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Torp Chey: Analysis of an Angkorian Kiln and Ceramic Industry, Cambodia

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Torp Chey: Analysis of an Angkorian Kiln and Ceramic Industry, Cambodia

Abstract

The following report describes archaeological research at the Torp Chey kiln site, Siem Reap, Cambodia. The kilns represent an Angkorian brown-glazed stoneware production industry dating to approximately the 12th–14th/15th centuries CE (radiocarbon dated). The Torp Chey kiln site contains one of the largest documented and archaeologically tested ancient kilns in the region (21.0 x 2.8–3.2 m; Kiln Mound no. 2). The kiln also reflects unique and sophisticated design and technology, such as the incorporation of three horizontal secondary firing trenches that basally transect four separate firing chambers. The creation of a sandstone rubble and clay base to the firing chambers and other features are also distinctive. The intention of this report is to provide updated research information, data, analysis, results and tentative interpretations for scholars and students in order to build a more comprehensive understanding of ancient ceramic industries and their implications in Mainland Southeast Asia. Although Angkor-focused, results are applicable to regional and global discourse as well as industry and economic production and supply chain models. We are eager to receive questions and feedback as well as provide additional information where possible.

Key Words: Archaeology; Cambodia; Angkor; Kiln; Ceramic Technology, Industry and Economics; Glazed Stoneware

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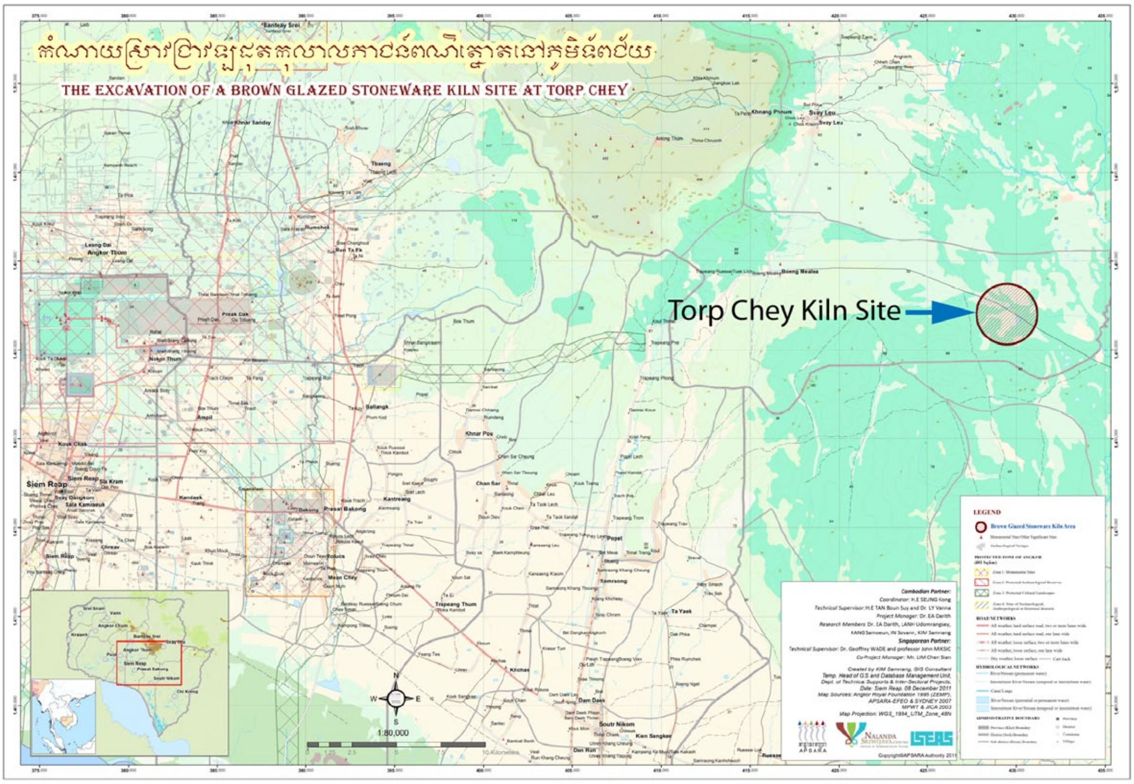
1: Introduction

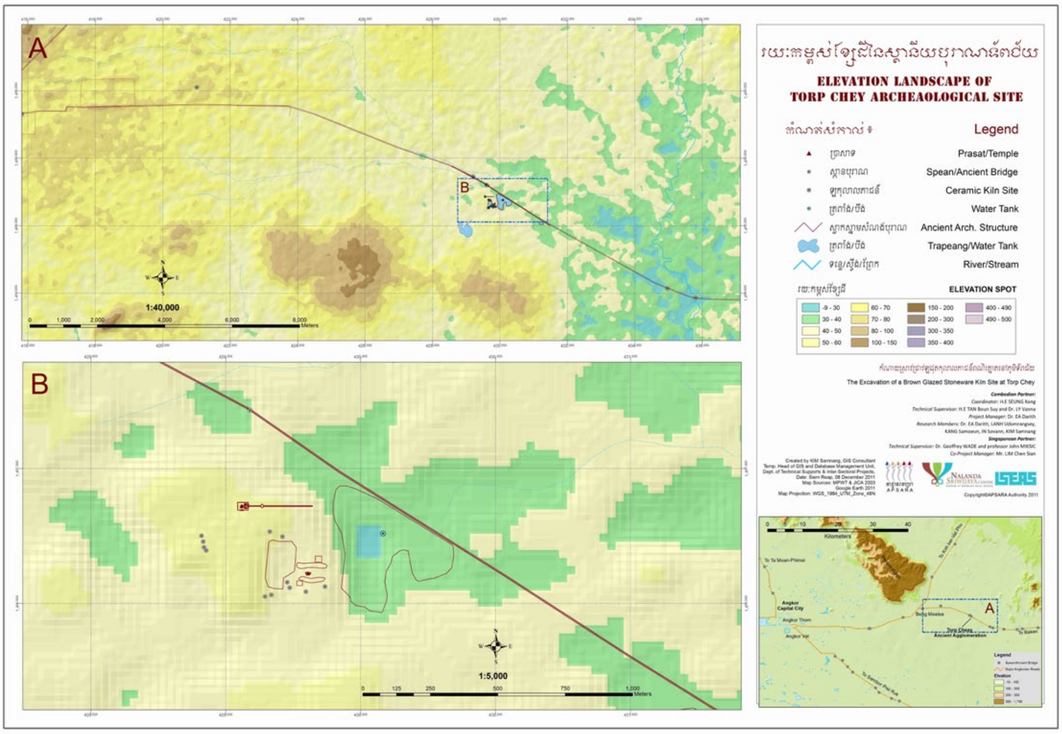
The following report describes archaeological research at the Torp Chey kiln site, Siem Reap, Cambodia (Figures 1 to 4). The kilns represent an Angkorian stoneware production industry dating to approximately the 12th–14th/15th centuries CE. Dates are based on five radiocarbon samples, comparison of pottery remains, and proximity to nearby architectural remains.

Figure 1: Location of Torp Chey kiln site



Note: Torp Chey is located east of the greater Angkorian urban landscape and temple complexes partially seen on the left of the map above as large rectilinear features; such as, walls, temple complexes, trapeang and baray-anthropogenic reservoirs.

Figure 2: Location of Torp Chey kiln site and elevation data



Note: Torp Chey is located in the flatter floodplain areas, although on slightly higher ground than areas normally inundated by flooding. Small hills exist to the south and west. However, the site remains proximate to consistent water sources, the road and the monuments.

The kilns are adjacent to the well-known Prasat Torp Chey Thom and Prasat Torp Chey Toch 12th and 13th centuries CE Angkorian monuments (i.e., *vahni-griha*, houses of fire;[1] popularly referred to as rest houses). The kilns are also located near the Angkorian East Road and is the first of several kiln sites (e.g., Veal Svay, Chong Samrong, Teuk Leck) along the road emanating from Angkor. These sites are also the first brown-glazed stoneware kilns recognized east of the Angkor capital. The social, economic, and network relations with each other, settlements and consumption areas (including the Angkor capital and prominent urban sites), as well as more distant kiln sites (if any) remain unknown. Importantly, the Torp Chey kiln site contains one of the largest documented and archaeologically tested ancient kilns in the region (21.0 x 2.8–3.2 m; Kiln Mound no. 2) characterized by a unique and sophisticated design and technology.

[1] *Vahni-griha* (also *agni-griha* in some references throughout the text) accords with inscriptional evidence from the Preah Khan stele dated to 1191 CE during the reign of Jayavarman VII (see Hendrickson 2008:67; Coedes 1941). *Darmasala*, *teap chei* (after the site), and a variety of other terms and phrases have been used to describe the structures as well—discussed and analyzed in detail by Hendrickson (2008).

Figure 3: Kilns and features at Torp Chey

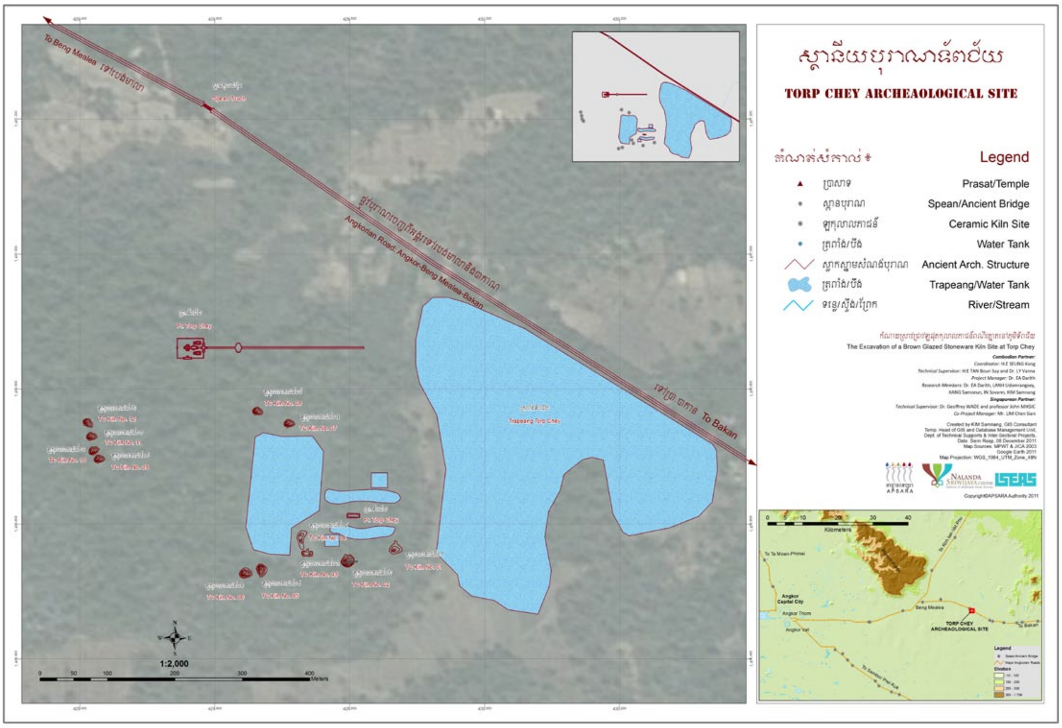
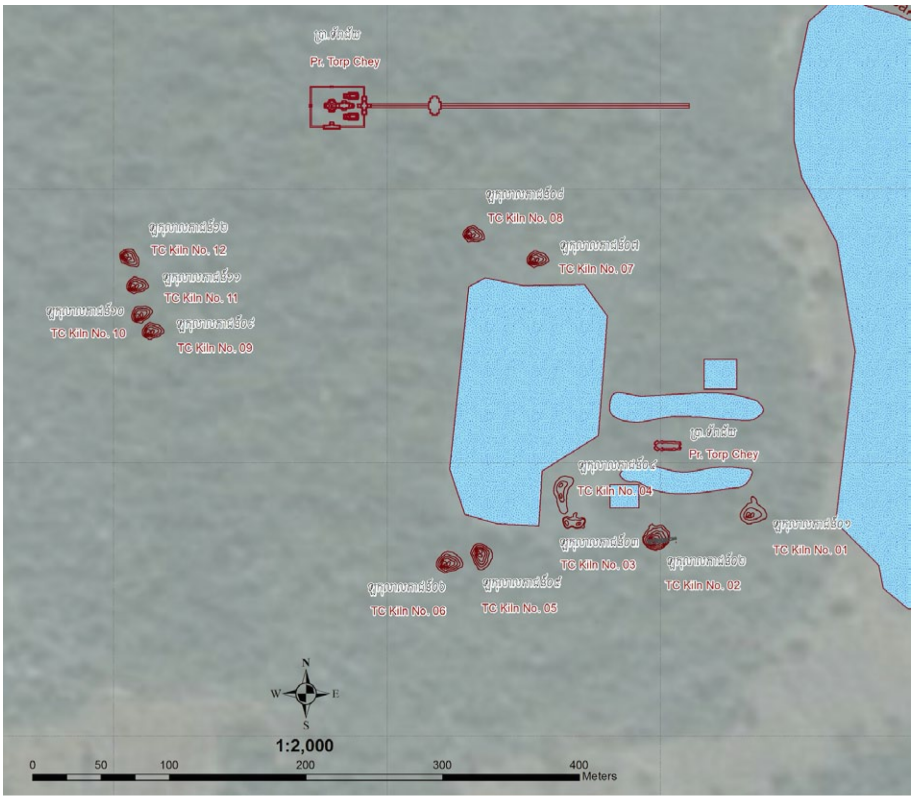


Figure 4: Enlarged image of kiln locations at Torp Chey (from Figure 3)



Approximately 12 kiln mounds were identified and mapped, each of which likely contain multiple superimposed kiln remains. Additional kilns in the area were noted but not mapped in detail. The kiln mounds contain thousands of large ceramic vessel fragments and other sherds, presumably wasters or discarded pieces that were broken during the firing process. Fired clay debris from the kiln roof and wall are also common around the kilns. Some ceramic remains may be non-local and unrelated to production products (e.g., storage and cooking vessels produced elsewhere); thus, indicating site use, occupation, and consumption/use of on non-local products.

Kiln Mound no. 2 was systematically excavated revealing three separate kiln structures that overlay and varyingly incorporate each other (Kilns I, II, and III of Kiln Mound no. 2—Kiln III being the uppermost; more recent; and structurally more complete). They were built, rebuilt and used for a period spanning two centuries or more. Kiln Mound no. 2 artifacts and surface scatters, as with other kiln mounds in the vicinity, indicate the primary products were Angkorian stoneware to include brown-glazed jars, roof tiles and animal figurines. Duration of use, size and number of kilns imply a sizeable industry for extra-local distribution.

Excavated deposits on the exterior of the kiln walls (approximately 25 m^2 in total) yielded an estimated 5,000 or more broken ceramics, large sherds and wasters—mostly medium to large fragments.[2] The large number of unglazed wasters may indicate that stonewares were pre-fired, cooled, glazed and re-fired at the site. Certain inherent flaws only emerge through breakage during the firing process where high heat, sintering and final shrinkage are significant factors. Pre-firing would allow identification and removal of defective pieces prior to final glazing and final firing, also allowing appropriate amounts of glaze application. Once defective pieces were removed and successful pieces identified, this would increase success rate of final firing and final glazed products, conserve glazing material, and increasing overall efficiency and effectiveness.

Beyond large overall size, the kiln displays unique engineering, particularly the incorporation of three horizontal secondary firing trenches that basally transect four separate firing chambers. This design likely allowed increased efficiency, production volume, and atmospheric control to include necessary temperature management (e.g., heat duration, distribution and flow; warming and cooling rates; etc.). Vent design is also unique, again relating to atmospheric control (e.g., air flow and exhaust), effectiveness and efficiency.

The lack of numerous central axis or internal roof supports is yet another unique factor. Earlier Angkor kilns frequently display a series of evenly spaced roof-support pillars. However, only three roof-support pillars were identified in two separate kiln floors despite the kiln's much larger size (Kiln Mound no. 2; Kilns II and III). Thicker walls were part of a wall and roof design that possibly reduced the need for internal supports; also providing increased volume for stoneware vessel production and perhaps better atmospheric and heat control. The shape of the clay and thatch roof cannot be fully discerned although

[2] These figures are rough estimates. The recovered assemblage of wasters and other remains are currently undergoing further analysis. A large portion of smaller sherds were not noted; thus, likely not indicative of a considerable amount of post-depositional breakage, trampling, etc. This may further support interpretation as a largely waster assemblage rather than habitation, other activity areas, combined activity areas, and so forth. Many waters are unglazed, perhaps broken during a pre-firing procedure before glaze application and final firing.

it appears arch-like due to the inward curvature of the existing walls. A grass thatched roof (to most likely include a bamboo frame) with applied wet clay is evident from grass thatch impressions in fragmented roof remains. The angle of inclination for the kiln (approximately 15–20 degrees) is also much lower than predecessor green-glazed kilns (often 30–40 degrees). The kiln construction results in an artificial mound, rather than the kiln being built on a dyke of a water reservoir like many earlier green-glazed kilns.

The incorporation of a sandstone rubble and clay base to the firing chambers is also distinctive. Sandstone and soil samples were analyzed using various techniques. It is suggested that sandstone rubble (gravel and chips) was obtained from waste debris derived during the final manufacture, dressing and fitting of sandstone architectural blocks to the proximate 12th and 13th century structures, particularly Prasat Torp Chey Toch. A reinforced stable floor was necessary because existing natural deposits could not independently provide needed stability. Additionally, the rubble may have allowed more secure placement of ceramics and increased drainage, better airflow, etc.—factors that may have increased kiln effectiveness, efficiency and success rates as well. A side loading door also increased efficient placement, arrangement and accessibility.

Radiocarbon dates (five samples) indicate usage of Kiln Mound no. 2 from the 12th–14th/15th centuries. This postdates or is contemporary with the nearby architectural remains. An earlier result from one sample, however, may indicate the use of old or mature wood sources for fuel.

The intention of this report is to provide updated research information, data, analysis, results and tentative interpretations for scholars and students in order to build a more comprehensive understanding of ancient ceramic industries and their implications in Mainland Southeast Asia. Although the geographic and temporal focus is Cambodia and Angkor, many results are applicable to regional and global discourse. We are eager to receive questions and feedback as well as provide additional information where possible.

The following working paper will provide:

Section 1: Introduction (this section).

Section 2: A cursory review of recent archaeological research on Angkorian kilns and ceramics. That is, a review of kiln and ceramic studies relevant to Mainland Southeast Asia and Angkorian ceramic traditions is offered. The review is basic and meant to provide a rudimentary context. It is noted that multiple efforts covering many relevant and specialized topics have been recently conducted. Our apologies are extended for omitting several critically important contributions in the discussion. Many details are available, however, and published through international teams in a variety of languages. Upcoming forums will result in increased understanding and further contributions. For example, the upcoming 2015 15th International Conference of the European Association of Southeast Asian Archaeologists with special sessions on ceramic industries will add invaluable insights. Unfortunately, this post-dates deadlines for this working paper.

Section 3: Mapping and basic analysis of the Torp Chey kiln site.

Section 4: Description and basic analysis of the Torp Chey excavation at Kiln Mound no. 2, Kilns I, II and III. The kiln structure, schematics and engineering are the primary topics with description of features, design, material, stratigraphy and comments on their various implications.

Section 5: Basic artifact descriptions of the stoneware products.

Section 6: Soil and sandstone rubble flooring analyses to include several laboratory efforts to further assess flooring and mound properties.

Section 7: Radiocarbon results and dating.

Section 8: A summary discussion and recommendations for further research, analysis and testing.

Additional Considerations:

Not all aspects of the industry and technology are covered in this working paper. It is regrettable, for example, that a detailed discussion of glaze technology is omitted at present. The brown stoneware glazing of the 11^{th}–15^{th} centuries is a notable departure from the earlier green-glazed wares of the 9^{th}–10^{th} centuries produced at kilns near the Angkor capital (e.g., Angkor area, Phnom Kulen area). Based on vessel examination (especially at the interfaces of glazed and non-glazed surfaces such as vessel feet and bases), glazes were likely dipped, painted or wiped onto vessels—many cases displaying very thick applications, although other glazing procedures are possible (powdered; added during placement of pots in kilns; a result of additives to the kiln atmosphere; natural additives in the firing atmosphere, etc.). The chocolate colored results dramatically contrast with the earlier green-glazed wares.

The chemical composition as well as possible glaze recipes used by artisans is not discussed in detail here, although significant research and experimental efforts are in place to shed further light (e.g., review Armand Desbat et al. experimental Angkorian kiln research; Sullivan 2014; also for compositional analysis on brown-glazed stonewares, see Desbat et al. 2015 CeraAngkor project XRF-WDS analysis to include Torp Chey brown-glazed stonewares; Grave et al. 2015—both of these papers to be presented in July 2015 at the International Conference of the European Association of Southeast Asian Archaeologists).[3]

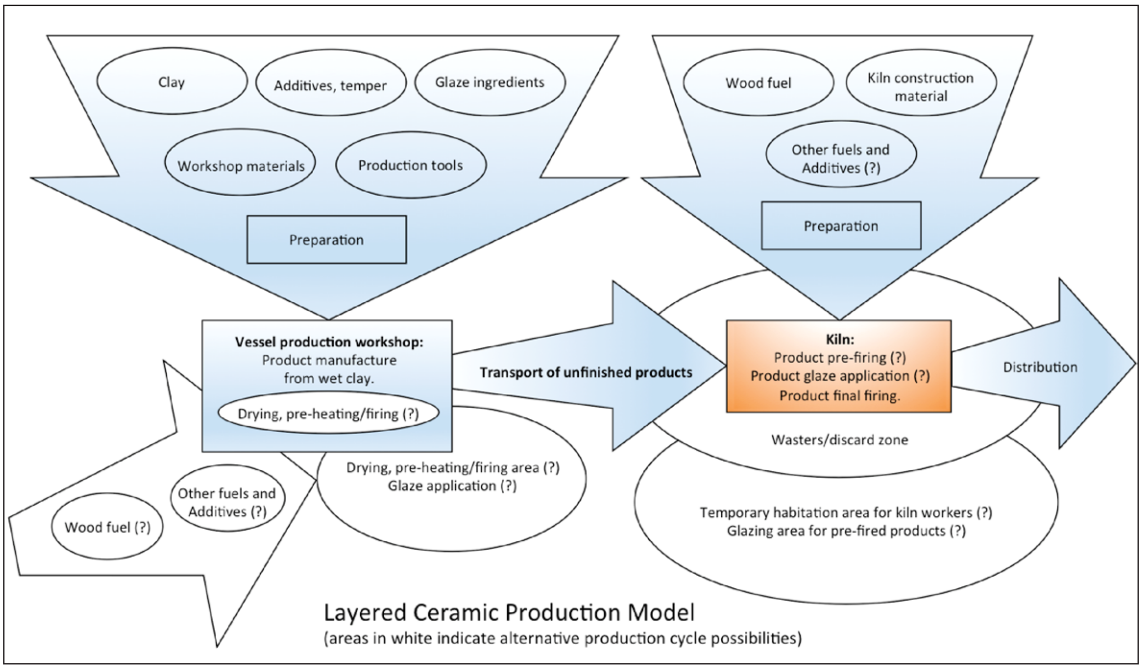
It is also unknown which part of the process glazes were applied (e.g., on dried vessels, partially fired bisque ware, etc.—see above). Neither pottery manufacturing nor glazing workshops were noted at the site. Only the kilns were discernable. Workshops may have been located elsewhere and it will be helpful to identify and test these sites in the future.

The glazing may have served functional and aesthetic purposes. It is evident that brown-glazed popularity increased dramatically and the brown-glazed wares have a wide distribution in lowland and upland sites, urban and remote. Many are still in circulation and use. Green-glazed stonewares continued to be produced, but also witnessed an increase in thickness and stronger color than the 9^{th}–10^{th} century predecessors. The green-

[3] Abstracts available online at: http://www.nomadit.co.uk/euraseaa/euraseaa15/panels.php5

glazed distribution may be much less widespread and prolific by comparison. Overall, the implications may reflect the distribution and control (or lack thereof) of production centers; and/or coincide with socio-political-economic power, influence and inclusiveness; nature of demand; and many other considerations. Of importance, the nature of demand may have witnessed a significant shift, where stoneware became a more common feature of average households and settlements in the latter Angkor period; perhaps more prominent status symbols in remote areas (or, arguably less if value decreased with ease of access and abundance); and/or reflect an increasing saturation and reach of distributions possibly facilitated by improved transport networks. Figures 5 and 6 describe ceramic production and distribution models relevant to Torp Chey.

Figure 5: Layered ceramic production model for Torp Chey



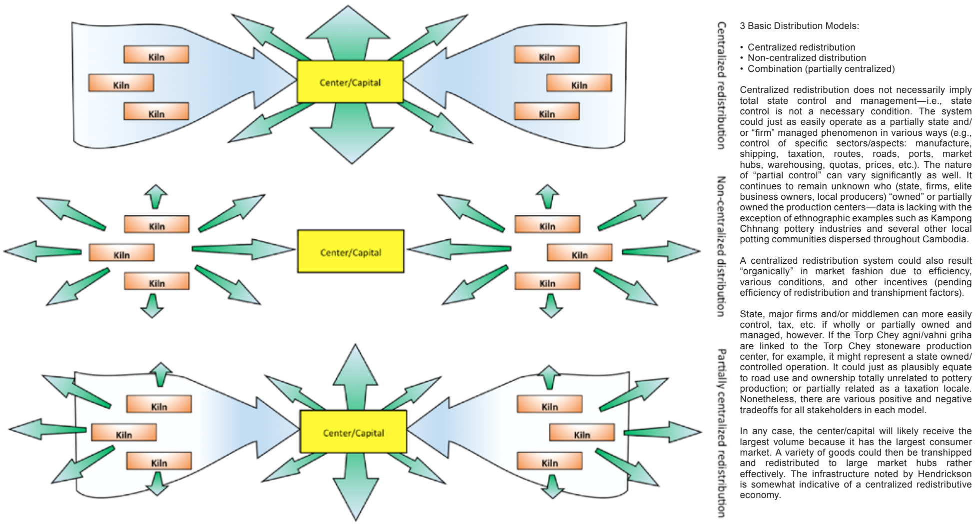
Note: The numerous amount of unglazed wasters (qualitative observation thus far) suggest that pre-firing unglazed ceramics was part of the production process. This would allow flawed products to be identified and removed before glazing and final firing at the kiln site. There is shrinkage during firing and sintering. Pre-firing would also increase effective and efficient glazing application and success rate. Ultimately, this increases labor and fuel efficiency at these stages. It serves as a good quality control feature as well. Given the unglazed wasters in the kiln area, it is likely that pre-firing was performed at the kilns and glazing was performed nearby.

Whether or not the wares were exported from the kiln area directly to customer communities, or, shipped to the Angkor capital or other centers in bulk along the East Road and subsequently redistributed[4] (or both) is also unknown. Compositional analyses of stoneware, clay sources and kiln material may help address a series of interesting hypotheses. For example, brown-glazed stoneware customers in the east may have received their goods from sub-regional producers and partners, while western kilns served different

[4] The nature of redistribution, even if centralized, remains unknown. Was it highly controlled and regulated or marketed freely? Did buyers come from elsewhere to obtain in bulk, or did distributors send bulk orders to various communities and markets? Several other possibilities can be hypothesized, but very little evidence is currently available to understand the supply chain, social and economic factors and the potential combinations and variability; to include "taxation" measures (if any).

populations. Alternatively, manufactories may have shipped goods in bulk to centers, or the capital, to be redistributed radially (synching with radial transportation networks noted by Hendrickson). Answers to these questions will help build a better understanding of exchange, redistribution and supply chain networks and economies (Figure 6). Results from the Khmer Production and Exchange (KPX) Project will greatly assist answering similar questions.

Figure 6: Torp Chey distribution and supply chain models



Additionally, the ecological impacts are not discussed in detail. What implications did the kiln production site have on the local environment, ecology and economies? For example, how much fuel was extracted and used? Was it sustainable? Did fuel types and sources change over time as a response to possible degradation or stress? Were fuel sources (i.e., wood) cultivated nearby as part of the industry? Were settlements located elsewhere due to pollution and danger? Were kilns intentionally placed near the rest houses (houses of fire; *vahni griha)* and the road for economic reasons—perhaps for incoming fuel as well as export shipping efficiency? Were all these features (rest houses, road, kilns and water ponds and *trapeang*) an integrated system? What were the implications for the larger scale ecologies (i.e., beyond the immediate local area)?

