The Agency for Cultural Affairs, Nara National Cultural Properties Research Institute, Japan and the APSARA Authority

2000. "Recent Research on Kiln Sites in the Angkor Area", *Udaya*, Vol 1: 217-234, Phnom Penh.

Yukitsugu, Tabata and Chhay, Visoth

2007. "Preliminary Report of the Excavation of the Anlong Thom Kiln Site, Cambodia", *Journal of Southeast Asian Archaeology*, Vol 27: 63-69

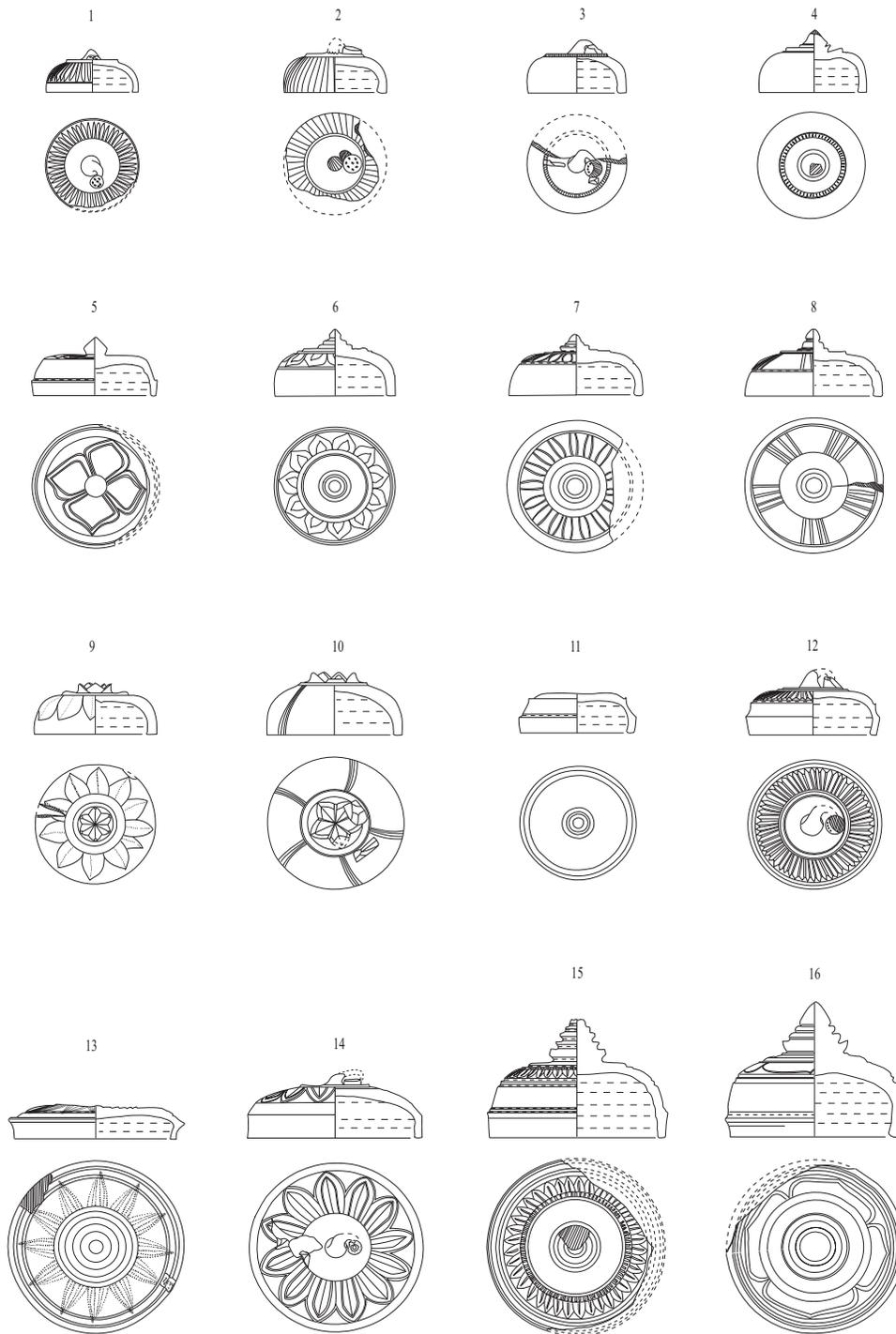
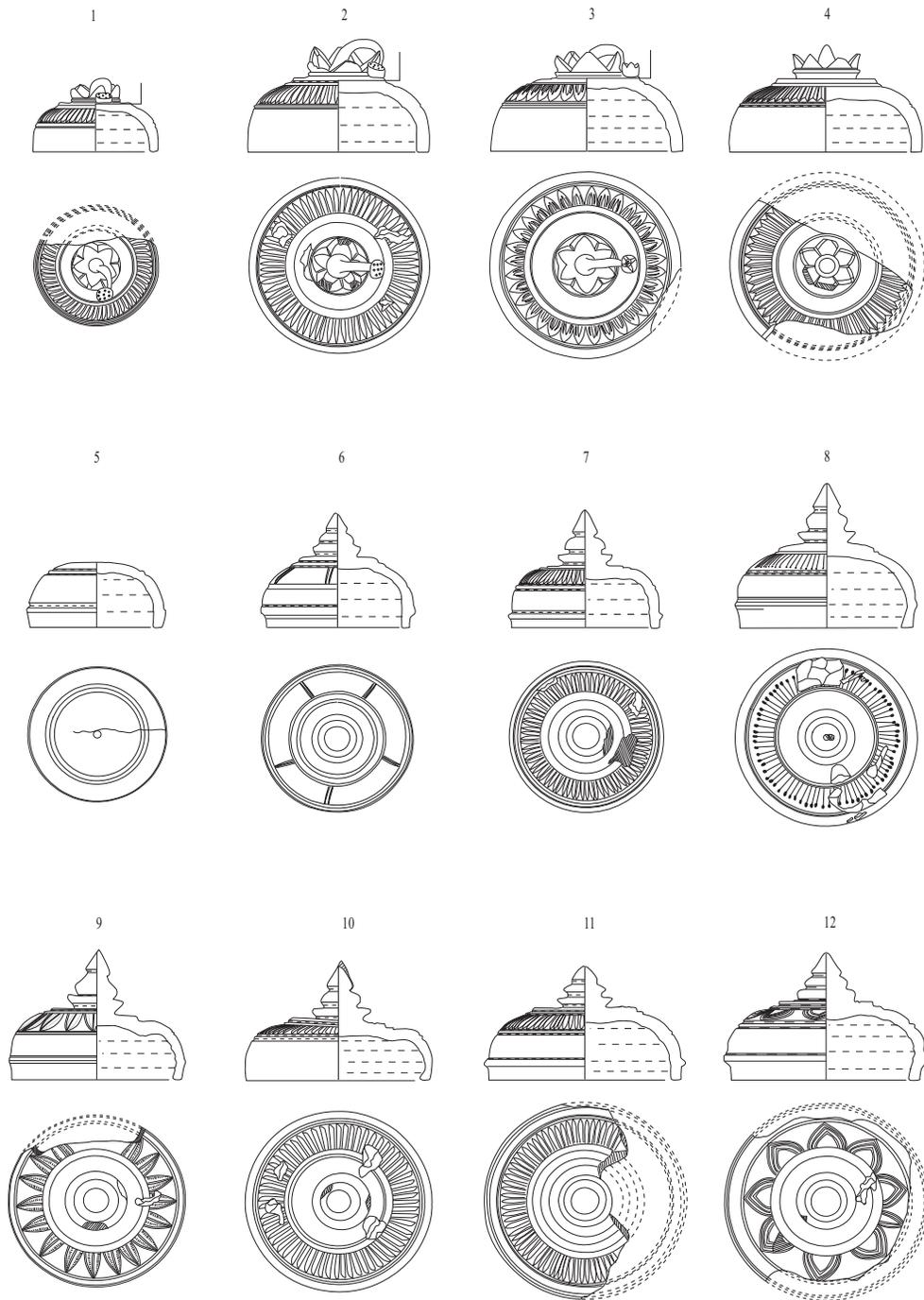


Figure 07. Lids of Covered Containers (Danlap and Kothh)





