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Frontispiece: Detail of Suzanne de Court, Mirror: *Venus Mourning the Dead Adonis* (1975.1.1236; Figure 3a, page 159)

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# Stone Materials Used for Lintels and Decorative Elements of Khmer Temples

◆  
Federico Carò, Martin Polkinghorne, and Janet G. Douglas

## ABSTRACT

*Intricately carved lintels occupy a privileged and symbolic position in Khmer temples. Their production was commissioned to highly specialized craftsmen with specific material and carving traditions. The stone of seven decorative lintels in The Metropolitan Museum of Art has been characterized by means of petrographic and textural analyses, together with the stone of twenty-nine other lintels and ornamental elements dating from the seventh to the thirteenth century now in the National Museum of Cambodia, Phnom Penh; the Musée National des Arts Asiatiques–Guimet, Paris; and the Arthur M. Sackler Gallery, Smithsonian Institution, Washington, D.C. Results suggest that particular stone types were selected by Khmer carvers for certain elements in the temple structure. Whereas blocks of sandstone from the Terrain Rouge Formation of Cambodia were used to build and clad the Angkor temples and for decorative lintels and other ornaments, quartz-rich sandstone was reserved exclusively for these decorated elements. This sandstone may originate from the Grès Supérieures Formation, a sedimentary sequence that extends into Thailand, Laos, and Vietnam.*

The Metropolitan Museum of Art holds several stone decorative lintels produced during the time of the Khmer Empire (sixth–fifteenth centuries). These objects belong to a special variety of Khmer sculptural arts that differ in several ways from freestanding sculpture. A true lintel is the upper horizontal component in the framework of a doorway, which is usually formed of four independent stone blocks held together by mortise and tenon fittings. A decorative lintel, on the contrary, is rarely load bearing and is located above the true lintel, supported by two similarly decorated colonnettes. Decorative lintels occupy privileged positions above the entryways of Khmer temples, watching over all those who pass through from the secular to the divine realms. In this role they define an important boundary. The forms and iconographies of the decorative lintels sought to maintain the temple in a permanent state of festival. Often they represent ephemeral decorations of garlands and *rincaux* that gave the impression of a building alive with celebrations.<sup>1</sup> The lintels are thought to have been carved in situ by specialized craftsmen employing a particularly time-consuming and expensive process, following established artistic conventions.<sup>2</sup>

Table 1 • Key Compositional and Textural Parameters of the Lintels and Carved Architectural Elements. The samples are listed in order of accession number and stone type (Type 1, white to light brown quartz arenite; Type 2, reddish quartz arenite; Type 3 and 3b, greenish-gray feldspathic arenite). Q = quartz; F = feldspar; L = rock fragments. Sorting ( $\sigma$ ): see note 28.

Accession Number	Collection	Description	Provenience	Date	Q (%)	F (%)	L (%)	Mean (mm)	Median (mm)	Sorting ( $\sigma$ )	Stone Type
1972.214	The Metropolitan Museum of Art	Lintel	Thailand, exact provenience unknown	1st half 11th c.	85.7	13.1	1.2	0.16	0.16	0.46	1
1985.390.1	The Metropolitan Museum of Art	Lintel (see Figure 1)	Cambodia or Vietnam, exact provenience unknown	7th c.	91.6	7.7	0.7	0.26	0.27	0.67	1
1992.192	The Metropolitan Museum of Art	Lintel	Cambodia or Thailand, exact provenience unknown	1st half 11th c.	96.2	3.1	0.8	0.26	0.27	0.60	1
1994.94	The Metropolitan Museum of Art	Lintel (see Figure 5)	Cambodia or Thailand, exact provenience unknown	1st quarter 11th c.	83.9	13.3	2.8	0.21	0.21	0.56	1
Ka1791	National Museum of Cambodia	Lintel	Wat Ang Kh	7th c.	78.7	14.8	6.6	0.20	0.20	0.51	1
Ka2096	National Museum of Cambodia	Lintel	Exact provenience unknown	7th c.	88.9	8.6	2.5	0.18	0.18	0.69	1
Ka3175	National Museum of Cambodia	Lintel (see Figure 9)	Wat Preah Theat	7th c.	94.7	3.1	2.3	0.32	0.34	0.46	1
MG17860	Musée Guimet	Lintel	Phnom Da	beginning 12th c.	95.9	2.3	1.8	0.26	0.27	0.57	1
MG18218	Musée Guimet	Lintel	Wat Baset	end 11th–beginning 12th c.	90.1	3.5	6.4	0.17	0.17	0.53	1
MG18324	Musée Guimet	Colonnnette	Phnom Da	beginning 12th c.	97.5	0.6	1.9	0.25	0.24	0.70	1
S1987.953	Arthur M. Sackler Gallery	Lintel	Cambodia or Thailand, exact provenience unknown	mid-11th c.	97.0	2.0	1.0	0.17	0.17	0.86	1
36.96.6	The Metropolitan Museum of Art	Lintel (see Figure 2)	Kôk Sla Ket	mid-10th c.	93.4	4.7	1.9	0.12	0.12	0.60	2
1994.111	The Metropolitan Museum of Art	Lintel	Cambodia or Thailand, exact provenience unknown	mid-10th c.	88.2	7.5	4.3	0.11	0.11	0.63	2
1996.473	The Metropolitan Museum of Art	Lintel (see Figure 4)	Cambodia, exact provenience unknown	2nd half 10th c.	80.1	18.2	1.7	0.11	0.10	0.52	2
1997.434.2	The Metropolitan Museum of Art	Colonnnette	Cambodia, exact provenience unknown	mid-10th c.	88.5	9.9	1.6	0.10	0.09	0.58	2
2003.142	The Metropolitan Museum of Art	Antefix	Cambodia, exact provenience unknown	3rd quarter 10th c.	87.6	12.0	0.4	0.11	0.10	0.63	2
MG17488	Musée Guimet	Lintel (see Figure 6)	Wat Kralanh	mid-11th c.	82.9	12.8	4.3	0.11	0.11	0.67	2
MG18913	Musée Guimet	Pediment	Banteay Srei	late 10th c.	87.8	7.7	4.4	0.12	0.13	0.68	2
Ka1748	National Museum of Cambodia	Lintel	Sambor Prei Kuk	7th c.	47.1	44.6	8.3	0.19	0.19	0.55	3
Ka1802	National Museum of Cambodia	Lintel	Preah Kô	9th c.	51.7	39.7	8.6	0.15	0.16	0.61	3
Ka2712	National Museum of Cambodia	Lintel (see Figure 3)	Kompong Cham Province, exact provenience unknown	mid-10th c.	43.0	49.0	8.0	0.16	0.17	0.50	3
Ka2763	National Museum of Cambodia	Lintel	Preah Vihear Province, exact provenience unknown	late 10th c.	37.6	52.6	9.8	0.16	0.17	0.53	3
Ka2844	National Museum of Cambodia	Lintel	Preah Khan of Kompong Svay/Bakan	end 12th–beginning 13th c.	51.7	38.3	10.0	0.18	0.18	0.53	3
MG14898	Musée Guimet	Frieze	Exact provenience unknown	last quarter 10th–beginning 11th c.	66.5	29.4	4.0	0.17	0.17	0.44	3b
MG18120	Musée Guimet	Pilaster	Beng Mealea	mid-12th c.	53.7	40.3	6.0	0.12	0.13	0.70	3
MG18121	Musée Guimet	Colonnnette	Beng Mealea	mid-12th c.	52.4	42.1	5.6	0.18	0.18	0.56	3
MG18197	Musée Guimet	Pediment	Preah Khan of Kompong Svay/Bakan	3rd quarter 12th c.	40.9	50.7	8.4	0.18	0.19	0.82	3
MG18219	Musée Guimet	Lintel	Bayon	end 12th–beginning 13th c.	46.0	45.5	8.5	0.18	0.18	0.64	3
MG18220	Musée Guimet	Lintel	Kapilapura	last quarter 9th c.	50.2	41.4	8.4	0.13	0.15	0.70	3
MG18853	Musée Guimet	Lintel	Sambor Prei Kuk	1st half 7th c.	55.8	38.7	5.5	0.10	0.10	0.73	3
MG18854	Musée Guimet	Lintel	Prasat Prei Khmeng	2nd half 7th c.	67.3	29.4	3.3	0.10	0.10	0.58	3b
MG18855	Musée Guimet	Lintel	Prasat Koki	early 9th c.	59.1	34.3	6.5	0.10	0.10	0.62	3
MG18857	Musée Guimet	Colonnnette	Prasat Prei Khmeng	2nd half 7th c.	66.5	29.2	4.2	0.10	0.10	0.60	3b
MG18858	Musée Guimet	Colonnnette	Kulen	early 9th c.	54.0	38.1	7.9	0.11	0.11	0.59	3
MG18879	Musée Guimet	Pediment	Prasat Sok Kraup	end 9th–beginning 10th c.	54.7	38.9	6.4	0.16	0.17	0.58	3
MG18890	Musée Guimet	Colonnnette	Wat Choeng Ek	1st half 7th c.	52.6	39.9	7.5	0.16	0.17	0.74	3

