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The place of Tam Hang in Southeast Asian human evolution

La place de Tam Hang dans l'Histoire évolutive de l'Homme en Asie du Sud-Est

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ABSTRACT

In February 1934, Jacques Fromaget of the Geological Service of Indochina discovered the Tam Hang rockshelter during prospecting work in Northern Laos. During his excavations, the geologist discovered seventeen anatomically modern human skulls. Ten of these skulls have been recovered in association with six largely-complete skeletons. These fossils, which are dated by ^{14}C to 15.7 ka, are used to address issues related to anatomical variation and migration in Southeast Asia during the Late Pleistocene. Excellent preservation of the skeletal material allows for estimation of body size and shape in a sample of young adults. Cranial metrics are also used to assess affiliations between Tam Hang and other Southeast Asian fossil samples in an effort to address questions about population migration. This fossil sample demonstrates that Late Pleistocene human activity may be productively addressed by continued work in the highlands of mainland Southeast Asia.

RÉSUMÉ

C'est en février 1934, lors d'une mission de prospection, que Jacques Fromaget, géologue auprès du Service géologique d'Indochine, a découvert l'abri sous roche de Tam Hang. Le site se situe sur le versant sud-est de la Chaîne annamitique septentrionale au nord du Laos. Le géologue a mis au jour, lors de ses fouilles, dix-sept crânes d'anatomie moderne, parmi lesquels dix ont été préservés. Six d'entre eux sont associés à du postcrânien. L'étude de ces fossiles, datés de 15,7 ka par le ^{14}C permet de mieux comprendre comment se sont opérées les migrations humaines en Asie du Sud-Est continentale durant le Pléistocène supérieur récent. L'excellent état de conservation de ces individus permet d'estimer la taille et la morphologie d'une population composée de jeunes adultes. Seules des recherches continues en Asie du Sud-Est continentale affineront nos connaissances sur les origines de l'Homme dans la région.

1. Introduction

The Late Pleistocene is associated with extreme climatic changes of the Last Glacial Period (LGP: 124–10 ka) and its peak at the Last Glacial Maximum (23–19 ka). In Southeast Asia, a decrease in oceanic temperatures and precipitation

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was accompanied by a reduction in sea level that exposed Sundaland, the continental shelf connecting the Southeast Asian mainland with Sumatra, Java and Borneo (Bird et al., 2005; De Deckker et al., 2003; Heaney, 1991; Wurster et al., 2011). This fundamental change in geography would have played a significant role in the settlement and migration patterns of animals in the region, including humans. At the end of this period, human populations again faced changing environments as sea levels rose and continental boundaries were reconstituted.

There is significant uncertainty regarding modern human occupation and migration in East and Southeast Asia during the Late Pleistocene because human remains from this time period are known from relatively few areas of East and Southeast Asia (Table 1). Uncertainty regarding early human occupation of the area is compounded by imprecise dating that is endemic to this part of the world (Brauer et al., 2004; Stringer and Andrews, 1988; Wolpoff et al., 2001).

The site of Tam Hang, Laos was discovered more than 70 years ago, but Late Pleistocene fossils from the site were recognized much more recently (Demeter, 2000; Fromaget, 1940a, 1940b; Fromaget and Saurin, 1936). Ten skulls and six partial skeletons are currently available. Despite the excellent preservation and rarity of this sample, it has not been widely known to the public. The current paper briefly describes the composition and preservation of the Tam Hang sample and provides information regarding stature and body size. In addition, we evaluate morphological features of this mainland Southeast Asian sample in the context of Late Pleistocene human evolution and migration.

2. The site of Tam Hang

Tam Hang is located in Hua Pan Province, northern Laos, at an elevation of 1120 m (20°24'N and 104°02'E) (Fig. 1). The site is a rockshelter with a geologically-active karstic network located at the base of the P'ou Loi Mountains in the Annamite Mountain Chain, which runs northwest to southeast along the Laos-Vietnam Border. In 1934, Tam Hang was discovered by Jacques Fromaget of the Geological Service of Indochina. Fromaget excavated three localities along 100-meters of the rockshelter (Fig. 2): North Tam Hang (THN), Central Tam Hang (THC) and South Tam Hang (THS). THS is significant for the paleontological and archaeological materials recovered from within and below the rockshelter. The walls and karstic network that comprise the Tam Hang rockshelter exposed an array of Middle Pleistocene mammalian fauna (Arambourg and Fromaget, 1938; Bacon et al., 2008, 2010; Fromaget, 1940a) (Fig. 2: THS1). Archaeological artifacts and human remains were recovered from sediments under the shelter (Demeter, 2000; Fromaget, 1936, 1937, 1940b; Fromaget and Saurin, 1936) (Fig. 2: THS2).

Unfortunately, no geological reports from excavations outside the rock shelter have been recovered. The archaeological collections recovered by Fromaget were only summarily described and have since been lost. Part of the human skeletal sample excavated from the site has been preserved and is currently accessible at the Musée de l'Homme, Paris. Of the seventeen human skulls discovered by Fromaget, ten have been recovered. Six of these are associated with largely-complete skeletons. Three of these individuals were sampled for radiocarbon dating. Only one skeleton (THS 10, rib fragment) contained enough collagen for a reliable ^{14}C date, yielding an age of 15.7 ± 0.8 ka (GR. 201-2000; Demeter, 2000).

2.1. Stratigraphy

The description of the stratigraphy left by Fromaget is unclear and thus unreliable for understanding the depositional processes at THS. Archaeological excavation conducted at the site in 2003 re-opened the region of Fromaget's original excavation and allowed additional study of the geology and stratigraphy of the site (Demeter et al., 2009). Two areas were opened: a 3-m-deep test pit adjacent to the site from which Fromaget recovered the human skeletons (Fig. 2; test pit) and 10 m^2 × 2-m-deep archaeological excavation underneath the rockshelter (Fig. 2; THS 2).

Analysis of the stratigraphy of THS demonstrates six successive layers of clays as well as two well-developed conglomerate beds dominating the deposits (Fig. 3). Cultural layers are identified as relevant. These layers are described from superior to inferior.

The most superior layer (Fig. 3, layer A) is 10–15 cm thick and contains organic matter. It is composed of a rich, sandy-argillaceous soil characterized by numerous *in situ* roots of extant plants. It is filled with a great deal of surface debris.

Layer B consists of brown to red-brown silty pelites that contain variable proportions of quartzite and arenite. Granule- to gravel-sized iron- and manganese-rich pisolith concretions are scattered throughout the profile from top to bottom (although they never exceed 1%). This layer produced artifacts such as circular engraved spindle whorls. Though rare, an occasional boulder or cobble is found in Layer B.

Layer C is an argillaceous-cemented conglomerate that is channel-shaped laterally. The pebbles consist of poorly-cemented argillaceous sandstone.

Layer D is similar in color and consistency to layer B. Ceramic fragments were recovered from this layer. These fragments are from pottery with impressed or incised decoration, and they have been formed using diverse clays (Demeter et al., 2009).

Layer E is characterized by large limestone boulders from a succession of rock collapses from the cliff. Their deposition in several layers clearly demonstrates that the conglomerate layer was formed by several deposits (rock collapses) over time. All of these blocks have the same slope descending along the shelter, and the archaeological surface of Layer E follows this same slope. Based on Fromaget's description (1940b), the human remains were recovered from this layer. The radiocarbon date derived from these remains of 15.7 ± 0.8 ka gives it a minimum age.

Layer F is the same color and consistency of layers B and D with brown to red-brown silty pelites that contain variable amounts of quartzite and arenite. The upper part of this layer has occasional boulders and cobbles. In the lower part of layer F, pebbles appear inside the pelites. These pebbles are formed by centimetre-sized argillaceous sandstone (as

Table 1
Major East and Southeast Asia modern human fossil sites by region.
Tableau 1
Principaux sites à Hommes modernes d'Asie extrême-orientale et du Sud-Est par région.

