Carving at the Capital: A stone workshop at Hariharālaya, Angkor

Martin Polkinghorne, Janet G. Douglas, Federico Carò *

Among the first questions that visitors and scholars ask of Angkor is: How was it made? Considerable resources were invested in the production of temples and sculptures, but surprisingly, studies that consider the operational characteristics of Angkorian builders and artisans have been no more than partial.[1] Some focused on bas-reliefs and architectural ornamentation from a small selection of monuments.[2] Others have examined the manufacturing techniques of finished sculptures.[3] A recent set of studies has begun to consider the locations of sandstone quarries that supplied building materials for the temples.[4] Another path is to appraise production as a major economic activity in terms of craft specialisation. Can we identify the workers, artisans and workshops that built and furnished shrines across Angkor and the Khmer lands? To what degree were they directed by a political elite? Can we specify the locations and methods for acquisition of raw materials and distribution of finished products? And how did all of this change over space and time? In 2011 a collaborative excavation and materials analysis team initiated archaeological research aimed at investigating sites of artistic production and this paper presents the resulting investigation of a sandstone dumping and production centre, analysis of associated material samples, and propositions about temple and sculpture manufacture at Angkor. The research focuses on production at Hariharālaya, a major urban centre and focus of regional political authority between the 8th and 9th centuries, a reputed settlement of the so-called founder of the Angkorian Empire, Jayavarman II (r. ca. 770 – ca. 830 CE), and precursor to the city of Yaśodharapura approximately 15 km to the northeast,

* Martin Polkinghorne (Flinders University), Janet G. Douglas (Freer Gallery of Art and Arthur M. Sackler Gallery, Smithsonian Institution), Federico Carò (Metropolitan Museum of Art).

1. This research was funded by an Australian Research Council Discovery Project Grant (DP110101968). Project collaborators include the APSARA National Authority, the École française d'Extrême-Orient, the National Museum of Cambodia, The Smithsonian Institution's Freer Gallery of Art / Arthur M. Sackler Gallery, the Metropolitan Museum of Art, and the University of Sydney Robert Christie Research Centre in Siem Reap. We extend our appreciation to H.E. Bun Narith, H.E. Tan Boun Suy, H.E. Ros Borath, Mao Lor, Tin Tina, An Sopheap, Chhay Rachna, Chea Socheat, Siyonn Sophearith, Oung Savanna, So Malay, and Damian Evans. Thanks to Christophe Pottier who offered invaluable advice. AMS ^{14}C analysis was made possible through an Australian Institute of Nuclear Science and Engineering (AINSE) Research Award (ALNGRA13009) and conducted by Quan Hua and Geraldine Jacobsen of the Australian Nuclear Science and Technology Organisation (ANSTO). The authors recognize the assistance of Kim Sokkhin and staff of the Conservation d'Angkor, and Thierry Zéphir and Pierre Baptiste of the musée Guimet. Special thanks to the fieldwork team: Hou Nolamony, Suy Pov, Hen Chenda, Sally MacLennan, students from the Royal University of Fine Arts, Phnom Penh, and dedicated workers.

2. G. Groslier 1921-1923: 206-208; B.P. Groslier 1969: 29-30; Pichard 1974: 126-127; Polkinghorne 2007a, 2007b, 2008.

3. Vincent 2012, Vincent *et al.* 2012, Polkinghorne *et al*. 2014.

4. Uchida *et al.* 2007, Rocks 2009, Uchida & Shimoda 2013.

commonly known as Angkor (Fig. 1). Study of a site related to temple building and the manufacture of sculptures considers different categories of craft specialisation at Angkor and connects the monuments and idols to the people who made them.

Identification and excavation

The area of the workshop was noted by archaeologists in 1943 when Angkor Conservator Maurice Glaize of the École française d'Extrême-Orient (EFEO) identified two large unfinished sculptures east of the outer enclosure of the Bakong temple. Glaize discerned the rough-hewn and distinctive 306 cm and 337 cm tall sculptures as unfinished representations of *Umāgaṅgāpatīśvara* similar to completed images located inside the central enclosure (Fig. 2).[5] Carved from a single piece of stone the highly specific images reasonably represents a triad of Śiva flanked by his consorts Umā and Gaṅgā like that mentioned in the 9th-century Bakong temple foundation stèle authored by king Indravarman I (r. 877 – 889).[6] A potential Angkorian workshop was not recognised by archaeologists until 1994 when the unfinished sculptures were repatriated to the Conservation d'Angkor storage facility in Siem Reap to protect them from looting.[7] At this time large amounts of sandstone chips were identified as production debitage and together with unfinished sculpture the site was earmarked as a production hub.[8]

The site occupies an area of approximately 400 m^2 directly west of the 3rd outer enclosure of the Bakong temple. A series of anthropogenic mounds and roughly hewn sandstone blocks are the primary observable archaeological features. A symmetrical emplacement of two mounds either side of the western axis road might be considered part of an earlier configuration of the Bakong temple complex, an aggregate sacred landscape of more than twenty-five shrines across approximately 4 km^2.[9] On the southern mound scatters of sandstone waste offer surface evidence of production activity. Sometime in the early 20th century a path was cut through the centre of the southern mound exposing additional manufacturing waste and providing an opportunity to recognise a 35 m section of the site.[10] Archaeological investigation and material characterisation reveal a site of considerable complexity that participated in the production of the Hariharālaya's material, political and sacred world.

Provisional chronology

Five test trenches were opened to establish the size, layout, chronology and output of the work-site and clarify the processes of sandstone working at Angkor (Figs. 3–6, 8,

5. Glaize 1939, 1943. DCA 219/ Sample #33, DCA 220/ Sample #34.

6. K. 826, st. XXIX, Cœdès 1937-1966, vol. I: 31-36, 1939: 220. See also Cœdès 1939: 220-221, Bhattacharya 1961: 85, Alvares 1992b: 29; cf. Jacques 1990: 47.

7. Vorn Ourng 1994.

8. Christophe Pottier (pers. comm. Sept. 2008).

9. Pottier 1996.

10. The road from the western axis of Bakong temple to Prei Monti temple and Kôk Srok village.

10).[11] Excavations and recovered material culture suggest at least six phases of occupation at the site.

Phase 1: Relates to the construction of the anthropogenic mounds, by the importation of sandy clay and clay to produce raised platforms. The combination of survey, excavation, and coring data estimate the soil volume of each mound to be 3000 m^3.[12] In plan, the mounds do not appear precisely symmetrical, but this may be the result of later interventions. Perhaps we can envisage paired mounds and buildings either side of the Bakong western axis, so emplaced to connect them with the greater Bakong temple complex of roads subsidiary shrines, and ponds.[13] On the basis of AMS ^{14}C analysis and a diagnostic Chinese ceramic sherd this earliest phase of the site occurred sometime between the late 8th and late 9th centuries. A charcoal sample provided for AMS ^{14}C was recovered at the top of the imported soil mound and before the foundation layers of the building described in Phase 2 (see table 1).[14] The charcoal sample was recovered adjacent to a fragment of Tang Dynasty Xing porcelain that might be dated to the late 8th century.[15] Coring suggests that there is none or little material culture below this excavated stratigraphic layer and construction of the mound and building described below likely occurred in close chronological succession.

	Lab ID	Sample ID	δ13C (‰)		14C Age (BP)		Calibrated Age (cal CE)(a)					Calibrated Age (cal CE)(b)				
			Mean	1σ	Mean	1σ	1σ range		2σ range		Median	1σ range		2σ range		Median
1	OZR030	BKO11 01079.16.01	-26.9	0.1	1175	25	775	890	770	950	840	880	975	780	985	920
2	OZR031	BKO11 01111.16.01	-27.3	0.1	1285	25	680	770	665	770	715	685	800	675	870	745

Table 1: AMS 14C Results.

Notes: All uncalibrated and calibrated ages were rounded off to the nearest multiple of 5. Calendar age conversion was carried out using: (a) IntCal13 calibration data, and (b) SHCal04 calibration data with a small offset of -21 +/- 6 yr due to monsoonal air-mass mixing (On these methods see Hendrickson *et al*. 2013: 41, 43, Table 1).

Phase 2: Following the establishment of the earth platforms, the southern mound was furnished with a building. Systematic coring did not find evidence of an equivalent building on the northern mound. Principal evidence for this structure is a building base or modénature rendered in laterite (Figs. 6 and 7). Aligned east-west and parallel to the western axis road of Bakong temple, moulded in the same style as the entry (*gopura*)

11. Based on previous archaeological investigations in the vicinity by EFEO (see Pottier *et al*. 2004, 2005), the excavation was assigned the coding abbreviation of "BKO" (Bakong).

12. An approximate calculation assuming each mound is an area of 50 m × 50 m, with a variable height above the original ground surface between 0.75 m and 1.25 m. The southern mound has a higher elevation compared the northern mound, logically the result of activities described between Phase 4 and Phase 6 below.

13. Pottier 1996.

14. OZR031.

15. Artefact #01111.01.02. Identified by Li Baoping (pers. comm. Feb. 2012). Among the earliest examples of an imported northern Chinese ceramic at Angkor, other fragments were recovered from the Hariharālaya Royal Palace excavations approximately 800 meters from this find (see Pottier *et al*. 2012: 299 sqq.).

and annex buildings of the Bakong and Preah Kô temples, we might correspondingly associate this building with a mid to late 9th-century construction.[16] Stratigraphic layers from inside and outside of the building are clearly distinguished. Inside, numerous compacted foundation layers contain mixed laterite and rhyolite rubble, brick fragments, and sandstone chips. With the exception of a few fragments of earthenware no ceramics were recognised within this building fill. A large posthole (diam. 45 cm) was the likely position of internal load bearing post that supported a building superstructure built in wood. Outside, the wooden roof is attested by large quantities of glazed stoneware roof tiles described in Phase 3 (Fig. 9). Below the roof tiles, a brick pavement indicates an external ground level associated with the operation of the laterite building.

At equivalent stratigraphic layers to the building base other trenches contain large deposits of sandstone chips. The sandstone pieces range in size from large fragments (approx. diam. 30 cm) to sandstone powder. The sandstone deposit does not appear directly related to the construction of the earthen mounds of Phase 1 or the laterite building base. We interpret the sandstone as secondary bulk dumping events related to the construction of a monumental sandstone structure, most likely the Bakong temple. The presence of fragments in trenches and soil cores on the edges of the southern mound, especially at its eastern edge adjacent to the bank of the Bakong third enclosure moat suggests a deposition within a short time frame (Figs. 5 and 8). We estimate the layer has a minimum volume of 40 m^3.[17] The material characteristics and interpretation of sandstone debitage from Phase 2 are described below.[18]

Phase 3: Sometime between the late 9th and mid 11th century, the laterite-based building collapsed or was demolished. Large amounts of glazed and unglazed stoneware roof-tiles adjacent, but outside and above the laterite base and foundation are logically the remains of a collapsed roof deposited in a single event. The context included concave canal tiles, convex joint-cover tiles, decorated eave tiles in the shape of stylised unfolding lotus petals (Fig. 9), and ridge finals; all the forms necessary to facilitate a roof covering. The tile shapes and decoration are representative of the late 9th century and match the building modénature and analogous tiles excavated from Hariharālaya.[19] Amongst the deposit context were many pieces of charcoal. One sample, presented for AMS ^{14}C analysis, dates the deposit and collapse of the building probably to the 10th century (see table 1).[20] Complementary ceramics from the lowest stratigraphic layers of Phase 3 include a number of unglazed stoneware rim and shoulder fragments associated with production from the Bangkong kilns.[21]

Phase 4: Is equivalent to late Angkorian occupation and the production of sandstone sculptures destined for renovations at Hariharālaya. Phase 4 stratigraphic layers see the appearance of Angkorian green and brown glazed stoneware, and fragments of Chinese

16. K. 826, Cœdès 1937-1966, vol. I: 31-36, Stern 1938c.

17. The sandstone debitage layer is recognised in Trenches 2, 3, and 4 and from numerous soil cores. It is difficult to calculate the volume of this deposit with precision, but triangulation of the relevant trenches and cores approximates a dumping area of 175 m^2 with variable heights between 0.20 m and 1.10 m.