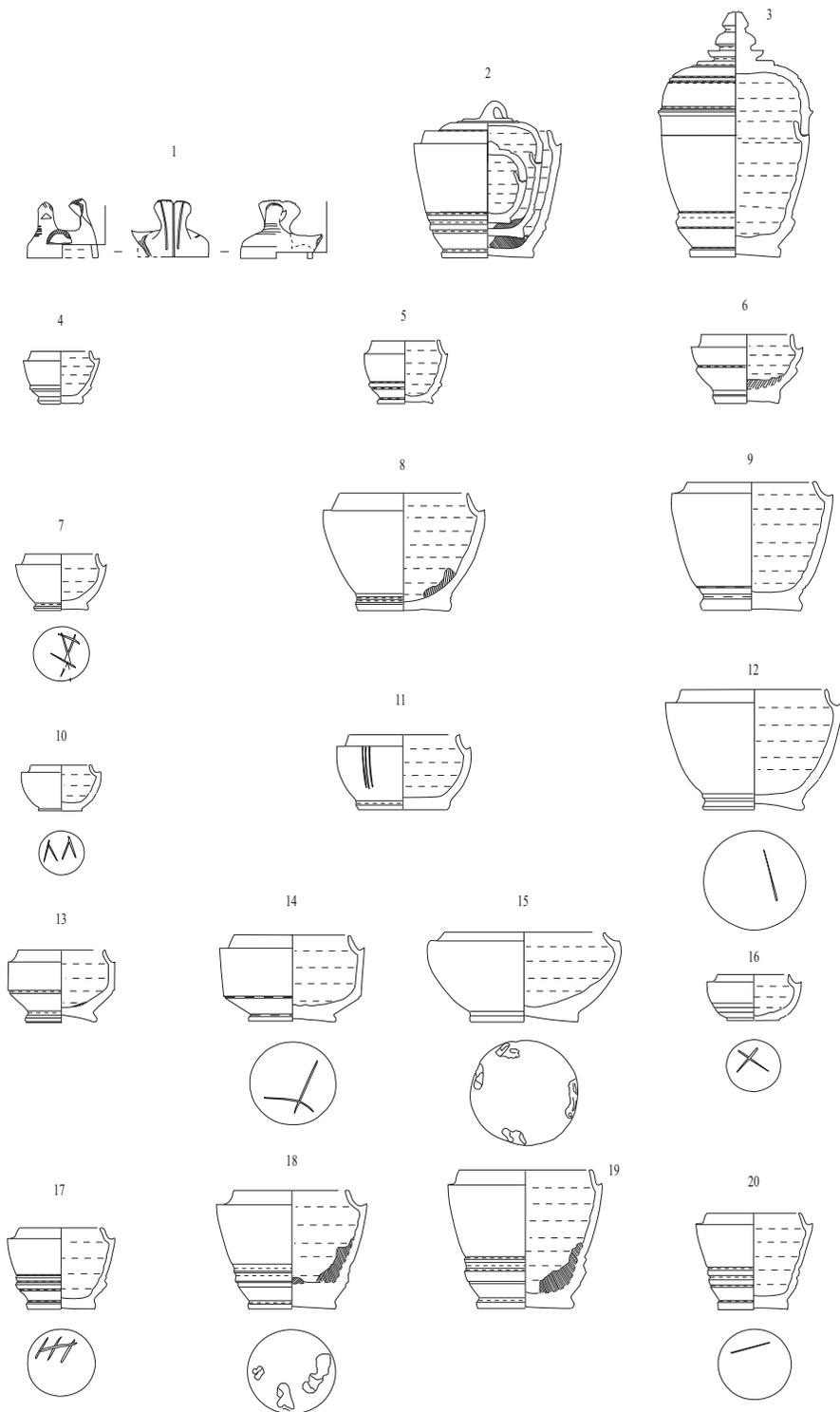


Figure 09. Covered Containers (Danlap and Kothh)



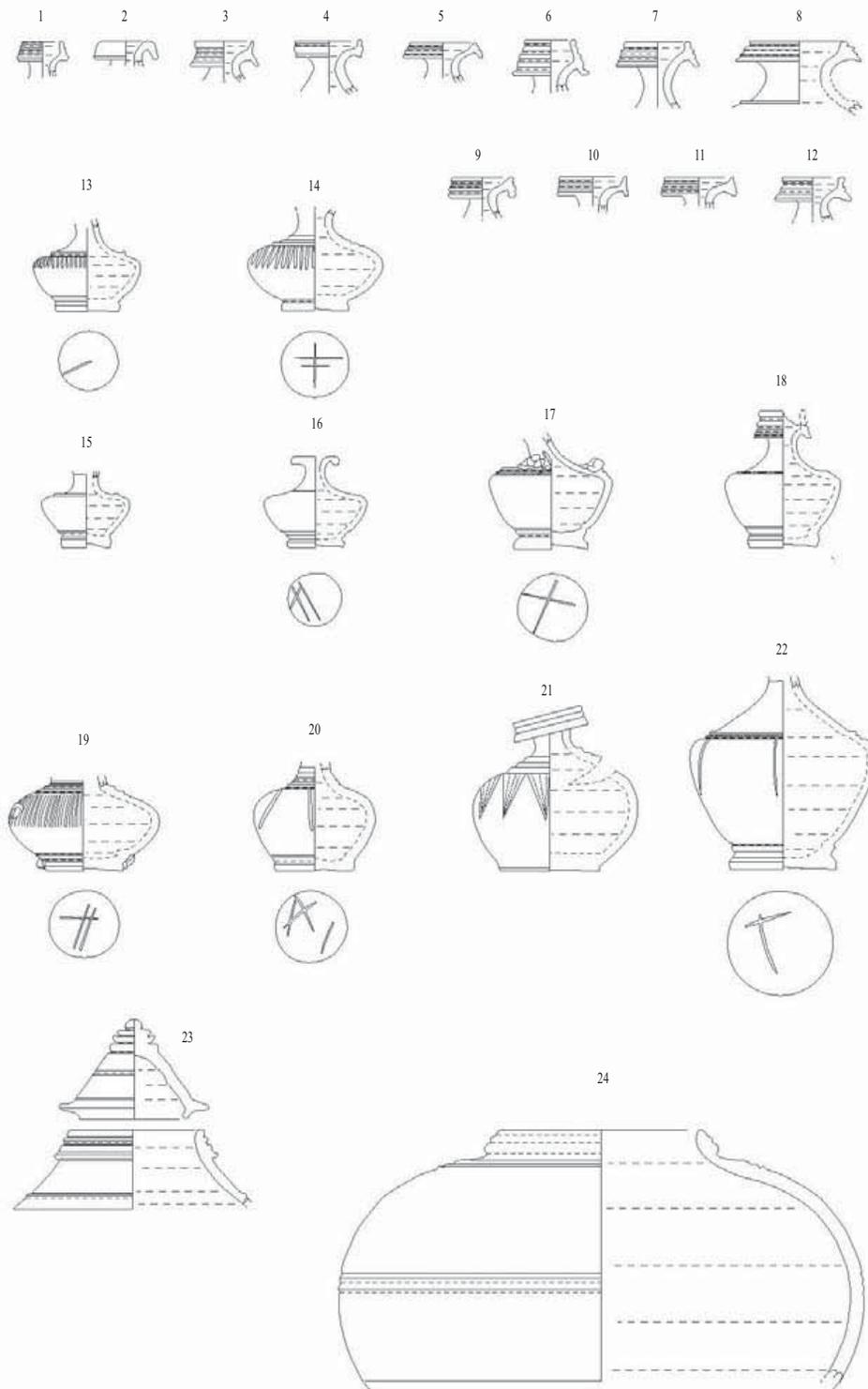


Figure 10. Containers (Kho h and K ala)





Plate 10. Kpoeurng:
roof tiles, TMK 02,
Thnal Mrech Kiln
site, Phnom Kulen.



Plate 11. Kumrop:
lids, the lids of Dan-
lap and Kothh, TMK
02, Thnal Mrech Kiln
site, Phnom Kulen.