In support of this hypothesis, previous technical studies suggest that specific stone materials were purposefully chosen for the production of these architectural elements, which are characterized by deeply carved, intricate details.<sup>3</sup> However, given the complex history of Khmer temples and the vast production of decorative elements,<sup>4</sup> it is difficult to draw any conclusion about patterns of stone choice and usage without considering a comprehensive and representative database of provenienced objects. Toward this end, this study aims to characterize by means of scientific analyses the stone materials used in the production of a selection of decorative lintels and other architectural ornamental elements, and ultimately to help unveil connections between Khmer artistic production and the geological sources of construction materials.

The twenty-four lintels and twelve decorative elements (colonnets, friezes, and peditments, as well as one antifix and one pilaster) examined for this study are in the collections of The Metropolitan Museum of Art, New York; the National Museum of Cambodia, Phnom Penh; the Musée National des Arts Asiatiques–Guimet, Paris; and the Arthur M. Sackler Gallery, Smithsonian Institution, Washington, D.C. They were produced over a range of dates consistent with the pre-Angkor (sixth–eighth centuries) and Angkor (ninth–fifteenth centuries) periods. Although rarely dated on the basis of epigraphic evidence, decorative

lintels are particularly respected chronological markers for Khmer art historians and archaeologists.<sup>5</sup>

The studied lintels and decorative elements originate from various locations in Cambodia, Thailand, and Vietnam. Those in the Musée Guimet and National Museum of Cambodia come with certain provenience, and most can be associated with specific sites (Table 1). From a stylistic perspective alone it is difficult to be precise about the origins of the lintels and decorative elements in The Metropolitan Museum of Art and the Arthur M. Sackler Gallery, but they are logically associated with temple sites north of the Tonlé Sap (Great Lake) and may even have come from what today is Thailand.

#### ICONOGRAPHY AND DECORATIVE MOTIFS

Five lintels from The Metropolitan Museum of Art have been selected for discussion, as they illustrate the iconography and decorative motifs common to classical Khmer sculptures. They range in dates from the seventh century to the early eleventh century.

The lintel with a mask of Kāla (1985.390.1; Figure 1) is of exceptional interest; its motifs indicate that it likely dates to the seventh century, making it the earliest included in this study.<sup>6</sup> Its central and dominating motif is the Kāla or Kirtimukha (face of glory), an extremely common central motif on decorative lintels thought to represent an aspect of Shiva

Figure 1 • Lintel with a mask of Kāla. Cambodia or Vietnam, exact provenience unknown, 7th century. White to light brown quartz arenite (Type 1 sandstone), H. 47.0 cm (18½ in.), L. 142.2 cm (56 in.), D. 25.4 cm (10 in.). The Metropolitan Museum of Art, Gift of Margery and Harry Kahn, 1985 (1985.390.1)





Figure 2 ♦ Lintel with carved figures. Kōk Sla Ket, mid-10th century. Reddish quartz arenite (Type 2 sandstone), H. 51.4 cm (20 ¼ in.), L. 124.5 cm (49 in.). The Metropolitan Museum of Art, Fletcher Fund, 1936 (36.96.6)

as time, who devours himself and destroys all things.<sup>7</sup> Kāla in this role is known by the Khmer as Rahu.<sup>8</sup> Rahu is associated with funerary and cremation rites and also possesses a bivalent nature as the first step toward new life. In this manifestation, Rahu is regarded as the demon of the eclipse, causing the darkness to make new light appear.<sup>9</sup>

In 1930, Victor Goloubew of the *École Française d'Extrême-Orient* (EFEO) proposed that the Kāla motif was adopted by the Khmer from Java.<sup>10</sup> Subsequent scholars have commented on this possible connection<sup>11</sup> but point to many examples of Khmer architectural decoration that predate those from Java. Mireille Bénisti argues that the indigenous influence from early Khmer art on the appearance and composition of the Kāla has been underestimated at the willing acceptance of a

Javanese inspiration and cites seventeen examples that predate the Javanese examples,<sup>12</sup> particularly those at Borobudur mentioned by Gilberte de Coral-Rémusat.<sup>13</sup> The Metropolitan Museum's Kāla lintel corroborates the theory that the motif as it developed in both Cambodia and Java most likely derives from a common source of influence in India.<sup>14</sup>

The Kāla motif on the Metropolitan Museum's lintel is distinctive in that it dominates the entire surface. Although different in representation, this Kāla is analogous in size to that on a lintel from Sala Prambei Lveng, in Thala Borivat, Stung Treng Province.<sup>15</sup> Between the Kāla's eyes is a fleuron emblem common to central motifs in other pre-Angkorian lintels.<sup>16</sup> The conscious transformation of motifs from simple to complex, or vice versa, may be defined as a form of stylization and was part of the

Figure 3 ♦ Lintel depicting Indra riding Airāvata. Kompong Cham Province, exact provenience unknown, mid-10th century. Greenish-gray feldspathic arenite (Type 3 sandstone), H. 49.0 cm (19 ¼ in.), L. 180.0 cm (70 ¾ in.), D. 11.0 cm (4 ¾ in.). National Museum of Cambodia (Ka2712)



repertoire of classical Khmer artists.<sup>17</sup> The interplay between the Kāla and fleuron suggests that the motifs were interchangeable and perhaps share a similar or double meaning. Below the Kāla mask are series of motifs common to pre-Angkorian lintels, including colonnette capitals with fleuron medallions, lotuses of the species *Nelumbo nucifera*, and hanging pendants that establish a seventh-century date for this work.<sup>18</sup>

The Khmer collection of The Metropolitan Museum of Art includes three examples of decorative lintels dating to the second half of the tenth century. One of these (36.96.6; Figure 2) comes from the Angkorian site of Kōk Sla Ket, located 4 kilometers south of the West Baray. The sculpture is dated stylistically to the mid-tenth century, which is consistent with an inscription found at the site.<sup>19</sup> According to photographs taken by the EFEO in 1933, the lintel is from the east facade of the north tower.<sup>20</sup> After being removed to the Conservation d'Angkor,<sup>21</sup> the lintel was acquired by The Metropolitan Museum of Art in February 1936 with six additional Khmer sculptures, including a bust of Hevajra (36.96.4) found outside the Gate of the Dead at Angkor Thom.<sup>22</sup>

This lintel's central motif of a caryatid lion flanked by additional lions issuing foliage branches from their mouths is reminiscent of the early tenth century, and it is possible that the lintel was carved by artists who had also worked at the early tenth-century capital

northeast of Angkor.<sup>23</sup> The top frieze captures seven *r̥ṣi* or ascetics in prayer. Lintels from the mid-tenth century display a consistency in the division of decoration on their surface. Arched foliage branches terminating in leafy curls, a regular and symmetrical number of offshoots above and below the branches, and the distinctive frieze are components also observed on a lintel from the National Museum of Cambodia (Ka2712; Figure 3).