Equally interesting, we do not know if this was a highly managed and controlled production system, or—as with the traditional Kampong Chhnang potting industry—a conglomeration of cottage, household, family industries with occasional large group or community integration (e.g., the ox-cart caravans that distribute Kampong Chhnang pots and stoves throughout Cambodia) that essentially produce at the scale of a massive industrial complex. How and who managed production and distribution? There is no direct evidence, for example, that the kilns were state or elite owned, operated and controlled. In fact, it is unknown if bulk products were taxed, for example, during transport across roads and stops at rest house complexes (e.g., road and rest house tolls/taxes, another possible function of rest house sites)[5] or taxed at redistribution centers similar to port taxes. There is no evidence for such practices, but it is not outside the realm of possibilities.

Were there specific gender and age roles, for example? Were the potters part-time ceramicists and full-time farmers, or vice-versa? That is, what was the nature of economic specialization overall for the local residents, and, the communities? This leads to further questions of specialization and ethnicity. It is argued, for example, the ethnic Kuay were the "iron–smiths" of the Khmer polity (Pryce et al. 2014). Did specific ethnic groups adopt the industry or were they defined by the industry?

Specialization, diversity, control and standardization are interesting concerns. Assessment at multiple scales from specific (e.g., individual, site, community), local, sub-regional and regional are equally important. What kind of diversity, homogeneity, and/or standardization is represented and what are the implications? To what extent does standardization of products, kilns (also kiln clusters), and distribution and consumption patterns exist (at multiple scales as well); what are the implications? Do certain nuances in product type variability and their ratios in the assemblage(s), product design/decoration variability and their ratios, and kiln design/technology variation (within and between kiln clusters as well as throughout time) represent a degree of individual or workshop autonomy, experimentation, innovation, egalitarianism, competition, standardization, etc.? Would vessel form weigh more importantly than decoration (i.e., have stronger interpretive implications; and would they have the same weights for different research questions)?

What degree of kiln design variability would we expect to represent high experimentation, normal expected random variability with few implications (except for some considerations such as descent "drift" over time and space), or a significant transformation of technology and/or market demand? Were specific kilns producing a specific spectrum of products or did all kilns produce relatively similar products and the same diversity of products (e.g., Kiln X producing jars and bowls, Kiln Y producing figurines and covered bowls/boxes, Kiln Z producing roof tiles and storage jars; or, all kilns produced the same repertoire of products; and what about design diversity or standardization)?

What will the wasters (failed and discarded products) tell us? We have to be careful when interpreting wasters as representative of the diversity and ratio of what was loaded and subsequently successfully produced, as we would expect certain vessels to have differential firing success rates. That is, some wasters may represent a dominance on one vessel type, but had a high failure rate; thus, were actually a smaller portion of both loaded and final products.

Were kilns controlled and managed by middlemen or elite? Were kiln managers told what to produce; when and what quantities? Were orders placed by wholesalers? Was it an open and free market where craftspeople and workshops competed relatively freely? Did certain communities cooperate in organized guilds or unions? What was the nature of these relations with other ceramic production communities?

A wide spectrum of questions can be addressed, but a much larger sample set and significantly more analysis is required to begin discerning accurate answers. Importantly,

[5] Similar speculations on tax locales and practices were proposed independently by Robert McCarthy and D. Kyle Latinis when reviewing the Torp Chey data for this report.

what data can we recover and how can this be analyzed to address such questions (i.e., methodology)?

Other items to consider include why the industry declined and eventually disappeared. Were they simply outcompeted extra-locally by developing Thai and Vietnamese producers, for example?[6] Did possible competitors have more access to outside regional and extra-regional markets and were they able to produce at cheaper costs? What were the roles and implications of Chinese industries (to include the time span of incipient industry to decline; see also Wong 2010; Cremin 2007)? Did traditional Khmer potters simply find other things to do rather than potting (i.e., fell out of popularity for local producers)? Was the decline related to other economic and political changes in the larger network, economy and polity? Did they simply just burn out their resources, abandon production, and move (an ecological-economic model)? Did their wares become internally less popular (i.e., decreased demand; possibly explaining some of the increase Thai and Vietnamese pottery in some late Angkor and post-Angkor assemblages)? A combination of factors, external and internal, provide several interesting models.

Another consideration is the role the Cheung Ek kilns in the south near Phnom Penh played (Phon 2002; Phon et al. 2013). Phon Kaseka has conducted extensive research at Cheung Ek, documenting 69 stoneware and earthenware kilns as well as numerous archaeological, architectural and landscape features. Earthenware kilns may date to the late Funan period ($5^{th}/6^{th}$ centuries CE), producing medium fired[7] fine paste wares and *kendi*. Many kilns produced stonewares during Angkorian periods (brown and green-glazed; unglazed and other varieties). The Cheung Ek kilns (CEK) may have a unique design technology and produced distinct ceramics as well. Two superimposed kilns measured 11.6 x 2.3 m and 3.5 x 17.7 m (26.7 m^2 and 47.5 m^2 respectively). They were built on artificial mounds with a slope of approximately 20 degrees—somewhat similar to Torp Chey. There are multiple floors (up to 7), and evidence indicates repeated use (for other tested kilns as well). There are identifiable fire boxes/fire trenches, although it is not yet clear if multiple fire boxes or firing trenches were in use for a single kiln. This adds a considerably new dimension to the stoneware production industry discussed throughout this paper. However, significant integration of Phon Kaseka's exciting research and the implications are reserved for the expansion of this working paper into a separate publication.

Although many questions are offered to the readers, these are certainly not an exhaustive list. The intention of the questions above is to assist readers to critically consider, examine and assess issues and implications as the data is presented throughout the following sections in hopes of stimulating further comments, debate and research. Ultimately, this working paper is intended to be reworked into a more comprehensive book publication. However, it is imperative to share as much as possible with the professional community at present in order to assist others with complementary research.

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6 Shipwreck cargoes have indicated substantial Thai and Vietnamese export markets as they emerged during the late Angkor and post Angkor periods (Kwa 2012; Brown n.d.). Interestingly, Khmer stonewares are not listed in shipwreck inventories, and do not seem to have been an export commodity external to the Khmer polity at all. This may be a "missed" or ignored opportunity—another possible factor leading to their economic waning, although it can be equally argued otherwise given the current limited data at present.

7 Slightly above the temperature range for normal low-fired earthenware pottery.

2: Review — Angkorian Ceramics and Kilns

The following summary review is intended to briefly introduce: 1) recent Angkorian glazed stoneware kiln research (i.e., a focus on one aspect of the production process—the kiln), and 2) a cursory history of Angkorian glazed stoneware ceramics research (i.e., a focus on the final products—the ceramics produced). The purpose is to provide readers with background and context. Minor comments and analysis may be of interest, although a detailed discussion and analysis is not provided.

The first part is also intended to provide a generic description of the variance, evolution and distribution of Angkorian kilns. In summary, smaller kilns producing green-glazed stoneware are earlier (approximately 9^{th}–10^{th}/11^{th} centuries CE) while larger kilns producing brown-glazed stoneware are later (11^{th}–14^{th}/15^{th} centuries CE).

The former early Angkor kilns are primarily clustered in areas around the Angkorian capital and Phnom Kulen (refer to Figure 7; Figures 8a and 8b highlight kiln schematics to include Buriram). The latter kilns (mid to late Angkor) were only known to occur west of the capital (e.g., Buriram, Ban Kruat and Ban Phuang, Thailand, see Brown 1981:43 and Rooney 1984:17; Banteay Meanchey, Cambodia; see Ea 2007) until recently with the discovery of the Torp Chey kilns (also referred to as Teap Chei—see Hendrickson 2008) and a few other kiln complexes along the Angkorian East Road (e.g., Veal Svay, Chong Samrong and Teuk Leck).

Figure 7: Distribution of kiln complexes noted in text

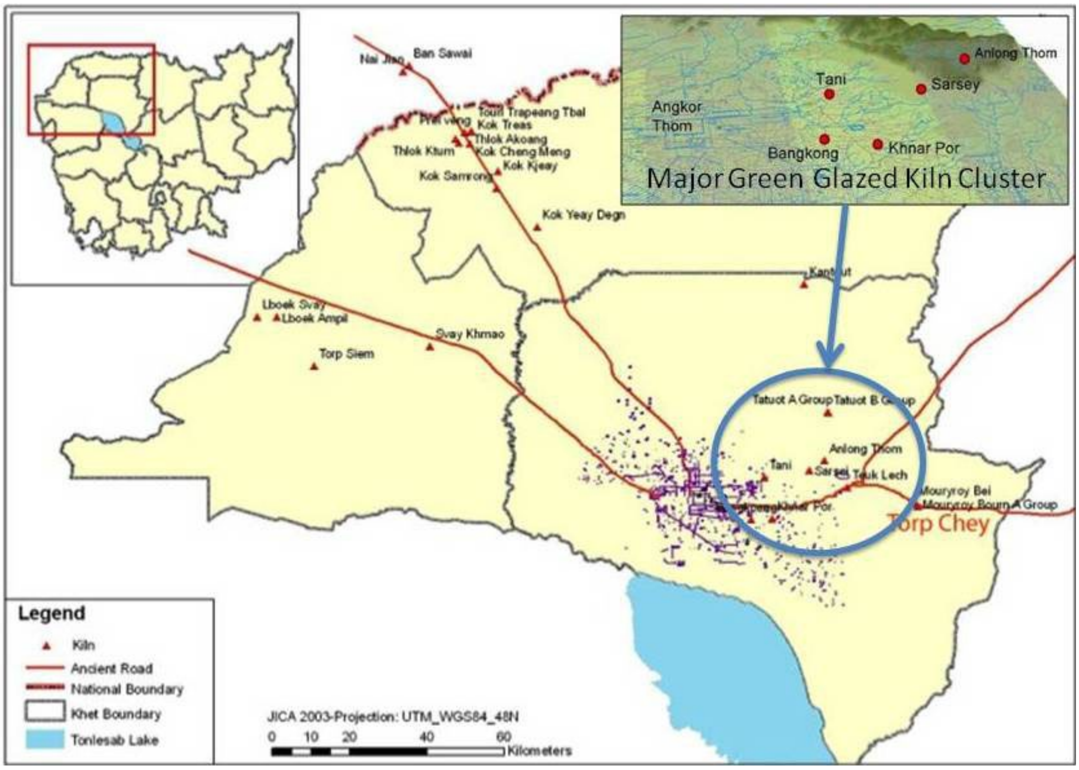
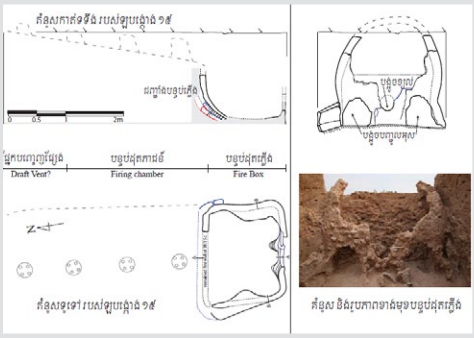
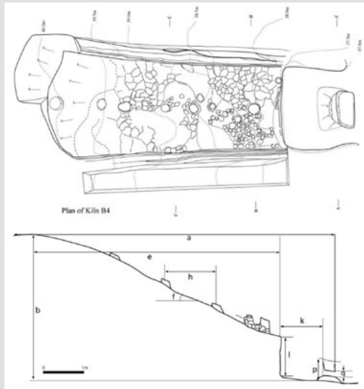


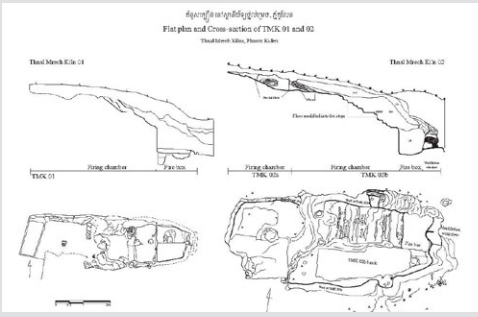
Figure 8a: Early stoneware kiln examples



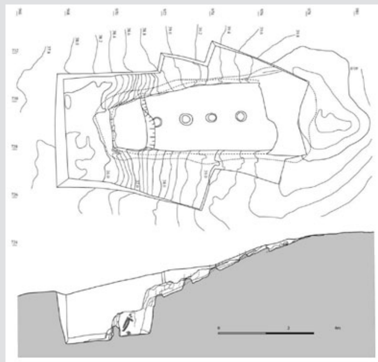
Bang Kong Kiln BK 15 (Chhay 2010)



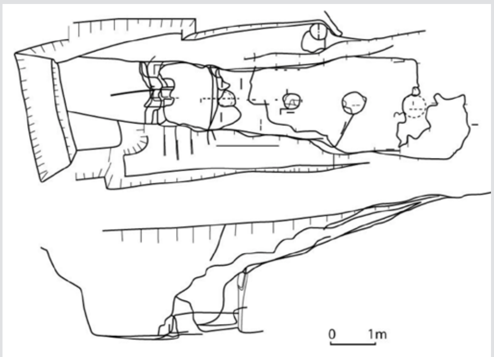
Tani Kiln B4 (Auyagi and Sasaki 2007)



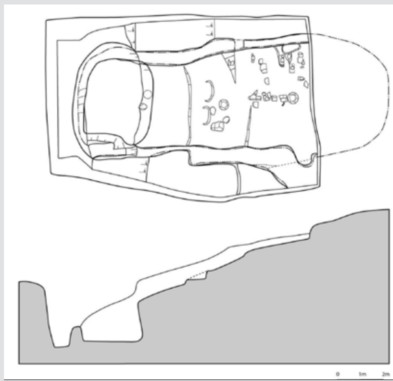
Thnal Mrech Kilns (Anlong Thom) TMK 01 (Tabata and Chhay 2007); and Kiln TMK 02 (Miksic et al 2008)



Tani Kiln A6 (Sugiyama et al 2005)



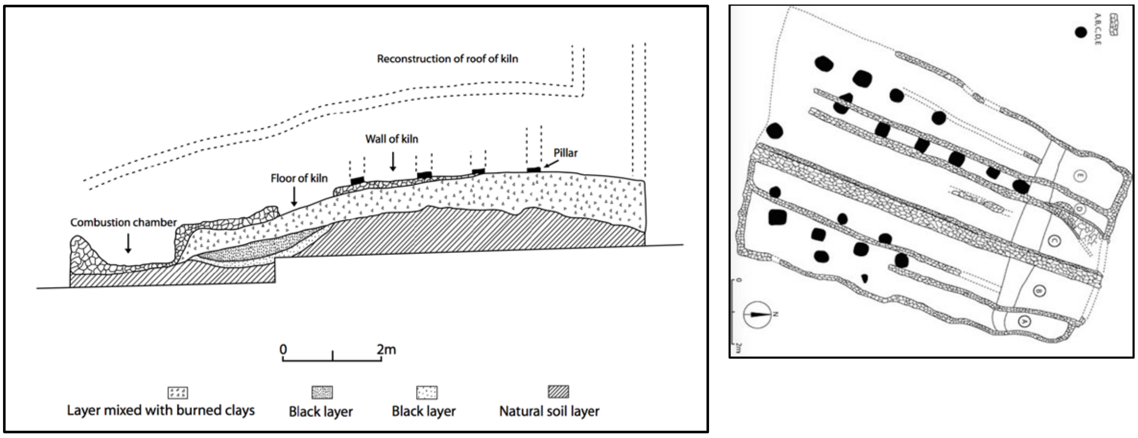
Knar Po Kiln B1 (Nakamura et al 2009)



Sar Sei Kiln A11 (Sugiyama et al 2008)

Note: The green-glazed stoneware kilns are generally defined by smaller size, single firing chambers and single firing boxes. They are all located near Phnom Kulen. The Anlong Thom kilns on Phnom Kulen are not depicted, but follow similar designs. Anlong Thom kilns form an extensive complex and large industry extending several hundred meters along the embankments of a lark berm/dyke (recent visual survey 2015 reconfirmed that scores of kilns and vast deposits of wasters occur). Some researchers claim Buriram kilns were clustered and shared walls; possibly a unique engineering and production design. Further research is required to best validate the design and accommodate Buriram into the basic typology. Buriram also may have had multiple overlapping production industries with both green and brown glazed wares produced.

Figure 8b: Buriram kiln



The Torp Chey kiln cluster[8] contains one of the largest identified and tested kilns to date. The kiln displays a unique design (i.e., technology, engineering), particularly the secondary fire trenches separating four firing chambers.[9] Because it is also part of a large cluster of kiln mounds (at least 12[10]) near an Angkorian stone structure (*vahni-griha*) and the Angkorian East Road, it is also considered part of a significant ceramic industry feeding a large extra-local demand throughout Angkorian territories.

The Buriram kilns in modern Thailand produced both green and brown-glazed stoneware (possibly to include the dual green and brown-glazed vessels). Buriram kilns may also represent unique design, technology and product variance. One of Buriram's distinguishing design is based on an interpretation of shared wall construction for multiple kilns and firing chambers, although this interpretation is not universally accepted (further testing is warranted).

The types of kiln clusters or kiln sites are also distributed in different geographic areas as noted above (green-glazed earlier kilns near the Angkor capital; brown-glazed later kilns dispersed to west and northwest; now to include the east;[11] and if Cheung Ek has a connected industry, this would move the dispersal sphere considerably south as well). The distributional relation to various physical and social variables is unknown as is their relationship to variant stoneware distributions in other archaeological contexts, such as ritual sites, trade sites, and habitation sties. Several intriguing hypotheses can

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8 A kiln site generally has multiple individual kilns. Some are referred to as "kiln groups". Evidence indicates that individual kilns were frequently reused as well as modified and reused periodically. Kiln sites may have been in use for long durations spanning 50 years or longer (perhaps centuries as evidence seems to indicate with Torp Chey).

9 The horizontal secondary firing chambers are located at the base of the kiln. This should not be confused with "dragon" kiln technology typical of East Asia/Chinese origin. Local technological innovation is perhaps a higher possibility than diffused technology; although the nature and degree of outside influence and knowledge transfer remains unknown.

10 Other kilns near proximate villages were noted; three were cursorily identified and assessed. Up to 20 or more kilns may exist in adjacent areas. These have yet to be validated, mapped and assessed.

11 Consideration of the Cheung Ek Kilns (CEK) will need to be integrated, perhaps adding significant depth and dimensions to understanding the industries at a larger scale throughout the ancient Khmer sphere of influence and interaction, especially production centers and supply chains.

be tested. The implications to social, cultural, political and economic dynamics is also intriguing, although correlations are yet to be thoroughly modeled and assessed.

It is emphasized that this summary is based on the existing sample population and may not accurately represent complete distribution, patterning, variance and evolutionary sequencing. It does, however, highlight a basic pattern and adds to our understanding of the current diversity. Nevertheless, beyond the cursory review provided below, the bulk of this paper remains focused on Torp Chey.

The second part of this section reviews the modern history of interest and research in Angkorian high fired ceramics (i.e., stoneware and glazed stoneware). Points related to kiln studies are included. It is divided into two sub-sections. Firstly, an explanation of the primacy of ceramic studies over kiln studies is offered with considerations of the Khmer industries. Secondly, a cursory summary of modern studies on Khmer stoneware and glazed ceramics is provided. It is by no means comprehensive. However, it provides a necessary background for understanding the history of Khmer ceramic studies evolving into an important independent specialty field.

2.1: Recent Angkorian Kiln Studies

Modern kiln research related to Angkorian stoneware began in Thailand earlier than Cambodia for many reasons, such as the security and conflict situation, capacity, funding, interest, awareness and access. Several kilns of Angkorian period relevance were identified in Thailand's northeast by the 1980s. Many kilns were built on artificial mounds, usually within the ubiquitous flat rice field landscape (Hein 2008).

Unfortunately, infrastructure and other physical development projects in northeast Thailand destroyed many ancient structures such as ancient roads, habitation sites, burial sites and kiln mounds—a tragic but expected problem with modernization and development that currently affects Cambodia as well. For example, more than 100 kilns had been identified prior to the construction of Lam Prathia Dam (also, Lam Taking Dam) in the 1970s, while only seven kiln mounds remained following completion (Nattrapatra 1990). Increased mitigation policies and efforts exist, but they are respectively not often enforced and sufficiently supported (manpower, expertise, funding, time); certainly not substantial enough to keep pace with development and other activities leading to site destruction.

In 1984, an excavation was carried out at Kok Lin Fa kiln in Lahan Sai district by the Fine Arts Department (Khawnyuen 1985). The department resumed excavation at the kiln sites of Nai Jian and Sawai in 1987 and a report of excavation results concerning the kiln structure and associated ceramics was published soon after (Nattrapatra 1990, Khawanyuen 1985, Srisuchat 1989). The Sawai kilns were between 3.0 to 4.0 m wide with up to three parallel fire boxes and a wide vent system at the upper end of the firing chamber. The vent extended across the upper width of the kiln. However, the upper sections of kiln mounds are eroded. Thus, detailed specifics are lacking (Hein 2008).

Following the discovery of kiln sites in the Angkor area in 1995, the study of Khmer kilns and associated ceramics in Cambodia emerged for the first time through joint research projects between APSARA Authority and several international teams; namely: NRICPN (1996–present); Sophia University Angkor International Mission (1995–early 2000s); Osaka Ohtani University (2006–2011), National University of Singapore (2007), and Nalanda-Sriwijaya Centre at the Institute of Southeast Asia Studies (ISEAS) (2011–

2012). Three kilns at Tani, two at Anlong Thom (Thnal Mrech), one at Sarsey, three at Bangkong, and one kiln at Torp Chey were excavated between 1996 to 2012. The structure of the kilns and the nature of the ceramic production have been well documented (Aoyagi et al. 1998–2001; Tabata 2004; Sugiyama et al. 2001, 2005; Chhay et al. 2007; Nakamura et al. 2009, 2010; Miksic et al. 2009). Other researchers who have studied kiln sites in Cambodia also include: Sumida (2000); Ea (2000, 2005, 2006, 2009); Chhay and Chap (2002); Phon (2002); Tabata (2003, 2004, 2008); Sok (2007); Tin (2004); Em (2005); San (2008); and Hendrickson (2008).

Systematic survey and research by Cambodian and international teams[12] from 1996 to present identified and documented previously unrecorded Angkorian stoneware kiln sites near the ancient Angkor capital (currently Siem Reap Province, Cambodia). The kiln sites are located along the ancient royal roads from the Angkor capital to other prominent archaeological sites representing significant nodes in the larger Angkorian socio-economic, political and cultural sphere: specifically the roads to Phimai, Sdok Kak Thom, and Bakan (Preah Khan Kampong Svay). The Torp Chey site lies along the eastern road towards Bakan and contains at least 12 kilns. An estimated 20 or more kilns are also located to the east of the site. The latter have yet to be formally surveyed and tested.

Relatively well documented and tested early Angkorian kilns are located at the Tani, Bangkoang, Khna Por, Anlong Thom, and Sar Sei Sites. Over 100 separate kilns at these sites have been identified. Several sites were excavated from 1996 to 2010.[13] Pottery production dates range from the 9^{th}–10^{th}/11^{th} centuries CE. Although sites are located approximately 20–45 km from the main Angkorian temple complexes known today, it is noted that they are within the ancient Angkorian capital areas to include Hariharalaya and Mahendraparavata.

Early kiln sites display internally similar structure and ceramic production technology. Kilns are oval and divided into distinct but basic structural and technological sections: 1) fire box, 2) firing chamber, and 3) vent/chimney. Overall dimensions are approximately 6.0 to 9.0 m in length; 1.5 to 3.6 m in width and approximately 1.0 m in height (total floor area of fire box and firing chamber ranging from approximately 7–20 m^2; total volume ranging from approximately 7–18 m^3; 5 kilns in the representative sample: Anlong Thom Kiln 1; Anlong Thom Kiln 2; Sarsei Kiln; Knar Po Kiln; Tani A6 Kiln; Bangkong Kiln excluded as firing chamber dimensions are indeterminate; see also Chhay et al. 2014 for a comparative set of kiln metrics).

The ceramics produced in the kilns consist of small green-glazed wares and larger unglazed wares. Kilns were used for multiple firings over long periods of time (i.e., multiple use rather than single use, although multiple reconstructions may have occurred at sever) as evidenced by consecutive layers and modifications to the kilns and kiln walls. The annual/seasonal volume and total volume of production remains unknown.

Of interest, however, is the Thnal Mrech Kiln Site (Miksic et al. 2009) which shows

[12] Teams include: APSARA Authority; Sophia University Angkor International Mission; National Research Institute for Cultural Properties, Nara; Osaka-Ohtani University; National University of Singapore and Archaeology Unit of the Nalanda-Sriwijaya Centre at the Institute of Southeast Asian Studies (AU-NSC-ISEAS) as mentioned in text.

[13] The Authority for the Protection and Management of Angkor and the Region of Siem Reap (APSARA), Sophia University Angkor International Mission, National Research Institute for Cultural Properties Nara (NRICPN), Osaka-Ohtani University, and the National University of Singapore.

evidence of use until approximately the 11^{th} century CE with the introduction of brown-glazed ware (albeit in small quantities at perhaps a terminal use of the kiln area). Kiln TMK02a has a comparatively larger volume and area than two other TMK kilns (almost 22.0 m^2 and 22.0 m^3 compared to the 10–15 m^2 range for the latter—TMK01a and TMK01b; TMK02b area and volume can not be determined; data from further analysis of Chhay et al. 2014). The cross-draft kiln(s) also display some unique design features as well.[14] Miksic et al. (2009:18) note:

> 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 ware after BP905 [905 BP]. 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 Roxanna Brown (1988).

Serendipitously addressing Brown's suggestion/hypothesis (1988), the recently excavated kiln sites located along the ancient roads (i.e., Torp Chey) were built and used during the later Angkorian era, approximately from the 11^{th}/12^{th}–14^{th}/15^{th} centuries CE (Hendrickson 2008). During this period, brown-glazed wares consisting of both small and large vessels were introduced to the potting industries, evidently becoming increasingly popular (in production, and perhaps demand), and subsequently dominating kiln assemblages (not necessarily assemblages in other site types, although this accords with Groslier's 1981 assessments). Green-glazed wares are absent in these kilns.

As implied, however, comparisons with contemporaneous habitation and other sites may reveal a different repertoire and representation of brown-glazed wares vis-à-vis other ceramics in circulation and use.[15] Additionally, the Buriram kilns continued production of green-glazed wares as well as brown-glazed wares to possibly include the two-color wares (e.g., green-glaze on upper vessel sections with brown-glaze on lower sections). Later green-glazed wares often display thicker and darker glaze. The earlier green-glaze wares are light green and yellow with comparatively thin glaze.

The Thai Fine Arts Department excavated brown-glazed kilns along the northwest road from Angkor to Phimai in Buriram Province in the 1980s. They uncovered several kilns with possible shared walls located across artificial mounds. The mounds were constructed for the kilns. The kilns are lengthier than the earlier Angkorian kilns (approximately 12.0–15.0 x 1.2–1.5 x 1.0 m; 14–25 m^2 floor plans; 22.5 m^2 total area and 22.5 m^3 total volume based on one set of estimates for five kilns.)[16] Unfortunately, an estimated 200 or more

[14] Metrics are available, but no estimated volumes, production volumes, possible fuel consumption, success rates, etc. have been calculated thus far. These concerns will be increasingly relevant in forthcoming analyses.

[15] It remains unknown if occurrences of brown-glazed wares equally dominate contemporaneous habitation site assemblages as well, and/or, if the demand—as represented in the occurrences in the assemblages—varied among different types of sites such as ceremonial sites versus habitation sites, and/or, varied along different socio-economic status residences, workplaces, ethnic sectors, urban-rural communities, industrial versus agricultural areas, and so forth.