Geographic Area	Site	Age (ka)	Preservation	References
Cambodia	Samron Sen*	3–1.2	Crania, postcrania	Mansuy, 1924
China	Huanglong Cave, Hubei	44–34 103–79	Teeth	Liu et al., 2010b
	Jingchuan*	48–15	Cranium	Wu and Poirier, 1995
	Laishiu, Hebei	28	Cranium, postcrania	Etler, 1996
	Liujiang, Guangxi*	10–67?	Cranium, postcrania	Woo, 1959a, 1959b; Wu and Poirier, 1995; Yuan et al., 1986
	Tianyuan Cave	35	Mandible, partial postcrania	Shang and Trinkaus, 2010; Tong et al., 2004
	Upper Cave, Zhoukoudian*	11–29	Crania, postcrania	Weidenreich, 1939; Wu, 1961; Wu and Poirier, 1995
	Lijiang, Yunnan Province	Late Pleistocene	Skull	Wu and Poirier, 1995
	Chuandong, Guizhou Province	Terminal Pleistocene/earliest Holocene	2 skulls, isolated incisor	Etler, 1996; Huang, 1989; Yu, 1984
	Zhiren Cave, Guangxi	> 100	Mandible	Liu et al., 2010a
	Ziyang, Sichuan*	7–39	Partial cranium	Woo, 1958; Wu and Poirier, 1995
Indonesia	Wadjak*	6.5	Cranium	Storm, 1995
Japan	Hamakita	ca. 14–17	Cranium, postcrania	Kondo and Matsu'ura, 2005; Suzuki, 1966
	Pinzu-Abu	26	Crania, postcrania	Hamada, 1985; Sakura, 1981, 1985
	Yamashita-cho	32	Postcrania (immature)	Kobayashi et al., 1971; Suzuki, 1983; Takamiya et al., 1975
	Minatogawa*	ca. 18	5–9 individuals (crania, postcrania)	Baba et al., 1998; Suzuki and Hanihara, 1982
	Shiraho-Saonetabaru Cave	16–20	Crania and postcrania	Nakagawa et al., 2010
Korea	Mandalli	Late Pleistocene	Parial skull, postcrania	Norton, 2000
	Ryonggok	46–48	Crania, postcrania	Norton, 2000
	Turubong Hungsugul	40–50	Skull, postcrania (juvenile)	Norton, 2000
Laos	Tam Hang*	15.8	Crania, postcrania	Arambourg and Fromaget, 1938; Bacon et al., 2008, 2010; Demeter et al., 2009; Fromaget, 1940b
	Tam Pong*		Crania	Demeter, 2000
Malaysia	Niah Cave	39–45	Cranium	Barker et al., 2007; Brothwell, 1960
Mongolia	Salkhit	16–28 35–65	Crania/Partial crania, postcrania	Coppens et al., 2008; Wu and Poirier, 1995
	Salawusu (Sjara-osso-gol)	35–65	Cranial fragments, postcrania	Licent et al., 1926; Woo, 1958; Wu and Poirier, 1995
The Philippines	Tabon cave	16–30	Crania, postcrania (fragmentary)	Detroit et al., 2004
Thailand	Ban Kao*	6	Crania, postcrania	Sorensen, 1967
	Moh Khiew	26	Postcrania	Matsumura and Pookajorn, 2002; Pookajorn, 1996
Vietnam	Cau Giat*	7.5	Crania, postcrania	Colani, 1930
	Dong Can*			Colani, 1930
	Dong Thuoc*			Colani, 1930
	Pho Binh Gia*	7.5	Crania	Mansuy, 1924
	Lang Cuom*	7.5	Crania	Colani, 1930
	Mai da Dieu*	20	Crania, postcrania	Ciochon and Olsen, 1986
	Mai da Nuoc*			
Sri Lanka	Fa Hein	ca. 33	Crania, postcrania	Kennedy and Zahorsky, 1997
	Batadomba lena	15 28.5	Crania, postcrania	Kennedy and Deraniyagala, 1989; Kennedy et al., 1987
	Beli lena Kitulgala	12	Crania, postcrania	Kennedy and Deraniyagala, 1989; Kennedy et al., 1987

Asterisks indicate specimens used in this cranial analysis (*les astérisques indiquent les spécimens étudiés*).

in Layer C). The density of the pebbles increases towards the base of the profile. A lithic industry that may be associated with the Hoabinhian tradition was identified in this layer (Demeter et al., 2009).

2.2. Archaeological context

In his 1938 publication, Fromaget briefly notes that some stone tools and some bone tools, such as fragmen-

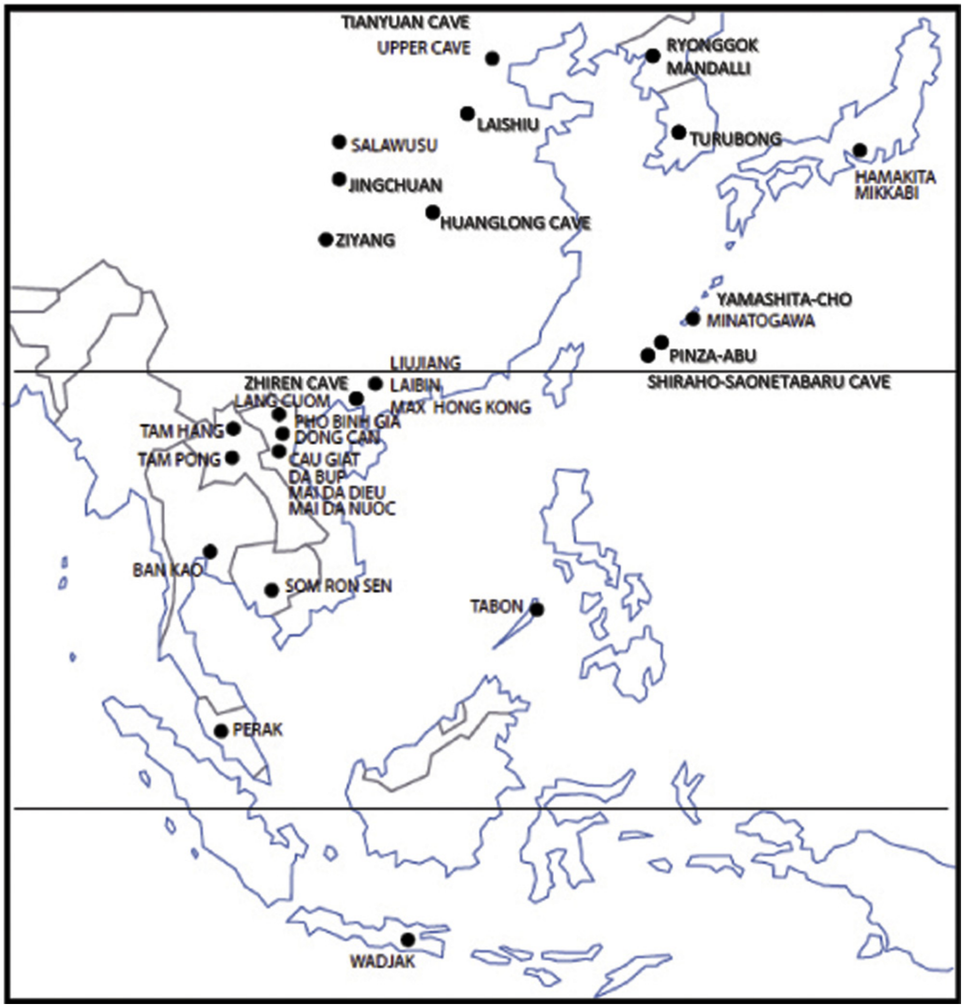

Fig. 1. Map of continental Southeast Asia with the site of Tam Hang in northeastern Laos. Other sites of interest mentioned in the text are also identified.

Fig. 1. Carte de l'Asie du Sud-Est avec le site de Tam Hang dans le nord-est du Laos. Les sites du Pléistocène sont marqués par des triangles pleins.

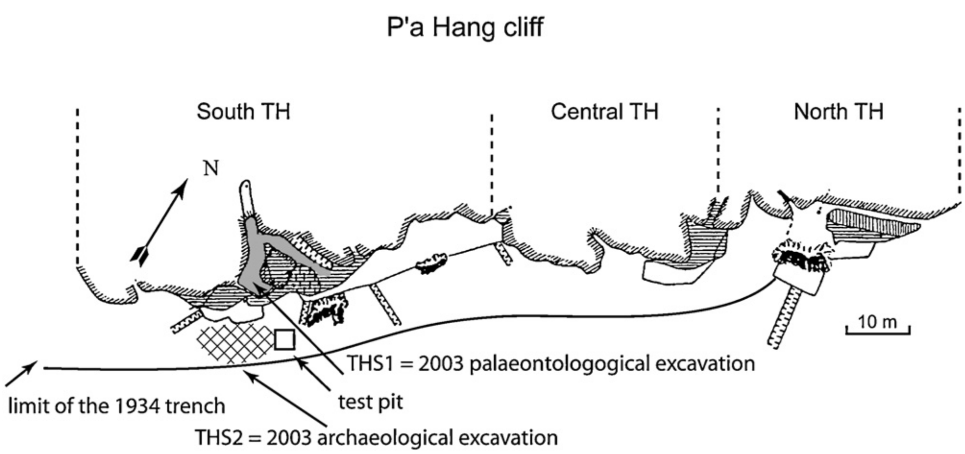

Fig. 2. Map of the Tam Hang site modified from Fromaget (1940a). Location of the test pit from which geological information was evaluated is identified.