18. See Sample #1-5.

19. Designated 'Type A' roof tiles. See Boisselier 1966: 364 - 366, fig. 67; Dumarçay 1973: 10-17, pl. XXXI, fig. 32, pl. XXXIX, fig. 59; Pottier *et al*. 2005: 9.

20. OZR030, artefact #01079.16.01.

21. E.g. Artefact #01088.01.03, a storage jar of the *Krala* family; for equivalent examples see Chhay *et al*. 2010: 12, 18, 20, and Desbat *et al*. 2008: 41 (Site 111, jars).

Qingbai porcelain.[22] Broken fragments of light brown glazed stoneware might originate from the southern Chinese province of Guangdong.[23] Significantly, a series of successive surfaces contain small localised dumps of sandstone debitage are suggestive of the sandstone carving process (Figs. 5, 6, and 10). The dumps are irregular in shape and vary in size with diameters between 10 cm and 50 cm and depths between 10 cm and 20 cm.[24] Samples presented for petrographic analysis from these layers are discussed below.[25] Correspondence of ceramic dating and stone lithotypes recognised in sculptures from the early 12th century onwards[26] likely locate this phase between the 12th and 13th centuries.

Phases 5 and 6: The last phases relate to site deposition after the 13th century. The ceramics of these layers are predominantly local earthenwares, unglazed stonewares, and brown glazed stonewares.[27] The presence of a few fragments of Chinese celadon and iron glazed stoneware conceivably from Fujian or Guangdong provinces indicate there was some activity at Hariharālaya during the last centuries of Angkor's dominance of mainland Southeast Asia.[28]

The highest levels of stratigraphy reveal 20th-century iron artefacts, perhaps related to the ongoing operation of a small smithing shop situated on the site.[29] The present resident and owner of this shop maintains his family have always lived and worked on the western bank of the Bakong 3rd enclosure moat and recalls his grandfather explaining how the ancestors made sculptures there. In 2011 the unfinished sculptures of *Umāgaṅgāpatīśvara* removed to Siem Reap are remembered by this resident and inhabitants of the Bakong village as Neak Ta, or local spirits of place.[30]

Petrographic analyses of materials

Dataset and method

Petrographic analyses were applied to understand production at the sandstone workshop, its relationship to sources of raw materials, and distribution of its completed outputs. Differentiation of sandstone types may additionally provide chronological information on the exploitation of geological formations and use of specific materials.[31] The sandstone samples were characterised and grouped according to their texture and mineralogical composition. The data was used to compare the sandstone materials of the excavated *in situ* debitage and unfinished sculpture, the temples of Bakong, Preah Kô, and satellite shrines, and a selection of finished sculptures originating from Hariharālaya in Cambodian

22. E.g. Khmer glazed: artefact #01024.01.03, #01026.0102, #04002.01.01, #04005.01.02; Qingbai: artefact #01015.01.02, #01042.01.02.

23. Artefact #01013.01.02. Identification by Louise Cort (pers. comm. Oct. 2012).

24. On stone carving also see Polkinghorne 2007a, 2007b, 2008, 2009, 2012.

25. Sample #30, #31.

26. See Lithotype 3, and our section 12th-century archaism and Angkorian sandstone choice below.

27. E.g. Artefact #01001B.01.01, #01001C.01.01.

28. Celadon: artefact #05002.01.01, #01001.01.01; iron glazed stoneware: artefact #01001D.01.02.

29. Blades / chisels: artefact #01002.03.01, #01002.03.03; axe head: artefact #01001B.03.01.

30. Interviews conducted with residents of the Bakong village May-November 2011.

31. Cf. Carò & Douglas 2013.

and international collections (see table 2, Fig. 11). Supplementary correspondence was made with petrographic data from known quarries and potential sources of sandstone provenance.[32]

Standard petrographic methods using point counting were performed on the thin-sectioned samples. A minimum of 200 grains were systematically identified and measured using Nikon Eclipse E600 and Zeiss Axioplan 2 polarized light microscopes. Key petrographic parameters, as well as grain size distribution and significant textural parameters, were derived by means of computer software modified after Balsillie *et al*.[33] The sandstone classification system used is based on the Gazzi-Dickinson method (Fig. 12).[34]

Analysis clusters most samples into three broad groups, according to their framework composition: Lithotype 1, a sandstone with similar amounts of quartz and feldspar, and relatively poor in lithic fragments; Lithotype 2, a sandstone with roughly equal amounts of quartz, feldspar and lithic fragments, and Lithotype 3, a quartz-poor sandstone rich in feldspar and volcanic lithic fragments. These lithotypes correspond with highly specific choices of material related to sandstone used for architecture, architectural ornamentation, and images of the gods, and were sourced from different quarries. We report the widespread choice of Lithotype 1 for temple architecture created during the 9th century. Lithotype 2 was used for rendering images of the gods from the 9th century, and is suggestive of long-distance trade in stone for the production of sacred images at the capital. Lithotype 3 is evidenced by workshop debitage and sculptures and attests to a 12th-century program of production at Hariharālaya in archaising artistic styles seeking to replicate images of the 9th century (see table 2).[35]

Lithotype 1: 9th-century debitage, and Bakong, Preah Kô, and associated temple architecture

Five debitage samples, thirteen samples from the Hariharālaya temples of Bakong and Preah Kô, and four reference samples from associated 8th to 10th-century Angkorian architectural ornamentation exhibit a similar assemblage of constituent framework grains and texture.[36] The sandstone of this lithotype group has an average composition of $Q_{48}F_{42}L_{10}$, and is composed of very fine to fine (0.08 to 0.17 mm), moderately well sorted, sub-angular to rounded grains, predominantly cemented by chlorite. Quartz monocrystalline grains predominate over polycrystalline varieties. Quartz grains with non-undulose extinction are more common than those with undulatory extinction. Feldspars are predominantly untwinned varieties of plagioclase and alkali feldspar

32. E.g. Carò & Douglas 2013.

33. Balsillie *et al*. 2002.

34. Gazzi 1966, Dickinson 1970.

35. See below.

36. Debitage samples: #01-#05; Hariharālaya temple and architectural ornamentation samples: #06-#18; 8th–10th architectural ornamentation reference samples: #19-#22 (see table 2). We note sample #18 from a sculpture yoni of the Bakong (tower east-north-east). *Yoni*, literally "womb," are sculptural representations of female sexual organs and form the base of images of gods designed to collect and funnel ritual libations. A sculpture of a deity and its *yoni* are habitually made of the same material. Sample #18 is from the *yoni* of the *Umāgaṅgāpatīśvara* n627 6870 and the authors cannot account for the difference of stone type in this instance (see characterisation below).

(75.7% of total feldspar), while polysynthetic twinned plagioclase is less common. Most show minor to severe alteration due to weathering.

Lithic fragments (L) constitute 10.9 ± 4.2 of the framework grains, and tend to have aphanitic textures commonly found in volcanic rocks. Metamorphic varieties include micaceous schist and phyllite, and a small number of sedimentary varieties such as chert and shale are present. Micas make up 5.1% of the grains, and include brown biotite and minor amounts of muscovite and chlorite. This mica content is relatively high, and results in the sandstone having black reflective specks to the naked eye. The accessory mineral content includes epidote, garnet, apatite, rutile, titanite, and opaque minerals. The overall grain composition reflects a mixed provenance of felsic igneous and metamorphic rocks with a minor sedimentary content.

The petrographic characteristics of the debitage and temple architecture samples are found to be most similar to those of sandstone quarries located in the eastern foothills of the Kulen range and from sculptures attributed to the sandstone formation called the Terrain Rouge.[37] Compared to published petrographic and textural data of Terrain Rouge sandstone, the Hariharālaya samples show some differences in finer grain size and slightly higher lithic fragment content. But the relatively high biotite content, predominantly chlorite cement, and the lithic fragment types which are of mixed geological provenance and strongly metamorphic, are consistent with the existing data for sandstone from the Terrain Rouge Formation, specifically the Kulen hills reputed as the primary sandstone sources of Angkor.

Lithotype 2: 9th-century sculptures

Seven samples from 9th-century sculptures from sites related to Hariharālaya are characterised by equal amounts of quartz, feldspar and lithic fragments.[38] This sandstone type has an average composition of $Q_{39}F_{29}L_{32}$, and is composed of fine-grained (0.14 to 0.20 mm) sand, which is moderately sorted, sub-angular to rounded, and predominantly cemented by authigenic chlorite. Quartz monocrystalline grains exceed polycrystalline varieties, while grains with non-undulose extinction are more common than those with undulatory extinction. Feldspars are principally untwined varieties of plagioclase and alkali feldspar, while polysynthetic twinned plagioclase is less common. Most show minor to severe alteration through weathering.

Lithic fragments (L) constitute 32.5 ± 3.4% of the framework grains. The grains are largely metamorphic in origin, constituting mostly phyllite and micaceous schist. Lithic fragments that are volcanic in origin are andesitic to rhyolitic in composition, and primarily aphanitic in texture. A small proportion of sedimentary lithic fragments are present, such as chert and shale. Micas make up 3.9% of the total grains, and consist mainly of brown biotite with minor amounts of muscovite and chlorite. Other accessory minerals include epidote, zircon and garnet. The overall grain composition reflects a mixed provenance with a strong metamorphic grain content. This sandstone appears to be slightly metamorphosed, as evidenced by the presence of epidote and calcite as secondary replacements of some framework grains, and authigenic chlorite between grains.

37. Delvert 1963, Contri 1972, Kucera *et al*. 2008, André *et al*. 2011, Carò & Im 2012.

38. 9th-century sculpture samples: #23-#29 (see table 2).

Sample #	Inventory #	Description	Provenance	Date (century CE)	Q	F	L	Mean grain size	Sorting
	Lithotype 1								
	Debitage, excavated from workshop								
01	BKO11 02011.20.01a	Debitage	Stone workshop	9th	33.5	54.1	12.4	0.11	0.60
02	BKO11 02020.20.01a	Debitage	Stone workshop	9th	45.6	38.2	16.2	0.08	0.50
03	BKO11 03039.20.01a	Debitage	Stone workshop	9th	37.7	42.7	19.6	0.10	0.58
04	BKO11 04006.20.01a	Debitage	Stone workshop	9th	44.2	40.9	14.9	0.10	0.59
05	BKO11 04006.20.02a	Debitage	Stone workshop	9th	37.9	47.8	14.3	0.11	0.55
	Architecture, Bakong								
06	BKO11 99001.20.01	Pyramid (2nd stage, south-west corner, retaining wall)	Bakong	9th	39.6	45.1	15.4	0.11	0.62
07	BKO13 02	*Nandin* (western side)	Bakong	9th	45.3	43.7	11.1	0.11	0.56
08	BKO13 04	Pedestal (in front of *prasat* east-south)	Bakong	9th?	56.5	34.9	8.6	0.11	0.58
09	BKO13 05	Pedestal (*prasat* east-south)	Bakong	9th?	51.0	41.9	7.1	0.15	0.45
10	BKO13 08	Elephant (pyramid, 1st stage, south-west corner)	Bakong	9th	47.9	43.2	8.9	0.11	0.59
11	BKO13 09	Pedestal	Bakong satellite (Prasat 3)	?	52.2	39.6	9.0	0.10	0.52
12	BKO13 10	Pedestal	Bakong satellite (Prasat 12)	?	47.7	42.1	10.3	0.17	0.45
	Architecture, Preah Kô								
13	PKO13 11	Pedestal (east line, south *prasat*), base of pedestal	Preah Kô	9th?	49.2	41.6	9.1	0.13	0.65
14	PKO13 13	Pedestal (west line, south *prasat*), base of pedestal	Preah Kô	9th?	48.6	44.8	6.6	0.11	0.56
15	PKO13 14	Dvārapāla (east line, south *prasat*, south-east corner)	Preah Kô	9th	51.6	38.8	9.6	0.10	0.59
16	PKO13 15	Pedestal (west line, central *prasat*)	Preah Kô	9th?	50.0	40.2	9.8	0.11	0.61
17	PKO13 20	*Nandin* (in front of northern *prasat*)	Preah Kô	9th	49.4	42.6	8.0	0.11	0.61
	Sculpture found in-situ								
18	BKO13 06	*Yoni* (*prasat* east-north)	Bakong	9th?	47.2	43.1	9.6	0.10	0.50
	Architecture, other 8th – 10th century								
19	MG18220	Lintel	Kapilapura	9th	50.2	41.4	8.4	0.13	0.70
20	MG18855	Lintel	Prasat Koki (Phnom Kulen)	8th - 9th	59.1	34.3	6.5	0.10	0.62
21	MG18879	Fronton (fragment of extremity)	Prasat Sok Kraup	9th - 10th	54.7	38.9	6.4	0.16	0.58
22	MG18858	Colonnette (fragment)	Prasat Khting Slap (Phnom Kulen)	8th - 9th	54.0	38.1	7.9	0.11	0.59

