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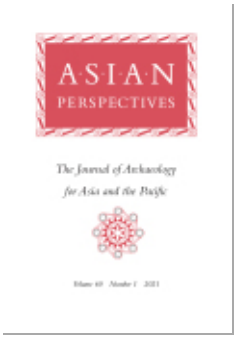

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ABSTRACT

The production of Khmer roof tiles underwent dramatic technical and stylistic changes during the pre-Angkorian (ca. C.E. 500–802) and Angkorian (C.E. 802–1431) periods. It has long been assumed that the regional expansion of Khmer political power and its intensive interregional trade and interactions with China during the Angkorian period were crucial factors in this transformation. This article presents the first integrated study on the production sequence and usage of Khmer roof tiles in Angkor (Cambodia) and its provincial centers in Northeast Thailand. Furthermore, it evaluates the extent to which the Khmer people made technological and social choices as they embraced new ceramic manufacturing technologies. Combining archaeological excavation findings with comparative analyses of two regions, this study argues that the contact the Khmer had with China motivated Khmer to begin roof tile production for elite residences and temples. The subsequent Khmer local architectural tradition is defined by distinctive production techniques of Khmer roof tiles and ancient ranking systems for roof tile usage in the greater Angkorian region. This article makes important observations about the specific choices that were made in the process of emulating the roof tile tradition. Roof tile manufacture and usage were ways for Khmer rulers to establish the legitimacy of their polities in mainland Southeast Asia. KEYWORDS: Mainland Southeast Asia, Angkor, China, roof tiles, kiln production, technological and social choices, exchange, emulation.

INTRODUCTION

Khmer roof tile production underwent dramatic change in terms of technical and stylistic traditions during the pre-Angkorian (ca. C.E. 500–802) and Angkorian (C.E. 802–1431) periods. "Roof tiles" is a collective term for baked clay roofing units designed to cover the tops of buildings and provide roof protection (Shen 2006:210). This study combines archaeological findings from recent excavations of roof tile production sites to summarize data on the production sequencing and usage of Khmer roof tiles in Angkor (Cambodia) and its provincial production centers in Northeast Thailand. More significantly, this work evaluates the extent to which the Khmer made technological and social choices to embrace new ceramic manufacturing technologies, especially by emulating Chinese cultural practices and architectural traditions. They

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selected between two or more options in a technological or social system with an understanding of their social consequences (Lemonnier 1993:7–8; van der Leeuw 1993:240). By combining recent excavation findings, historical accounts, an ethnographic study, and comparative analyses of two regions, this article aims to improve current understanding of the distinctiveness of Khmer roof tile production traditions and usage in the greater Angkorian region. Furthermore, it provides new insights on the impact of the Chinese on Khmer royalty during the ninth to fifteenth centuries.

According to a Chinese account, the pre-Angkorian Kingdom of Chenla, which covered modern Cambodia, South Laos, Northeast Thailand, and South Vietnam, lasted from approximately C.E. 500 to 800. Its capital was in Sambor Prei Kuk in what is now the Kampong Thom Province of Cambodia. The Angkorian period (C.E. 802–1431) is the name given to the time of the Khmer Empire, which ruled a broad territory in mainland Southeast Asia including Cambodia, Northeast Thailand, South Vietnam, Laos, and Tenasserim in Myanmar. Its capital was in Angkor in the Siem Reap Province of Cambodia (Chen et al. 2002; Stark 2004:101). The term "Khmer" refers to a culture that existed in this area over many centuries including the Angkorian period.

Based on the typological attributes of Khmer roof tiles, previous studies have highlighted the foreign cultural influences that shaped Khmer roof tile production traditions. During the pre-Angkorian period, the Khmer absorbed some Indian elements in their roof tile production, then incorporated Chinese influences during the Angkorian period. The Indian elements are most noticeable in the unglazed earthenware ceramic rectangular flat tiles with troughs and two holes that have been discovered at the sites of Angkor Borei (ca. 500 B.C.E.–C.E. 500) in Takeo Province, Cambodia; Oc Eo (ca. 200 B.C.E.–C.E. 700) in Vietnam's Mekong Delta; and Sambor Prei Kuk (the late sixth to early seventh centuries) in Kampong Thom Province, Cambodia (Fig. 1). Comparing tiles excavated from Oc Eo, Angkor Borei, and Sambor

Fig. 1. Pre-Angkorian unglazed earthenware flat tiles from Sambo Prei Kuk (left and center) and Angkor Borei (right) (Source: Lun 2009).

Prei Kuk with those from Kedah (ca. C.E. 600–700) in Malaysia, Palembang (C.E. 650–1377) in South Sumatra, Java (ca. C.E. 700–1300) in Indonesia, and other sites located in Vietnam, researchers concluded that Chinese architectural forms and ceramic tile decorations had become the prototypes for Khmer tiles after the Funan (ca. first to sixth centuries) and Chenla (ca. late sixth to early ninth centuries) periods (Boisselier 1966:363–366; Dumarçay 1973:43–44; Lun 2009; Malleret 1959:298–300; Manguin 2006*a*:288, 2006*b*; Rooney 1984:81; Stark 2003:216).

The manufacture of roof tiles during the Angkorian period can be divided into two phases, with Phase 1 dated from the ninth to twelfth centuries and Phase 2 dated from the twelfth to fifteenth centuries. Crucial factors in architectural transformation during the Angkorian period have long been assumed to include regional expansion, inter-regional trade, and exchange with China as the Khmer sought to increase political power (Boisselier 1966; Dumarçay 1973; Manguin 2006*a*; Parmentier 1935; Rooney 1984; Silice and Groslier 1924–1926; Stark 2004) (Table 1). As a critical indicator of Khmer imperial expansion, roof tiles are an excellent entry point for understanding the extent to which the Khmer made decisions to embrace new ceramic manufacturing technologies, especially Chinese cultural practices and architectural materials.

An analysis of Khmer roof tiles also provides essential information on regional stylistic variations and local preferences during the pre-Angkorian and Angkorian periods (Dumarçay and Royère 2001; Talbot 2001:118). Regional variation in the use

TABLE 1. MAJOR CHARACTERISTICS OF KHMER ROOF TILE PRODUCTION DURING THE ANGKORIAN PERIOD

CHINESE DYNASTIC PERIODS	KHMER SOCIO-POLITICAL DEVELOPMENTS	ROOF TILE PRODUCTION DEVELOPMENTS
Phase 1 Early Angkorian Period (ca. C.E. 802–1100)		
Tang (C.E. 618–907)	Imperial expansion by Suryavarman I (C.E. 1002–1050)	Unglazed roof tiles found and produced in Northeast Thailand and Angkor
Five Dynasties and Ten Kingdoms (C.E. 907–960)	Inter-regional trade with China increases during Suryavarman II (C.E. 1113–1150)	Green, light yellow, and brown glazed tiles appear in Angkor
[Nanhan Kingdom (C.E. 917–971)]	Khmer tile production for elite residences and temples begun	Thnal Mrech kiln develops as Khmer ceramic production center
Northern Song (C.E. 960–1127)		"Coiling on mold" method used for curved and flat tiles
		3-part, cross-draft kilns: fire box, firing chamber, vent
Phase 2 Later Angkorian Period (ca. C.E. 1100–1431)		
Southern Song (C.E. 1127–1279)	More Chinese ceramics imported to Angkor	Simplified curved tile with eave tile notches produced at Torp Chey kiln
Yuan (C.E. 1271–1368)	Intensive interregional exchange between Khmer polity and China to mid-15th c.	Brown glazed tiles most common type
Ming (C.E. 1368–1644)		Molding with textile pattern increases tile-forming efficiency
		4-part, cross-draft kilns: fire box, firing chamber, fire trenches, vent

Fig. 2. Map of sites with roof tile assemblages mentioned in text (Southeast Asia base map from *d-maps.com*, URL: d-maps.com/carte.php?num_car=69&lang=en).

