

Radiocarbon dating of Angkorian art and monuments

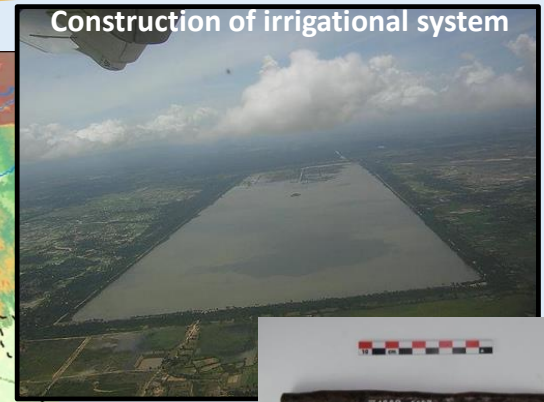
Direct dating of iron reinforcements



Emmanuelle Delqué-Količ, Stéphanie Leroy, Jean-Pascal Dumoulin and the LMC14 Team



The Khmer Empire (IXth - XVth c. CE)



A multidisciplinary approach to evaluate the role of iron (production, trade, consumption) in the expansion of the Khmer Empire (9th to 15th c. CE)
Dir. Stéphanie Leroy

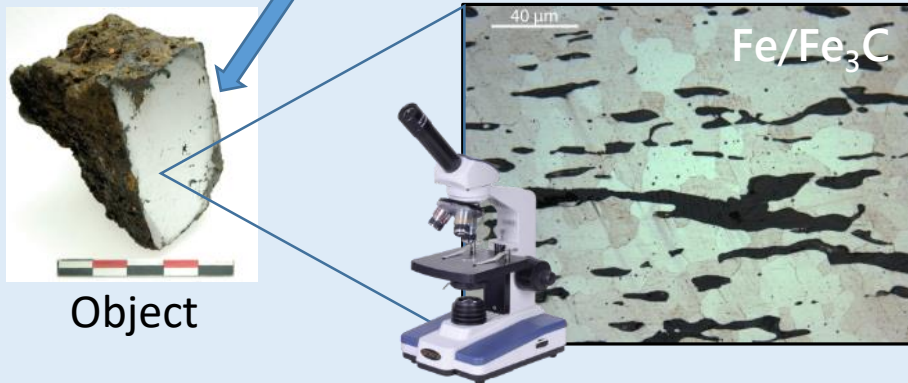
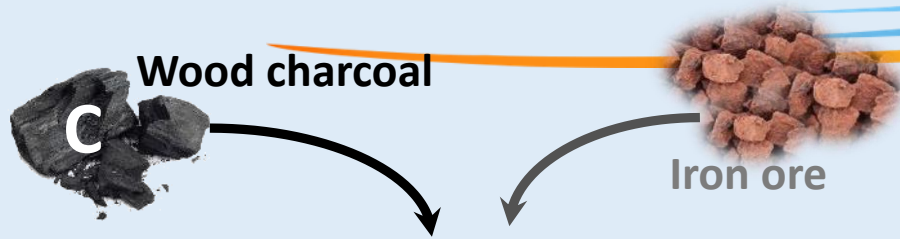
Angkor, monumental city

ANGKOR



HISTORICAL CHRONOLOGY :
interpretation of epigraphic sources/
stylistic evidences
→ Sources of debate

Datation ^{14}C du fer



^{14}C Dating

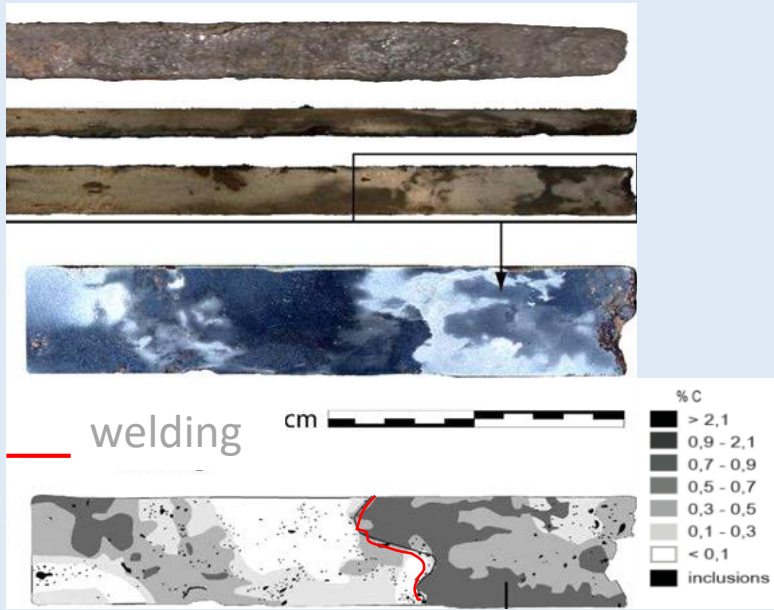


Manufacturing date of the metal

- ➔ Heterogeneous material with low carbon content
- ➔ Artefact history

Datation ^{14}C du fer

Metallographic observation of a cross section (optical microscope)



Object



Cutting, polishing



HNO_3 (3%) etching

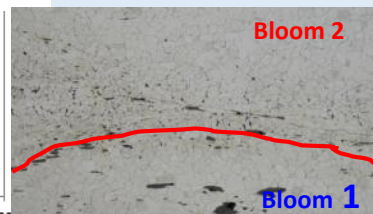
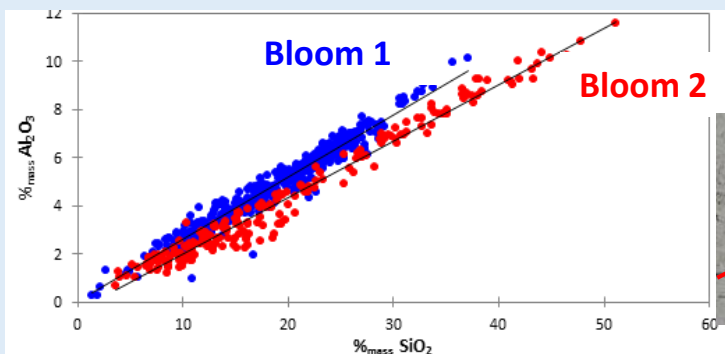


Distribution and content of carbon



Welding lines : Recycling metal ?

Compositionnal analysis of the slag inclusions (SEM-EDS)



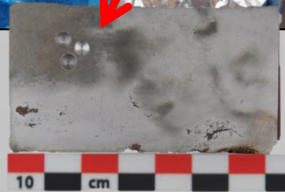
Use of flux (CaCO_3) ?

Recycling (made with different blooms) ?

^{14}C dating of iron

Sampling

- Drilling with TiN or CoB coated drills in the **most carburized areas**
- 50 to 1000 mg of iron

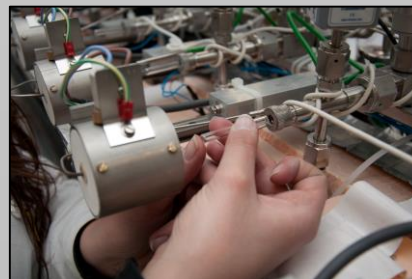


Combustion, Graphitization

- Iron particles + CuO (CuO/Fe=5) + Ag wire, 850°C, 5 h

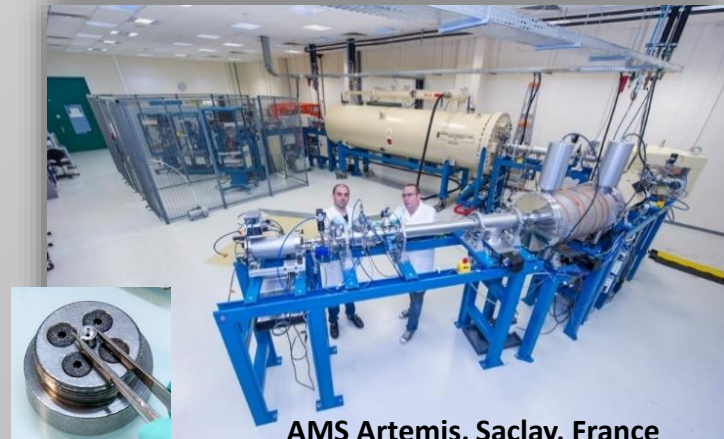


- $\text{CO}_2 + 2\text{H}_2 \rightarrow \text{C} + 2\text{H}_2\text{O}$, with Fe at 600°C



Measurement

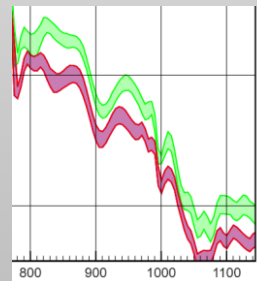
- AMS Artemis, Pelletron NEC 3MV, graphite source



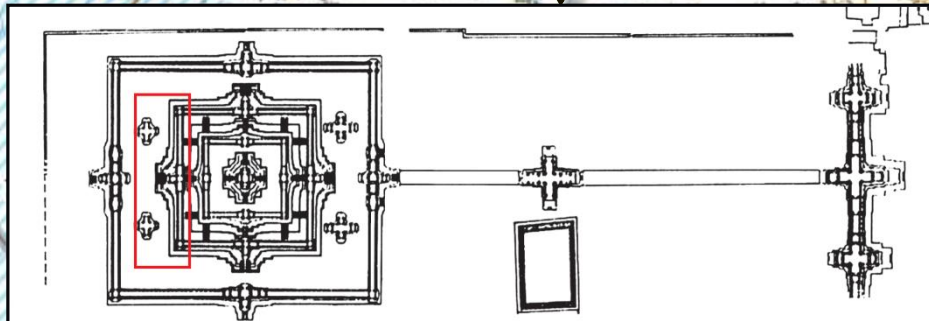
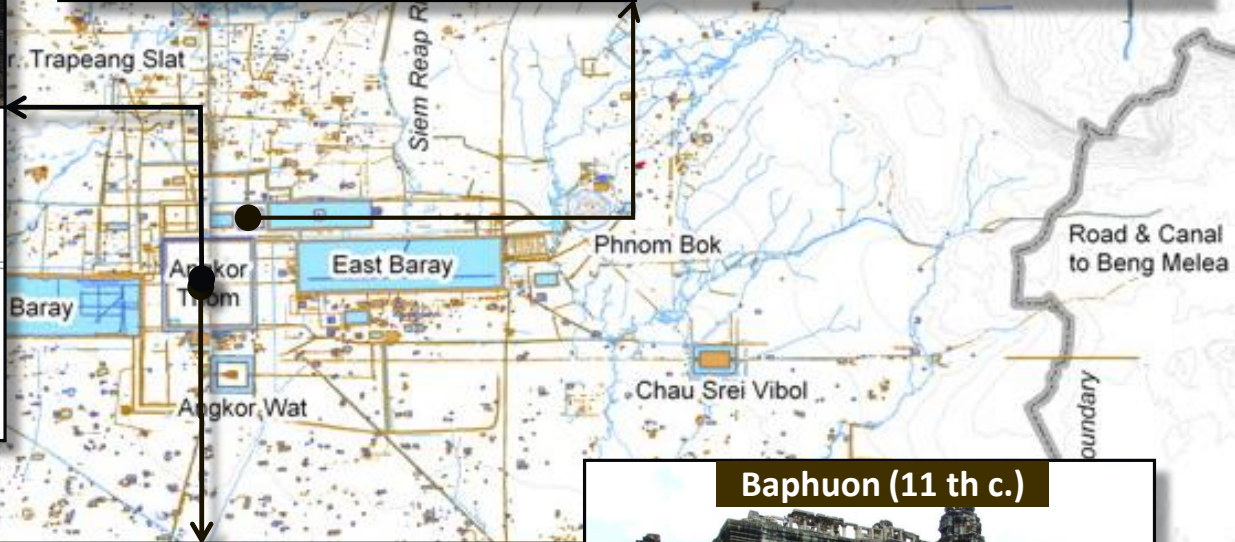
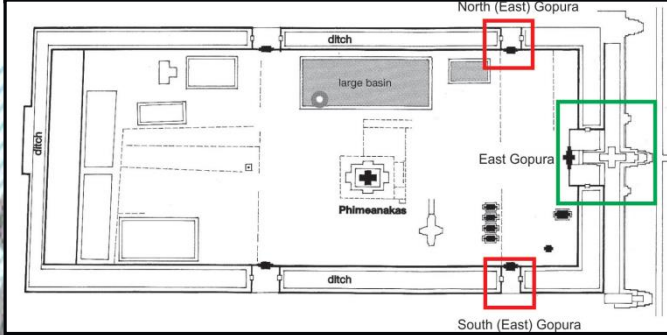
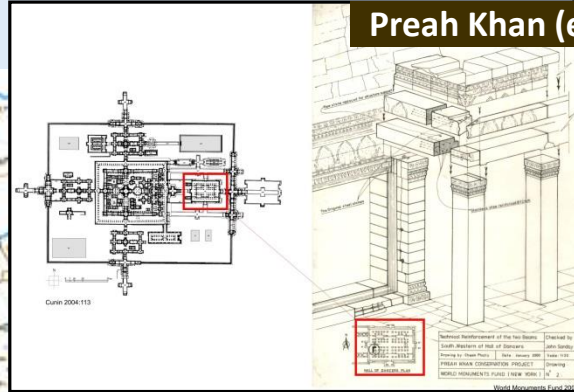
AMS Artemis, Saclay, France

Calibration

- North/South hemisphere influence
 - ✓ Mix_Curves("SE Asia", "NH", "SH", 50, 10)



Angkor monuments



Angkor monuments

Royal Palace (11th c.)