Fig. 2. Carte du site de Tam Hang modifiée d'après Fromaget (1940a). La localisation du sondage dont les niveaux ont été identifiés est notée.

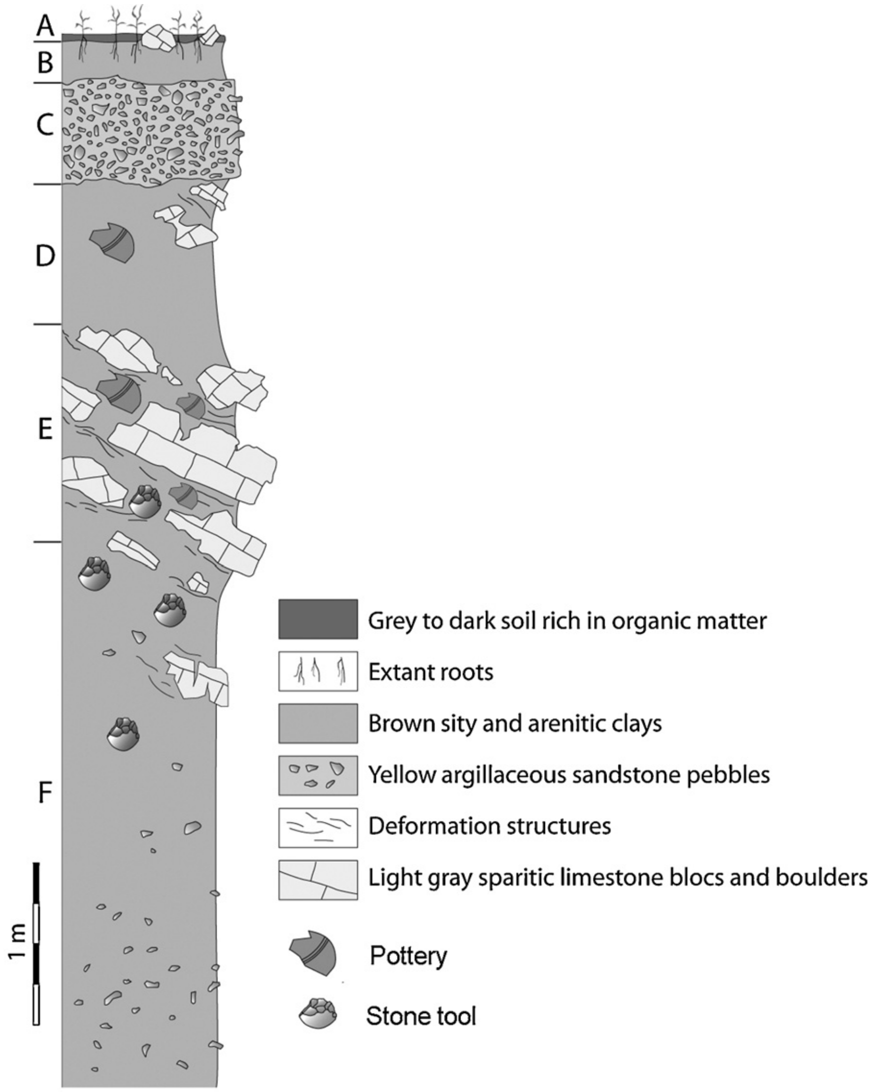

Fig. 3. Stratigraphy of Tam Hang South with levels A–F identified. Section drawn by P. Duringer in Demeter et al. (2009).

Fig. 3. Stratigraphie de Tam Hang Sud avec les niveaux A–F. Profil réalisé par P. Duringer d'après Demeter et al. (2009).

tary assegais, were found in the same layer as the human remains. There is no additional information on the archaeological material from the site, and this material is no longer available.

2.3. *Anthropology*

The fossil material from Tam Hang is not widely known and has not been described in detail in any easily available publication. As such, the sample composition is briefly described here and in accompanying tables (Tables 2–5), and standard osteometrics are provided for the crania (Table 6) and postcrania (Tables 7 and 8). The majority of the osteometric measurements follow standard Martin's method updated by Brauer (1988). Clarifications are provided when non-standard measurements are used. Most linear measurements are provided to the nearest 0.1 mm and angles to the nearest degree.

The age of each individual was determined by dental formation and occlusal wear in combination with degree of cranial suture obliteration. Sex was determined based on pelvic remains for individuals with associated pelves or appropriate pelvic fragments (THS 2, 3, 7, 11, 13, 14), in addition to the overall gracility or robusticity of cranial and mandibular superstructures.

2.3.1. *Tam Hang North 3 (THN 3)*

Tam Hang North 3 (THN 3) is the well-preserved cranium of a young adult female (Fig. 4a, b). It shows some fractures across the parietal and frontal bones. The frontal bone is complete, and the zygomatic arches are well preserved. The maxilla is complete, and all maxillary teeth are erupted with the exception of the M^2, which was just beginning to erupt. The right and left M^3 and left P^3, I^2 and I^1 had fallen from the alveolar bone *post-mortem*. The

Table 2
Inventory of the Tam Hang fossils that are preserved and currently available from Fromaget's 1934 excavation.
Tableau 2
Inventaire des fossiles provenant des fouilles de Fromaget de Tam Hang en 1934, qui sont actuellement conservés et disponibles.

Specimen	Preservation	Age	Sex
THN 3	Cranium	Young adult	Female
THS 2	Cranium, postcrania	Young adult	Female
THS 3	Cranium, postcrania	Adult	Female
THS 4	Cranium	Adult	Male
THS 7	Cranium, postcrania	Adult	Female
THS 10	Cranium	Adult	Female
THS 11	Cranium, postcrania	Young adult	Female
THS 13	Cranium, postcrania	Adult	Female
THS 14	Cranium, postcrania	Young adult	Male
THS 22	Cranium, postcranial fragments	Adult	Female

Table 3
Preservation of axial skeletons of Tam Hang sample. Presence of an element is indicated by R (right) and L (left) for bilateral bones or an X for midline structures. Numbers indicate the number of vertebrae preserved.
Tableau 3
Conservation des squelettes axiaux de l'échantillon de Tam Hang. La présence d'un élément est indiquée par un R (droit) et L (gauche) pour les os bilatéraux ou un X pour les structures uniques. Les nombres indiquent le nombre des vertèbres conservées.

	THS 2	THS 3	THS 7	THS 11	THS 13	THS 14
Cervical vertebrae	7	7	–	3[a]	4[a]	7
Thoracic vertebrae	12	12	4[a]	11[a]	9[a]	12[a]
Lumbar vertebrae	5	5	5	5	5[a]	5
Sternum	X[a]	X	X[a]	–	–	X[a]
Sacrum	X[b]	X[b]	X[a]	X[a]	X[a]	X
Ossa coxae	R, L[b]	R, L[b]	R[a], L[a]	R[a], L[a]	R[a], L[a]	R, L

[a] Fragmentary/partially preserved (*fragmentaire/partiellement conservé*).
[b] Elements are fused together by sediments (*éléments fusionnés par le sédiment*).

mandible is well preserved, and all mandibular teeth are erupted except for the M_2.

2.3.2. Tam Hang South 2 (THS 2)

Tam Hang South 2 (THS 2) is a young adult female with a partial cranium and associated skeleton (Fig. 4c, d and Fig. 5). The face is missing, and only the left basal segment of the zygomatic arch is preserved. The mandible is fragmentary. The M_3 are not erupted; the left I_1 and I_2 are absent, whereas the right I_1, I_2 and P_4 are present. Significant alveolar resorption suggests that the left incisors were lost ante-mortem.

A nearly complete postcranial skeleton is preserved. All elements of the vertebral column and all long bones of the upper and lower limbs are preserved with only slight post-mortem damage. There is a complete pelvis, and the

Table 4
Presevation of upper limb bones of Tam Hang sample. Presence of an element is indicated by R (right) and L (left).
Tableau 4
Conservation des membres supérieurs de l'échantillon de Tam Hang. La présence d'un élément est indiquée par un R (droit) et L (gauche).