[16] This estimate range is based on readily available metrical data during report production. It will require refinement to enhance accuracy.

kilns were destroyed by development activities. The shared wall architecture at Nai Jiang Kiln in Buriram (though a debatable feature) is relatively distinct. The production of both green and brown types of glazed wares, and possibly the combined brown and green-glazed ware (separate brown and green-glazed zones on a single vessel) is also intriguing.

Three kilns along Angkorian East Road have been recently excavated. Torp Chey was excavated by AU-NSC-ISEAS and APSARA Authority in 2011–2012. Chong Samrong Kiln was excavated by APSARA Authority and the Smithsonian in 2013 for training Southeast Asian researchers on the techniques of kiln excavation and subsequent artifact management (Hein et al. 2015; Hein and Ea 2013). Although the kiln appears roughly similar to Torp Chey (length: 20.0 m; inner wall: 3.2 m; outer wall: 3.6 m; total internal area: 64.0 m^2; total area including wall dimensions: 72.0 m^2), it contains only one fire box, one secondary firing trench, and two firing chambers). If Chong Samrong is earlier than Torp Chey, it may represent an important node in the evolutionary development and variability.[17] Finally, the Veal Svay Kiln has been excavated by APSARA Authority and the Nara Institute since 2013, but work is still ongoing. The kiln is smaller than Torp Chey and Chong Samrong; exhibits one fire box, no secondary firing trenches, one firing chamber and has a vent. Length is unconfirmed and the width is about 1.4 m. Again, final results may add considerably to understanding evolution and variability.

Phon Kaseka's (Phon et al. 2013) efforts at Cheung Ek with Cambodian and international teams has identified 69 kilns near the well-known Killing Fields site just outside of Phnom Penh. Habitation sites, architectural remains, landscape features and a large circular (750 m diameter) earthen wall are part of the site complex. Kilns may range from as early as the 5^{th}–7^{th} centuries CE (producing higher fired earthenwares; fine paste ware and *kendi* associated with Funan sites such as Angkor Borei and Oc Eo) to Angkor and post-Angkor periods.

Many of the kilns produced green, dark-green and brown-glazed stonewares. Two superimposed kilns measure 11.6 x 2.3 m and 3.5 x 17.7 m (26.7 m^2 and 47.5 m^2 respectively). The latter is considerably large—more comparable and similar in many ways to Chong Samnong and Torp Chey. Fire boxes/firing trenches were noted, but it is unknown if multiple firing trenches were associated with one kiln. Kiln slopes are around 20 degrees and they are built on artificial mounds. Multiple floors and other evidence indicates successive and repeated uses. A comment on the minimal presence of wasters suggests that ancient artisans/technicians associated with the tested kilns may have enjoyed considerably high success rates with production; although it was also suggested wasters may have been used for fill elsewhere. Although well outside of the immediate Angkor Capital urban area, southern Cambodia was well within the influence sphere and political-economic umbrella of Angkor. However, how much autonomy, control and synchronized, coordinated and/or competitive efforts there were (with ceramics industries, for example) is another set of questions entirely. Continued efforts at Cheung Ek and distilling the true nature of the industry will have significant implications for many research models.

[17] It is noted that Chong Samrong is slightly less lengthy than Torp Chey, but does yield a slightly larger total area. Total firing chamber area may be even larger considering only one secondary firing trench was noted. For practical purposes here, both kilns will be treated as similar in area and volume. Further considerations are important, however, when multiple sites comparisons of volume, production volume/capacity, fuel consumption, engineering, etc. will be conducted.

As stated, APSARA Authority and the Archaeology Unit of the Nalanda-Sriwijaya Centre at the Institute of Southeast Asian Studies (AU-NSC-ISEAS), Singapore, identified and excavated the brown-glazed kiln site along the east road to Bakan at Torp Chey—the subject of this report. Excavations were conducted from 1 December 2011 to 10 January 2012. Interestingly, the Torp Chey Kiln no. 2 revealed a structure and technology differing from the earlier period kilns and the Buriram kilns. Again, the excavated Torp Chey kiln is 21.5 m long and 2.8 m wide (3.2 m wide in cross-section measuring from the outer walls; interior area: 60.2 m^2; total area: 68.8 m^2). It contains three secondary fire trenches that separate four firing chambers with other aforementioned unique design features. It is one of the largest kiln structures found in Southeast Asia to date. Volume of production is tentatively hypothesized to be much higher than the normal range for earlier kilns. Comparative distribution is unknown, but may be wider as well; depending on the nature of economic distribution or redistribution.[18] The total industry production volume compared to the earlier green-glazed industry is unknown; but again, hypothesized to be larger.[19]

2.2: Khmer/Angkorian Stoneware Ceramics and Related Kiln Studies

2.2.1: Primacy of Ceramic Studies above Kiln Studies

Formal research on Khmer ceramics began much earlier than kiln research despite early identification of kiln sites at Phnom Kulen (Aymonier 1901). However, this is not unusual. The primacy of ceramic studies over kiln studies deserves additional explanation in the following paragraphs.

Firstly, the primacy of ceramic studies is not surprising as ceramics are ubiquitous at many sites and perhaps the most prolific of all archaeological remains. Ceramics are abundant. Kilns are not. Ceramics also occur in numerous archaeological contexts (i.e., a large repertoire of site types). Additionally, ceramic studies are standard aspects to a wide corpus of archaeological research and analysis endeavors—past and present.

Kilns are more limited in number and frequently form a separate, discrete production site class. For example, Miksic et al. (2009) found almost no habitation site remains or indicators of habitation at Thnal Mrech, concluding that the kilns themselves are likely located outside of residential settlements; "… to avoid impinging on the habitation zone" (Miksic et al. 2009:4). Factors such as clay, workshop and/or fuel source locations, environmental impact in habitation areas (e.g., damage to or impingement on other productive village areas and resources; pollution/irritants, perhaps even safety of people and animals), etc.

Kiln research is often treated as a specialty subject. By comparison, basic ceramic

[18] Brown-glazed stonewares may have had wider distribution overall, but particular kilns may have supplied limited areas depending on the economic distribution/redistribution system in place (see above and below).

[19] It cannot be discounted that foreign ceramics may have filled significant demand; e.g., a considerable amount of Chinese stonewares were recovered from various Angkorian period sites: noted by Groslier, see Cremin 2006; see also Wong 2010 who analyzed the ratio in numerous sites indicating a relatively small but important percentage and perhaps a significantly important contribution to status and other variables.

studies are more common and relatively normative. Most amateur and professional archaeologists have at one point in their training, experiences and careers studied and analyzed ceramics. Additionally, past attention at kiln sites often focus on the ceramics produced at the kilns and their temporal context rather than the kilns themselves. Again, Miksic et al (2009:3) note that, "… 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" highlighting the "gravitational pull" of the potsherds (as well as repelling forces vis-à-vis report production and attention to thorough kiln analysis).

Ceramic typologies and seriations dominate many past studies in normative archaeology. Attention to ceramics occurring in various archaeological sites (e.g., habitation sites) and their styles, decorations, types, morphologies, functions, etc. was more common than attention to ceramic production sites—production technology often being deduced from the characteristics and properties of the ceramic remains. Studies were frequently site-specific classifications, typologies and seriations used for dating and "relatedness" (affinity) to other sites/assemblages (often acting as proxy social units) within temporal-geographic material culture traditions. Incidentally, Miksic et al. (2009) developed a useful paradigmatic classification scheme for the Thnal Mrech kiln research, applicable to the larger corpus of Angkorian ceramics. Their classification scheme also incorporates local terminology enriched with particularly useful ethnographic information—thus, incorporating ethnographic, kiln-site assemblage, museum collection and other archaeological assemblage considerations.

Many past and present studies also focus on earthenware pottery rather than kiln-fired stoneware. Earthenware is geographically and temporally the most abundant class of ancient ceramics. Production was presumably localized in many if not most cases. Production technology likely prioritized various open-firing practices rather than the use of formal kilns. Thus, kiln studies were not necessary (i.e., irrelevant). Kilns simply did not exist and/or were not used for most local earthenware production.

Additionally, a demand for ancient ceramics by lay people and art collectors did not necessarily support or advance systematic research interests in production technology (and economics) at kiln sites with perhaps few exceptions (e.g., Chinese stonewares, glazed wares and porcelain kilns receive considerable attention; Thai kilns have also received a fair degree of attention). Furthermore, demands of lay people and collectors did not strengthen adherence to ethical heritage research, preservation, protection and management protocol by today's standards. In fact, the demand arguably had the opposite effect. Demand drove and still drives collecting and looting (and arguably the identification of loopholes in the legal systems, as well as more sophisticated black market operations and networks). Demand in this sector does not effectively drive detailed research, particularly on kilns. Rather, basic typologies, age ranges, cultural affiliation and quality of craftsmanship were sufficient for collectors and the suppliers.

It is also unfortunate that looting has become far more prevalent in recent times despite legal frameworks and punitive measures designed to deter looting. For example, in the 1920s Khmer ceramics were commonly sold in antique shops in Bangkok. These ceramics were excavated (illegally by today's laws) from kilns in northeast Thailand (W.A. Graham 1986). By the 1960s, Khmer ceramics were being sold even more widely at many antique shops in Bangkok. Subsequently, many private collectors from foreign countries have been acquiring increasingly more volume.[20] The open antiquities stalls and stores throughout Cambodia have demonstrated a visibly increased volume of trade in looted ceramics (and other artifacts) as well as the number of stalls and shops in increasingly more locations since the 1990s (at pace or perhaps at even higher rates with increased tourism volume). Interviews with local looters over the years (e.g., Banteay Meanchey, Preah Vihear, and Takeo[21]) also support claims for increased demand and trade volume associated with black and gray market operations (please refer to HeritageWatch for additional information to include substantial efforts combatting illicit trade).

2.2.2: Khmer Ceramic Studies

Since the 1970s, the study of Khmer ceramics—based on professional archaeological and art historical approaches—developed appreciably (Figures 9a and 9b). Experts reached a general consensus on the uniqueness and aesthetic values of Khmer ceramics. An exhibition of Khmer ceramics in Singapore in 1981, organized by the Southeast Asian Ceramic Society, encouraged Khmer ceramics experts, Bernard P. Groslier, Roxanna Brown, and Dawn Rooney, to contribute chapters to a seminal book on the subject (Stock 1981). This signified the inception of research on Khmer ceramics as a more formally defined field of academic study. It has continued to form a basis for the study of Khmer ceramic chronology and typology by subsequent researchers interested in Cambodia and northeast Thailand.

From 1959 to 1975, B. P. Groslier, then director of the École Française d'Extrême-Orient (EFEO) and also of Angkor Conservation Office in Siem Reap, conducted excavations at Sambor Prei Kuk in Kampong Thom Province as well as Roluos, Srah Srang, and the Royal Palace at the Angkor Thom site, Siem Reap Province. The excavations and pottery analysis form the basis for dating Khmer ceramics through the association of specific

[20] Despite lucrative industries now producing fakes in addition to increased and stricter heritage protection laws, looting continues almost unchecked. Many major markets have stalls dedicated to selling antiquities to tourists and collectors (some more discretely than others). Many dealers are able to produce faux or questionably "legal" documents claiming authenticity (or replicas if so desired) and legal ownership; especially ceramics, beads and various metal, stone and glass artifacts; even rings and bangles including attached skeletal remains such as finger and arm bones. More upscale antique shops are equally abundant and engage in similar practices. The black and "gray" markets are arguably dealing in more volume than ever, especially non-bulky and prolific artifacts mentioned above, to include vast amounts of pottery. Consumers include souvenir collectors which are dramatically increasing with the increased volume of tourists. The number of looted sites and looter pits strewn across the landscape suggests an even higher volume (many artifacts being taken across borders). These artifacts elude the main protection and repatriation radar afforded to statuary, architectural pieces, and rare or prized artifacts that dominate traditional collector demands.

There may be some argument that art collector demand did support interest in kiln research, however. For example, to gain access to wares produced at kilns and/or authenticate a vessel production location and age (e.g., Chinese kilns); but this is not the case with Khmer kiln sites to our knowledge.

[21] Kyle Latinis (personal communication) has periodically checked markets and interviewed low-tier looters (to include many locals who do not even know they are technically looting) since the 1990s to qualitatively assess trajectories. Dougald O'Reilly and his teams at Heritage Watch have maintained a dedicated campaign to research and deter looting. The program ranges from public outreach, awareness and education to legal efforts at repatriation.

types with stratigraphic layers and the dates of monuments known through inscriptional and art historical research. Groslier classified Khmer ceramics according to the reigns of kings starting from "the birth of an art" in the reign of Indravarman to "the end of an art" in the reign of Jayavarman VII (Groslier 1981).

Roxanna Brown, a Southeast Asian art historian and ceramics expert conducted excavation research and restoration work at Prasat Ban Phluang (Ban Phluang temple) in Surin, Thailand between 1972 to 1975. This temple, made of sandstone and laterite and built in the 11th century CE Baphuon style, was restored in the 1970s by an American architect, V. Childress in cooperation with Thai Fine Arts Department. As a final step in the restoration in 1975, Childress excavated the base of the temple and uncovered half a dozen nearly complete vessels and some 4,000 sherds, from which 270 recognizable vessels could be reassembled. Another 126 earthenware shapes were recognized. Many of the remains, however, were too fragmentary for reconstruction or further morphological assessment. Brown and Childress later published descriptions and analytical results of the sherds excavated from that site (Brown and Childress 1978).

In 1973, Brown studied the Ban Sawai kiln in Surin Province which was identified later as a habitation site; not a kiln. She also published the chemical analysis of sherds from that site (Brown et al. 1974). In the first edition (1977) and second edition (1988), she wrote chapters on Khmer wares in *The Ceramics of South-East Asia, Their Dating and Identification*. She further studied the Phnom Kulen kilns, *lie de vin* wares, the Buriram kilns, Prasat Ban Phluang, and dating of Khmer ceramics from Indravarman style to Bayon style (Brown 1988).

Dawn F. Rooney, also a Southeast Asian art historian, contributed to the catalog of the Khmer ceramic exhibition in Singapore with Groslier and Brown in 1981 (Rooney 1981). She wrote her MA thesis on Khmer ceramics and studied typology, clays, potting techniques, decorations, glazes, kilns, firing techniques, and uses in greater detail (Rooney 1984). She later edited a catalog of Khmer ceramics from the Kamratan collection for an exhibition at Toyama Museum of Fine Arts in Japan (Rooney 1990).

John Guy, a renowned art historian and Southeast Asian ceramics expert, wrote on Khmer ceramics found at Phnom Kulen and the Korat Plateau by analyzing architectural ceramics, kilns, their wares, and external influences in *Ceramic Traditions of South-East Asia* (Guy 1989). He subsequently analyzed the shapes/morphology of various ceramic wares as well as uses of ceramics, published in *Southeast Asian Glazed Ceramics* (Guy 1992). In Guy's lecture "A Reassessment of Khmer Ceramics", he set out his views on the origins of Khmer ceramics, reviewed the repertoire of wares, and examined the architectural and social context (Guy 1997).

In 1984, Yabe Yoshiaki and Hasebe Gakuji studied Khmer ceramics and demonstrated that their emergence and development were independent of external influence (Yabe 1978; Hasebe 1984, 1989), that is, direct diffusion of technologies (from China, for example) did not occur. This does not necessarily prove, however, that concepts of medium and high-fired ceramic technology, especially through kiln technology, were not influenced from outside sources. For example, the circulation of high-fired ceramics from extra-regional origins (e.g., China) may have influenced potters and their customers/supporters to consider changes in various technologies in order to meet demands, emulate, replicate, compete with, etc. foreign ware markets. Nonetheless, it appears that the industry developed a unique tradition independently. Arguably, this pattern is perhaps reflected in temple construction, with earlier forms appearing more "borrowed" in form; then quickly evolving and being redesigned into unique Khmer layouts, expressions, meanings and purposes.

Figure 9a: Khmer green and brown-glazed stoneware, samples

Note: Represented are a limited selection of Khmer green glazed and brown glazed stoneware ceramics. Actual assemblages and collections indicate substantial diversity of vessel forms as well as designs and decorations. Nevertheless, several fall into readily identifiable and/or designated functional and stylistic typologies (classification schemes) with a fair degree of consistency. Some categories are highly standardized. There are important implications related to standardization of certain forms; and equally important implications with categories exhibiting high degrees of variation.

Figure 9b: Khmer green glazed wasters from Anlong Thom, Phnom Kulen

While most early studies on Khmer ceramics were conducted by foreigners, Thong Bunthourn, a Cambodian archaeologist, made his contribution to the study of Khmer ceramics by analyzing typology during the Angkor period using the collections at the National Museum of Cambodia for his undergraduate degree (Thong 1995).

Examining Khmer ceramics at the Phimai National Museum and kilns in the Ban Kruat district, Sugiyama Hiroshi compiled a catalog of green and brown-glazed wares (Sugiyama 1995). He also studied the structures of Sawai and Nai Jian kilns (Sugiyama 1995). He further investigated ceramics excavated from Tani Kiln A6 and analyzed their general characteristics (Sugiyama 2004a). He and his colleagues produced a notable final report (Sugiyama et al. 2005). Another Japanese scholar of note, Tsuda Takenori, examined Khmer green-glazed wares with particular interest in the technology of early examples (Tsuda 1998–99).

In 2000, Marc Franiatte published his research on Khmer ceramics excavated in Angkor Thom. He analyzed typology, clay body, and glazes (Franiatte 2000). Meanwhile, Louise Allison Cort, curator of ceramics at the Freer Gallery of Arts and the Arthur M. Sackler Gallery of Smithsonian Institution, devoted an extensive study on Khmer ceramics from the Hauge Gifts by comparing stoneware and earthenware, the repertoire of shapes, dating, technology (shaping, decorating, glazing, and firing), production, functions of Khmer stoneware ceramics, relationships to other indigenous media and regional traditions, as well as exchange and trade factors (Cort 2000).

Many other contributors are equally important, and we hope the readers find it forgivable that we have not acknowledged all of them in this publication. However, they remain sincerely appreciated. Additionally, there are several other current research and experimental projects that have recently increased our understanding substantially; not only archaeology, but art history, epigraphy, geology, materials sciences, history and economics among several other fields. It is unfortunate that they cannot all be detailed here, but comments on the relevance of several projects are provided in the following sections. Workshops, conferences and other forums this year (2015; e.g., European

Association of Southeast Asian Archaeologists) attest to the accelerating interests, new discoveries, new models, and new directions in the field. We hope to incorporate these into future upgrades to this paper.

Finally, it is noted that several ceramic studies in Cambodia from the Neolithic earthenware pottery and metal age ceramics to Funan Period fine paste wares have been conducted. However, these will not be reviewed here. Additionally, it is re-emphasized that current studies at Cheung Ek (Phon Kaseka) have identified 69 kilns, some of which date to the late Funan period; others tentatively in the range of stoneware production within the Angkorian and post-Angkorian traditions. As this is the focus of upcoming reports (also in conjunction with ISEAS research), results are not detailed here. Nonetheless, these research studies are important contributions and add considerably to a greater understanding of Cambodian and regional traditions, industries, economics, influence and technologies; to include temporal trends and evolutionary factors having relevance on the development of stoneware industries.

3: Mapping and Analysis of Torp Chey Kilns

The Angkor Archaeological and Historical Park in Siem Reap, Cambodia and other similar parks in Southeast Asia have increasingly utilized advanced technology, Geographic Information System (GIS) and Remote Sensing (RS) to identify, research, preserve and maintain invaluable heritage to include recent efforts on kiln research. For example, the Angkor Archaeological Parks successfully carried out GIS and RS research to identify and analyze significant archaeological sites in Siem Reap. Results subsequently assisted the determination of relevant boundaries for the Angkor protected zone (401 km^2) for inscription into the World Heritage List of UNESCO in 1992.

Of equal importance, APSARA Authority, EFEO and the University of Sydney revealed detailed characteristics of structures, settlement zones and landscape modifications related to the ancient Angkor Capital urban complex from Phnom Kulen to the Tonle Sap through sophisticated GIS and RS techniques from 1999 to 2007. At this time (2004–2008), the Living Angkor Road Project (LARP) was also conducted after having successfully identified and assessed archaeological remains along the Angkorian road from the Angkor Capital to Vimayapura (Phimai Temple). In addition, the project also utilized LARP data in more detail to study the iron smelting site at Khvav along the Angkorian road from Angkor Capital to Bakan (Preah Khan Kompong Svay) by applying these technologies. In recent years, the use of LIDAR[22] RS and analysis has led to a veritable revolution in understanding the magnitude, breadth, distribution and intricacies of a much more complex network than previously imagined.

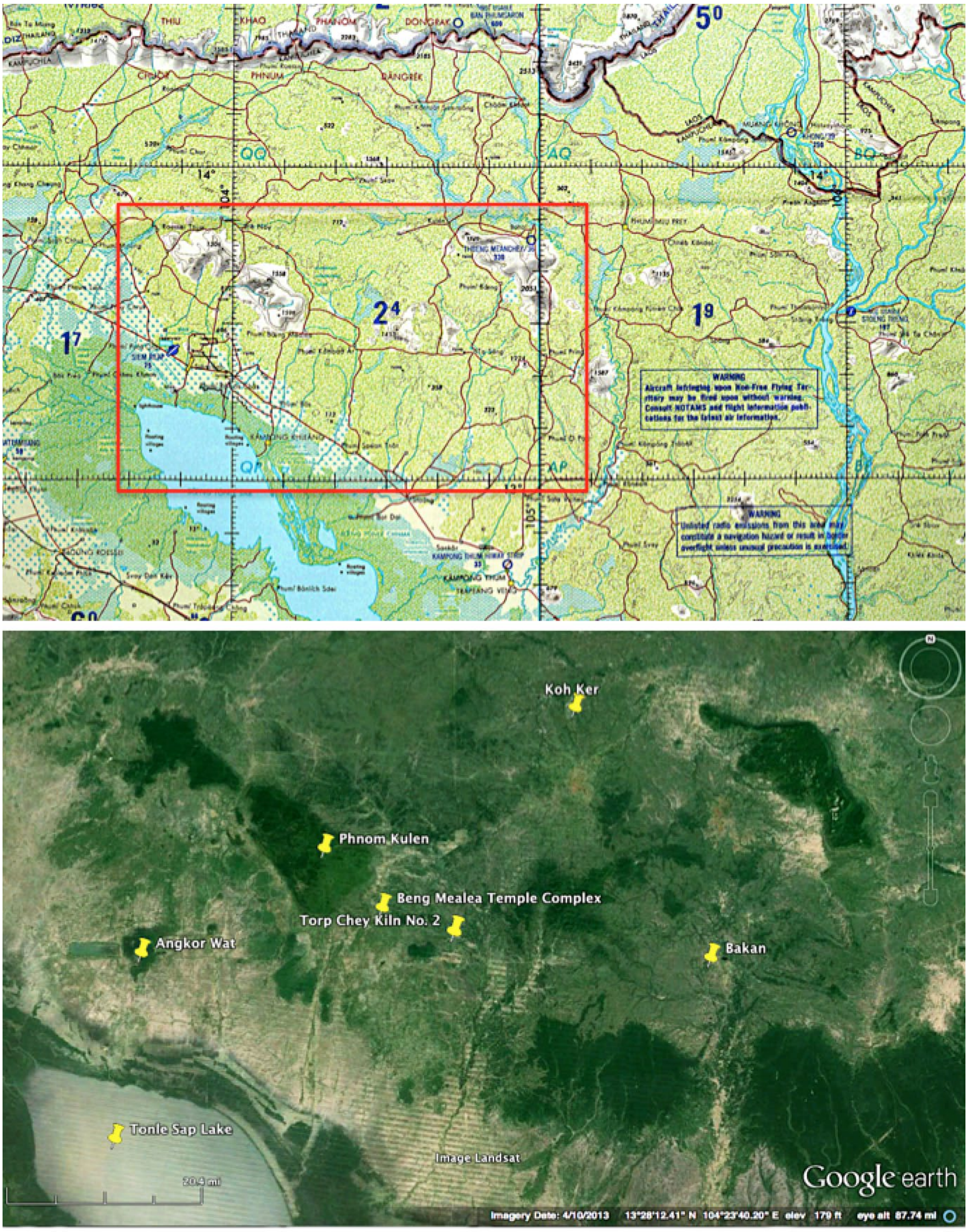
Due to the highly informative results and increased scientific output that these approaches generate, APSARA Authority and ISEAS applied GIS and RS technologies as part of their archaeological collaborative research project: "*The Excavation of a Brown-glazed Stoneware Kiln Site at Torp Chey*". The application of various technologies

[22] LIDAR: Light Detection and Ranging (also Light and Radar); remote sensing technology which uses lasers to measure distances to target areas from overhead flight paths. The data can be rendered to high-light landscape features and architecture remains beneath forest and other cover; also to generate high resolution maps.

contributed to productive project outcomes.

3.1: Torp Chey Site: Major Archeological Sites and Features

Figure 10: Map of major sites



Note: Location of Torp Chey kiln in relation to northern Cambodia to include Koh Ker, Beng Mealea, Angkor, Phnom Kulen and the Tonle Sap. The red square in the topographic map above approximates to the Google Earth image depicted below.

The Torp Chey Site (Figures 10) consists of two *prasat* (temples/architectural structures; but more specifically in this case, *agni griha (vahni-griha)*, rest houses or houses of fire; Figures 11 and 12), 12 kiln mounds,[23] a large pond, and other small ponds around Prasat Torp Chey Toch. The two *prasat* are: Prasat Torp Chey Toch, a rest house constructed during the reign of king Jayavarman VII; and Prasat Torp Chey Thom (also referred to as *guide d' etape* by Henry Parmentier; constructed during the reign of king Suryavarman II). Prasat Torp Chey Thom is located approximately 300 m north of Prasat Torp Chey Toch and 200 m south of the ancient road from Beng Mealea to Bakan. The large pond named Trapeang Torp Chey (Torp Chey pond) is located to the south, closer to the ancient road, and measures approximately 300 x 300 m.

Figure 11: Prasat Torp Chey Toch

Figure 12: Prasat Torp Chey Thom

23 An additional three kilns are located in neighboring villages, and up to 20 more kilns are estimated to exist in the area.

3.2: Torp Chey Site: Geography and Relation to Beng Melea and Bakan (Preah Khan at Kampong Svay)

The Torp Chey Site is located in Torp Chey Village, Beng Mealea Commune, Svay Leu District, Siem Reap Province (Universal Transverse Mercator [UTM] coordinates: 429797; 1486544; Figures 13 to 15). The site is situated between two mountainous formations located approximately 30 km apart: Kulen Mountain on the west, Khtum Mountain on the east. The natural slope from the west to the east led to the formation of the Chhi Kreng River. The Torp Chey Site is located west of river approximately 7.0 km from Ta Ong Bridge.

The site stands on a hill approximately 40–50 m above sea level. A small plateau runs east–west approximately 2.0 km south of the Torp Chey Site. Trapeang Torp Chey (anthropogenic water feature; pond) is located to the east of the site. Northeast of Torp Chey, there are two other sources of water: one from Kulen Mountain via Beng Mealea Stream and another from the Kaun Damrei Stream on the east. These two streams meet at Bok Stream near the ancient road which runs near the Torp Chey site and forms the source of water for Trapeang Torp Chey and the surrounding area.

The Torp Chey kiln site was discovered in early 2007 when LARP teams conducted a survey along the Angkorian road which leads east from Beng Mealea temple to Bakan. Mitch Hendrickson (2008a; 2008b) also identified and assessed the site in conjunction with his research on road networks and infrastructure. Beng Mealea is a large temple built in the 12th century. The temple and the surrounding area were modified during the Bayon period (Jayavarman VII; 1181–1220 CE). The temple complex was an important area, possibly a significant urban complex with large communities in the area. Infrastructure was well-developed to include the road(s), rest house(s), hospital(s), and a large water reservoir on the east. Ceramic kilns, temples and other architectural remains are located south of the main temples. The kiln industry may have been contemporaneous with and economically synched to Beng Melea's development and period of prominent occupation, various industries and other activities.