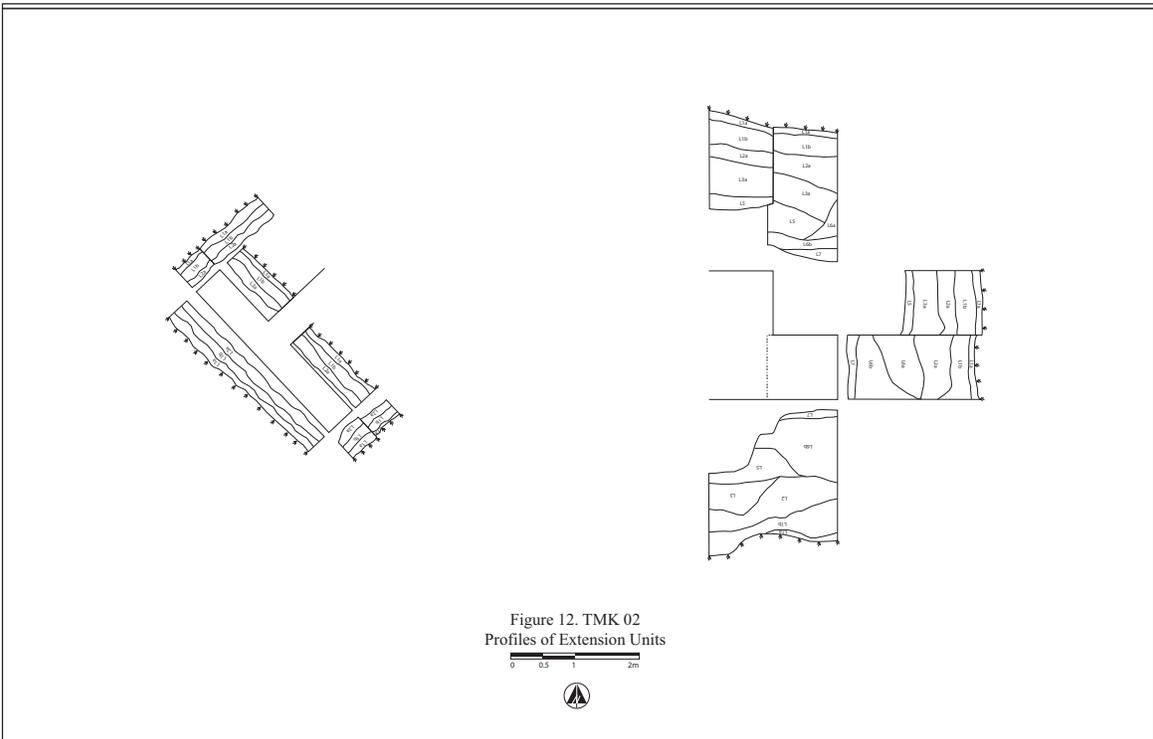
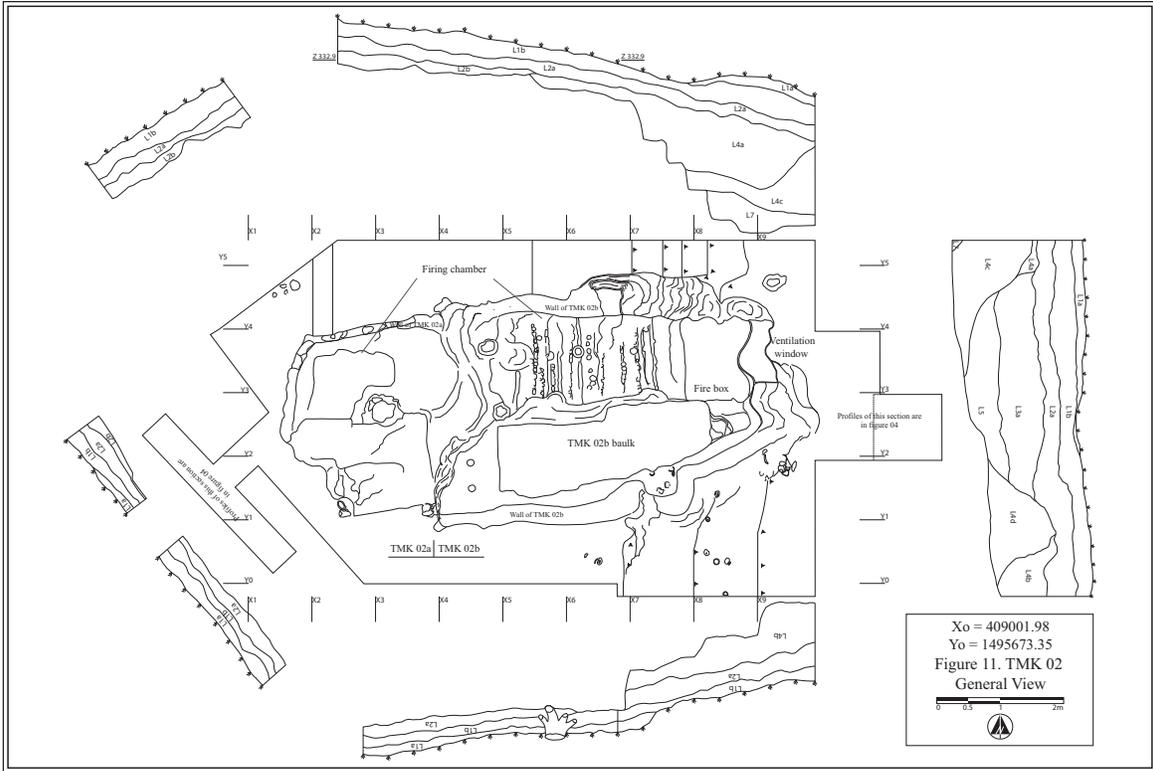


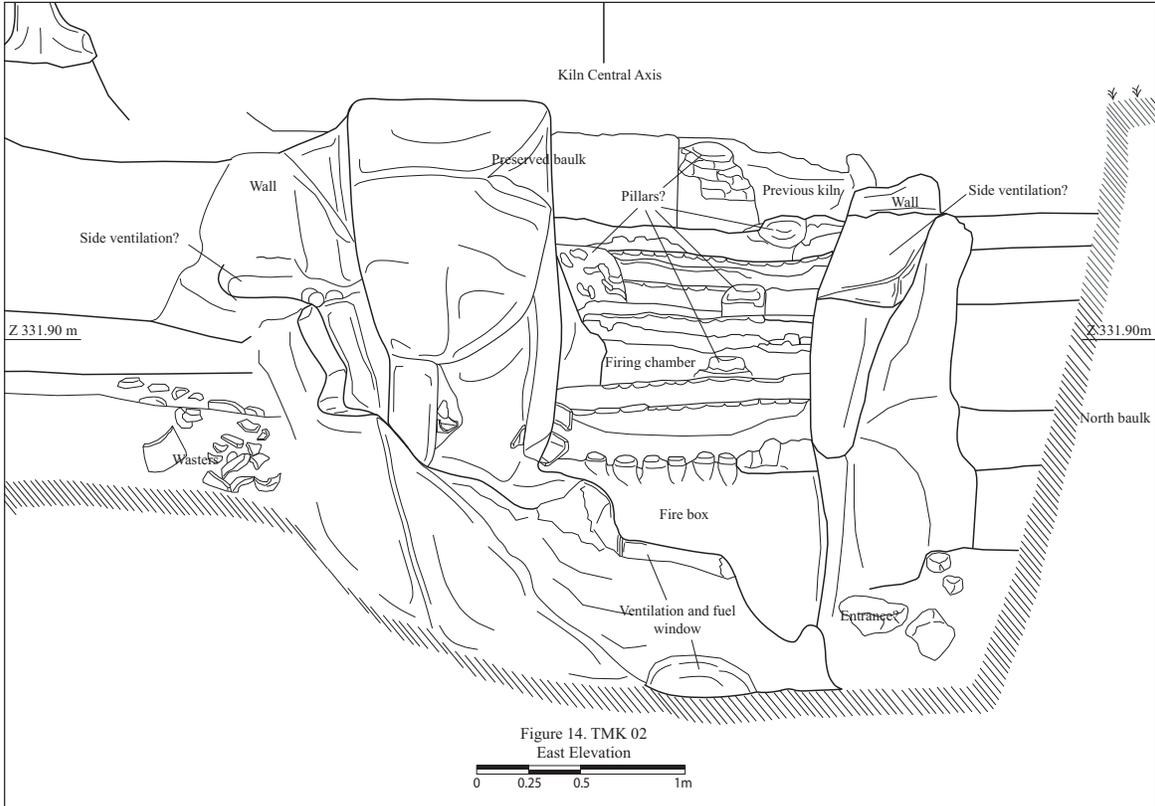
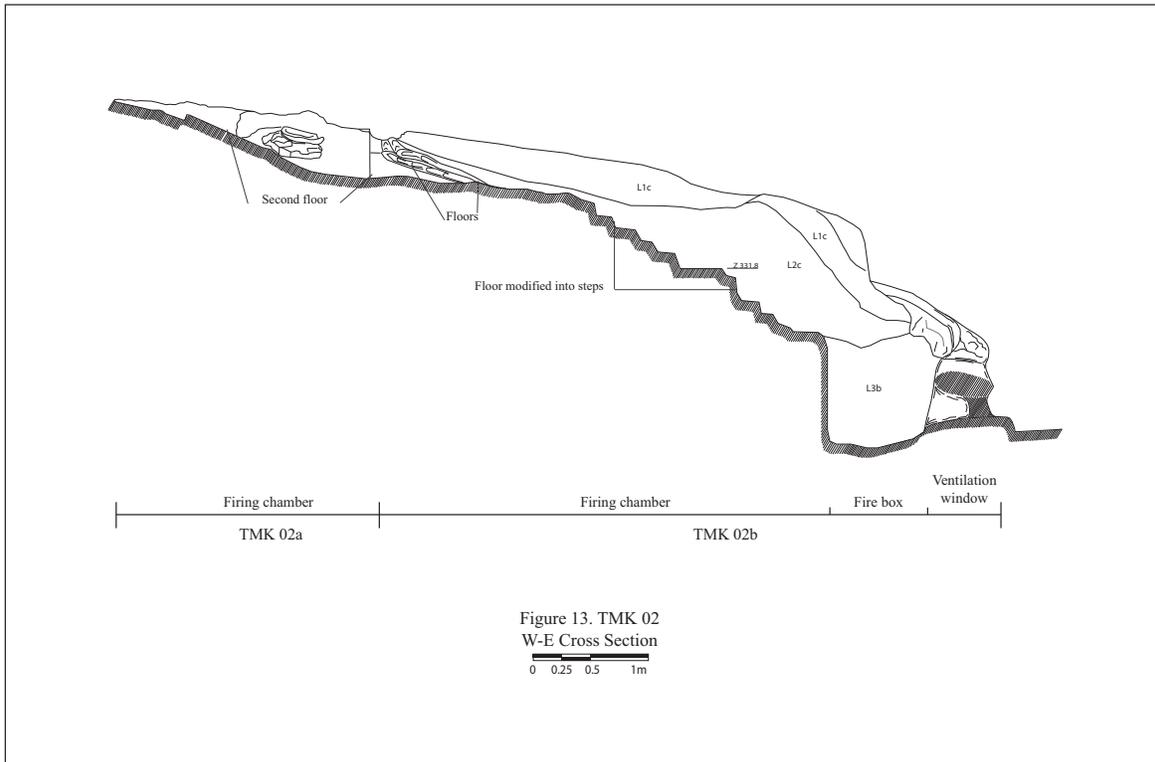
Plate 12. Danlap
and Kothh contain-
ers, TMK 02, Thnal
Mrech Kiln site,
Phnom Kulen.