Preah Khan (end of 12th c.)



Typological classification

Metallographic observations



Preah Khan & Canal to Beng Melea

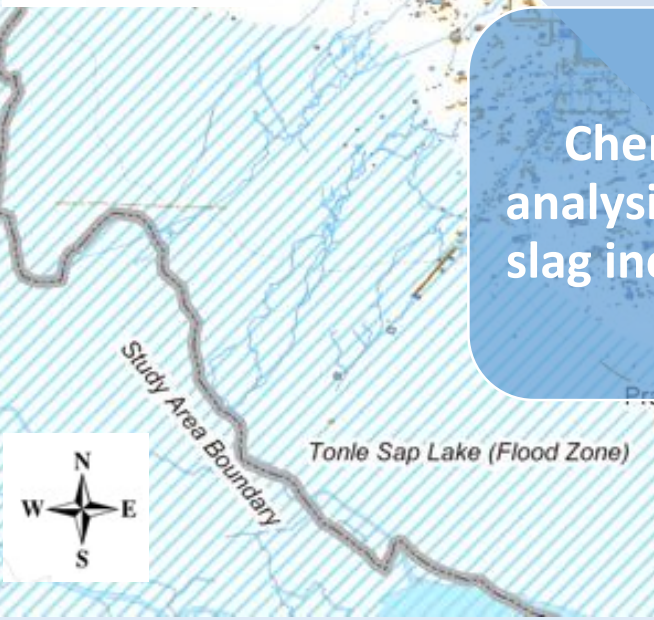
Chemical analysis of the slag inclusions

Radiocarbon dating

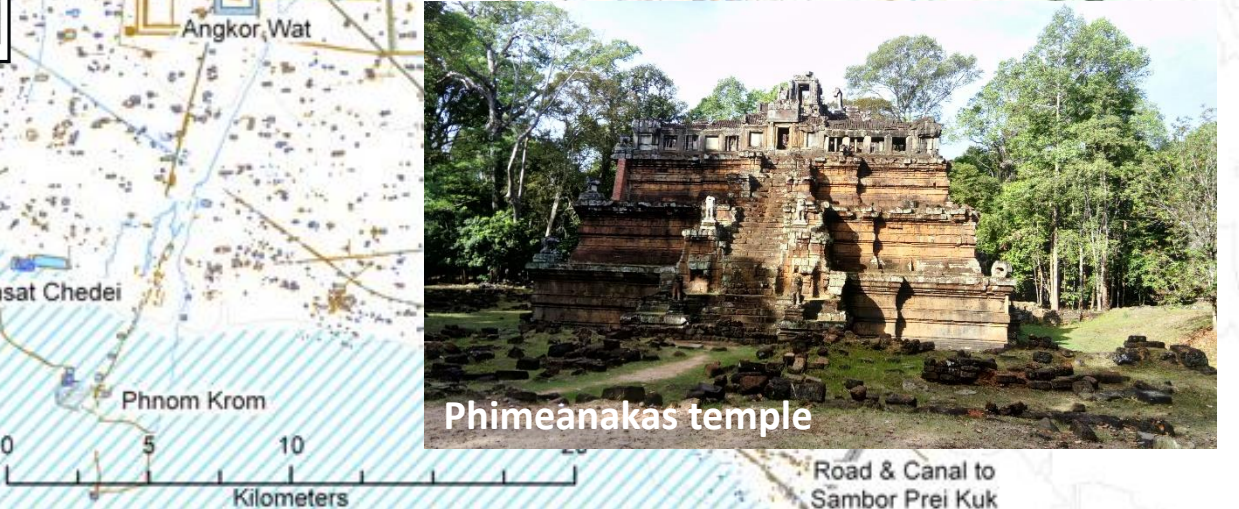
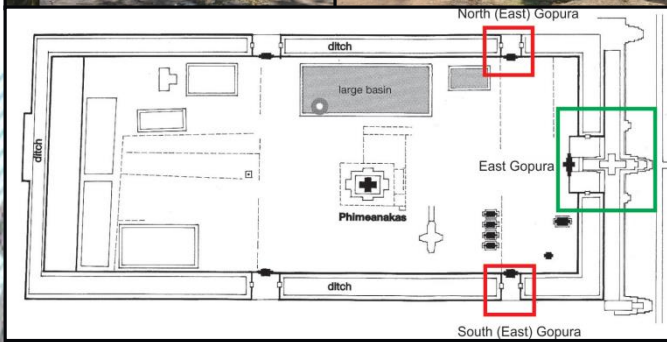
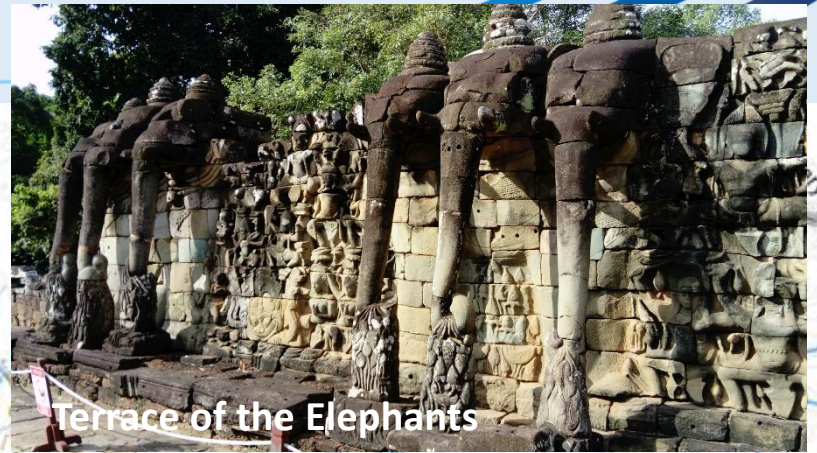
Baphuon (11th c.)





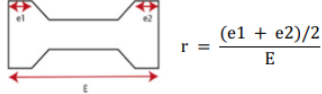


Baphuon



The Royal Palace



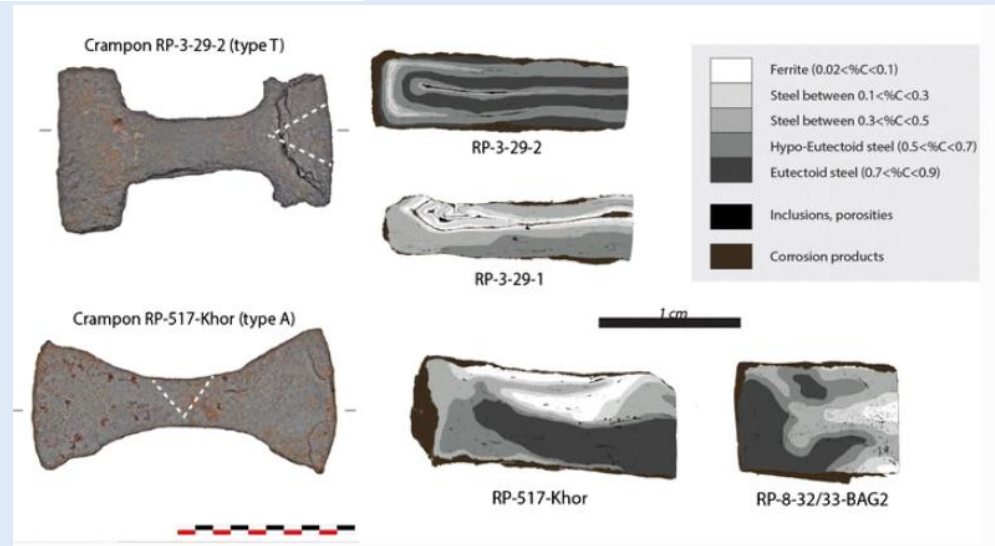
The Royal Palace

LEVEL 1 General shape	LEVEL 2 Ends shape			LEVEL 3 Body dimensions
Shape 1 is characterized by a Straight angle T (also called "en double T" in previous works)	T			T1; T2; T3
	1 Short end ($R < 3$)	2 Medium end ($3 < R < 4$)	3 Long end ($4 < R$)	L: $l > 200$ mm M: $180 \text{ mm} < l < 200$ mm S: $l < 180$ mm
	 $R = \frac{(l1 + l2)/2}{L}$			
Shape 2 is characterized by an Obtuse angle I ($\text{Angle} > 90^\circ\text{C}$ (called "en double T" in some works)	I			
	1 Tight end ($r > 7$)	2 Large end ($r > 7$)	3 Flared end	4 Roundish end
	 $r = \frac{(e1 + e2)/2}{E}$			Ratio (R) = length (l) / width (w) T: $R < 5$ M: $5 < R < 6$ F: $6 < R < 7$ VF: $R > 7$
Shape 3 is characterized by no visible angle Curve A (also called "en double queue d'aronde" in previous works)	A			A1; A2; A3
	1 Roundish end	2 Straight end	3 Asymmetrical end	Ratio (R) = length (l) / width (w) T: $R < 5$ M: $5 < R < 6$ F: $6 < R < 7$ VF: $R > 7$
				

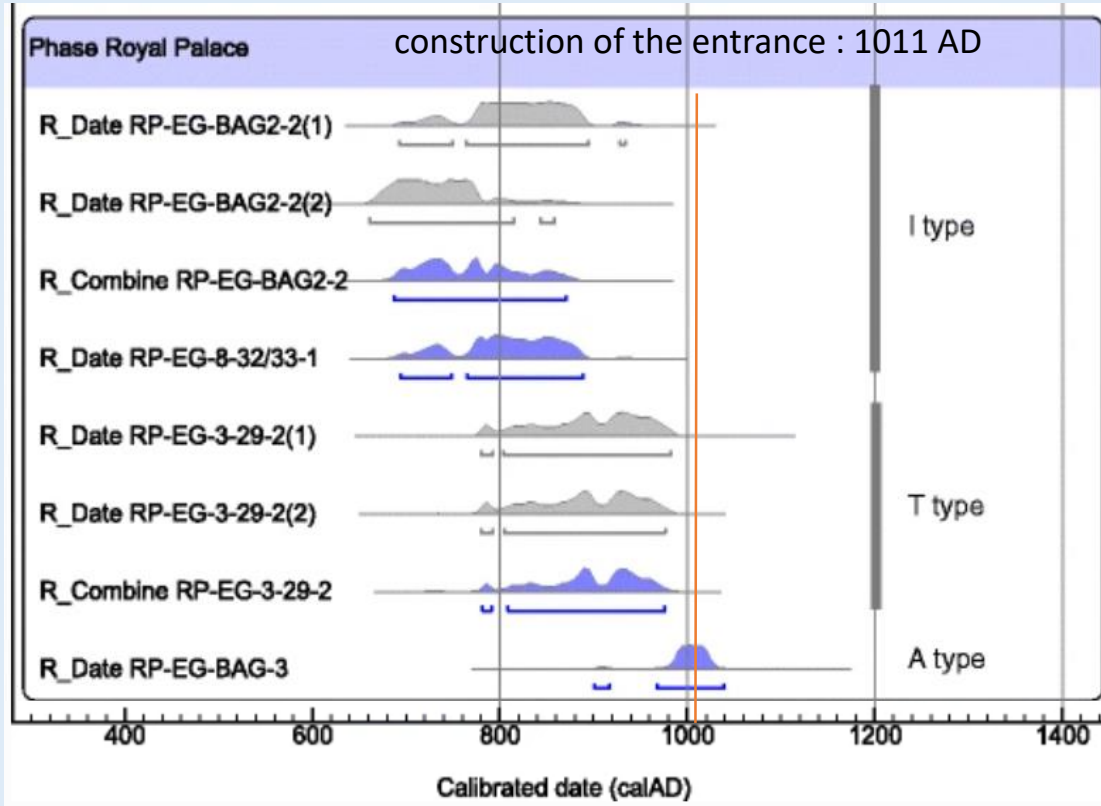
Shape « T »

