

USING IN-SLAG CHARCOAL AS AN INDICATOR OF ‘TERMINAL’ IRON PRODUCTION WITHIN THE ANGKORIAN PERIOD (10TH TO 13TH C. CE) CENTRE OF PREAH KHAN OF KOMPONG SVAY, CAMBODIA

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ABSTRACT

Recent fieldwork by the Industries of Angkor Project (INDAP) has identified the first extensive evidence of iron production within an Angkorian Khmer (9th to 15th centuries CE) centre at Preah Khan of Kompong Svay (Preah Khan) in Preah Vihear province, Cambodia. This immense 22 km² temple complex appears to be an outpost of Khmer settlement situated in close proximity to Phnom Dek (“Iron Mountain”), the richest known source of iron oxide in Cambodia. Combined with the fact that Preah Khan’s temple architecture dates between the late 10th to early 13th centuries, the period that the Khmer greatly expanded their territorial influence, our primary hypothesis is that this complex was established to gain access to and monitor production of iron for the capital of Angkor. The vast number and size of these iron slag concentrations, some up to 5 m in height by 35 m in length, precludes the use of traditional excavation and dating methods. Instead, this paper employs ¹⁴C dating of ‘in-slag’ charcoal from surface slag cakes to produce a spatial chronology of late or ‘terminal’ industrial activities. The results indicate that metallurgy was ‘last’ practiced at various locations within Preah Khan in the mid-13th to late 17th centuries, with three distinct clusters between the late 13th and late 15th centuries. Based on this initial survey of surface collections it appears that iron production at Preah Khan occurred after the final phase of masonry construction. More significantly, this work provides the first robust set of dates for late Angkorian and Middle period industrial activities in Cambodia.

BACKGROUND

The introduction of iron was a significant factor in the development of Cambodian society, from its initial appearance at prehistoric radial sites (5th century BC to 3rd c. AD) to the rise and fall of historic state-level societies in the Pre-Angkorian, Angkorian and Post-Angkorian (or Middle) periods. The majority of evidence for this versatile material is associated with the Angkorian period (9th to 15th c. AD) when the Khmer built the elaborate temple complexes of Angkor and greatly expanded their influence across most of mainland Southeast Asia (Fig. 1). Metal implements (see Fig. 2) are frequently depicted in the statuary and processions of Khmer armies and day-to-day scenes of village life on the bas relief galleries of Angkor Wat, Bayon and Banteay Chhmar temples. Iron artifacts in the form of tools, bangles and weapons are also frequently recovered from prehistoric and historic period excavations (see Albrecht et al. 2000; O’Reilly et al. 2006; Pottier et al. 2005; Reinecke et al. 2009) while chisels and architectural crampons to carve and stabilize masonry coursing have been frequently found during the restoration of Angkorian temples (Nafilyan 1967). While these data sets demonstrate the use of iron over two millennia there has been no direct investigation of the history of iron production

and its impact on Cambodian society. A primary explanation of this scholarly lacuna is an emphasis on more abundant and aesthetically appealing materials such as ceramics, pre-Angkorian and Angkorian bronzes and the thousands of masonry temples scattered around the country. A more significant factor is the extremely poor preservation of iron objects as well non-uniform distribution and complexity of evidence for iron ore mining, smelting and iron smithing hearths.

FIGURE 1 HERE.

FIGURE 2 HERE

The most detailed information about Cambodia's iron working past is derived from late 19th century accounts of the Kuay, an ethnic minority inhabiting the forests around Phnom Dek ('Iron Mountain') approximately 130 km east of Angkor (Moura 1882; Duffosé 1934). The Kuay, or Kuay Dek ("Iron people") are known to have smelted iron using the bloomery process until the mid 20th century. Dupaigne's (1987) thesis on Kuay metallurgy collated existing oral traditions, histories and ritual practices and includes a list of twelve different iron working sites in the forests surrounding Phnom Dek. Unfortunately, as Dupaigne's focus was ethnographic and not archaeological, no efforts were made to determine the age or technological characteristics of these sites.

Discovery of the first 'ancient' iron production site in Cambodia is attributed to Étienne Aymonier at the Angkorian centre of Preah Khan of Kompong Svay (Preah Khan), the massive 22 km² state-level temple complex situated between Angkor and Phnom Dek, 30 km west of the latter. In his inventory of the stylistically-dated 10th to 13th century masonry remains within Preah Khan, he identified 'scories du fer' on the banks of the moat surrounding the central temple precinct, known as the Bakan (1900:430-431). No efforts were made to investigate this finding until Claude Jacques noted the presence of one other slag concentration on his plan of Preah Khan (Jacques and Lafond 2004:264). Despite several extensive site inventories across Cambodia (Lunet de Lajonquière 1902-1911; Bruguier and Phann 2005) and many archaeological investigations within the Greater Angkor region, Preah Khan remains the only Angkorian site with evidence of iron working within its enclosure walls. Over the past five years, numerous iron production sites associated with the historic period have been discovered along the Northwest road connecting Angkor to the regional centre of Phimai in modern day Thailand (Living Angkor Road Project 2008), at the village of Khvao on the east road between Angkor and Preah Khan (Im 2011), and in the region of Chhep in northeastern Preah Vihear province (Thuy 2010). The chronology for these metallurgy sites, including our work at Preah Khan, was initially based on diagnostic ceramics. Results of radiometric analyses from several of these locations have been conducted but are awaiting publication.

Following the initial discoveries at Preah Khan, the Industries of Angkor Project (INDAP) began a multi-disciplinary research programme to investigate the industrial and settlement history of this regional Khmer centre. The immense temple complex appears to be an isolated outpost of Khmer settlement situated in close proximity to Phnom Dek, the richest known iron oxide source

in Cambodia. Combined with the fact that Preah Khan's temple architecture dates between the late 10th to 13th centuries – the period that the Khmer greatly expanded their territorial influence – and it is connected to Greater Angkor by a state-level road with multiple types of support infrastructure (Hendrickson 2010), our primary hypothesis is that it was established to gain access to and monitor production of iron for the capital of Angkor. INDAP is currently studying iron production and supply networks to provide a new picture of how regional Khmer centres functioned – from an economic and political point of view - within the broader framework of an empire that incorporated most of mainland Southeast Asia. The project has four specific objectives: 1) identify the nature and extent of production of industrial materials and the human settlement that would have supported these on-site activities; 2) discover when the city was founded and if it was, from its foundation, an industrial settlement; 3) determine if the location of the city and its industrial capacity were linked directly to material demand from Angkor; and, 4) reveal precisely when Preah Khan and its industries declined.

The first step toward answering these questions is documenting the extent and history of industrial sites within Preah Khan. Fieldwalker surveys have dramatically expanded on the initial discovery by recording eighteen distinct metallurgy sites (Fig. 3) characterized by a dense distribution of industrial waste products (tuyères [air delivery pipes], slags, furnace wall) with one or more raised mounds. Macroscopic inspection of such surface finds strongly suggests both smelting and smithing were practiced, but as the specific production activity is being determined by excavation and laboratory study, we will for the time being refer to these sites as 'slag concentrations'. Within Preah Khan, the slag concentrations are restricted to the eastern half of the enclosure between the 3rd and 4th enclosure walls and are almost universally associated with Angkorian period water infrastructure. This spatial patterning corroborates Kuay ethnographic accounts that smelting sites were always positioned near a source of water (Dupaigne 1987:206). Three of the largest tanks (Baray, Trapeang Thom, Trapeang Thnal) lack any evidence of iron-related activities though complete survey along the 2.7 km long Baray was prevented due to dense forest cover and the presence of several active landmine fields along the south bank.