A second lintel (1996.473; Figure 4) from the second half of the tenth century in the Metropolitan Museum is in the style of Banteay Srei. The fine carving and complexity of decorative motifs from this period have led numerous scholars to consider the period between approximately 940 and 990 as among the pinnacles of Khmer art.<sup>24</sup> The central motif depicts Yama, the god of death, atop his Vāhana, the buffalo, holding a *danda*, or club. In this context Yama is designated as a Lokapāla or Dikpāla, both directional deities. This identification confirms that the lintel originally faced south in the configuration of the temple tower.

A third tenth-century lintel in the Metropolitan Museum collection (1994.111) depicts a Kāla face ridden by Indra holding a *vajra* (thunderbolt).<sup>25</sup> Of particular interest are the motifs of celestial beings praying in fleurons forming the lintel frieze. Each of these small representations depicts the torso of a crowned figure with hands together in a gesture of praying, positioned within a triangular vegetal



Figure 4 • Lintel with Yama on buffalo. Cambodia, exact provenience unknown, second half of the 10th century. Reddish quartz arenite (Type 2 sandstone), H. 59.7 cm (23½ in.), L. 137.2 cm (54 in.). The Metropolitan Museum of Art, Gift of The Kronos Collections, 1996 (1996.473)





Figure 5 • Lintel with a mask of Kāla and Dikpāla. Cambodia or Thailand, exact provenience unknown, first quarter of the 11th century. White to light brown quartz arenite (Type 1 sandstone), H. 58.4 cm (23 in.), L. 170.2 cm (67 in.). The Metropolitan Museum of Art, Gift of R. Hatfield Ellsworth, in honor of Florence and Herbert Irving, 1994 (1994.94)

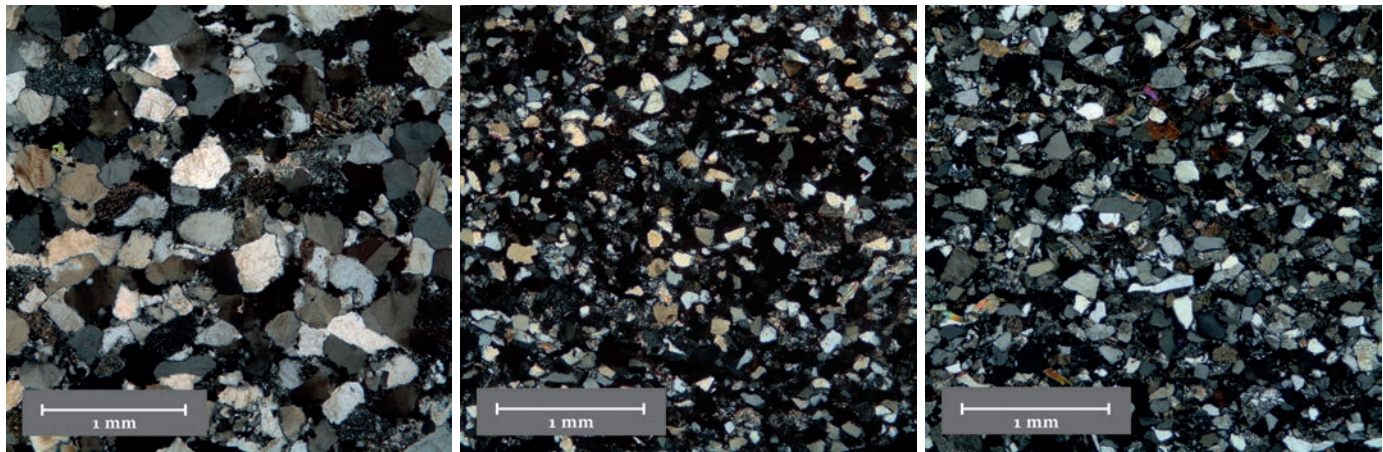
frame. Nearly identical celestial beings praying in fleurons make their first appearance in lintels from Koh Ker, the Khmer capital from about 921 to 944, approximately 85 kilometers northeast of Angkor. These motifs recur for the next fifty years, continuing even after the court returned to Angkor (Yaśodharapura) from Koh Ker. The same artistic workshop that contributed to the foundations of the king Jayavarman IV at Koh Ker followed the new sovereign back to Angkor, suggesting that despite political change or instability, the artisans shadowed the center of power and were not tied to a particular administration.<sup>26</sup>

The last decorative lintel at The Metropolitan Museum of Art under consideration here (1994.94; Figure 5) dates to the first decades of the eleventh century and can be associated

with lintels from the Khleangs and the Royal Palace of Angkor Thom. The principal motif is again the Kāla, which issues from its mouth two garlands that terminate in curls of foliage. The monster supports a seated brahmanic divinity, perhaps the most common motif on decorative lintels but whose details are often confused and indistinct and therefore difficult to identify. From their seated position known as *rājalilāsana* (Sanskrit, meaning “pose of royal ease”), the figures are usually associated with Dikpāla and are identified with a monarch, as can be seen on the lintel in Figure 5. Iconographically, this lintel is similar to a lintel from the Musée Guimet (MG17488; Figure 6), especially in the Kāla face with extended arms and the frieze of pendants and fleurons. Variation of the central motif (Umāheśvara) and



Figure 6 • Lintel depicting Umāheśvara on Kāla. Wat Kralanh, mid-11th century. Reddish quartz arenite (Type 2 sandstone), H. 79.0 cm (31 1/8 in.), L. 174.0 cm (68 1/2 in.), D. 52.0 cm (20 1/2 in.). Musée National des Arts Asiatiques—Guimet (MG17488)



a

b

c

additional depth of carving suggest an affinity to the Baphuon style and a slightly later date in the mid-eleventh century.

#### PETROGRAPHY OF THE STONE MATERIALS

The addition of petrographic analysis to the suite of interpretive tools applied to Khmer sandstone sculpture has considerable potential to answer questions raised by art-historical studies. Petrographic analysis requires that a small fragment of stone be removed for thin-section preparation, that is, mounted on a glass slide and polished to a thickness of 30 microns. For this study fragments were removed from already damaged areas, generally located at the bottom edges of the lintels.

For each thin section, the nature, dimensions, and abundance of the various constituent grains were assessed using a polarized light microscope.<sup>27</sup> The number of grains analyzed varied with each sample according to its size and also depended on grain size and sorting,<sup>28</sup> but usually at least 300 points were counted. The classification scheme adopted is that proposed by Paolo Gazzi and by William R. Dickinson, which uses the relative abundance of quartz (Q), feldspar (F), and rock fragments (L) to assign specific names to different species of sandstone.<sup>29</sup> Further information regarding the texture of the rock was recorded, including the size, sorting, shape, and arrangement of the constituent elements. With few exceptions, the

objects studied were carved from three main types of sandstone, designated herein as Types 1, 2, and 3 (Figures 7, 8; see also Table 1).