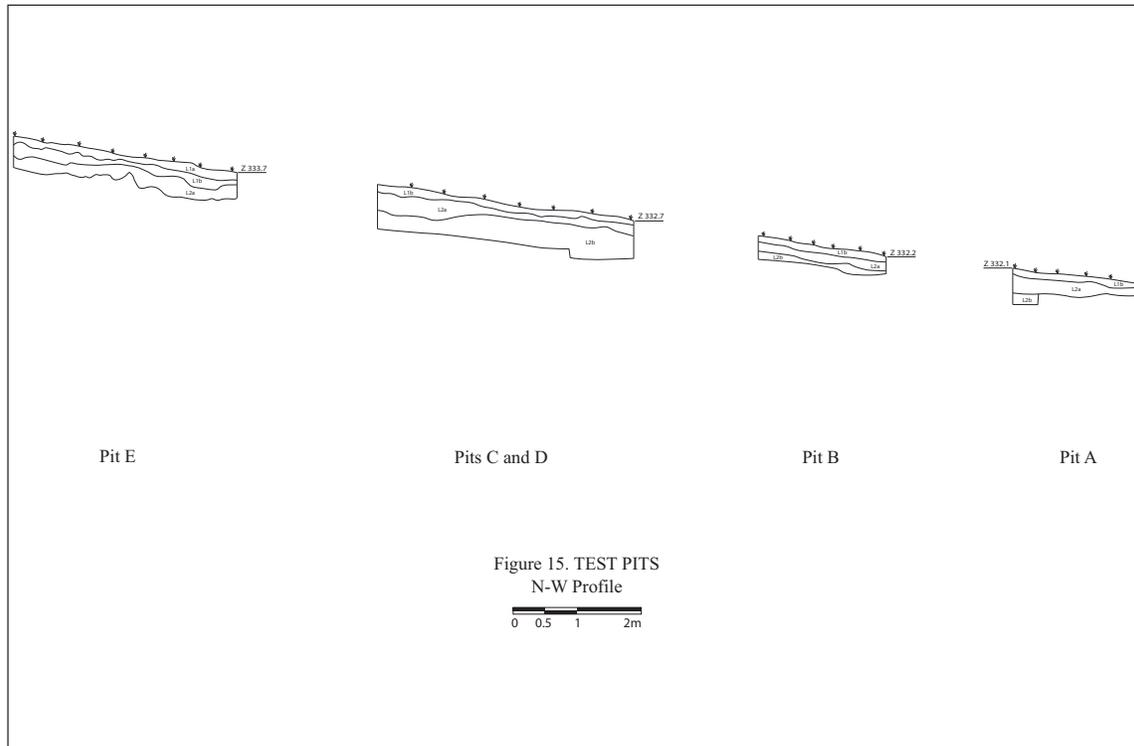


Plate 13. Khouch
containers, TMK 02,
Thnal Mrech Kiln
site, Phnom Kulen.

Appendix A
Plans, Sections, and Geological layers
(Figures 11-15)







Stratigraphic Descriptions

- L1a: Yellowish brown to dark yellowish brown. Sandy loam, moderate force is required to break clods.
- L1b: Grayish brown to dark yellowish brown. Sandy loam, weak force is required to break clods.
- L1c: Light yellowish brown to dark yellowish brown. Sandy loams, very strong force required to break clods.
- L2a: Pale brown to dark yellowish brown. Sandy loam, moderate force is required to break clods.
- L2b: Dark brown to dark yellowish brown. Sandy loam, moderate force is required to break clods.
- L2c: Yellow to dark yellowish brown. Loamy sand, very weak force is required to break clods.
- L3a: Yellowish brown. Sand is a mixture between newly-deposited layer 2 and eroded particles of layer 3; very weak force is required to break clods.
- L3b: Yellowish brown (5/6 to 5/8). Loamy sand, 50% of which comprises fragments of burnt clay from the kiln structure. Weak force is required to break clods.
- L4a: Very pale brown to yellowish brown. Sandy loam, moderate force is required to break clods.
- L4b: Brownish yellow to yellowish brown. Sandy loam, moderate force is required to break clods.
- L4c: Light gray to dark yellowish brown. Loam with fine sand, moderate force is required to break clods.
- L4d: Light yellowish brown to dark yellowish brown. Sandy loam, moderate force is required to break clods.
- L5: Reddish yellow to strong brown. Fine sand: eroded from burned clay (kiln roof), very weak force is required to break clods.
- L6: Strong brown. Sandy loam, moderate force is required to break clods.
- L7: Brownish yellow. Silty clay loam: natural soil of the dike surface, moderate force is required to break clods.

Appendix B

Radiocarbon Dates

INSTITUTE OF GEOLOGICAL AND NUCLEAR SCIENCES LTD.

PO Box 31312, Lower Hutt, New Zealand
 Phone (+64 4) 570 4671, Fax (+64 4) 570 4657

RADIOCARBON CALIBRATION REPORT

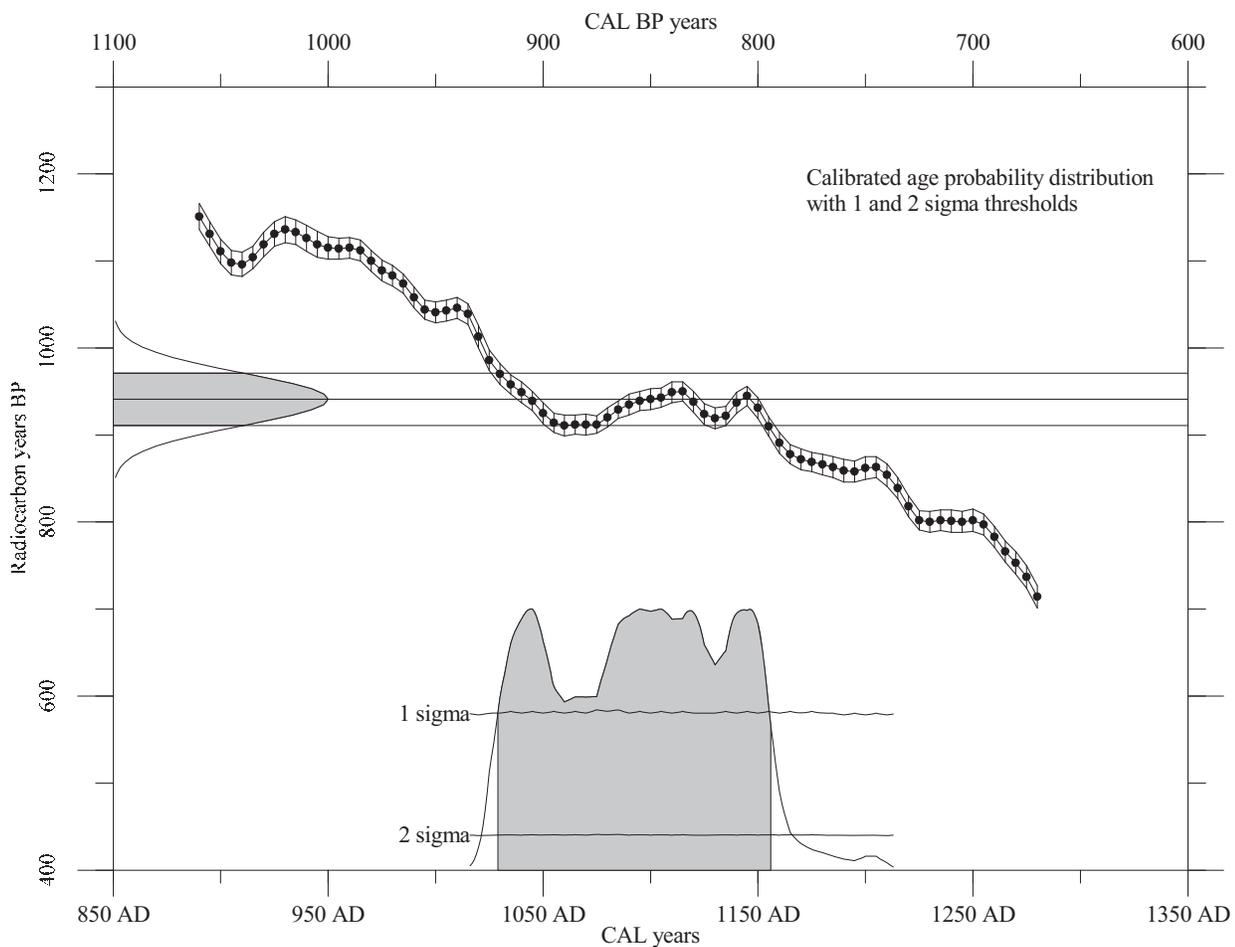
NZA 27632 CONVENTIONAL RADIOCARBON AGE 941 ± 30 years BP

Atmospheric data from Reimer et al (2004);

PJ Reimer, MGL Baillie, E Bard, A Bayliss, JW Beck, C Bertrand, PG Blackwell,
 CE Buck, G Burr, KB Cutler, PE Damon, RL Edwards, RG Fairbanks, M Friedrich,
 TP Guilderson, KA Hughen, B Kromer, FG McCormac, S Manning, C Bronk Ramsey,
 RW Reimer, S Remmele, JR Southon, M Stuiver, S Talamo, FW Taylor,
 J van der Plicht, and CE Weyhenmeyer (2004), Radiocarbon 46:1029-1058

CALIBRATED AGE in terms of confidence intervals (Smoothing parameter: 0, Offset: 0)

2 sigma interval is 1022 AD to 1166 AD	928 BP to 784 BP (97.2% of area)
1 sigma interval is 1029 AD to 1156 AD	921 BP to 794 BP (92.5% of area)



INSTITUTE OF GEOLOGICAL AND NUCLEAR SCIENCES LTD.