Table 2. Angkorian Period Excavated Kiln Sites with Documented Roof Tiles in Cambodia and Thailand

Site	Province	Date C.E.	Number of Kilns	Kiln Excavated	Types	Glazes	Other Products	References
Early Angkorian Period (ca. C.E. 802–1100)								
Thnal Mrech (TMK)	Siem Reap	800–1200	2	TMK01, 02	Aa, Ab, Ba, Bb, C, D	Green, yellow, brown, grayish white, unglazed	Box, urn, bowl, bottle, basin, jar	Chhay & Chap 2002; Miksic et al. 2009; Tabata & Chhay 2007; Wong 2010
Tani (TK)	Siem Reap	800–1100	26	TKA6, B1	Aa, Ab, Ba, C, D	Green, yellow, grayish white, unglazed	Box, urn, bowl, bottle, basin, jar	Agency for Cultural Affairs et al. 2000; Aoyagi & Sasaki 2007; Marriner et al. 2018
Khok Lin Fa	Buriram	900–1200	30	Khok Lin Fa	Ba	Green	Box, urn, bowl, bottle, jar, dish, figurine, bell	Fine Arts Department 1989; Khwanyue 1985
Khok Khi Lek	Buriram	900–1200	80	Khok Khi Lek	Aa	Unglazed	Bowl, lamp	Khwanyue 1985
Sarsei (SSK)	Siem Reap	1000–1200	29	SSKA11	Aa, Ba, C, D	Green, yellow, unglazed	Box, urn, bowl, bottle, basin, jar	Sok 2003; Tin 2003
Khnar Po (KPK)	Siem Reap	1000–1200	19	KPKA6, A11, B1, C3	Aa, Ba, C, D	Unglazed	Box, urn, bottle, basin, jar	Marriner et al. 2018; Ōsaka 2009
Later Angkorian Period (ca. C.E. 1100–1431)								
Torp Chey (TC)	Siem Reap	1100–1300/1400	15	TCK02	Aa, Ba, Ac, C	Brown, unglazed	Bottle jar, animal figurine, semi-circular object	Ea 2013, 2015

of unglazed tiles in Northeast Thailand indicates that the Angkorian polity expanded into provincial districts and influenced local architectural preferences. Based on Dumarçay's (1973) classification of Khmer roof tiles, Pottier (1994), Talbot (2001), and Marui (2005) extended and analyzed information on the new roof tile forms found at Prasat Phanom Wan and Prasat Hin Phimai in Northeast Thailand and Banteay Kdei in Angkor Thom. The unglazed roof tiles excavated at these three sites suggested that different roof tile sequences may have emerged in Angkor compared to Northeast Thailand (Fig. 2, Table 2). The type, shape, and manufacturing techniques used in the production of Khmer roof tiles in South Vietnam and Cambodia that were of particular interest included: the type of glazed and unglazed roof tiles unearthed in Angkor Thom; the eave tiles bearing human or animal motifs on the surface of the Angkor Wat Western Causeway; and various types of curved, flat, and eave tiles discovered in Roluos, Siem Reap (Choi and Pottier 2015; Hanatani 2004; Hirano 2005; Lun 2009; Marui 1999:179).

Most Khmer structures were built of wood rather than stone during the Angkorian period, with roof tiles an important addition to the construction of traditional Khmer wooden beams. The dwellings depicted in the bas relief of the Bayon Temple suggest that ceramic tiled roofs topped wood-pillared structures at Angkor. Khmer monuments, including stone buildings starting in the tenth century C.E., were also roofed with tiles supported by beams. Such ceramic roofs have been relatively understudied compared to the stone architecture of Angkor (Dumarçay and Royère 2001:101, 11). Our research aims to fill this gap by comparing and analyzing the physical attributes, manufacturing technologies, roofing methods, and ranking systems of Khmer and Chinese roof tiles. These four components were selected for our investigation because of the availability of relevant archaeological research and historical accounts. With reference to the theoretical *chaîne opératoire* (the series of operations that transforms a substance from a raw material into a manufactured product) concept, this article not only focuses on how Khmer roof tiles were made but also draws on Chinese roof tile production as the main model for studying how the Khmer made and used roof tiles during the Angkorian period. This approach allows us to shed light on the transformation of specific styles of roof tiles from the pre-Angkorian to the Angkorian period and how new production sequences reflected the technological and social choices of the Khmer.

KHMER TILE PRODUCTION SITES IN CAMBODIA AND NORTHEAST THAILAND

According to integrated analyses of survey and excavation discoveries, Angkorian period unglazed and glazed roof tile manufacturing sites were all located in Siem Reap Province in Cambodia and Buriram Province in Northeast Thailand (Desbat 2011; Ea 2010). This article relies on roof tile studies from 23 sites and excavations at 12 kilns in these provinces. The kilns in Cambodia were located near the Royal Palace of Angkor and along the road to Phimai (Fig. 3, Table 2). Roof tile artifacts were found at the kilns in Siem Reap (Ea 2010, 2015) (Table 3). Khmer kilns found in Northeast Thailand include: the Ban Sawai kiln in Surin; Ban Baranae, Ban Tanon Noi, Nai Jian, and Ban Kruat kilns in Buriram; and Ban Ya Kha kiln in Nakhon Ratchasima Province. These kilns produced ritual and utility vessels such as cooking pots, covered boxes, urns, and

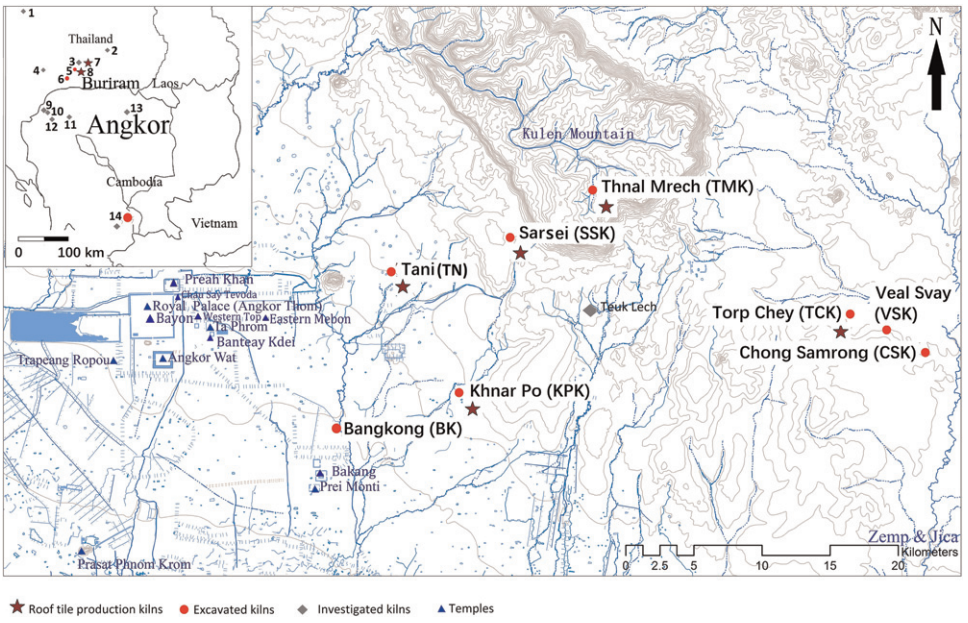

Fig. 3. Distribution of ceramic production sites mentioned in text in Angkor (main map) and Cambodia and Northeast Thailand (inset map): (1) Ban Ya Kha; (2) Ban Sawai; (3) Ban Thanon Noi; (4) Ban Baranae; (5) Ban Kruat; (6) Nai Jian; (7) Khok Khi Lek; (8) Khok Lin Fa; (9) Lboek Svay; (10) Lboek Ampil; (11) Svay Khmau; (12) Torp Siem; (13) Kan Tourt; (14) Cheung Ek (maps created by Zemp & Jica, used courtesy of APSARA Authority).

water jars (Brown 2000; Brown et al. 1974; Chandavij 1990; Chanthawit 1995; Khwanyue 1985; Rooney and Smithies 1997). According to archaeological data from Authority for the Protection and Management of Angkor and the Region of Siem Reap (APSARA Authority) and international research teams in Angkor, not all of the kilns in Cambodia produced roof tiles. Some kilns, such as the Bangkong kiln in Siem Reap, Cambodia, specialized in producing daily and ritual-use vessels. However, around 26 percent of the total ceramic assemblage from Thnal Mrech kiln number two (TMK02) consisted of roof tiles (Miksic et al. 2009:12–15).