	Lithotype 2								
	9th century sculptures								
23	DCA n730 3980	Head of Female deity	Stone workshop	9th	32.7	33.6	33.6	0.14	0.83
24	BKO13 07	Sculpture feet / tang (triad, *prasat* north-east)	Bakong	9th	32.1	28.9	38.9	0.18	0.88
	Sculpture, 9th century from Hariharālaya								
25	DCA n627 6870	Umāgaṅgāpatiśvara	Bakong	9th	40.1	32.0	27.9	0.20	0.83
26	Ka940	Head of Śiva	Preah Kô	9th	39.6	27.5	33.0	0.17	0.77
27	Ka1634	Viṣṇu	Prasat Thmâ Dap, Phnom Kulen	9th	33.1	35.3	31.6	0.16	0.77
28	MG18862	Female deity	Bakong	9th	50.5	19.3	30.3	0.14	0.92
29	Met 2003.592.1	Female deity	?	9th	42.1	25.7	32.2	0.15	0.97
	Lithotype 3								
	Debitage from workshop								
30	BKO11 01004.07.01a	Debitage	Stone workshop	12th - 13th	13.9	27.7	58.4	0.19	0.87
31	BKO11 01007.20.01a	Debitage	Stone workshop	12th - 13th	27.2	47.1	25.7	0.09	1.08
	Sculpture, workshop in-situ								
32	BKO13 01	Unfinished *yoni*	Stone workshop	12th?	17.2	32.3	50.5	0.25	0.74
33	DCA 219	Unfinished Umāgaṅgāpatiśvara	Stone workshop	12th?	10.4	38.3	51.4	0.20	0.76
34	DCA 220	Unfinished Umāgaṅgāpatiśvara	Stone workshop	12th?	10.9	37.1	50	0.21	0.83
	Sculpture found in-situ at Bakong and Preah Kô								
35	BKO13 03	Sculpture feet (south pyramid *gopura*)	Bakong	12th?	14.7	44.6	40.7	0.24	0.64
36	PKO13 12	Yoni (east line, north *prasat*)	Preah Kô	12th?	21.8	35.1	43.1	0.25	0.84
37	PKO13 16	Sculpture feet (west line, central *prasat*)	Preah Kô	12th?	24.2	44.6	31.2	0.19	0.62
38	PKO13 18	Yoni (west line, northern prasat)	Preah Kô	12th?	20.2	50.0	29.8	0.16	0.83
39	PKO13 19	Sculpture feet (western *gopura*)	Preah Kô	12th?	9.1	48.7	42.2	0.18	0.73
	Sculpture, 12th century from Hariharālaya								
40	DCA n62	Male deity	Bakong	12th	11.1	50.3	38.7	0.18	0.66
41	DCA n120 6871	Female deity	Bakong	12th	12.7	43.9	43.4	0.20	0.74
42	DCA n268 6872	Female deity	Bakong	12th	9.8	50.3	39.9	0.18	0.74
43	Ka1644	Śiva	unknown (likely Hariharālaya)	12th	14.7	34.5	50.9	0.22	0.73
	Unknown lithotypes								
44	DCA n607 3979	Male deity	Bakong	9th	15.0	62.9	22.2	0.11	0.63
45	MG18217	Lintel	Kôk Po A	9th	33.3	36.0	30.7	0.14	1.00

Table 2: Compositional and textural parameters of sculpture and sandstone from Bakong, Preah Kô and Hariharālaya.
Parameters are Q = quartz, F = feldspar, L = lithic fragments, mean grain size, and sorting.

Currently, little can be said about the geological provenance of the Lithotype 2 group, but judging from the overall composition and the nature of lithic grains, we consider that it could originate either from a Triassic formation widely exposed in Cambodia,[39] or from younger sedimentary sequences such as the Jurassic Terrain Rouge (Fig. 20).

Lithotype 3: 12th–13th-century stone workshop debitage and sculptures

The last lithotype group is intermediate between feldspathic arenite and lithic arenite, and can be clearly distinguished as they are quartz-poor, and particularly rich in volcanic lithic fragments. The samples were acquired from two debitage deposits and three unfinished sculptures from the workshop site (including the two roughly-hewn *Umāgaṅgāpatīśvara*), the remains of five in situ sculptures from Bakong and Preah Kô temples, and four sculptures originating from Hariharālaya (conventionally dated to the 9th century).[40] We might also include three sculptures of the 12th to early 13th century installed at Hariharālaya.[41] They are texturally immature volcaniclastic sandstones, and show an average composition of Q16F42L42. Overall, the sandstone is composed of fine to medium-grained (0.09 to 0.25 mm), moderately well to poorly sorted, sub-angular to rounded grains predominantly cemented by chlorite. Monocrystalline quartz grains exceed polycrystalline varieties, while grains with non-undulose extinction are more common than those with undulatory extinction. Feldspars are principally untwinned varieties of plagioclase and alkali feldspar, while polysynthetic twinned plagioclase is less common. Most show minor to severe alteration through weathering.

Lithic fragments constitute 41.9 ± 9.3% of the framework grains. Most are andesitic to rhyolitic in composition, and the most common textures are microlithic to aphanitic and typical of volcanic rocks. The relatively high microlithic fragment content is a major characteristic that distinguishes this lithotype, although some contain more aphanitic lithic fragments. Metamorphic varieties include phyllite and micaceous schist. A small proportion of sedimentary varieties such as chert and shale are present. Sandstone in this lithotype group often contain a significantly high amount (approximately 8%) of amphibole (var. hornblende) which typically has green to brown pleochroism. Detrital mica makes up 1.3% of the grains, and mainly consists of brown biotite with minor amounts of muscovite and chlorite. Other more minor accessory minerals include clinopyroxene, biotite, zircon and titanite. The overall grain composition reflects a mixed provenance of andesitic igneous, primarily volcanic, rocks with a minor sedimentary content. These sandstones have undergone post-diagenetic changes and probable low-grade metamorphism. Authigenic chlorite is present between grains, and this material, along with finely-divided iron hydroxides, acts as natural cement. Epidotisation, a low-grade metamorphic process, has occurred primarily in the feldspar

39. Sotham 1997, Douglas *et al*. 2010, Carò & Douglas 2013.

40. Debitage samples: #30-#31; unfinished sculptures from the workshop site, samples: #32-#34; Bakong and Preah Kô in situ sculpture, samples: #35-#39; sculpture from Hariharālaya conventionally dated to the 9th century, samples: #40-#43 (see table 2). See below for the revised chronology of sculptures commonly attributed to the 9th century. The provenance of Ka1644 (sample #43) is unknown, but based on the similarity of the *sampot* (cloth worn around the lower body) with n62 (sample #40 from Bakong), and of the coiffure (specifically the diadem) with Ka1645 (from Lolei) we infer that this sculpture is likewise from Hariharālaya. On the female deity Ka1645 see Zéphir (1997: 202) and below.

41. Characterised and published by the authors in Carò & Douglas 2013: Viṣṇu (DCA# n51 3456) from Trapeang Phong, Viṣṇu (DCA# n306 4629) from Bakong, and transformed Avalokiteśvara (DCA# n186 2720) from Preah Kô. Also see Discussion, Implications and Conclusions below.

grains where epidote has replaced some of the primary minerals. Calcite is also present in some samples, replacing existing grains and filling pore space within the fine-grain matrix. Lithotype 3 samples likely originate from outcrops of the Triassic sedimentary formation normally associated with sculpture from the late 12th to early 13th century.[42]

Unknown lithotypes (outliers)

Although these three groups have been clearly defined using petrographic methods, two samples had petrographic characteristics that did not clearly fall into any of the categories. These samples are considered to be outliers composed of unknown lithotypes. One is a 9th-century sculpture of a male deity from Bakong temple,[43] and the other a 9th-century architectural lintel from the temple of Kôk Po located north of the West Baray of Angkor.[44] It is necessary to study more samples to determine if these outliers are attributable to natural variations in known sandstone types, or whether they originate from unknown geologic sources.

Discussion

Activities at the workshop

The stone workshop of Hariharālaya participated in temple building and sculpture carving production at different phases of the operational life of Angkor. The combination of excavation and material characterisation can review manufacturing activities at the workshop and transformations in the material landscape of Hariharālaya.

Sometime from the mid 9th century a laterite building was established on a raised earthen mound aligned with the western axis road of the Bakong temple (Phases 1 and 2). At around the same time, sandstone debitage with a volume of at least 40 m^3 was deposited at the site. The largest construction activity at this time was Indravarman I's renovation of the Bakong,[45] and feasibly the debitage could be a relocation of this material. It is widely accepted that sandstone temple ornamentation, and likely architectural sculpture, were manufactured on site. Sandstone blocks were first positioned in place and teams of artisans set to work creating symbolic visions of heaven on earth.[46] The petrographic correspondence of architecture,[47] architectural ornamentation,[48] and large debitage dumping events[49] with the feldspathic arenite of Lithotype 1 and the Terrain Rouge formation[50] suggests the

42. Sotham 1997, Douglas *et al*. 2010, Carò & Douglas 2013. See below for discussion of Lithotype 3 and sculpture of the early to mid 12th century.

43. Sample #44 (see table 2).

44. Sample #45 (see table 2).

45. Construction activity is declared by K. 826, see Cœdès 1937-1966, vol. I: 31-36. On 9th century renovation at Bakong see Pottier 1996.

46. E.g. see Dumarçay & Royère 2001: 16-17; Polkinghorne 2008.

47. Sample #06.

48. Samples #07-#12.

49. Samples #01-#05.

50. See Carò & Im 2012.

site was the recipient of a mass secondary placement of debitage related to production at Bakong. We might propose that the debitage relates to a fraction of the waste produced by completion of the Bakong temple pyramid stone facing and architectural ornamentation. It is estimated that the Bakong pyramid is clad with over 4000 standardized sandstone blocks, and additionally contains numerous architectural elements rendered in stone (Fig. 14). Sandstone blocks were introduced to the temple site from Terrain Rouge quarry fields north-east of Hariharālaya at the foot of the Kulen hills and finished on-site. Subsequently, the waste of this process was discarded just beyond the temple enclosure. The site may additionally be the secondary emplacement of debris from the manufacture of architectural elements and ornamentation from nearby temples also made in Lithotype 1 (Fig. 15).[51]

Abandonment and collapse of the excavated laterite building in the 10th century likely relates to the movement of the political administration from Hariharālaya to Yaśodharapura and new investments in hydraulic and temple infrastructure centred around Phnom Bakheng (Phase 3).[52] At a later time, between the 12th and early 13th century, the decommissioned 9th-century building and site were the focus of sandstone sculpture manufacture (Phase 4). Images of the gods were produced by executing a staged process beginning with rough dressing, through to detailed rendering of ornamentation and polishing.[53] The primary archaeological signature of these activities is demonstrated by numerous localised debitage dumps and *in situ* unfinished sculptures. Samples from the discarded sandstone chips and unfinished sculptures are identified as Lithotype 3,[54] a stone choice typically identified with sculptures of the late 12th to early 13th century.[55] We propose that the *in situ* unfinished sculptures, including the *Umāgaṅgāpatīśvara* were initiated at the workshop site from the early to mid 12th century as replicas or replacements of original 9th-century models (Figs. 2, 16 and 17).

12th-century archaism and Angkorian sandstone choice

By considering the archaeological context of production debitage and petrographic analysis of selected finished sculptures from Hariharālaya we can propose that the stone choice from Triassic formations, previously coupled to production under Jayavarman VII (r. 1182/1183 – *ca*. 1220 CE) in the late 12th and early 13th centuries,[56] be retroactively extended to include the early and mid 12th century. An assemblage of early and mid 12th-century sculptures is characterised as Lithotype 3, a stone preference not known for this period.