PO Box 31312, Lower Hutt, New Zealand
 Phone (+64 4) 570 4671, Fax (+64 4) 570 4657

RADIOCARBON CALIBRATION REPORT

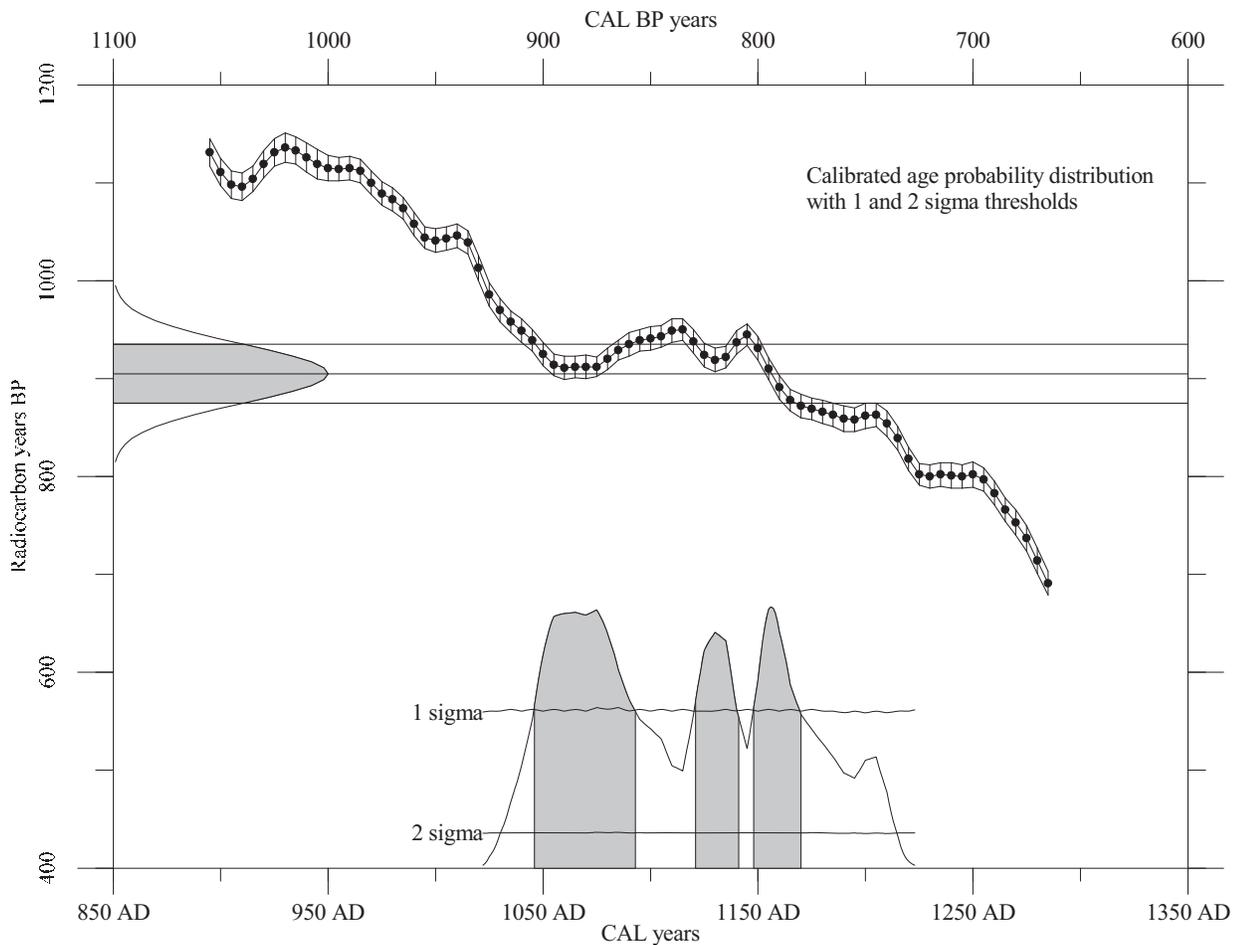
NZA 27633 CONVENTIONAL RADIOCARBON AGE 905 ± 30 years BP

Atmospheric data from Reimer et al (2004);

PJ Reimer, MGL Baillie, E Bard, A Bayliss, JW Beck, C Bertrand, PG Blackwell,
 CE Buck, G Burr, KB Cutler, PE Damon, RL Edwards, RG Fairbanks, M Friedrich,
 TP Guilderson, KA Hughen, B Kromer, FG McCormac, S Manning, C Bronk Ramsey,
 RW Reimer, S Remmele, JR Southon, M Stuiver, S Talamo, FW Taylor,
 J van der Plicht, and CE Weyhenmeyer (2004), Radiocarbon 46:1029-1058

CALIBRATED AGE in terms of confidence intervals (Smoothing parameter: 0, Offset: 0)

2 sigma interval is 1031 AD to 1215 AD	919 BP to 735 BP (99.0% of area)
1 sigma interval is 1046 AD to 1093 AD	904 BP to 857 BP (35.2% of area)
plus 1121 AD to 1141 AD	829 BP to 809 BP (13.7% of area)
plus 1148 AD to 1170 AD	802 BP to 780 BP (15.3% of area)



INSTITUTE OF GEOLOGICAL AND NUCLEAR SCIENCES LTD.

PO Box 31312, Lower Hutt, New Zealand
 Phone (+64 4) 570 4671, Fax (+64 4) 570 4657

RADIOCARBON CALIBRATION REPORT

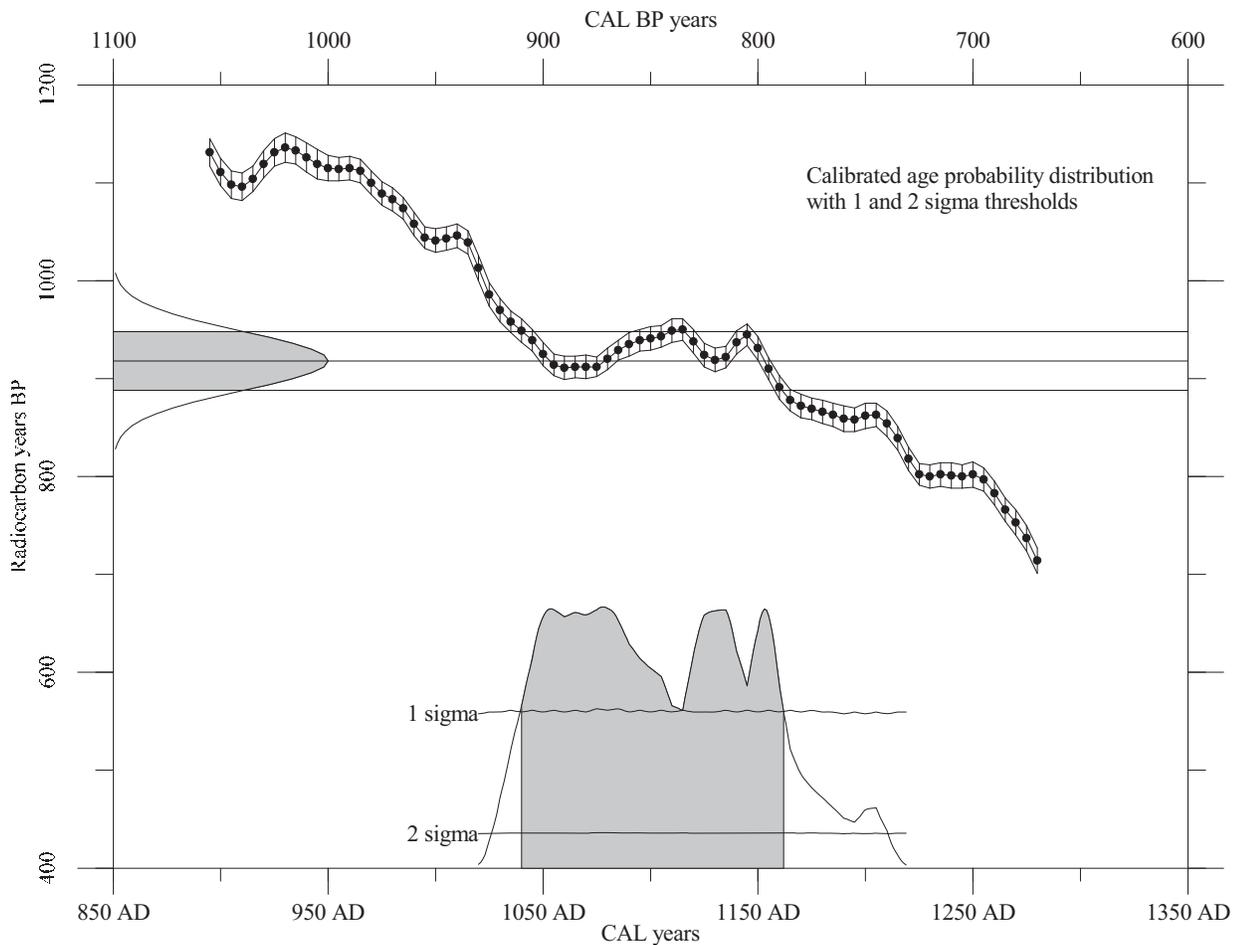
NZA 27634 CONVENTIONAL RADIOCARBON AGE 918 ± 30 years BP