	THS 2	THS 3	THS 7	THS 11	THS 13	THS 14	THS 22
Scapula	R[a], L[a]	R[a], L[a]	R[a], L[a]	R[a], L[a]	R, L	R[a], L[a]	–
Clavicle	R, L	R, L	R, L	R[a], L	R, L[a]	R, L	–
Humerus	R, L	R, L	R[a], L	R, L	R[a], L[a]	R, L[a]	R[a], L[a]
Ulna	R[a], L[a]	R, L[a]	R, L[a]	R[a], L[a]	R[a], L[a]	R, L	–
Radius	R, L	R, L	R, L	R, L	R[a], L[a]	R, L	–
Scaphoid	L	R	R, L	R	R	L	–
Lunate	R, L	L	–	–	R, L	–	–
Triquetrum	–	–	–	R	–	L	–
Trapezium	–	R	R, L	–	R, L	L	–
Trapezoid	–	–	R, L	–	R, L	L	–
Capitate	R, L	–	R, L	–	R, L	R, L	–
Hamate	R, L	R, L	R, L	–	R, L	R, L	–
Metacarpals[b]	R I-VL I-V	R I-VL I, III-V	R I-VL I-III, V	R IL II-IV	R I-III, VL I-III, V	R I-VL I-V	–
Phalanges, proximal[c]	9	10	9	7	7	9	–
Phalanges, intermediate[c]	2	8	6	–	5	6	–
Phalanges, distal[c]	–	5	4	–	5	5	–

[a] Fragmentary/partially preserved (*fragmentaire/partiellement conservé*).
[b] Roman numerals indicate which metacarpals are preserved (*les chiffres romains indiquent quels sont les métacarpiens conservés*).
[c] Phalanges are not sided; number indicates total number of phalanges preserved (*les phalanges ne sont pas latéralisées ; les chiffres indiquent le nombre total de phalanges conservées*).

Table 5
Preservation of lower limb bones of Tam Hang sample. Presence of an element is indicated by R (right) and L (left).
Tableau 5
Conservation des membres inférieurs de l'échantillon de Tam Hang. La présence d'un élément est indiquée par un R (droit) et L (gauche).

	THS 2	THS 3	THS 7	THS 11	THS 13	THS 14	THS 22
Femur	R, L	R, L	R[a], L[a]	R[a], L[a]	R[a], L[a]	R, L	–
Tibia	R, L	R, L	L[a]	R, L	R, L[a]	R[a], L	R[a], L
Fibula	R[a], L	R[a], L	–	R, L	R, L	R[a], L	–
Patella	R	L	–	R, L	R, L	R, L	–
Talus	L	R, L	L	R, L	R, L	R, L	–
Calcaneus	R	R, L	L	R[a], L	R[a], L	R, L	R
Navicular	R	L	L[a]	R[a]	L	R, L	–
Cuboid	R, L	R	R, L	R, L	R[b], L	R, L	–
Medial cuneiform	–	–	R, L	R	L	R, L	–
Intermediate cuneiform	–	–	–	R, L	L[a]	R, L	–
Lateral cuneiform	R, L		L	R, L	R	R, L	–
Metatarsals[b]	R I, IV, VL I[a], V[a]	R I-VL I-III, V	RI-III, VL IV, I[a], V[a]	R I-VL I-V	R I, III-VL I, III-V	R I-VL I-V	–
Phalanges, proximal[c]	5	8	6	4	3	9	–
Phalanges, intermediate[c]	–	1	–	–	–	3	–
Phalanges, distal[c]	1	1	–	–	–	2	–

[a] Fragmentary/partially preserved (*fragmentaire/partiellement conservé*).
[b] Roman numerals indicate which metacarpals are preserved (*les chiffres romains indiquent quels sont les métacarpiens conservés*).
[c] Phalanges are not sided; number indicates total number of phalanges preserved (*les phalanges ne sont pas latéralisées ; les chiffres indiquent le nombre total de phalanges conservées*).

sacrum and ossa coxae are fused together by sediments in accurate anatomical position.

2.3.3. *Tam Hang South 3 (THS 3)*

Tam Hang South 3 (THS 3) is an adult female with a complete cranium and mandible (Fig. 4e, f and Fig. 5). The frontal bone is very well preserved, as are the zygomatic arches. The maxillae are complete, and all of the maxillary teeth are present, except the left M^2 and I^2, which have been broken down to the root *post-mortem*. The right I^2 was lost ante-mortem, and the M^1-M^3 segment has been broken post-mortem. The mandible is complete, and all of the mandibular teeth are present and erupted with the exception of the I_2, which has also been lost.

THS3 has a nearly complete, well-preserved skeleton with slight post-mortem damage. The complete vertebral column is present and well-preserved. A complete sacrum is fused by matrix to the left os coxa. The right os coxa is complete. The pubic symphysis is obscured by matrix, and a small part of the left pubic bone is fused in this matrix. The long bones are present with some damage to the epiphyses.

2.3.4. *Tam Hang South 4 (THS 4)*

Tam Hang South 4 (THS 4) is an adult male with a well-preserved cranium, despite fractures across the parietal bones and on the frontal bone along the superciliary arches (Fig. 4g, h). The zygomatic arches are preserved, and the maxillae are complete. There is slight alveolar prognathism. On the right side, the M^1, P^3, $\bar{C}$, I^1 and I^2 are absent. On the left side the I^1, I^2, $\bar{C}$ and M^3 are missing. The mandible is relatively complete, but lacks mandibular condyles and coronoid processes. On the right side of the mandible the I_1, C̦, P_3, P_4 and the M_1 are present. On the left side the M_3, M_2 root, P_4 and P_3 are present. All of the teeth are erupted, but the left M_2 was lost ante-mortem.

Table 6
Tam Hang cranial metrics. M° refers to the Martin measurement number (Brauer, 1988). Linear measurements are in millimeters.
Tableau 6
Mesures crâniennes des individus de Tam Hang. M° se réfère aux numéros des mesures de Brauer (1988). Les mesures sont en millimètre.

	THN 3	THS 2	THS 3	THS 4	THS 10	THS 11	THS 13	THS 14	THS 22
Max cranial length (M°1)	164.0	156.0	176.0	171.0	185.0	181.0	161.0	181.0	167.0
Basion-nasion length (M°5)	91.0	86.0	96.0	99.0	105.0	91.0	91.0	95.0	95.0
Basion-bregma height (M°17)	125.0	130.0	134.0	135.0	145.0	134.0	135.0	140.0	120.0
Max cranial breadth (M°8)	129.0	135.0	137.0	142.0	144.0	135.0	146.0	153.0	120.0
Max frontal breadth (M°10)	105.0	116.0	116.0	115.0	121.0	116.0	120.0	125.0	101.0
Min frontal breadth (M°9)	88.5	104.0	95.0	93.5	94.0	99.0	93.0	100.0	86.0
Nasoalveolar (upper facial) height (M°48)	64.5	–	63.5	65.0	77.0	65.0	72.5	74.0	58.0
Nasospinale-prosthion height (M°48-1)	20.0	–	20.0	15.0	21.0	18.0	22.0	21.0	16.0
Interorbital breadth (M°50)	25.0	–	27.0	34.0	28.0	26.5	26.0	26.9	22.0
Bizygomatic breadth (M°45)	120.0	–	126.0	129.0	142.0	126.0	128.0	143.5	114.0
Basion-prosthion length[a]	91.0	–	86.0	93.5	98.0	87.0	92.0	93.5	87.5
Mastoid height, R[b]	26.0	25.0	27.5	37.0	34.5	30.0	25.0	36.0	25.0
Mastoid height, L[b]	26.0	26.0	28.0	36.0	34.5	30.0	25.0	36.0	–

[a] Measurement taken as in Twiesselman and Brabant (1967) (*mesures relevées selon* Twiesselman et Brabant (1967)).
[b] Measurement taken as in Broca (1875) (*mesures selon* Broca (1875)).

Table 7
Tam Hang long bone lengths. M° refers to the Martin measurement number (Brauer, 1988). Parentheses indicate estimated measurements due to bone damage. All measurements are in millimeters.
Tableau 7
Mesures de longueurs des os longs des individus de Tam Hang. M° se réfère aux numéros des mesures de Brauer (1988). Les chiffres entre parenthèses indiquent les mesures estimées en raison de l'état fragmentaire des os. Les mesures sont en millimètres.