FIGURE 3 HERE

In addition to the spatial patterning there is considerable variation in the abundance of industrial waste at each site. The smallest concentration is raised 0.2-0.3 m above the ground surface while the largest reaches 5 m in height and spans over 37 m across the bank of a reservoir. This variation presumably corresponds to the scale, intensity, and/or longevity of production at each site. The primary objective therefore is to establish a chronology of these sites and examine their relationship to the development of Preah Khan and the broader expansion and fall of the Khmer Empire.

DATING IRON PRODUCTION SITES: A RELATIVE CHRONOLOGY

A relative timeline for the slag concentrations within Preah Khan can be established through topographic association with Angkorian infrastructure and comparison of technological attributes of tuyères. The construction date of an Angkorian temple complex such as Preah Khan relies initially on Sanskrit and Khmer language inscriptions carved into sandstone doorjambs or on large stele positioned inside or near the temple grounds. Texts frequently list the exact dedication

date of a temple or provide the day that a temple inventory was created; the architectural style of that building is therefore linked to this text and it becomes indicative of a particular king or period in Khmer history. Water infrastructure (*trapeang* [water tanks], canals, embankments), which are an essential part of Khmer religious and urban design, are usually built in association with masonry temples and can be relative dated with particular masonry building phases. By examining the relationship between these features it is possible to distinguish a temple or piece of infrastructure as being a single or multi-component construction and also define the duration and peaks of large-scale works.

Preah Khan has only one dated text (K. 161, 1010 AD [Kern 1888]) but the masonry architecture represents at least three distinct styles typical of the mid-late 11th (Baphuon style), early 12th (Angkor Wat style) and late 12th-13th (Bayon style) centuries AD (see Mauger 1939; Stern 1965; Jacques and Lafond 2004; Cunin 2004). Inside the massive 4th enclosure wall, which is partially double-banked with an internal moat, are two different types of water tanks: 1) large, 'state-level' reservoirs such as the Baray and Boeng Kroam associated with the overall architectural plan and layout; and 2) several smaller tanks characteristic of village and/or household temples commonly found in the Angkorian period. Angkorian tanks are typically rectilinear and oriented east-west along the main axis (see Pottier 1999; Evans 2007). The majority of tanks at Preah Khan follow the east-northeast (ene) alignment of its masonry constructions. Notable exceptions are Sre Tomnup, Trapeang Ach Dek Thom and Trapeang Ach Dek Toch, which share the east-west orientation but show markedly different layouts (quadrilateral, rectangular, square). Since there is no known Pre-Angkorian occupation within Preah Khan and there is limited evidence for reservoir construction during the Post-Angkorian period in Cambodia, Sre Tomnup most likely represents a late Angkorian phase construction. Based on surface evaluation, the superposition of the slag concentration on top of these embankments indicates post-construction iron manufacturing. One potential exception is Boeng Kroam Location 2 (BK-2) which appears to be integrated within the bank and therefore may pre-date the reservoir, completed sometime in the early-to-mid 12th c. AD. The majority of sites, however, were active after the earthen infrastructure was completed and therefore likely post-date the mid-12th century.

The second method for developing a relative chronology is that forging/smithing components often change form through time. While tuyère dimension, number, and orientation can imply major technological differences, in our studies such differences seem to be primarily chronological. Substantial numbers of clay tuyères are associated with recent Kuay sites (Dupaigne 1987:208; Hendrickson and Pryce 2011) and these artifacts also represent the most abundant and easily quantifiable aspect of iron technology at the Preah Khan concentrations. Measurements of mean bore diameter and thickness of tuyères from fifteen surface collections and three excavations (Fig. 4) show a general homogeneity across Preah Khan. This lack of variation suggests the existence of a single technological tradition; whether this represents a period of production or continuous practice by a specific group needs further chronological and technological investigation.

In summary, by combining the evidence from the topographic relationships discussed above the earliest use of this technology at Preah Khan appears to be after the completion of major Angkorian infrastructure. Radiometric dates from multiple sites are required to determine

whether the spatial distribution of slag concentrations within Preah Khan represents a matter of years or centuries of industrial activity.

FIGURE 4 HERE.

DATING IRON PRODUCTION SITES: CALENDRICAL METHODS

Three techniques each with their own pros and cons are traditionally used to establish calendrical dates for iron production sites: archaeomagnetism, thermoluminescence (TL), and either conventional or accelerator mass spectrometry (AMS) radiocarbon dating. Archaeomagnetism is the ideal method for determining the final smelting event at a site (see Crew 2002; Powell 2003; Abrahamsen et al. 2003) but, as with TL dating (Godfrey-Smith and Casey 2003), it often requires *in situ* furnace structures and the techniques are both time-consuming and require specialized field procedures and calibration. At Preah Khan, small test excavations of three slag concentrations have failed to identify *in situ* furnace structures suitable for dating (Hendrickson et al. 2010; Hendrickson et al. 2012). Destruction of the furnaces to extract the bloom and repeated use of the same location are likely causes of the extremely disturbed and complex remains. A more viable possibility is the direct dating of slags using geomagnetic archaeointensity (Ben-Yosef et al 2010) however again the approach requires extensive calibration that varies depending on latitude. Even with the successful identification of a furnace and quantity of slag, the sheer number and size of iron-related sites within Preah Khan precludes the use of these techniques to identify a spatial history across the entire site.

Radiocarbon dating carbon samples from excavated sections is the most accessible technique as charcoal and charred wood – in most cases – are extremely abundant in both smelting and smithing contexts. This technique is also the most commonly used for documenting the chronology of a single context or furnace (Greenfield and Miller 2004; Eliyahu-Behar et al. 2012). The application of excavated charcoal to document temporal dynamics of metallurgical activities across a region is, for understandably practical reasons, much rarer. One notable exception is a study based in Jutland, Denmark (Rasmussen et al. 2006) that obtained seventy-three dates from carbonized straw and charcoal at the base of slag pits from eleven different smelting sites. The single-use of each slag pit furnace enabled the researchers to identify trends in production over a period of two hundred years however this result is somewhat unique as it required extensive excavation, with one site exposure totaling over 50,000m² (ibid.:129)

The use of excavated charcoal is complicated not only by the ubiquitous stigma of old wood but also by issues of site taphonomic processes and sampling (Killick and Fenn 2012:565). Excavated or stratigraphic charcoal can experience downward (and potentially upward) displacement within a loosely packed industrial matrix of slag and large furnace wall fragments. From a fieldwork perspective, a further drawback is that stratigraphic charcoal requires laborious and time-consuming excavation to properly identify the association of each fragment. Given the vast number and size of the slag concentrations within Preah Khan – some up to 5 m in height and 40 m in diameter – excavation is not a viable option if we want to establish a spatial history of iron production across the site.

Another source of furnace-related carbon that is rarely employed is charcoal collected from within a large piece of slag or a slag cake (see Bachmann 1982:8). A slag cake (Fig. 5) is commonly produced inside the furnace as a by-product of the smelting process. Each cake represents the product of one or more discrete smelting events that often trap remains of the unused fuel (charcoal). Compared with excavated samples, dating ‘in-slag’ charcoal has several immediate advantages. First, once cooled a sample cannot move within the cake unless it was incompletely encased in slag or the cake is subsequently cracked open. Second, the slag also prevents external contamination by younger charcoal. Finally, since slag cakes are frequently found on the surface of concentrations it is possible to collect and date multiple sites at one time. Based on superposition a slag cake found on the top of a large concentration likely represents a more recent or ‘terminal’ smelting event. Recent work by Park and Rehren (2011) demonstrated the utility of in-slag samples however their study dated only a single piece of wood from one slag sample. In our case study we propose to use ‘in-slag’ charcoal within several large cakes located on the surface of the concentrations around Preah Khan.