Only very limited and fragmentary evidence has been recorded about the procurement of raw materials for Khmer roof tiles (Ea 2010; Grave et al. 2017:19–20). Most researchers have suggested that the raw materials for Khmer roof tile production were acquired near the kilns. That is, artisans made use of locally available raw material sources and used various types of clay to produce roof tiles. For instance, the clay found at the Thnal Mrech kiln was derived from weathered sandstone and contained iron leached from upland soils while clay from the Torp Chey kiln contained high concentrations of iron and laterite fragments. The clay colors ranged from white and light yellow to red, gray, and darker shades. Similarly, ceramic workshops and kilns were built at the site of clay deposits in China. Tang brick and tile bun kilns excavated in the early layer of the Hanyuan Hall of the Daming Palace site in Shaan Xi dated to the seventh century C.E. and those from the Sui-Tang Palace in Luoyang in Henan were dated to C.E. 605–731 (Xiong 1995:127; Zhongguo 1997:368).

Table 3. Sites with Khmer Kilns and Roof Tile Assemblages

SITE	PROVINCE	COUNTRY	DATE	TYPE	GLAZE	REFERENCES
Pre-Angkorian Period (ca. C.E. 500–802)						
Angkor Borei	Takeo	Cambodia	ca. 500 B.C.E.–C.E. 500	Flat	Unglazed	Lun 2009; Stark 2003
Oc Eo	An Giang, Mekong Delta	Vietnam	ca. 200 B.C.E.–C.E. 700	Flat	Unglazed	Hirano 2005; Malleret 1959; Manguin 2006*a*, 2006*b*
Sambor Prei Kuk	Kampong Thom	Cambodia	ca. late 500–early 600	Flat	Unglazed	Lun 2009
Angkorian Period (C.E. 802–1431)						
Bakang	Siem Reap	Cambodia	ca. 800	Aa, Ba, C, D		Choi and Pottier 2015
Ban Non Sawang and Kok Kloy	Buriram	Thailand	ca. 900–1200	C, D		Chanthawit 1995
Prasat Phanom Wan	Buriram	Thailand	ca. 1000	Aa, Ba, C, D	Unglazed	Pottier 1994
Prasat Hin Phimai	Buriram	Thailand	ca. 1000–1100	Aa, Ba, C, D	Unglazed	Talbot 2001
Royal Palace	Siem Reap	Cambodia	ca. 1000–1200	Aa, Ba, C, D	Green, unglazed	Cort 2000; Lun 2009; Pottier 1994
Western Causeway, Angkor Wat	Siem Reap	Cambodia	ca. 1100–1200	Aa, Ba, C, D	Unglazed	Marui 1999
Northern Library of Bayon	Siem Reap	Cambodia	ca. 1100–1200		Green, unglazed	Naho 2000
Takeo	Siem Reap	Cambodia	ca. 1000	Aa, Ba	Green, unglazed	Zhongguo 2015
Banteay Kdei	Siem Reap	Cambodia	ca. 1100	Aa, Ba, C, D	Unglazed	Marui 2005
Chau Say Tevoda	Siem Reap	Cambodia	ca. 1100–1200	Aa, Ba	Green, unglazed	Qiao & Li 2000
Preah Khan	Siem Reap	Cambodia	ca. 1100–1200	Aa, Ba, C, D	Green, unglazed	Chhan 2000
Western Top	Siem Reap	Cambodia	ca. 1100–1200	Aa, Ba	Brown, unglazed	Nara 2012; pers. comm. Sok 2007
Teuk Leuh kiln	Siem Reap	Cambodia	–	–	Brown, unglazed	Ea 2010, 2015

ANGKORIAN PERIOD ROOF TILE TYPES

Khmer Roof Tiles

The first time glazed tiles were made in the Khmer area was during the Angkorian period (ca. ninth to twelfth centuries). There were four primary types: (A) curved tiles; (B) flat tiles; (C) eave tiles; and (D) finials (Fig. 4). Curved tiles had a semi-cylindrical cross-section with a pointed protrusion on the interior (Fig. 4Aa). The flat tiles were semi-rectangular with a ridge applied to the exterior surface (Fig. 4Ab). Each eave tile had two parts: a body consisting of a curved tile and a head that was produced from a mold. In one type of eave tile, a vertical clay strip was applied to the back of the tile head, possibly to strengthen the upright head (Fig. 4C). Eave tiles had decorative motifs such as lotus buds, Buddhist shrines, and guardian faces. There were two types of lotus bud shapes, one with a flat base and one with two notches at the base (Fig. 4C). Finally, the Khmer made finial tiles. Each finial had a pointed baluster tip and a curving base that functioned as a hip join; finials were affixed to the top of the roofline (Fig. 4D). The protrusions on curved tiles (Fig. 4Ab), ridges on flat tiles (Fig. 4Ba), and notches in some of the eave tiles (Fig. 4C) appear to have been designed to interlock rows of roof tiles to prevent slippage. Such designs are not found in the Chinese roof tiles of this period, however (Cort 2000:98; Ea 2013, 2015; Miksic et al. 2009). Archaeologists also discovered some unique roof tile shapes at the Thnal Mrech (TMK, Thnal Mrech means "pepper road") and Tani (name of the local village) kilns dated from the ninth to twelfth centuries C.E. These included light yellow glazed flat tiles with two ridges on their exterior surfaces (from both kilns), a tile with an oblique angle shape on its edge (from TMK), and a curved tile with a curved angle (from Tani).

Curved tiles and eave tiles might have been made together in one work area because curved tiles often constituted the bodies of eave tiles. These two types of tiles may gradually been favored because they simplified production, whereas finials required more steps in production because they incorporated both coiling and molding techniques. New archaeological findings from Torp Chey kiln number two (TCK02) dated from the twelfth to fifteenth centuries C.E. support this trend. Flat, curved, and eave tiles have been discovered at this site, but no finial has yet been found. The shape of the curved tiles integrates characteristics of earlier curved tiles with the notch feature of eave tiles by adding notches to the underside (Fig. 4Ac). Thus it is possible that Khmer roof tile production became simplified over time from the early Angkorian to the later Angkorian period.

Khmer roof tiles can be further classified as glazed stoneware, unglazed stoneware, and unglazed earthenware according to whether the tile is glazed and the porosity of clay materials. Visual observation suggests that unglazed earthenware clay tile bodies were porous, orange in color, and not very vitrified (Fig. 5C). Comparing the types of roof tiles found at different Khmer ceramic production sites suggests that TMK may have been the first kiln site established to satisfy the demands of Khmer royalty and officials for roof tiles of the highest quality and of different varieties (Wong 2010:71–73). For example, most of the roof tiles from TMK02 (currently stored by APSARA Authority) are flat glazed stoneware tiles with body clay colors in gray, grayish white, or orange and are glazed light yellow or light green. Curved tiles, eave tiles, and finials come both glazed and unglazed, but where glazed use the same colors as the flat stoneware tiles. Unglazed stoneware roof tiles are usually found in two colors:

Fig. 4. Types of roof tiles from Khmer kiln sites: (Aa–Ab) curved tiles (TMK 02); (Ba–Bb) flat tiles (TMK 02); (Ac) curved tile from Torp Chey (TCK02); (C) eave tile with two notches (TMK02); (D) finial from Thnal Mrech (TMK02) (photos by Wong Wai Yee Sharon and Ea Darith).

gray or orange (Fig. 4D, Fig. 5 top). This color scheme may have resulted from the use of different clay colors and the firing atmosphere in the kilns. Brown glazed stoneware flat, curved, and eave tiles were also unearthed at TMK. The brown glaze is a lighter