Atmospheric data from Reimer et al (2004);

PJ Reimer, MGL Baillie, E Bard, A Bayliss, JW Beck, C Bertrand, PG Blackwell,
 CE Buck, G Burr, KB Cutler, PE Damon, RL Edwards, RG Fairbanks, M Friedrich,
 TP Guilderson, KA Hughen, B Kromer, FG McCormac, S Manning, C Bronk Ramsey,
 RW Reimer, S Remmele, JR Southon, M Stuiver, S Talamo, FW Taylor,
 J van der Plicht, and CE Weyhenmeyer (2004), Radiocarbon 46:1029-1058

CALIBRATED AGE in terms of confidence intervals (Smoothing parameter: 0, Offset: 0)

2 sigma interval is 1027 AD to 1211 AD	923 BP to 739 BP (99.2% of area)
1 sigma interval is 1040 AD to 1162 AD	910 BP to 788 BP (84.1% of area)



INSTITUTE OF GEOLOGICAL AND NUCLEAR SCIENCES LTD.

PO Box 31312, Lower Hutt, New Zealand
 Phone (+64 4) 570 4671, Fax (+64 4) 570 4657

RADIOCARBON CALIBRATION REPORT

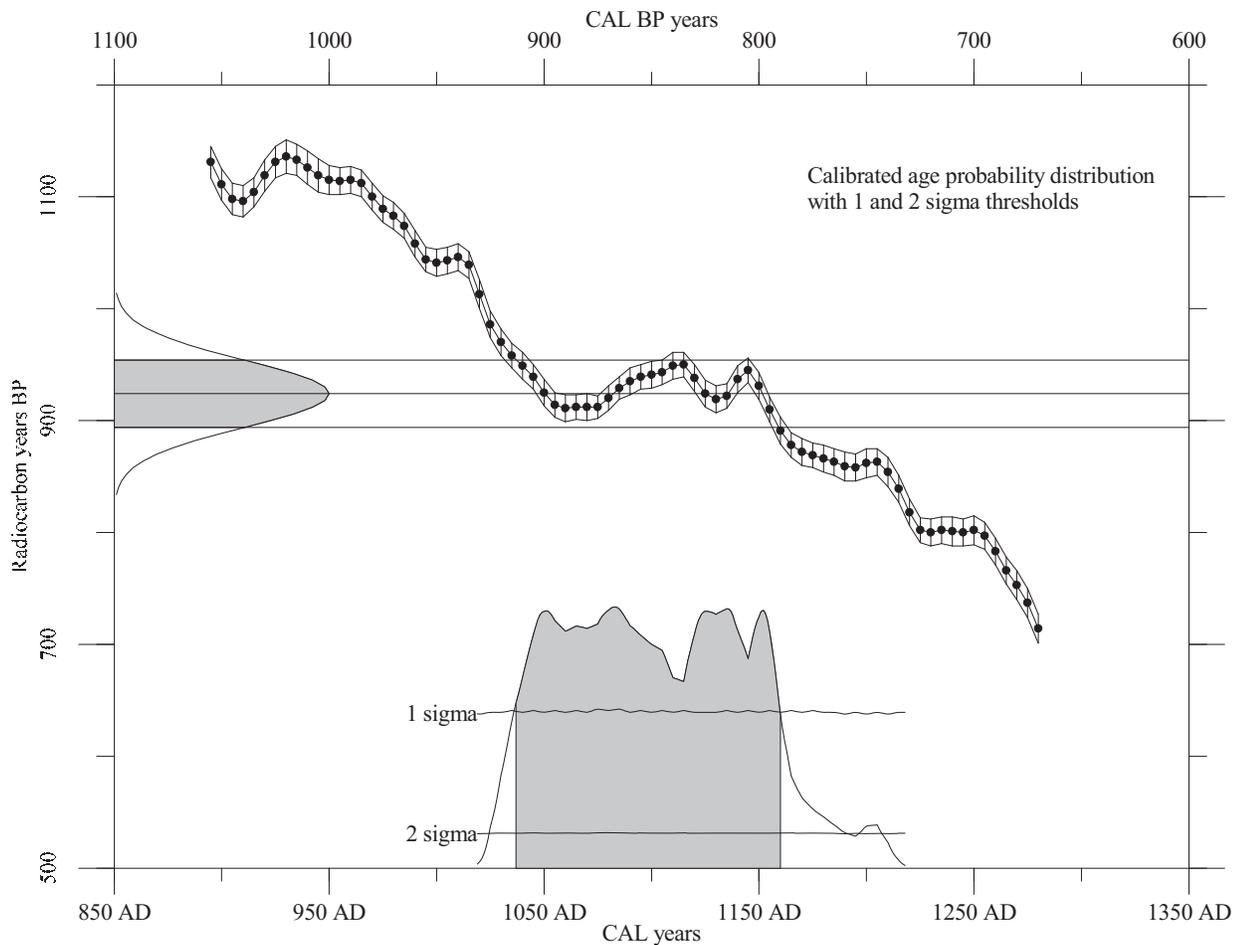
NZA 27635 CONVENTIONAL RADIOCARBON AGE 924 ± 30 years BP

Atmospheric data from Reimer et al (2004);

PJ Reimer, MGL Baillie, E Bard, A Bayliss, JW Beck, C Bertrand, PG Blackwell,
 CE Buck, G Burr, KB Cutler, PE Damon, RL Edwards, RG Fairbanks, M Friedrich,
 TP Guilderson, KA Hughen, B Kromer, FG McCormac, S Manning, C Bronk Ramsey,
 RW Reimer, S Remmele, JR Southon, M Stuiver, S Talamo, FW Taylor,
 J van der Plicht, and CE Weyhenmeyer (2004), Radiocarbon 46:1029-1058

CALIBRATED AGE in terms of confidence intervals (Smoothing parameter: 0, Offset: 0)

2 sigma interval is 1025 AD to 1208 AD	925 BP to 742 BP (98.7% of area)
1 sigma interval is 1037 AD to 1160 AD	913 BP to 790 BP (87.2% of area)



INSTITUTE OF GEOLOGICAL AND NUCLEAR SCIENCES LTD.

PO Box 31312, Lower Hutt, New Zealand
 Phone (+64 4) 570 4671, Fax (+64 4) 570 4657