FIGURE 5 HERE

Interpretation based on the analysis of in-slag charcoal must take into account specific problems related to both old wood and slag cake taphonomy. Old wood or curated fuel could appear within slag cakes via four different processes. First, old wood was transformed into fuel for a smelting event sometime after it initially became separated or was removed from the parent tree. This represents the ‘classic’ case for old wood and could be partially resolved through the difficult process of determining the type of wood. The second possibility is that the inclusions represent charred wood or charcoal that was curated and used at a later date. Since wet or saturated charcoal is a less viable fuel – and Cambodia’s monsoon inundates the landscape for at least four months each year – this explanation would require the presence of long-term dry storage. As there is no evidence for this practice either ethnographically or archaeologically in Cambodia this factor can be discounted as a source of interpretive bias. The third possibility is that the in-slag charcoal represents old fuel incorporated into the newly molten slag. Given that the bloomery furnaces found at Preah Khan are enclosed systems it is unlikely this issue would be a frequent occurrence. One final consideration is that the carbonized material trapped within the pores of the cake may represent a combination of ash, charcoal and other organic debris from multiple wood types of different ages (Robyn Veal, pers. comm., August 2012). Samples dated from different parts of one ‘piece’ of material trapped in a pore could potentially be comprised of both old and new fuel sources; however this occurrence would be very rare and the temporal gap between parent smelting events likely short enough as to not fit within date ranges for radiocarbon dating.

Arguments against post-smelt movements of slag cakes are based on the rationale that they are unlikely to be randomly transported far from the point of origin. Slag cakes can have both cultural and economic value however there is no regional evidence for either. Movement at the point of origin is expected during extraction of the bloom, construction of a new furnace at the same location, or through natural erosion processes and gravity however the cake will be representative of a smelt at that furnace. The null hypothesis for dating in-slag charcoal is that it represents the time range around the smelting event that created the cake. Taking into

consideration the issues raised above, this method will at least provide a *terminus post quem* of metallurgical activity at a given location.

A preliminary test of this approach was conducted by comparing excavated (stratigraphic) and in-slag charcoal from Boeng Kroam Location 1 (BK-1), a 2 m high slag concentration positioned on top of the north bank (Hendrickson et al. 2010). AMS radiocarbon results from both charcoal sources yielded comparable date ranges demonstrating that BK-1 was likely a short-term industrial deposit (ibid.). From this preliminary test, and taking into consideration the issues raised above, it is argued that in-slag charcoal is a reliable indicator of individual smelting activities. Returning to the primary goal of this paper, in-slag charcoal from the surface of slag concentrations are used to create a spatial history of late or ‘terminal’ iron production across Preah Khan. By establishing one end of the production timeline we can then target excavation at specific sites for more detailed chronological and technological analysis.

STUDY SITES AND SAMPLE DESCRIPTION

Sample collection for this pilot study was completed in December 2010 via ground survey of the eighteen slag concentrations inventoried within Preah Khan. As the objective is to establish ‘terminal’ metallurgy events, emphasis was placed on selecting slag cakes found on top of each concentration or, in some cases, on its upper edges. A total of fifteen surface slag cakes (SSC) were recovered from six different Angkorian features: Boeng Kroam, Phlau Kuk Dek, east moat of the Bakan, Sre Tomnup, Trapeang Ach Dek Thom and Trapeang Ach Dek Toch (Fig. 3 and Fig. 6). As will be discussed below, samples were successfully analysed from twelve SSC.

FIGURE 6 HERE

Boeng Kroam (“Lower Lake”)

Also known as Boeng Sre (see Mauger 1939), this is the largest reservoir inside Preah Khan (850 m x 450 m x 3 m). Ceramics and roof tiles found on each of the banks indicate the presence of Angkorian and post-Angkorian occupation. Evidence of metal production is restricted to the north bank and these sites represent the largest slag concentrations known within Preah Khan. Four distinct slag concentrations (BK-1 to BK-4) have been identified.

BK-1 has two similar-sized slag mounds (A - 18 m x 15 m; B -16 m x 11 m) located on the top of the bank. Excavation of Mound A identified a 1.2 m industrial deposit that post-dated construction of Boeng Kroam and subsequent AMS analysis of in-slag and stratigraphic charcoal indicated it was generated in mid-15th century (see discussion above). No further slag cakes were collected for this location for this study. The largest concentration currently identified in Preah Khan is at BK-2. Here, the industrial deposit covers the height of the internal bank surface over 40 m across the face. As discussed above, the topographic relationship suggests that the iron production site may pre-date the embankment. Excavation at the top of the bank in 2010 identified industrial deposits from the mid-15th to mid-18th century (Hendrickson et al. 2012). Since numerous slag cakes were visible across the surface of the concentration SSC samples were taken from the top, middle and base of the slope (SSC-7, SSC-8 and SSC-9, respectively) to test whether the surface material represents a vertically stratified sequence. BK-3 is a low-lying slag concentration (~30 m x 14 m) on the external edge of the bank near the western corner

of the reservoir. One slag cake (SSC-10) was collected from the upper part of the feature between two slightly raised areas (~0.2-0.3 m) that may indicate individual production areas. On the eastern end of the embankment Boeng Kroam, BK-4 consists of three low mounds across the surface of the embankment. Mounds A and B are both irregular in form while Mound C has a consistent long axis, more similar to the large examples seen at BK-1. Samples were obtained from the west edge of Mound A (SSC-11) and the top of Mound B (SSC-12).

Phlau Kuk Dek (“Slag Hill Road”)

The ox cart track connecting Boeng Kroam to Prasat Steung cuts across this raised embankment (PKD) midway between the Bakan moat and the Baray (see Fig. 3). Slag is scattered north of the track but on the south side is a well-defined slag concentration and mound measuring approximately 40 m by 26 m and reaching ~1.5 m in height. One slag cake (SSC-13) was collected from the lower southern edge of the concentration.

East bank of Bakan Moat

This site (G3E) corresponds with the concentration identified by Aymonier in the late 19th century. Iron production debris is clearly visible within the light forest scattered over an area of approximately 80 x 22 m, however it likely represents several distinct production areas. Complete survey was hindered by the potential for unexploded ordinance and landmines; only the area in front of the Gopura was cleared during recent work. Defined mounds are not evident but given the broad distribution of industrial material visible on the surface it likely represents several different period of metallurgical activity. One SSC was taken from the northern (G3E-N) and southern (G3E-S) ends of the concentration (SSC-14 and SSC-15, respectively). In addition, slag presumed to originate from this industrial deposit was also found inside the masonry *gopura* (entryway) of the Bakan. This relationship with an Angkorian structure has two potentially important chronological implications. First, if the slag was used as a foundation material it would indicate iron production *before or during* completion of the gopura early to mid 12th century. Or, slag was used to fill holes in the masonry flooring at some point after construction. While excavation is required to document whether the slag is truly beneath the building we can use in-slag dating to determine when the date of the upper part of the concentration – the likely source of patchwork material – was produced. This may indicate filling of holes or that slag was used as a foundation material for the site. In the latter case, the slag concentrations on the east bank would pre-date construction of the temple. While the results from in-slag dating will not conclusively answer this issue, it will provide initial data for this complex and important taphonomic relationship.