In the 12th century there was a systematic program of restoration at Hariharālaya. In 1944 Glaize discerned renovations at Bakong and considered the sanctuary atop the central pyramid dated no earlier than the second half of the 11th century. Glaize also observed a curious archaism of the structure that incorporated a veritable collection of different artistic styles ranging from the late 9th to the mid 12th centuries.[57] The chronology was

51. As evidenced by samples from Preah Kô temple; samples #13-#17.

52. Dated pollen concentrates from sediment cores at Bakong temple also show a decrease in the intensity of agricultural land-use around the temple from the late 9th century (Penny *et al*. 2006).

53. Polkinghorne 2008, 2009.

54. Samples #30-#34.

55. Douglas & Sorensen 2007, Carò & Douglas 2013.

56. See below for additional examples of 12th-century sculptures composed of Lithotype 3 carved in the style of the 9th century.

57. Glaize 1944: 271. Also see Alvares 1992b: 32.

refined further when the principal tower was recognised as a construction of the first half of the 12th century in the Angkor Wat style.[58] Later, a sculpture from Hariharālaya was identified as an early to mid 12th-century copy of a 9th-century model (Fig. 18).[59] These studies combined with materials characterisation, and a re-examination of sculpture can identify nine additional images rendered in an archaising style of the 8th and 9th centuries.[60] Scrutiny of decorative details including the garments (*sampot*), coiffure, posture, and the precision of carving illustrate a mix of 9th and early to mid 12th century styles.

Confirmed 9th-century sculptures are made of Lithotype 2, their posture is perceptibly supple, and they are carved with a very high level of detail. Conversely, early to mid 12th-century archaising copies are made of Lithotype 3, and are rigid without the regularity of carving or decoration. The pleats of the garments are not rendered in relief, but merely incised, and specific decorative elements on the headdress are characteristic of their later date (Figs. 18 and 19).[61] Unfinished *Umāgaṅgāpatīśvaras* from the Bakong workshop site are also rendered in Lithotype 3, and appear equally cumbersome, suggesting they too were commenced from the early to mid 12th century as copies of 9th-century templates.[62]

Lithotype 3 is analogous with specific sandstones already known for late 12th and early 13th-century sculptures. In previous studies, three distinctive types of grains characterised this sandstone type, including albitized feldspar, feldspar laths in the form of andesitic lithic fragments, and amphibole (var. hornblende).[63] These studies focussed on sculptures from the late 12th and early 13th century and supplementary sampling can appraise the earliest use of sandstone categorised as Lithotype 3 from the early to mid 12th century. Additional evidence of archaising restoration may be present on confirmed 9th-century sculptures. For example, a female deity from the Bakong temple[64] bears the marks of repair arguably attributable to the 12th century. Moreover, employment in the late 12th to early 13th century of Lithotype 3 is evidenced at Hariharālaya by images of Viṣṇu and a transformed Avalokiteśvara that adhere to the stylistic conventions of that period.[65]

58. Boisselier 1952a: 223.

59. Alvares 1992a: 21-22, 1992b: n. 50; Zéphir 1997: 202, after Le Bonheur. Image Ka1645, Rājendradevī in the form of Gaurī, from the southwest sanctuary tower of Lolei temple, was identified by the inscription K. 331 (Aymonier 1883: 470, 1901: 456–457).

60. DCA 219/ Sample #33, DCA 220/ Sample #34, DCA n62/ Sample #40, DCA n120 6871/ Sample #41, DCA n268 6872/ Sample #42, Ka1644/ Sample #43. It is feasible to add another three sculptures to this list (BKO12 03/ Sample #35, PKO13 16/ Sample #37, PKO13 19/ Sample #39). Although only the feet remain they are rendered in Lithotype 3 and are stylistically staid like their confirmed 12th-century counterparts. Similarly, the Harihara of Trapeang Phong (Ka951) composed in an 8th-century style complete with a redundant arch to support its extended arms can be identified with certainty as Lithotype 3 by qualitative petrographic analysis. We might also include the Śiva of Trapeang Phong (n299 3460, Angkor National Museum) whose stance is rigid and has crudely carved decorative elements (cf. Woodward 2010: 90).

61. See Zéphir 1997: 202. See incised *sampot* of DCA n62/ Sample #40, DCA n120 6871/ Sample #41, DCA n268 6872/ Sample #42, Ka1645, Ka1644/ Sample #43, Ka951 (8th-century style), the rudimentary and imprecise decoration on the headdress of Ka951 (8th-century style), and diagnostic 12th century chignon covers decorated with rows of lotus on Ka1645 and Ka1644/ Sample #43.

62. DCA 219/ Sample #33, DCA 220/ Sample #34.

63. Douglas & Sorensen 2007, Carò & Douglas 2013.

64. MG18862.

65. Viṣṇu DCA n51 3456 from Trapeang Phong, Viṣṇu DCA n306 4629 from Bakong, transformed Avalokiteśvara DCA n186 2720 from Preah Kô. See Carò & Douglas 2013.

Sources of Angkorian sandstone, networks of transportation and degrees of state control

The primary source of Hariharālaya's sandstone was reasonably the nearby Terrain Rouge formation of the Kulen hills, approximately 25 km to the northeast. Samples of the secondary deposit of sandstone debitage and Hariharālaya temple architecture are identified as feldspathic arenite (Lithotpye 1) and demonstrate the local origin of this material. By contrast, sculptures classified as Lithotype 3, and possibly Lithotype 2, are believed to be of Triassic age, and were quarried from comparatively remote locations. Absence of these sandstone outcrops in the Angkor area suggests the material was transported considerable distances either to be worked into images of the gods, or presented as finished sculptures.

We associate Lithotype 3 samples to prior petrographic analysis of late 12th to early 13th-century sculptures and field samples. The former study revealed that sandstone used for such sculptures from across the Angkorian kingdom was compositionally similar to sandstone exposed near Svay Damnak, a village approximately 16 km southeast of Preah Khan of Kompong Svay (Bakan) in Preah Vihear province and over 100 km from Angkor (see Fig. 20).[66] Although remains of quarrying activity in the form of wedging and splitting was found in the area of Svay Damnak, further archaeological study of the Triassic formation is needed to conclude that sandstone was quarried from this area and employed to create sculptures. Nevertheless, we can hypothesise that the Lithotype 3 stone identified in 12th-century sculptures here originates from the same formation. Other quarried outcrops of the Triassic sedimentary formation are known in Kratie province, although their composition differs from our Lithotype 3. We do not know the precise location of the outcrops utilised for Lithotype 2, but its overall composition may also correspond with a Triassic sedimentary formation and suggest this source was quarried for the raw materials of sculpture as early as the 9th century.

Recognition of a sandstone trade supplements the study of overland and riverine or canal based transportation networks.[67] If we consider the quantities of sandstone used for sculpture rendered from the Triassic formations[68] and the appreciable weight of this material,[69] the logistics of quarrying and the coordination of haulage across large distances required many hundreds of individuals. Logically an endeavour of this magnitude required an organisational framework with a degree of state-level direction or control. After all, the principal patrons of temple and sculpture manufacture were the kings of Angkor. We can also conceive that additional sculpture workshops were necessary at Angkor as well as at provincial centres like Preah Khan of Kompong Svay (Bakan). The proximity of Preah Khan of Kompong Svay to known Triassic formations may suggest that there were sculpture workshops at this site.

66. Carò & Douglas 2013.

67. See also Hendrickson 2010, Uchida & Shimoda 2013.

68. Total numbers are difficult to estimate, but the authors have previously identified 57 sculptures made from Lithotype 3 (see Carò & Douglas 2013). We might also consider an inscription from the temple of Preah Khan of Angkor that mentions 20,400 statues of gods rendered in materials including stone, distributed across the kingdom of Jayavarman VII (K. 908, D, st. CXXVII, in Cœdès 1941: 280, 297).

69. Approximately 25 ton per cubic meter. DCA 220, the unfinished *Umāgaṅgāpatīśvara* from the workshop (variable dimensions: H: 3.37 m, W: 1.51 m, L: 0.82 m) weighs approximately 104 ton carved into a rough form.

For example, one so-called late 12th-century portrait image of king Jayavarman VII,[70] and another seated figure with hands in *dhyānamudrā*[71] both found at Preah Khan of Kompong Svay (Bakan) are identified as quartz-poor, volcanic-rich sandstone of Triassic age,[72] recognised as the Lithotype 3 group of this study.

Implications and conclusions

The conjunction of excavation at a production centre and materials characterisation of debitage and finished outputs has implications for both disciplinary research and the focused field of Angkorian studies. Numerous scholars have deliberated the significance of Hariharālaya by applying stylistic analysis to its sculptures.[73] The recognition of a total of at least twelve archaising 12th-century images executed as 9th-century replicas[74] suggests the political administration based in central Angkor (Yaśodharapura) invested considerable material resources in maintaining and transforming the works and memory of an earlier urban capital. This evidence is in contrast with conventional historical interpretations that argue the 12th-century kings of Angkor had no interest in connecting themselves with their 9th and 10th-century predecessors.[75] Further consideration of activity and restoration at Hariharālaya in the 12th century is required.

The late 9th-century iconographic program of the Bakong is described by its foundation stèle and privileges the worship of Śiva through the installation of a *liṅga* atop the summit of the pyramid. The *liṅga* was surrounded by eight manifestations of Śiva that were presumably revered as sculptures in the eight brick towers of the first enclosure.[76] The inscription also designates the hierarchical emplacement of additional sculptures including one *Umāgaṅgāpatīśvara* that we logically associate with the triad recovered from the first enclosure.[77] The original position of this image is not known. Neither is that of an additional completed *Umāgaṅgāpatīśvara* triad found near the first enclosure eastern entry *gopura*.[78] The Śaiva representational configuration is supplanted by a new focus on the Vaiṣṇava cult in the 12th century consistent with religious preferences during the reign of Sūryavarman II (r. 1113/1114 – ca. 1150).[79]

From this time we observe an reconstruction of the central Bakong *prasat* and production of at least twelve new, but archaising sculptures. These actions are simultaneously reverent of Indravarman I's genealogy and subversive of his religious pantheon. For example, the 12th-century archaising sculpture of Rājendradevī in the form of Gaurī

70. Ka2851 (The National Museum of Cambodia).

71. Ka2770 (The National Museum of Cambodia).

72. Carò & Douglas 2013.

73. Stern 1932, 1938c, Boisselier 1952b, Dupont 1955, Dalsheimer 2001, Woodward 2010.

74. See footnote 76 for a list of the relevant archaising sculptures.

75. Cœdès 1968: 152-154.

76. K. 826, st. XXV, K. 826, st. XXIX (Cœdès 1937-1966, vol. I: 31-36).

77. K. 826, st. XXVIX (Cœdès 1937-1966, vol. I: 31-36). DCA n627 6870/ Sample #25. Also see Boisselier (1952b) for recognition of the Harihara mentioned in the inscription.

78. Alvares 1992b: 29. Pottier (pers. comm. April 2016) suggests the original location of one sculpture was in a shrine of the third enclosure.

79. Alvares 1992b: 32-33, Cœdès 1968: 162.

identified by an inscription in the southwest sanctuary tower of Lolei temple reproduces the original sculpture of Indravarman I's maternal grandmother, evidently in an act of piety.[80] Whereas the physical reorganisation of Indravarman I's pantheon at Bakong, which might have included the replacement of the central *liṅga* with an image of Viṣṇu,[81] and certainly the installation of a reappropriated *Umāgaṅgāpatīśvara* into a renovated brick tower,[82] repurposes the preceding iconographic order. We also note another comparatively small renovation in the late 12th to early 13th century represented by an image of Viṣṇu.[83] Whatever the new significance of the iconographic changes, *Umāgaṅgāpatīśvara* played an important role, and new sculptures of this representation were commissioned but not completed at the stone workshop west of the temple.

Apprehension of a major program of archaism at Hariharālaya opens the way for critical investigation of artistic style and the problematic coupling of chronology to iconographic and decorative types.[84] The Angkorian artisans were certainly aware of their own art history and other instances of archaism are known.[85] Nuanced analyses that employ conventional stylistic methodologies together with material studies will reveal new anomalies; for sculptures can no longer be dated only by their styles.