	Side	Humerus (M°1)	Radius (M°1)	Ulna (M°1)	Femur (M°1)	Tibia (M°1a)	Fibula (M°1)
THS 2	R	270.0	220.0	(227.0)	390.0	(320.0)	–
	L	267.0	224.0	(227.0)	387.0	327.0	316.0
THS 3	R	265.0	207.0	225.0	402.0	337.0	–
	L	263.0	209.0	–	402.0	(330.0)	328.0
THS 7	R	(267.0)	217.0	243.0	–	–	–
	L	278.0	215.0	244.5	–	–	–
THS 11	R	257.0	197.0	–	–	308.0	299.5
	L	255.0	(194.0)	–	(360.0)	311.0	303.0
THS 13	R	(288.0)	(212.0)	–	(409.5)	347.0	338.0
	L	(283.0)	–	–	(410.0)	(334.0)	339.0
THS 14	R	315.0	255.0	276.0	435.0	–	–
	L	–	258.0	276.0	436.0	374.0	369.0
THS 22	L	–	–	–	–	337.0	–

2.3.5. *Tam Hang South 7 (THS 7)*

Tam Hang South 7 (THS 7), an adult female, has a cranium that is very fragmentary and sediment-filled (Fig. 4i, j and Fig. 6). The mandible is complete.

There is an associated partial postcranial skeleton that is poorly preserved. The long bones of the upper limb are intact, but only proximal portions of the femora and left tibia are preserved. The pelvis is represented by fragments of the sacrum and ossa coxae.

2.3.6. *Tam Hang South 10 (THS 10)*

Tam Hang South 10 (THS 10) is an adult female represented by a well-preserved cranium (Fig. 7a, b). Only the right sides of the frontal, parietal and occipital bones are missing. The maxillae are complete and all the teeth are present with the exception of the left P^3, $\bar{C}$ and I^1 and the right $\bar{C}$. There is slight alveolar prognathism. The mandible is well preserved, but it is broken along the symphyseal plane and the mandibular condyles are broken.

2.3.7. *Tam Hang South 11 (THS 11)*

Tam Hang South 11 (THS 11) is a young adult female represented by a metopic cranium that is well preserved despite many fractures on the parietal and frontal bones (Fig. 6 and Fig. 7c, d). The zygomatic arches and the maxillae are preserved. All of the teeth are erupted except the right M^3, and the right C through I^1 were lost post-mortem. The mandible does not show any alveolar

Table 8
Tam Hang stature and body mass estimates. AP indicates anteroposterior; SI indicates supero-inferior. Parentheses indicate estimated measurements due to bone damage.
Tableau 8
Estimations de la stature et de la masse corporelle des individus de Tam Hang. AP indique antéropostérieur ; S indique supéro-inférieur. Les chiffres entre parenthèses indiquent les mesures estimées en raison de l'état fragmentaire des os.

	THS 2	THS 3	THS 7	THS 11	THS 13	THS 14	THS 22[e]
Femoral head AP diam (mm) – rt	39.7	39.1	(36.4)	–	–	48.0	
Femoral head AP diam (mm) – lt	39.3	39.9	(37.0)	–	–	47.8	
Femoral head SI diam (mm) – rt	36.1	37.0	36.5	–	–	47.5	
Femoral head SI diam (mm) – lt	37.6	38.1	(34.0)	–	–	47.1	
Stature (cm)[a]	148.2	151.3	–	139.7	153.1	162.5	152.6
Bi-iliac breadth (mm)	257.0	260.0	–	244.6[b]	259.0[b]	258.0	
BM – fem head (kg)[c]	45.0	45.3	39.6	–	–	66.3	
BM – stature/BIB (kg)[d]	55.8	58.0	41.8	51.1	54.7	68.8	

[a] Stature is estimated using femoral or tibial length as indicated in the text (*la stature est estimée en utilisant les longueurs des fémurs ou des tibias, comme indiqué dans le texte*).

[b] Bi-iliac breadth is estimated for THS 11 and THS 13 as indicated in the text (*les largeurs bi-illiaques sont estimées pour THS 11 et THS 12, comme indiqué dans le texte*).

[c] Body mass estimated from femoral head diameter following McHenry (1992). Details can be found in the text (*les masses corporelles sont estimées à partir des diamètres des têtes fémorales, selon McHenry (1992). Les détails peuvent être trouvés dans le texte*).

[d] Body mass estimated from stature and bi-iliac breadth. Details can be found in the text (*les masses corporelles sont estimées à partir de la stature et de la largeur bi-iliaque. Les détails peuvent être trouvés dans le texte*).

[e] Only tibia preserved for this individual so body mass was not estimated (*seuls les tibias ont été préservés pour cet individu, ainsi la masse corporelle n'a pas pu être estimée*).

Fig. 4. Pictures of the Tam Hang specimens described in the text. Pictures taken by V. Laborde and A. Fort.

Fig. 4. Photographies des spécimens de Tam Hang décrits dans le texte. Photographies réalisées par V. Laborde et A. Fort.

prognathism and is slight in its features, but has a well developed mandibular symphysis. The mandible is well preserved, and all the teeth are erupted except for the left M_3.

THS 11 preserves a partial vertebral column. Four right ribs (most likely 5–8) are complete, but imbedded in sediment; these represent the only complete ribs from any of the Tam Hang individuals. The long bones are preserved,

Fig. 5. Pictures of the Tam Hang specimens described in the text. Pictures taken by V. Laborde and A. Fort.
Fig. 5. Photographies des spécimens de Tam Hang décrits dans le texte. Photographies réalisées par V. Laborde et A. Fort.

although both the right and left proximal femora are damaged. There is a partial sacrum and several fragments of the right and left ilia.

2.3.8. *Tam Hang South 13 (THS 13)*

Tam Hang South 13 (THS 13) is an adult female with a metopic cranium (Fig. 7e, f and Fig. 8). The maxillae are complete and all of the maxillary teeth are present except for the right I^2. The mandible is well preserved and only the right mandibular condyle is missing.

THS 13 preserves a partial vertebral column that is significantly damaged. All of the long bones of the upper and lower limbs are present, but have significant damage to the epiphyses. Both femora are preserved but are absent the femoral head. The right side of the sacrum is intact, and there are five additional pelvic fragments that include the right and left iliac blades, the partial right and left ischial tuberosities and the right acetabulum and pectinate line.

Fig. 6. Pictures of the Tam Hang specimens described in the text. Pictures taken by V. Laborde and A. Fort.
Fig. 6. Photographies des spécimens de Tam Hang décrits dans le texte. Photographies réalisées par V. Laborde et A. Fort.

2.3.9. *Tam Hang South 14 (THS 14)*

Tam Hang South 14 (THS 14) is a young adult male (Fig. 7g, h and Fig. 8). The cranium is well preserved, but the coronal section of the frontal bone, the left parietal and the left temporal bones are fractured. The left zygomatic arch is missing. The maxillae are complete and all of the teeth are present except the I^2, which was lost ante-mortem. The mandible is complete. All of the teeth are erupted, with the exception of the left M_3 and the right M_1. Furthermore, the incisors have been lost. There is slight alveolar prognathism.

The postcranial skeleton of THS 14 is well preserved and unique in its large size. The vertebrae are present with little post-mortem damage, although the bodies of T10–12 are fused in anatomical order by matrix. The long bones are complete with the exception of the right tibia and fibula, which are missing their distal shafts and ends. The femora of THS14 are notable for their large size relative to the other Tam Hang individuals and their strong linea asperae that approach pilasters. The sacrum and ossa coxae are complete with only small post-mortem fractures, and they can be articulated, making this one of three complete pelves from the Tam Hang sample.

2.3.10. *Tam Hang South 22 (THS 22)*

Tam Hang South 22 (THS 22) is an adult female. The cranium is fairly well preserved, but the right temporal and parietal bones are absent, and fractures run across the left parietal and frontal bones (Fig. 7i, j and Fig. 9). The zygomatic arch is preserved, and the right upper maxilla is fragmentary. All of the teeth are erupted, but some of them have been lost post-mortem. The right mandibular body is missing. There is slight alveolar prognathism.

The THS22 postcranial skeleton includes a complete left tibia and fragments of the right tibia, right and left humeri and right calcaneus. The right tibia is represented by two shaft fragments that form a single midshaft piece approximately 79 mm in length. The humeral fragments include a proximal shaft fragment from the level of the muscular attachment for the *deltoideus* muscle (preserved length = 96 mm) and a distal fragment with the medial epicondyle (preserved length = 138 mm). A proximal left humeral shaft fragment that is missing the humeral head and tuberosities but includes the intertubercular groove and crests of the tuberosities is also present (preserved length = 101 mm). A partial right calcaneus with the talar articular surfaces is also associated with THS 22.