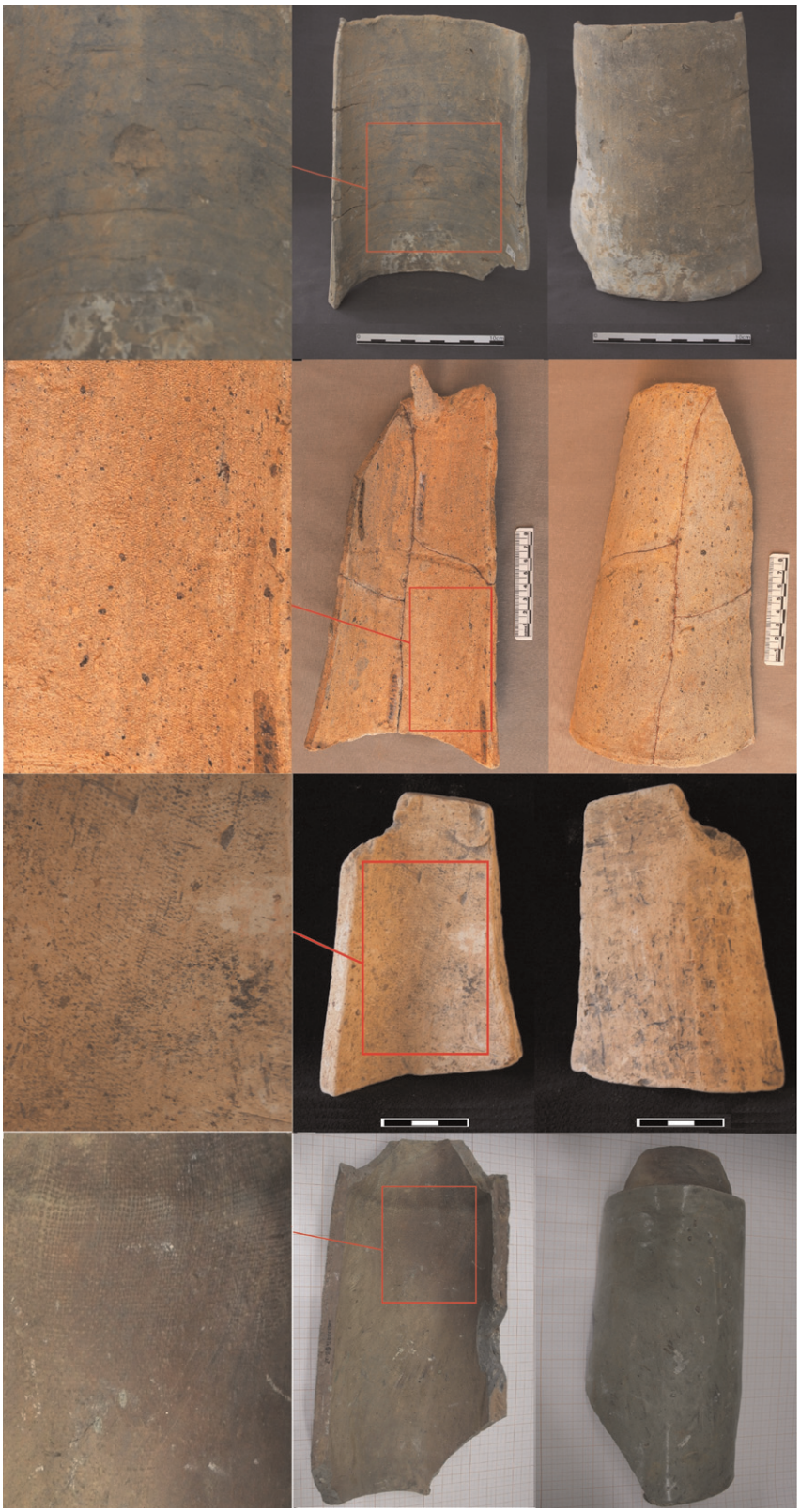

Fig. 5. Forming vestiges in tile interiors: (top) Aa type curved tile with coiling vestiges from Thnal Mrech (TMK02); (top middle) Ac type curved tile with textile impression from Torp Chey (TCK02); (bottom middle) B type flat tile with textile impression from Western Top Temple; (bottom) A type curved tile with textile impression from Nanhan Royal Palace (photos by Wong Wai Yee Sharon and Ea Darith).

and shinier color than used on brown glazed stoneware from Buriram. In 2008, Sok reported similar brown stoneware at the Sarsei kiln site; this was the first time that curved and flat tiles with limited brown glaze application had been found. The Tani and Sarsei kilns manufactured green-glazed stoneware, unglazed stoneware, and earthenware roof tiles, with unglazed stoneware types predominating amongst the unearthed artifacts. The Khnar Po kiln mainly produced unglazed stoneware and earthenware roof tiles. Brown glazed stoneware tile is the most common type of roof tile from the Torp Chey kiln (Ea 2015; Sok 2008:40; Wong 2010:66–67) (Fig. 4Ac).

Chinese Roof Tiles

Unglazed flat tiles have been discovered in palace sites dating to the early Western Zhou period (1100–771 B.C.E.). By the late Western Zhou period, all the basic roof tile categories were being produced. Chinese roof tiles are classified into four major types: curved tiles, flat tiles, eave tiles or semi-circular tile-ends, and ridge tiles. Chinese curved roof tiles were cut from a long semi-cylindrical tile with a curved surface (Fig. 6A). The Chinese flat tile has a quarter- cylindrical section, but is slightly wider at one end than the other (Fig. 6B). There are two major types of eave tiles: tile-ends and drip tiles. The structure of the tile-end is similar to that of the Khmer eave tile, with a tile head joined to a curved tile body. The shape of the Chinese tile-end is different from that of the Khmer eave tiles, however. Most of the tile-ends dating from the Northern and Southern Dynasties period (C.E. 420–589) to the Qing dynasty (C.E. 1644–1911) are circular. The head of the tile-end is joined to the end edge of a curved tile (Fig. 6Cb 1–4). The drip tile is a quarter cylinder-shaped tile with a petal-shaped drip at its edge (Fig. 6Ca). The shapes of tile ends and drip tiles were designed to direct rainwater to the ground.

Ridge tiles was used to build a ridge on the roof for protective and ornamental purposes. Some buildings had covers in the form of animal heads (i.e., of a sea monster, dragon, or lion) that fit at the end of the ridge (Guo 2002:26–28, 77–78). Different kinds of animal-head ridge tile covers have been unearthed at the Nanhan Royal Palace in Guangzhou, which was the capital of the Nanhan (Southern Han) Kingdom; these were dated to C.E. 917–971 (Fig. 6Da–Dd). Nanhan was one of ten kingdoms that emerged after the collapse of the Tang Dynasty (C.E. 618–907); its territory covered modern-day Guangdong, Guangxi, Hainan, and part of northern Vietnam (Chen 2010:255–270)

Three major types of Chinese roof tiles—unglazed red tiles, gray tiles, and polished gray tiles—were created using the techniques for red pottery, gray pottery, and black pottery, respectively (Zhongguo 1993:434, 448). The craftsmanship of the polished gray tiles was similar to that of the black pottery, and a technique known as "carbon-impregnation" was used to give the tile its black color. The color was obtained through complete combustion of wormwood, straw, and pinewood. This was followed by a dense smoke treatment in the final stages of the firing process. The carbon particles in the smoke condensed and permeated the tile surface. Higher quality tiles with lower porosity were subsequently produced. This type of black tile was usually used for roofing buildings that housed members of the highest social classes (Guo 2002:65, 70). The black glazed mandarin ducks and lotus pool tile-end from the Nanhan official hall is a typical example of this black tile (Fig. 6Cb2). Khmer potters did not emulate these surface treatments and firing techniques, however.

Fig. 6. Types of roof tiles from Nanhan Royal Palace: (A) curved tile; (B) flat tile; (Ca, Cb1–4) eave tiles, (Ca) "Dishui" (drop of water), (Cb1–4) "Wadang" (tile-end) in black glazed mandarin ducks and lotus pool, green glazed monster head, unglazed double phoenix, and brown glazed lotus flower motifs; (Da–Dd) ridge tiles in the form of dragon and animal heads (photos by Wong Wai Yee Sharon).

FORMING METHODS IN THE MANUFACTURING SEQUENCE

Comparing the methods used to form Chinese roof tiles with the methods used by Khmer potters suggests that Khmer artisans may have emulated Chinese forming techniques. There were three techniques used in the creation of Chinese roof tiles: coiling, slab work, and molding. Usually, these techniques were combined with tile-making processes.