After over ten years of cumulative study dedicated to systematically characterising the sandstone of Angkor,[86] a pattern of sandstone choice is beginning to emerge. Angkorian stonemasons used one broad lithotype for architecture and its ornamentation (mostly quartz and feldspathic arenite, including Lithotype 1 of the present study), and another for sculptures of deities (a variety of immature, lithic sandstones of dark, greenish colour, including Lithotypes 2 and 3 of the present study).[87] Sandstone selection for sculptures does not appear to correspond with geographical or geological proximity, technical specifications of the material, the social or organisational context of production units, or the political administration of the state. Alternative hypotheses may find agreement with Angkorian belief systems evidenced from the epigraphic record. For example, the Bakong foundation stèle indicates that the central *liṅga* was made of stone procured from a riverbed.[88] Likewise, another inscription, K. 245, suggests the deliberate search for an appropriate stone to create a sculpture.[89]

Elaboration of sandstone production combined with the recent discovery of a copper-base alloy workshop[90] and ongoing studies of ceramic manufacture[91] advance research of

80. Ka1645; K. 331, Aymonier 1883: 470, 1901: 456-457.

81. Alvares 1992b: 33.

82. Tower east-north.

83. DCA n306 4629. See also Alvares 1992b: 34.

84. Polkinghorne 2007a: 117-165, 2011: 333-346.

85. Coral Rémusat 1940: 47, Polkinghorne 2007a: 157-159.

86. Douglas and Sorensen 2007; Uchida *et al.* 2007; Carò *et al*. 2014, 2015; Douglas *et al*. 2010; Carò & Douglas 2013; Uchida & Shimoda 2013.

87. Unpublished characterisation and observation suggests that stone from Triassic sedimentary formations, like those of Lithotypes 2 and 3, were also habitually chosen for inscriptions.

88. K. 826, st. XXXV, 881 CE, from Bakong: see Cœdès 1939: 33, 35.

89. K. 245, st. XVII, 10th century, from Prasat Ta Kam: Ang Choulean n.d., Cœdès 1937-1966, vol. III: 91-92. The authors are grateful to Siyonn Sophearith for bringing this reference to our attention.

90. Polkinghorne *et al*. 2014.

91. E.g. see Desbat *et al*. 2008, Chhay *et al*. 2010, Grave *et al*. 2015

classic period Southeast Asian production systems in the context of established theoretical frameworks.[92] Specialised crafts were fundamental to the creation and transformation of the Angkorian material, political and spiritual world. Yet the operational parameters of different specialisations require additional study. For instance, the degree of economic centralisation for the procurement of raw materials was likely different to the political control over products commissioned from the workshop artisans. The Hariharālaya workshop was logically attached to the political elite in the 12th century because of the nature of its sacred outputs and its proximity to the Bakong temple. The Angkorian elite understood well the power of temples and sculptures to confer political legitimacy and spiritual authority. Correspondingly, they consolidated power through controlling networks of production related to temples and sculpture. When we consider that highly specific stone lithotypes were quarried, transported, carved into images of the gods, and distributed to temples, the Hariharālaya stone workshop can be recognised as a transitory hub in the complex web of production specialists operating across the landscape of mainland Southeast Asia.

REFERENCES

Abbreviations

BEFEO: Bulletin de l'École française d'Extrême-Orient
DCA: Depot Conservation d'Angkor
EFEO: École française d'Extrême-Orient (French School of Asian Studies)
K.: "Khmer", inscription inventory number prefix
Ka: The National Museum of Cambodia inventory number prefix
MG: Musée Guimet inventory number prefix
n: "new", Dépôt de la Conservation d'Angkor inventory number prefix
RCA: *Rapport de la Conservation d'Angkor* [manuscript, unpublished, EFEO Archives]

Alvares, Sharon
1992a *L'iconographie des monument du X^e siècle à Angkor : répertoire*, Paris, Université Sorbonne Nouvelle – Paris 3, [D.E.A., unpublished thesis].
1992b "L'iconographie du temple du Bakong de sa fondation à la fin du XIII^e siècle," *Histoire de l'art* 20, pp. 27-38.

Ang, Choulean
n.d. "Bikarana – Consider", at Khmerenaissance, http://www.khmerenaissance.info/excepts_linguistics/38_bikarana.html, accessed on the 21/06/2015.

92. E.g. see van der Leeuw 1977, Brumfiel & Earle 1987, Costin 1991, 2001, 2005, Wailes 1996, Janusek 1999, Earle 2011.

André, Marie-Françoise, Bruno Phalip, Olivier Voldoire, Franck Vautier, Yves Géraud, Mhammed Benbakkar, Christopher Constantin, Fabienne Huber & Gilles Morvan
2011 "Weathering of sandstone lotus petals at the Angkor site: a 1000-year stone durability trial," Environmental Earth Science 63, pp. 1723-1739.

Aymonier, Étienne
1883 "Quelques notions sur les inscriptions en vieux khmer", *Journal Asiatique* 8/1, pp. 441–505.
1901 *Le Cambodge: II. Les provinces siamoises*, Paris, Ernest Leroux.

Balsillie, James H., Joseph F. Donoghue, Kenji M. Butler, & Jennifer L. Koch
2002 "Plotting equation for Gaussian percentiles and a spreadsheet program for generating probability plots," *Journal of Sedimentary Research* 72, pp. 929-943.

Bhattacharya, Kamaleswar
1961 *Les religions brahmaniques dans l'ancien Cambodge d'après l'épigraphie at l'iconographie*, Paris, EFEO.

Boisselier, Jean
1952a "Bĕn Mãlã et la chronologie des monuments du style d'Ankor Vat," *BEFEO* 46/1, pp. 187-226.
1952b "Le Harihara de Bàkon," *BEFEO* 46/1, pp. 253-256.
1966 Asia du Sud-Est: I. Le Cambodge. Paris, Manuel d'archéologie d'Extrême-Orient, Picard.

Brumfiel, Elizabeth M. & Timothy. K. Earle
1987 "Specialization, exchange, and complex societies: an introduction," in Elizabeth M. Brumfiel & Timothy K. Earle (eds.), *Specialization, exchange, and complex societies*, Cambridge, Cambridge University Press, pp. 1-9.

Carò, Federico & Janet G. Douglas
2013 "Nature and provenance of sandstone used for Bayon style sculptures produced during the reign of Jayavarman VII," *Journal of Archaeological Science* 40/1, pp. 723-734.

Carò, Federico & Im Sokrithy
2012 "Khmer sandstone quarries of Kulen Mountain and Koh Ker: a petrographic and geochemical study," *Journal of Archaeological Science* 39, pp. 1455-1466.

Carò, Federico, Polkinghorne, Martin & Douglas, Janet G.
2014 "Stone materials used for lintels and decorative elements of Khmer temples," in *Metropolitan Museum Studies in Art*, *Science, and Technology* 2, New York, Metropolitan Museum, pp. 51-68.
2015 "Stones of the Gods: material choice in peninsular Southeast Asia", Paper presented at the 15th Meeting of the European Association of Southeast Asian Archaeologists, Paris, July 2015.

Chhay Rachna, Chhay Visoth, Em Sochata & Tho Thon
2010 *Stoneware Production, Bangkong Kiln Site and their conservation plan*, Siem Reap, Department Conservation of Monuments in Angkor Park and Preventive Archaeology, APSARA Authority [Internal report].

Cœdès, George
1937–1966 *Inscriptions du Cambodge*, Hanoi / Paris, EFEO (8 vols).
1939 "Une statue de Siva récemment découverte à Bàkon (Cambodge)," *BEFEO* 39/2, pp. 220-221.
1941 "La stèle du Práḥ Khăn d'Aṅkor," *BEFEO* 41/2, pp. 255–301.
1968 *The Indianized States of Southeast Asia*, edited by Walter F. Vella, translated by Sue Brown Cowing, Honolulu, East-West Center Press.

Contri, Jean P.
1972 "Notice explicative sur la feuille Tbeng-Meanchey," in *Carte Géologique de Reconnaissance à 1/20000*. Paris, Editions du Bureau de Recherches Géologiques et Minières.

Coral-Rémusat, Gilberte de
1940 *L'art khmer. Les grandes étapes de son évolution*, Paris, Les Éditions d'art et d'histoire (Études d'art et d'ethnologie asiatiques 1).

Costin, Cathy. L.
1991 "Craft Specialization: Issues in Defining, Documenting, and Explaining the Organization of Production," in M. Schiffer (ed), *Archaeological Method and Theory vol. 3*, Tuscon, University of Arizona Press, pp. 1-55.
2001 "Craft Production Systems," in Gary M. Feinman & T. Douglas Price (eds.), *Archaeology at the Millennium. A Sourcebook*, New York, Kluwer Academic/ Plenum Publishers, pp. 273-327.
2005 "Craft Production," in Christopher Chippendale & Herbert D. G. Maschner (eds.), *Handbook of Archaeological Methods*, Lanham, Altamira Press, pp. 1034-1107.

Dalsheimer, Nadine
2001 *Les collections du musée de Phnom Penh. L'art du Cambodge ancien*, EFEO, Paris.

Desbat, Armand, Adeline Beuken, Dominique Laduron, Eric Llopis, Christophe Pottier, Anne Schmitt, Chea Socheat, Uong Savana, Alice Vierstraete
2008 Programme Cerangkor: Recherches sur les ateliers de potiers angkoriens. Rapport 2008, EFEO, Siem Reap [Unpublished report].

Delvert, Jean
1963 "Recherches sur l'érosion des grès des monuments d'Angkor," *BEFEO* 51/2, pp. 453-534.

Dickinson, William R.
1970 "Interpreting detrital modes of greywacke and arkose," *Journal of Sedimentary Petrology* 40, pp. 695-707.

Douglas, Janet G. & Sorena S. Sorensen
2007 "Mineralogical characteristics of Khmer stone sculpture in the Bayon style," in Janet. G. Douglas, Paul Jett & John Winter (eds.), *Scientific Research on the Sculptural Arts of Asia, Proceedings of the Third Forbes Symposium at the Freer Gallery of Art*, Washington, DC, Archetype Publications in association with the Freer Gallery of Art, Smithsonian Institution, pp. 115-124.

Douglas, Janet G., Frederico Carò & Christian Fischer
2010 "Evidence of Sandstone Usage for Sculpture during the Khmer Empire in Cambodia through Petrographic Analysis," *UDAYA Journal of Khmer Studies* 9, pp. 1-18.

Dumarçay, Jacques
1973 *Charpentes et tuiles khmères*, Paris, EFEO (Mémoires Archéologiques 8).

Dumarçay, Jacques & Royère, Pascal
2001 *Cambodian Architecture, Eighth to Thirteenth Centuries*, Translated by M. Smithies, Leiden, HdO Brill.

Dupont, Pierre
1955 *La statuaire préangkorienne*, Ascona, Artibus Asiae.

Earle, Timothy
2011 "Redistribution and the political economy: the evolution of an idea," *American Journal of Archaeology* 115, pp. 237–244.

Gazzi, Paolo
1966 "Le arenarie del flysch sopra cretaceo dell'Appennino modenese: correlazioni con il Flish di Monghidoro," *Mineralogica and Petrographica Acta* 16, pp. 69-97.

Glaize, Maurice
1939 *Mars 1939. Bakong. Rapports de la Conservation d'Angkor*, Paris, EFEO [Unpublished, archives].
1943 *Avril-Mai 1943. Bakong. Rapports de la Conservation d'Angkor*, Paris, EFEO [Unpublished, archives].
1944 *Les Monuments du groupe d'Angkor*, *Guide*, Saigon, Albert Portail.

Grave, Peter, Miriam Stark, Ea Darith, Lisa Kealhofer, Tan Boun-Suy, and Tin Tina
2015 "Differentiating Khmer Stoneware Production: An NAA pilot study from Siem Reap Province, Cambodia," *Archaeometry*, doi:10.1111/arcm.12220.

Groslier, Bernard Philippe
1969 "Angkor. The Terrace of the Leper King," *Nokor Khmer* 1, pp. 18–33.