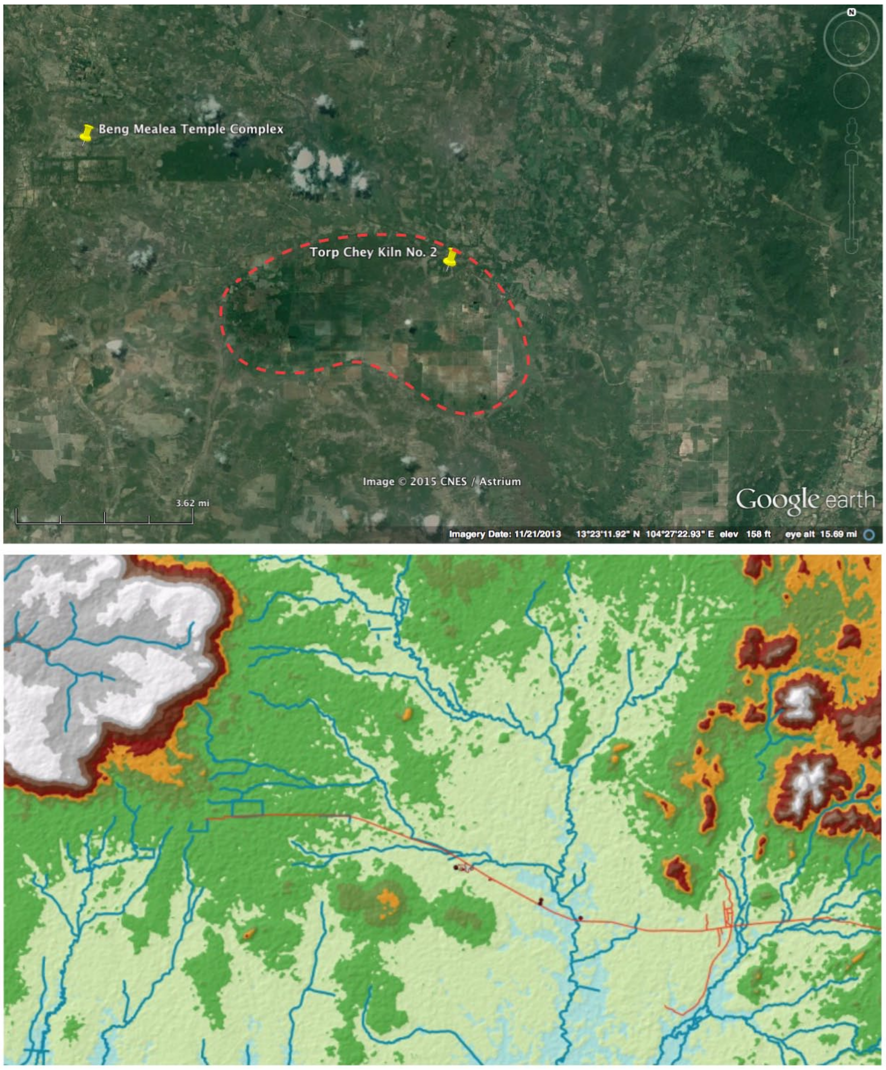
Beng Mealea is also considered an important node in the distribution of economic products, particularly iron, to the capital and throughout the empire from at least the early 12th century (Hendrickson 2007). Centralized control, production and distribution/redistribution are important hypotheses that have implications for understanding the ceramic industry as well. How much autonomy or control was there; who controlled it (kings, territory/industry ministers or managers, local elite, craft guilds, communities, individuals, etc.); how was it managed; how was it taxed or subsidized; etc. remain important questions. Are the dynamics and nature of the iron industry, for example, a useful proxy for understanding the ceramic and other industries?

Bakan is another large temple complex site with numerous landscape features and modifications as well as urban and industrial components. It contains a large water reservoir, temples, and iron smelting sites. At Bakan, iron was made for supplying tools, weapons, and other materials/products to the Angkor capital and other places. Halfway between Beng Mealea and Bakan, there is also an iron smelting site at Khvav. Five iron smelting mounds were identified at the site and two mounds were excavated by the APSARA team. The excavation confirmed the existence of iron smelting through the presence of tuyères, burned clay, and slag.

Many rest houses were constructed along the East Road from Beng Mealea to Bakan at intervals of about 15–17 km. The roads are associated with ancient bridges, ponds, and occupation mounds. Torp Chey Toch is situated approximately 17 km to east–southeast of Beng Mealea and contains the first sandstone rest house along the east road to Bakan. Torp Chey Toch is built close to the East Road and to Torp Chey Thom. As stated, 12 ceramic kiln mounds are located close to each other near both Prasat Torp Chey Toch and Prasat Torp Chey Thom. Among those, ten kiln mounds remain relatively intact, although two have suffered from looting activities in the upper layer.

3.3: Torp Chey Site Mapping and Survey

Figure 13: Google Earth and Astergram images (Astergram not to scale)

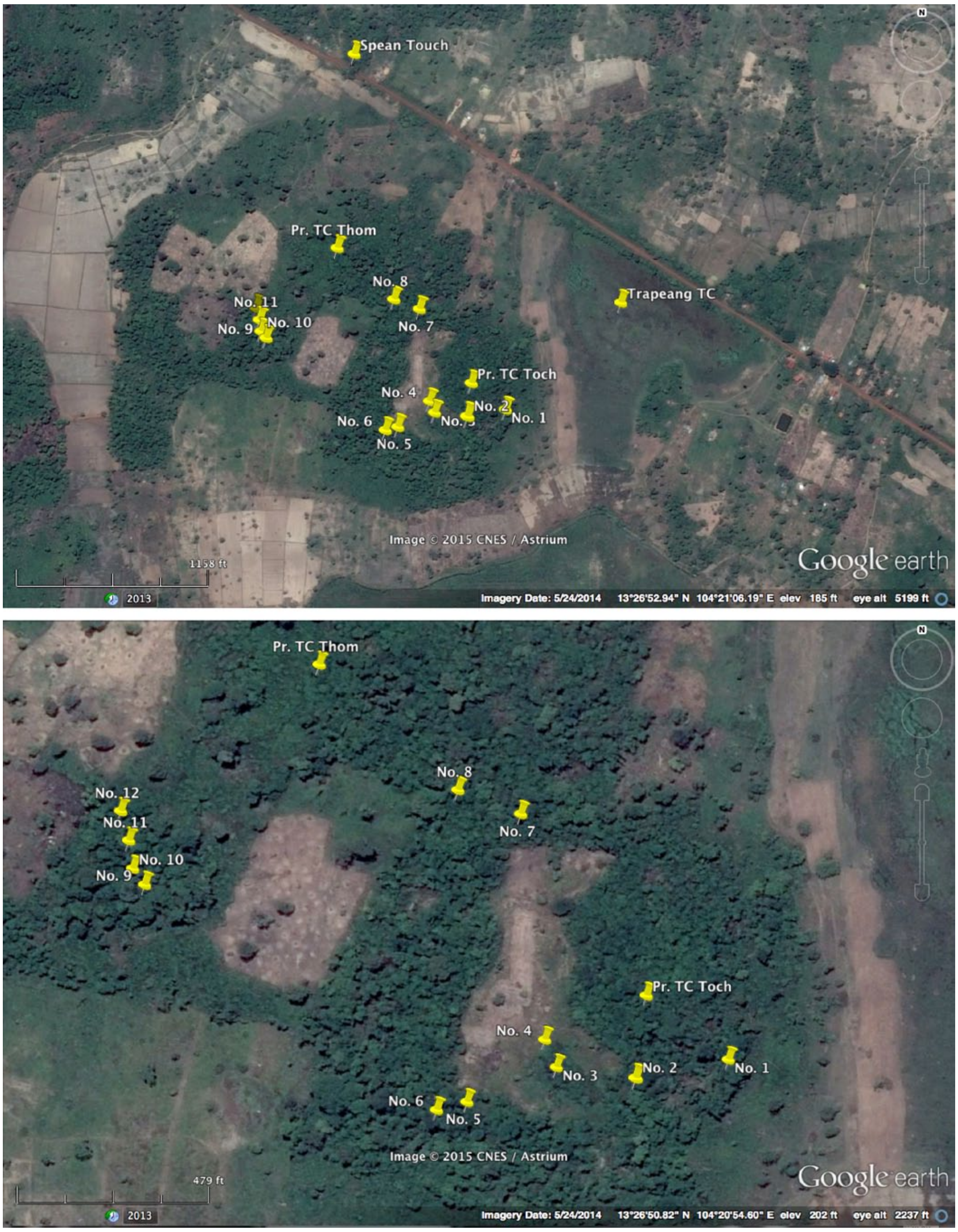


Note: This image allows assessment of Torp Chey in relation to drainages, roads and other features. Note the bean-shaped area approximately 5 km wide with gridded (square) agricultural plots to the west and south of Torp Chey. This may relate to natural topography, past land use and settlement. The antiquity is unknown and warrants further investigation. Compare also with Beng Mealea's very discernable rectilinear features, topography and drainage seen in both images.

Throughout the Torp Chey project, geo-spatial data comprising both existing and new data were utilized to study and interpret the Torp Chey complex (Figures 13–15). This analysis was paired with "ground truthing/validation" to include physical survey, direct measurement, and assessment at the site locations. The coordinates of 15 kilns and four archaeological sites/features were recorded (three kilns outside of the main cluster; Table 1). Test excavations were subsequently conducted at Kiln no. 2, along with various analyses (e.g., radiocarbon dating-AMS, magnetic susceptibility, sieve and hydrometer tests; see sections below).

Figure 14: Google Earth image highlighting all sites mentioned in Table 1

Figure 15: Google Earth images at varying scales (data from Table 1)



Note: Concentric image analysis can be useful for identifying patterns and relations (or lack thereof) among natural and anthropogenic features at varying scales.

Table 1: Coordinates for Torp Chey kilns and features

No	Kiln	UTM_X	UTM_Y	Village	Commune	District	Province
1	Kiln No. 01	429868	1486563	Torp Chey	Khvav	Chikreng	Siem Reap
2	Kiln No. 02	429797	1486544	Torp Chey	Khvav	Chikreng	Siem Reap
3	Kiln No. 03	429737	1486558	Torp Chey	Khvav	Chikreng	Siem Reap
4	Kiln No. 04	429728	1486579	Torp Chey	Khvav	Chikreng	Siem Reap
5	Kiln No. 05	429669	1486532	Torp Chey	Khvav	Chikreng	Siem Reap
6	Kiln No. 06	429646	1486526	Torp Chey	Khvav	Chikreng	Siem Reap
7	Kiln No. 07	429710	1486748	Torp Chey	Khvav	Chikreng	Siem Reap
8	Kiln No. 08	429663	1486766	Torp Chey	Khvav	Chikreng	Siem Reap
9	Kiln No. 09	429428	1486696	Torp Chey	Khvav	Chikreng	Siem Reap
10	Kiln No. 10	429419	1486708	Torp Chey	Khvav	Chikreng	Siem Reap
11	Kiln No. 11	429416	1486729	Torp Chey	Khvav	Chikreng	Siem Reap
12	Kiln No. 12	429410	1486751	Torp Chey	Khvav	Chikreng	Siem Reap
13	Kiln No. 13	433944	1484983	Samrong	Khvav	Chikreng	Siem Reap
14	Kiln No. 14	433898	1484776	Samrong	Khvav	Chikreng	Siem Reap
15	Kiln No. 15	436008	1484003	Chong Spean	Khvav	Chikreng	Siem Reap
16	Pr. Torp Chey Toch	429805	1486612	Torp Chey	Khvav	Chikreng	Siem Reap
17	Pr. Torp Chey Thom	429559	1486860	Torp Chey	Khvav	Chikreng	Siem Reap
18	Spean Touch	429590	1487217	Torp Chey	Khvav	Chikreng	Siem Reap
19	Trapeang Torp Chey	430083	1486759	Torp Chey	Khvav	Chikreng	Siem Reap

3.3.1: Geo-spatial Data Used

- General Topographic Survey Map, scale to 1:100,000, 2003
- General Topographic Survey Map, scale to 1:50,000, 1960
- Landsat 7 satellite image, 2002–3
- SPOT 5 satellite image (Google Earth) 2011
- The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) (ASTERGDEM), Spatial resolution 15 m, Dec 1999

3.3.2: GIS and RS Compatible Survey Equipment Used

- Global Positioning System (GPS): Garmin GPS Map 76s (accuracy -/+ 5.0–10.0 m)
- Total Station Machine: Sokia SET30R and its peripherals
- Military Manual Compass
- 50 m Roll Tape(s)

3.3.3: Archaeological Measurement and Survey Methodology

The Torp Chey research project covers approximately 100 hectares of sample area (UTM_P48N_WGS84 coordinates: 1487340, 1486334, 429313, 430387). The location of each archaeological site and their boundaries were tracked and identified by GPS. Each site was measured and mapped on paper with the addition of relevant details. Data was plotted and redrawn into the following GIS and RS applications: ArcGIS Desktop 10.0, ArcScene 10 (3D) extension, Google Earth, Garmin Mapsource, and Erdas Imagine 9.2, for the interpretation and analysis of the general characteristic of Torp Chey archaeological complex.

3.3.4: Establishment of Ground Control Points (GCP) Using a Total Station

Throughout Siem Reap City and Angkor Park, Ground Control Points (GCPs) were installed during the French colonial period to assist mapping of monuments and urban planning projects. However, Torp Chey is located approximately 55 km by road due east of the Angkor Capital site and a proximate GCP has yet to be installed in the area. Thus, an arbitrary and expedient GCP was established which has an approximate tolerance of +/- 5.0 m for X and Y coordinates, and +/- 2 .0–5.0 m for Z coordinates. This was derived by using a hand held GPS device (Garmin GPS map 62s).

After obtaining X, Y, and Z coordinates, the team installed temporary GCPs along the ancient road, starting from a small ancient bridge at the eastern section; turning about 650 m from the southern part of the road to Kiln no. 2, nearby Torp Chey Toch (Table 2). Between Kilns no. 1 and no. 2, the team established two permanent concrete GCPs. This accommodated the total station survey equipment used for detailed plotting and recording related to excavations at Kiln no 2. These two GCPs are: APSARA BM01 (X: 429823.829, Y: 1486546.656, Z: 61.347) and APSARA BM02 (X: 429851.526, Y: 1486545.631, Z: 60.732). These GCPs may be adjusted to absolute/universal locations using a higher capacity Differential Global Positioning System (DGPS) machine in future projects.

Table 2: List of temporary and permanent concrete GCPs

No	Name	UTM_X	UTM_Y	MSL (Z)
1	A2	429588.732	1487214.869	60.845
2	A3	429585.539	1487221.866	60.572
3	A4	429795.784	1487098.605	59.688
4	A5	429762.148	1487128.138	59.538
5	B1	429912.06	1487002.291	60.399
6	B2	429913.133	1487008.566	60.412
7	B3	430012.805	1486388.478	60.986
8	B4	430018.854	1486388.691	61.098
9	C1	429871.116	1486560.409	62.874
10	B5	429806.672	1486539.576	61.793
11	B6	429804.83	1486533.398	61.221
12	B7	429804.829	1486533.398	61.222
13	BM1	429823.829	1486546.656	61.347
14	BM2	429851.526	1486545.631	60.732

3.3.5: Mapping Results

Ground survey and measurement at Torp Chey with the total station, GPS, GIS and RS data resulted in the following products:

- Torp Chey archaeological map (scale 1:2,000)
- General topographic map of Torp Chey location in relation to Angkor (scale 1:80,000)
- 3D digital model of kiln no. 2 (multiple views; scale 1:100)
- Point elevation spot and excavation trench map (scale 1:130)
- Ceramic kiln structure and its point elevation (scale 1:130)
- Land-use and Torp Chey archaeological site map (scale 1:2,000)
- General point elevation of Torp Chey and its surrounding area (scales 1:40,000 and 1:5000)

3.3.6: Basic Descriptions of the Mapped Kiln Mounds

Table 3 summarizes the basic dimensional metrics. It is noted that wasters occur in almost all kiln areas. Only a visual observation was made. No sample of surface remains were recovered for comparative analyses. The density, type variance and other specifics remain unknown.

Table 3: Basic kiln metrics

Kiln	x (length) m	y (width m)	z (height) m	Area (x*y) square m	Volume (x*y*z) cubic m	Slope direction
1	25.0	15.0	4.0	375.0	1500.0	W to E
2	25.0	15.0	4.0	375.0	1500.0	
3	20.0	15.0	3.5	300.0	1050.0	W to E
4	20.0	35.0	5.0	700.0	3500.0	N to S
5	17.0	14.0	3.0	238.0	714.0	W to E
6	18.0	12.0	3.0	216.0	648.0	W to E
7	13.0	10.0	2.0	130.0	260.0	E to W
8	15.0	8.0	1.5	120.0	180.0	E to W
9	17.0	12.0	4.0	204.0	816.0	E to W
10	15.0	8.0	1.5	120.0	180.0	NE to SW
11	15.0	10.0	2.0	150.0	300.0	E to W
12	25.0	17.0	4.5	425.0	1912.5	SE to NW
13	15.0	13.0	3.5	195.0	682.5	E to W
14	10.0	13.0	3.0	130.0	390.0	N to S
15	17.0	20.0	2.5	340.0	850.0	N to S
Total	267.0	217.0	47.0	4018.0	14483.0	
Avg	17.8	14.5	3.1	267.9	965.5	
Std Dev	4.5	6.5	1.1	157.9	873.6	

Note: It is unknown to what extent area and volume directly correlate to estimated production volume; volume may be overestimated due to mound curvature, but underestimated as complete wall height may not be accurate and roof curvature and associated height and volume is not included. These calculations are meant to be a comparative proxy metrics. Slope direction may be related to engineering related to airflow, exhaust, ventilation for example.

- Kiln no. 1 is located approximately 70 m southeast of Prasat Torp Chey Toch. The mound's dimensions are: 25.0 m E–W (east to west axis), 15.0 m N–S (north to south axis); and 4.0 m high. The mound is highest on the west, and slopes gradually downwards to the east. The top of the mound was looted over an area of approximately 1.0 x 2.0 m. The floor and wall of the kiln appear looted from the trench as well. On the top of the site and throughout the surrounding area of the mound, there are many pieces of brown-glazed jars and basins, and roofing fragments (clay chunks, many with thatch impressions) from the kiln.

- Kiln no. 2 is located approximately 60 m south of Prasat Torp Chey Toch. The mound size is similar to Kiln no. 1: 25.0 m E–W, 15.0 m N–S, and reaching 4.0 m in height. The mound is well preserved. Many fragments of brown-glazed jars, roof tiles, and kiln roofing are located on top of the mound and scattered throughout the surrounding area.

- Kiln no. 3 is located approximately 40 m west of Kiln no. 2. The mound's dimensions are: 20.0 m E–W, 15.0 m N–S, and 3.5 m in height. The mound is highest on the west and slopes gradually downward on the east. Many fragments of brown-glazed jars and pieces of kiln roof material are located on top of the mound and scattered throughout the surrounding area.

- Kiln no. 4 is located approximately 70 m southwest of Prasat Torp Chey Toch. The mound's dimension are: 20.0 m E–W, 35.0 m N–S, and 5.0 m in height. The mound slopes gradually downward to the south. Many fragments of brown-glazed jars and basins, and pieces of the kiln's roof are located on top of the mound and scattered throughout the surrounding area.

- Kiln no. 5 is located approximately 60 m southwest of Kiln no. 3. The mound measures 17.0 m E–W; 14.0 m N–S, and 3.0 m in height. The mound slopes gradually downwards from the west to east. Many fragments of brown-glazed jars and pieces of the kiln's roof are located on top of the mound and scattered throughout the surrounding area.

- Kiln no. 6 is located approximately 10 m west of Kiln no. 5. The mound's dimensions are: 18.0 m E–W, 12.0 m N–S, and 3.0 m in height. The mound is highest on the west and gradually slopes to the east. The western and southern parts of the mound have been looted. There are many fragments of brown-glazed jars, basins, roof tiles, and pieces of the kiln's roof are located on top of the mound and scattered throughout the surrounding area.

- Kiln no. 7 is located approximately 120 m northwest of Prasat Torp Chey Toch. The mound measures 13.0 m E–W, 10.0 m N–S, and 2.0 m in height. The mound is highest on the east and gradually slopes downward to the west. Many fragments of brown-glazed jars, roof tiles, and pieces of the kiln's roof are located on top of the mound and scattered throughout the surrounding area.

- Kiln no. 8 is located approximately 30 m west of Kiln no. 7. The mound's dimension are: 15.0 m E–W, 8.0 m N–S, and 1.5 m in height. The mound is highest on the east and slopes gradually downward to the west. Many fragments of brown-glazed jars, and pieces of the kiln's roof are located on top of the mound and scattered throughout the surrounding area.

- Kiln no. 9 is located approximately 120 m northwest of Prasat Torp Chey Thom. The mounds' dimensions are: 17.0 m E–W, 12.0 m N–S, and 4.0 m in height. The mound is highest on the east and slopes gradually downward to the west. Many fragments of brown-glazed jars and pieces of the kiln's roof are located on top of the mound and scattered throughout the surrounding area.

- Kiln no. 10 is located approximately 6 m northwest of Kiln no. 9. The mound measures 15.0 m from NE–SW, 8.0 m SE–NW, and 1.5 m in height. The mound is highest on the northeast and gradually slopes downward to the southwest. Many fragments of brown-glazed jars, basins, and pieces of the kiln's roof are located on top of the mound and scattered throughout the surrounding area.

- Kiln no. 11 is located approximately 6 m northwest of Kiln no. 10. The mound's dimensions are 15.0 m E–W, 10 m N–S, and 2.0 m in height. The mound is highest on the east and gradually slopes downward to the west. Many fragments of brown-glazed jars and basins are located on top of the mound and scattered throughout the surrounding area.

- Kiln no. 12 is located approximately 10 m northwest of Kiln no. 11. The mound measures 25.0 m NW–SE, 17.0 m SW–NE, and 4.5 m in height. The mound is highest on the southeast and gradually slopes downward to the northwest. Many fragments of brown-glazed jars, basins, and pieces of the kiln's roof are located on top of the mound and scattered throughout the surrounding area.

- Kiln no. 13 is located in Samrong Village, in the eastern part of Torp Chey Village. The mound measures 15.0 m E–W, 13.0 m N–S, and 3.5 m in height. The mound is highest on the east and gradually declines to the west. Many fragments of brown-glazed jars and basins are located on top of the mound and scattered throughout the surrounding area.

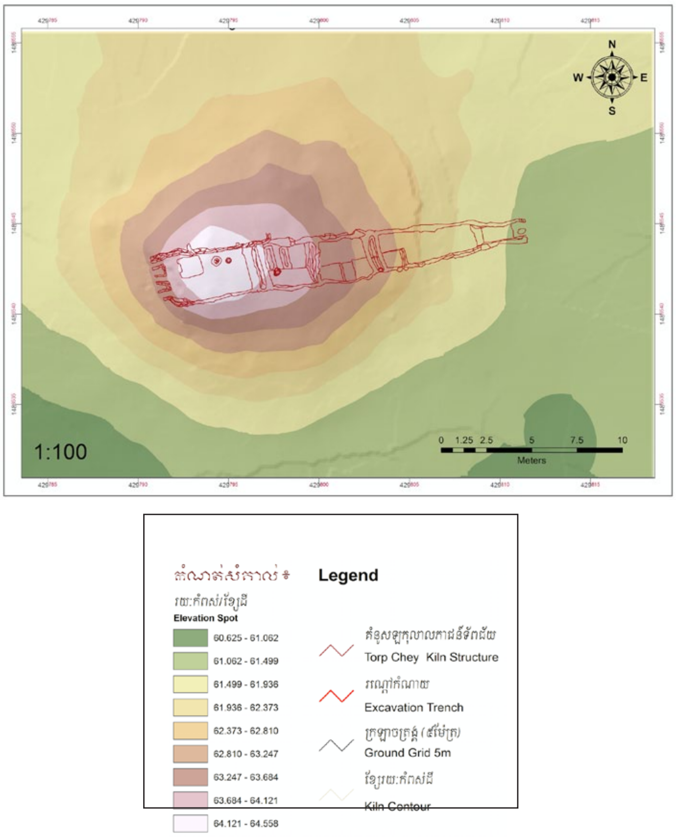
- Kiln no. 14 is also located in Samrong Village, in the eastern part of Torp Chey Village. The mound's dimensions are: 10.0 m E–W, 13.0 m N–S, and 3.0 m in height. The mound is highest on the north and gradually declines toward the south. A looter's pit is located on the top of the mound and pieces of roof tiles were found on the surface.

- Kiln no. 15 is located in Chong Spean Village, in the eastern part of Torp Chey Village. The mound measures 17.0 m E–W, 20.0 m N–S, and 2.5 m in height. The mound is highest on the north and gradually declines toward the south. Many fragments of brown-glazed jars and pieces of roof tiles are located on top of the mound and scattered throughout the surrounding area.

3.3.7: Three-dimensional (3-D) mapping of Kiln no. 2

With two GCPs the absolute measurements (x, y, z coordinates) of the kiln and its shape was readily derived with the total station and associated software (ArcGIS Desktop 10). Hundreds of control points allowed development of the 3D model of Kiln Mound no. 2 (Figures 16 to 19). The image can be rotated in any direction; sections can be used for comparing profiles, plan views, and oblique views.

Figure 16: 3-D image of Torp Chey (plan view, color)



Note: This legend applies to Tables 16, 17 and 19.

Figure 17: 3-D images of Torp Chey (3/4 and frontal views, color)

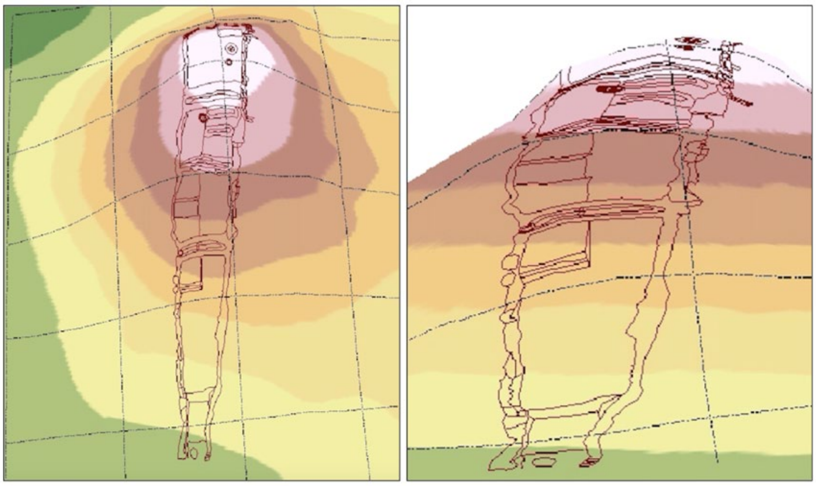
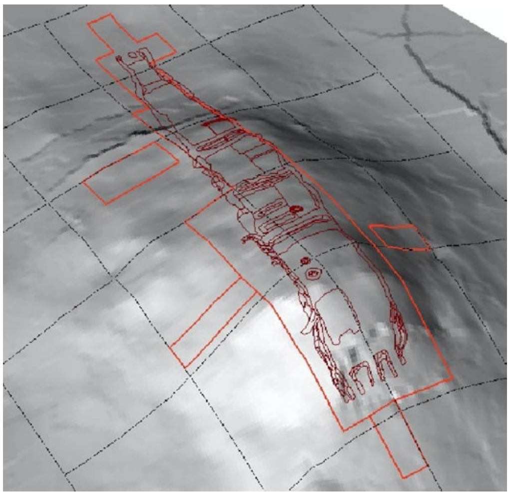


Figure 18: 3-D image of Torp Chey: Oblique view with testing grid, grayscale



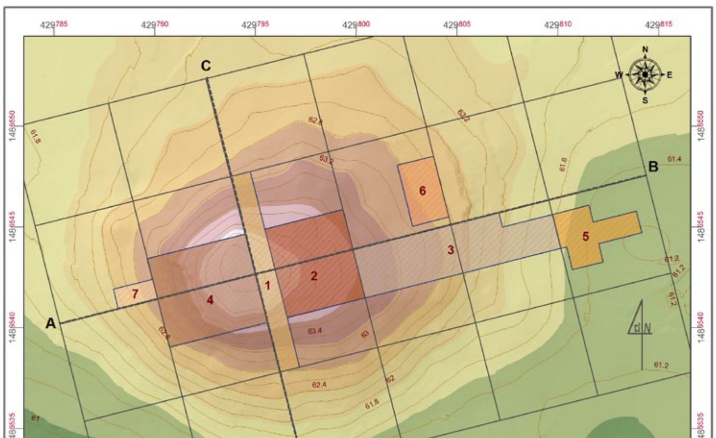
4: Excavation

4.1: Description of Kiln Mound no. 2

The ground plan of Kiln Mound no. 2 is oval, measuring approximately 25.0 m from the west (top) to the east, and about 15.0 m from the north to the south. The mound is well preserved. At the onset of excavations, Kiln Mound no. 2 was covered with grass, saplings and a few large trees. Larger trees were preserved in place.

