Terminal Pleistocene human skeleton from Hang Cho Cave, northern Vietnam: implications for the biological affinities of Hoabinhian people

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Abstract An excavation at the cave site of Hang Cho in northern Vietnam resulted in the discovery of a terminal Pleistocene human skeleton in a relatively good state of preservation. The material culture from this site belongs to the pre-ceramic Hoabinhian period. An AMS radiocarbon date on a tooth sample extracted from this individual gives a calibrated age of 10450 ± 300 years BP. In discussions of the population history of Southeast Asia, it has been repeatedly advocated that Southeast Asia was occupied by indigenous people akin to present-day Australo-Melanesians prior to the Neolithic expansion of migrants from Northeast Asia into the area. Cranial and dental metric analyses were undertaken in order to assess the biological affinity of early settlers in this region. The results suggest that the Hang Cho skeleton, as well as other early or pre-Holocene remains in Southeast Asia, represent descendants of colonizing populations of late Pleistocene Sundaland, who may share a common ancestry with present-day Australian Aboriginal and Melanesian people.

Key words: Hang Cho, Vietnam, skeleton, Southeast Asia, Hoabinhian, AMS dating, biological affinity

Introduction

The study of the population history of Southeast Asia is complex due to various migration processes, the intermixing of populations throughout prehistory, poor sample sizes and limited radiometric dating. In general terms, Southeast Asia is thought to have been originally occupied by indigenous people (sometimes referred to as Australo-Melanesians) that subsequently exchanged genes with immigrants from North and/or East Asia, during the Holocene, leading to the formation of present-day Southeast Asians (Callenfels, 1936; Mjlsberg, 1940; Von Koenigswald, 1952; Coon, 1962; Jacob, 1967). More recent studies based on late Pleistocene and early Holocene human remains represented by specimens from Niah Cave in Borneo (Brothwell, 1960; Kennedy, 1977; Barker et al., 2007), Tabon Cave on Palawan Island, Philippines (Fox, 1970; Macintosh, 1978; Dizon et al., 2002), Guu Gunung Runtjih in Peninsular Malaysia (Zuraina, 1994, 2005; Matsuura and Zuraina, 1999) and Moh Khiew Cave in Thailand (Matsuura and Pookajorn, 2005) have provided additional support for the existence of an ‘Australo-Melanesian’ lineage in ancient Southeast Asia (for a review see also Oxenham and Tayles, 2006). Nevertheless, our knowledge of pre-ceramic period peoples is still incomplete as a number of past studies were based on sub-adult or poorly preserved material. Discoveries of new specimens from the pre-ceramic period, coupled with detailed morphometric analyses, are required to assess the hypothesis of a Pleistocene occupation of Southeast Asia by Australo-Melanesians.

To address this issue the authors have focused on Hoabinhian sites, which were widely expanding over the mainland Southeast Asia during the late Pleistocene and early Holocene, in order to excavate additional human skeletons from this under-sampled period. Over the last half century Vietnamese archeologists have devoted much of their efforts to the study of the Hoabinhian, a term in Southeast Asia loosely equivalent to what in Europe would be called the Mesolithic, or pebble-tool complex (Tan, 1980, 1997). Current-
ly more than 120 Hoabinhian sites have been discovered and studied in Vietnam, the majority being limestone caves and rock shelters conducive to good preservation of human remains. Unfortunately, only a few late Hoabinhian sites, such as Mai Da Nuoc and Mai Da Dieu (Cuong, 1986), have provided well-preserved skeletal material.

In 2004, our multinational project team excavated the cave site of Hang Cho in northern Vietnam. This site, previously known to have early Hoabinhian cultural material (Thuy and Doi, 1998), revealed an early inhumation burial. The aims of this paper are to: (1) describe this cave site and the material cultural context; (2) provide an absolute date (AMS) of the human skeleton; (3) discuss the preservation and dentocranial morphology of this specimen; and (4) present the results of qualitative and quantitative comparisons of this specimen with prehistoric and modern samples from East/Southeast Asia and the Southwest Pacific in order to resolve the aforementioned issue of the biological affinity of these early Southeast Asian peoples.