2.3.11. *Pathology*

Although not pathological, the presence of a persistent metopic suture in two of the individuals from Tam Hang is noteworthy, given that its frequency in modern human populations is 1 to 12% (Skrzat et al., 2004). This suture normally closes between the first and second years of life and is completely fused by year three, although it may remain patent to year seven. The frequency among this sample is unusually high at 20% (2 of 10 individuals).

Fig. 7. Pictures of the Tam Hang specimens described in the text. Pictures taken by V. Laborde and A. Fort.

Fig. 7. Photographies des spécimens de Tam Hang décrits dans le texte. Photographies réalisées par V. Laborde et A. Fort.

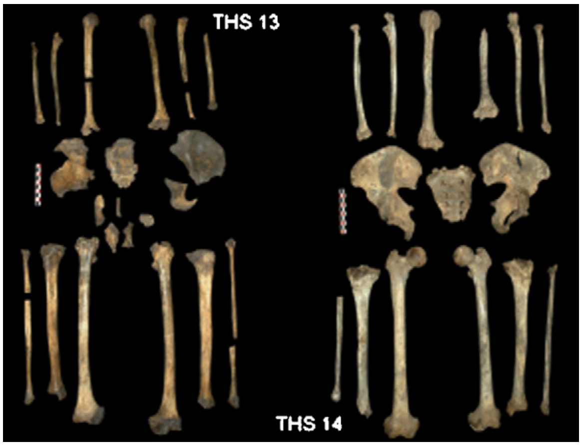

Fig. 8. Pictures of the Tam Hang specimens described in the text. Pictures taken by V. Laborde and A. Fort.
Fig. 8. Photographies des spécimens de Tam Hang décrits dans le texte. Photographies réalisées par V. Laborde et A. Fort.

Six of these individuals show tooth ablation (THS 2, THS 3, THS 4, THS 7, THS 10, THS 14). These tooth avulsions from Tam Hang represent some of the oldest known from eastern Asia.

The postcranial skeleton is remarkable for its lack of pathology. There are no degenerative conditions seen on any of the bones, which is consistent with the young adult age of the specimens. Only post-mortem fractures are present. Although these individuals are small in stature relative to other Late Pleistocene samples (Shackelford, 2007), there is no evidence of congenital dysplasia or environmental stress.

3. Materials and methods

Analyses of the Tam Hang fossil material address several issues related to anatomical variation and migration patterns in Southeast Asia during the Late Pleistocene. Given their excellent preservation, the postcranial bones are used to estimate body size and shape. Cranial metrics were then used to assess affiliations between Tam Hang and other Southeast Asian fossil samples in an effort to address questions about population migration.

Fig. 9. Pictures of the Tam Hang specimens described in the text. Pictures taken by V. Laborde and A. Fort.
Fig. 9. Photographies des spécimens de Tam Hang décrits dans le texte. Photographies réalisées par V. Laborde et A. Fort.

3.1. Stature and body mass estimation

The preservation of the Tam Hang skeletons provides optimal data for estimating stature and body size in this mainland Southeast Asian sample. This is a particularly important exercise given the characteristically diminutive size of Asian early modern humans as well as questions raised by the unprecedented small size of the *Homo floresiensis* specimen from Java (Brown et al., 2004; Fitzpatrick et al., 2008; Morwood et al., 2005). Furthermore, body size influences a range of biological and life history factors (Fleagle, 1978; Hens et al., 2000; Smith and Jungers, 1997), and our ability to reconstruct these in fossil humans relies on the accurate prediction of body size.

Stature is highly correlated with the length of the long bones in human populations, particularly those of the lower limbs (Trotter and Gleser, 1952, 1958). However, estimating stature for individuals that fall outside the range of average modern human reference samples, for example small-bodied individuals, have been shown to be more accurately estimated using reference populations of similar size (Feldesman and Lundy, 1988; Feldesman et al., 1989, 1990; Jungers, 1988; McHenry, 1991; Olivier, 1976). For this reason, stature estimation was performed with sex-specific formulae for Japanese devised by Fujii (1960) from femoral and tibial lengths.

Body mass was also reconstructed using lower limb dimensions. Two distinct methods provide reliable estimates of body mass. The first is a mechanical method that estimates body mass from femoral head size, given the mechanical significance of the hip for weight-bearing in bipedal locomotion (Grine et al., 1995; McHenry, 1992; Ruff et al., 1991). These models have been used to estimate body mass in fossil and modern human populations and vary slightly in regards to the reference samples from which the formulae were derived. The Ruff et al. (1991) sex-specific model performs most accurately in a middle size range, tending to under-estimate at the upper end of the body mass distribution and over-estimate at the lower end of the distribution. McHenry's (1992) model was derived to predict body mass in small, early hominins and used small-bodied populations as reference samples. As a result, it is most accurate when predicting body mass for small-bodied humans. Conversely, Grine et al. (1995) used large-bodied populations to create a model for predicting body mass, making it more accurate in prediction at the upper end of the body mass distribution. Formulae from McHenry (1992) were used to estimate body masses for the Tam Hang skeletons.

The second method for estimating body mass is non-mechanical and models the human body as a cylinder using stature and bi-iliac breadth (Ruff, 1991, 1994, 2000). This method is very reliable when appropriate reference samples are used (Auerbach and Ruff, 2004; Holliday and Ruff, 1997; Ruff, 1994, 2002). It does, however, require preservation of the long bone and pelvis of an individual or a considerable amount of estimation. Given fossil preservation, it is often preferable to estimate body mass using femoral head diameter to reduce the number of estimated measurements. However, body mass estimates from these two methods give similar results when applied to fossil humans (Auerbach and Ruff, 2004; Ruff et al., 1997).

Both methods were used for the Tam Hang specimens given the differential preservation of the skeletons. When possible, both methods were used for the same individual so that the estimates could be compared and verified. THS 2, 3 and 14 have well-preserved femora and pelves, making both methods of body mass reconstruction straight-forward. The remaining Tam Hang specimens (THS 7, 11, 13) require substantial estimation for either method to be applied. The femoral heads of THS 7 are damaged, and their femoral head diameters are estimated. Only the proximal portions of each femur are preserved, so body mass was only estimated using the mechanical model. THS 11 and 13 are missing the right and left femoral heads but preserve intact femoral shafts. As a result, body mass is only estimated using the non-mechanical model.

For the non-mechanical model, stature for each individual was estimated as described above. Bi-iliac breadth was estimated for THS 11 and 13 using the general equation from Trinkaus et al. (1999) with reference values taken from Neolithic Japanese samples (Baba and Endo, 1982).

3.2. Comparative analysis of Tam Hang crania

In order to contextualize Tam Hang, the crania were evaluated relative to other available Pleistocene material from East and Southeast Asia. The comparative sample includes 45 early modern humans from Cambodia (Samron Sen), China (Jinchuan, Liujiang, Upper Cave, Ziyang), Indonesia (Wadjak), Japan (Minatogawa), Laos (Tam Hang, Tam Pong), Thailand (Ban Kao) and Vietnam (Pho Binh Gia, Lang Cuom, Dong Thuoc, Cau Giat, Dong Can, Mai Da Dieu, Mai Da Nuoc) (Table 1). Details of sample composition can be found in Demeter (2000).

Although this is a geologically-cohesive sample, it is not a temporally-cohesive one. The geological ages of the fossil samples span at least 30–40,000 years (Table 1). Furthermore, there are uncertainties regarding the stratigraphic association or dating of some of these fossils (Norton, 2000; Shen et al., 2002; Wu and Poirier, 1995). While this clearly cannot be considered a similarly-aged sample, it can be assumed that no speciation events are observable and evolutionary processes had a minimal impact on the sample.

Data include twelve craniofacial measurements chosen in part based on previous studies demonstrating which variables account for the largest proportion of geographical variation (Hanihara, 1993; Pietrusewsky, 1990, 2010) (Table 6). These data have been reduced and size-corrected (see Demeter, 2000; Demeter et al., 2003 for details). Multidimensional scaling analysis (MDS) was applied to the data to graphically identify patterns of spatial variation between Tam Hang and other fossil specimens (Seber, 1984; Torgerson, 1958). Using a function minimization algorithm, the data points (fossil specimens) are moved in two-dimensional space so that the observed distance between points is analogous to the similarity between these points, i.e. points close together are more similar to one another in the traits being evaluated than are points far apart. Initial analysis was performed to evaluate inter-specimen differences. A second analysis was performed to examine inter-sample differences for the purpose of assessing regional trends in craniofacial morphology.