#### WHITE TO LIGHT BROWN QUARTZ ARENITE

Type 1 sandstone varies in color from white to light brown, depending on the amount of iron oxides present, and has a crisp appearance. Using petrography, this sandstone is classified as a fine- to medium-grained, moderately well-sorted to well-sorted quartz arenite. Grains are subrounded to subangular in shape and are cemented by abundant authigenic quartz. Kaolinite cement arranged in coarse stacks of pseudo-hexagonal plates is also abundant and postdates the quartz overgrowth. The shapes of the original grains are often revealed by a thin hematite coating on their surfaces.

Monocrystalline undulose quartz grains are the most abundant constituent. The quartz often appears cloudy from inclusions. Polycrystalline quartz is subordinate and mostly strained and foliated, with sutured contacts. Also present but rare are grains of cryptocrystalline quartz. Feldspar content is generally low but can reach 15 percent of the total grains. Feldspars are often weathered or kaolinized.

Rock fragments do not exceed 7 percent of the framework grains. Among them, most characteristic are aphanitic volcanic rock fragments, low-grade metamorphic rocks

Figure 7 • Micrographs of the three main identified lithotypes (crossed Nicols): (a) medium-grained, white to light brown quartz arenite (Type 1 sandstone); (b) very fine-grained, reddish quartz arenite (Type 2 sandstone); (c) very fine- to fine-grained, greenish-gray feldspathic arenite (Type 3 sandstone)

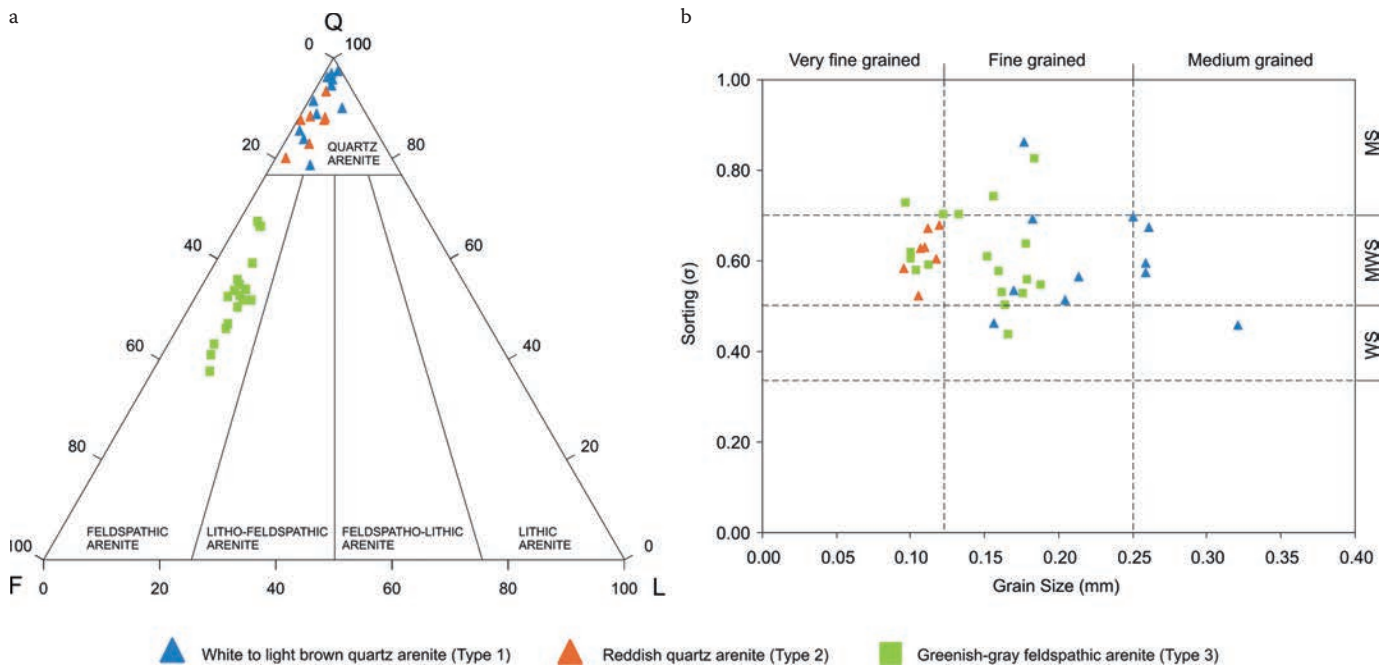


Figure 8 • Petrographic and textural characteristics of the lintels studied:

(a) framework grain composition grouped according to the relative abundance of quartz (Q), feldspar (F), and rock fragments (L) following Gazzi 1966 and Dickinson 1970; (b) classification of the sandstone types according to sorting and grain size of the constituent grains following Folk and Ward 1957.

WS = well sorted; MWS = moderately well sorted; MS = moderately sorted

(phyllite), and fragments of argillaceous mudstone. Some of the sedimentary rock fragments, such as the argillaceous component, have been squeezed to form pseudomatrix. Heavy minerals<sup>30</sup> are rare and include grains of rutile, tourmaline, zircon, and epidote. A fine-grained matrix, often pigmented by the abundant iron oxides, is present in variable amounts between the framework grains.

When the sandstone is extremely quartz-rich and devoid of iron oxides, opaque minerals, and matrix, it is white to light gray, as in the lintel from the National Museum of Cambodia depicting Indra riding Airāvata (Ka3175; Figure 9). With the increase of the above-mentioned accessory minerals, the sandstone attains a reddish-brown color, like the Metropolitan Museum’s lintel with a mask of Kāla and Dikpāla (1994.94; see Figure 5) and the Musée Guimet’s lintel depicting scenes from the *Rāmāyana* (MG18218).

#### REDDISH QUARTZ ARENITE

Type 2 sandstone has a characteristic reddish color. Petrographically, this rock is classified as very fine-grained, moderately well-sorted quartz arenite. Grains are subrounded to rounded in shape and are cemented by fine-grained

kaolinite and authigenic quartz in variable proportions. Characteristic is the abundant hematite cementation that occurs as grain-coating and pore-filling and accounts for the color of this sandstone.

Undulose and nonundulose monocrystalline quartz grains dominate the framework, while feldspar is subordinate and usually weathered. Polycrystalline strained quartz and cryptocrystalline quartz are also present. Rock fragments are sparse and include aphanitic volcanics, phyllite, siltstone, and mudstone. Fragments of igneous rock with micrographic texture are present but very rare. Accessory muscovite is often bent between the grains. Heavy minerals are rare and include ilmenite, rutile, tourmaline, and zircon. A fine, brown matrix of clay-size particles rich in iron oxides is occasionally deposited between the grains, possibly as a result of mechanical compaction of preexisting rock fragments.

#### GREENISH-GRAY FELDSPATHIC ARENITE

Type 3 sandstone is a greenish-gray feldspathic arenite; it constitutes almost half of the samples. This sandstone is composed of very fine to fine, moderately well-sorted to well-sorted, subangular to rounded grains, cemented



predominantly by chlorite. Calcite and authigenic quartz and feldspar can be also present in variable amounts. The degree of compaction and cementation varies.

Mono-, poly- and microcrystalline quartz grains, both undulose and nonundulose, are the most abundant framework constituents. Feldspar makes up about 40 percent of the framework grains and is dominated by plagioclase, with minor alkali feldspar. Both fresh and altered feldspars are present.