The upper parts of both kiln walls were visible around the top of the mound in a semi-circular shape. After clearing the mound, a datum point was set up at the center of the top of the kiln. East–west and north–south axes were set up across the datum point and five meter grids were set up around the mound over an area of 30.0 m east–west and 20.0 m north–south (Figure 19).

Figure 19: Plan view of Torp Chey kiln with excavation unit grid numbers



Each five meter grid was named from the datum point by counting the number from "0" to the east, west, north and south. For example, E0S0 grid is located at the southeast corner of the datum point and S0W0 grid is located at the southwest corner of the datum point.

A systematic surface collection was performed by grids in order to understand the distribution of artifacts around the mound. Many pieces of kiln roof were found on the top of the mound due to the collapse of the roof on the floor. The kiln appears undisturbed since the time of abandonment (disuse). No major modern or ancient disturbances such as looting or intentional destruction/clearance is evident. Pieces of brown-glazed jars and roof tiles were also found on the mound.

4.2: Excavated Units

Seven units were excavated at Kiln Mound no. 2. Three distinct kiln structures were noted. These overlaid and partially incorporated each other. The uppermost is Kiln III (i.e., Kiln structure III) while the lowermost and presumably oldest is Kiln I. The number of times each kiln structure was reused (or, if it represents a single firing event or multiple firing events—most likely the latter) is unknown. Overlying kilns (Kiln II and III) may have been rebuilt or partially rebuilt from earlier kiln remnants, in some cases clearly maintaining kiln design integrity and former structural components. Total unit area excavated was approximately 94 m^2. Of note: the kiln mound itself is mostly artificial; sloping approximately 20 degrees. The mound is a result of kiln construction; differing from earlier kilns which were often built onto or into natural mounds.

- Unit 1 (1.0 x 10.0 m) was set up north–south across the kiln body in the grids S0E0 and N0E0 to locate both walls of the kiln and assess the slope of the mound.
- Unit 2 (4.0 x 5.0 m) was set up to the east, next to Unit 1 in the grids S0E0 and S0N0 to follow both walls.
- Unit 3 (3.0 x 10.0 m) was set up to the east, next to Unit 2 in the grids S0E1 and S0E2 to follow both walls and the right half of the kiln body.
- Unit 4 (4.0 x 5.0 m) was set up to the west, next to Unit 1 in the grids S0W0 and N0W0 to follow the upper part of both walls and vent.
- Unit 5 (2.0 x 4.0 m) was set up to the east of Unit 3 in the grid S0E3 to identify the fire box and the eastern part of the fire box.
- Unit 6 (2.0 x 3.0 m) was set up north of Unit 3 about 50 cm in the grid N0E1 to further assess the deposits and potential waste and/or discard remains.
- Unit 7 (1.0 x 2.0 m) was set up west of Unit 4 in the grid N0W1 to assess the deposit located west of the vent.

Only the right half of the kiln from Units 1 to 5 was excavated in order to expose the stratigraphy of the kiln floor(s) and preserve potential for future testing or preservation. Layers (Roman numerals) do not necessarily conform from one unit to the next. For example, Layer II in Unit 2 is not the same depositional layer as Layer II in Unit 7.

Unit 1 was divided into two sub-units: from the datum point to the south was sub-unit T001S (1.0 x 5.0 m) and to the north was sub-unit T001N (1.0 x 5.0 m). The excavation began from the top of the mound and both side walls. The kiln body was identified on the top of the mound and the excavation continued at the northern and southern parts of the kiln body to expose the deposit. Excavations were conducted by identifiable layers at 10 cm arbitrary levels. Deposits were not systematically screened, though removed soils were thoroughly examined for material culture and ecofact remains. Artifacts (almost exclusively ceramics and kiln structure fragments) were recovered. An estimated 5,000 ceramic fragments are awaiting further analyses.

T001N (Table 4) was excavated to a depth of approximately 3.0 m below surface at the northern part of the kiln body. Several brown-glazed jars (with lugs), roof tiles, kiln roof and wall were found in the 11 layers as described below.

Table 4: T001N

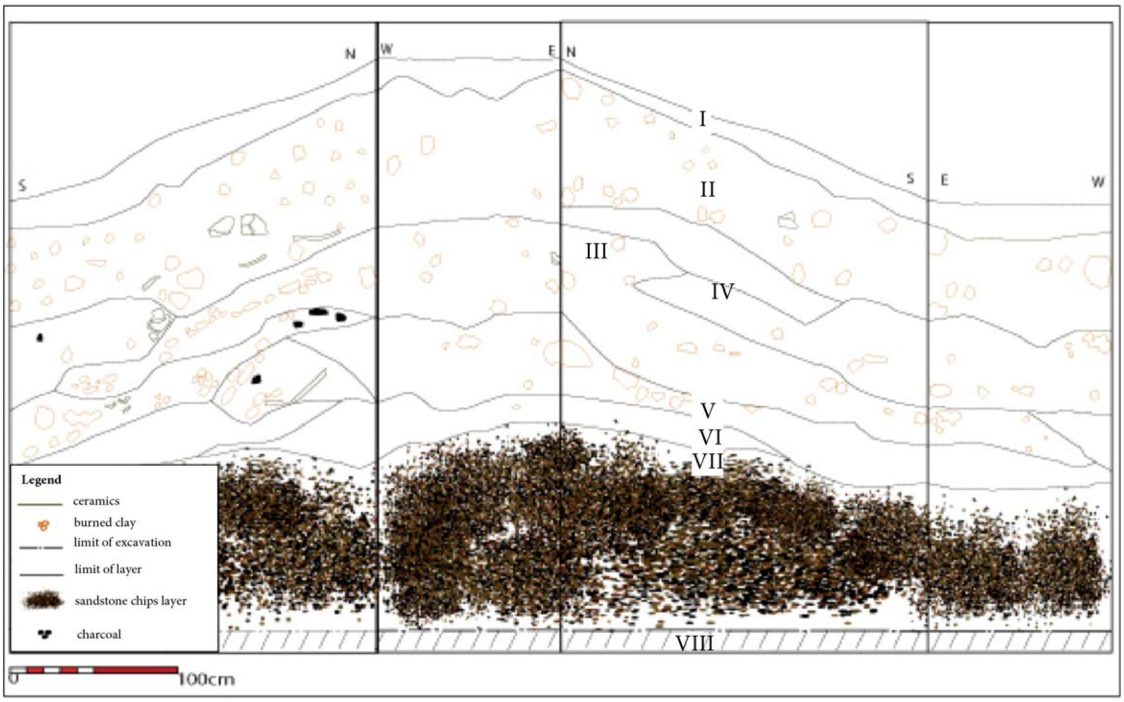
Layer	Depth (Thickness)	Soil/Deposit	Comments
I	0–15 cmbs* (15 cm)	Brown soil and sand.	Surface layer: post-depositional accumulation; few artifacts.
II	15–75 cmbs (60 cm)	Brown sandy soil; several large pieces of burned and raw clay	The burned clay derives from the broken walls and the roof of the final kiln.
III	75–115 cmbs (40 cm)	Light gray soil; coarse sand and small burned clay pieces	Likely the waste remains of the kiln floor.
IV	115–149 cmbs (34 cm)	Dark gray soil; coarse sand; small burned clay and sandstone fragments	Likely the waste remains of the kiln floor.
V	149–174 cmbs (25 cm)	Dark soil; several large fragments of burned clay	Formed by the deposit/debris of the kiln's wall and roof.
VI	174–184 cmbs (10 cm)	Dark gray ash	Likely the first ash disposed near the kiln body after the kiln was used.
VII	184–199 cmbs (15 cm)	Large pieces of burned clay	Likely formed from kiln wall and roof deposits/debris.
VIII	199–214 cmbs (15 cm)	Dark gray clay; small pieces of sandstone	Probably formed during kiln construction.
IX	214–242 cmbs (28 cm)	Dark gray clay	Formed during the construction of kiln body.
X	242–292 cmbs (50 cm)	Dark gray clay; many sandstone chips	Sandstone chips were deposited/placed directly on the natural soil to build the kiln foundation.
XI	292+ cmbs	Gray reddish natural soil.	Pre-kiln construction; natural underlying deposit.

* cmbs = cm below surface

T001S (Table 5 and Profile Image) was excavated to a depth of approximately 3.0 m at the southern part of the kiln. Many brown-glazed jars with lugs, roof tiles, kiln roof fragments, and wall fragments were found throughout eight layers.

Table 5: T0001S

Layer	Depth (Thickness)	Soil/Deposit	Comments
I	0–20 cmbs (20 cm)	Brown clay with fine sand	Surface layer: post depositional accumulation; biomass.
II	20–76 cmbs (56 cm)	Brown gray soil with fine and coarse sand, burned clay and small pieces of charcoal.	Formed from kiln waste deposits.
III	76–122 cmbs (46 cm)	Blackish soil with fine and coarse sand; burned clay	Brown-glazed jars; Formed from kiln waste deposits.
IV	122–157 cmbs (35 cm)	Blackish soil with sand and ash.	Formed from kiln waste deposits.
V	157–167 cmbs (20 cm)	Orange and grayish soil with sand, burned clay and charcoal.	Formed from kiln waste deposits.
VI	167–192 cmbs (25 cm)	Blackish soil with pieces of charcoal and sand.	Formed from kiln waste deposits.
VII	192–272 (80 cm)	Greenish gray soil with sandstone chips.	The sandstone chips were deposited directly on the natural soil to form the kiln foundation.
VIII	272+ cmbs	Gray reddish natural soil.	Underlying natural deposit.

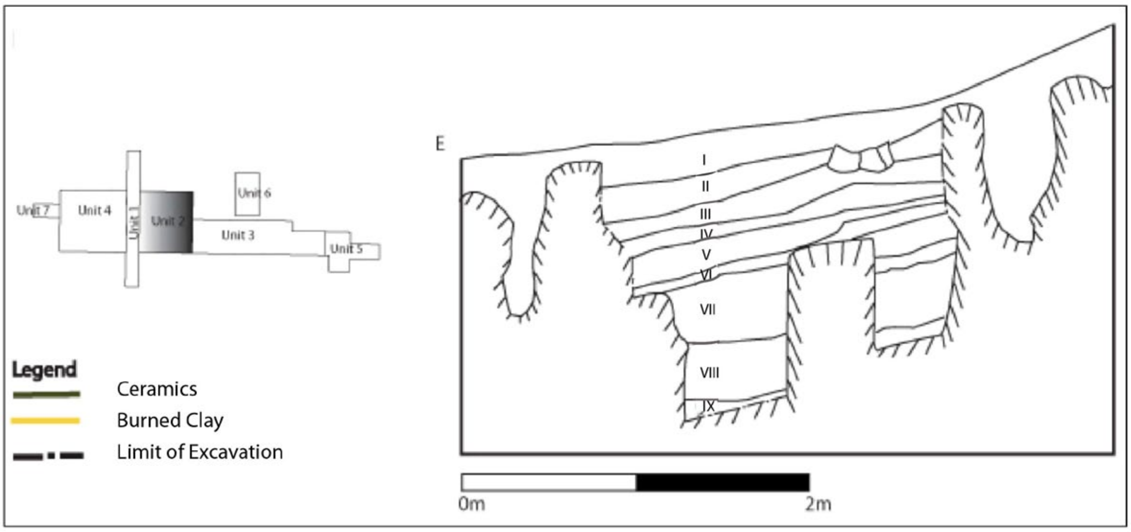


Profile: Unit 1S

Unit 2 (Table 6 and Profile Image) was located east of Unit 1. The excavation of this unit was designed to follow both walls. After confirming the location of both walls, excavations only covered the right half of the kiln body in order to preserve the left half for future needs; e.g., re-excavate the site, validate data, further assess the cross-section, preserve for site museum development, etc.

Table 6: Unit 2

Layer	Depth (Thickness)	Soil/Deposit	Comments
I	0–24 cmbs (24 cm)	Brown gray soil with sand and clay including many pieces of burned clay.	Burned clay fragments are pieces of roof that collapsed on the floor of Kiln no. III.
II	24–44 cmbs (20 cm)	Brown gray sandy soil with fine and coarse sand including a thin layer of clay floor.	This layer is floor no. 4 of Kiln no. II, the construction of which included a 3.0 cm thick clay layer and a 17.0 cm thick layer of fine and coarse sand. One floor of this kiln included a thin layer of orange clay with a thick layer of fine and coarse sand on top of it. The sand layer was likely designed to stabilize pots for firing. Three more layers below have a similar structure.
III	44–82 cmbs (38 cm)	Thick, brown gray fine and coarse sandy soil on top and orange clay at the base.	Layer is floor no. 3 of Kiln no. II.
IV	82–100 cmbs (18 cm)	Thick, brown gray fine and coarse sandy soil on top and orange clay at the base.	Layer is floor no. 2 of Kiln no. II.
V	100–128 cmbs (28 cm)	Thick, brown gray fine and coarse sandy soil on top and orange clay at the base.	Layer is floor no. 1 of Kiln no. II.
VI	128–168 cmbs (40 cm)	Orange soil with burnt clay.	This soil was used to fill the secondary fire trench of Kiln no. I for making Kiln no. II.
VII	168–184 cmbs (16 cm)	Dark soil mixed with the ash.	Soil accumulated on the last floor of Kiln no. I.
VIII	184–201 cmbs (17 cm)	Orange soil with burned clay.	No data/comments.
IX	201+ cmbs	Orange sandy soil.	No data/comments.



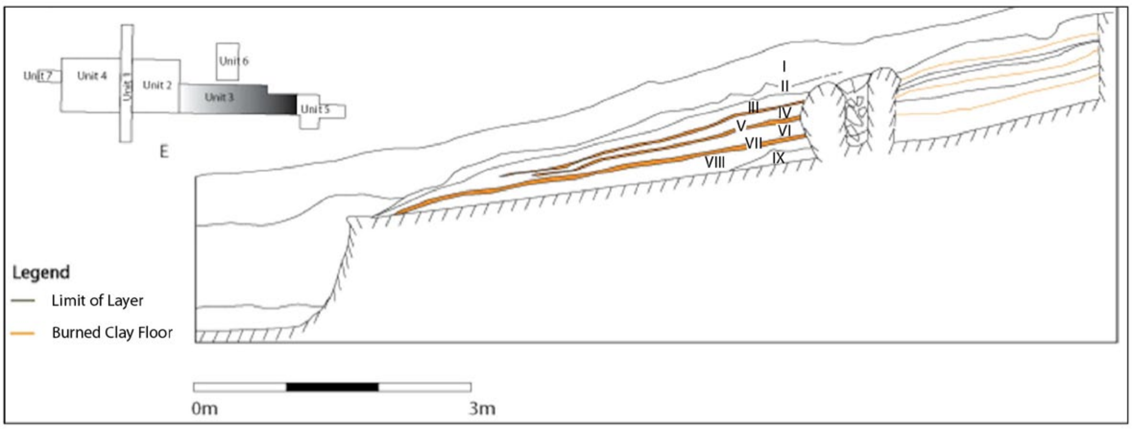
Profile: Unit 2

Four unique secondary fire/firing trenches were identified in the unit. Three floors of Kiln no. II were identified. A kiln roof support pillar was identified on the last floor of Kiln no. III. Two secondary fire trenches belong to Kiln no. II and III. The other two fire trenches situated below belong to Kiln no. I. This unit was excavated to approximately 2.0 m below the surface of the Kiln no. III and Kiln no. II. Nine layers were identified in this unit.

Unit 3 (Table 7 and Profile Image): Located east of Unit 2. The excavation of this unit was designed to follow the walls and secondary fire trenches of the kiln to the eastern part approximately 10.0 m. Two secondary fire trenches, two firing chambers and a fire box were identified. The excavation was conducted to a depth of approximately 190 cmbs until the last floor of Kiln no. I was reached.

Table 7: Unit 3

Layer	Depth (Thickness)	Soil/Deposit	Comments
I	0–74 cmbs (74 cm)	Gray brown hard soil mixed with sand, clay, burned clay, and small pieces of ceramic.	Layer formed by fragments of the collapsed roof after the kiln was abandoned.
II	74–92 cmbs (18 cm)	Gray soil mixed with sand and pieces of ceramics.	Layer is composed of soil deposited on Kiln no. III floor after it was abandoned.
III	92–104 cmbs (14 cm)	Gray soil mixed with fine and coarse sand, and small pieces of ceramics.	Layer contains considerable amounts of sand placed on the thin clay floor—used for adjusting the pots upright for firing without using any support.
IV	104–107 cmbs (3 cm)	Orange clay.	Layer is the third (last) floor of Kiln no. II formed by a thick clay layer covering the second floor of Kiln no. II.
V	107–121 cmbs (14 cm)	Gray orange soil mixed with fine and coarse sand, and small pieces of ceramic.	Sand layer used for adjusting pots for firing. The function is similar to layer III.
VI	121–126 cmbs (6 cm)	Orange clay.	Layer is the second floor of Kiln no. II; similar to layer IV.
VII	126–146 cmbs (20 cm)	Gray soil mixed with fine and coarse sand, and pieces of ceramic.	Layer functioned similar to layers II and V. The sandy soil was added on the first floor of Kiln no. III.
VIII	146–149 cmbs (3 cm)	Orange clay.	This thin layer is the first floor of Kiln no. II.
IX	149–167 cmbs (18 cm)	Brown soil mixed with coarse sand and pieces of ceramic.	Layer is composed of soil placed on the last floor of Kiln no. I to make Kiln no. II.



Profile: Unit 3

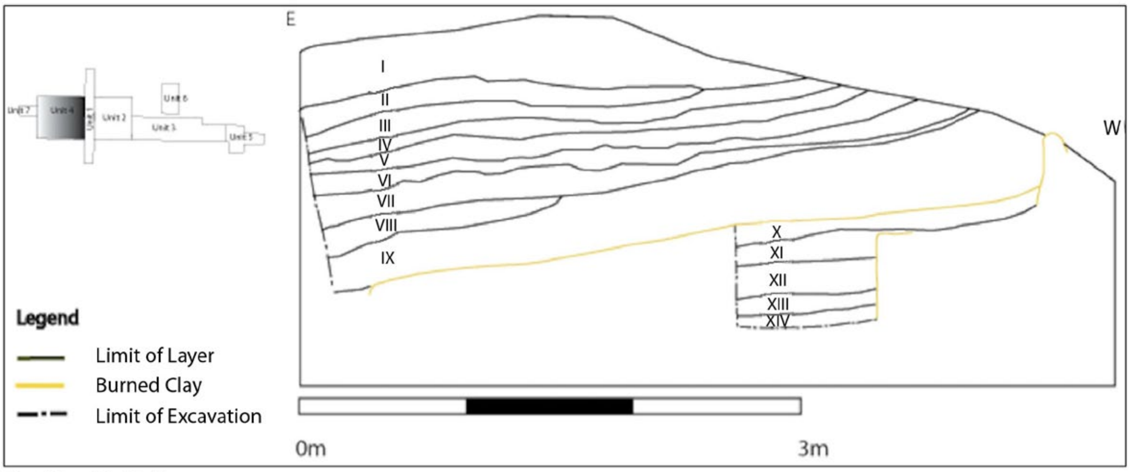
There are many layers in the profile of the two firing chambers. Only the layers of the firing chamber between the fire box and the secondary fire trench are detailed here. The structure of the fire box, two secondary fire trenches and two firing chambers will be discussed later.

Unit 4 (Table 8 and Profile Image): Located west of unit 1, measuring 5.0 x 5.0 m. The excavation of this unit was designed to follow both walls to the west to find the end of the kiln. The unit was excavated approximately 2.0 m from the surface to the last floor of Kiln no. I. It is a fairly complex unit due to several features. Identified structures include the following:

- Several layers of the floors of Kiln no. II
- Half of the secondary fire trench of Kiln no. I was confirmed to exist under the secondary fire trench of Kiln no. II.
- Last floor of Kiln no. II
- Two pillars of Kiln no. II
- Vent of Kiln no. II
- Part of the vent of Kiln no. I was found under the floor of Kiln no. II.

TABLE 8: UNIT 4

Layer	Depth (Thickness)	Soil/Deposit	Comments
I	0–40 cmbs (40 cm)	Brown gray soil with sand, raw clay and burned clay.	The soil is highly compacted; layer formed with fragments of the collapsed roof after the kiln was abandoned.
II	40–54 cmbs (14 cm)	Gray hard soil with fine and coarse sand and clay.	Layer formed by soil deposited on the kiln floor before the kiln collapsed.
III	54–67 cmbs (13 cm)	Gray soil mixed with sand and burned clay.	This layer is the lowermost floor of kiln no. III.
IV	67–79 cmbs (12 cm)	Orange soil mixed with fine and coarse sand and burned clay.	No data/comments.
V	79–89 cmbs (10 cm)	Orange soil mixed with fine and coarse sand and burned clay.	No data/comments.
VI	89–99 cmbs (10 cm)	Gray soil mixed with ash, burned clay, and fine and coarse sand.	No data/comments.
VII	99–114 cmbs (15 cm)	Gray, hard soil mixed with burned clay, and fine and coarse sand.	No data/comments.
VIII	114–127 cmbs (13 cm)	Gray, fragile soil mixed burned clay, and fine and coarse sand.	No data/comments.
IX	127–167 cmbs (40 cm)	Gray orange soil mixed with sand and burned clay.	Layer is compacted soil which forms the base of floor of Kiln no. II.
X	167–180 cmbs (13 cm)	Orange soil mixed with burned clay, and fine and coarse sand.	This layer is the lowermost floor of Kiln no. II.
XI	180–190 cmbs (10 cm)	Orange soil with fine and coarse sand, and burned clay.	No data/comments.
XII	190–210 cmbs (20 cm)	Orange, hard compacted soil with clay and sand.	Layer consists of soil prepared for the foundation of Kiln no. II.
XIII	210–218 cmbs (8 cm)	Orange gray soil with sand and burned clay.	No data/comments.
XIV	218–228 cmbs (10 cm)	Yellow gray hard soil.	No data/comments.

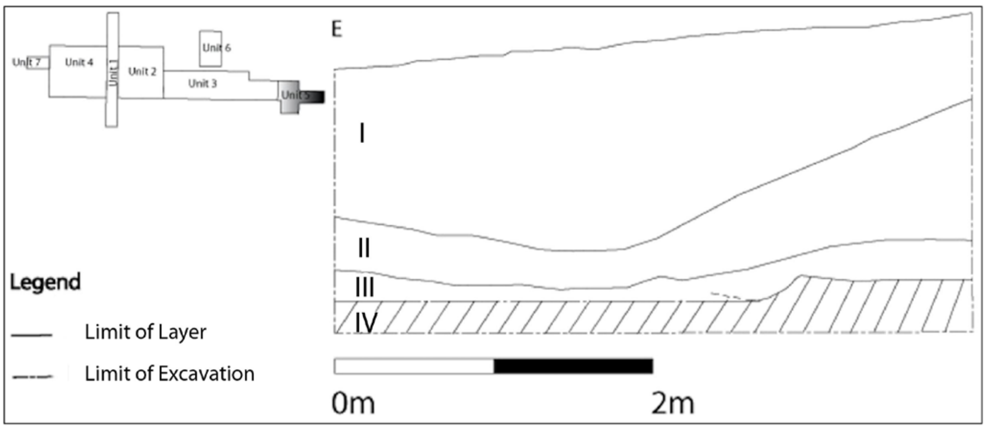


Profile: Unit 4

Unit 5 (Table 9 and Profile Image): Located east of unit 3, measuring 3.0 x 4.0 m. The excavation of this unit was designed to follow the front part of kiln. The Unit was excavated to a depth of approximately 2.0 m below the surface of the upper part of the natural soil. There are four main layers of this unit as follows:

Table 9: Unit 5

Layer	Depth (Thickness)	Soil/Deposit	Comments
I	0–125 cmbs	Brown soil with fine sand, sticky clay and large burned clay.	This layer was deposited on the collapsed roof of the fire box and firing chamber.
II	125–159 cmbs (34 cm)	Dark brown soil with fine sand, burned clay, and pieces of ceramics.	No data/comments.
III	159–189 cmbs (30 cm)	Dark soil with sand, burned clay, pieces of ceramics and charcoal.	Layer is base of fire box.
IV	189+ cmbs	Yellow gray sticky soil.	Underlying natural soil.

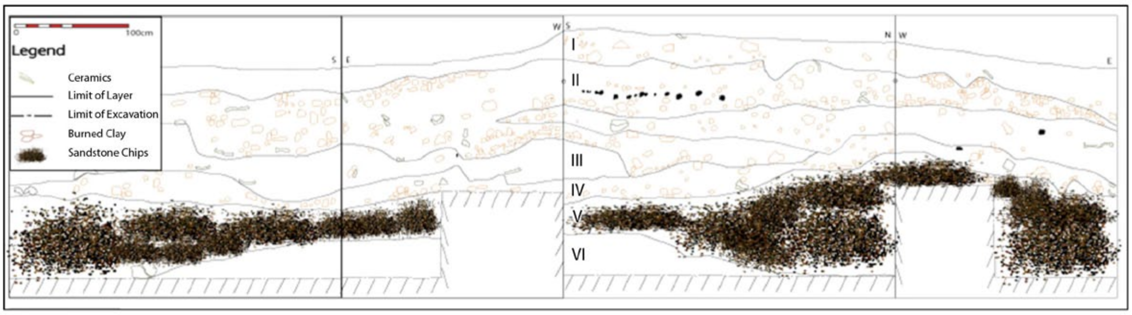


Profile: Unit 5

Unit 6 (Table 10 and Profile Image): Located north of unit 3 measuring 2.0 x 3.0 m. The excavation of this unit was designed to find waste from the kiln. The unit was excavated to a depth of approximately 2.6 m from the surface to the natural soil. There are six layers of this unit as follows:

Table 10: Unit 6

Layer	Depth (Thickness)	Soil/deposit	Comments
I	0–53 cmbs (53 cm)	Dark gray soil with fine sand.	Overburden; natural deposit after kiln abandoned.
II	53–113 cmbs (60 cm)	Brown soil with fine and coarse sand, burned clay and pieces of ceramics.	Layer is the upper part of waste layer.
III	113–163 cmbs (50 cm)	Dark red soil with sand, burned clay, and pieces of ceramics.	This layer is the underlying waste layer.
IV	163–193 cmbs (30 cm)	Dark red orange soil with sand, burned clay.	No data/comments.
V	193–268 cmbs (75 cm)	Green gray soil with sand and many sandstone chips.	Sandstone chips were used to form the foundation of kiln.
VI	268+ cmbs	Yellow gray soil with sand and clay.	Underlying natural deposit.