Sre Tomnup (“Ricefield Dam”)

Sre Tomnup (SRT), also known as Trapeang Trach, is a large (~200m x 168/220 m) quadrilateral tank southeast of the Bakan. As discussed above, its shape poses an issue for establishing a relative chronology as it is atypical of Angkorian period reservoir designs. Slag fragments are found on each bank but clearly distinguishable concentrations are predominantly found on the east as well as south and west. Each of the seven locations concentrations are positioned on top of the bank and continue onto either the internal or external sides. Unlike Boeng Kroam, these mounds are less distinct and do not appear to be integrated within the walls. SSC were only

collected from three sites: SRT-4 (top of bank, SSC-4), SRT-5 (middle of bank, SSC-5), and SRT-6 (base of bankment, SSC-6).

Trapeang Ach Dek Thom (“Big Iron Slag Pond”)

Trapeang Ach Dek Thom (TOM) is a classic example of a rectangular (104 m x 46 m), cardinally-aligned Angkorian tank. Slag is visible at several places along the north bank but the only concentrations currently identified are located on the south side. The largest, TOM-1, is a low-relief concentration extending across the width of the bank and the exterior face (~18 x 7 m). TOM-2 and TOM-3 are smaller sites defined by a broad distribution of slag and tuyères but no slag cakes. A single fragment of unidentified blue-on-white porcelain recovered near Location 3 indicates post-14th century activity at the site (Brown 2009). Given the limited number of SSC visible on the surface of the three locations, two slag cakes were collected TOM-1 (SSC-2 and SSC-3) on the northern and southern sides of the industrial deposit.

Trapeang Ach Dek Toch (“Little Iron Slag Pond”)

This square tank is the smallest (35 m x 31 m) reservoir showing evidence of metallurgy within Preah Khan. Surveys in 2009 identified slag on both the east and west banks however subsequent clearing in 2010 revealed that the main slag concentration spread across the southeast corner from the top of the bank toward the exterior of the reservoir (~25 m x 9 m). Test excavation in December 2010 and AMS dating of stratigraphic charcoal revealed activity between the 14th to 18th centuries (Hendrickson et al. 2012). Total station mapping also revealed a second concentration (Location 2) 30 m to the west comprising four small mounds ranging between 7 to 16 m in length and raised up to 0.60 m above the ground surface. A single SSC was recovered from the top of Mound 1 at TOC-2 (SSC-1).

METHODS

Each SSC was photographed *in situ* and its coordinates were recorded using a Trimble Juno GPS to be integrated within the ArcGIS 9.2 spatial database of Preah Khan. The SSC was unearthed and weighed with a Pesola Macro-Line Spring Scale. Cake size varied considerably from 5 to 32 kg with a mean mass of 14.6 kg. Each SSC was cut in half using a water-cooled industrial band saw to expose charcoal samples and left to air-dry. After photographing the cut faces of each cake (Fig. 5), charcoal fragments were individually collected for analysis. In cases where charcoal was not visible in the cut section a rock hammer was used to create new faces. No species identification was carried out on these samples to test the old wood problem due to a lack of comprehensive botanical references available in Cambodia.

One or more fragments of charcoal were recovered from each of the fifteen slag cakes for AMS ¹⁴C dating. A total of twenty two in-slag charcoal were initially pre-treated using the acid-alkali-acid (AAA) method. The pre-treated samples were then converted to graphite (Hua et al. 2001) for ¹⁴C analysis using the STAR AMS Facility at ANSTO (Fink et al. 2004) with a typical precision of ≤0.4% (1σ). Seven samples from Phlau Kuk Dek (OZN859 and OZN860), Sre Tomnup (OZN876 and OZO389) and Trapeang Ach Dek Toch (OZN871 and OZO390), and Boeng Kroam (OZN858) were destroyed during the pretreatment due to small sample size and were therefore not dated in this study (see Table 1). Multiple charcoal from SSC collected on the

east moat of the Bakan G3E (SSC-14 and SSC-15) were used to test for fuel age variation within each individual cake.

Atmospheric ^{14}C over tropical regions in Southeast Asia is a result of Northern and Southern Hemisphere air-masses mixing via the monsoon systems (Hua et al. 2004, 2012; Hua and Barbetti 2007). As a consequence, a regional ^{14}C offset for Thailand, which is not far from our study sites in Cambodia, was reported (Hua et al. 2004). The weighted average of ^{14}C age offset between Thailand and the internationally ratified radiocarbon calibration curve for the Southern Hemisphere SHCal04 (McCormac et al. 2004) for the period AD 1620-1780 is -21 ± 6 yr (with Thailand being younger). We therefore used the OxCal program version 4.1.3 (Bronk Ramsey 2009) and SHCal04 curve with an offset of -21 ± 6 yr for age calibration of our ^{14}C dates.

RESULTS AND DISCUSSION

Fifteen AMS radiocarbon results were obtained from twelve SSC (Table 1). This represents seven separate slag concentrations from the banks of four different Angkorian reservoirs. Initial comparison of the calibrated ages (Fig. 7) shows a possible temporal range of ‘late’ iron production activities between the early 11th to early 17th centuries. This range can be reduced by eliminating old wood/aged fuel from slag cakes with multiple dates (e.g., SSC-15 and SSC-14). Median ages for the three samples from SSC-15 (OZN862, OZO799 and OZN863) represent the earliest dates of any concentration in Preah Khan. However since OZN862 and OZO799 are at least 100 years older than OZN863, the former two charcoal fragments must represent old wood or aged fuel. Barring the unlikely occurrence that this SSC was included in a later smelt, the youngest date for SSC-15 is the mid 13th century. A similar disparity is noted within SSC-14 (OZO798 and OZO861) where the latest production date for the cake is the late 15th century. Based on the calibrated 2-sigma age ranges, the refined overall date range within Preah Khan is between the early 13th to mid or late 17th centuries.

TABLE 1 HERE.

FIGURE 7 HERE

The length of time that a site may have been used to make or work metal can be further restricted by comparing results of different cakes from a single site (G3E; TOM-1; BK-2) and from different mounds in the same site (BK-4). The two cakes from G3N (SSC-14 and SSC-15) are separated by roughly 225 years while the two dates from TOM-1 (SSC-2 and SSC-3) are 145 years apart. At BK-2, the upper SSC (OZN877, SSC-7) was indeed the youngest while the middle cake (OZN878, SSC-8) and the lower cake (OZN879, SSC-9) yielded the oldest date and the middle date from the site, respectively. This is contrary to their relative ‘stratigraphic’ position on the bank. As with TOM-1, the range between the cakes at BK-2 is approximately 160 years. Based on this preliminary data the concentration does not appear to pre-date construction of the reservoir. Mound A (OZN881, SSC-11) and B (OZO391, SSC-12) at BK-4 show the most dramatic temporal range being over three centuries apart. Given the large age range it seems unlikely that this could represent old wood or curated fuel. The AMS dates, albeit representing only surface collections, provide strong evidence for the duration of use and reuse of particular locations for metal-related activities.

The spatial distribution of sites sampled within Preah Khan extends over 100 hectares with a maximum distance of 3 km between BK-3 to TOC-2. By comparing the spatial histories derived from the in-slag charcoal (see Table 2) there is no coherent pattern of sequential use within the enclosure walls. Boeng Kroam, the largest Angkorian feature with evidence of metallurgy, has three concentrations with different ages clustering between the late 13th to late 15th centuries as well as one as recent as the 17th century. What is significant, both methodologically and in relation to the history of production, is that contemporary metallurgy was carried out at other sites far removed from Boeng Kroam (e.g., OZN872 at TOM-1 and OZN881 at BK-4 around late 13th century; OZN877 at BK-2 and OZN861 at G3E around early 14th to late 15th centuries; OZN879 at BK-2 and OZN874 at SRT-4 in early 15th century). One potential explanation is that production was limited by fuel sources in the immediate vicinity. Re-use of a particular location decades – or hundreds – of years after the initial production may be directly related to re-growth of local forest. In short, there is no apparent spatial patterning in the use of particular sites across Preah Khan; instead the water infrastructure features were used and re-used at different times with gaps in activity of at least a century or more. From a technical perspective, the shared tuyère morphology from each of the SSC concentration sites strongly supports the presence of a continuing tradition throughout this time range. It should be noted that the Preah Khan tuyères are markedly different from those identified with 19th and 20th century Kuay sites in the Phnom Dek region (Hendrickson and Pryce 2011) and the massive examples associated with early or pre-Angkorian production sites in the Chhep region of northeast Cambodia (Thuy 2010) and from Ban Kruad in northeast Thailand (Yoopom 2010:99).