4. Results and discussion

4.1. Stature and body mass estimation

Stature estimates reveal variation in size among the Tam Hang individuals ranging from approximately 140 cm to 163 cm (Table 8). Five of the individuals have stature estimates from 140–153 cm. The height of THS 14, the sole male individual identified in the postcranial skeletal remains, is considerably taller at 163 cm. This individual is also unique within the sample with respect to the large size and strength markers found throughout the skeleton. These estimates are comparable to those for the individuals from the site of Minatogawa, Japan (Baba and Endo, 1982). Using the same formulae from Fujii (1960), stature for the male Minatogawa I specimen is estimated to be 153 cm; average stature for the Minatogawa females ($n = 3$) is estimated to be ca. 152 cm (Baba and Endo, 1982).

As previously noted, body mass was reconstructed using both a mechanical method incorporating femoral head size and a non-mechanical model incorporating stature and bi-iliac breadth. When possible, both methods were used for the same individual in order to compare and verify their efficacy.

Body mass estimates calculated from femoral head diameter range from approximately 40–45 kg for the five females, and in the case of the male THS 14 specimen, 66 kg (Table 8). Body mass estimates determined with a non-mechanical method range from approximately 51–58 kg; again, THS 14 falls well above the other individuals at 68.8 kg (Table 8). For two specimens (THS 2, 3), the body mass estimates are considerably different using these two methods, with the non-mechanical method providing a larger estimate (in the case of THS 2, 45 kg vs. 55.8 kg; in the case of THS 3, 45.3 kg vs. 58 kg). There are several related explanations for this discrepancy. Both THS 2 and 3 are females, so the differences between estimates may be related to the width of the pelves in these small-statured individuals. Alternatively, the lower limb articular surfaces in these small individuals as measured by femoral head diameter may lead to an underestimation of body mass. The remaining individual for whom both methods could be employed without estimating any parameters, THS 14, is a male with a relatively narrow pelvis and relatively large femoral head diameter. The two methods of estimations yielded similar results for THS 14 (66.3 kg vs. 68.8 kg).

In a comparison of mechanical (i.e. femoral head diameter) and nonmechanical (i.e. bi-iliac breadth and stature) methods for body mass estimation, Auerbach and Ruff (2004) found that for the majority of populations, these techniques give roughly equivalent results. One major exception to this finding was for the smallest-bodied samples used in their analyses, female African Pygmies and Andaman Islanders (31–42.7 kg). For these samples, estimates from femoral head diameters were much greater than those from stature and bi-iliac breadth, although the amount of difference between estimates varied based on which formula was used. The difference between body mass estimates varied from an average of 19.98% (7.38 kg) and 14.87% (5.45 kg) for Pygmoid females when the Ruff et al. (1991) and Grine et al. (1995) formulae were used, respectively, to 3.17% (1.03 kg) when the McHenry (1992) formulae were used.

These results may provide little explanation for the discrepancy in body mass estimates for the Tam Hang individuals. In contrast to findings from Auerbach and Ruff, body mass estimates for Tam Hang from stature and bi-iliac breadth are consistently greater than those from femoral head diameter. Additionally, while Tam Hang is small in size, body mass for this sample is more similar to Auerbach and Ruff's "smaller non-Pygmoid" individuals (40.7–60.8 kg), which showed much smaller differences in estimates using mechanical and nonmechanical formulae with no directional bias (−1.8 to 2.79 kg).

Large differences between different methods of body mass estimation may also be due to methodological issues associated with the regression model used in formulae utilizing femoral head diameters (Auerbach and Ruff, 2004). The accuracy of least squares prediction is greatest at the center of the distribution of the reference sample and lowest at the upper and lower ends of its distribution, compounding error when dealing with individuals at the extremes of body size.

The sex differences in body size within this sample should also be considered given the average stature and body mass of the five females (average stature = 148.1 cm; average body mass = 52.3 kg) and the single male individual (stature = 162.5 cm; body mass = 68.8 kg). While this may indicate sexual dimorphism within modern human populations of the region, it is more likely that this difference reflects the sex bias that is present in this sample. However, it calls attention to the redundancy of using robusticity or size to determine sex in Tam Hang and other Southeast Asian samples.

Estimated statures and body masses for Tam Hang indicate relatively diminutive size when evaluated relative to non-Asian samples. This is also true when compared to pan-Old World samples of the same time period (Table 9) (Shackelford, 2005, 2007). However, analyses of both prehistoric and modern human samples demonstrate that this body size is characteristic of Asian populations, representing what is normal in this region (Auerbach and Ruff, 2004; Fitzpatrick et al., 2008; Migliano et al., 2007; Shackelford, 2005, 2007). As demonstrated recently by Fitzpatrick et al. (2008), prehistoric hunter-gatherers tended to be small-statured by modern western standards. This appears to be the case in the Late Pleistocene of Southeast Asia as well, given the accordance in size between Tam Hang and Minatogawa. More importantly, as Fitzpatrick et al. (2008) point out, normal stature and body mass in prehistoric and – based on all available evidence – Late Pleistocene Southeast Asia differs from that of other regions and is only relatively small when based on a western standard.

4.2. Comparative cranial analyses

Analyses were performed to evaluate both inter-specimen differences (Fig. 10) and inter-sample differences (Fig. 11) that characterize features of cranial shape. Most obviously, this multivariate space demonstrates that the two Chinese fossils Jinchuan and Ziyang are outliers relative to the remaining sample. They do not, however, share morphological similarities to one another given the distance between them (Fig. 10).

An assessment of morphological similarity at an individual level identified two groups that are roughly separated along the *y*-axis of the scatterplot in Fig. 10. Each group is associated by common morphology. For the cluster to the right of the *y*-axis, a common morphological suite of characters includes a high, long cranium, broad calvarium, broad face and thick cranial bones. The second group of fossils shared morphology characterized by an anteroposteriorly-short, high cranium with a broad calvarium, a narrow frontal bone and a broad face with a wide interorbital space.

These morphological clusters also share a geographic commonality. With only a few exceptions, individuals clustered to the right of the y-axis of the scatterplot come from coastal or insular sites and are separated from an inland group of fossils. The coastal/insular sample ($n = 22$) includes specimens from Vietnam (Lang Cuom, Dong Thuoc, Pho Binh Gia, Mai Da Nuoc, Cau Giat and Dong Can), Cambodia (Samron Sen), Japan (Minatogawa), Indonesia (Wadjak) and China (Liujiang and Upper Cave). Tam Hang falls with the second sample ($n = 20$), as do specimens from Laos (Tam Pong), Vietnam (Than Hoa, Mai Da Dieu and Lang Cuom), Thailand (Ban Kao), and a single individual from each of Upper Cave, China and Minatogawa, Japan. With the exception of five individuals (Mai Da Dieu, Upper Cave 3, Minatogawa 4, Lang Cuom 9 and 11), this sample comes

Table 9
Comparison of body mass and stature for regional Late Pleistocene (20–10 ka) samples. Asian sample includes individuals from Tam Hang and Minatogawa. Data from Shackelford (2007).

Tableau 9
Comparaison de la masse corporelle et de la stature pour les échantillons régionaux du Pléistocène supérieur (20–10 ka). L'échantillon d'Asie inclut Tam Hang et Minatogawa. Données de Shackelford (2007).

	Asia	Europe	Nile Valley	Mediterranean
Body mass (kg)				
Mean	52.9	66.0	60.9	66.2
SE	2.34	1.94	1.07	1.36
n	10	21	37	38
Stature (cm)				
Mean	149.1	161.4	166.0	168.6
SE	3.52	1.51	1.00	0.998
n	6	19	31	37

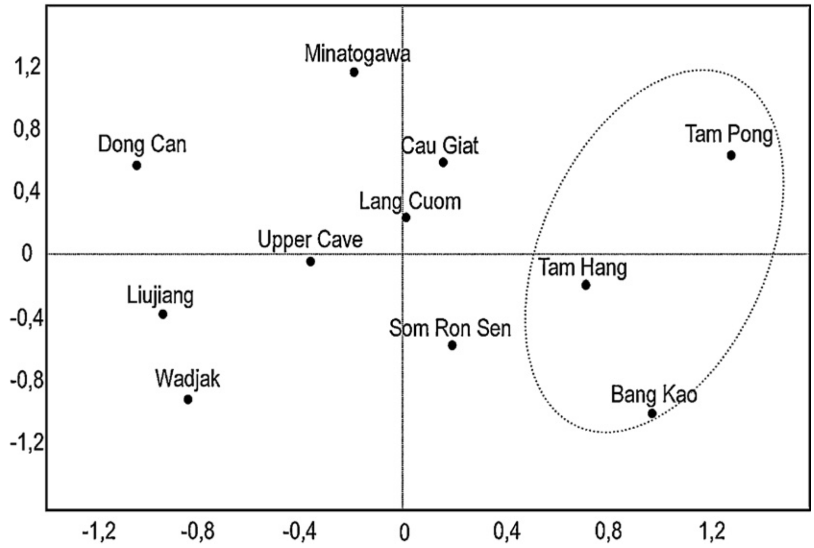

Fig. 10. Multidimensional scaling scatterplot of the specimens.