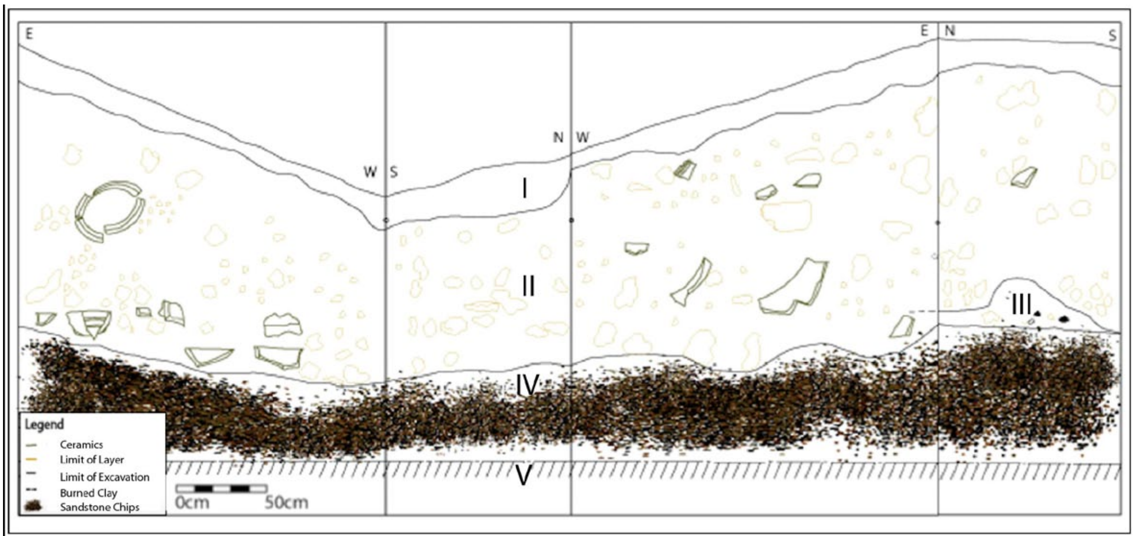


Profile: Unit 6

Unit 7 (Table 11 and Profile Image): Located west of unit 4 measuring 1.0 x 2.0 m. The excavation of this unit was designed to assess the deposit near the vent. The unit was excavated approximately 2.4 m below the surface to the natural soil layer. There are five layers as follows:

Table 11: Unit 7

Layer	Depth (Thickness)	Soil/deposit	Comments
I	0–20 cmbs (20 cm)	Gray, loosened soil.	This layer is post firing ash mixed with soil—perhaps a mix of removed ash and soil.
II	20–144 cmbs (124 cm)	Gray orange soil with coarse sand, burned clay, and pieces of ceramics.	This layer is composed of broken roof and ceramic fragments.
III	144–184 cmbs (30 cm)	Dark red gray soil with burned clay and charcoal.	No data/comments.
IV	184–254 cmbs (70 cm)	Green gray soil with sand, sandstone chips and pieces of laterite.	No data/comments
V	254+ cmbs	Yellow gray soil with sand and clay.	Underlying natural deposit.



Profile: Unit 7

4.3: Kiln Structure and Dimensions

The kiln (Figures 20 to 22) is built of clay at an inclined angle on the mound (approximately 15–20 degrees). It has a semi-rectangular plan along an east–west longitudinal axis, widening slightly toward the higher end. There are: a single fire box, four separate firing chambers, three secondary firing trenches, one loading doorway in the northern wall of a firing chamber, and an air vent toward the back of the kiln with three smoke holes.

Figure 20: Plan view of Torp Chey kiln, panoramic photo

Figure 21: Cross sections and plan views of Torp Chey Kiln, line drawing

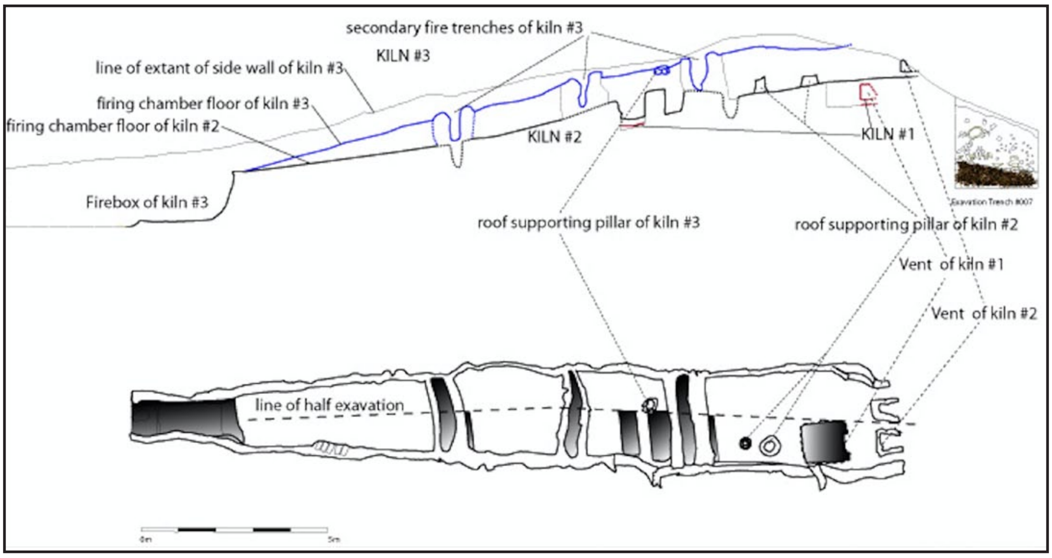


Figure 22: Frontal view of Torp Chey kiln

The three secondary firing trenches are located between the firing chambers. They are unique and may indicate side-stoke ports were used where additional fuel (i.e., wood, to include oxygen/air intake) could be added in order to manage the temperature and atmosphere inside the kiln. Other features of the kiln include one pillar on the floor of firing chamber no. 3 and two pillars on the floor of firing chamber no. 4 (there may be mirror pillars in unexcavated areas). At least three kilns were constructed which overlapped with each other and were of slightly different sizes.

Kiln no. I (the earliest) is located directly under Kilns no. II and III. The excavation confirmed only the vent structure which appeared as holes and a wall between the holes. The wall is 51 cm in length and is located 80 cm from the wall of the vent associated with Kiln no. II. Therefore, Kiln no. II was 80 cm longer than Kiln no. I.

Kiln no. II was constructed on top of Kiln no. I. The excavation confirmed a fire box, four firing chambers, three secondary fire trenches, two pillars and a vent.

Kiln no. III was constructed on top of kiln no. II. Both kilns were probably similar in size. Excavations confirmed the location of the fire box, three secondary fire trenches, a pillar, and four firing chambers. The vent was not identified; it may have been constructed on the vent of Kiln no. II based on the curve of both walls of firing chamber no. 4.

The kiln(s) measures 21.45 m in length; the maximum width of the outer wall is 3.2 m (near the vent); and the narrowest width is 1.4 m (near the fire box). Size/dimension details and estimates[24] of the kiln structures are as follows—these metrics are almost exclusively related to Kiln III:

- Length of Kiln no. III (uppermost, most recent kiln) from the fire box to the vent: 21.45 m
- Width of the kiln:
  - Near the fire box: 1.4 m
  - Near the vent: 3.2 m
- Estimated height: varies—see below
- Estimated fuel chamber area: 7.6 m^2
- Estimated fuel chamber volume: 8.4 m^3
- Estimated firing chamber area: 37.0 m^2
- Estimated firing chamber volume: 36.9 m^3
- Estimated kiln area: 49.0 m^2 (44.6 m^2 when section totals are summed)[25]
- Estimated volume: 45.3 m^3

- Fire box:
  - Length: 3.0 m
  - Width in front of fire box: 1.4 m
  - Width near the wall of firing chamber no. 1: 1.8 m
  - Height of wall in front of fire box: 98 cm
  - Height of wall near the firing chamber: 1.25 m

[24] Some measurements may slightly vary from metrics mentioned earlier due to rounding and estimation variance.

[25] These totals are less than the aforementioned 60–69 m^2; differences are due to use of different estimated averages during separate calculations. The calculations here are likely more accurate.

  - Inclination from the floor of firing chamber to the base of fire box: 40 cm.
  - Estimated area: 4.8 m^2
  - Estimated volume: 5.4 m^3

- Firing Chamber no. 1:
  - Length: 4.9 m
  - Width near fire box: 1.74 m
  - Width near secondary fire trench no. 1: 2.40 m
  - Height of wall near firing chamber: 45 cm
  - Height of wall near the secondary fire trench no. 1: 95 cm
  - Estimated area: 10.1 m^2
  - Estimated volume: 7.1 m^3

- Secondary Fire Trench no. 1:
  - Length: 2.6 m
  - Width: 35 cm
  - Depth: 68 cm
  - Estimated area: 0.9 m^2
  - Estimated volume: 0.6 m^3
  - Thickness of both side walls: 40 cm

- Firing Chamber no. 2:
  - Length: 2.93 m
  - Width near secondary fire trench no. 1: 2.35 m
  - Width near secondary fire trench no. 2: 2.75 m
  - Depth from upper part of wall to the floor of kiln no. 2: 1.1 m
  - Estimated area: 6.1 m^2
  - Estimated volume: 8.2 m^3

- Secondary Fire Trench no. 2:
  - Length: 2.5 m
  - Width: 30–35 cm
  - Depth: 85–95 cm
  - Estimated area: 0.8 m^2
  - Estimated volume: 0.7 m^3
  - Thickness of both side walls: 30 cm

- Firing Chamber no. 3:
  - Length: 2.7 m
  - Width near secondary fire trench no. 2: 2.75 m
  - Width near secondary fire trench no. 2: 2.95 m
  - Depth from upper part of wall to the floor kiln no. 2: 63–90 cm
  - Estimated area: 7.7 m^2
  - Estimated volume: 5.9 m^3

- Secondary Fire Trench no. 3:
  - Length: 2.9 m

- Width: 30–44 cm
- Depth: 1.6 m
- Estimated area: 1.1 m^2
- Estimated volume: 1.7 m^3
- Thickness of both side walls: 30 cm

• Firing Chamber no. 4:
  - Length: 4.5 m
  - Width near fire trench no. 3: 2.6 m
  - Width near vent: 3.2 m
  - Depth from upper part of wall to the floor of kiln no. 2: 1–1.4 m
  - Estimated area: 13.1 m^2
  - Estimated volume: 15.7 m3

• Vent:
  - Total length: 2.8 m
  - North hole: 23 cm
  - Middle hole: 40 cm
  - South hole: 30 cm
  - Two walls located between the three holes above
    - South wall: 50 cm wide and 50 cm high from floor of kiln no. 2
    - North wall: 68 cm wide and 60 cm high from floor of kiln no. 2

• Walls of Kiln: 10–15 cm thick; 50–110 cm high; estimated volume: 2.1 m^3

• Pillars:
  - The Pillar on the floor of firing chamber no. 3 of Kiln no. III is 15 cm in height and 36 cm in diameter; estimated volume: 15,260 cm^3 (0.015 m^3)
  - The other two pillars on the floor of firing chamber no. 4 of Kiln no. II include a big pillar: 40 cm in height and 57 cm in diameter; estimated volume: 102,018.6 cm^3 (0.102 cubic m); and a small pillar: 38 cm in height and 40 cm in diameter; estimated volume: 45,341.6 cm^3 (0.045 m^3)

• Loading Doorway: approximately 1.0 m wide; located on the north wall of firing chamber no. 3 of kiln no. II.

4.4: Fire Box

Figure 23: Fire box

The fire box (Figure 23) of Kiln no. III is semi-rectangular in shape. The size of the kiln necessitates the aid of the secondary fire trenches to maintain sufficient temperatures for sufficient durations, and, to maintain relatively even control of heat distribution. The stoke holes and air hole in front of the fire box are no longer visible.

There is separate wall for a fire box constructed near the fire box of Kiln no. III which may be part of the wall of Kiln no. II. The wall of the fire box near the firing chamber inclines approximately 40 cm from the top to the base. The southern wall was damaged near the stoke hole. The walls of the fire box are not smooth. Several pieces of clays were roughly pasted on the walls. Precision, consistency and evenness were apparently unnecessary.

Several operational fire box floors appear to exist but exact determinations of the natures and layouts of each would require further excavation.

The floor of fire box is black. Charcoal remains are mixed with the soil. The fire box was constructed through the underlying natural layer to a depth of approximately 50 cm below the floor. Many fragments of the kiln's wall and roof as well as other ceramics/wasters were discarded around the fire box.

The exact type of fuel (presumably wood) remains unknown. Wood identification may be possible with appropriate samples. The estimated quantity of fuel used for firings also remains unknown. Experimental efforts and further physical/physics analysis of the kiln and product metrics may allow relevant estimates to be deduced.

4.5: Firing Chambers

Figure 24a: Firing chambers, frontal view

Figure 24b: Rear firing chambers

Figure 24c: Firing chambers, top view

The most unique feature of the kiln was the presence of secondary fire trenches on the uppermost kiln (Kiln III); dividing the floor of the single firing chamber into four parts (i.e., effectively creating four contiguous firing chambers) (Figures 24a, b and c). This is a previously unseen technology, with the exception of Chong Samrong Kiln (which displays one secondary firing trench). It is unknown if this represents independent innovation or diffused technology.

Nevertheless, it seems to represent a significant technological shift; perhaps due to a need for more production volume and efficiency (as well as indicative of more confidence in firing success), and/or a need to feed increasing demand. Of note, this technological innovation (or introduction) along with other technological trait analyses in comparison to other kiln sites mentioned in the review may be critically important to further techno-cultural transmission studies (see Pryce et al. 2014 for an interesting techno-cultural transmission analysis of Angkorian and ethnic Kuay iron working technology). By extension, this may be an interesting topic for those interested in ceramic studies to include related ethnoarchaeological, ethnographic and ethno-historic ceramic studies in the region.

Firing chamber no. 1 extends from the wall of the fire box to secondary fire trench no. 1. Firing chamber no. 2 is located between secondary fire trenches nos. 1 and 2. Firing chamber no. 3 lies between secondary fire trenches nos. 2 and 3. Firing chamber no. 4, the last chamber, is between the secondary fire trench no. 3 and the vent.

Firing chamber nos. 1 and 4 appear almost similar in size; that is, more than 4.0 m in length. However, firing chamber no. 4 is more than twice the volume (note: volumes are rough proxy estimates; actual usable volume may be quite different because true height and curvature is unknown—more accurate estimates are possible with further analysis). The other two firing chambers have similar lengths, but also different volumes. Does volume for each firing chamber and secondary firing trench relate to type and number of vessels stacked and fired; heat, thermal, combustion, temperature physics, and pottery forming physics; both, none, etc.? How do firing chamber properties relate to the secondary fire trenches?

If we compare ratios (Table 12) in an upwards heat flow direction, similarities between firing chambers 3 and 4 and secondary firing trenches 2 and 3 are most consistent despite significant variance in volume. These are also the chambers furthest removed from the fire box (primary heat source). Although the volumes of firing chambers 1 and 2 are comparable (and only slightly larger than firing chamber 3), the fuel capacity ratio is completely different (in an upwards direction). Firing chamber 2 seems to have needed far less added fuel and heat support from secondary firing trench 1 (not unexpected given the proximity to the Fire Box and Firing Chamber 1). The fire box would have contained the most fuel given the volume. Thus, the proximity of secondary firing trench 2 and firing chamber 2 likely require minimal fuel additions to maintain high heat. The volume of firing chamber 4 is around twice that of any other. Why? This is an interesting consideration. For example, did the cumulative heat from firing trenches 2 and 3 suffice for the doubled volume in firing chamber 4? Were different products put in different chambers for specific reasons; firing chamber 4 require a slightly diminished amount of fuel and heat? It is difficult to determine with present data.

Table 12: Proxy Volume ratios

	Volume m^3	Ratio: FT/FC	Ratio: FC/FT	Surrounding Fuel Volume m^3	Ratio (FC/SFV) (SFV/FC)
Fire Box	5.4	0.76	(1)		1.18-(4)
Firing Chamber 1	7.1	(4)	1.31	6.0 (5.4 + 0.6)	0.85-(1)
Secondary Firing Trench 1	0.6	0.073	(4)		6.31-(2)
Firing Chamber 2	8.2	(1)	13.7	1.3 (0.6 + 0.7)	0.16-(3)
Secondary Firing Trench 2	0.7	0.119	(2)		2.45-(3)
Firing Chamber 3	5.9	(3)	8.4	2.4 (0.7 + 1.7)	0.41-(2)
Secondary Firing Trench 3	1.7	0.108	(3)		9.24-(1)
Firing Chamber 4	15.7	(2)	9.24	1.7 (1.7 + n/a)	0.11-(4)

FT = Firing Trench; FC = Firing Chamber; Fire Box calculated as FT; SFV = Surrounding Fuel Volume—the total of all FC surrounding a specific FC.
(#) = Column/category rank.

Note: The ratios may play an important factor in heat control and efficiency or may have been completely unrelated—in need of further research to determine relevance (if any). Fire box to firing chamber ratios for other kilns do demonstrate some possible patterns. The supplemental tables below (data from Chhay et al. 2014) include Torp Chey with only the fire box volume included and Torp Chey with firing trench metrics added to the fire box. Accurate firing chamber volume is not provided, which introduces another layer of error. Buriram and Chong Samrong are also excluded from this analysis as well as a few kilns with insufficient data due to missing measurements (e.g., several kilns were truncated or damaged by development activities—firing chamber info was destroyed). If the ratios relate to fuel efficiency (an analytical assumption "stretch" by all means), larger kilns such as Torp Chey and Cheung Ek (CEKc) are not necessarily more efficient. There may be some indication that efficiency may be seen in medium capacity kilns (e.g., 20 m^2). Alternatively, many of the smaller kilns seem least efficient. Again, it is emphasized that a large degree of potential error occurs in the data. Some of the data may represent kiln mound size rather than actual internal kiln volume and area.

As previously noted, only the right half of Kiln no. 2 was excavated. The profile of all floors of the firing chambers are clearly visible from the surface, through the floors of Kiln no. III, and to the last floor of Kiln no. II. The stratigraphic layers clearly show that the formation of kiln no. III overlapped with kiln no. II.

For the construction of the firing chambers in kiln no. III, mixed soil including coarse sand and small burned clay was added to the remains of Kiln no. II to craft the floor base. Subsequently, a layer of fine sand with clay approximately 3.0 cm thick was applied to the base, covering the firing chamber areas to form the floor surfaces. Finally, sand was added on the floor surfaces in order to level the bases of ceramics during the firing process. The construction of floor no. 1 of Kiln no. III is the same (suggesting similar technology was used throughout the lifespan—estimated 200+ years; see below); the remaining floors are also constructed in similar fashion. The excavation confirmed three floors of Kiln no. II. A roof support pillar appeared only in the firing chamber no. 3 of Kiln no. III. The two other pillar remnants were identified in firing chamber no. 4 of Kiln no. II (possibly Kiln no. II's largest chamber).

4.6: Secondary Fire Trenches

Figure 25a: Secondary firing trench

Figure 25b: Secondary firing trench and adjacent firing chamber

Figure 25c: Secondary firing trench, alternate angle, close-up

Three secondary firing trenches (Figures 25a, b, c) in Kiln no. III were clearly defined. The firing trenches are basal—extending beneath each associated kiln floor. All secondary firing trenches are curved and have two walls. Walls of the trenches increased in height following the construction of new floors in the kiln. Secondary firing trench no. 1 clearly shows the three phases of construction associated with the three phases of kiln floors.

Remnants of the first phase indicates the floor was made of yellowish clay approximately 23 cm in height; the second phase was made of orange clay about 15 cm height; and the last phase was made of yellowish clay about 25 cm in height. The top of the secondary firing trench is higher than the floor of the kiln by about 13 cm.

The firing trench walls were made by adding large irregularly placed pieces of clay. They were then covered with a thin layer of clay. The top of the secondary firing trench is curved from the wall to the floor of kiln. The inner walls are dark gray as a result of firing. There are many pieces of charcoal, ash and pieces of the kiln roof on the interior. Other secondary firing trenches have similar construction. The main variation is size, but not apparently technology, morphology/overall basic design, or primary function.

The three secondary firing trenches of Kiln no. III are easily discernible. However, under the floor of firing chamber no. 3 of Kiln no. II, there are two trenches which have much wider dimensions and are located close together. The eastern part is smaller than the western part. The bases of both trenches contain ash and charcoal which confirm that their purpose was connected with the firing process, but their function could not be positively determined.

The western wall of the western trench is similar to a sloping fire box wall. On its upper part there are pieces of clay pasted over the wall as if repairs had been made (possibly indicating multiple uses/events). The repaired area did not display smoke discoloration from firing, however. This enigmatic structure could not be explained clearly, but it could be hypothesized that a large fire box was made and later abandoned, perhaps because the space was too large.

On the side of the secondary firing trench is an opening about 1.0 meter wide that was probably constructed for loading the pots and adding fire wood into the fire box.

The purpose of constructing the secondary fire trenches was likely to maintain dispersed fuel and continued heat inside the kiln to also provide temperature consistency and control. The heat from the main fire box would not be sufficient to achieve the desired stoneware and glazed qualities in the distal chambers.

Again, it is noted that this represents a unique technological variation from earlier green-glazed stoneware kiln technology in the Angkorian capital and from contemporaneous technology noted thus far in the western Angkorian kiln sites. The technology appears distinct from dragon kiln technology; thus partially precluding technological diffusion. At present, the design, engineering and technology can be hypothesized as an independent innovation with a possibility of some outside influence. The purpose may have been to increase efficiency, effectiveness and meet a greater production demand. Additionally, because it necessitates significant investment in construction, fuel and quantity of pots to be fired (perhaps also, size), we can assume a relatively high level of expected firing success by the craftsmen.

Nevertheless, success and failure rates are unknown (failures exhibited by the occurrence of wasters). Wasters are expected. The observed wasters in this case are more likely a result of pot production flaws inherent in pre-fired vessels rather than kiln or firing failures. Vessels and products (e.g., figurines) with many applique or fused attachments and vessels having air pockets, water pockets, cracks and other potential points of risk and failure during the firing process would likely have increased failure rates. A general comparison of wasters and failed firings to kiln productive capacity/potential will be useful for future studies. An additional analysis may be able to discern which vessels/ products had higher failure rates as well.

4.7: Vents

Figure 26a: Vents

Figure 26b: Kiln vents and pillar

The vents (Figures 26a and 26b) of Kiln no. I were discovered under the floor of Kiln no. II, located 80 cm from the vent of Kiln no. II. This indicates that Kiln no. II was larger than Kiln no. I.

The vents of Kiln no. III were not identifiable. However, the walls were built on the walls of Kiln no. II. Evidence suggests the builders added clay to repair the kiln from the inside. Therefore, the vents of Kiln no. III and Kiln no. II were probably constructed to overlap or replace/repair each other.

The vents consisted of three horizontal tube-like holes measuring 20.0 cm, 32.0 cm, and 40.0 cm in diameter; positioned close to the floor at the blunt end of the kiln and extended approximately 50.0 cm through the kiln mound to the end at the mound slope. Between the three holes, there are two walls measuring 53.0 cm and 70.0 cm. Both walls are 50.0 cm above the floor.

Vents of this type have not been previously discovered in Southeast Asia (Hein 2012). This adds another unique dimension to the technological innovations. The two walls between the three holes may function as an enclosure to provide atmospheric control, temperature control, airflow, and/or prevent the smoke and air in the kiln from moving too fast.

4.8: Pillars

Figure 27a: Pillar (top view)

Figure 27b: Pillars, oblique view

The roof-support pillars (Figures 27a and 27b) are not as numerous and closely spaced as those in other early excavated kilns in the Angkor area. Early kilns in the Angkor area have pillars arranged about 1.3 m apart along the central axis of the kiln. The Torp Chey Kiln, however, provides no evidence of a centerline (central axis) series of roof-support pillars. Only one pillar was identified in Kiln III and two in Kiln II (i.e., pillar technology was used and identifiable. Thus, there appears little need for extensive pillar support. Presumably, the walls and roof provided sufficient roof support with a few exceptions.

The differences likely relates to overall design and wall + roof thicknesses. The walls of the Torp Chey Kiln are about 12.0 cm thick, whereas the walls of early kilns in Angkor are 5.0–8.0 cm thick (Ea 2009). Roof shape/design (e.g., convex/arch, as indicated in slight curvatures of clay roof remnants), material (i.e., probably a bamboo structure covered by grass/thatch and then covered in clay as exhibited by thatch impressions in the backed roof fragment clay) and construction may be a factor, although the exact roof design is unknown due to collapse. Further reconstruction may be possible, and may yield interesting results.

On the floor of Kiln no. III, only one pillar was found in firing chamber no. 3 close to the kiln's center line. This may indicate a single row of roof-supporting pillars was used. Pillars do not appear in the other three firing chambers of Kiln no. III.

Two pillars were found on the floor of Kiln no. II on the right-hand side of firing chamber no. 4, a location coinciding with the vertical portion of the ceiling where the cross-sectional arch would have been much shallower and in need of support. The two pillars are located 58.0 cm from each other and 35.0–43.0 cm from the right wall. Though both are 40.0 cm in height, their diameters vary: one is 40.0 cm while the other is 57.0

cm. The two pillars would have been matched by others on the left-hand side although no evidence was observed (unexcavated half).

The pillars were made of clay with holes in the center indicating that bamboo or wooden sticks had likely been used to stabilize the pillar during construction after which the organic material burnt out during firing. Other possible functions of the central hole are unknown.

4.9: Walls and Roof

Figure 28a: Kiln walls

Figure 28b: South wall of unit 6 showing floor rubble in profile

Walls were made of rubble and clay (Figures 28a and 28b). No bricks were used. The height of the kiln walls range between 50.0 to 110.0 cm. They are 10.0–15.0 cm thick. The thickness of the walls seem strong enough to support the kiln roof without roof-support pillars. The inner parts of the walls are rough. Clay was pasted on the walls by hand to cover damaged parts. Finger marks were present.

The surface of the inner walls of Kiln no. III was covered with a thin layer of clay, the surface color having changed to blue gray after the kiln was used. The paste can be seen on all the walls of the four firing chambers. The surface of the inner wall is gray, the middle part is dark red and the outer surface of the wall is orange.

Figures 29a and 29b: Thatch impressions in roof rubble

As stated, many pieces of roof rubble display a thatch pattern on the inner surface (i.e., thatch impressions left in raw moist clay prior to firing) (Figures 29a and 29b). A thatch and bamboo[26] roof frame may have been constructed to support a wet clay roof construction. The nature of the impressions suggests that the organic frame had burnt out during firing rather than physically removed before firing. The thickness of the roof rubble is approximately 12.0–15.0 cm. The thickness of the roof indicates a robust construction that did not require further roof-support pillars as noted above.

4.10: Loading Doorway

A loading doorway was identified at the midpoint of the right-hand wall of firing chamber no. 3 of Kiln no. II. The doorway was located directly on the floor of Kiln no. II. The loading doorway of Kiln no. III was not identified.

Approximately 3.0 m in front of the existing loading doorway there is a small mound where fragments of ceramics, kiln roof, and ash were deposited. The doorway was approximately 1.0 meter wide. The height could not be determined.

The wall thickness at the lower part of the doorway varied in width from 15.0 cm to about 30.0 cm, and thinned with height. There was no evidence to demonstrate what material (if any) was used to close the doorway for firing. Loading the kilns through the fire box would be difficult and cumbersome. A side door in the middle firing chamber is more convenient and advantageous, also convenient given the secondary fire trenches.