TABLE 2 HERE.

Returning to the primary objective of this paper, the in-slag results suggest three periods of late or ‘terminal’ production within Preah Khan: late 13th to early 14th (OZN878 at BK-2; OZN881 at BK-4; OZN873 at TOM-1), early-mid 15th (OZN879 at BK-2; OZN874 at SRT-4; OZN872 at TOM-1), and late 15th centuries (OZN877 at BK-2; OZN861 at G3E; OZN880 at BK-3). The fact that widely separated sites share similar time ranges supports the argument that the in-slag charcoal represent the period of industrial activity rather than old wood or aged fuel. The historical implications of these results are quite significant as it shows that iron production definitely took place *after* the last masonry construction in Preah Khan, most likely during the mid-13th century. The regular appearance of most slag concentrations on top of the Angkorian water infrastructure, the lack of associated Angkorian period ceramics and the discovery of imported blue-on-white sherds support this argument. From an historical perspective, the SSC are not coincident with the important Khmer expansions between the 11th to 13th centuries. By contrast, eight of the AMS dates point to late or terminal production around the end of the Angkorian period in the 14th and 15th centuries. This period saw the Khmer frequently engage in numerous conflicts with neighbors such as Ayutthaya and culminated in the sacking of Angkor in 1431 (Cœdès 1968:236-237). It is tempting to suggest a direct correlation between the need for iron during times of conflict and the sites within Preah Khan however this cannot be corroborated without more extensive investigation into the slag concentrations to test their time-depth. Instead these results provide new information about the nebulous time period following the completion of the last known masonry construction in Angkor likely in the late 13th century

(see Finot 1925; Provost-Roche 2010:81), the last stone inscription written in the early 14th century (Billard and Eade 2006) and the events of the 15th to 17th centuries currently reconstructed from accounts based on the Royal Cambodian Chronicles (Mak 1981; Khin 1988). Combined with the recent dates obtained from jar burials in the Cardamom Mountains (see Beavan et al. 2012) this research continues to expand our knowledge of the important era following the collapse of the state-level institutions at Angkor.

CONCLUSION

Based on the results obtained from Preah Khan it is argued that in-slag charcoal from SSC provide a viable data set for obtaining an initial range of late iron production across a large site or region. Old wood or aged fuel, the perpetual bugbear of archaeologists, can never be eliminated from this discussion however its impact can be minimized through the process of taking multiple samples from each cake and selecting metallurgy sites that are considerably spaced apart in the landscape. Since the location of an iron producing/working site is normally constrained by proximity to fuel rather than mineral source (Rostoker and Bronson 1990:184), a cluster of similar dated sites such as those sampled within Preah Khan likely represents a period of metallurgical activity or, at the very least, wood collection. This patterning would not be visible had we focused on one or two sites.

From this pilot study there appear to be three ‘terminal’ periods of metallurgical activities each post-dating the final phase of masonry temple construction. While older iron production sites will no doubt be identified, we must now be cautious about interpreting the role of Preah Khan as an iron production centre during the peak expansionist periods of the Khmer Empire. By correlating the in-slag dates with tuyère measurements from the same sites it appears that the technological tradition at Preah Khan may have remained consistent from the mid-13th through to the early 17th centuries. More significantly, the study of metallurgical sites has demonstrated a much more lengthy and dynamic history than that derived solely from the evidence of two and a half centuries of masonry architecture and a single epigraphic source. While the results do not provide evidence of iron production during the peak of the Angkorian Empire they offer new insight into economic activities within the Middle Period, an era in Cambodian history that has received very little archaeological attention.

Radiocarbon dating of in-slag charcoal cannot replace chronometric approaches such as archaeomagnetism and TL at well-excavated sites. Given that hundreds of slag concentrations have now been identified across Cambodia (Living Angkor Road Project 2008; Living Angkor Road Project 2009; Thuy 2010; Im 2011) the dating of in-slag samples collected from the surface of multiple sites offers an effective and reliable method for obtaining a ‘terminal’ history on a regional scale that can be used to target specific sites for intensive excavation.

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REFERENCES

- Abrahamsen N, Holm Jacobsen B, Koppelt U, De Lasson P, Smekalova T, Voss O. 2003. Archaeomagnetic Investigations of Iron Age Slags in Denmark. *Archaeological Prospection* 10:91-100.
- Albrecht G, Haidle MN, Chhor S, Heang LH, Heng S, Heng T, Mao S, Sirik K, Som S, Thuy C et al. . 2000. Circular Earthwork Krek 52/62: Recent Research on the Prehistory of Cambodia. *Asian Perspectives* 39:20-46.
- Aymonier É. 1900. Le Cambodge: I. Le royaume actuel. Paris: Ernest Leroux. 477 p.
- Bachmann H-G. 1982. The Identification of Slags from Archaeological Sites. London: Institute of Archaeology.
- Beavan N, Halcrow S, McFadgen B, Hamilton D, Buckley BM, Shewan L, Sokha O, Fallon S, Miksic J, Armstrong R et al. . 2012. Radiocarbon Dates from Jar and Coffin Burials of the Cardamom Mountains Reveal a Previously Unrecorded Mortuary Ritual in Cambodia's Late- to Post-Angkor Period (15th–17th Centuries AD). *Radiocarbon* 54:1-22.
- Ben-Yosef E, Tauxe L, Levy TE. 2010. Archaeomagnetic Dating of Copper Smelting Site F2 in the Timna Valley (Israel) and its implications for the Modelling of the Ancient Technological Developments. *Archaeometry* 52(6):1110-1121.
- Billard R, Eade JC. 2006. Dates des inscriptions du pays khmer. *Bulletin de la École française d'Extrême-Orient* 93:395-428.
- Bronk Ramsey C. 2009. Bayesian analysis of radiocarbon dates. *Radiocarbon* 51:337-360.
- Bruguier B, and Phann N. 2005. Carte archéologique du Cambodge. MCBA-EFEO. Phnom Penh: Commission Nationale du Cambodge pour l'UNESCO.
- Cœdès G. 1968. The Indianized states of Southeast Asia. Honolulu: University of Hawaii Press.
- Crew P. 2002. Magnetic Mapping and Dating of Prehistoric and Medieval Iron-working Sites in Northwest Wales. *Archaeological Prospection* 9:163-182.
- Cunin O. 2004. De Ta Prohm au Bayon. Analyse comparative de l'histoire architecturale des principaux monuments du style du Bayon. Nancy: L'Institut National Polytechnique de Lorraine. 482 p.
- Duffosé M. 1934. Monographie des peuplades Kouys du Cambodge. *Extrême Asie* 83:553-568.
- Dupaigne B. 1987. Les maitres du fer et du feu. Étude de la metallurgie du fer chez les Kouys du nord du Cambodge, dans le contexte historique et ethnographie de l'ensemble Kmer [Ph.D]. Paris: Ph.D. 659 p.
- Eliyahu-Behar A, Yahalom-Mack N, Shilstein S, Zukerman A, Shafer-Elliott C, Maeir AM, Boaretto E, Finkelstein I, and Weiner S. 2012. Iron and bronze production in Iron Age IIA Philistia: new evidence from Tell es-Safi/Gath, Israel. *Journal of Archaeological Science* 39(2):255-267.
- Evans D. 2007. Putting Angkor on the Map: A New Survey of a Khmer 'Hydraulic City' in Historical and Theoretical Context. Sydney: University of Sydney. 245 p.
- Fink D, Hotchkis M, Hua Q, Jacobsen G, Smith AM, Zoppi U, Child D, Mifsud C, van der Gaast H, Williams A et al. . 2004. The ANTARES AMS Facility at ANSTO. *Nuclear Instruments and Methods in Physics Research B* 223-224:109-115.