RADIOCARBON CALIBRATION REPORT

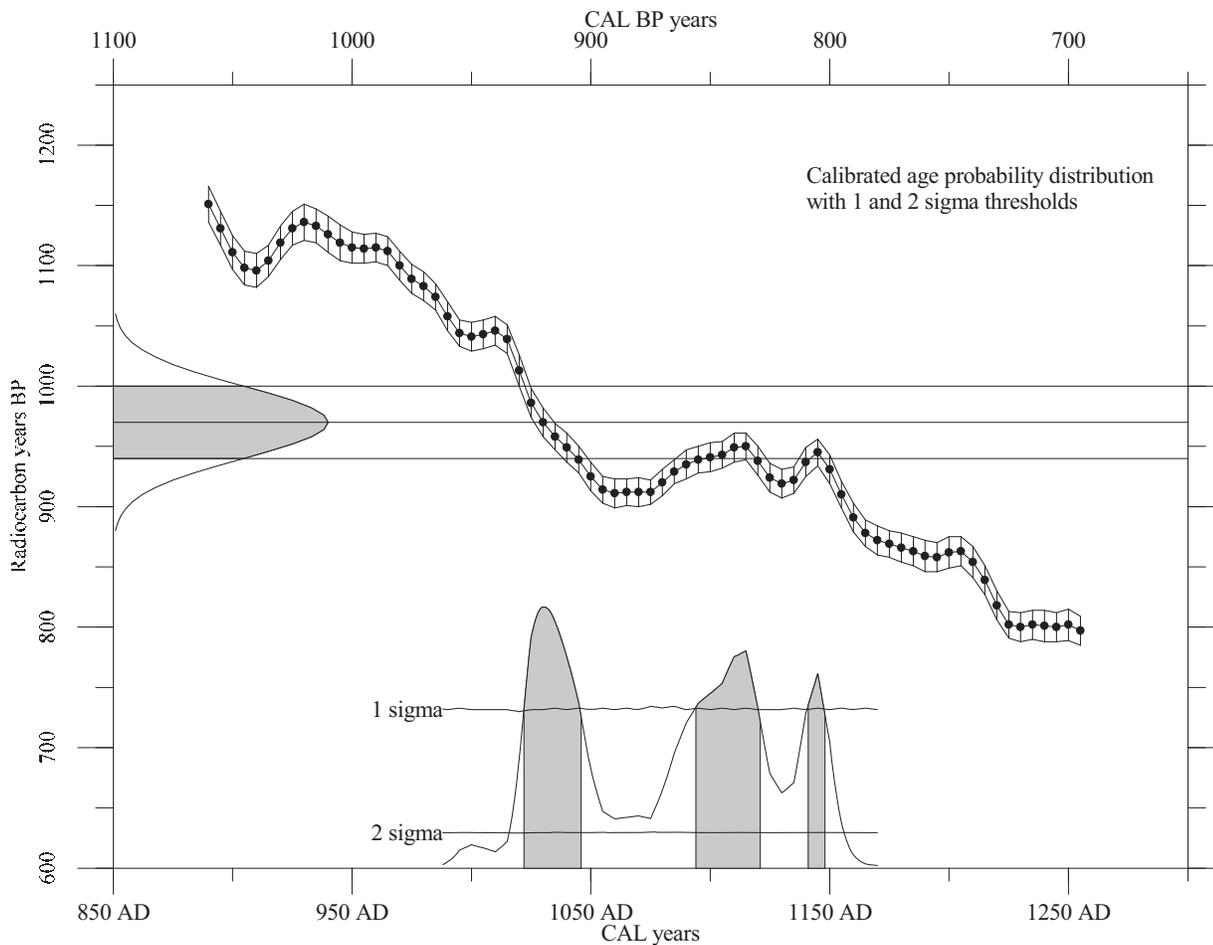
NZA 27640 CONVENTIONAL RADIOCARBON AGE 970 ± 30 years BP

Atmospheric data from Reimer et al (2004);

PJ Reimer, MGL Baillie, E Bard, A Bayliss, JW Beck, C Bertrand, PG Blackwell,
 CE Buck, G Burr, KB Cutler, PE Damon, RL Edwards, RG Fairbanks, M Friedrich,
 TP Guilderson, KA Hughen, B Kromer, FG McCormac, S Manning, C Bronk Ramsey,
 RW Reimer, S Remmele, JR Southon, M Stuiver, S Talamo, FW Taylor,
 J van der Plicht, and CE Weyhenmeyer (2004), Radiocarbon 46:1029-1058

CALIBRATED AGE in terms of confidence intervals (Smoothing parameter: 0, Offset: 0)

2 sigma interval is 1016 AD to 1157 AD	934 BP to 793 BP (96.5% of area)
1 sigma interval is 1022 AD to 1046 AD	928 BP to 904 BP (27.3% of area)
plus 1094 AD to 1121 AD	856 BP to 829 BP (25.8% of area)
plus 1141 AD to 1148 AD	809 BP to 802 BP (6.3% of area)



**Appendix C. Summary of analysis of the pottery collected from Thnal Mrech
Kiln 02 (TMK) and from surface of the Bangkong kiln group kiln site (BK)**

By E.H.Y. Wong

University of Sydney

Introduction

During the last fifty years, analysis of the chemical composition of ceramic pastes has become a useful adjunct in the study of archaeological ceramics, both in the area of assigning provenance to sherds of unknown attribution and in the study of distribution of the ceramic industry in the societies under study.

The present investigation is a pilot study conducted on material excavated from the Thnal Mrech Kiln site on the Kulen Plateau. The results of the elemental analysis, which included major, minor, and trace elements, are compared to those obtained from surface sherds collected from a kiln site at Bangkong, near Roluos.

While small in scale, this study serves as an initial assessment of the feasibility of further ceramic analytical study in the area and provides some insight into the production aspect of ceramics in the Angkorian period.

Samples submitted for analysis:

30 samples from the excavation of Thnal Mrech Kiln 02, consisting of:

- 13 samples of the predominant buff fabric vessels and box covers
- 5 samples of brown fabric roof tiles
- 7 samples of red-brown fabric vessels
- 4 samples of kiln supports
- 1 sample of dark grey fabric vessel

14 samples from surface collection of Bangkong kiln group consisting of:¹

- 10 samples of the predominant brown fabric vessels
- 3 samples of red-brown fabric vessels
- 1 clay disc

¹ This component of the research was funded by the Greater Angkor Project, a collaborative project between the University of Sydney, École Française d'Extrême-Orient and APSARA, the Cambodian government body responsible for the management of Angkor and Siem Reap. Funding is provided by the Australian Research Council (DP0211012 and DP0211600).

Sample preparation:

The samples were given identification numbers, catalogued and photographed before being sectioned with a diamond saw. The surfaces were taken off to avoid contamination. They were washed individually in beakers placed in ultrasonic baths for 20 minutes and dried on clean filter paper for 24 hours. Each sample was powdered manually using an agate mortar and pestle and placed in a sterile plastic container for transportation to the Geochemical Laboratory in the Royal Holloway, University of London for analysis.

Analytical protocol:

The powdered samples were dissolved with hydrofluoric and perchloric acids and also by fusion with lithium metaborate and analysed by inductively-coupled plasma atomic emission spectroscopy (ICP-AES) and inductively-coupled plasma mass spectroscopy (ICP-MS). The elements measured included:

Si, Al, Fe, Mg, Ca, Na, K, Ti, P, Mn (quoted as weight per cent oxides) and Ba, Co, Cr, Cs, Cu, Li, Nb, Ni, Rb, Sc, Sr, Ta, Th, Tl, U, V, Y, Zn, Zr and the rare earth elements - La, Ce, Pr, Nd, Sm, Eu, Gd, Dy, Ho, Yb, Lu (quoted as parts per million [ppm] element).

Lithium metaborate fusion:

0.2g of powdered sample was weighed into a graphite crucible and 1.0g of LiBO_2 added. The powders were carefully mixed and fused at 900 C for 20 minutes. The resulting mixture was dissolved in 200ml of cold 5% nitric acid. Ga is added to the flux to act as an internal standard to achieve an instrumental precision within 1 % for the major elements.

ICP-AES analysis

This solution was then analysed for Si, Al, Fe, Mg, Ca and Zr by ICP-AES using a Perkin Elmer Optima 3300R. The instrument was calibrated with natural and synthetic standards.

ICP-MS analysis

The solution was also used to analyse for Cs, Nb, Rb, Ta, Th, Tl, U, Y, and the rare earth elements (REEs) – La, Ce, Pr, Nd, Sm, Eu, Gd, Dy, Ho, Er, Yb, Lu using ICP

Mass Spectrometry. The instrument used was a Perkin Elmer Elan 5000 and the instrument was calibrated with natural and synthetic standards.

Hydrofluoric and perchloric acid digestion of the sample:

0.2 of powdered sample was dissolved in 6ml of HF and HClO₄ (2:1 mixture). This was then evaporated to dryness, cooled and dissolved in 20ml of 10% HNO₃.

This solution was analysed by ICP-AES for Na, K, Ti, P, Mn, Ba, Co, Cr, Cu, Li, Ni, Pb, Sc, Sr, V, & Zn.

Precision for the measurement of the major elements (notably Si) was improved by the use of internal standardisation. Accuracy was monitored by the concurrent analysis of five internal laboratory standards (KC10, KC11, KC12, KC14 and RH21) and two national reference materials (SCO1 and RGM1). Elemental concentrations were determined for the above elements using primary reference solutions and the analyses converted stoichiometrically to conventional oxide formulations for the major and minor constituents.

Working detection limits are well below 5 parts per million (ppm) for the ICP-AES analysis and 1 ppm for the ICP-MS analysis with a typical precision of 1%-1.5% RSD (relative standard deviation) when the concentration is 100 times greater than the detection limits.

Statistical analysis:

For the present analysis, elements in which two or more of the standards exceeding +/-10% of the quoted values have been excluded from the statistical analysis.

Statisti-XL 1.7 version has been used in the computation of the principal component analysis (PCA) and the discriminant analysis (DA) of the elemental values. The values are standardized for analysis using correlation matrix for the PCA and covariance matrix for DA with exclusion of elements in which tolerance limit is <0 .001.

Results:

The PCA shows good clustering of the various fabric groups, with PC 1 accounting for 53.4% and PC 2 accounting for 15.5% of the variance (see Figure 1). PC 1 is dominated by the REEs (ranging from 0.823 to 0.908), Al_2O_3 (0.874), Sr (0.866), Ba (0.816), Rb (0.812) and SiO_2 (-0.818). PC 2 is determined by Fe_2O_3 (0.816), Hf (-0.676), MnO (0.630) and CaO (0.628).