The abundance of rock fragments is typically about 4 percent and only rarely exceeds 10 percent. Characteristic lithic fragments are volcanic (andesite), metamorphic (phyllite, quartzite, micaceous schist), and sedimentary (argillite, shale, siltstone) in origin. The heavy minerals assemblage consists mostly of hematite, magnetite, ilmenite, rutile, titanite, garnet, epidote, zircon, apatite, monazite, and tourmaline, in varying proportions. This assemblage reflects a mixed provenience with strong metamorphic and felsic igneous influence, as other authors have pointed out.<sup>31</sup> Within the Type 3 group it is possible to distinguish a small subset (Type 3b) of very fine-grained, quartz-rich feldspathic arenite characterized by abundant biotite.

#### GEOLOGICAL PROVENIENCE

This study of the mineral composition and texture of the sandstones used for lintels and other decorative architectural elements helps to correlate the lithotypes identified to specific geological formations<sup>32</sup> and, in turn, to more narrowly defined geographic regions within the territory of the Khmer Empire.

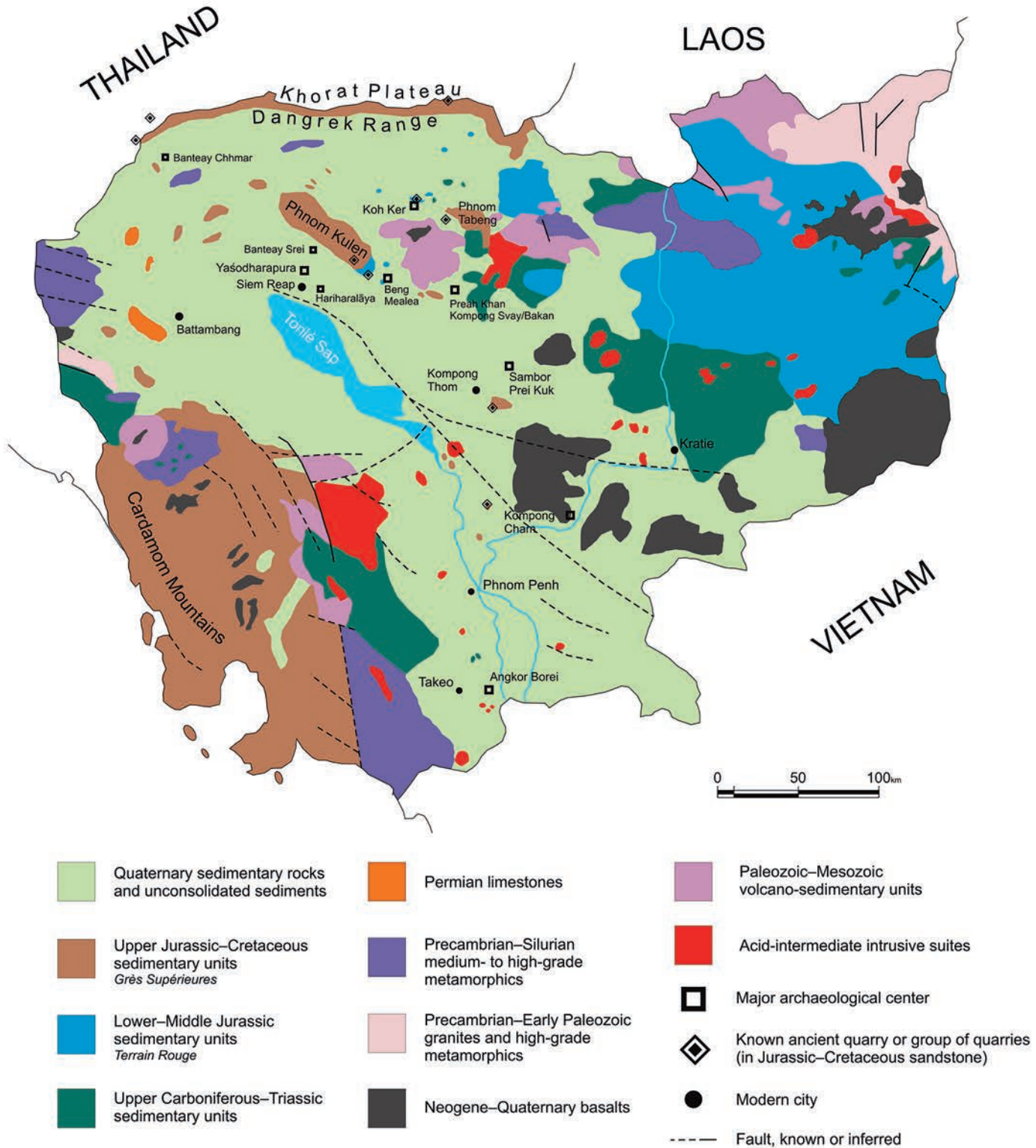
All three lithotypes have strong affinities with sedimentary rocks constituting part of the Khorat Group,<sup>33</sup> a nonmarine Mesozoic sedimentary sequence that outcrops in the Khorat Plateau of Thailand and extends into Cambodia and Laos. In Cambodia the sandstones are well represented by the Dangrek Range in the north, where its steep flanks form a natural border with Thailand; in the central region by Phnom Kulen and Phnom Tabeng (in Khmer, *phnom* means “mountain” or “hill”), in Siem Reap and Preah Vihear Provinces respectively; and in the southwest by the Cardamom Mountains (Figure 10). Numerous scattered outcrops of sandstones and conglomerates with similar characteristics are exposed in subhorizontal beds in isolated hills of low altitude and limited extension in central and eastern Cambodia. This sequence was described in detail by various

Figure 9 • Lintel depicting Indra riding Airāvata. Wat Preah Theat, 7th century. White to light brown quartz arenite (Type 1 sandstone), H. 68.0 cm (26¾ in.), L. 154.0 cm (60¾ in.). National Museum of Cambodia (Ka3175)

Figure 10 • Simplified geological map of Cambodia based on United Nations 1993, with locations of major Khmer archaeological sites

geologists in the late 1960s during early attempts to complete a systematic geological mapping of Cambodia. The overall stratigraphy has been variously interpreted, but the most often cited Mesozoic formations of the Khorat Group in

Thailand from the Late Triassic to the Middle Cretaceous are Nam Phong, Phu Kradung, Phra Wihan, Sao Khua, Phu Phan, and Khok Kruat (Figure 11).<sup>34</sup> In Cambodia, the last four formations of the Khorat Group are known as



Ma	PERIOD		KHORAT GROUP	CAMBODIA (Sotham 1997)	THAILAND		Major lithologies (Racey et al. 1996)
				(Workman 1977)	(DMR 1992)		
65	CRETACEOUS	Upper	KHORAT GROUP	Grès Supérieures Formation	Maha Sarakham Formation	Maha Sarakham Formation	Light brown arkosic sandstone and evaporites
		Middle			Khok Kruat Formation	Khok Kruat Formation	Fine- to coarse-grained, reddish-brown arkosic sandstone, siltstone and conglomerate
		Lower				Phu Phan Formation	Medium- to coarse-grained, white to brown, quartz-rich sandstone
144	JURASSIC	Upper		Terrain Rouge Formation	Phra Wihan Formation	Sao Khua Formation	Fine grained, red-brown to purple sandstone
		Middle			Phra Wihan Formation	Phra Wihan Formation	Fine- to coarse-grained, white to yellow-brown, quartz-rich sandstone
		Lower		Phu Kradung Formation	Phu Kradung Formation	Red-brown sandstone, siltstone and mudstone	
206					Nam Phong Formation	Red-brown conglomerate, sandstone and mudstone	
248	TRIASSIC	Upper	Indosinian Triassic Formation		Huai Hin Lat Formation		Greenish-gray, immature sandstone with shale interbeds
		Middle					
		Lower					