The "coiling on mold" method was invented between the Western Zhou and Western Han period (202 B.C.E.–9 C.E.) (Zhongguo 1993:447–448; Li 1996:313–314). There were two mold shapes for coiling: cylindrical and trough-shaped. The cylindrical mold was used for making both curved and flat tiles. First, the clay bar was

prepared and coiled on the cylindrical mold. After that, the exterior surface of coiled clay bars was smoothed using a cloth made with water and a clay anvil wrapped with a cord. They were then removed from the mold, and the cylindrical biscuit was cut into halves (for curved tiles) or quarters (for flat tiles). Cord patterns were found on each tile's interior surface.

Chinese trough-shaped flat tiles were created using a similar method, but a piece of woven mat was placed on the mold before the coiling process. After coiling the clay bars on the woven mat, the coiled clay bars were melted together by a beating process which strengthened the clay wall. The head of a tile-end was made using a mold with different engraved patterns and then joined by hand to its body. Evidence for the forming process of the eave tile ends—a ceramic mold for eave tiles with an engraved pattern—was discovered in the Tani kiln site dated from ninth to twelfth centuries (Fig. 7 top left and right).

Fig. 7. Forming and firing tools and wasters of Khmer roof tiles: (top left and right) ceramic mold for eave tile from Tani (TN); (bottom left) waster of stacked curved tiles from Thnal Mrech (TMK02); (bottom right) clay slab stand for vertically stacked tiles from Thnal Mrech (TMK02) (photos by Wong Wai Yee Sharon and Ea Darith).

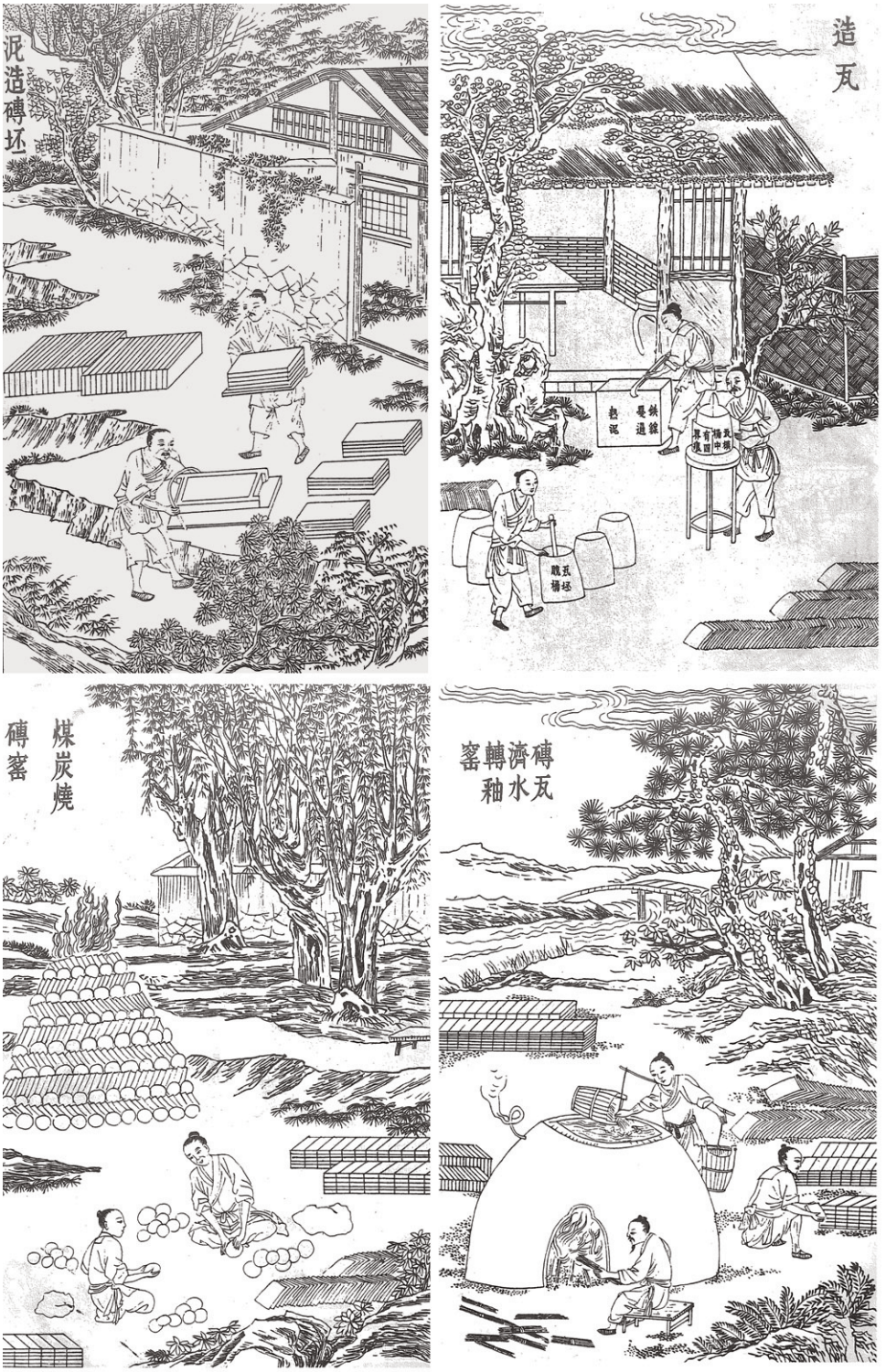

Fig. 8. Drawings from *Tiangong kaiwu* [Creations of Nature and Man] of Chinese tile and brick production sequences in the seventeenth century: (top left) producing brick by mud; (top right) making tiles by barrel-molding technique; (bottom left) using coal to fire bricks in the kiln; (bottom right) pouring water on the top of the kiln to create an oxygen-deficient environment (from Song 1998:225–228).

The "barrel" (or "tub") molding method emerged during the early Eastern Han period (C.E. 25–220). This was an important innovative step in Chinese tile-making techniques. Chapter 15 of the *Yingzao fashi* (the State Building Standards), a book written by Li Jie in C.E. 1103 (Liang 2015:321–322), mentions the barrel molding method. This method greatly improved the quality and quantity of tile-making by speeding up the tile-making forming process, applying regular shapes and thicknesses to the tile biscuit, and smoothing both the exterior and interior surfaces (Zhongguo 1993:447–448; Guo 2002:93; Liang 2015:321–322). Further archaeological evidence is necessary to determine whether the barrel molding method was used in the Angkorian area.

Chinese tile-making saw some further improvements during the Ming dynasty (C.E. 1368–1644). The *Tiangong kaiwu* (Creations of Nature and Man), a book written by Song Yingxing in C.E. 1637 (Song 1998), mentions the "cylindrical molding" method, which combined slab work with molding techniques. Once the sliced clay layer is lifted from the cylindrical core mold, it is wrapped around a cylindrical inner tube. The tub has four vertical strips, which are distributed on the surface to create four tiles. When the tile biscuit is slightly dry, it is removed from the mold; the four tile pieces fall apart naturally (Guo 2002:93; Song 1996:136). The cylindrical molding method was originally derived from the barrel-molding technique and was popular from the beginning of the Ming dynasty, and can be seen in the drawings reproduced in Figure 8 (top right).

The textile used in the "coiling on mold" often left an impression on the inside of the tiles. Such textile impressions provide evidence that Khmer potters may have adopted this technological innovation from the Chinese to produce both curved and flat tiles. There are obvious traces of coiling in Khmer tiles from the Angkor kilns, especially on the interior side of unglazed tiles. The tiles were first formed in a wooden mold with two rectangular indentations. The indentations were sprinkled with ash then the potter sprinkled ash on the curved tile mold and placed a flat tile on top. Next, the tile biscuit was smoothed and shaped with wettened fingers to get the tile biscuit to slide off without distorting its shape (Perryman 2000:139, 140, 143). Khmer potters seem to have applied slip paste, ash, or some other substance with a wooden paddle in order to flatten the edges of the coils and grooves and smooth the tile surface.