**Description of Hang Cho Cave and its Cultural Context**

**Topology**

The Hang Cho site is situated at the foot of a limestone mountain located in Luong Son district, Hoa Binh province, approximately 50 km southwest of Hanoi, northern Vietnam (20°50′24″N and 105°30′11″E, see Figure 1). The cave, which formed several tens of meters above the present alluvial plain, opens towards the southwest. The width of the main entrance is 11 m with an average height of 15 m. The subsidiary entrance has a width of 8 m and a height of 10 m (Figure 2). The main chamber expands to a depth of 18 m and a width of 20 m at its largest extent (Figure 3). The floor of the cave slopes 1.2 m up to the northeast wall of the main cave, with a hard deposit of freshwater shells at the higher part of the floor. There is good natural light in the cave and the path leading to it is quite manageable by foot. A large and flat valley extends in front of the cave, an area that is today utilized for rice agriculture, while the main entrance to the cave opens several meters above this field (Figure 2).

**Past and present excavations**

In 1926 and then 1932 the French archeologist M. Colani, who first detected this site, discovered dozens of stone tools at Hang Cho Cave and identified them as belonging to a
Hoabinhian cultural assemblage. As her excavation notes were not published, the location of her excavation trench is unknown.

Following M. Colani’s work, the Vietnamese Institute of Archaeology investigated Hang Cho Cave by opening a test trench (2 m × 2 m) (Figure 3) in 1997 and found artifacts manufactured from whole pebbles and flakes. The presence of a substantial number of pebbles with circular depressions identify the Hoabinhian nature of the assemblage (Tan, 1997), although there are still a considerable number of traditional chopper-chopping tools. Hang Cho site was settled by early Hoabinhian people between c. 12000 and c. 10000 years BP (Thuy and Doi, 1998).

In 2003, research members of the Hanoi National University and the Seoul National University sampled the freshwater shell mounds formed in the main chamber (this sampling point is shown in Figure 3), in order to derive AMS dates. The shells provide calibrated dates ranging from 14100 ± 300 years BP at the lowest layer to 9710 ± 50 years BP at the highest layer (Seonbok et al., 2004). These dates suggest the possibility that the human occupation of this cave continued for more than 4000 years and suggest that the Hoabinhian cultural layers belong to the terminal Pleistocene and early Holocene periods.

Our multinational excavation project took place in 2004, with members consisting of archeologists and anthropologists from Vietnam, Japan, Australia, and students from Korea. Four excavation trenches were set up in various areas of the cave, labeled Pit I, Pit II, Pit III, and Pit IV (Figure 3) with a total excavated area of 43.7 m². The stratigraphy, material cultural, and deposition of the inhumation burial are described in the next section of this paper.

Stratigraphy and cultural context

Each excavation trench was divided into 1 m² grids labeled with numbers. The soil was carefully removed from every artificially identified layer of sediment of 10 cm in thickness. Based on looseness of soil and the presence of holes, the disturbed areas were identified. The soil was screened through a 3 mm wide metal mesh to detect small fragmental bones and flakes of stone tools.

Stratigraphic profiles of representative sections are shown in Figure 4. The stratigraphy of the four excavated pits within the main cave and rock shelter areas are basically similar. The upper part of the cultural layers had been removed or disturbed, while the remaining layers below the surface disturbance are uneven in thickness and generally thinner around the mouth of the cave. The cultural layers have an average thickness of about 1.0–1.5 m, although the color of the layers and the volume of molluscan shells contained show variations depending on which excavated pit is examined. The composition of layers and the cultural material in each pit are summarized below. The condition of the inhumation burial is discussed in the description for Pit III. Vertebral faunal remains found within the Hoabinhian cultural layers will be reported at a later date.

Pit I

Pit I, excavated area 7.5 m² and located under an overhang on the west side of the cave, revealed nine stratigraphic layers. The upper portion in Layers I (surface soil), II (yellow soil) and III (charcoal and ash) were disturbed, whereas the lower portions lying below the burned soil in Layer IV (light brown soil) was relatively stable. This lower level revealed fresh-water shells, small lithic flakes, and animal bones, while the upper portion included a few fragments of cord-marked pottery. From Layer V (yellow-brown soil), many potsherds, ornaments made from sea shells, and a bark-cloth beater were found. These findings are associated with the late Neolithic or the early Metal period (approximately 3500 years BP). From Layer VI (brown soil including a small number of broken shells) a cluster of Hoabinhian lithic artefacts were uncovered. The lithics found in this layer were smaller than those found in Pits II–IV. From Layers VII (dark brown soil with numerous shells) through Layer VIII (dark brown soil with small numbers of broken shell), down to Layer IX (dark brown soil with few shells), lithic implements and flakes, bones, loess, and burned soil with charcoal and shells were encountered.