- Finot L. 1925. Inscriptions d'Angkor XI. Temple de Mangalārtha. Angkor Thom. *Bulletin de l'École française d'Extrême-Orient* 25:393-406.
- Godfrey-Smith DI, Casey JL. 2003. Direct thermoluminescence chronology for Early Iron Age smelting technology on the Gambaga Escarpment, Ghana. *Journal of Archaeological Science* 30(8):1037-1050.
- Greenfield HJ, Miller D. 2004. Spatial patterning of Early Iron Age metal production at Ndondondwane, South Africa: the question of cultural continuity between the Early and Late Iron Ages. *Journal of Archaeological Science* 31(11):1511-1532.
- Hendrickson M. 2010. Historic routes to Angkor: Development of the Khmer road system (9th to 13th centuries CE) in mainland Southeast Asia. *Antiquity* 84(324):480-496.
- Hendrickson M, Penny D, Cooke C, Pryce TO, Hua Q. 2010. Industries of Angkor Project: Preah Khan of Kompong Svay (Bakan). December 2009 Field Report. Sydney: University of Sydney.
- Hendrickson M, Pryce TO. 2011. Industries of Angkor Project: Iron Kuoy Project. March 2010 Field Campaign Report. Sydney: University of Sydney. p 49.
- Hendrickson M, Pryce TO, Hua Q, Phon K, Chan S. 2012. Industries of Angkor Project: Preah Khan of Kompong Svay (Bakan). December 2010 Field Report. Sydney: University of Sydney.
- Hua Q, Barbetti M. 2007. Influence of atmospheric circulation on regional $^{14}\text{CO}_2$ differences. *Journal of Geophysical Research* 112, D19102, doi:10.1029/2006JD007898.
- Hua Q, Barbetti M, Levchenko VA, D'Arrigo RD, Buckley BM, Smith AM. 2012. Monsoonal influence on Southern Hemisphere $^{14}\text{CO}_2$. *Geophysical Research Letters* 39, L19806, doi:10.1029/2012GL052971.
- Hua Q, Barbetti M, U. Z, Fink D, Watanasak M, Jacobsen GE. 2004. Radiocarbon in tropical tree rings during the Little Ice Age. *Nuclear Instruments and Methods in Physics Research B* 223-224:489-494.
- Hua Q, Jacobsen GE, Zoppi U, Lawson EM, Williams AA, Smith AM, McGann MJ. 2001. Progress in radiocarbon target preparation at the ANTARES AMS Centre. *Radiocarbon* 43:275-282.
- Im S. 2011. Ancient Iron Industry Project at Khvao: The Excavation Campaign 2010 and Preliminary Report. 20th ICC Technical Meeting. Siem Reap, Cambodia. June 8-9. p 13.
- Jacques C, Lafond P. 2004. L'Empire Khmer. Cités et sanctuaires Vth-XIIIth siècles. Paris: Fayard.
- Khin S. 1988. Les Chroniques royales du Cambodge: II. Paris: EFEO.
- Killick D, Fenn T. 2012. Archaeometallurgy: the study of preindustrial mining and metallurgy. *Annual Review of Anthropology* 41:559-575.
- Living Angkor Road Project. 2008. Living Angkor Road Project Phase II Progressive Report, October 2007-March 2008. Nakon Nayok: Chulachomklao Royal Military Academy. p 200.
- Living Angkor Road Project. 2009. Nakon Nayok: Chulachomklao Royal Military Academy.
- Lunet de Lajonquière É. 1902. Inventaire Descriptif des Monuments du Cambodge. Paris: Ernest Leroux.
- Mak P. 1981. Chroniques royales du Cambodge (de 1594 à 1677). Paris: École Française d'Extrême-Orient.

- Mauger H. 1939. Prah Khan de Kompon Svay. *Bulletin de l'École française d'Extrême-Orient* 39(2):197-220.
- McCormac FG, Hogg AG, Blackwell PG, Buck CE, Higham TFG, Reimer PJ. 2004. SHCal04 Southern Hemisphere calibration, 0–11.0 cal kyr BP. *Radiocarbon* 46:1087–1092.
- Moura J. 1882. Fabrication du fer chez les Cuois du Compong-Soai. *Revue d'Ethnographie* 1:435-437.
- Nitta E. 1997. Iron-smelting and salt-making industries in northeast Thailand. In: Soejono RP, and Welch DJ, editors. *Indo-Pacific Prehistory: The Chiang Mai Papers*. 16 ed. Chiang Mai, Thailand: Indo-Pacific Prehistory Association. Australian National University.
- O'Reilly D, von den Driesch A, Voeun V. 2006. Archaeology and Archaeozoology of Phum Snay: an Iron Age Cemetery in Northwest Cambodia. *Asian Perspectives* 45(2):188-211.
- Park J-S, Rehren T. 2011. Large-scale 2nd to 3rd century AD bloomery iron smelting in Korea. *Journal of Archaeological Science* 38(6):1180-1190.
- Parmentier H. 1935. La construction dans l'architecture khmère classique. *Bulletin de l'École française d'Extrême-Orient* 35:243-311.
- Pottier C. 1999. Carte Archaeologique de la Region d'Angkor. Zone Sud [Unpublished Ph.D]. Paris: UFR Orient et Monde Arabe, Université Paris III - Sorbonne Nouvelle. 3 Vols p.
- Pottier C, Llopis E, Soutif D, Tan C, Chevance J-B, Kong V, Chea S, Demeter F, Bacon A-M, Bouchet N et al. . 2005. Mission Archéologique franco-khmère sur l'aménagement du territoire Angkorien. Campagne 2005. Rapport. MAFKATA. Siem Reap: École Française d'Extrême-Orient. Centre de Siem Reap - Angkor. p 133.
- Powell A.J. 2003. Archaeomagnetic dating of furnaces and other features excavated at Hagg End and Ewecote, Bilsdale, North Yorkshire. Department of Archaeological Sciences. Bradford: University of Bradford. p 86.
- Provost-Roche L. 2010. Nouvelles perspectives pour la connaissance de l'histoire de la fin de la période angkorienne au Cambodge: notes sur quelques bas-reliefs de la galerie intérieure du Bayon. *Arts Asiatiques* 65:79-94.
- Rasmussen KL, Rahbek U, Voss O. 2006. Radiocarbon dating of the iron production in furnaces in Jutland. *Journal of Danish Archaeology* 14:127-138.
- Reinecke A, Vin L, Seng. S. 2009. The first golden age of Cambodia: excavation at Prohear. Bad Langensalza Embassy of the Federal Republic of Germany Phnom Penh.
- Rostoker W, Bronson B. 1990. Pre-Industrial Iron. Its Technology and Ethnology. Philadelphia: Univ Museum Pubns. 232 p.
- Stern P. 1965. Les monuments Khmers du style du Bayon et Jayavarman VII. Paris: Presses Universitaires de France.
- Thuy C. 2010. Report on New Discovery of Forges. Chep-Mluprey 10th to 16th January 2010. Proposal to Inventory Prehistoric Sites in Cambodia. Phnom Penh: Royal Academy of Cambodia. p 78.
- Yoopom I. 2010. The study of ancient iron-smelting furnaces at Ban Khao Din Tai, Ban Kruad district, Buriram province [MA]. Bangkok: Silpakorn University.