Interestingly, textile impressions were not found on the interior of tiles from the TMK02 and Tani kilns dating to the ninth to twelfth centuries (Fig. 5 top). A comparison of tiles from TMK with those from the Nanhan Royal Palace site in Guangzhou dated to the tenth century demonstrated that textile impression traces were clearly noticeable only in the flat and curved Chinese tiles (Fig. 5 bottom). A textile pattern was found on the interior of curved Khmer tiles found at the Torp Chey kiln, which dates to the twelfth to fourteenth or fifteenth centuries (Fig. 5 top middle). Textile impressions were also discovered on flat tile sherds from the fifteenth-century layer of the Western Top Temple site in Angkor Thom (Fig. 5 bottom middle). The textile impressions in Khmer tiles were not as deep as the traces in Chinese tiles, however (pers. comm. Sok Keo Sovannara 2007). Nevertheless, the evidence suggests that Khmer roof tile production underwent some technological advancement in forming methods by the later Angkorian period (ca. C.E. 1300–1400). The Khmer potters may have emulated some Chinese techniques such as slab work and molding in order to make their tile production processes more efficient.

GLAZING IN THE MANUFACTURING SEQUENCE

Glazing is one of the most important surface treatments for roof tiles. The purpose of glazing is to waterproof and improve the appearance of tiles. Khmer roof tiles are classified by glaze color as brown, light yellow, or green. Findings from the TMK and Sarsei kilns indicate that high quality yellow and green glaze was applied to the surface of unglazed tiles that were grayish-white, dark gray, red, or orange. The tiles were glazed either by pouring or dipping.

The comparison of Khmer glazed tiles with Chinese tiles presented another major discovery. Whereas the top and bottom sides of flat Khmer tiles were usually fully glazed, only the exposed parts of Chinese tiles were glazed. Only half of the upward surface of flat tiles and the three-quarters of the downward surface of curved tiles were glazed (Fig. 4Ba, Fig. 6A,B). It is believed that Chinese potters used a wooden ladle to pour glaze onto tiles. This has been deduced by reference to the glazing techniques demonstrated by potters from the Glass Glazed Tiles Company in Liuli Village in Beijing, China, as seen by the first author (Fig. 9). This also demonstrates that the aims and standards for roof tile production in the two ceramic industries were different. Increasing the efficiency and quantity and reducing the cost with standardized work quality were major goals of Chinese roof tile production, even for roof tiles supplied to the palace (Zhongguo 1993:448). By contrast, archaeological evidence from TMK suggests that one of the major aims of Khmer roof tile production was to produce glazed ceramic tiles that were high in quality and limited in quantity (Tabata and Chhay 2007).

Fig. 9. Production sequence for glazing tiles in Liuli Village, Beijing: (top left) pouring glaze from a ladle; (top right) drying flat tiles; (bottom left) stacking tiles vertically in a kiln; (bottom right) chopping out ceramic separators between tiles (photos by Wong Wai Yee Sharon).

Table 4. Comparison of Roof Tile Production Methods and Traditions from Ninth to Fifteenth Centuries

PRODUCTION SEQUENCES/ TRADITIONS	ANGKOR, CAMBODIA	CHINA
Raw material sources	Various	Various
Tile types	Curved, flat, eave, finial	Curved, flat, eave, ridged
Body colors	Gray, grayish white, orange, red, dark gray	White, yellowish white, grayish white, red, gray, black
Glaze colors	Light green, light yellow, brown	Light green, green, yellow, black
Eave tile decorations	Connected pearls, lotus flower, lotus petal, lotus bud, Buddhist shrine, guardian face	Connected pearls, lotus flower, lotus petal, Buddhist image, monster face, double phoenix
Forming methods	Coiling on mold, molding	Coiling on mold, slab work, barrel molding
Glazing methods	Dipping	Dipping and pouring
Stacking methods	Vertical stacking by clay slab separators	Vertical stacking by ceramic separators
Kiln types	Cross-draft	Dragon, bun, big, down-draft, glass-glaze
Other products fired in kiln	Box, urn, bowl, bottle, basin, jar	Bricks

Limited information is available regarding how Khmer roof tiles were stacked in the firing structures. However, some slab-shaped kiln furniture that was used for stacking tiles has been excavated at the TMK, Tani, and Sarsei kilns (Tabata 2005) (Fig. 7 bottom right). As seen in Chinese production, Khmer tiles may have been placed in a vertical position and packed with other ceramic vessels, such as boxes, urns, bowls, bottles, basins, and jars, in the same kiln for mixed firing (Fig. 7 bottom left and right, Fig. 8, Fig. 9 bottom left).

Khmer potters used cross-draft kilns for roof tile production. TMK02 was an elongated oval kiln that measured 8.2 m in length and 2.1–2.7 m in width and had three parts: fire box, firing chamber, and vent (Miksic et al. 2009:7). The Torp Chey kiln (TCK02) was an elongated oval kiln that measured 21.45 m long and 3.2 m wide and had four parts: fire box, firing chamber, fire trenches, and vent (Ea 2015:55, 60).

In China, roof tile production was derived from pottery production technology rather than porcelain-making techniques. During the Sui-Tang period (C.E. 581–907), apart from the brick and tile kilns that specialized in roof tile firing, it was quite popular to use dragon kilns to fire bricks and tiles together with other ceramic vessels; a dragon kiln is a cross-draft kiln type with an upward slope that provides a strong draft for firing (Xiong 1995:127). During the Song dynasty, "big kilns" were specially created for firing bricks and tiles; they were 7.2 m in height and 5.8 m in diameter and included a door (1.8 × 0.8 m). The other kilns specified in *Yingzao fashi* were all down-draft kilns; these permitted hot air to flow up and down before being released through a chimney (Liang 2015). After the formation of the tile body, ceramic tiles underwent a firing process in the kiln; they were subjected to very high heat levels in order to harden the tile body and create the surface glaze (Liang 2015:324). *Tiangong kaiwu* mentions another type

of kiln called the "glass glaze" kiln (Song 1998). Bricks and tiles which had already been fired once and coated with a glazing mixture were fired on the second day. On the third day, the kiln was opened to cool. Then tiles were unloaded on the fifth day (Guo 2002:30, 70). The glass-glazed roof tiles produced in modern Beijing are similar in terms of tile stacking and firing techniques to those of the Ming period. Unglazed tiles were usually fired once and glazed tiles twice in China. However, it seems that both glazed and unglazed tiles were fired only once in the Khmer roof tile production process.

Table 4 summarizes the comparisons between Khmer and Chinese tile types, body and glaze colors, forming methods, kilns, and other techniques discussed so far.

USAGE

Historical and archaeological evidence suggests that Khmer roof tiles were used in constructing the royal palace, major royal family halls, residences of royal family members and higher officials, and religious structures such as temples in Angkor and Northeast Thailand. Bas-reliefs on Khmer temples show roof tiles being placed over wooden beams.

The distribution and usage of different types of tiles vary. Curved and flat tiles with oblique angles have recently been discovered at the TMK and Tani kiln sites in Angkor. The "guardian face" eave tiles and flat-headed curved tiles used on temple roofs have only been found in sites in Northeast Thailand. The unglazed guardian face and "Kala" face (glorious face) eave tiles were produced in the Buriram kiln. Ban Non Sawang and Kok Kloy in the Prakonchai district of Buriram Province in Northeast Thailand may have been other centers of roof tile production, as archaeologists have discovered "lotus petal" eave tiles and finials in these areas (Chanthawit 1995:68, 71, 73).

Although archaeological sites in the Angkorian region have yielded Khmer roof tiles only in limited quantities, the roof tiles found in Angkor and Northeast Thailand can be compared based on shape, glaze, and type. It is possible that glazed roof tiles were mainly used in Angkor. A French team excavated 1500 glazed eave tiles from the Royal Palace site at Angkor Thom (Cort 2000:98; Pottier 1994). Although Chau Say Tevoda and Preah Khan Temple in Angkor Thom yielded some tile shards with light green glaze, only unglazed tiles have been discovered at Prasat Phanom Wan and Prasat Hin Phimai. It seems that the unglazed type forms the largest portion of the total roof tile assemblage.