Shape « I »

Shape « A »



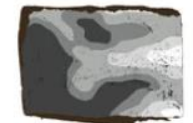
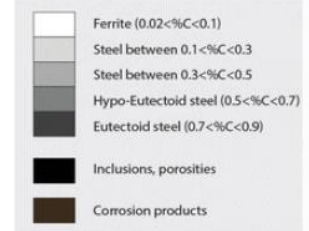
The Royal Palace



Shape « I »

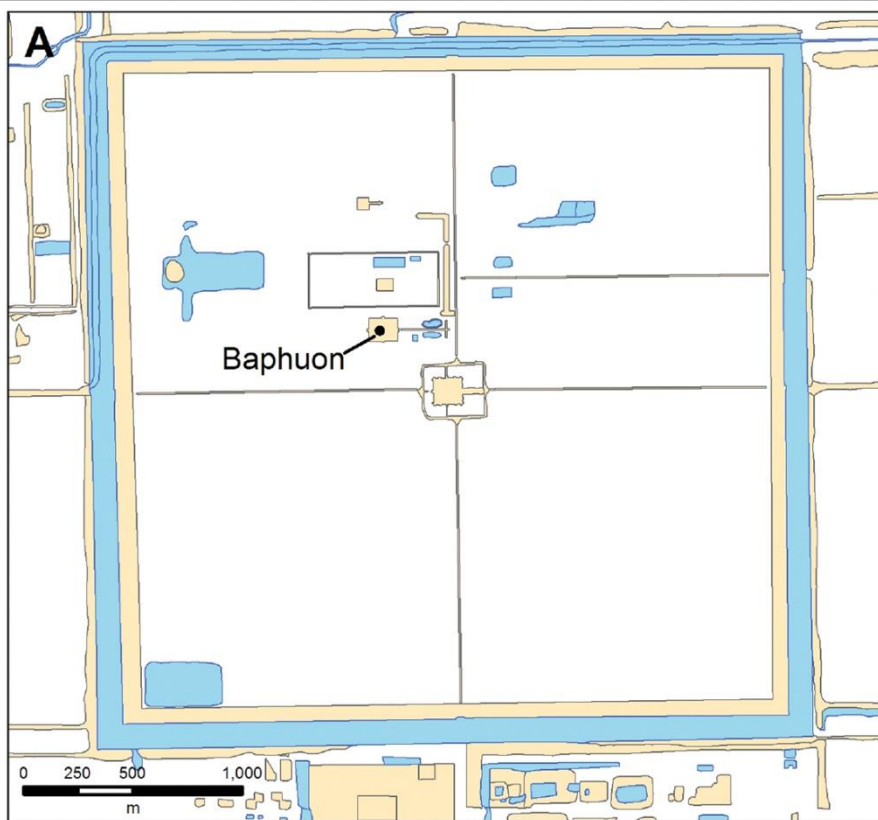
Shape « T »

Shape « A »

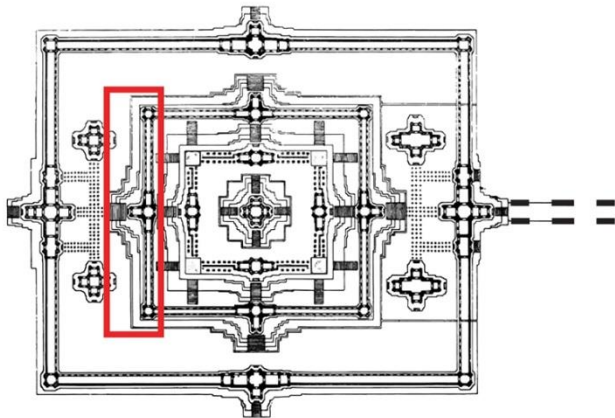


1 cm

Baphuon



C



Construction phase

- Indirect historical accounts
- Mistaken associations from unrelated inscriptions



Work of Udayadityavarman II (1050-1066)

Critical examination of this datation

(P. Royère 2006, W. A. Southworth 2008, ...)

Modification phase

- Later modification
- No 'official' record
- key evidence of Theravada Buddhist power
- Final moments of the royal presence in Angkor (beg. 16th c.)

Baphuon

Anastylosis by P. Royère (2006)

ETAGE 3

Reclining Buddha

50m

45m

40m

35m

30m

ETAGE 2

ETAGE 1

BPN30006



BPN30001



BPN30002



BPN30009



« A » crampons

BPN-30001



BPN-30002



BPN-30006



BPN-30009



BPN-30009(1)

BPN-30009(2)



0 10 cm

10 cm

10 cm

10 cm

10 cm

Baphuon

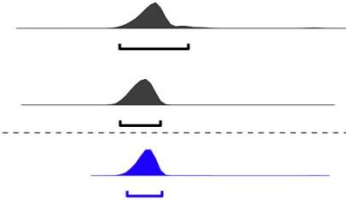
Leroy et al. (2015). PLOS ONE
Construction and Modification of the Baphuon Temple Mountain in Angkor, Cambodia.

Reclining Buddha modification

BPN-30009(1)

BPN-30009(2)

Combine BPN-30009



Construction phase

BPN-30006

BPN-30002(1)

BPN-30002(2)

Combine BPN-30002

BPN-30001(1)

BPN-30001(2)

Combine BPN-30001

600 800 1000 1200 1400 1600

Calibrated date (calAD)

Baphuon

Leroy et al. (2015). PLOS ONE
Construction and Modification of the Baphuon Temple Mountain in Angkor, Cambodia.

RECLINING BUDDHA MODIFICATION

BPN-30009(1)

BPN-30009(2)

Combine BPN-30009

CONSTRUCTION PHASE

BPN-30006

BPN-30002(1)

BPN-30002(2)

Combine BPN-30002

BPN-30001(1)

BPN-30001(2)

Combine BPN-30001

600

800

1000

1200

1400

1600

Calibrated date (calAD)

Jayavarman V
Suryavarman I
Udayadityavarman II

Standard hypothesis but:

- Indirect historical accounts
- Mistaken associations from unrelated inscriptions
- Brief reign

Baphuon

Leroy et al. (2015). PLOS ONE
Construction and Modification of the Baphuon Temple Mountain in Angkor, Cambodia.

RECLINING BUDDHA MODIFICATION

BPN-30009(1)

BPN-30009(2)

Already associated with the
Ta Keo temple (975- ...)

Standard hypothesis but:

- Indirect historical accounts
- Mistaken associations from unrelated inscriptions
- Brief reign

CONSTRUCTION PHASE

BPN-30006

BPN-30002(1)

BPN-30002(2)

Combine BPN-30002

BPN-30001(1)

BPN-30001(2)

Combine BPN-30001

Jayavarman V
Suryavarman I
Udayadityavarman II

600

800

1000

1200

1400

1600

Calibrated date (calAD)

Baphuon

Leroy et al. (2015). PLOS ONE
Construction and Modification of the Baphuon Temple Mountain in Angkor, Cambodia.

RECLINING BUDDHA MODIFICATION

BPN-30009(1)

BPN-30009(2)

Already associated with the
Ta Keo temple (975- ...)

Standard hypothesis but:

- Indirect historical accounts
- Mistaken associations from unrelated inscriptions
- Brief reign

CONSTRUCTION PHASE

BPN-30006

BPN-30002(1)

BPN-30002(2)

- Responsible for re-establishing Khmer dominance
 - Not yet associated with his own temple

BPN-30001(1)

BPN-30001(2)

Combine BPN-30001

600

800

1000

1200

1400

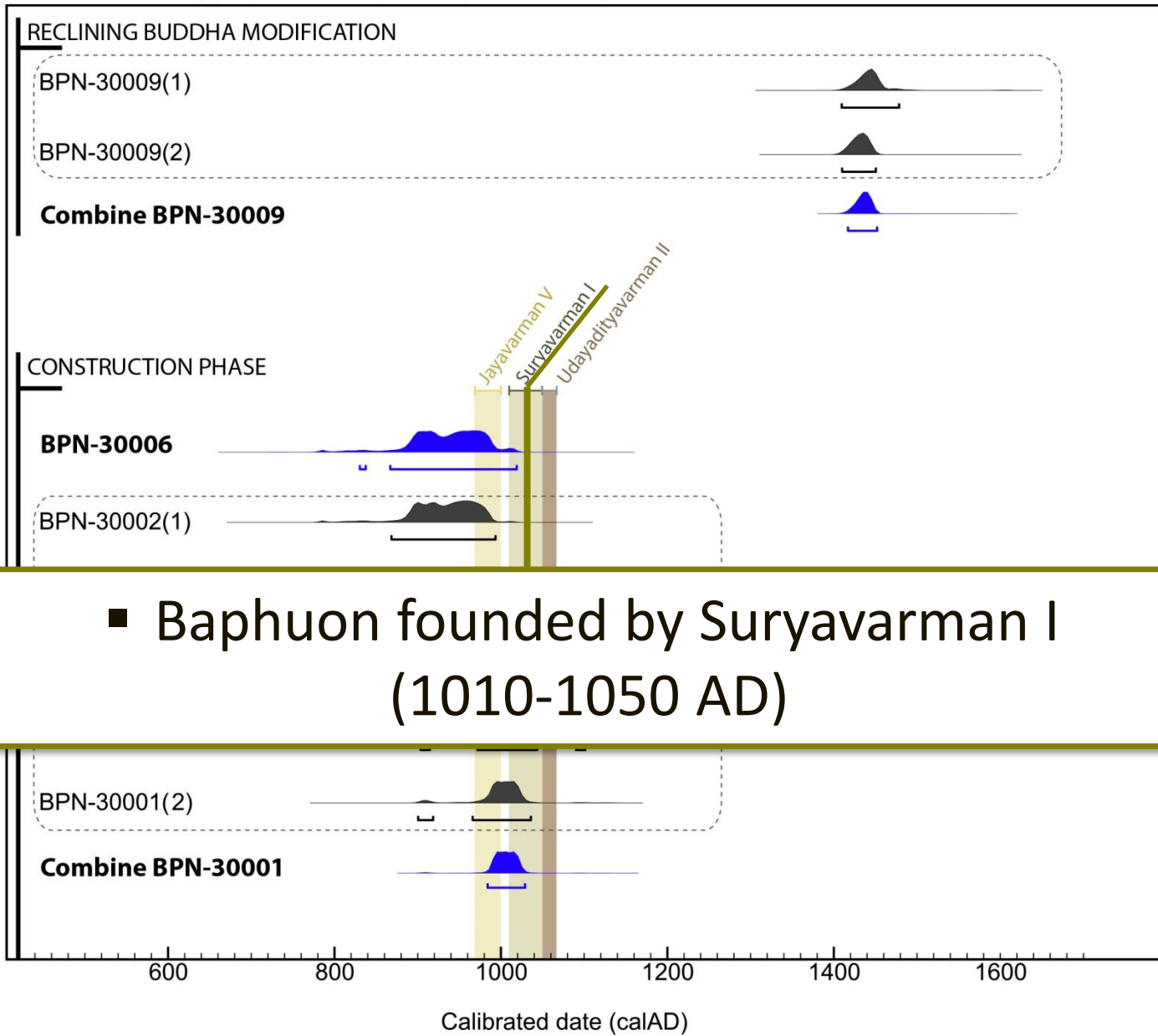
1600

Calibrated date (calAD)