5: Artifacts

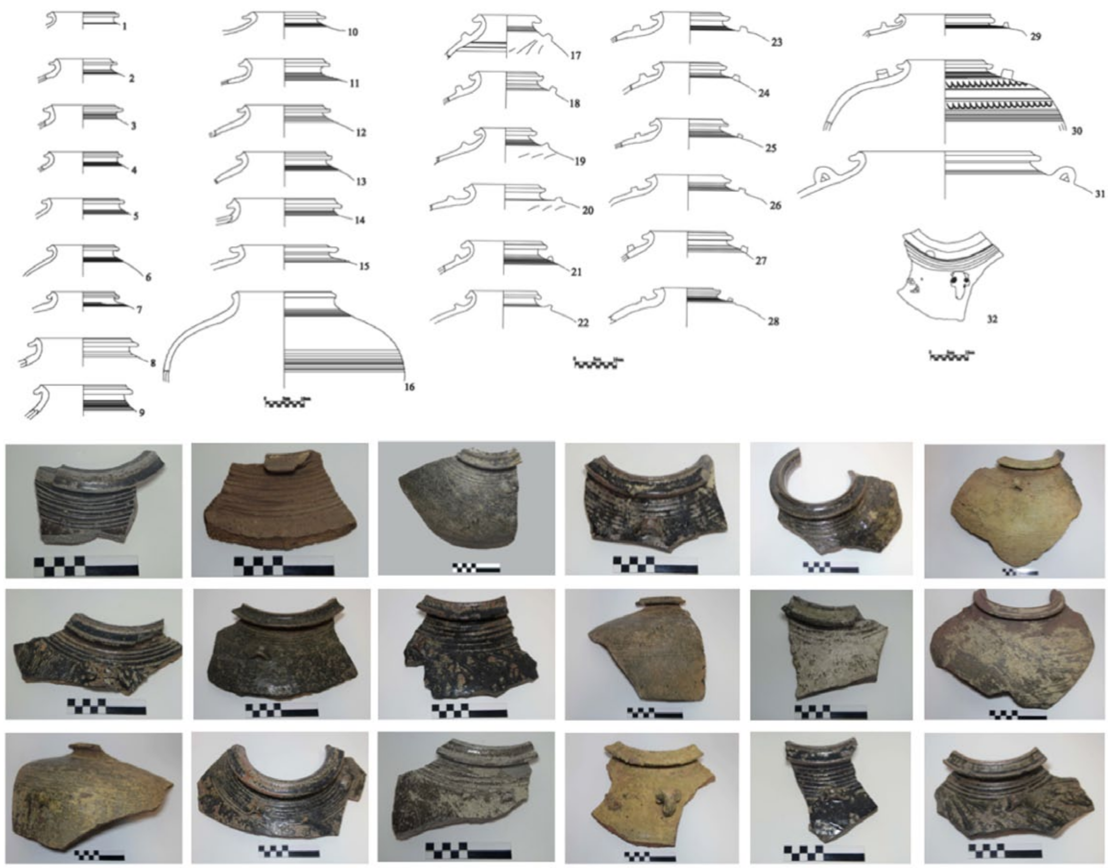
Excavations primarily yielded jars (mostly brown-glazed jars), bottles, roof tiles, animal-shaped figurines and sandstone chips. Fired clay rubble was prominent as it composed a majority of the kiln walls and roofing. Analysis of the sandstone chips is provided in the following section. It is noted that compositional studies of Khmer stoneware sherds from numerous sites are being undertaken to assess sources, technology and exchange. Preliminary and past results are not summarized here, however. Morphology and types are cursorily discussed below. It is hoped that further metrical analysis to include estimated

[26] Buriram kiln data indicates use of bamboo for roof construction.

counts, densities, ratios, etc. will be conducted in the near future. The ceramic assemblage analysis is pending.

5.1: Cylindrical Jars

Figure 30: Cylindrical jars, select samples



Note: Line drawing numbers and photographs are not synched. Some artifacts were not photographed. Likewise, some artifacts do not have line drawings. The intention is to demonstrate representative variability.

Many ceramic stoneware jar sherds were recovered (Figure 30) representing upper (rim neck), body, and/or lower parts (base, foot). Complete, intact jars were not recovered. It is presumed complete vessels were removed and transported elsewhere. Fragments of vessels may have resulted from breakage during production rather than post-depositional processes.

Sizes and shapes of complete vessels, however, can be reconstructed through comparison of sherds with intact jars (the Vat Reach Bo ceramic collection in Siem Reap provides an excellent comparative repertoire). The sizes of recovered fragments range from approximately 5.0–50.0 cm with thicknesses ranging from 2.0–5.0 cm. Most sherds have brown-glaze; some are unglazed.

Typical jar forms have a cylindrical or oval body with a sloping shoulder, short neck, wide mouth, and flattened, everted rim. These are variously called "storage jars", "barrel-shaped jars", or "wide-mouth vats" (Ea 2009). Generally, the form is tall with height greater than the width of the base.

The jars exhibit several types of decorations on the shoulder and above the base, generally banded, with various patterns such as incised lines, swollen decorative bands, waved-lines patterns, lotus petal patterns, and star-shaped patterns. Some sherds have short diagonal lines impressed between tiers of wavy lines on the shoulders. Lugs occur on some jars. Generally, the cylindrical jars are divided into two main types: those with attached lugs and those without. Frequency of lugged versus not-lugged is unknown. Lugs were formed separately and attached prior to firing. In most cases lugs do not have a hole through which a cord could be passed. The lugs themselves were small, indicating that they may have been decorative rather than strictly functional.

Some samples have a hole on the base. The hole was made during the forming process; not after firing. The purpose is undetermined. Vessels with similar holes are noted in other assemblages.

Vessel types are further classified as follows:

- Type 1: Jar without lugs, short neck, and an everted rim. The lower part is missing—no information on base.
- Type 2: Jar without lugs, short neck, rounded body and slightly everted rim. The lower part is missing—no information on base.
- Type 3: Jar with 3–4 lugs, wide mouth measuring 13.0–20.0 cm in diameter, short neck, and everted rim. The lower part is missing—no information on base.
- Type 4: Jar with 3–4 lugs, wide mouth from 25.0 to 50.0 cm in diameter, short neck, unglazed, and rolled rim. The lower part is missing—no information on base.
- Type 5: Jar with a lug in the shape of an elephant head on the jar's shoulder, wide mouth, short neck, and everted rim. The lower part is missing—no information on base.

5.2: Large-sized Jars

Figure 31: Large-sized jar/basin

Jars with a large mouth and body of almost identical diameter are called "large-size jars" or "wide-mouth jars" or "basins" (Ea 2009)(Figure 31). Fewer of these jars were produced compared to cylindrical jars. The diameter of mouth rims range from 16.0–30.0 cm. The jars are covered with brown-glaze. The mouth rim is normally rolled or sometimes everted and there are tiers or ridges on the shoulder. The types of large-size jars are classified as follows:

- Type 1: Jar with everted mouth rim and rounded body.
- Type 2: Jar with everted mouth rim and cylindrical body.

5.3: Baluster-shaped Bottles

Figure 32: Baluster-shaped bottles, select samples

Note: Line drawing numbers and photographs are not synched. Some artifacts were not photographed. Likewise some artifacts do not have line drawings. The intention is to demonstrate representative variability.

Many fragments of baluster-shaped bottles were identified (Figure 32). They typically have brown-glaze. The form of this bottle is recognized from the shape of the neck and shoulder. The tall form has a baluster body, tubular neck, everted mouth rim, wide shoulder, and pedestal base. These are perhaps the most typical Khmer wares, especially in large size wares with brown and two-color glazes (Ea 2009). The vessels were also produced in a wide range of rim diameters from approximately 20.0 to 50.0 cm. They often exhibit a variety of decorative patterns on the body. Incised geometric bands on the shoulder also characterize this vessel form. Some bottles have lugs on the shoulder. The types are classified as follows:

- Type 1: Bottle has a baluster form with brown-glaze, tubular neck, everted mouth rim, wide shoulder, and pedestal base.
- Type 2: bottle has a baluster form with brown-glaze, tubular neck, everted mouth rim, wide shoulder, pedestal base and lugs on the shoulder.
- Type 3: Similar shape to type 2, but there is a tier/ridge between the rim and shoulder.

5.4: Roof Tiles

Figure 33: Roof tiles, select samples

Three kinds of roof tiles were uncovered (Figure 33): round tiles, flat tiles, and eave tiles. No ridge ornament tiles were found at this site.

Round tiles are found in both unglazed and brown-glazed versions, made from reddish-dark or orange clay. They were likely formed by making a coiled cylinder with a size smaller at one end and larger at the opposing end. The finished coil was then cut into two or three sections. Beveled edges are observed on most pieces. Round and pointed protuberances made by attaching clay pieces are seen on the smaller end. They were likely used for holding tiles in place. This form differs from the examples found at early kilns in the Angkor area in which the protuberances were attached to the center of the tile. The Torp Chey tiles were produced in almost identical sizes ranging from 24.0 to 26.0 cm length, the larger width from 14.0 to 15.0 cm, the smaller width from 10.0 to 11.0 cm, and height from 6.0 to 9.0 cm.

The production techniques of flat tiles are similar to those used for round tiles. They appear in both unglazed and brown-glazed versions. They are also formed by coiling and are "C"-shaped. The exterior surfaces of the larger end have applied horizontal ridge-shaped protuberances. The protuberance is also different from those found in early kilns in the Angkor area in which the protuberance is usually located in the center of the tile. The Torp Chey tiles were produced in near-identical sizes ranging from 24.0 to 26.0 cm length, the larger width from 17.0 to 18.0 cm, the smallest width from 15.0 cm to 16.0 cm, and the height from 4.0 to 5.0 cm. This reflects a degree of standardization.

Round tiles with attached lotus bud-shaped faces are termed eaves tiles. The lotus bud-shaped faces were likely made in molds because some tiles have identical shapes and sizes. The faces of eaves tiles bear two patterns. One eaves tile has line patterns and two other eaves tiles display human faces wearing a crown with two flowers on either side of the face. One eaves tile is covered with brown-glaze and the other is unglazed.

5.5: Semi-circular Ceramic Object

Figure 34: Semi-circular ceramic object

A semi-circular object made of solid gray unglazed clay was identified at Unit 7, layer V (Figure 34). The item is 1.0 cm thick and its semi-circle arc has a diameter of 7.0 cm. The other half was not recovered. It is possible this may have been a bracelet fragment.

However, it is equally possible it may have been some form of support or spacer, although no other supports or spacers were readily identified.

5.6: Animal-shaped Figurines

Figure 35: Animal-shaped figurines-select samples

Three types of animal-shaped figurines were recovered: elephant, horse, and cow (Figure 35). The animals were made of dark red or gray clay and pasted with light yellow slip or brown-glaze. The bodies are solid.

5.6.1: Elephants

Six pieces of elephant figurines were found: one head, three bodies, and two legs. The head was broken from the body. It was found in unit 7, layer IV, and measures 7.0 cm in length and 5.5 cm in width. The broken part has a round cross-section which indicates the head and body were made separately then joined together before firing; clay was added to smooth the joint. Because of the fuse separate part production (pre-firing conjoining technology), several heads became separated from bodies. The head has two large ears, two tusks, one nose/trunk (broken at the lower part), and a light yellow slip.

Three bodies without heads were recovered. Body no. 1 was excavated from unit 6, layer IX, and measures 8.0 cm in length, 4.3 cm in width and 7.8 cm in height (the recovered head retains "joining" traces between itself and Body no. 1). The rear left foot was broken at the lower part. The tail joins on the upper part of the right leg. The body was covered with brown-glaze.

Body no. 2 was excavated from unit 6, layer X, and measures 12.5 cm in length, 4.1 cm in width and 9.5 cm in height. The head and left half of the body were not recovered. The body is covered with brown-glaze.

Body no. 3 was excavated from unit 7, layer IV, and measures 12.0 cm in length, 3.5 cm in width and 9.0 cm in height. The head and right half of the body were not recovered. On the top of the neck, there is a round spot which probably retains a trace connection between the head and body. The tail was fastened to the back to the left back leg. The elephant was made of gray clay and yellow slip.

The two legs were broken from their bodies. The bodies were not recovered. Leg no. 1 is made of gray clay pasted with brown-glaze and is solid. Its dimensions are 3.0 cm in length and 2.0 cm in diameter. Leg no. 2 is made of dark red clay and covered with slip. The leg has a joint where it was affixed to the body. The piece is 5.0 cm in length, 1.7 cm in diameter at the base and 3.5 cm diameter at the joint between leg and body.

5.6.2: Horse

One small horse made of solid clay was found in unit 6, layer IV. It measures 8.4 cm in length, 4.0 cm in width and 3.2 cm in height. The neck was broken from the body, but recovered in the same context. The right leg and the top of the back are broken. There are two humps on the back. The tail is fixed to the leg. The horse is made of solid gray clay without glaze.

5.6.3: Cows

Two small cows made of solid clay were found. Cow no. 1 was found in unit 2, layer I, and measures 5.0 cm in length, 3.0 cm in width and 3.0 cm in height. It has a hump on its back. The left horn was broken, and the left leg was not recovered. The tail is attached to the right leg. The cow is made of gray orange clay, solid and unglazed. Cow no. 2 has lost its head and the lower part of its four legs. It also has a hump on its back. It is 5.0 cm in length, 3.5 cm in width and 4.0 cm in height. The body is covered with brown-glaze.

5.7: Wasters

Excavated deposits on the exterior of the kiln walls (approximately 25 m^2 in total) yielded an estimated 5,000 or more broken ceramics, large sherds and wasters—mostly medium to large fragments.[27] The large number of unglazed wasters may indicate that stoneware were pre-fired, cooled, glazed and re-fired at the site. Some inherent flaws only emerge through breakage during the firing process. Pre-firing would allow identification and removal of defective pieces prior to final glazing and final firing. Pre-firing would also accommodate

[27] These figures are rough estimates. The recovered assemblage of wasters and other remains are currently undergoing further analysis. A large portion of smaller sherds were not noted; thus, likely not a considerable amount of post-depositional breakage, trampling, etc. This may further support interpretation as a largely waster assemblage rather than habitation, other activity areas, combined activity areas, and so forth.

almost all potential shrinkage and eliminate almost all water molecules. Once defective pieces were removed and successful pieces identified, this would increase success rate of final firing and final glazed products, conserve glazing material, and increasing overall efficiency.

5.8: Discussion

Many discussion topics and analytical points are provided in descriptions above. Only a few additional points are covered in the following.

Firstly, it may seem unusual that roof tiles and jars (utilitarian pieces, many of which were somewhat standardized in size and shape—especially the roof tiles; although some are fairly well decorated) are also fired with animal figurines, but few other utilitarian types. This representation may relate to standardization, specialization, production diversity as well as other economic concerns (e.g., “made to order” repertoire of products). It may relate to the types of products that had high failure rates (e.g., bowls and other jar types may have had significantly greater firing success rates, and are thus underrepresented in a waster assemblage). Nevertheless, the presence of the observed variety indicates an industry with speculatively mid-range diversity, rather than a highly specialized production output focused on a limited type repertoire of highly standardized products (e.g., bricks only, roof tiles only, storage jars only, and so forth), or, a highly diversified production output representative of all types in circulation. It cannot be argued, however, that the tiles were highly standardized—possibly “made to order” standardized dimensions, or standard industry dimensions. The degree of jar standardization is unknown. It is also unknown if the recovered samples represent complete diversity or only a small percentage of the diversity.

Finally, the possibility of unglazed wasters representing pre-firing/pre-testing needs further analysis and consideration. This has production process implications. It is possible that pre-firing allowed elimination of flawed pieces. Subsequently, durable pieces were then glazed (presumably at or nearby the kiln site) and re-fired. This possibly increases overall effectiveness and efficiency along several variables. Glaze material can be conserved. Overall fuel costs may be conserved. The likelihood of defective pieces “exploding” or breaking and collapsing during firing and subsequently breaking other intact pieces during final firing is reduced. Further analysis of the excavated assemblage and waster category may shed significant light on this possibility. Further site testing may reveal a workshop area for glazing as well.

6: Analysis of Soil and Sandstone Chips

As identified in previous sections of this report, Torp Chey Kiln no. 2 appears to be built on a foundation of sandstone rubble carefully spread in a layer approximately 50.0 cm thick directly on the natural underlying soil deposits. Other preparation of natural soils (trenching, adding fill, etc.) prior to floor preparation is unknown. No evidence indicates significant excavation or filling prior to kiln construction.

Covering the sandstone rubble layer is another layer of compacted clayey soil approximately 10.0 cm thick. This likely provided a stable platform for construction and rendered a loose gravel/rubble layer into a solid conglomerate base.

Based on excavation pits to the north, east, and west, the sandstone rubble base extends outward at least 4.5 m from the kiln wall. The full extent of the rubble base is unknown. We assume it extends under the firing chamber but not under the kiln fire box below the midpoint of the main section of the firing chamber. It remains unknown if the sandstone rubble foundation is unique to this individual kiln or was the standard method of construction for all other kilns in the area.

The relationship of the sandstone flooring with the nearby monumental architecture may assist with understanding temporal as well as constructional relationships. Several field and laboratory tests were performed on the monuments as well as soil and sandstone excavated from the kiln site. In addition to the magnetic susceptibility of the monuments of Prasat Torp Chey Thom and Prasat Torp Chey Toch, the following tests were performed on soil and sandstone samples from the kiln excavation site: magnetic susceptibility of selected sandstone rubble, sieve analysis grain size distribution, potentiometric hydrogen ion concentration (pH) test, Udden–Wentworth grain-size classification, hydrometer test of fine grain soil less than 75μm/0.075 mm, rudimentary flotation, and microscopic sample comparison of sandstone elements. The following summaries are partially extracted from inter-team communications and reports.

6.1 Magnetic Susceptibility

The sandstone rubble foundation of Kiln no. 2 and the sandstone at the adjacent two temples, Prasat Torp Chey Thom and Prasat Torp Chey Toch, were sampled for magnetic susceptibility in an effort to estimate relatedness and a relative date for Kiln no. 2 based on the homogeneity of sandstone from at least one of the temples. Because the relative dates of temple construction are known based on the styles of the two temples, Hindu and Buddhist, which are consistent with the reigns of Suryavarman II (1113–1150 CE) and Jayavarman VII (1181–1220 CE), magnetic susceptibility testing may provide added information as to the origin of the rubble, as well as the quarry from which the original sandstone was procured. It was hypothesized that the rubble from the Kiln no. 2 floor was derived from finished/dressing temple stones, or from the same sandstone source.

6.1.1: Magnetic Susceptibility: Theory and Instrument

Magnetic susceptibility is defined as the degree to which a substance can be magnetized. In mathematical terms, this is the ratio k of the intensity of the magnetization $\mathbf{I}$ to the magnetic field $\mathbf{H}$ that is responsible for the magnetization.

$k\mathbf{H}=\mathbf{I}$

From Faraday's law, it is known that a moving electrical charge generates a magnetic field. The inverse corollary to this is that a magnetic field can also influence a moving electrical charge. Therefore, an oscillating electromagnetic field will be influenced to varying degrees by magnetically susceptible material.

Based on current research in the Angkor area, it is known that sandstone occurrences have a distinctive magnetic and/or electromagnetic signature making it possible to trace sandstone used in monuments to the quarry site.

The measurements of magnetic susceptibility were carried out using a non-intrusive, hand-held Kappameter model KT-5 manufactured by Geofyzika Brno. The microkappa measures the quantity called "apparent" susceptibility. In general it differs from the "true" susceptibility independent of the size and geometric shape of the rock object measured. The Kappameter is calibrated for the idealized case in which the pick-up coil is attached to an absolutely smooth surface confining a half-space filled with magnetically homogeneous and isotropic medium with the susceptibility of k. In this case, the following relation holds between the true susceptibility k and the apparent susceptibility k' k=k' /) 1-k'/2) (SI system).

6.1.2: The Sample

Each remnant in the total sample of ten was measured five times. The average or mean of magnetic susceptibility of each sample was calculated. Where anomalies occurred, retesting verification was performed. None of the samples were less than 50 mm thick and smaller than 100.0 mm. Factory correction factors were applied to those samples where surface unevenness was 1.0 mm or more, but less than 10.0 mm. When surface unevenness was greater than 10.0 mm, the sample did not qualify for testing.

This metering process was used in petrological investigations carried out in the Bayon in 2005–2006 and established measurement results that revealed three architectural periods based on the ranges of magnetic susceptibility that oscillated between 0.8 to 2.3 x 10^{-3} SI Unit (Uchida and Cunin 2005). Other similar investigations across a wide range of Angkorian period monuments were also conducted providing additional results (Clark 2007). The classified phases of the Angkorian period and the identification of quarry sites based on magnetic susceptibility are presented in a format similar to those elucidated in the *Journal of Archaeological Science* 34 (2007: 934) (Uchida et al. 2007).

6.1.3: Results

Tests of magnetic susceptibility were performed by Professor Etsuo Uchida of Wasada University indicating that Prasat Torp Chey Thom had varied magnetic susceptibility based on the different buildings in the complex (Uchida, McCarthy and Ea correspondence 2012). The central sanctuary measured a mean of 3.97 x10^{-3}, the northern library 3.91 x 10^{-3}, and the east *gopura* 3.22 x 10^{-3} SI Unit. Similar independent results were obtained in the recent testing. According to Professor Uchida, Prasat Torp Chey Toch measured 3.12 x 10^{-3} SI Unit. Independent testing of Prasat Torp Chey Toch showed a slightly smaller SI Unit mean of 2.98 x10^{-3} with a median of 2.85 x10^{-3} SI Unit, standard deviation of 1.2554 and variance of 1.5762.

The confidence level is 95% +/- 4% that the magnetic susceptibility of the sample is within the population mean. The results of the independent test are within the boundaries of previous results.

The sandstone sample from Kiln no. 2 was similarly tested for magnetic susceptibility. The sample was limited due to the size constraint of the available samples. The sample had a mean magnetic susceptibility of 2.68 and median of 2.78 x10^{-3} SI Unit, standard deviation of 0.8037 and a variance of 0.0646.

These statistics from an extremely limited sample of Kiln no. 2 are not consistent with the independent testing done at Prasat Torp Chey Toch and those performed by Professor Uchida. However, the sandstone used in the kiln may have been altered via the physical and chemical process associated with the kiln's function.

While this testing does not prove conclusively that the "kiln sandstone" was or was not a result of the Prasat Torp Chey construction or related to the parent material and quarry source, it does provide a comparative basis for the carbon-14 dating of the charcoal from the fire box, and thermoluminescense testing of the kiln product scatter of large, heavily potted jars and roof tiles.

Of importance: four of the sandstone samples and one non-sample item demonstrate at least one prepared or dressed flat surface on the sandstone (i.e., evidence of stone working for architectural pieces; not gravel/rubble for kiln floors). Two samples have hauling and hoisting-preparation holes clearly indicating a quarry process (Figures 36a and 36b). As emphasized, these features would not typically occur on rubble used for kiln flooring. The evidence thus suggests that the rubble derived from architectural pieces was perhaps obtained from sandstone architectural pieces at the *prasat*, or from fitting, reducing and dressing sandstone for use in the *prasat* architecture.

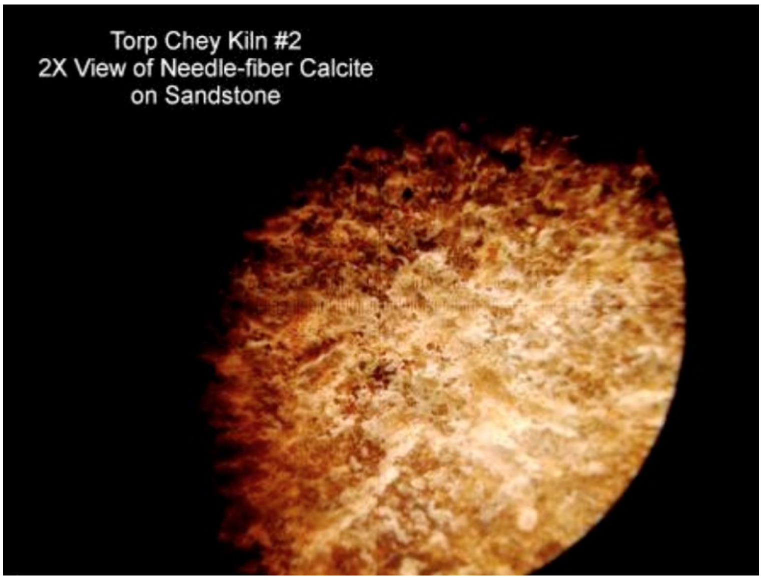
Figure 36a: Prepared/dressed sandstone

Figure 36b: Hauling and hoisting holes

6.2: Fourier Transform Infrared Spectroscopy (FTIR) and Microscopy Analyses on Calcite

With the exception of two of the sandstone samples not taken from the subsurface feature surrounding the kiln, a white cementation-like material has partially formed on the exterior (Figure 37). Testing by Fourier transform infrared spectroscopy (FTIR) disclosed that the white substance is calcite (Douglas, Sackler, McCarthy and Ea correspondence 2012). The sample effervesced with diluted HCL.

Figure 37: Needle-fiber calcite



Microscopic examination disclosed a fibrous nature unusual for calcite, and generally termed needle-fiber calcite. According to research done by Varrecchia and Varrecchia (1994) some formations of needle-fiber calcite are related to biomineralization of specific fungal hyphae while others are probably products of physiochemical precipitation related to soil conditions. Additional testing and research are required to determine the origin of the calcite deposits.

6.3: Soil Samples and Analysis

Two soil samples were taken from Kiln no 2. A soil sample of 2.1 kg was obtained from the northeast excavation pit (sample no. 1). This layer contained a high density of sandstone chips of varying sizes along with other soil gradients. A second sample of 584 g of natural soil was taken below the rubble layer (sample no. 2).

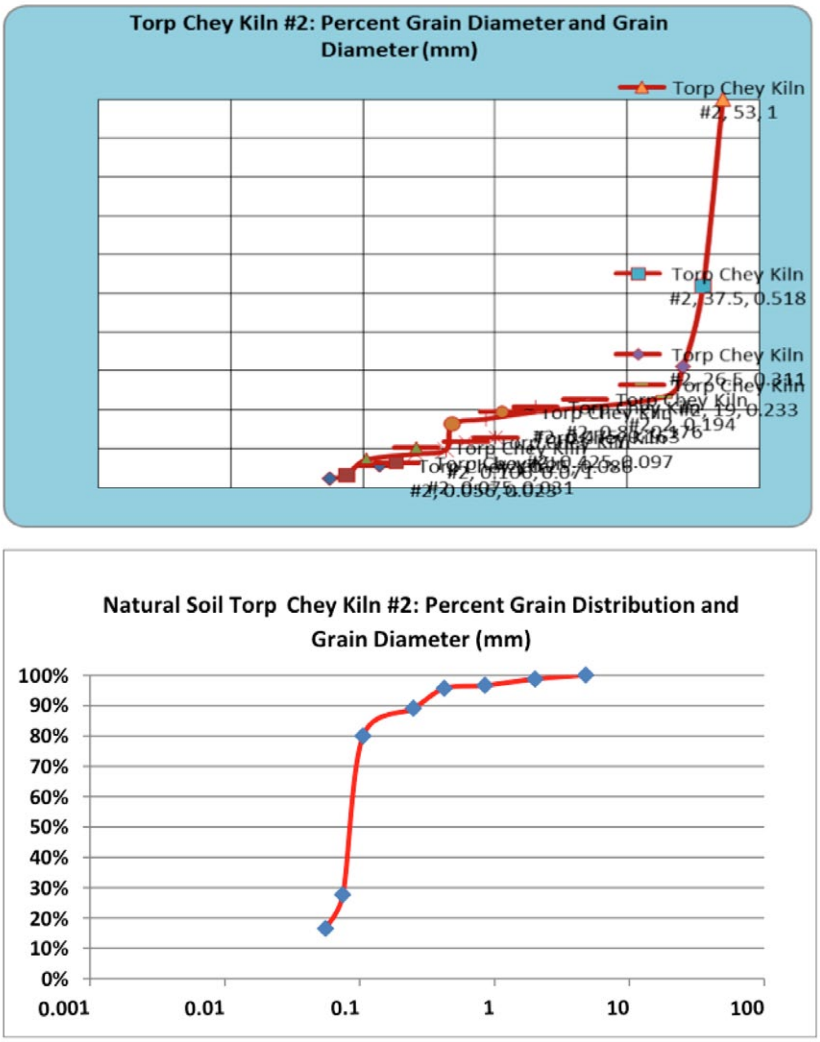
6.3.1: Potentiometric Hydrogen Ion Concentration (pH) Test

Sample no. 1 had a pH value of 7.6. Sample no. 2 had a pH value of 6.0. There may be some relevance to the disparities. It could be a result of production activities. It may have other implications. Further comparative and physical analyses will be useful.

6.3.2: Sieve Test

Sample no. 1 (sandstone chips and rubble) was washed to remove various debris and create a solution. It was then sieved through screens ranging from 54 mm to 0.075 mm. Subsequently it was slowly dried and re-sieved using a circular sieve motion. The samples were later examined and weighed. The results show that more than 50% of the sample contains sandstone chips larger than 57 mm, and that the entire sample was composed of elements that have their origin in processed sandstone as opposed to natural weathering process (Figure 38). The sample also contained a small amount (0.08 g) of biologically generated components, and 5.75 g of laterite pisoliths.

Figure 38: Grain size data and charts



The soil identified as natural soil (sample no. 2) was tested in a similar manner. Results indicate 57.6% of soil has a very fine sand particle size approximately 0.106 mm. Over 90% of the sample was less than 0.5 mm. No elements above 4.75 mm were found in the sample tested. It has been suggested that the composition of the natural soil would make the kiln site subject to potential slumping, water infiltration, and soil leaching, making it an unstable platform for heavy industrial activity; hence the need for a rubble/ gravel base.