These findings suggest that glazed and unglazed roof tile types may have had specific meanings related to a ranking system for roof tiles, imperial expansion, and regional variation under the Khmer polity. This is supported by a historical document written by Zhou Daguan (C.E. 1266–1346) in 1296 entitled *Zhenla fengtuji jiaozhu* 真腊风土记校注 [Notes on the Customs of Cambodia]. Chapter 2 on the "Royal Palace" and chapter 5 on "The three religious groups" (i.e., Brahmins, Buddhists, and Saivas) are most pertinent (Zhou 2006). In chapter 2, Zhou compares tiles used on different buildings within the royal compound:

> The Royal Palace and the official buildings and homes of the nobles all face eastward. The Royal Palace stands to the north of the Golden Tower and the Bridge of Gold; starting from the gate, its circumference measures nearly one and a half miles [2.4 km] . . . . The tiles of the central building are made of lead; other parts of the palace are covered with ceramic tiles that are yellow in color. (Zhou 2006:64, 67–68)

This record indicates that Khmer royalty and major officials were permitted to roof their family shrines and major halls with specific kinds of tiles depending on rank. In chapter 5, Zhou mentions that places of worship such as Buddhist and Saiva temples also had tiled roofs. Archaeological findings demonstrate that bricks were used in large quantities in the construction of Brahmin temples during the Angkorian period. In the Royal Palace, tiles used in the central dwelling were made of lead and other parts of the buildings used ceramic tiles, which were yellow in color. Referencing Groslier's (1921) study, Chinese historian and archaeologist Xia Nai (Zhou 2006:67–68) suggests that the "lead tiles" may have been wrapped in tin foil, while "yellow ceramic tiles" probably used a yellow glaze. However, Pottier (1997:189–191) suggested that the lead tiles found near the Royal Palace at Angkor were formed exactly like the terracotta ones and that their positioning must have been carried out in the same way (see also Dumarçay and Royère 2001:10). Zhou did not specify the material or the color of the tiles used on the Brahmin, Buddhist, and Saiva temples. However, archaeologists have discovered brown glazed and unglazed curved and flat tiles at the Western Top temple (ca. twelfth to thirteenth centuries) in Angkor Thom (Nara 2012:150–151).

Hundreds of glazed eave tiles have been excavated from the Royal Palace site at Angkor. The eave tiles are most clearly associated with elite buildings and royal residences. The glazed tiles not only functioned to waterproof buildings, they also filled an aesthetic purpose. The use of high-temperature calcium wood ash glaze for glazing the yellow and light green glazed tiles was noticeable in the TMK02 samples (Wong 2010:136, 163). In Prasat Hin Phimai and Prasat Phanom Wan in Northeast Thailand, all of the excavated roof tiles were unglazed and the tiles were relatively smaller and narrower compared to the average tile sizes from the Angkorian temples (Cort 2000:98; Talbot 2001:115–117).

Based on Zhou's description of roofing materials and the archaeological evidence, it seems that at least four kinds of roofing materials were being used in Angkor: lead tiles, yellow glazed tiles, unglazed tiles, and straw. We suggest that these types were related to a social ranking system involving the royal court, state officials, religious institutions, and common people. Regarding this ranking system, one thing can be affirmed: neither rich nor poor commoners were allowed to put tiles on their house roofs in Angkor. Only

Table 5. Classification of Roofing Materials on Khmer Dwellings in the Customs of Cambodia

Identity	Place	Dwelling	Roofing Material
King	Royal Palace	Central dwellings	Lead tiles wrapped in tin foil
		Other dwellings	Yellow glazed tiles
Royal relatives and highest officials	Residence	Family temples and main halls	Tiles
		Other dwellings	Straw thatch
Religious	Brahmin	Temples	?
	Buddhist		Roof with tile
	Saiva		Roof with tile
Common people	Residence		Thatched with straw

officials' houses, family temples, and main halls were allowed to have tile roofs; other dwellings, and common people's residences were probably thatched with straw (Table 5).

When the materials and the colors of the tiles used in Khmer buildings are compared to those used in China, we find that the underlying roofing principles are similar between the two traditions. As mentioned in *Yingzao fashi*, a Chinese ranking system was reflected in its architecture. The Song formulated standards for three building categories (i.e., hall, major hall, and house) and there were seven grades on the quality scale for single or multi-story constructions intended for halls, palaces, gatehouses, subsidiary buildings, ordinary houses, and military regimental buildings (Guo 2002:30, 56). A famous Chinese painting of the twelfth century, entitled *Qingming shanghetu* [Along the River during the Qingming Festival], depicts urban life in the Song capital Bianjing (now Kaifeng in Henan). Painted by Zhang Zeduan (C.E. 1085–1145), the painting shows roofs constructed of tile, straw, or a combination of materials. Only the major aristocratic houses were roofed with tiles, while all the commoners' dwellings were covered with straw or a combination of tile and straw (Zhongguo 1993:264).

During the Ming and Qing dynasties (C.E. 1368–1912), the use of different colors of glass glazed tiles (*liuliwa*) on different buildings was legislated. Glass glazed tiles have a thin layer of brilliantly colored glass, including green, blue, yellow, and black. All the major types of tiles (i.e., curved, flat, eave, ridge) were used on state buildings such as bell and drum towers and temples. Yellow glazed tiles were only used on royal buildings, while green tiles were mainly used for the dwellings of royal relatives, official buildings, and temples (the size was the same as for ordinary standardized tiles) (Guo 2002:56).

Archaeological discoveries in China hint that a ranking system was prevalent before the emergence of the Song dynasty. The earliest evidence of the use of high sodium and potassium lime glazed tiles is in Guangzhou. In the early Western Han period, thin celadon glazed flat tiles, curved tiles, and *wansui* (meaning "thousand ages," an auspicious term used by Chinese emperors) tile-ends began to appear in on the roofs of the palace and the official hall of the Nanyue Kingdom (B.C.E. 203–111). The celadon glaze was thin and brushed evenly across the tile surface (Nanyue and Guangzhoushi 2008:255). The enormous palaces of the Sui-Tang period (C.E. 581–907) used large amounts of glass glazed (*liuli*) tiles for roofing; however, this glaze was applied to low-temperature fired pottery (Zhongguo 1993:449). Roof tiles glazed with high calcium ash at high temperatures emerged in Guangzhou from the early tenth century onward in the Nanhan Kingdom (C.E. 917–971). These roof tiles were widely used in the construction of large buildings such as palaces and official halls. The colors of the tile bodies were black, yellow, green ash-glazed, green lead-glazed, an unglazed yellow-white, or grayish. Special motifs have been found at the Nanhan palace site, including a double phoenix pattern on the tile-ends (Nanyue and Guangzhoushi 2008:226–233, 247). Considering Zhou's descriptions of a ranking system for roof tiles and roofing materials alongside the archaeological findings from Cambodia, Northeast Thailand, and China, it seems quite possible that the Khmer polity emulated the Chinese roof tile ranking system to establish its own political legitimacy.

While the Khmer emulated the Chinese roof tile ranking system, the basic principles, or concepts underlying Khmer and Chinese architectural forms remained different. Khmer royal palaces and temples were laid out in a mandala plan that represented the universal power of the celestial mountain realms and Khmer kings,

whereas Chinese architectural plans after the Western Zhou period reflected their admiration for the notion of harmony between humans and the universe (*tianren heyi*).

Another difference between the two traditions is that Khmer during the Angkorian period combined wood with stone in their constructions, while wooden architecture alone was the soul of the ancient Chinese architectural tradition (Cheng 1991:30; Dumarçay and Royère 2001:80, 111; Fu 1984:10–11). However, the Khmer may have emulated Chinese roofing techniques, especially the methods for adding tiles to a wooden framework. It is also possible that they emulated the major Chinese tile categories, since Khmer during the Angkorian period used similar half- or semicylindrical tiles (i.e., curved), quarter-cylindrical tiles (i.e., flat), and eave tiles. Khmer flat tiles were usually laid directly on the wooden roof framework, whereas curved tiles usually covered the flat tiles. The Khmer probably copied the Chinese "over-and-under" tile roofing method which combines the two tile types. Flat quarter-cylindrical tiles are used under tiles and the half-cylindrical tiles are used as over tiles. When we reexamine the Khmer roof construction method carefully, we find that they executed a simplified version of the Chinese tile layout. Curved tiles covered the joints between parallel rows of quarter-cylindrical tiles. This generated a ribbed texture on the roofs of royal and official buildings. The Khmer designed their tiles to interlock with features such as protrusions on curved tiles, ridges on flat tiles, and notches at the base of eave tiles. The edges of flat tiles were inserted into the notches of curved tiles to help hold them in place. Such features are absent from Chinese roof tiles.