Jayavarman V
Suryavarman I
Udayadityavarman II

Baphuon

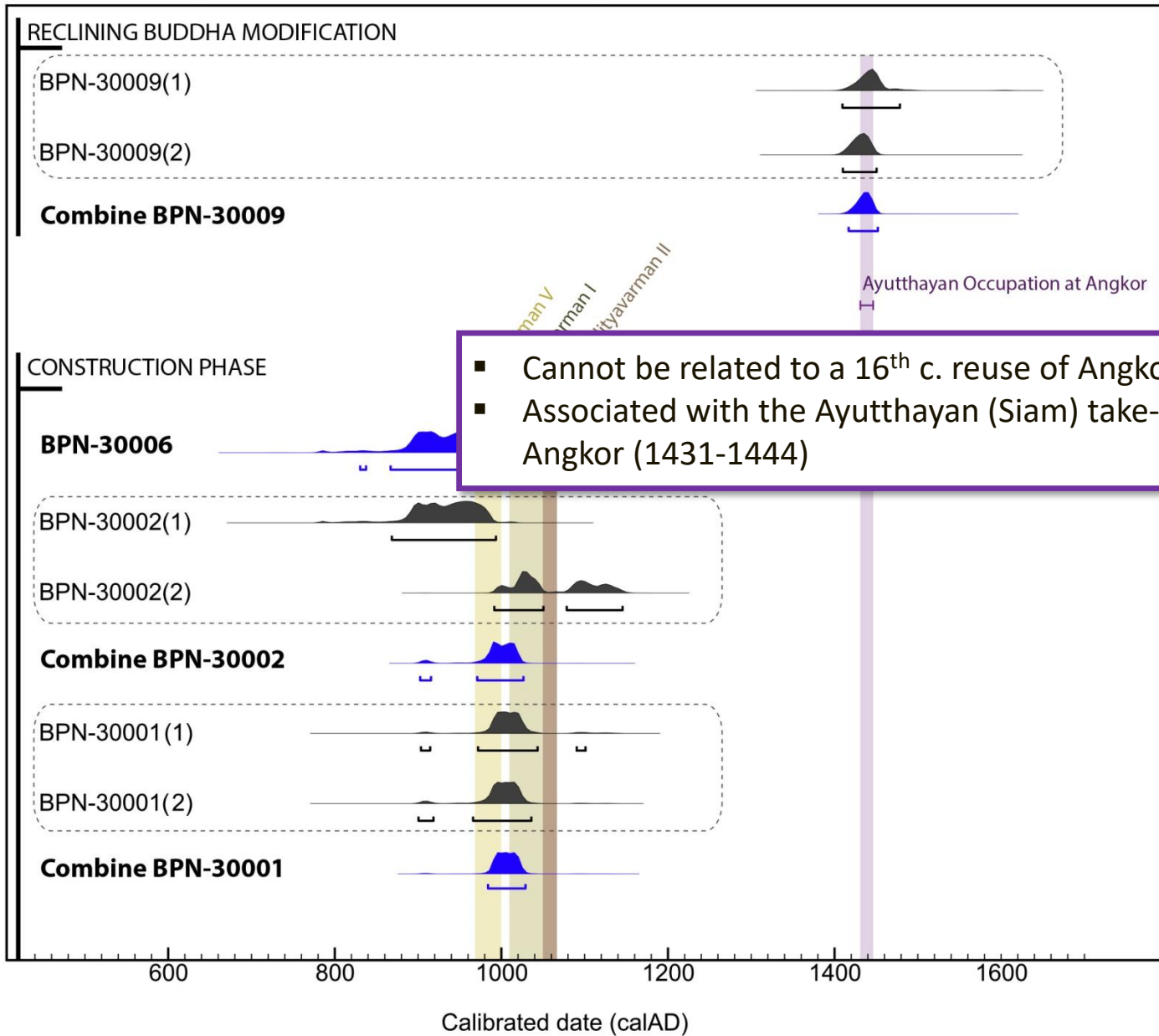
Leroy et al. (2015). PLOS ONE
Construction and Modification of the Baphuon Temple Mountain in Angkor, Cambodia.



Baphuon

Leroy et al. (2015). PLOS ONE

Construction and Modification of the Baphuon Temple Mountain in Angkor, Cambodia.

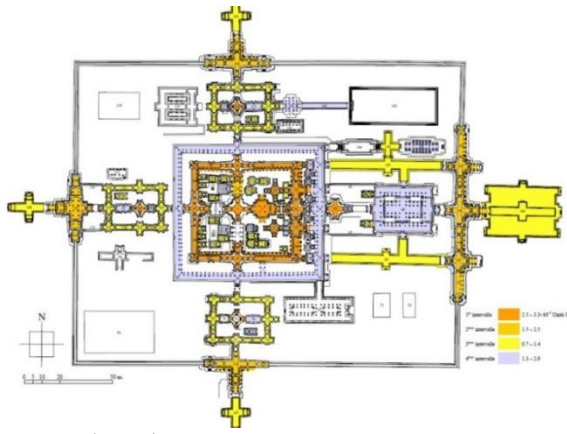


Angkorian architecture

→ Consecration date 1191
 Stele of Preah Khan
 -Jayavarman VII (1181-1218)-



Preah Khan (end of 12th c.)



Cunin (2004)

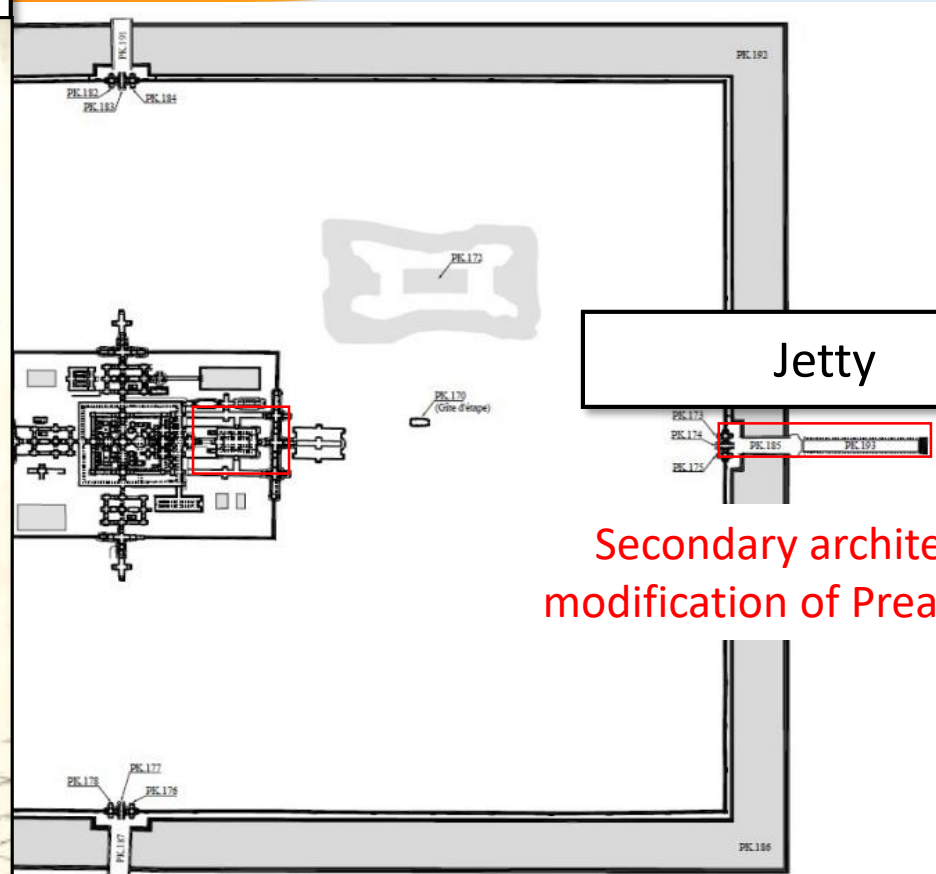
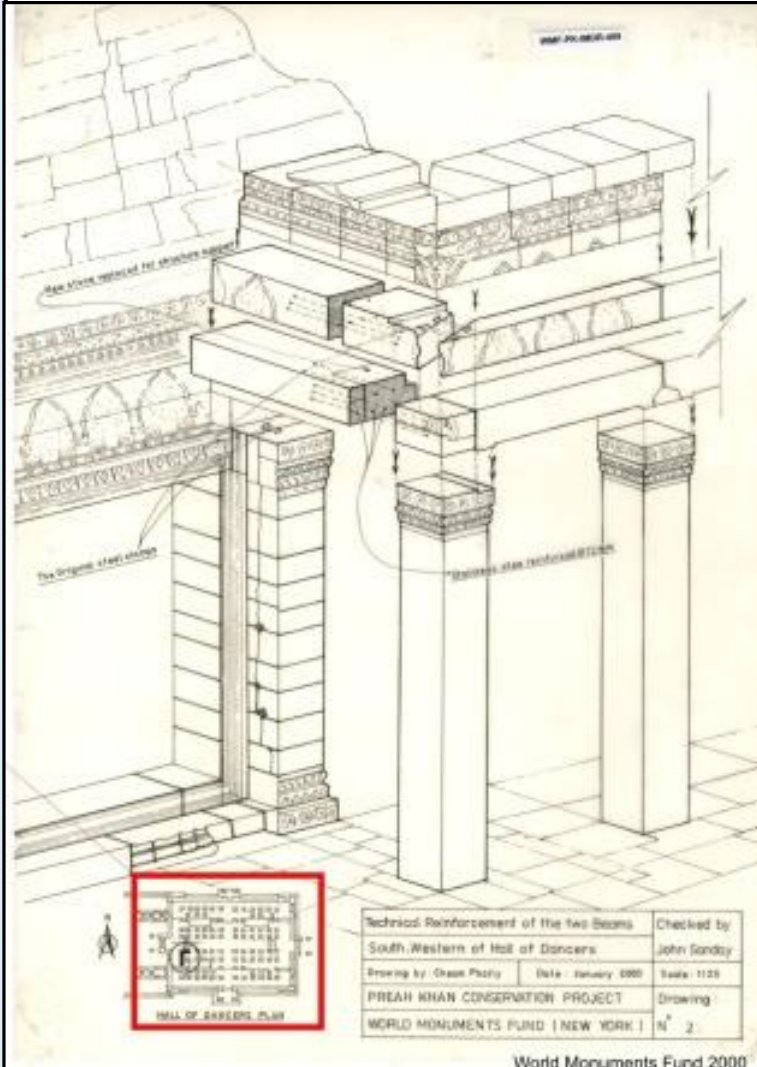


(Coedes, 1941)