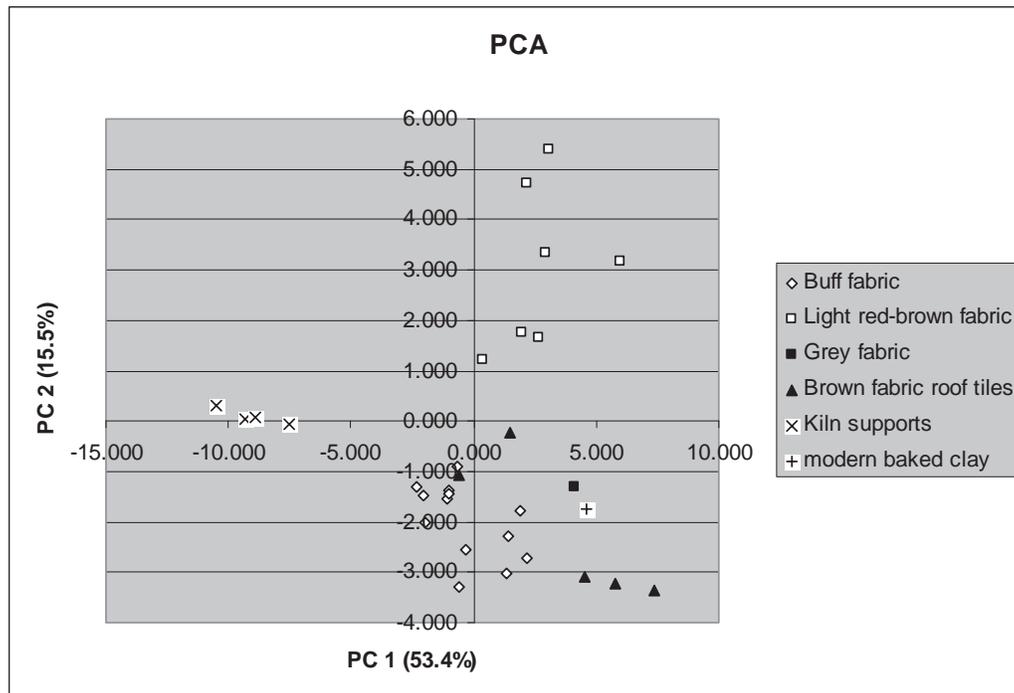


Figure 1 PCA of ceramics samples from Thnal Mrech Kiln 02

* 'modern baked clay' is a clay sample collected in the Kulen plateau by a traditional potter who then baked the small brick at 1200°C.

Figure 1 suggests reasonably good separation of clay components used in the red-brown ware. There is some overlap in the buff fabric and the brown fabric tiles.

A larger sample group would clarify the situation. The kiln supports are distinguished by a high content of SiO_2 .

When the BK samples are added to the graph they cluster as a group with the light red-brown fabric from the TMK group. The clay disc, however, clusters with the kiln supports collected from the excavation of Thnal Mrech Kiln (see Figure 2).

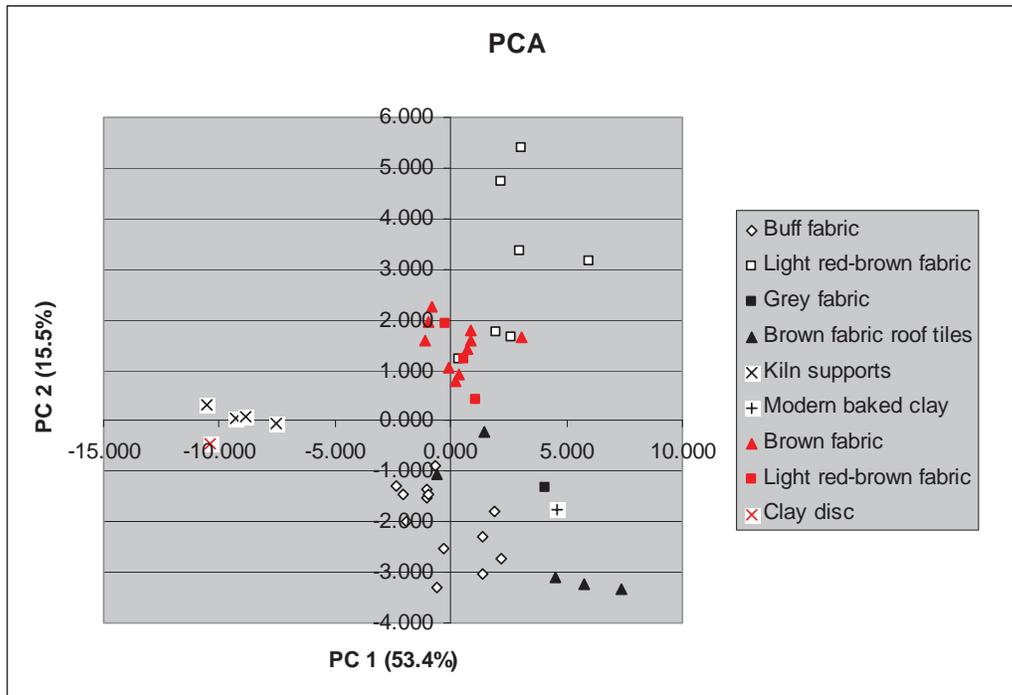


Figure 2 PCA of samples from Thnal Mrech Kiln 02 and Bangkok kiln group surface collection

Discriminant analysis performed on the data shows a more distinct pattern of clustering (see Figure 3).

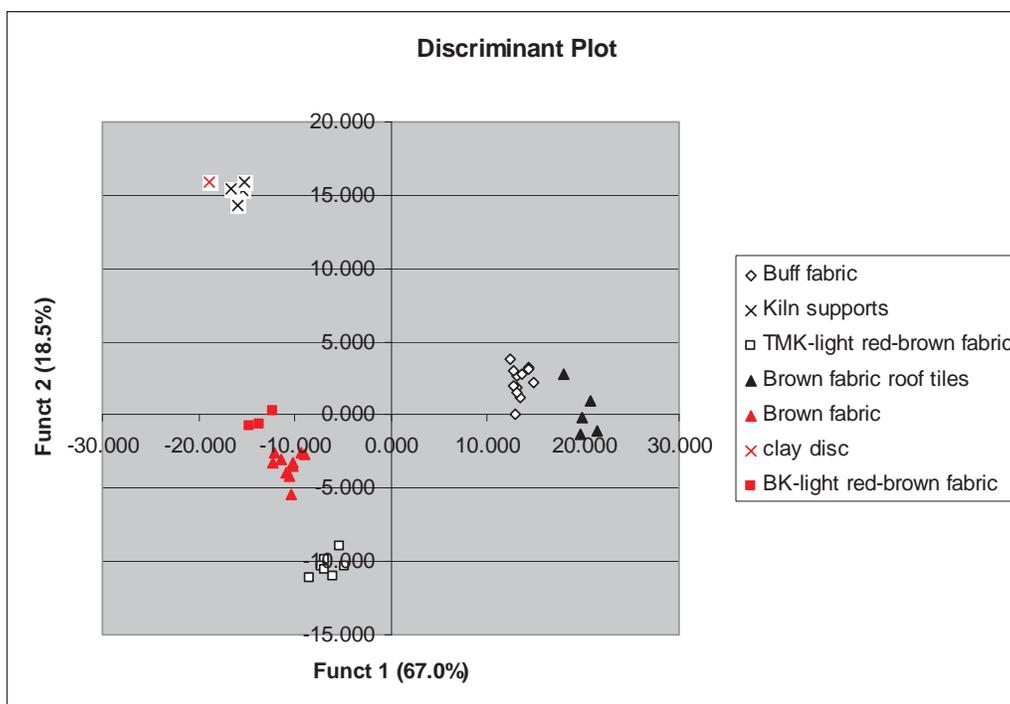


Figure 3 Discriminant analysis of samples from Thnal Mrech Kiln 02 and Bangkong kiln group surface collection

*TMK samples are represented by the black and black/white symbols

**BK samples are represented by the solid red and red cross symbols

***The single grey fabric sample from TMK and the baked clay sample have not been included in this analysis.

The buff fabric vessels and the brown fabric roof tiles from Thnal Mrech Thom are separated from the Bangkong samples, the kiln supports and the light red-brown fabrics by Function 1 which is dominated by Nd (-6.281), Pr (-6.100) and Sc (-5.820). Nd and Pr are both light REEs and Sc is a trace element.

Conclusions

From this pilot study of two sites it can be concluded that there is scope for the use of elemental study for sourcing of production of ceramics. The different fabric groups separate reasonably well within a production site on principal component analysis and between the sites when discriminant analysis is used. Obviously, more samples of

comparable stylistic wares from different kiln sites and associated clay sources are required before a meaningful database for comparison of excavated materials can be achieved. It is also important that a comprehensive range of trace elements, including the rare earth elements, be included in the analysis.

Acknowledgements

The author is grateful to the Greater Angkor Project for supporting the analytical work, Dr John Miksic and APSARA Authority for the invitation to their joint excavation at Thnal Mrech in January 2007 and the kind assistance and support of the staff of APSARA Authority and Dr Dan Penny in obtaining the ceramics for this study.