Groslier, George
1921–1923 "Seconde étude sur la psychologie de l'artisan cambodgien," *Art et archéologie khmers* 1/2, pp. 205–220.

Hendrickson, Mitch
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, Mitch, Quan Hua & Thomas Oliver Pryce
2013 "Using in-slag charcoal as an indicator of 'terminal' iron production within the Angkorian period (10th–13th centuries AD) center of Preah Khan of Kompong Svay, Cambodia," *Radiocarbon* 55/1, pp. 31–47.

Jacques, Claude (with Dumont, René)
1990 *Angkor*, Paris, Bordas.

Janusek, John W.
1999 "Craft and Local Power: Embedded Specialization in Tiwanaku Cities," *Latin American Antiquity* 10/2, pp. 107-131

Kucera, Jan, JanK. Novák, Karel Kranda, Jaroslav Poncar, Ivana Krausová, L. Soukal, Olivier Cunin, Milos Lang
2008 "INAA and petrological study of sandstones from the Angkor monuments," *Journal of Radioanalytical and Nuclear Chemistry* 278, pp. 229-306.

van der Leeuw, Sander
1977 "Towards a study of the economics of pottery making," in B. L. van Beek, R. W. Brandt & W. Groenman-van Waateringe (eds.), *Ex Horreo*, Amsterdam, University of Amsterdam, pp. 68-76.

Ourng Vorn
1994 *The report of collection two block of statue from the west of Bakong Temple*, 15th June, 1994, Angkor Conservation, Siem Reap [Unpublished Report].

Penny, Dan, Christophe Pottier, Roland Fletcher, Mike Barbetti, David Fink & Hua Quan
2006 "Vegetation and land-use at Angkor, Cambodia: a dated pollen sequence from the Bakong temple moat," *Antiquity* 80, pp. 599–614.

Pichard, Pierre
1974 "Note sur quelques ouvrages inachevés à Pimai et à Panom Rung," *Art and Archaeology in Thailand*, Bangkok, Fine Arts Department, pp. 121–130.

Polkinghorne, Martin
2007a *Makers and Models: Decorative lintels of Khmer temples*, *7th to 11th centuries*, Sydney, The University of Sydney, 2 vols [Unpublished PhD Thesis].
2007b "Artists and Ateliers: Khmer Decorative Lintels of the ninth and tenth centuries," *Udaya – The Journal of Khmer Studies* 8, 219–241.
2008 "Khmer decorative lintels and the allocation of artistic labour," *Arts Asiatiques* 63, pp. 21–35.
2009 "The Artists of Angkor: contemporary and medieval stone workshops in Cambodia," *TAASA Review*, *The Journal of the Asian Art Society of Australia* 18/4, pp. 10–12.
2011 "Individuals under the Glaze: Local transformations of Indianisation in the decorative lintels of Angkor," in Manguin, P.-Y., Mani, A. and Wade, G. (eds.), *Early Interactions between South and Southeast Asia: Reflections on Cross-Cultural Movements*, Singapore, ISEAS Publishing, pp. 329–342.
2012 "Decorative lintels and ateliers at Mahendraparvata and Hariharalaya," in Klokke, M. J. and Degroot, V. (eds.), *Materializing Southeast Asia's Past*, Singapore, NUS Press, pp. 205–217.

Polkinghorne, Martin, Christophe Pottier, & Christian Fischer
2013 "One Buddha can hide another," *Journal Asiatique* 301/2, pp. 575–624.

Polkinghorne, Martin, Brice Vincent, Nicolas Thomas, David Bourgarit
2014 "Casting for the King: The Royal Palace Bronze workshop of Angkor Thom," *BEFEO* 100, pp. 327–358.

Pottier, Christophe
1996 "Notes sur le Bakong et son implantation," *BEFEO* 82, pp. 339–348.

Pottier, Christophe, Annie Bolle, Rethy. K. Chhem, Fabrice Demeter, Kyle Latinis, Tessa Boer-Mah, Rœland Stulemeijer, Manas Watanasak, & Seila Yam
2004 *Mission archéologique Franco-Khmère sur l'aménagement du territoire angkorien (MAFKATA). Campagne 2004. Rapport*, Siem Reap, EFEO [Unpublished Report].

Pottier, Christophe, Annie Bolle, Eric Llopis, Dominique Soutif, Cyril Tan, Jean Baptiste Chevance, Vireak Kong, Sosheat Chea, Sang Sum, Fabrice Demeter, Anne-Marie Bacon, Nicolas Bouchet, Caroline Souday, & Mélanie Frelat
2005 *Mission archéologique Franco-Khmère sur l'aménagement du territoire angkorien (MAFKATA). Campagne 2005. Rapport,* Siem Reap, EFEO [Unpublished Report].

Pottier, Christophe, Armand Desbat, Marie-France Dupoizat & Annie Bolle
2012 "Le matériel céramique à Prei Monti (Angkor)," in Vincent Lefèvre (ed.), *Orientalismes. De l'archéologie au musée. Mélanges offerts à Jean François Jarrige*, Turnhout, Brepols, pp. 291–317.

Rocks, D
2009 "Ancient Khmer Quarrying of Arkose Sandstone for Monumental Architecture and Sculpture," in *Proceedings of the Third International Congress on Construction History*, *Cottbus*, Berlin, Neunplus1, pp. 1235-1242.

Sotham, Sieng
1997 "Geology of Cambodia," in *Coordinating Committee for GeoScience Programs in East and Southeast Asia Technical Bulletin* 26, pp. 13–23.

Stern, Philippe
1932 "La transition de l'art préangkoréen à l'art angkoréen et Jayavarman II," *Études d'Orientalisme, vol. 1*., Musée Guimet, Mélanges Linossier, Paris, Ernest Leroux, pp. 507-524.
1938c "Hariharalaya et Indrapura," *BEFEO* 38/1, pp. 175-197.

Uchida Etsuo, Olivier Cunin, Suda Chiyuki, Ueno Akyio & Nakagawa Takeshi
2007 "Consideration on the construction process and the sandstone quarries during the Angkor period based on the magnetic susceptibility," *Journal of Archaeological Science* 34/6, pp. 924-935.

Uchida Etsuo & Shimoda Ichita
2013 "Quarries and transportation routes of Angkor monument sandstone blocks," *Journal of Archaeological Science* 40/2, pp. 1158-1164.

United Nations
1993 Geological Map of Cambodia, New York, United Nation Economic and Social Commission for Asia and the Pacific.

Vincent, Brice
2012 *Saṃrit. Étude de la métallurgie du bronze dans le Cambodge angkorien (fin du XI^e – début du XIII^e siècle)*, Paris, Université Sorbonne Nouvelle – Paris 3 [Unpublished PhD Thesis]

Vincent, Brice, David Bourgarit & Paul Jett
2012 "Khmer Bronze Metallurgy during the Angkorian Period (Twelfth to Thirteenth Centuries): Technical Investigation of a New Selected Corpus of Artifacts from the National Museum of Cambodia, Phnom Penh," in Paul Jett, Blythe McCarthy & Janet G. Douglas (eds.), *Scientific Research on Ancient Asian Metallurgy: Proceedings of the Fifth Forbes Symposium at the Freer Gallery of Art*, London, Archetype Publications, pp. 122–151.

Wailes, Bernard
1996 "V. Gordon Childe and the Relations of Production," in Bernard Wailes (ed.), *Craft Specialization and Social Evolution: In Memory of V. Gordon Childe*, Philadelphia, The University Museum of Archaeology and Anthropology, University of Pennsylvania, pp. 3-16.

Woodward, Hiram W.
2010 "Dvaravati, Si Thep, and Wendan," *Bulletin of the Indo-Pacific Prehistory Association* 30, pp. 87–97.

Zéphir, Thierry
1997 "Rājendradevī in the form of Gaurī," in Jessup, Helen Ibbitson, and Zéphir, Thierry (eds.), *Sculpture of Angkor and Ancient Cambodia: Millennium of Glory*, Washington D.C., National Gallery of Art, pp. 202–203.

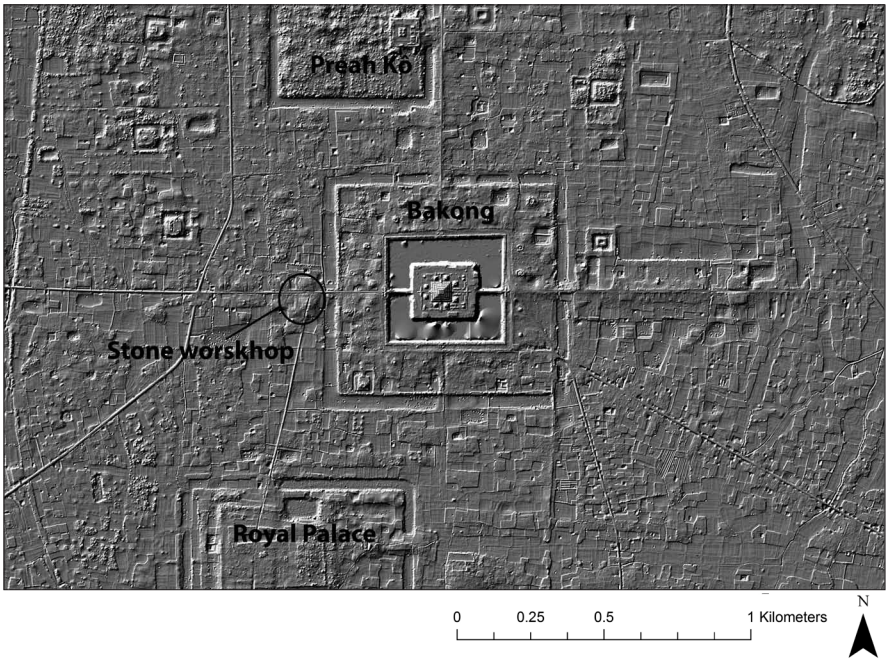

Figure 1. Central Hariharālaya, location of stone workshop, LiDAR (Image courtesy Khmer Archaeology LiDAR Consortium).

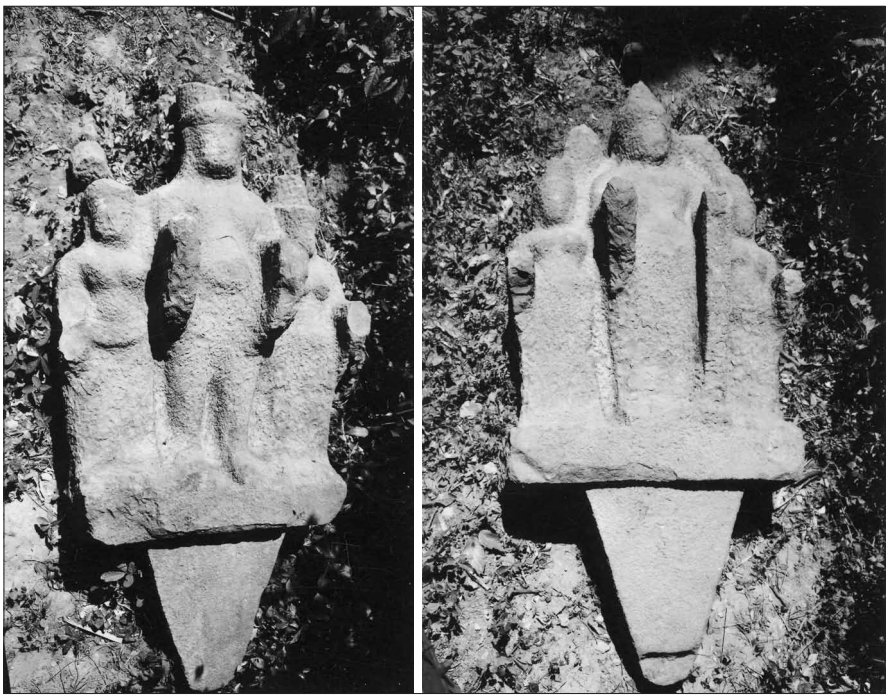

Figure 2. Unfinished Umāgaṅgāpatiśvara at Bakong workshop (left: 219/ Sample #33 [cliché EFEO, fonds Cambodge EFEO_CAM08084_2], right: 220/ Sample #34 [cliché EFEO, fonds Cambodge EFEO_CAM08084_3], images taken August 1964).