Figure 11 • Mesozoic stratigraphy of Cambodia (based on Sotham 1997) correlated to the Khorat Group formations of Thailand. Two published interpretations of the stratigraphy in Thailand are presented (Workman 1977; DMR 1992), with the most representative lithologies for each formation. Modified after Racey et al. 1996, p. 8. A wavy line indicates an unconformity; a dashed line indicates an uncertain sedimentary boundary.

the Grès Supérieures Formation, a designation introduced by French geologists to indicate the subhorizontal continental sediments occupying the highlands of western and northern Cambodia.<sup>35</sup> These rocks, mostly quartz-rich sandstones and conglomerates, are considered separately from the Lower–Middle Jurassic fluvial and lacustrine sequence known as the Terrain Rouge Formation, roughly corresponding to the Phu Kradung Formation, and from the Indosinian Triassic sequence that occupies the lowermost unit of the Khorat Group and is known in Thailand as the Nam Phong Formation. In this framework, the well-known quarries at the foot of Phnom Kulen are located at the upper portion of the Terrain Rouge Formation, close to the contact with the Grès Supérieures Formation, which is in turn quarried on top of Phnom Kulen, close to Prasat Rong Chen.<sup>36</sup>

At the present time, a geological provenience of the quartz arenite (Types 1 and 2) used for

lintel production cannot be identified with precision. However, geological and petrographic data confine the source of these lithotypes to the upper members of the Khorat Group, corresponding to the Grès Supérieures Formation of Cambodia. The medium-grained, white to light brown quartz arenite (Type 1 sandstone) may originate from the Phra Wihan and the Phu Phan Formations. These formations are known to include white to light-buff, very fine- to coarse-grained sandstones, tightly cemented by authigenic quartz and characterized by extensive kaolinitization.<sup>37</sup> Furthermore, these sandstones are often iron stained and differently colored, as can be seen in modern quarries in Banteay Meanchey Province, as well as in the ancient quarries of Ban Khao Luk Chang, Ta Phraya, and Preah Vihear, scattered along the Dangrek Range.

The mineralogy of Phra Wihan sandstones is dominated by monocrystalline, mostly

undulose quartz, while feldspars and rock fragments are sparse. Heavy minerals, including rutile, tourmaline, and zircon, are also rare. Similar medium- to coarse-grained, quartz-rich sandstone that is light in color is also abundant in the Phu Phan Formation and is difficult to distinguish from Phra Wihan lithotypes even at the microscopic scale.

The very fine-grained, hematite-rich, reddish sandstone (Type 2) identified in this study could originate from either the Phra Wihan or the Sao Khua Formations. Similar lithotypes dominated by quartz grains, scarce feldspar, and rock fragments cemented by abundant hematite and kaolinite occur in both these formations;<sup>38</sup> they could potentially be found on top of Phnom Kulen, although there are currently no petrographic data to confirm this possibility.

Finally, petrographic analysis indicates that the greenish-gray feldspathic arenite in this study (Type 3 sandstone) belongs to the upper portions of the Terrain Rouge Formation, considered equivalent to the Lower–Middle Jurassic Phu Kradung Formation of Thailand. This subcontinental sequence is characterized in its upper section by very fine to fine, moderately well-sorted sandstone, intercalated with mudstones and calcrete horizons. The sandstone is mineralogically and texturally quite homogeneous and comparable to sandstone found in the provinces of Siem Reap and Preah Vihear, where this formation constitutes extensive portions of the foothills of Phnom Kulen and crops out in isolated hills and numerous riverbeds of northern Cambodia.<sup>39</sup>

Because Terrain Rouge sandstones with similar petrographic characteristics are widely distributed throughout the regions, it is almost impossible to identify the geographic provenience for any of the Type 3 lintels studied. One of the possible sources of feldspathic arenite (Type 3 sandstone) is the well-known and well-studied quarry district active in the Angkor period, located at the eastern foothills of Phnom Kulen, about 40 kilometers northeast of Angkor. This area is scattered with open quarries of variable size and geometry that

follow the sandstone attitude and form a complex system of stone exploitation. Stepped surfaces with clear chisel marks, wedge holes, and channels indicative of the removal of sandstone blocks are evidence of quarrying activity that most likely relates to the construction of the Angkor temples.<sup>40</sup> Several quarries of feldspathic arenite are known also in Koh Ker<sup>41</sup> and close to Prasat Kdak,<sup>42</sup> and it is highly probable that others exist in locations still unknown.

#### **KHMER PRODUCTION OF LINTELS AND DECORATIVE ELEMENTS**

The current article reports results for a corpus of twenty-four lintels and twelve decorative elements of various dates and origins and provides the basis for further research on Khmer practices of stone sourcing and usage. This pilot study shows that the sandstones used belong to Mesozoic sandstone formations readily available in Cambodia, especially in the northern part of the country. Half of the analyzed objects are made with the same sandstone (Type 3), a greenish-gray feldspathic arenite, extensively used in the construction of Angkor temples.<sup>43</sup> The remaining objects are carved from other lithotypes (Types 1 and 2 sandstone) rarely employed in the temples for structural purposes, suggesting that these stones were deliberately selected by Khmer carvers for the production of decorative lintels. The findings for the twelve ornamental architectural elements included in the study are similar.

Numerous technical studies of Angkor temples indicate that the majority of the stone blocks were quarried from the Terrain Rouge Formation (Type 3 sandstone in this study).<sup>44</sup> Conversely, the use of quartz-rich sandstones from the Grès Supérieures Formation (Types 1 and 2 sandstones in this study) as the predominant building material is reported for monuments situated in Thailand close to the Khorat Plateau, where the choice of stone seems to be influenced by the surrounding geology.<sup>45</sup>

The occurrence of quartz arenite (Types 1 and 2 sandstones) lintels in many temples in

present-day Cambodia, where other lithotypes were more accessible and abundant or where no sandstone at all was available in the vicinity, clearly demonstrates that the choice of a specific building material is not necessarily based on its local availability. Understanding how and why specific lithotypes have been used in lintel production and whether the selections differ from standard Khmer temple building practices is a complex task that needs to take into account a number of variables.

One fruitful approach may be to investigate the organization of stone workshops and artisans in charge of the ornamentation of the temples. Recognizing similarities and differences in large quantities of decorative material might allow some of it to be attributed to individual sculptors or workshops. For instance, decorative lintels and colonnettes were usually fixed in place before being carved.<sup>46</sup> The correlation of these elements from specific temple sites to a specific lithotype (e.g., Phnom Da: MG17860, MG18324, Type 1 sandstone; Beng Mealea: MG18120, MG18121, Type 3 sandstone; Prasat Prei Khmeng: MG18854, MG18857, Type 3b sandstone) suggests that both were sourced from the same quarry and supplied at the same time. By comparing stone type, carving methods, and finishing techniques of decorated elements from various sites, it is possible to infer some general trends of stone usage and learn about frequent practices of stone workshops.

Three lintels and a colonnette from the Musée Guimet and the National Museum of Cambodia (MG18855, MG18220, MG18858, Ka1802) were created in close succession in the ninth century. These objects and others from the period are demonstrative of a rise in artistic standardization at a time of continuity in stone provisioning. An increase in artistic standardization is evident in materials produced at the time when the administrative center of the region shifted from Mahendrapavarta (Phnom Kulen) back to Hariharālaya (Roluos). There were concurrent settlements at Mahendrapavarta and Hariharālaya,<sup>47</sup> but the lintels

and temples appear to have been produced only when each city was the abode of the reigning monarch and the focus of the burgeoning empire.<sup>48</sup> During this period lintels show increased usage of the same repertoire of motifs across the city and throughout Khmer-controlled territory. Two different sites in Hariharālaya even appear to have identical lintel designs.<sup>49</sup> Although there were developments in iconography, the uniform lithotype (Type 3 sandstone) used for lintels from Mahendrapavarta and Hariharālaya is suggestive of an ongoing workshop tradition using the same stone sources as Phnom Kulen.