Preah Khan

Hall of Dancers

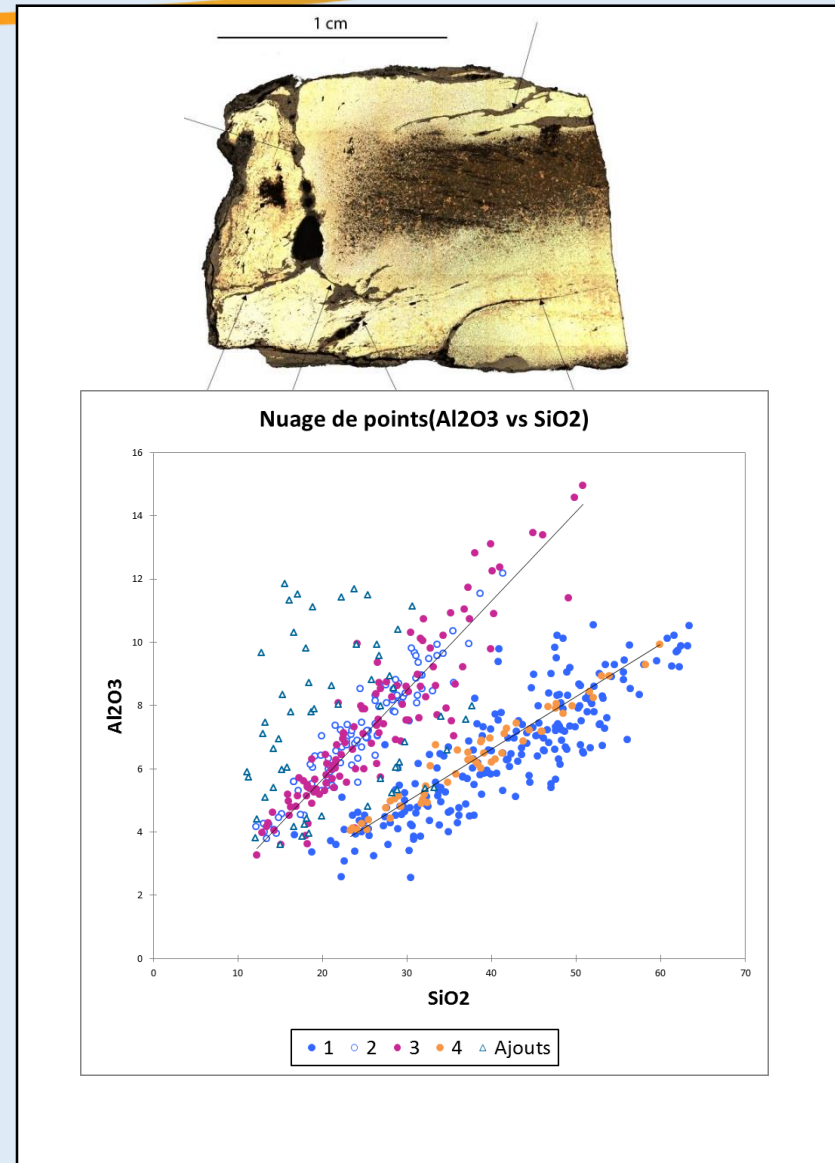
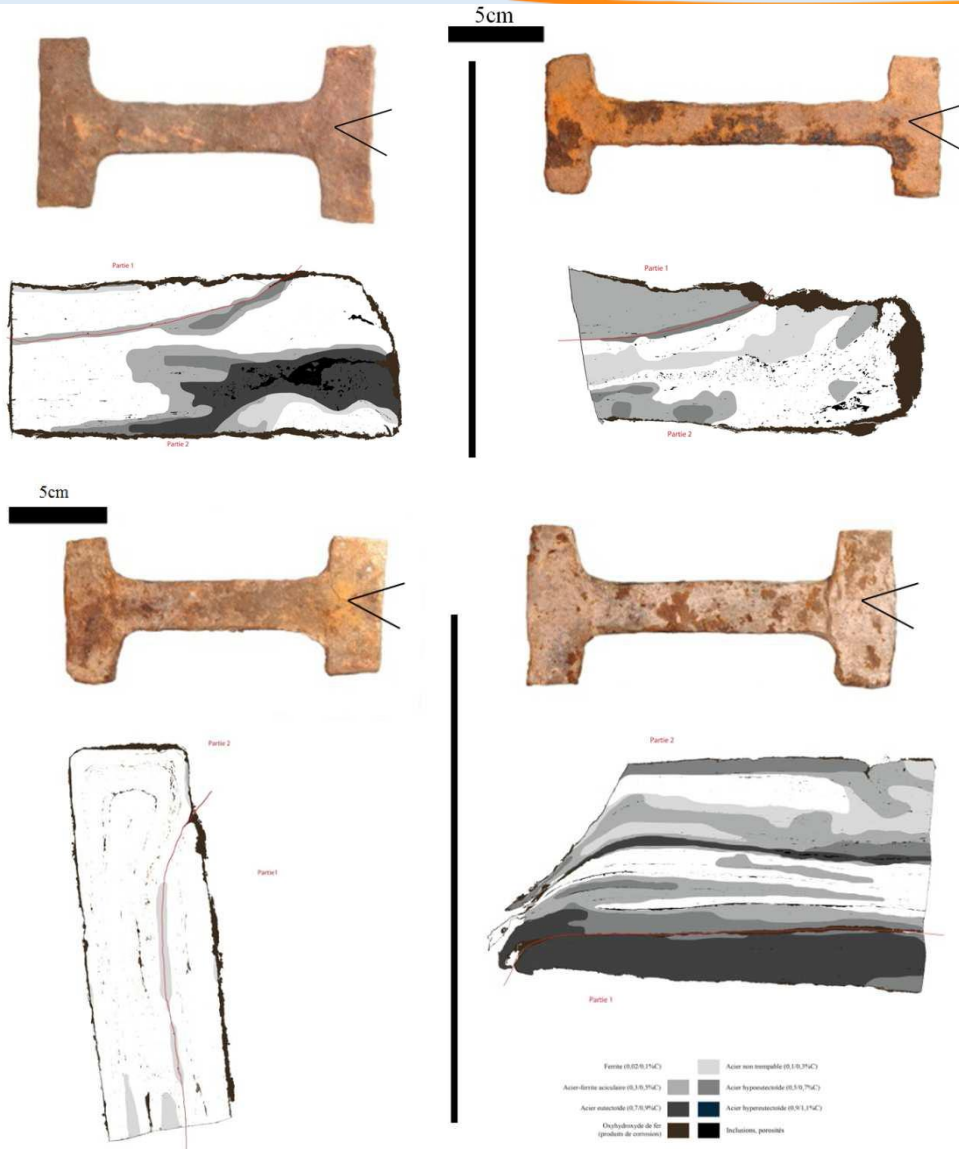


Jetty

Secondary architectural
modification of Preah Khan ?

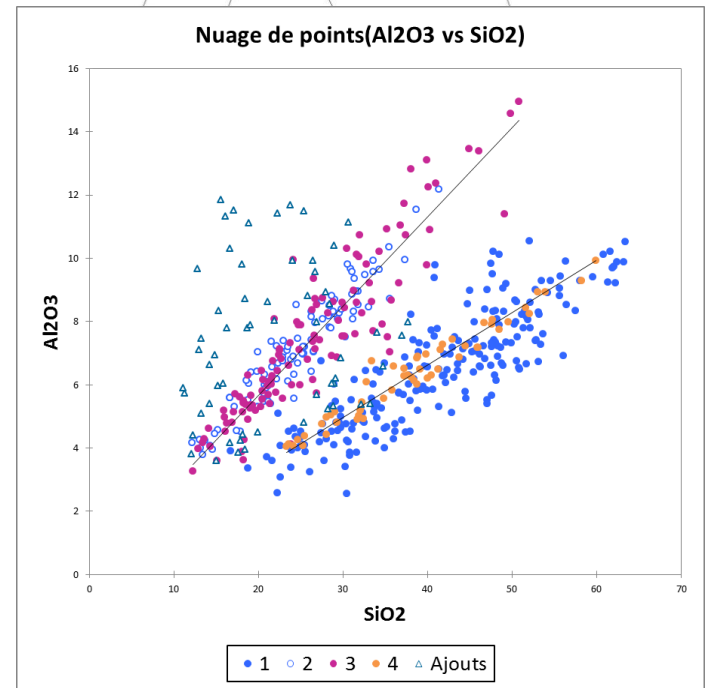
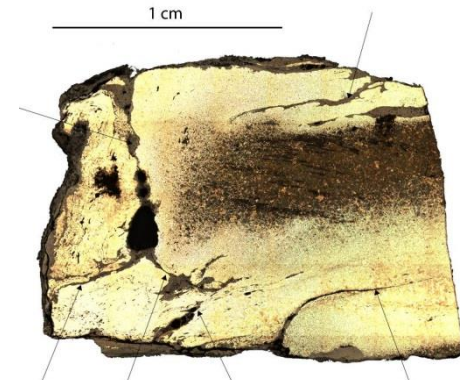
Preah Khan

« T » crampons



« T » crampons (30 samples)

Crampon	Sample name	Location	Number of PPMs of different origins identified
PK4	4.1	Hall of Dancers	1
	4.2		
PK5	5.1	Hall of Dancers	2
	5.2		
PK7	7.1	Jetty	2
	7.2		
PK9	9.1	Hall of Dancers	2
	9.2		
PK10	10.1	Hall of Dancers	1
	10.2		
PK11	11.1	Hall of Dancers	3
	11.2		
PK12	12.1	Hall of Dancers	2
	12.2		
PK13	13.1	Hall of Dancers	2
	13.2		
PK14	14.1	Hall of Dancers	2
	14.2		
PK15	15.1	Hall of Dancers	1
	15.2		
PK16	16.1	Hall of Dancers	1
	16.2		
PK17	17.1	Hall of Dancers	2?
	17.2		
PK18	18.1	Hall of Dancers	2
	18.2		
PK19	19.1	Hall of Dancers	1
	19.2		
PK20	20.1	Hall of Dancers	1
	20.2		



Preah Khan

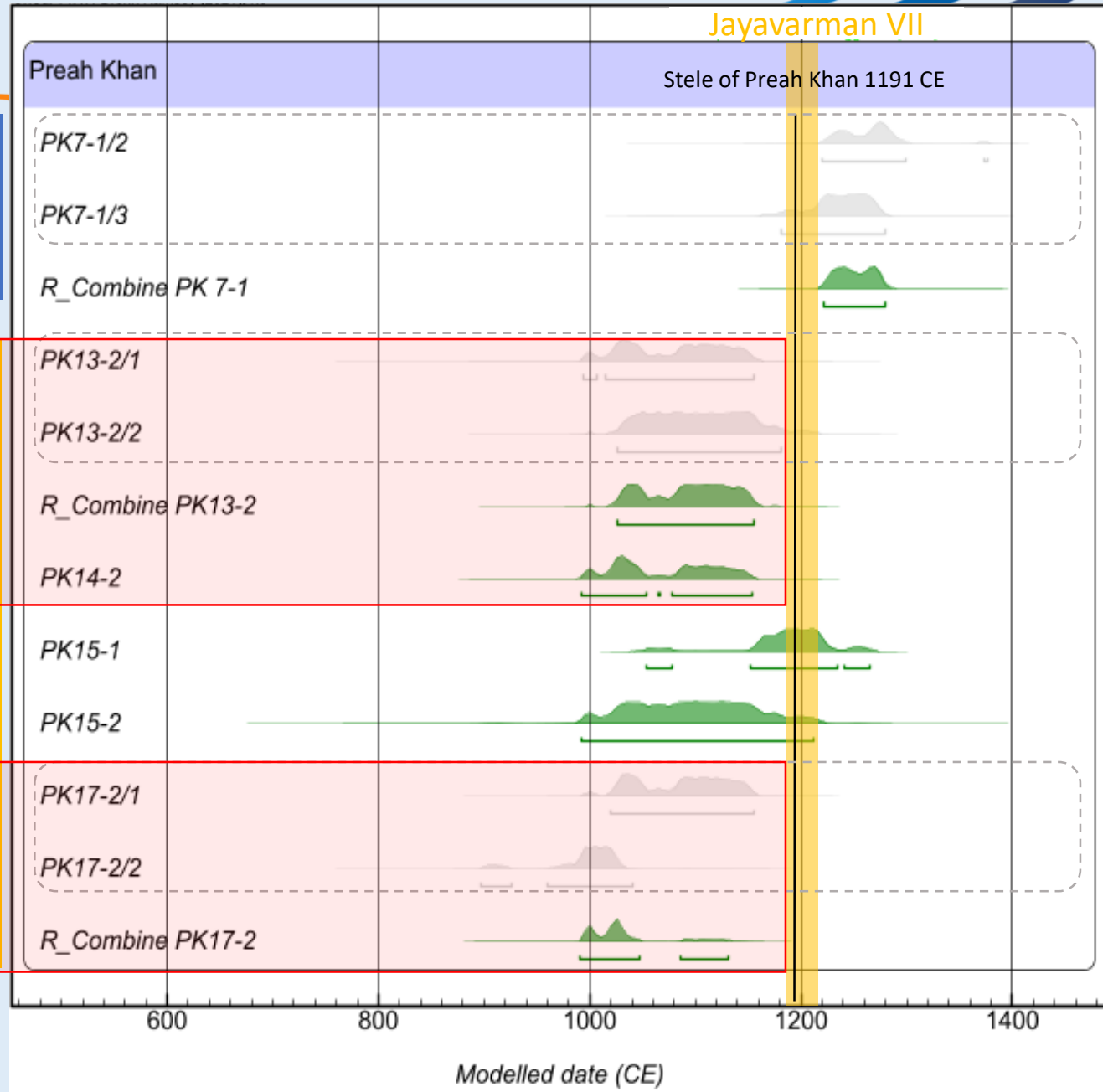
Jayavarman VII

Jetty

Re-used iron ?