6.3.3: Hydrometer Test

A simple hydrometer test was performed on each sample. The samples were placed in 1000 ml graduated cylinders filled with water, agitated, and left to settle. The water cleared within approximately two hours forming gradient bands at the cylinder bottom. The results clearly suggested the absence of fine clays and the presence of silt and sand as identified on the Udden–Wentworth classification scale.

6.3.4: Summary Soil and Sandstone Chip Analyses

Both Prasat Torp Chey Thom and Prasat Torp Chey Toch were sampled for their magnetic susceptibility. Results also compared a sample of sandstone rubble taken from Kiln no. 2. The sample from the kiln does not closely align with that of Prasat Torp Chey Thom or Prasat Torp Chey Toch. However, this non-alignment should not be taken as evidence that the sandstone of the kiln was not obtained from the dressing of stones to construct the *prasat*. The range possibly overlaps. Given the proximity of the location of Prasat Torp Chey to Kiln site no. 2, there is a robust likelihood that the sandstone rubble of the kiln foundation originated from the *prasat*.

It is evident that sandstone was used as a basement and stabilizing platform for Kiln no. 2. The sieve analysis and hydrometric tests of the natural soil provide insight into the reasoning behind the creation of a basement to stabilize the kiln site structure. It appears the floor prevented shifting and provided a barrier from water infiltration.

Additional kiln sites in the area need to be researched and/or at least test excavated to determine if the rubble base platforms were applied consistently in kiln construction in the area. The rubble sample indicated that all elements had their origin in processed sandstone. Little can be learned from the pH tests without additional examination of the surrounding soils and the soils that make up the kiln sites. Further sampling of subsurface sandstone associated with the kiln, and the needle-fiber calcite residue require more research.

Note: There is one element that needs clarification but is not investigated thoroughly in this report. Prasat Torp Chey Toch, which is usually associated with the ancient road system as a *vahni griha/agni griha* (house of fire) or rest house, is further from the road (i.e., may not be directly linked). In fact, it is the only monument of its kind not on the north side of the road with the open windows facing the road. It may seem somewhat inappropriate or unusual to place such a structure within an industrial complex of 12 kilns; unless the structure perhaps provided alternative usage other than a rest house or "house of fire."

It is more likely that the kilns were constructed during or after Prasat Torp Chey Toch was built—the sandstone debris being used for the kiln flooring—and possibly after the *prasat* no longer functioned as a house of fire, *agni griha*, shrine or religious activity area (i.e., after the ritual and related functions fell out of prominent use). That is, the sandstone used for the kiln foundation may have resulted from the construction of the *prasat* (i.e., debris and chips from shaping, fitting and dressing the stone), but the kiln was built during or following the construction and/or abandonment of the *prasat* for intensive religious/ritual purposes.

Alternatively, if the kiln industry were contemporaneous with the *prasat* use (Prasat Torp Chey Thom: rest house, early 12^{th} century, Suryavarman II-era; Prasat Torp Chey Toch: rest house, $12^{th}/13^{th}$ century, Jayavarman VII-era) and there was a functional relationship (direct or indirect), it would strongly support Hendrickson's (2008) conclusion that the rest houses and related features (e.g., water control features, road, kilns, etc.) are part of a complex set of activities in an area which may be well integrated, including a production zone related to the infrastructure and road network. If the pottery production occurred well outside of the Torp Chey *prasat* construction and use (e.g., 14^{th}–15^{th} centuries; although terminal use of the *prasat* remains unknown), the hypothesis is less robustly supported. If the kiln industry existed prior to *prasat* construction, other hypotheses could be drawn, such as strategic placement of the rest house vis-à-vis an existing industrial pottery producing center or community.

The radiocarbon dating (below) suggests that the kiln may have been in use from the 12th century onwards and possibly postdates the *prasat* construction (Prasat Torp Chey Thom at least). It remains plausible that the kiln significantly postdates the *prasat* construction, but the time frame for *prasat* abandonment or reduction in use and possible overlap with the kiln is undeterminable. Again, with current information, it does not appear that the kiln(s) or the ceramic production industry pre-dated the *prasat* erection; rather quite the opposite—the kiln postdates or overlaps the *prasat* construction.

6.5.3: Analysis of Laterization of the Soils of Torp Chey Kiln Area (by Dr Tan Boun Suy)

It is well known that the Siem Reap water contains high quantities of iron.

According to the Japanese International Cooperation Agency report (JICA 2000) the iron concentration of Siem Reap river ranges from 0.31 to 1.50 mg/L. This is a reason why laterization of soils frequently occur in Siem Reap. The objective of the following analysis is to study the importance of laterization in the soils of the Torp Chey kiln area.

Methodology: Four auger samples were collected along an east–west transect from the Torp Chey kiln to the pond in February 2013 (Fig). Auger borings reached a depth of 1.0 meter.

Open forest covers the slope. Sparse shrubs occur at the lower sections. Between site 3 and site 4 the ground is flat and contains rice fields (dry season). Site 4 is on the edge of the pond.

Sample site 1 was chosen outside the disturbed area of the kiln. Sample site 2 is 30 m from site 1; site 3 is 60 m from site 2; and site 4 is 20 m from site 3. The samples allow for a representative profile along a transect moving downslope from Torp Chey Kilns towards the flat agricultural area.

Soils from each sample were carefully examined.

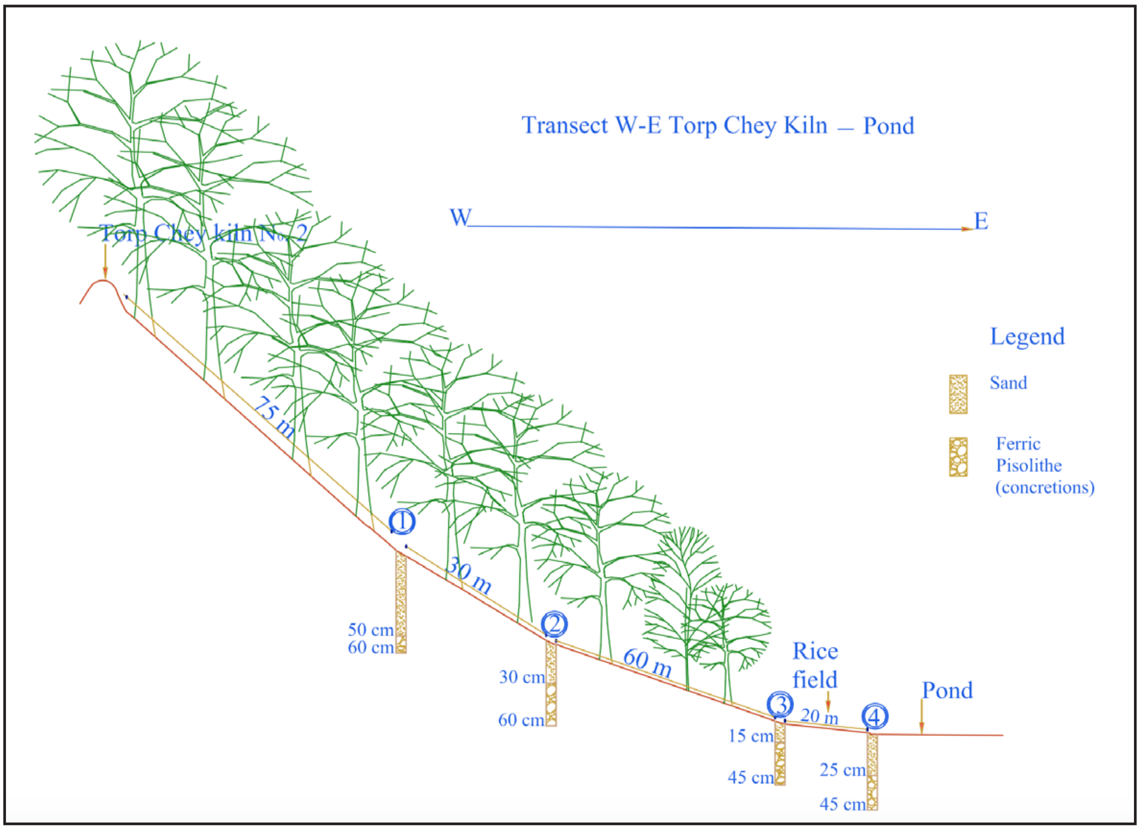
Results: The soils are sandy in samples from sites 1, 2 and 3, Clayey loam in found in site 4 samples. Soils horizons are interrupted by a laterite pebble layer with the following thickness:

Site 1: 10 cm (from 50 to 60 cmbs)
Site 2: 30 cm (from 30 to 60 cmbs)
Site 3: 30 cm (from 15 to 45 cmbs)
Site 4: 20 cm (from 25 to 45 cmbs)

Comments: Iron migrated with water movement in the form of $Fe2+$ soluble in the water. It accumulated in the lower part of the slope. The desiccation transforms $Fe2+$ to $Fe3+$ (insoluble) explaining the formation of laterite pebbles, especially at the foot of the slope. This phenomenon is encountered in many tropical areas (FAO, 1974). At the edge of pond (Site 4), laterite pebbles are less prolific due to the balance of water levels throughout the seasons.

Conclusion: According to C. D. Crocker (1962) this soil is classified in the Plinthite Podzols group. They are a senile product of weathering under the alternating wet season–dry season. They are the end result of continued leaching of ancient Red-Yellow Podzol.

Figure 39: Locations and profiles of soil auger samples



Note: Slope of mound not to scale.

7: Radiometric Dating

Five charcoal samples from Torp Chey Kiln no. 2 were selected for C14 dating (Table 13). Two samples (TC.03 and TC.05) were selected for radiometric plus standard service, while three samples (TC.01, TC.02 and TC.04) were selected for accelerator mass spectrometry (AMS) standard service. The C14 dating analysis was conducted by Beta Analytic, Inc. The charcoal samples were selected from five different excavated units and five different layers. Two methods of analysis were used for comparative purposes.

Table 13: Radiocarbon samples and results

Sample	Unit	Layer	Service	Measured Age	C13/C12	Conventional	2 Sigma Calibration
TC.01	T001N	VIII	AMS-Standard Beta No. 328425	860+/- 30BP	-27.2 o/oo	820+/- 30BP	Cal AD 1160 to 1270 (Cal BP 790 to 680)
TC.02	T002	I	AMS-Standard Beta No. 328426	660+/- 30BP	-27.8 o/oo	610+/- 30BP	Cal AD 1290 to 1410 (Cal BP 660 to 540)
TC.03	T003	III	Radiometric PLUS Standard Beta No. 328427	710+/- 30BP	-27.2 o/oo	670+/- 30BP	Cal AD 1280 to 1320 (Cal BP 670 to 630), Cal AD 1350 to 1390 (Cal BP 600 to 560)
TC.04	T005	IV	AMS-Standard Beta No. 328428	1740+/- 30BP	-28.0 o/oo	1690+/- 30BP	Cal AD 260 to 300 (Cal BP 1690 to 1650), Cal AD 320 to 420 (Cal BP 1630 to 1530)
TC.05	T006	II	Radiometric PLUS Standard Beta No. 328429	830+/- 30BP	-27.7 o/oo	790+/- 30BP	Cal AD 1210 to 1280 (Cal BP 740 to 670)

The radiocarbon dating results of sample TC.01 in unit T001N from layer VIII[28] indicates dates between 1160 to 1270 CE. This most likely reflects the earliest date of kiln operation and fits within stylistic pottery and proximate architectural estimates. Sample TC.02 in unit T002 from layer I (taken from the uppermost floor of firing chamber no. 3) yields dates between 1290 to 1410 CE. This dating probably reflects the latter phase of kiln operation. Samples TC.03 and TC.05 were taken from layers II and III between layer I and layer VIII of above samples. Two samples dated from 1280 to 1320 CE and from 1210 to 1280 CE likely reflect the middle period of kiln operation. However, sample TC.04 in unit T005 from layer IV (taken from the fire box) dated from 260 to 300 CE which was much older than the four earlier samples. This sample may not be accurate as it was taken from the fire box where several kinds of woods were used. Results suggests old wood was probably used for firing.

Note: The old wood possibility is equally interesting as it attests to the nature of the fuel. Larger, mature trees as a wood-fuel source may have been preferred as bulk fuel material; and larger pieces of wood with higher volume to surface area ratio may have had advantages. The type of species remains unknown, but undoubtedly certain woods were preferred due to various burning characteristics and availability.

The radiocarbon dating of sample TC.01 dates the start of kiln operation between 1160 to 1270 CE, while sample TC.02 dates the last kiln operation between 1290 to 1410 CE. The sandstone chips used for the construction of basement of the Kiln no. 2 are linked to the date of Prasat Torp Chey Toch which, as mentioned previously, was constructed

[28] The charcoal sample was taken from the northern part of the northern wall, the lowest layer of the excavated unit, and is probably from the earliest kiln operation.

during the reign of king Jayavarman VII (1181 to 1220 CE). Therefore, it can be speculated that Kiln no. 2 probably operated for more than 200 years.

8: Conclusion

Torp Chey kiln is unique compared to other Khmer kiln sites excavated in the Angkor and Buriram areas. The mapping, excavation, results and various technical analyses have been introduced and described throughout this paper. The intention is to inform and benefit the larger research community. Basic analyses, hypotheses and speculations have been injected throughout the discussion. These comments are intended to assist with further modeling and research.

A comparative "kiln industry" assessment provides somewhat of a spatial, chronological, technological and economic developmental (evolutionary) framework for understanding Angkorian stoneware and glazed pottery production. It is proposed that there are two major temporal and spatial trends represented by significant "threshold transitions" in kiln and glaze technology and style-decoration-form of products. This is also represented by glaze color and thickness among other dimensions. An economic dimension (i.e., production, distribution, consumption; supply and demand; supply chain) is most likely related to the transitions as well. Additionally, changes probably coincide with various social dimension changes to include factors such as identity, inclusiveness, consumption by different socio-economic classes, ethnic and gender specialization, access by more ethnically and geographically distanced groups within evolving exchange networks, etc. Some of these blanks may never be filled, but they are worth consideration in model building.

All possible complexities aside, the simplified phases proposed here are: stage 1—early Angkor, small, green-glazed kilns and stoneware, single fire box and single firing chamber; and stage 2—later, larger, Angkor brown-glazed kilns and stoneware—at least some containing multiple firing trenches in addition to a fire box and multiple firing chambers. Stage 2 also represents a wider distribution. The nature of changes in network distribution and consumption remain unknown. Several testable models are possible. Trends related to increased/decreased efficiency, standardization, diversity, overall production volume (not necessarily capacity per kiln and single firing event) and related factors remain unknown. Neither industry seems to have witnessed massive external distribution outside of the Angkor-Khmer area of influence; unlike later Thai and Vietnamese industries where various shipwrecks and occurrences in archaeological sites (including Cambodia) from around the 14th century onwards attest to a much larger extra-local market.

Stage 1 early stoneware and glazed ware kilns excavated in the Angkor area such as Anlong Thom (Thnal Mrech), Sar Sei, Khnar Por, Bangkong, and Tani have almost identical structures and sizes (chamber floor areas ranging from an estimated 10–20 m^2; the larger range is likely overestimated as support pillars have not been subtracted and some dimensions may suggest mound size rather than firing chamber size). Their kiln structures can be divided into three parts: fire box, firing chamber and vent (chimney). They are comparatively simple. The ceramics produced in the Angkor area are mainly green-glazed and unglazed stoneware with limited shapes/forms dating approximately from the 9th–10th centuries CE. Glazes are thin, almost translucent yellow in many cases.

However, the kilns and products do exhibit considerable sophistication in craftsmanship, technology and production capacity at that particular time and place within the larger region. A significant shift had occurred and technological thresholds had been overcome from the earthenware products of the previous centuries and millennia. Nevertheless, sophisticated earthenware production at relatively higher temperatures and using kiln technology may have developed by the latter Funan period (1st–6th centuries CE—standard historical fixed dates, although not necessarily synched with archaeological data); evidenced by the Cheung Ek research. How did this transition affect the pre-existing earthenware and fine paste ware production and consumption economies existing at that time (e.g., the spouted *kendi* and related jars and other vessels); or other earthenware potting industries? Did the different products serve different purposes? Did this coincide with a larger market network shift and change in demand and consumption? We would expect continuity in many earthenware potting industries. They certainly exist throughout historic and modern times to fill significant demands (e.g., Kampong Chhnang stoves and pottery are found in almost every household and business in Cambodia).

Were, how, and to what degree were changes (particularly technological) influenced or possibly diffused from elsewhere? Perhaps it was an organic independent development; exposure to products and ideas; or, involved direct input from outside technical experts. Chinese products and production technology are the most parsimonious source of outside influence, however indirect and incomplete any influence may have been. Despite outside influence possibilities (i.e., various forms of diffusion), styles and technologies are fairly unique to the immediate Angkor capital area with a somewhat wider distribution—i.e., production sites are limited to areas around the capital, but distribution and consumption are more widespread as evidenced by occurrences in other site types such as habitation and settlement sites. There seems to be very limited, if any, extra-local export and consumption beyond Khmer dominated territories. For example, early Khmer green-glazed wares were not exported in bulk to maritime ports in the Straits or South China Sea and elsewhere based on current available data; they do not appear in abundance in non-Angkorian settlement sites outside the Angkor sphere.

Whether or not this technology and production capacity evolved rapidly or slowly is equally unknown. The same can be said of its eventual decline—with equally unknown answers to whether demand and production simply decreased and/or demand for new wares and new technologies with perhaps greater capacity and efficiency eclipsed the green-glazed tradition. There is industry overlap to be sure. It does not appear as if wholesale replacement suddenly occurred. This also leads to "which came first" and "correlation or causation" arguments which cannot be sufficiently resolved at present. Looking further back in time, it is again noted that kiln technology may also have evolved from further south in the Funan area (e.g., Phon Kaseka et al.'s research at Cheung Ek). However, the relationship, if any, is unknown.

The emergence of Stage 2 brown-glazed stonewares characteristic of the 11th–15th centuries CE and the different kiln technologies represent a second major transition. This does not mean that transitional phases, possibly exemplified by Chong Samrong and Thnal Mrech, did not occur. In fact, an abrupt transition may be more indicative of significant diffused technological shifts, while a slower "evolving" transition may be indicative of an internal evolutionary process representing more internal innovation.

By comparison, the excavated kilns in the Buriram kiln mound area are larger and produced multiple stoneware and glazed wares. Many kilns were possibly constructed to share walls, suggesting another technological innovation (though this is not universally confirmed as accepted). The ceramics produced in the Buriram area are mainly brown-glazed wares with some unglazed and green-glazed wares. There may be some transitional indicators, or, possibly a "combined tradition" aspect. It was noted above that Buriram may be the production location for the notable and quite unique half-green/half-brown-glazed wares.

The temporal-spatial placement in the evolutionary trajectory of stoneware and glazed ware production certainly warrants further investigations. Early thinner green-glazed wares seem to have been produced at kilns in the Angkor capital vicinity. Brown-glazed wares (and later thicker green-glazed wares) seem to have a wider distribution of production sites. It is noted that the brown-glazed kiln tradition was predominantly thought to be located west and northwest of the capital until the discoveries at Torp Chey (to possibly include south at Cheung Ek).

The Torp Chey kiln represents yet another significant threshold, but within the Stage 2 brown-glazed tradition. The kiln(s) displays a considerably different structure, technology and capacity from those found in Angkor and Buriram; perhaps also Cheung Ek and Chong Samrong. As represented by Kiln no. 2 (excavated) they are among the longest, largest and most sophisticated (complex) of the kiln types, consisting of four firing chambers on a long single floor and three secondary fire trenches heated by a single fire box. The sandstone gravel flooring is unique; as well as the ventilation design, thickened walls and decreased internal roof supports. Chong Samrong kilns may fit within the tradition as well—exhibiting large capacity and secondary firing trenches; possibly being a more simplified earlier development.

Again, the Torp Chey discovery raises the question of how a kiln of this type evolved or was introduced. The kiln, for example, is designed to use a side stoking method, which is not known elsewhere in Southeast Asia. As stated, this may suggest diffused influence from an origin where similar technology was used, or, it may have been a result of independent innovation. Relations to, or innovations inspired by, metal working technologies further east of Torp Chey where the need for high heat and temperature control were necessary, cannot be discounted either.

Nevertheless, the technology could have been introduced as an "idea" and may not necessarily have involved foreign potters or technicians (Hein 2012). According to John Miksic (2009), the Khmers were second only to the Chinese in mastering the technique of producing stoneware and in the ability to produce glaze. The Chinese had long been in trade contact with Angkor and even Chenla and Funan, and Chinese pottery was certainly in circulation. The Chinese influence cannot be wholly ignored, although the type and degree of influence remains obscure. The Cambodian potters may have developed a system to imitate an "idea" of larger kilns, multiple chamber kilns, supplementary fire/fuel sources, for example; and had a strong desire to imitate glazed stoneware production they were familiar with from extra-regional circulation (i.e., Chinese wares). As it stands, however, we can only argue that archaeological evidence indicates Khmer potters were possibly inspired by Chinese imports in circulation, but developed innovative techniques, glazing and kiln design.

The kiln technology development is best demonstrated by Torp Chey Kiln no. 2 excavation results. The size, for example, displays an increase in length of kilns from 6.0–9.0 m (Angkorian green-glazed ware kilns) to 21.5 m (Torp Chey). The volume increased dramatically as well, to include increased volume due to decreased frequency of internal support pillars. There is a shift from a single firing chamber and single fire box (earlier kilns) to four firing chambers (Torp Chey); the addition of three secondary fire trenches to support and control appropriate temperature and atmospheric conditions; a reduction of the slope of the firing chamber from 30–40 degrees (early kilns) to approximately 15–20 degrees (Torp Chey); the introduction of clay and sandstone gravel flooring to support the sandy layer, also allowing assisting with pot placement, leveling, and adjustment effectiveness; the construction of walls and roofing with appropriate thickness (also decreasing the need for internal supports); and the creation of a loading doorway to enable easy access to the kiln in the upper section.

The kilns produced brown-glazed wares characteristic of the later Angkor phases from the 11th–15th centuries. Radiocarbon dates at Kiln no. 2 in Torp Chey are more restricted to 12th/13th–14th/15th centuries CE. Torp Chey is also located east of Angkor along the road and associated with the architectural rest house structures of Prasat Torp Chey Thom (12th century; Suryavarman 12th style) and Prasat Torp Chey Toch (13th century; Jayavarman VII style) as well as proximate to the Angkorian east road. The nature of a stoneware production community, industry and identity is unknown, although the density of kilns suggest a thriving and relatively large export industry (i.e., to Khmer areas beyond the production site and the capital) that may have been in production for two centuries or longer according to radiocarbon dating results and comparative temporal association with proximate architectural features as well as the pottery assemblages.

The relation to sites in the immediate proximity (i.e., the temples/rest houses) is unknown. Were they integrated? Workshops and habitation features have not been identified, but they possible exist. It is plausible that the architectural and other features indicate a state-controlled production system, or perhaps a state or elite-managed system that also supported a larger community. This may have incorporated other industries, road transport, taxation, ceremonial/ritual/religious functions, etc. However, it is equally plausible that a specialized production community operated independently with family or community ownership and overall management; perhaps integrated with state or other enterprises in various ways such as use of distribution/shipping systems and roads owned and taxed by others. The inscriptional and historic data are silent on these matters.

To perhaps unfairly simplify, it is reiterated that the production of Angkor stoneware ceramics and kiln technology advanced in two primary stages as recapped in the following (not dismissing that variation and important nuances existed which may have played important roles in technological and production shifts):

Stage 1: Kilns were constructed and arranged on artificial dykes surrounding water structures. Kiln mounds were small, oval in shape and measured approximately 10 m in width, 15 m in length and 2.0–3.0 m in height (the mound size; not the kiln size). Kilns in these mounds measured approximately 1.8–3.6 m in width and 6.0–9.0 m in length. They were divided into three parts: fire box, firing chamber and chimney (vent). Kilns were reconstructed on top of each other when older kilns degraded and new kilns were required. Clay support pillars were arranged in the middle of the firing chamber to support the roof. The slopes of the kilns were between 30 to 40 degrees. Kiln tools were required to level pots during the firing process. Ceramics produced in this stage were limited in shapes/forms and could be divided into two types: green-glazed and unglazed wares. Green-glazed wares were usually small in size, (e.g., covered boxes, bottles, bowls, small jars, some roof-tiles and water jars). Unglazed wares, on the other hand, were larger in size. These included basins, water jars, cylindrical jars and roof-tiles. Kiln sites of this early stage probably date from the early 9th to 10th century and are located in the Angkor region such as Anlong Thom (Thnal Mrech), Sar Sei, Tani, Bang Kong, and Khnar Por.

Stage 2: Kilns were constructed and distributed on artificial mounds. Kiln sites were located more widely, especially along Angkorian roads from the capital to Bakan, to Phimai, and to Sdok Kak Thom. The sizes of the mounds are larger than those in stage 1, measuring approximately 20.0 m in width, 30 m in length, and 3.0–4.0 m in height. They produced brown-glazed and unglazed stoneware.

Taking Kiln no. 2 at Torp Chey as representative of advanced stage 2 kiln technology advancement, we can analyze its difference with those kilns representing stage 1:

Kiln no. 2's length is 21.45 m, and the width is 3.2 m. It is divided into fire box, four firing chambers, three secondary fire trenches, and vents. Pillars supporting the roof were not necessary and were used only in few places. The slope of the kiln was reduced and sand was used to level the wares instead of kiln tools. Ceramics produced during this stage exhibit development of shapes of ceramics from stage 1 in terms of the variety. Brown-glazes were applied to both small and large products.

Green-glazed wares were still produced, though the glazes were thicker and darker. These were not produced at Torp Chey, rather they were produced elsewhere (e.g., Buriram). The most interesting wares in this stage are the small jars with animal figures and application of two colors on a single pot. Kiln sites in stage 2 probably date from the 11th century to the end of Angkor period.

The various analyses have been summarized above. As always, more survey, testing and analyses is recommended. The waster assemblage, for example, deserves a much closer examination. The presence of unglazed wasters may indicate a pre-firing process to eliminate flawed pieces. Flawed pieces could damage other pieces during final firing. They would also waste glaze material, fuel and kiln space. If pre-firing and glazing were conducted on-site or near the kiln site, there may be evidence of a workshop yet to be identified. It is assumed that pre-firing and subsequent glazing would increase overall efficiency and effectiveness in the production chain (at least a certain segment of the overall production chain). Whether or not this is also a new innovation or introduction in the overall production process compared to Stage 1 or other Stage 2 sites is unknown.

In summary, it is understood that further research, different types of complementary research and additional comparative studies will allow several models to be tested, more nuanced models to be developed, and a refined understanding of both industry and technology to include a wide spectrum of related implications. Experimentation and ethnoarchaeological studies, for example, need further support and integration. We may know the volumes of firing chambers and fire boxes/trenches, but this does not necessarily equate to fuel consumption (only maximum fuel capacity at any given time). We do not know the duration of firing and the amount of stoking and reloads that occurred (we can estimate temperatures reached and energy needed to achieve and sustain it with the given kiln and ceramic parameters). Other studies such as wood fuel identification will be equally important. As mentioned, the KPX project will help shed light on distribution vis-à-vis production centers. Compositional analyses, waster assemblage analysis, fuel analysis and larger site area survey and testing to understand other site components such as possible workshop and habitation areas remain areas needing critical considerations and efforts as well.

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The project was placed under the overall leadership of H. E. Bun Narith from APSARA Authority and Ambassador K. Kesavapany from ISEAS.

Other fieldwork and analytical contributors include the following personnel in accordance with the MoU:

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Trainee Students from Royal University of Fine Arts: Mr. Norv Sopheak, Mr. Ou Kongkea, Mr. Tuy Phearen, Mr. Pick Meanheng, and Mr. Kam Sokun.

Independent Researchers: Dr. Don Hein joined the final stage of the excavation to confirm the kiln structure with financial support from Friends of Khmer Culture Inc (FOKCI). Mr Robert McCarthy prepared the soil and sandstone chip analysis from Torp Chey Kiln and Temple

Additional staff from ISEAS: Ms. Foo Shu Tieng