Figure Captions

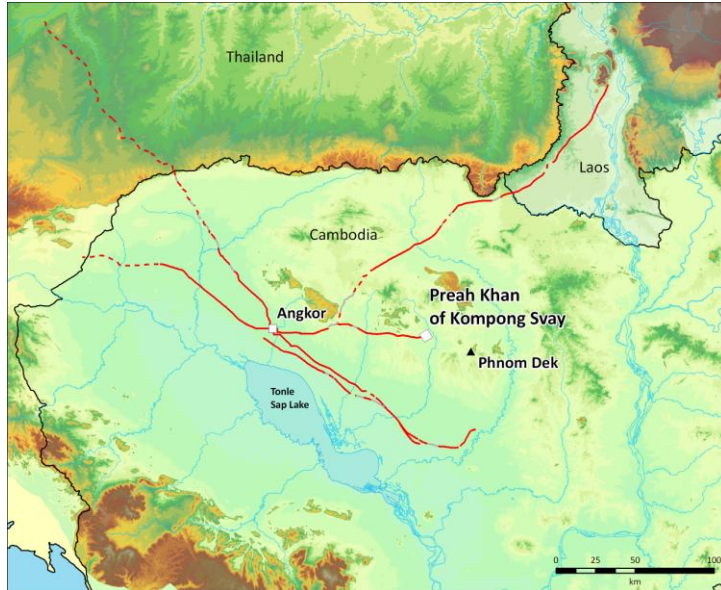


Figure 1. Map of Cambodia showing location of sites discussed in the text and distribution of the Angkorian Khmer road system



Figure 2. Evidence of iron objects used by the Angkorian Khmer. Clockwise from upper left: bas relief depicting Khmer soldiers fighting with metal-tipped spears and other weapons; Dvarapala carving with a metal sword; iron architectural crampon from the East Gopura of the Royal Palace in Angkor Thom; sandstone naga balustrade showing recessed T-shaped holes that once held a metal crampon to ensure stability of adjacent sandstone blocks

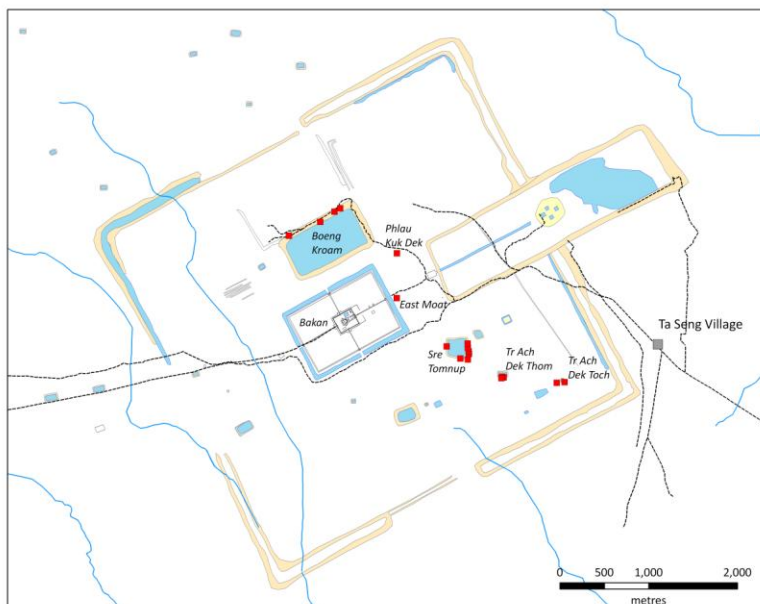


Figure 3. Map of Preah Khan showing location of known slag concentrations

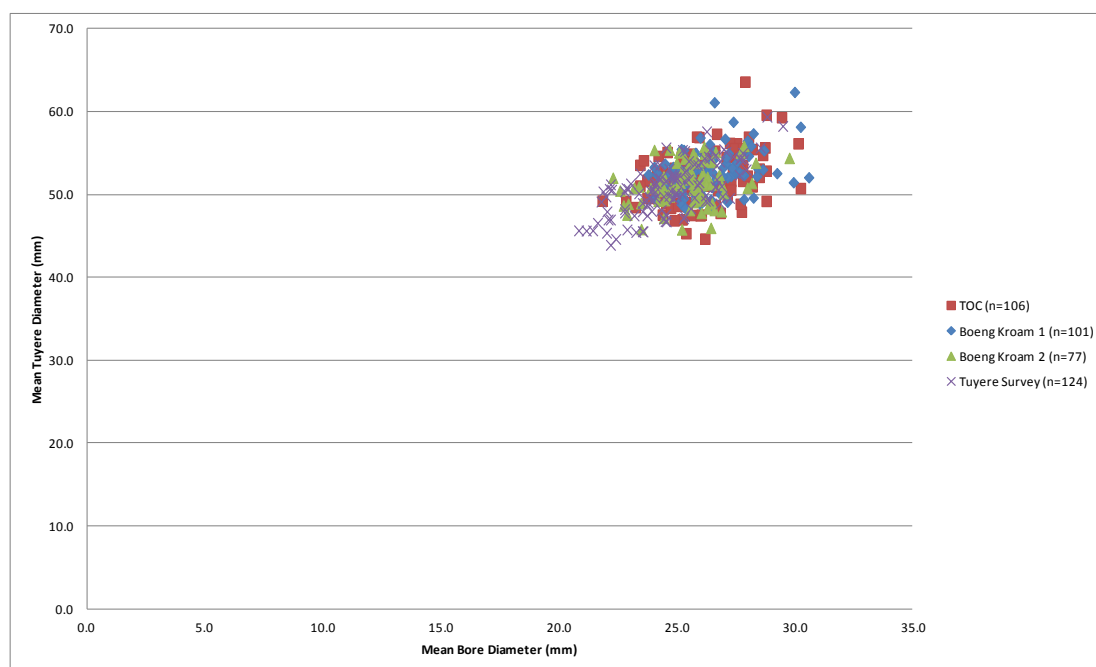


Figure 4. Comparison of tuyère dimensions from excavated sites (BK-1; BK-2; TOC) and surface samples (Tuyère Survey) within Preah Khan.



Figure 5. Example of a surface slag cake. Left – complete cake *in situ*. Right – section of same cake showing locations of charcoal trapped inside the slag matrix