Hall of Dancers

Re-used iron ?



Preah Khan

Jayavarman VII

Jetty

Preah Khan

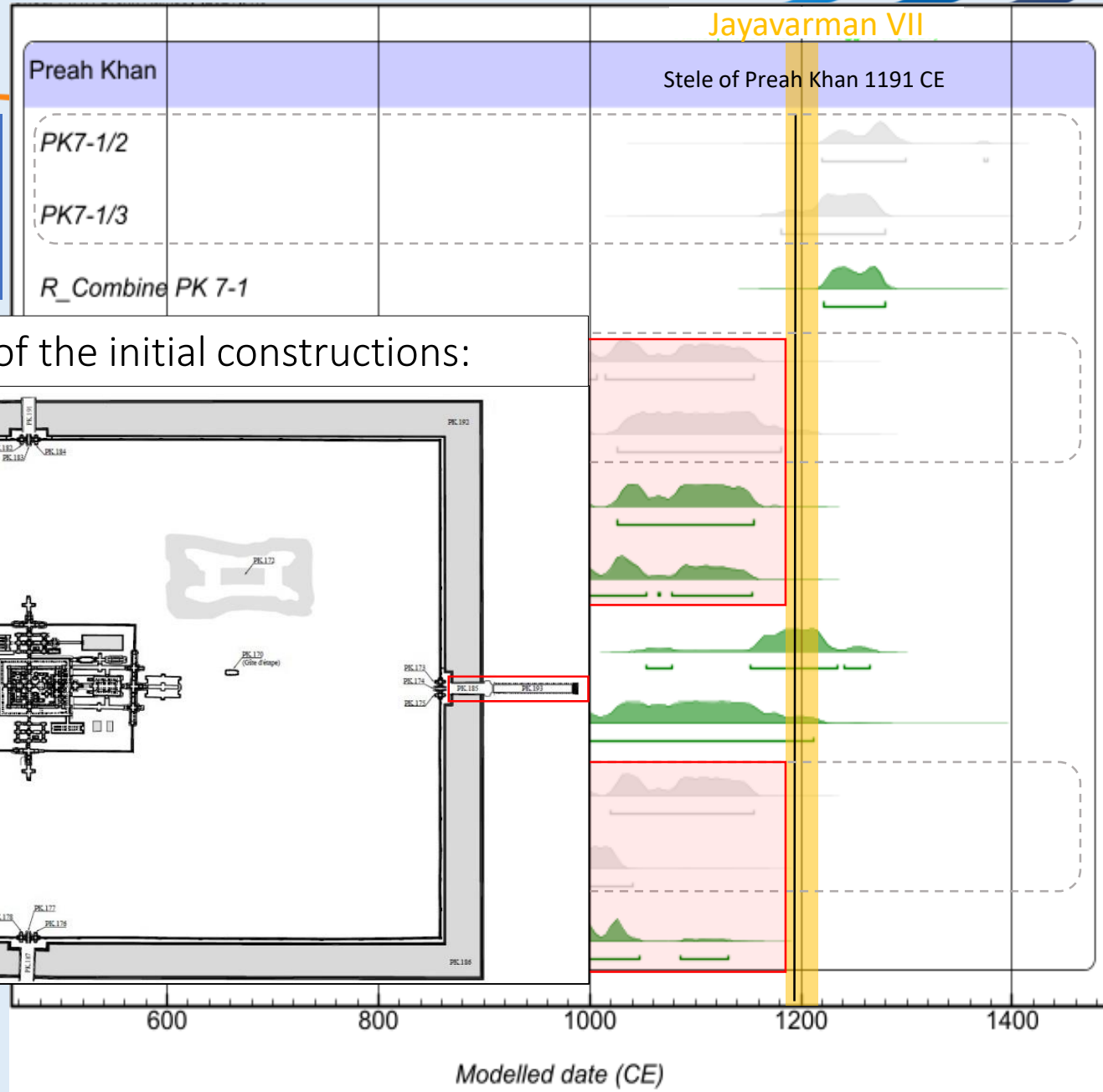
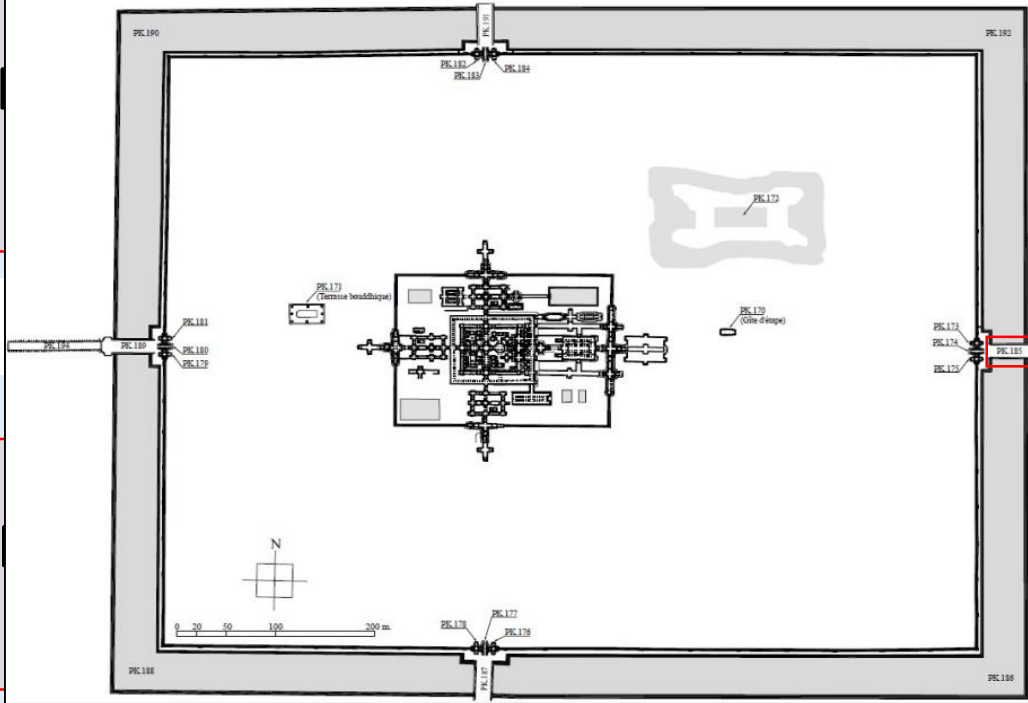
Stele of Preah Khan 1191 CE

PK7-1/2

PK7-1/3

R_Combine PK 7-1

Jetty not part of the initial constructions:



Modelled date (CE)

Radiocarbon dating of iron crampons

Royal Palace (11th c.)

Preah Khan (end of 12th c.)

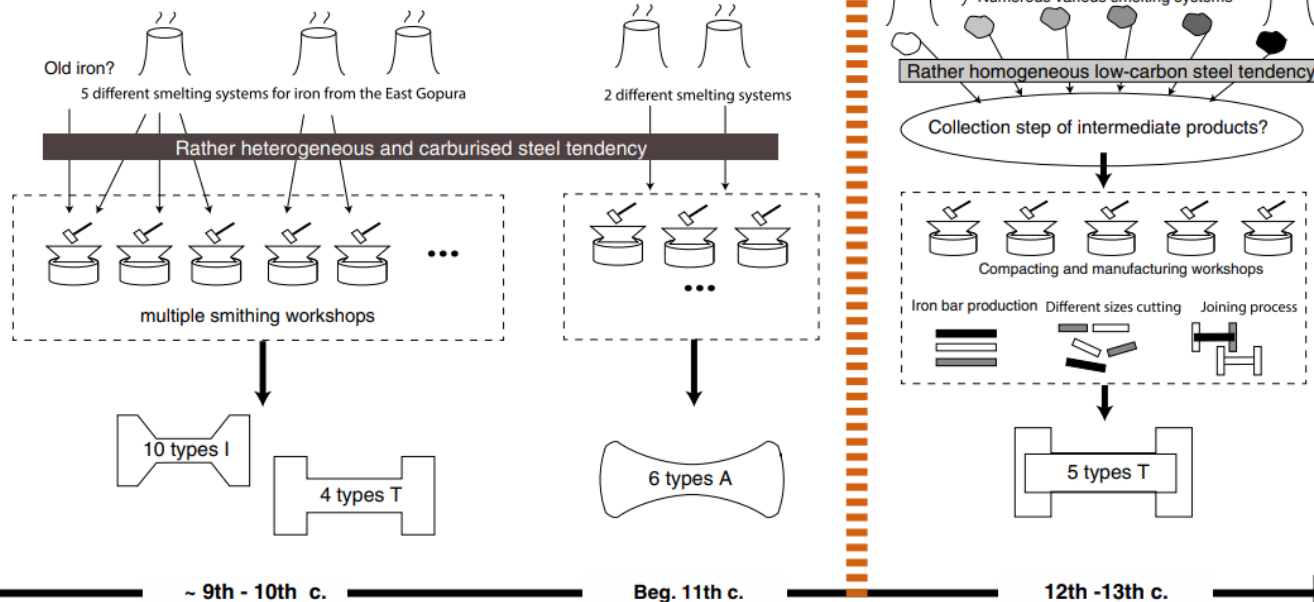
Radiocarbon dating of iron crampons :

- Dating the construction phases of the Angkor's monuments
- Bring a chronological framework for re-construction of the pre-modern iron economy

Royal Palace

Royal Palace - Baphuon

Preah Khan



Leroy et al. 2017. AAS

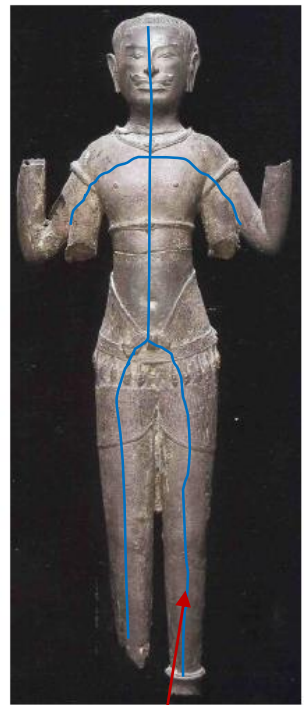
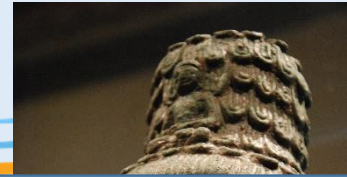
Baphuon

Khan & Canal to Beng Melea

th c.)

time period of expansion and massive construction in the Khmer empire

The bronze statues



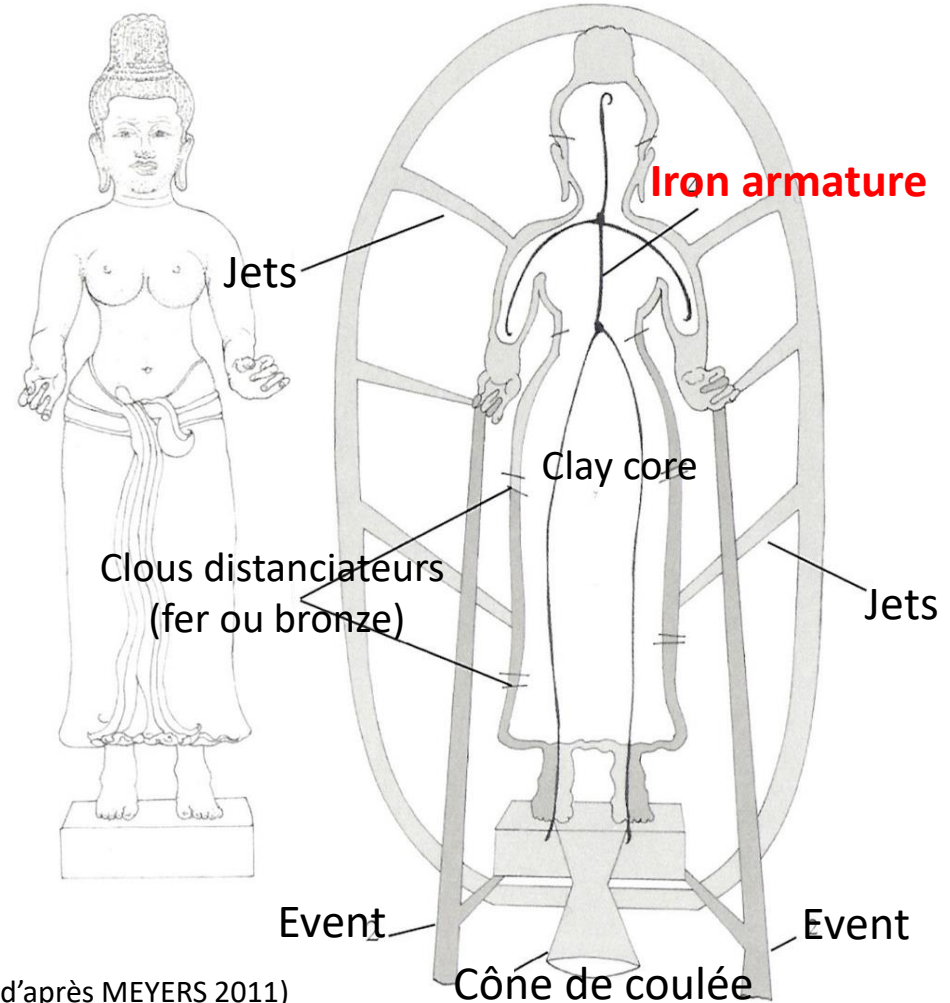
©RMN-Grand Palais (MNAAG, Paris)/T. Ollivier.