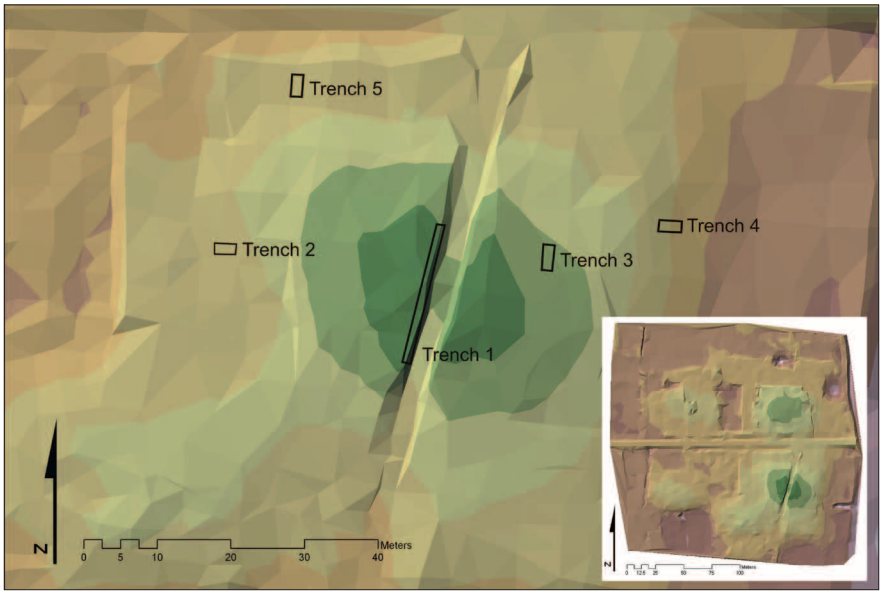

Figure 3. Topographic plan of Bakong stone workshop,
including position of excavation trenches.
Plan: Oung Savanna, Chea Socheat, Martin Polkinghorne.

Figure 4. Excavation Trench 1, general view from the north-east.
Photo: Martin Polkinghorne.

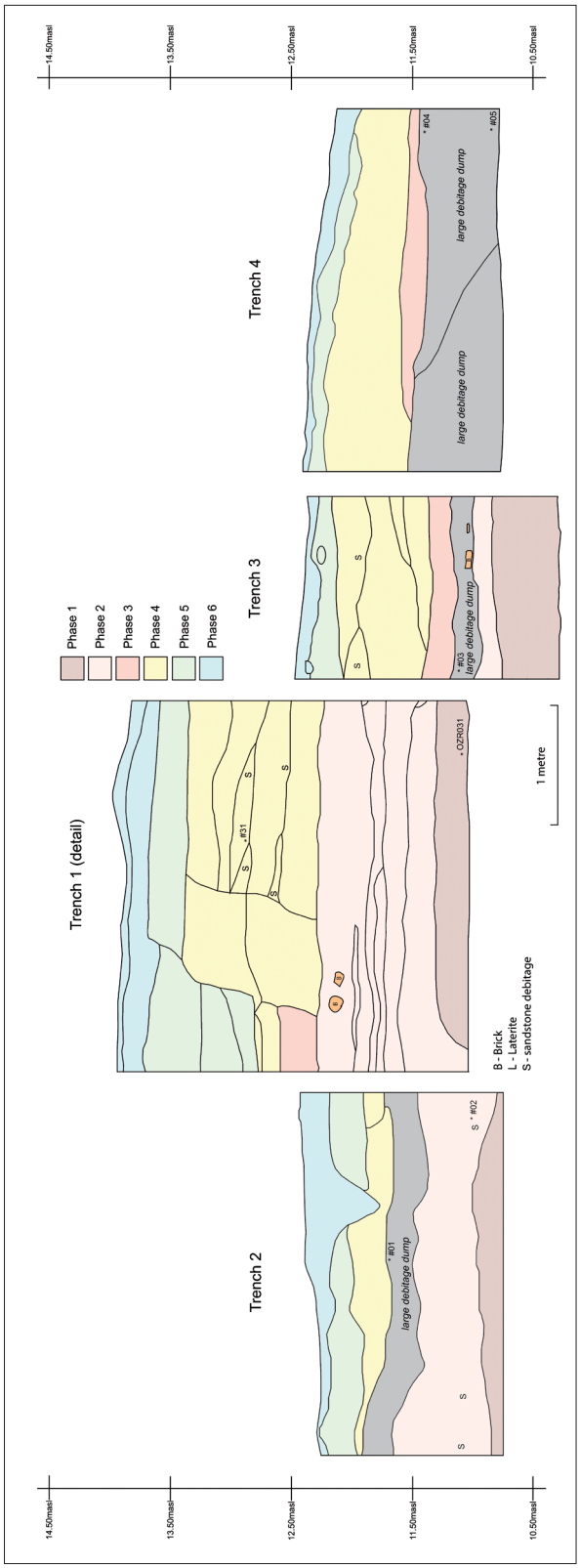

Figure 5. Details of stratigraphic sections: Trenches 1 - 4.
Drawings: Martin Polkinghorne, Suy Pov, Hou Nolamony, and Sally MacLennan.

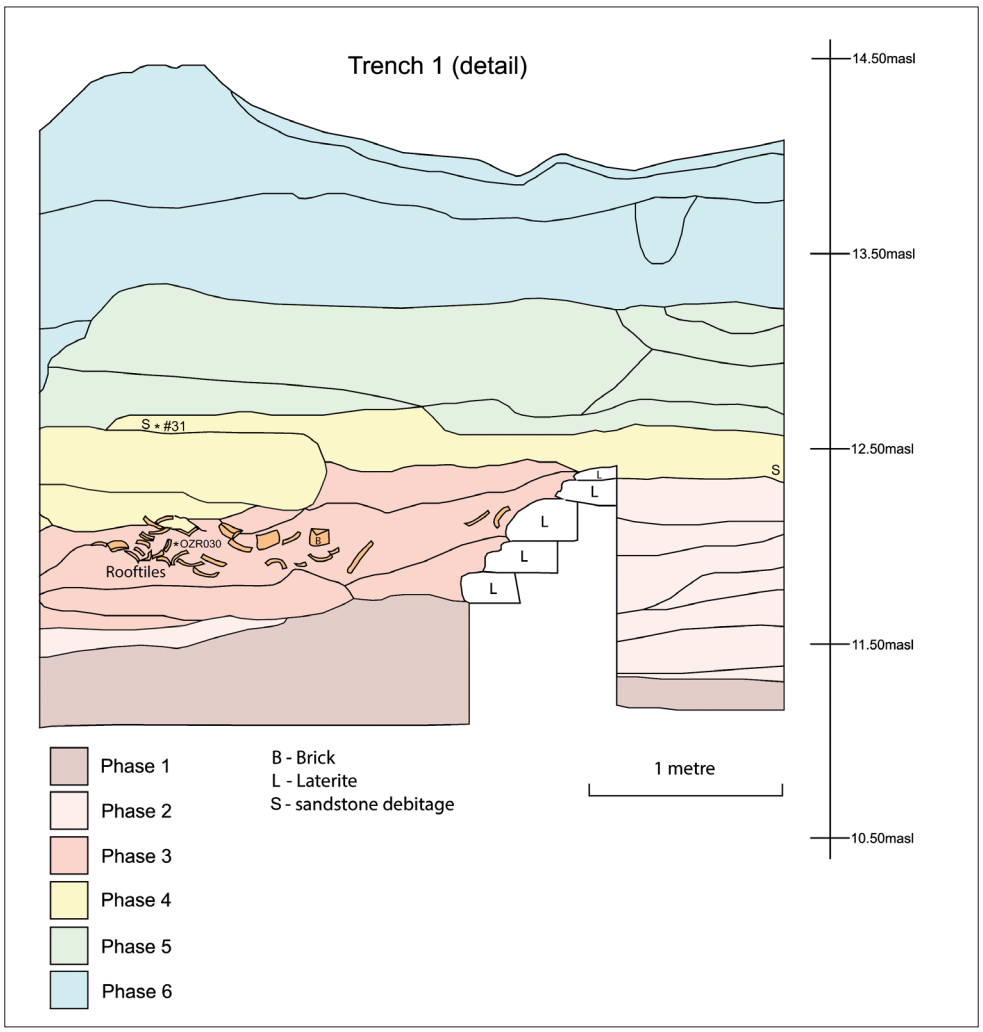

Figure 6. Detail of stratigraphic section: Trench 1 (west wall).
Drawing: Martin Polkinghorne and Suy Pov.

Figure 7. Building modenature and rooftile deposit (Trench 1). Photo: Sally MacLennan.

Figure 8. Excavation Trench 4, west wall, stratigraphic section, illustrating sandstone debitage dump (Phase 2). Photo: Martin Polkinghorne.

Figure 9. 9th century glazed rooftiles from collapsed roof (Phase 3, Artefact #01109.01.02). Photo: Martin Polkinghorne.

Figure 10. Excavation Trench 1, West wall, stratigraphic section, illustrating localised debitage dump (Phase 4).
Photo: Hen Chenda.

Figure 11. All sculptures (Numbers correspond to Sample # and data listed in Table 2): 6. BKO11 99001.20.01; 7. BKO13 02; 8. BKO13 04; 9. BKO13 05; 10. BKO13 08; 11. BKO13 09; 12. BKO13 10; 13. PKO13 11; 14. PKO13 13; 15. PKO13 14; 16. PKO13 15; 17. PKO13 20; 18. BKO13 06; 19. MG18220 (Courtesy musée Guimet); 20. MG18855 (Courtesy musée Guimet); 21. MG18879 (Courtesy Musée Guimet); 22. MG18858 (Courtesy musée Guimet); 23. DCA n730 3980 (cliché EFEO, fonds Cambodge EFEO_CAM08067), 24. BKO13 07 (cliché EFEO, fonds Cambodge EFEO_CAM08054); 25. DCA n627 6870 (cliché EFEO, fonds Cambodge EFEO_CAM07930); 26. Ka940 (Courtesy National Museum of Cambodia); 27. Ka1634 (Courtesy National Museum of Cambodia); 28. MG18862 (Courtesy musée Guimet); 29. Met 2003.592.1 (Courtesy Metropolitan Museum of Art); 32. BKO13 01; 33. DCA 219 (cliché EFEO, fonds Cambodge EFEO_CAM08084_2); 34. DCA 220 (cliché EFEO, fonds Cambodge EFEO_CAM08084_2); 35. BKO13 03; 36. PKO13 12; 37. PKO13 16; 38. PKO13 18; 39. PKO13 19; 40. DCA n62 (cliché UNESCO DCA Inventory cl01a236); 41. DCA n120 6871 (cliché UNESCO DCA Inventory cl40-227); 42. DCA n268 6872 (cliché UNESCO DCA Inventory cl03-227); 43. Ka1644 (Courtesy National Museum of Cambodia); 44. DCA n607 3979 (cliché UNESCO DCA Inventory cl07a245); 45. MG18217 (Courtesy musée Guimet). Otherwise noted all photos Martin Polkinghorne and Hen Chenda.