Both Khmer and Chinese embellished the edges of roofs with eave tiles. The Chinese eave tiles known as drip tiles were used for draining rainwater from the roof top. They also used ridge tiles to cover ridges on the roof. A terracotta ornament, usually in the shape of a dragon or sea monster, often terminated the main ridge of a Chinese roof and an antefix (an upright ornament) can be seen on major Song buildings (Guo 2002:31, 79; Talbot 2001:116). These specialized roof tile forms were mainly utilized in the construction of Chinese royal courts, official halls, and religious buildings, while the majority of common people's roofs were covered with simple flat tiles (Zhongguo 1993:445). The Khmer also used eave tiles on religious buildings. The beam structure of the Eastern Mebon at Angkor is relatively simple compared to the cruciform plan depicted in bas-relief on other Khmer temples (Dumarçay and Royère 2001:11). Bas-reliefs show that eave tiles were placed at the corners of the roofs of cruciform shrines. In the twelfth century, roof-valleys were constructed on both sides of a shrine beam and the beam work was hidden by the corner tiles.

DISCUSSION

Analyses of Chinese archaeological ceramic remains, historical accounts, and ethnographic studies of the selected craft that provide cross-cultural behavioral data for an archaeological purpose enabled us to identify distinctive traditions in Khmer roof tile production and potential technological exchange networks related to roof tile production across mainland Southeast Asia. We also see obvious changes in the production and usage of roof tiles between the pre-Angkorian and Angkorian periods. In any discussion of Khmer traditions of ceramic production, it is important to note essential aspects of the technique as well as those open to change. What technological or social choices were made concerning any given technique? Some technical aspects that can be considered for such discussions have been provided here. First, one can note

that there were various categories of Khmer roof tiles. Glazed and unglazed stoneware curved, flat, and eave tiles were used during the Angkorian period. Khmer artisans manufactured tiles in various shapes and for various purposes: the curved tiles faced upward, the relatively flat canal-shaped tiles faced downward, and tile-ends joined with curved tiles were placed on the eaves. Second, because of the influence of Buddhism, some Chinese eave tile motifs such as connected pearls, lotus flowers, lotus petals, and images of Buddhist shrines were pressed onto Khmer tile-ends. Third, tile forming techniques changed over time in Angkor. It went from the coiling on mold method of the early Angkorian period to the molding method with a textile pattern in the later Angkorian period, which may have been influenced by Chinese techniques (Table 4). The mold probably controlled the shape and kept the tile in a fixed position during manufacture. Most importantly, molding increases the efficiency of tile forming and reduces drying time, so requires lower skill levels to produce ceramic tiles (Arnold 1988:220–221).

Regarding the positioning of tiles on roofs, the Khmer may have been emulated the traditional Chinese "over-and-under" tile roofing method. Their most obvious emulation of Chinese elements was in adopting a ranking system for roof tiles in order to demonstrate their centralized political and religious power in the region. This tendency is displayed in the Khmer's use of colors for their roof tiles that paralleled the feudal ranking system depicted in Chinese texts and found in archaeological excavations. Ranked from higher to lower status, the Khmer tiles included: lead tiles (sometimes wrapped in tin foil); brown, yellow, or green glazed tiles; and unglazed gray or orange tiles.

This study also examined the technological and social choices made by Khmer potters for the purposes of producing and using ceramic roof tiles. The environmental and cultural conditions of Angkor both favored and limited ceramic development. For instance, Khmer artisans chose simplified types of roof tiles for production purposes (Arnold 1988:231). Moreover, the use of glazed roof tiles was restricted to palaces or official buildings in the Angkorian area. This study also demonstrated that the Khmer ceramic industries evolved in terms of ceramic specialization for roof tile production. According to the archaeological data from Khmer ceramic production sites, roof tile production centers were mainly located in the Angkorian region near the Royal Palace (i.e., Thnal Mrech, Sarsei, Tani, and Khnar Po kilns) and along the ancient road to Phimai (i.e., Khok Lin Fa and Khok Khi Lek in Buriram in Northeast Thailand in the early Angkorian period and Torp Chey kiln in Siem Reap in the later Angkorian period). Compared to other contemporary Khmer kilns (not all which produced roof tiles), the Thnal Mrech kiln supplied the greatest variation and highest quality of roofing tile types, including several colors, diverse shapes, and decorative forms. This indicates that each kiln had its own ceramic specialization.

The development of the Thnal Mrech kiln as a Khmer ceramic production center may have involved Khmer royalty along with local artisan communities. Two factors could have stimulated a socioeconomic need for technological innovation of Khmer roof tile production. First, increased population pressure due to the territorial expansion of the Angkor Empire under Suryavarman I during the eleventh century (C.E. 1002–1050), along with the emergence of a state religion as the population shifted from Hinduism to Buddhism, may have led to roof tiles being used as material symbols of centralized political and religious power. Second, there was an increasing need for ceramic products as a medium of exchange. The establishment of the Khmer polity's

diplomatic and economic relationship with China was maintained through the provision of tributes and trade. As recorded in the annual *Song huiyao jigao* (Song Government Manuscript Compendium) in C.E. 1116, 1120, and 1121, these exchanges increased during the reign of Suryavarman II (C.E. 1113–1150) (Stark 2006:164–165; Xu 1957:7713). Chinese ceramics were imported into the Angkorian region during this time. Intensive interregional trade and other forms of exchange continued between the Khmer polity and China until the mid-fifteenth century. This potentially provided technological networks related to roof tile production that would have facilitated the Khmer emulation of Chinese craftsmanship. Thus this study comparing the production and usage processes of Khmer and Chinese roof tiles reconfirms the likelihood that various forms of exchange between the Khmer and Chinese polities intersected during the Angkorian period.

CONCLUSION

In summary, Khmer roof tile production underwent dramatic change in terms of technical and stylistic traditions from the pre-Angkorian to Angkorian period. Pre-Angkorian Khmer artisans had already absorbed some Indian elements in their unglazed earthenware ceramics, as is seen in their rectangular flat tiles with troughs and two holes. Chinese traditions and styles had an impact on Khmer roof tile production during the Angkorian period. Using tiles instead of thatch for roofing, producing glazed tiles, changes to the shapes of curved and flat tiles, and adoption of the "over-and-under" method for laying tiles on roofs occurred during the Angkorian period (Parmentier 1935:253; Silice and Groslier 1924–1926:47). The roof tiles were used as a visual demonstration of the legitimacy and prosperity of the Khmer divine kingship.

This article makes important observations about the specific choices involved in the process of emulation. Compared with the complicated structure of Chinese wooden architecture, the Khmer used simpler, localized, and more pragmatic building methods for their large construction projects. Nevertheless, Khmer contact with China may have motivated the production of tiles for elite Khmer residences and temples. The Khmer local architectural tradition is particularly defined by the distinctive production techniques of Khmer roof tiles and the ancient ranking systems for roof tile usage in the greater Angkorian region. Manufacturing and using roof tiles were a way for the Khmer to establish the legitimacy of their polity in mainland Southeast Asia.

We should note that the Khmer were involved with important polities other than China. The Cham and Javanese people provided alternative models for Khmer architecture and construction technology. Recent roof tile discoveries in Central Vietnam provide new evidence of a possible cultural transmission through Champa rather than directly from other areas with similar technologies (Barocco et al. 2019; Yamagata et al. 2019). Khmer artisans might also have been inspired by stone carving and metallurgy, including the skills of mold carving, decorative design, and firing techniques; this would have facilitated a possible knowledge transfer to Khmer ceramic industries (Dumarçay and Royère 2001:45; Hendrickson et al. 2013; Polkinghorne et al. 2015). As more archaeological data becomes available, further studies must be conducted to better understand these processes.

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