Iron armature



Visnu, XIth c., ©National Mus

« Lost-wax casting »



(d'après MEYERS 2011)

Dating bronze statues



Diamonds : 1100-1150 AD

Angkor Vat style : XII^e s

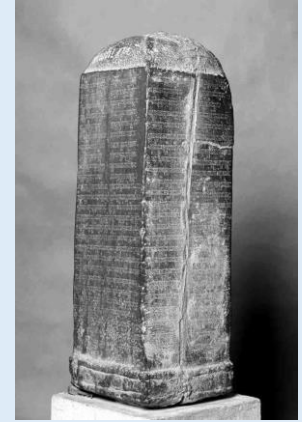
Flowers : 1175-1200 AD



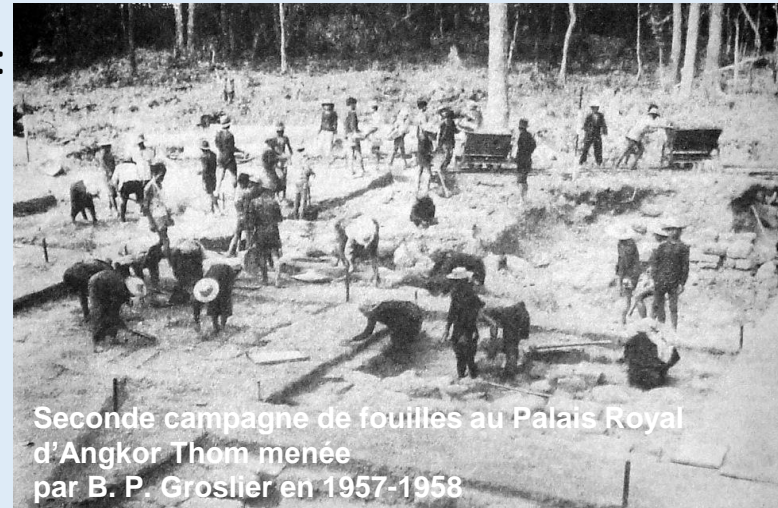
Photos : B. Vincent

Iconographic and stylistic criteria : more complex than in the stone statues

Engraved stones, stories of chinese pilgrims, rare royal chronicles



Archaeological context : Careful, not necessarily the original location



Seconde campagne de fouilles au Palais Royal d'Angkor Thom menée par B. P. Groslier en 1957-1958

physico-chemical methods :

- TL on the clay
- ¹⁴C on organic remains trapped in the clay

→ ¹⁴C dating of iron armatures

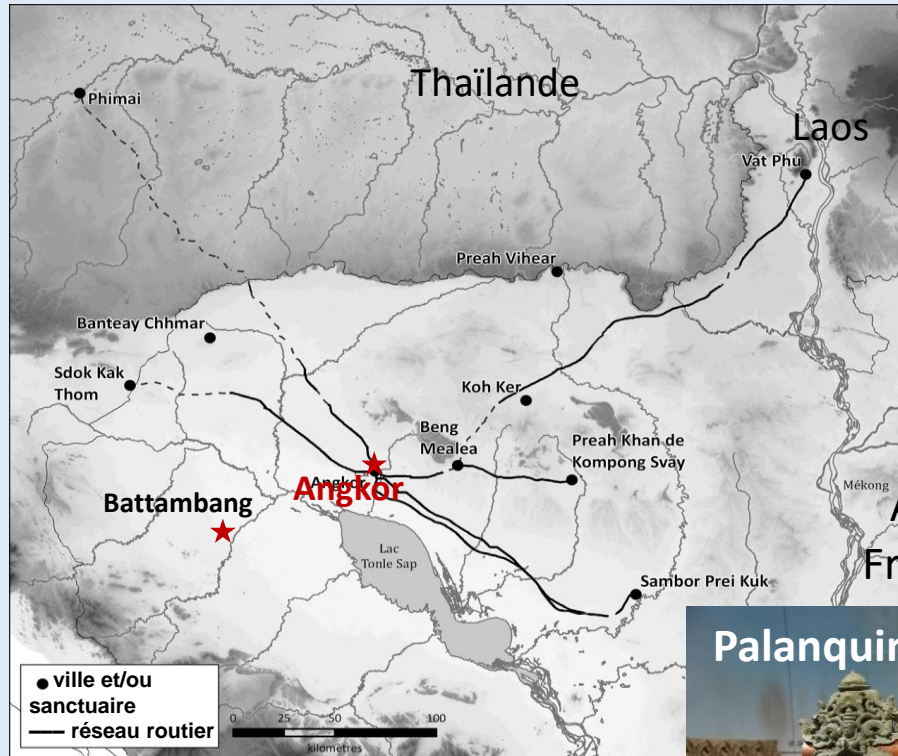
Dating bronze statues



MA 1339 Vishnu

©RMN-Grand Palais (MNAAG, Paris)/T. Ollivier.

Musée National des Arts
Asiatiques, Paris, curator P. Baptiste



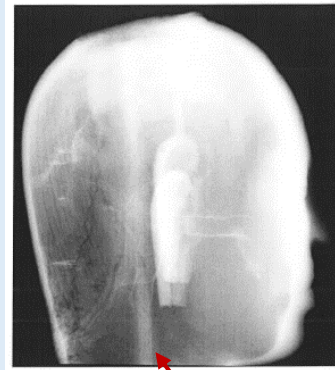
Asian Art Museum of San
Francisco, curator F. McGill

Palanquin fittings (inv. 1992.346)

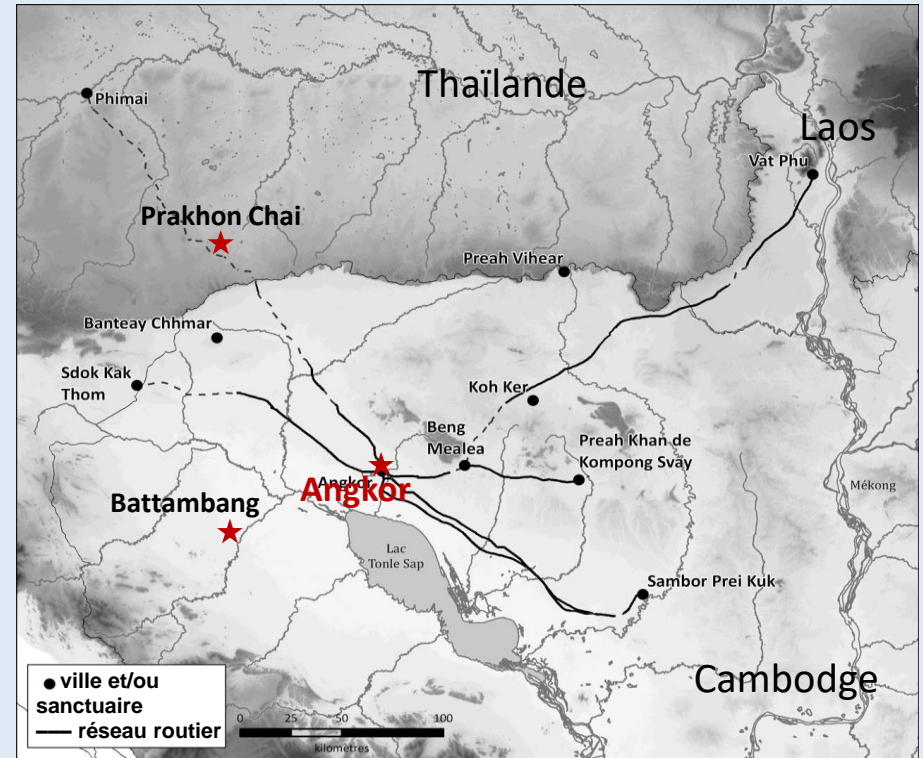


Vishnu (inv. MA1339)

Musée National des Arts Asiatiques, Paris, curator P. Baptiste



Armature



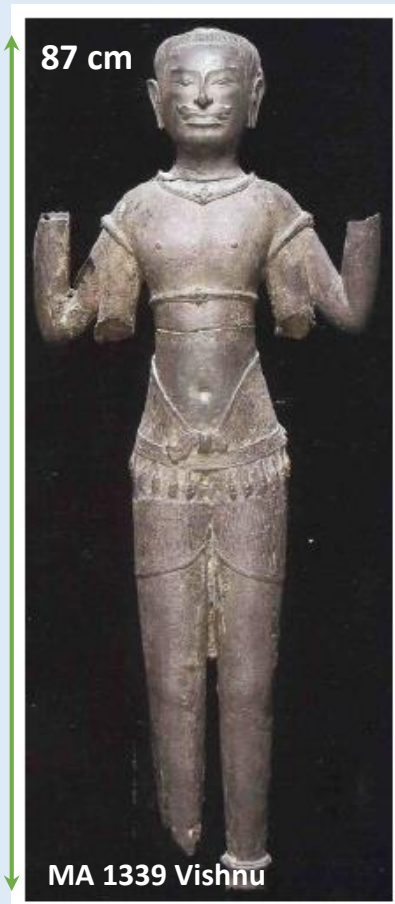
©RMN-Grand Palais (MNAAG, Paris)/T. Ollivier.

→ Origin : Battambang district ?

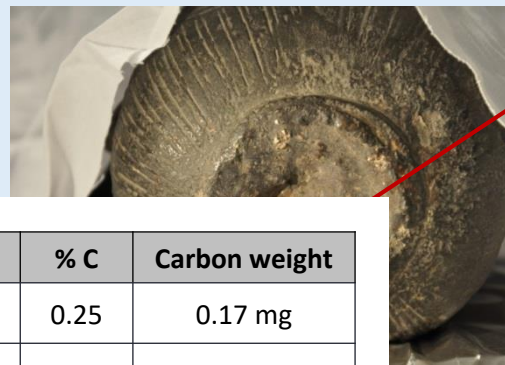
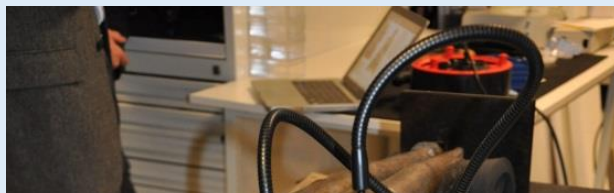
→ « modern » copy or late XIst c. ?