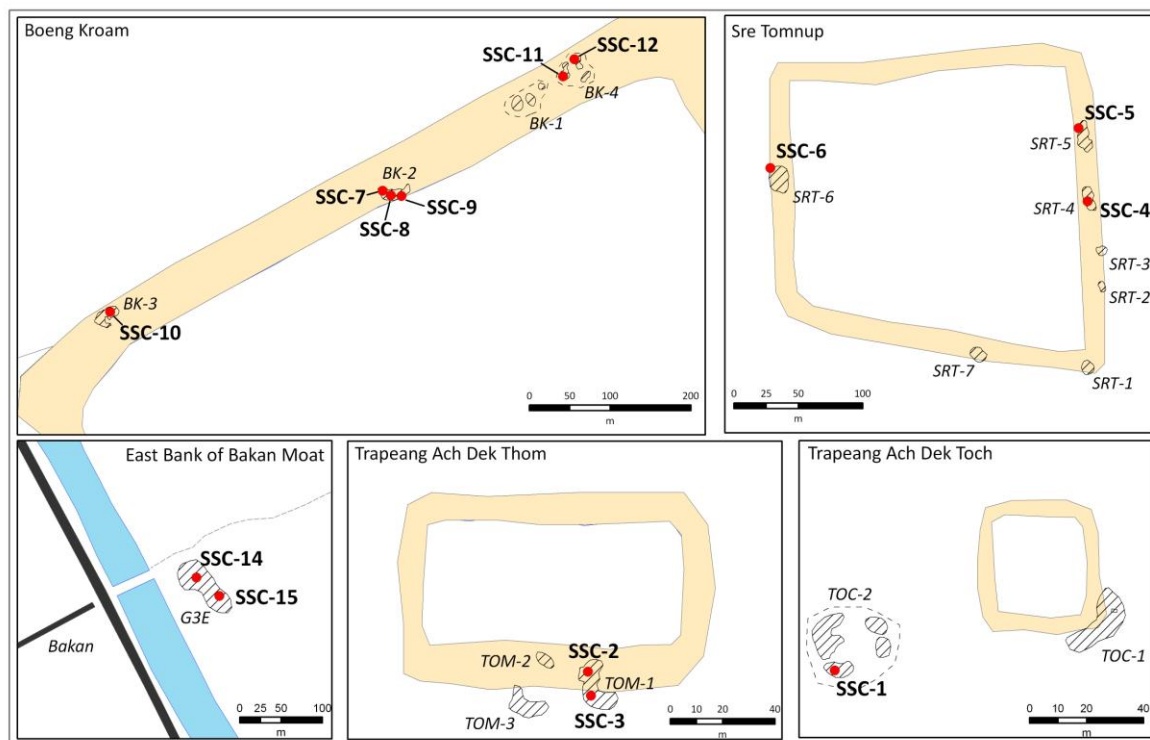


Figure 6. Locations of Surface Slag Cakes (SSC) collected for radiocarbon dating within Preah Khan. Note – for this paper SSC were not collected from the excavated sites at BK-1 and TOC-1

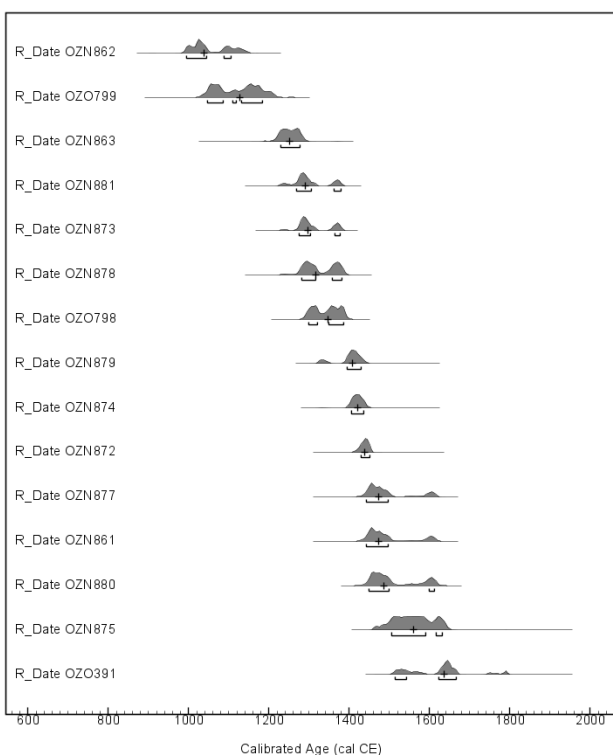


Figure 7. Calibrated radiocarbon ages of in-slag charcoal from Preah Khan

Lab ID	Sample ID	SSC	Site	Feature	$\delta^{13}\text{C}$ (‰)	^{14}C Age (BP)		Calibrated Age (cal CE) *					
						Mean	1 σ	1 σ age range		2 σ age range		median	
OZN881	SHB-11-BK-4-1	SSC-11	BK-4	Boeng Kroam	-25.6	735	35	1265	1380	1225	1385	1290	
OZO391	SHB-12-BK4-2-1	SSC-12			-24.8	275	30	1510	1670	1505	1800	1635	
OZN858**	SHB-12-BK-4				-	-	-	-	-	-	-	-	
OZN880	SHB-10-BK-3	SSC-10	BK-3		-25.7	415	35	1445	1615	1435	1625	1485	
OZN877	SHB-7-BK-2-top	SSC-7	BK-2		-27.9	430	35	1440	1500	1425	1625	1475	
OZN878	SHB-8-BK-2-middle	SSC-8			-26.0	705	40	1280	1385	1270	1395	1315	
OZN879	SHB-9-BK-2-bottom	SSC-9			-25.6	560	35	1390	1430	1320	1445	1410	
OZN859**	SHB-13-Encl-4-1	SSC-13	PKD		Phlau Kuk Dek	-	-	-	-	-	-	-	-
OZN860**	SHB-13-Encl-4-2					-	-	-	-	-	-	-	-
OZN862	SHB-15-G3E-S-1a	SSC-15	G3E	East moat of the Bakan	-24.0	1025	30	990	1110	985	1145	1035	
OZO799	SHB-15-G3E-S-1b				-25.8	930	35	1045	1185	1035	1210	1125	
OZN863	SHB-15-G3E-S-2				-28.6	790	35	1225	1280	1205	1295	1250	
OZO798	SHB-14-G3E-N-2	SSC-14			-24.7	665	30	1295	1390	1290	1395	1345	
OZN861	SHB-14-G3E-N				-24.9	430	35	1440	1500	1425	1625	1475	
OZN875	SHB-5-SRT-5	SSC-5	SRT-5	Sre Tomnup	-25.8	335	35	1500	1635	1475	1645	1560	
OZN874	SHB-4-SRT-4	SSC-4	SRT-4		-24.3	535	30	1405	1435	1395	1450	1420	
OZN876**	SHB-6-SRT-6	SSC-6	SRT-6		-	-	-	-	-	-	-	-	
OZO389**	SHB-6-SRT-6-1				-	-	-	-	-	-	-	-	-
OZN873	SHB-3-TOM-1S	SSC-3	TOM-1	Trapeang Ach Dek Thom	-25.2	725	30	1275	1380	1230	1390	1295	
OZN872	SHB-2-TOM-1	SSC-2			-26.1	485	25	1425	1450	1410	1460	1440	
OZN871**	SHB-1-TOC-2	SSC-1	TOC-2	Trapeang Ach Dek Toch	-	-	-	-	-	-	-	-	
OZO390**	SHB-1-TOC-2-2				-	-	-	-	-	-	-	-	-

Note:

* - Age calibration was performed using OxCal program version 4.1.3 and SHCal04 data set with a small offset of -21 ± 6 yr. All ages were rounded off to the nearest multiple of five.

** - Sample did not survive during the pre-treatment

Table 1. Calibrated AMS results from SSC collected at Preah Khan

Angkorian Feature	Site	AMS (n)	10th	11th c.			12th c.			13th c.			14th c.			15th c.			16th c.			17th c.			18th		
			late	early	mid	late	early	mid	late	early	mid	late	early	mid	late	early	mid	late	early	mid	late	early	mid	late	early	mid	late
Boeng Kroam	BK-1	9														*	*										
	BK-2	3											*			*		*									
	BK-3	1															*										
	BK-4	2												*								*					
Bakan Moat	G3E	5		x	x	x	x	x	x		*			*			*										
Sre Tomnup	SRT-4	1														*											
	SRT-5	1																*									
Trapeang Ach Dek Thom	TOM-1	2										*				*											

x = old wood

* = median age for each sample

Table 2. Comparison of 2-sigma date ranges from individual slag concentrations at Preah Khan