During the early to mid-tenth century the number of monuments constructed in durable materials (brick and sandstone) increased markedly,<sup>50</sup> and a proliferation of homogeneous lintel designs emerged that identified these foundations. Uniformity of motifs and composition are observed on the lintel friezes, which illustrate the implementation of a design repertoire that had likely been committed to memory in a workshop environment. From the combination of three or four distinctive motifs that characterize the work of a particular workshop, one motif in particular—the celestial being praying in a fleuron—was perhaps the most idiosyncratic.<sup>51</sup> This and associated motifs of polylobe fleurons and *romyuol* flowers appear on the friezes of three of the lintels in the Metropolitan Museum (1994.111; 36.96.6, see Figure 2; 1996.473, see Figure 4).<sup>52</sup> That these lintels, likely originating from sites separated by large geographical distances, share the same lithotype (Type 2 sandstone) supports the suggestion that they are the product of a tenth-century tradition characterized by a preference for a specific type of stone.

Among the lintels that were studied, those from the early and mid-eleventh century possibly originating in present-day Thailand and now in the Metropolitan Museum (1972.214; 1992.192; 1994.94, see Figure 5) and the Arthur M. Sackler Gallery (S1987.953) are rendered in white to light brown quartz arenite (Type 1 sandstone). This sandstone is consistent with



sedimentary formations widely exposed in northern Cambodia, along the Dangrek Range, and on the Khorat Plateau, which is the region the lintels are thought to come from. In this case, workshops may have been influenced by the surrounding geology in the choice of the stone for their various commissions.<sup>53</sup>

Undoubtedly, a large dataset on stone materials from provenienced objects can offer valuable support to current studies on material usage and building practices during the Khmer Empire. However, given the fragmentary information available regarding the provenience of many of the lintels in museum collections, as well as the large spatial distribution of the sandstone outcrops, conclusions for now remain speculative.

It is clear that the three identified types of sandstone were used simultaneously across the Khmer Empire and within the same temple complexes, and it is likely that their concurrence was determined by several concomitant factors, including geography, geology, technical knowledge and skill, and, more generally, building traditions. A better understanding of building materials and traditions, as well as the specific organization of workshops, can best be achieved by focusing the investigation on individual structures in situ for which building phases and dates have been established. Such an approach would reveal the distribution of the stone materials in the temple structure and help establish the relationship among stone types, typology of surface finishing, functions within the temple, and building phases.

The study of the stone materials used for sculpture has significant potential to enhance understanding of the provisioning, production, and distribution of classical Khmer art. Stone characterization is useful for addressing specific questions about the authenticity and provenience of carved architectural elements and can complement archaeological studies that consider networks of control and acquisition of resources, the relationships among the state, temples, and artistic workshops, and aspects of the economy of the Khmer Empire.

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## NOTES

- 1 Dagens 2002, p. 236.
- 2 Polkinghorne 2007a; Polkinghorne 2007b, pp. 187–202; Polkinghorne 2008.
- 3 Baptiste et al. 2001, pp. 137–38; Carò 2009; Douglas, Carò, and Fischer 2010.
- 4 Polkinghorne 2007b, pp. 234–36.
- 5 Coral-Rémusat 1940; Stern 1927.
- 6 The lintel with a mask of Kāla is unique and warrants separate study for its relevance to issues relating to the dating of Khmer art and decorative lintels between the seventh and ninth centuries, a subject of considerable academic discourse. Presently, the principal issue is the chronology and duration of decorative elements attributable to the Kompong Preah style (see especially Bénisti 2003; Boisselier 1968; Woodward 2010b). A new synthesis is required that critically appraises decorative material linked to epigraphic material, recent absolute dates from archaeological contexts (e.g., Pottier and Bolle 2009), and analogous sculpture in the round. Similarly it must consider archaism, innovation, and peripheral and parallel artistic developments. Though the stylized fleuron emblem between the Kāla's eyes on the Metropolitan Museum lintel (1985.390.1) is associated with the central motif of Kompong Preah style, the majority of motifs can be ascribed to the Prei Khmeng style; therefore it is likely the lintel was produced in the first half of the seventh century.
- 7 Snodgrass 1985, pp. 307, 312–13.
- 8 Marchal 1951, p. 32; Ang 2004, pp. 85–98.
- 9 Ang 2004, pp. 85–98.
- 10 Coral-Rémusat 1951, p. 43.
- 11 Bosch 1960; Coral-Rémusat 1933, p. 190; Coral-Rémusat 1936, pp. 427–35; Coral-Rémusat 1940, pp. 48–50; Marchal 1938; Stern 1934, p. 253; Stern 1938b, p. 127.
- 12 Bénisti 1973, pp. 119–38.
- 13 Coral-Rémusat 1933, p. 190; Coral-Rémusat 1936, pp. 427–35; Coral-Rémusat 1940, pp. 48–50.
- 14 More recently Woodward (2010a, pp. 44, 145 n. 20) suggested decorative influences from China.
- 15 Thanks to Heng Piphai, student at the University of Hawai'i at Manoa, for alerting the authors to this similarity. See Carte Interactive des Sites Archéologiques Khmers (CISARK), <http://www.site-archeologique-khmer.org/core/showsite.php?id=637> (accessed September 27, 2013).
- 16 For example, at Kuk Roka (see CISARK, <http://www.site-archeologique-khmer.org/core/showsite.php?id=1595> [accessed September 27, 2013]), Olok (see Boisselier 1968, figs. 11–13; Stern 1938a, pl. LVII), Prei Khmeng (see Christian Pottier, Alexandrine Guerin, Heng Than, Im Sokrithy, Koy Tchan, and Eric Llopis, “Mission Archéologique Franco-Khmère sur l'Aménagement du Territoire Angkorien [MAFKATA],” Campagne 2000 Rapport, EFEO, Siem Reap; Angkor National Museum, N.526), Sambor (see National Museum of Cambodia, K11778; Boisselier 1968, fig. 23), Yeay Poan (S1, Sambor Prei Kuk, see Bénisti 1977, fig. 5).
- 17 Polkinghorne 2007b, pp. 160–63.
- 18 For example, at Ak Yum (see Boisselier 1968, figs. 18–22; Stern 1938a, pl. LVI), Ampil Rolum (see Parmentier 1927, fig. 53), Kompong Preah (see Boisselier 1968, fig. 1), Kuk Roka (see CISARK, <http://www.site-archeologique-khmer.org/core/showsite.php?id=1595> [accessed September 27, 2013]), Tuol Kuhear (see Boisselier 1968, fig. 33), Yeay Poan (S1, Sambor Prei Kuk, see Bénisti 1977, fig. 5).
- 19 Inscription K.522. See Coëdès 1953, p. 119.
- 20 EFEO photo cliché fonds Cambodge INVLU12404.
- 21 “Chronique” 1933, p. 1134; see also EFEO photo cliché fonds Cambodge INVLU16242.
- 22 Singaravélou 1999, pp. 251–56; see also Sharrock 2007, pp. 277–81.
- 23 Polkinghorne 2008.
- 24 For example, Giteau 1965, pp. 79–84.
- 25 Included in this study but not illustrated. For an image, see <http://www.metmuseum.org>.
- 26 Polkinghorne 2008.
- 27 A Zeiss Axioplan 2 polarized light microscope was used at The Metropolitan Museum of Art, and a Nikon Eclipse E600 polarized light microscope was used at the Freer Gallery of Art and Arthur M. Sackler Gallery.
- 28 The sorting ( $\sigma$ ) of a sandstone refers to the distribution of the grain-size values around the mean grain size. The higher the sorting ( $\sigma$ ), the more dispersed are the values around the mean.
- 29 Gazzi 1966; Dickinson 1970.
- 30 Heavy minerals are detrital minerals having a specific gravity greater than about 2.9.
- 31 Contri 1972, p. 7; Kučera et al. 2008, p. 305.
- 32 A formation is a body of rock strata that can be distinguished from others by specific physical characteristics.
- 33 A group includes two or more formations that are related to one another.
- 34 Dating such sedimentary formations is problematic and has been the subject of much debate. It is important to bear in mind that evidence for their reported ages is not conclusive. However, this study follows ages and stratigraphy reported in the available 1:200000 geological map of Cambodia published by the Bureau de Recherches Géologiques et Minières and later used by other authors (United Nations 1993; Sotham 1997).
- 35 Contri 1972, pp. 10–11; Dottin 1972, p. 8; Alabouvette 1973, p. 8.
- 36 See CISARK, <http://www.site-archeologique-khmer.org/core/showsite.php?id=460> (accessed September 30, 2013). Other quarries in the Grès Supérieures Formation can be seen at Phnom Santuk (see CISARK, <http://www.site-archeologique-khmer.org/core/showsite.php?id=191> [accessed September 27, 2013]), and Phnom Batheay (see CISARK, <http://www.site-archeologique-khmer.org/core/showsite.php?id=1189> [accessed September 27, 2013]).
- 37 Racey et al. 1996, pp. 20–24.
- 38 Ibid., pp. 20–26; Uchida, Ito, and Shimizu 2010, p. 562.
- 39 Contri 1972, p. 9; Alabouvette 1973, p. 9.
- 40 Delvert 1963, pp. 479–84.