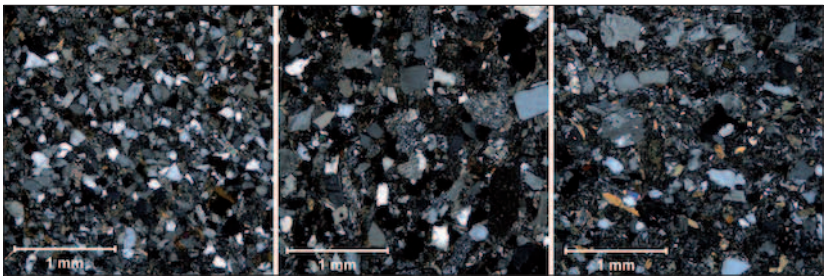

Figure 12. Micrographs under crossed polarized light showing sculpture sandstone types: a. Lithotype 1- Architectural sculpture from Preah Kô, Dvārapāla, east line, south prasat, southeast corner, Sample #15/ PK013 14; b. Lithotype 2 – 9th century Umāgaṅgāpatiśvara from Bakong, Sample #25/ n627 6870; c. Lithotype 3. 12th century Viṣṇu from Bakong, Sample #40/ DCA n62. Images: Janet Douglas

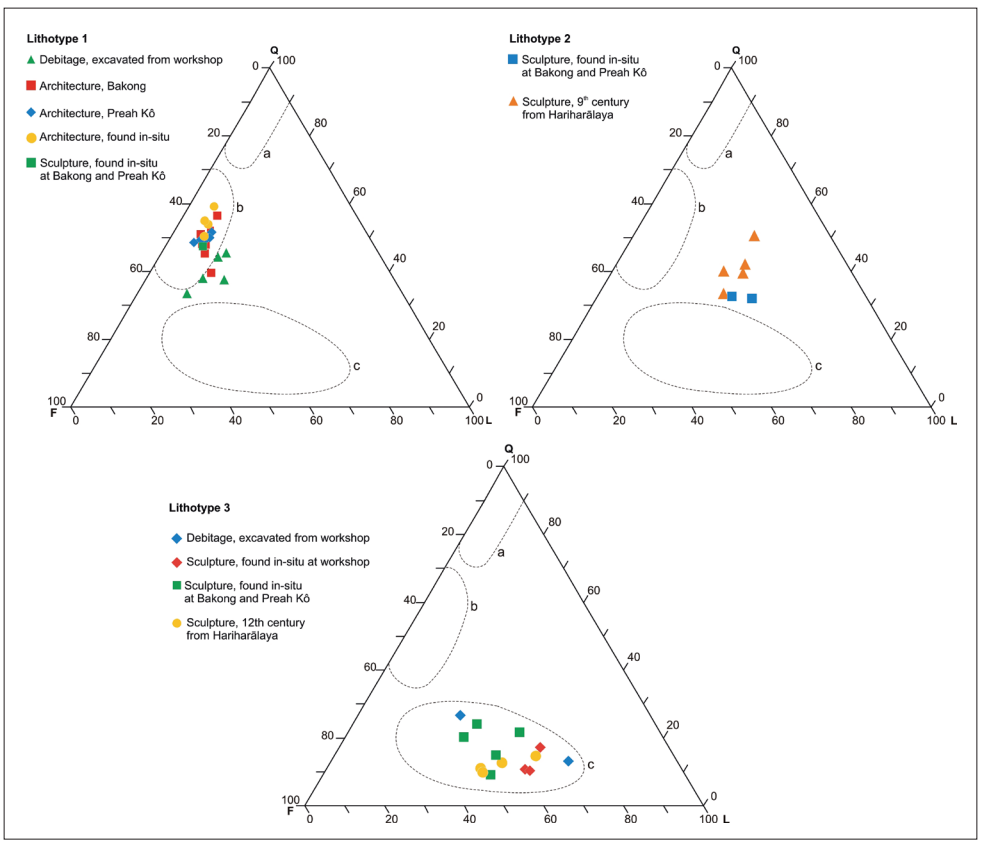

Figure 13. Ternary plots of the primary grain composition (Q: quartz; F: feldspar; L: lithic fragments) of the lithotypes 1, 2 and 3 in this study. The dashed lines show compositional regions of the three main lithotypes identified through petrographic characterisation in Cambodia to date: Region a: Quartz arenites of Upper Jurassic-Cretaceous age (Carò et. al. 2014); Region b: Feldspathic arenites of Lower-Middle Jurassic age (Carò and Im 2012); Region c: Volcanoclastic sandstones of Triassic age (Carò and Douglas 2013). Plots: Federico Carò.

Figure 14. Bakong pyramid blocks, first stage, north-east corner. Photo: Martin Polkinghorne.

Figure 15.
Dvārapāla, Preah Kô, east line, north prasat, north-east corner), example of architecutral ornamentation.
Photo: Martin Polkinghorne.

Figure 16. Umāgaṅgāpatiśvara in-situ, DCA n627 6870/
Sample #25, first enclosure, east-north tower (cliché
EFEO, fonds Cambodge EFEO_CAM07930).

Figure 17.Unifinished yoni in-situ, BKO13 01/ Sample #31.
Photo: Martin Polkinghorne.

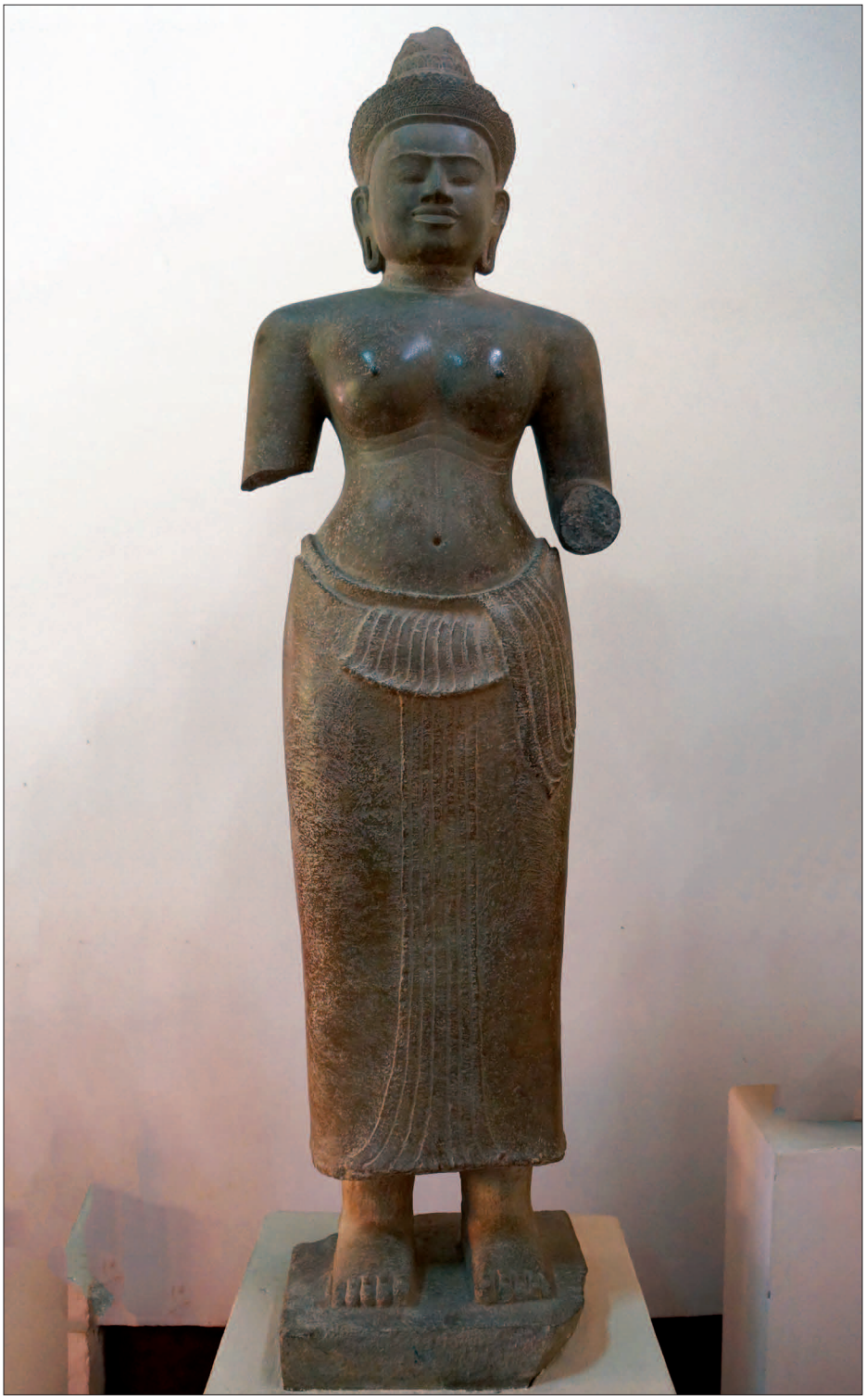

Figure 18. 12th century sculpture in the style of the 9th century, Rājendradevī in the form of Gaurī, from the southwest sanctuary tower of Lolei, Ka1645, National Museum of Camdodia (Image courtesy the National Museum of Cambodia).

Figure 19. Comparison of Female Deities; left: Met 2003_592_1/ Sample #29, 9th century, unknown provenance (Image courtesy Metropolitan Museum of Art); right: DCA n120 6870/ Sample #41, 12th century, Bakong (cliché UNESCO DCA Inventory cl40-227).

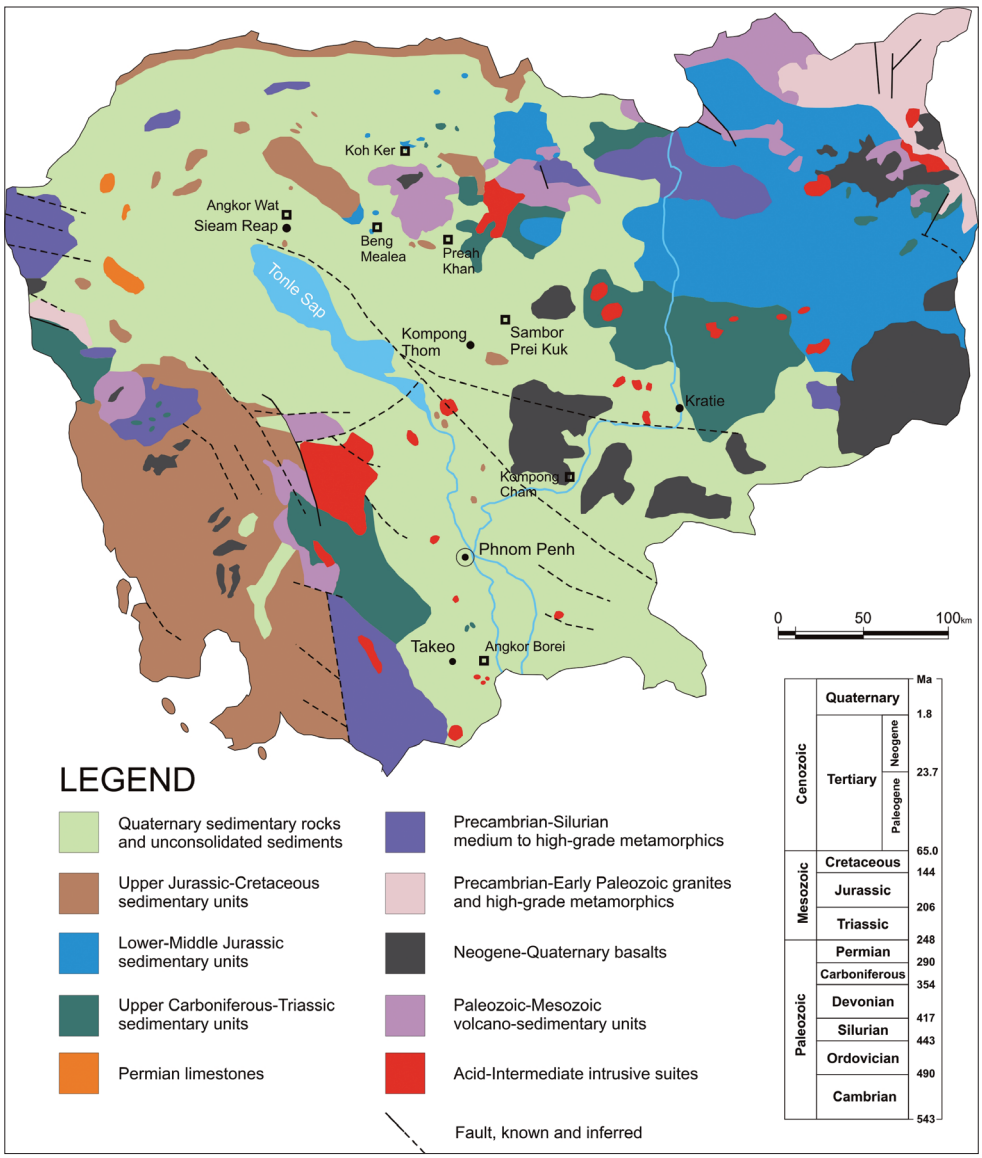

Figure 20. Simplified geological map of Cambodia, modified after United Nations 1993 (Douglas *et al.* 2010). Map: Federico Carò.