Vishnu (inv. MA1339)

Musée National des Arts Asiatiques, Paris, curator P. Baptiste

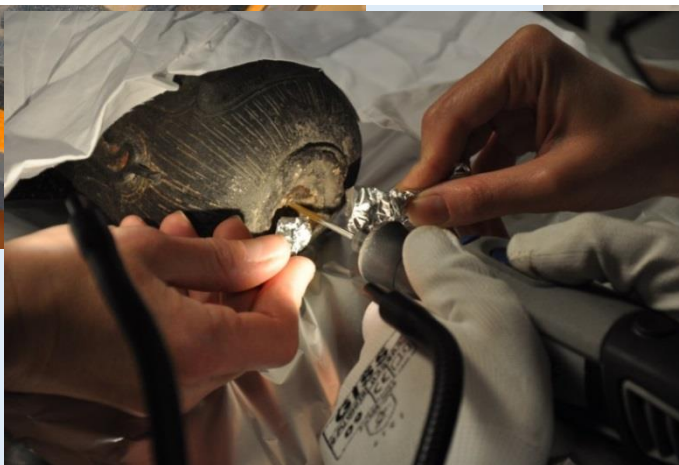


©RMN-Grand Palais (MNAAG, Paris)/T. Ollivier.



Armature
#1 cm²

Reference	Sample	Sample weight	% C	Carbon weight
SacA 48243	MA1339-2	67 mg	0.25	0.17 mg
SacA 48245	MA1339-4	109 mg	0.22	0.24 mg



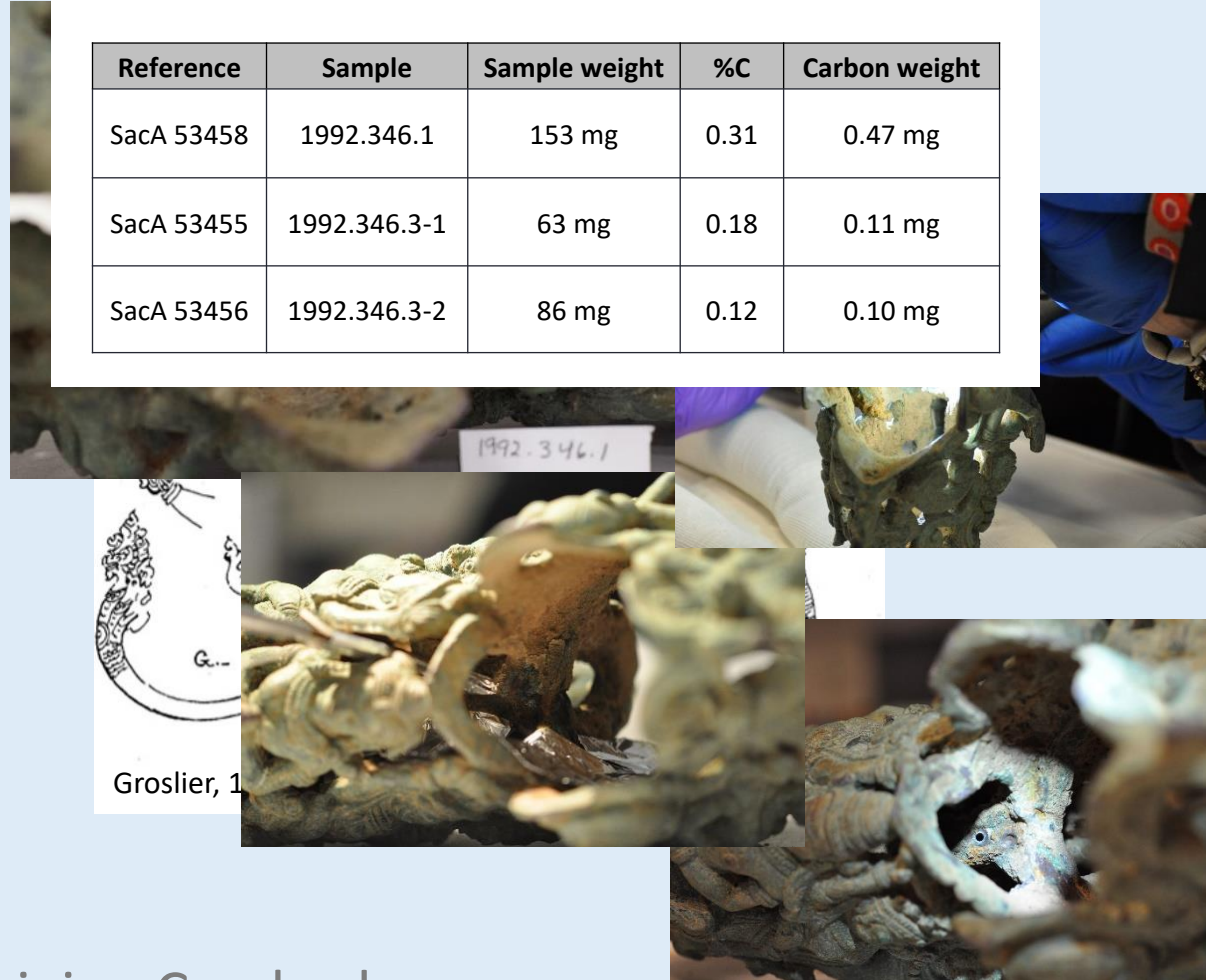
→ Attributed to the Baphuon style, XIth c.

Palanquin fittings (inv. 1992.346)

Asian Art Museum of San Francisco, curator F. McGill



Reference	Sample	Sample weight	%C	Carbon weight
SacA 53458	1992.346.1	153 mg	0.31	0.47 mg
SacA 53455	1992.346.3-1	63 mg	0.18	0.11 mg
SacA 53456	1992.346.3-2	86 mg	0.12	0.10 mg



→ Origin : Cambodge

→ late XIIth to beg. XIIIth c. or modern copy ?

Radiocarbon results of the bronze objects



MA 1339 Vishnu

©RMN-Grand Palais
(MNAAG, Paris)/T.
Ollivier.



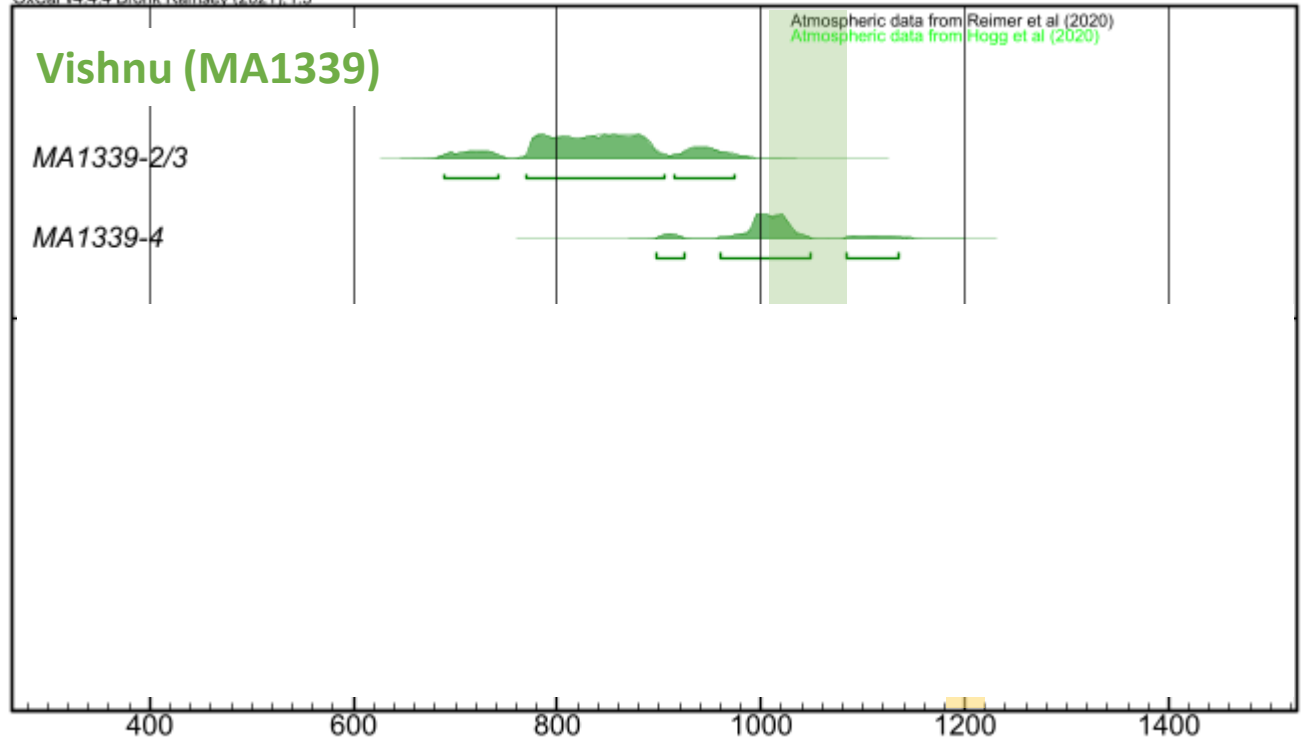
Palanquin fittings - hook

OxCal v4.4.4 Bronk Ramsey (2021): r:5

Vishnu (MA1339)

MA1339-2/3

MA1339-4



- ✓ Close collaboration with the conservators
- ✓ Thorough review of the objects before sampling (corrosion of the metal, object safety, preservatives, restorations ?)
- ✓ Small samples → adaptation of the conditions of preparations and measurements

Thanks to :

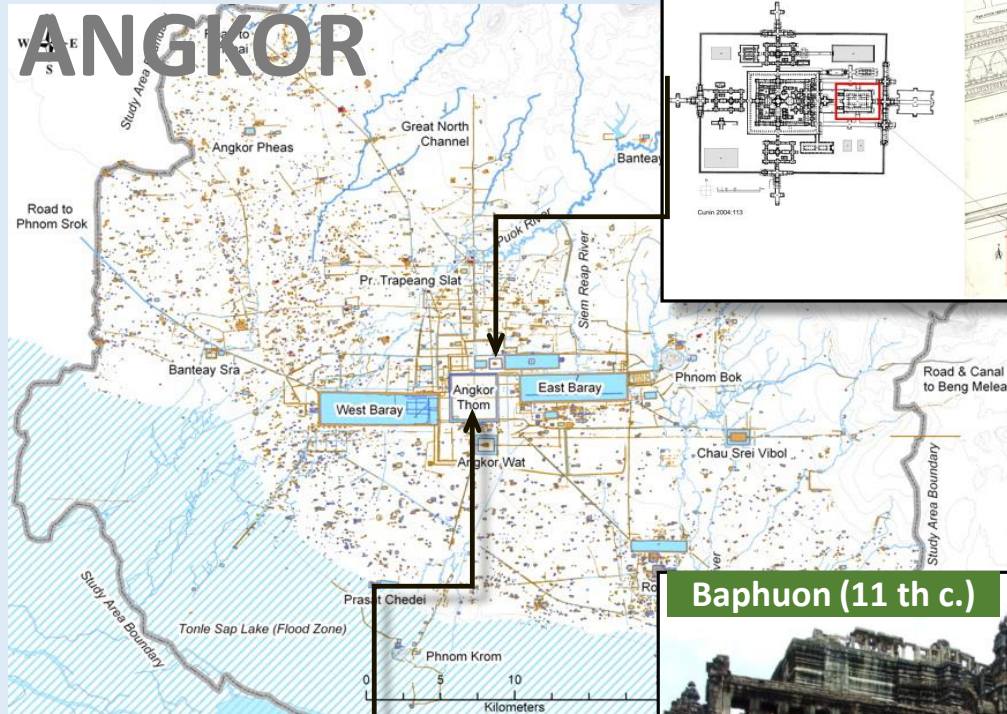
APSARA National Authority (Cambodia)
Ministry of Culture and Fine Arts (Cambodia)



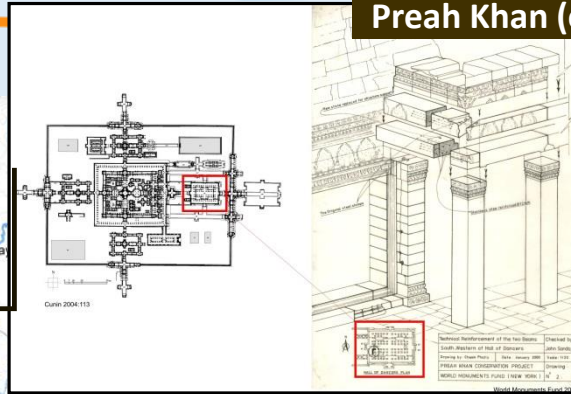
To go further...

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Angkor, monumental city



Preah Khan (end of 12th c.)



Baphuon (11 th c.)