Fig. 10. Projection multidimensionnelle des spécimens.

from inland sites. While this plot shows a general distinction between these groups, there is an absence of clustering among fossils.

The group composed of insular and coastal sites is associated by common morphology that includes a high, long cranium and broad face. Given the uncertainty of the geological age of Liujiang (Shen et al., 2002), the age range of this sample is uncertain; with the inclusion of fossils from Upper Cave, however, it can be established that this morphological pattern had been established by ca. 30–20 ka and was present until 1.2 ka (Samron Sen). This pattern of similar morphology may indicate a history of migration and continuous coastal peopling.

The second group of fossils includes primarily inland groups that are characterized by short, high crania with broad calvaria and narrow frontal bones. Based on the fossils analyzed here, this morphology was present from ca. 30–20 ka (Upper Cave 3) to 6 ka (Ban Kao). There is more geographic variability within this group, including four coastal or insular sites that share these morphological similarities (Lang Cuom, Minatogawa, Mai Da Dieu and Upper Cave). In addition to the geographic discontinuity of these four sites, these analyses also demonstrate that several sites have individuals demonstrating each of these morphologies. At both Lang Cuom and Upper Cave, for example, part of the sample is grouped with the "coastal" morphology while the remaining individuals cluster with the morphological characteristics of the "inland" samples.

An evaluation of samples shows a pattern similar to that seen among individual fossils, with the inland sites (Tam Hang, Tam Pong and Bang Kao) grouping together on the right side of the scatterplot (Fig. 11). As in the distri-

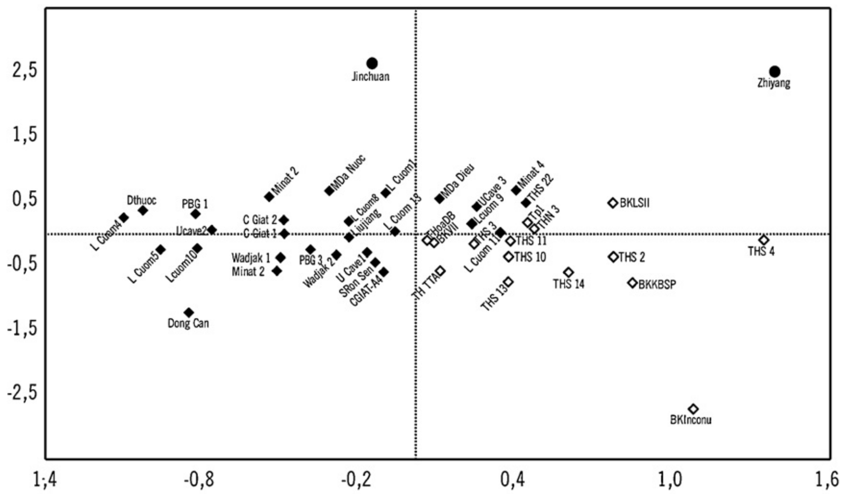

Fig. 11. Multidimensional scaling scatterplot of the samples.

Fig. 11. Projection multidimensionnelle des groupes.

bution of individual fossils, there is no clear grouping of samples.

A homogeneity of spacing was revealed on the MDS plots (Figs. 10 and 11), suggesting the absence of clustering. This configuration does not mean that neighbouring populations on the plots are geographically close. In fact, in a related analysis of these fossils, a complete absence of correlation was demonstrated between distance matrices based on biometrical measures and on the corresponding geographic distances, indicating the absence of any latitudinal cline in the pattern of morphological change (Demeter, 2000). Instead, it should be considered that the variability between fossils demonstrated here is the result of different migration patterns in the early peopling of East and Southeast Asia with both coastal and inland routes being utilized.

5. Conclusion

The site of Tam Hang, northern Laos presents a unique opportunity to evaluate the anatomy of modern humans present in mainland Southeast Asia in the Late Pleistocene. In doing so it also provides the opportunity to consider the paths of dispersal and migration that were available to humans throughout the environmental stresses of the Last Glacial Maximum and the overall picture of human behaviour and evolution in Southeast Asia.

The completeness of the skeletons allows for an accurate assessment of body size, indicating the small size of the skeletons. Stature and body mass in this sample, however, is consistent with other Late Pleistocene and Holocene humans from East and Southeast Asia. In addition, preliminary analysis of this sample indicates that Tam Hang is characterized by generalized lower limb diaphyseal gracility (Shackelford, 2005, 2007), which contradicts expectations based on other East and Southeast Asian postcranial samples that have been described as musculoskeletally robust as reflected in cortical bone deposition, robusticity indices and bony indicators of muscle size (Baba and Endo, 1982; Kennedy, 1999, 2000; Kennedy and Zahorsky, 1997; Kennedy et al., 1987; Kimura and Takahashi, 1992; Trinkaus and Ruff, 1996). However, other measures of robusticity suggest that mechanical efficiency is achieved through adjustments in muscle moment arms in the lower limbs, which offset the loads on the femoral and tibial diaphyses and additional research will provide further information (Shackelford, 2005, 2007).

Analysis of a limited sample of East and Southeast Asian crania provided here reveals a patterned discontinuity in morphology between fossils across the region. Multiple explanations may explain this pattern, but it is suggestive of migration routes utilized by modern humans during the Late Pleistocene. By at least 30,000 years ago, a characteristic morphology was in place in northern China, and humans with similar anatomy continued to populate the coastlines of East and Southeast Asia until prehistoric times. This southern migration is closely related to the climatic deterioration that accompanied the Last Glacial Period and made northern latitudes increasingly uninhabitable. A second morphological pattern is recognized in the high plains of mainland Southeast Asia from at least 30,000 years ago, and these traits persist throughout the region and towards the coastline for the remainder of the Late Pleistocene and into the Holocene. Considering the varied morphology that is demonstrated at some sites in China and Vietnam, there is the possibility that southerly-migrating populations encountered a second group of humans.

While this analysis provides a single additional sample to those currently known from East and Southeast Asia, Tam Hang is well dated and gives information about the lesser-known mainland region of Southeast Asia. Due to the rarity of fossil preservation and insecure dating for many of the available fossils from this region, many questions remain regarding the earliest appearance of modern humans and the migration and dispersal of modern humans in this area (for a recent review see Kaifu and Fujita (2011)). These questions continue particularly in light of discrepancies between information from fossil and archaeological evidence (Mellars, 2006) and inferences from nuclear DNA (Consortium, 2009), the Y-chromosome (Ke et al., 2001) and the mitochondrial genome (Kong et al., 2011).

Analyses of the earliest migrations from Southeast to East Asia by modern humans consistently indicate a coastal route. With respect to migration northward from Southeast to East Asia, multiple lines of evidence have indicated that initial migrations occurred through a coastal route (Field and Lahr, 2006; Lahr and Foley, 1998; Macaulay et al., 2005; Mellars, 2006). Other routes of migration, however, were not precluded (Hu et al., 2009; Kaifu and Fujita, 2011; Matsumura and Pookajorn, 2005; Matsumura et al., 2008). A lack of data has played a large part in preventing investigation of inland migration routes. An expansion of the analyses of East Asian fossils to include those from Tam Hang and other available evidence from mainland Southeast Asia is a first step in clarifying these questions.

The Tam Hang sample has great potential to further the understanding of human migration in Southeast Asia. Anatomy of the individuals indicates affinities with earlier sites as well as Holocene and modern Southeast Asian samples from the same region. For many years the majority of anthropological and paleontological excavation has occurred in island and coastal Southeast Asia; however, many more questions regarding Late Pleistocene human activity may be addressed by continued work in the highlands of the mainland.

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