- 41 Evans 2009; Carò and Im 2012.
- 42 See CISARK, <http://www.site-archeologique-khmer.org/core/showsite.php?id=1170> (accessed September 27, 2013).
- 43 Delvert 1963, pp. 469–76; Uchida, Ito, and Shimizu 2010, pp. 551–58.
- 44 For example, Saurin 1954, p. 621; Delvert 1963, pp. 453–54; Uchida et al. 2007, pp. 294–95; Kučera et al. 2008, p. 299.
- 45 Uchida, Ito, and Shimizu 2010, pp. 572–73.
- 46 The many unfinished and partially finished lintels in temples throughout the Khmer world suggest that this carving was one of the final tasks of temple decoration. See Polkinghorne 2007b, pp. 205–9; Polkinghorne 2008, pp. 25–26.
- 47 Penny et al. 2006; C. Pottier, A. Bolle, E. Llopis, D. Soutif, C. Tan, J. B. Chevance, V. Kong, S. Chea, S. Sum, F. Demeter, A.-M. Bacon, N. Bouchet, C. Souday, and M. Frelat, “Mission archéologique Franco-Khmère sur l’aménagement du territoire angkorien (MAFKATA),” Campagne 2005 Rapport, EFEO, Siem Reap.
- 48 Polkinghorne 2013.
- 49 O Ka-aek (IK589.07) has a lintel design identical to four examples from Preah Kô temple. It depicts Aśvin (cavaliers) with weapons riding three-headed crowned Nāga (mythical serpents). The distinctiveness of this design indicates that the same artist, from the same workshop, who worked upon Preah Kô lintels also fashioned the O Ka-aek lintel. See Polkinghorne 2007a.
- 50 The increase in construction during this period is marked by an increase in inscriptions, which are often placed on doorjambs (see, e.g., Lustig 2009, esp. fig. 42).
- 51 Polkinghorne 2007a.
- 52 *Romyuol* is a traditional Khmer floral decorative motif (*Kbach*) similar to a water lily (*Nymphaea lotus*) or a hibiscus flower (*Hibiscus sagittifolius*).
- 53 Uchida, Ito, and Shimizu 2010, p. 572.

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Department of Scientific Research, The Metropolitan Museum of Art: Figures 7, 8, 10, 11

Musée National des Arts Asiatiques–Guimet, Paris: Figure 6

National Museum of Cambodia, Phnom Penh: Figures 3, 9

**ថ្មដែលយកមកប្រើប្រាស់សម្រាប់ ធ្វើផ្តែរ និង សម្រាប់តុបតែង លំអក្នុងប្រាសាទខ្មែរ**

**សង្ខេប**

ចម្លាក់ផ្តែរដ៏ល្អឥតខ្ចោះដែលជាបុព្វសិទ្ធិ និងជានិមិត្តរូបសម្រាប់ប្រាសាទខ្មែរ។ ចម្លាក់ផ្តែរសម្រាប់ប្រាសាទនីមួយៗត្រូវបានគណៈកម្មការជ្រើសរើសជាដាច់ខាតក្នុងដំណាក់កាលសាងសង់ប្រពៃណី។ ក្បាច់ចម្លាក់ផ្តែរក៏ទាំងប្រាំពីរនៅសារមន្ទីរសិល្បៈ Metropolitan ដែលត្រូវបានគេបង្ហាញនូវទេពកោសល្យ និងភាពប្តឹងប្រសប់ តាមរយៈអគ្គន័យនៃការសិក្សាសិលាចារិក និងស្នាដៃជាមួយនឹងផ្តែរម្តេចប្រាំបួនផ្សេងទៀត ហើយនិងកស្មតាងមួយចំនួនទៀត ដែលមានតាំងពីសតវត្សទី៧ ដល់សតវត្សទី១៣។ បច្ចុប្បន្ននេះ ផ្តែរទាំងនោះគឺនៅសារមន្ទីរជាតិកម្ពុជា ស្ថិតនៅទីក្រុងភ្នំពេញ សារមន្ទីរ Musée National des Arts Asiatiques–Guimet ស្ថិតនៅទីក្រុងប៉ារីស និងសារមន្ទីរ Arthur M. Sackler Gallery, Smithsonian Institution ស្ថិតនៅទីក្រុង Washington, D.C. សហរដ្ឋអាមេរិក។

តាមលទ្ធផលស្រាវជ្រាវបង្ហាញថា ប្រភេទថ្មសម្រាប់ធ្លាក់ក្នុងប្រាសាទ គឺបានជ្រើសរើសដោយជាងចម្លាក់ខ្មែរ។ ជាការពិតណាស់ប្រភេទថ្មគត់ដែលប្រើប្រាស់ក្នុងការសាងសង់ប្រាសាទគឺមានលក្ខណៈ ជាផ្ទាំងៗ ដែលកកើតឡើងពីដីក្រហម (from the Terrain Rouge Formation) ក្នុងប្រទេសកម្ពុជា ហើយថ្មកក ដែលមានល្បាយម៉ដ្ឋ ត្រូវប្រើប្រាស់សម្រាប់ធ្លាក់លំអ ដូចជាសម្រាប់ធ្លាក់ផ្តែរប្រាសាទ និងគ្រឿងលំអផ្សេងៗ។ ថ្មកកប្រភេទនេះប្រហែលកើតឡើងពី Grès Supérieures Formation និងកំណកដីដែលលាតសន្ធឹងដល់ប្រទេសថៃ ប្រទេសឡាវ និងប្រទេសវៀតណាម។

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**ABSTRACT TRANSLATED BY SO MALAY AND THO THON**