Pit II

Pit II is in the northwest part of the main chamber, and has an excavated area of 16 m². The cultural layers of this pit were more reddish in colour than those of Pit I, were porous, and contained many shells, small lithic flakes, and bone artefacts. The north–western part of the pit was quite intact, whereas the south–western part in Layer IA (brown porous soil) was disturbed to a depth of approximately 50 cm from the ground surface. From Layer IB (darkish brown soil mixed with a large number of shells), a considerable number of Hoabinhian artifacts were uncovered. This layer included a thin layer of pinkish clay which was made of burned soil. Layer IC consisted of brownish–pink porous soil with many shells where a considerable number of lithic implements and a thin calcified clay expansion including charcoal were uncovered. Layer II (brown porous soil) contained fewer lithics than the upper layer.

Pit III with the inhumation burial

Pit III (11.2 m² excavated area) was opened in the middle of the main chamber and extended past the drip line. The top layers, with a depth of 80 cm (Layers I and II), were heavily disturbed. The hard brown soil in Layer III, which included a 2 m × 2.5 m hearth, was stable and provided numerous lithic artifacts of Hoabinhian culture and molluscan shells. The inhumation burial, found beside the hearth, appears to have been dug from the top of the hearth levels (Figure 5). The apparent grave cut, which was devoid of grave goods, was 80 cm wide and 148 cm long, with the head directed toward the east (the head at a depth of 82 cm, the body at a depth of 92 cm from the ground surface). The supine body was buried in a flexed position with the knees raised (and subsequently disturbed and damaged at a later date).

Pit IV

Pit IV, at a higher elevation than the other pits and with an excavated area of 9 m², was located at the eastern end of Hang Cho Cave. Under the surface soil of Layer I, compact shell (land snail) layers (Layer III) spread at the rear of the pit to an approximate depth of 70 cm. The dark brown soil in
Layer IV provided many broken molluscan shells, fish bones, small animals, and small lithic flakes with retouched edges. Entering Layers V and VI (black soil and compact dark brown soil, respectively) the number of lithics and molluscan shells tended to decrease. The bottom of Pit IV was covered by a culturally sterile yellowish-brown soil (Layer VII).

**Lithic artefacts**

A total of 1523 Hoabinhian lithics were found in situ: Pit I, \( n = 144 \); Pit II, \( n = 700 \); Pit III, \( n = 310 \); Pit IV, \( n = 369 \). Heavy cutting tools and scrapers made of cobbles were the most frequently encountered lithics. In terms of typology the following were identified: choppers and chopping tools with cutting edges on the longitudinal edges, ‘Sumatraliths’ or oval/almond-shaped unifacial artifacts, thick discoid flaked...
cobbles, short and elongated axes, edge-polished adzes, large stones with many small surface pits, and a few shell scrapers. The most representative Hoabinhian lithics are illustrated in Figure 6. At Hang Cho Cave unifacial artifacts outnumber bifacial ones, while many flakes shows signs of use wear.

Dating the Skeleton

In typical AMS measurements, 1 mg of carbon, corresponding to 2.5 mg of collagen, is sufficient to determine the radiocarbon age with an uncertainty of 40 years. If collagen is initially greater than 1% of one-quarter of the fresh bone weight, then 0.25 g of bone will produce enough carbon for radiocarbon dating. However, many skeletal remains, especially older samples and those from tropical regions, do not contain enough collagen. One of the authors (M.Y.) dated the Hang Cho skeleton using a newly developed micro-scale 14C dating technique (see references below).

The left lower canine root of the Hang Cho human skeleton was first cleaned by brushing and an ultrasonic bath. Organic matter attached to the surface was removed in a solution of 0.1 M HCl and 0.2 M NaOH. The sample was crushed into fine powder by a freezer mill. The powder was then sealed in a semipermeable membrane and gently reacted with 1 M HCl to remove hydroxyapatite. The remaining matter was heated at 90°C in deionized water to extract collagen. The solution was filtered by a glass filter and lyophilized. The extracted ‘collagen’ was then analyzed for radiocarbon dating. For details of the process of collagen extraction, see Yoneda et al. (2002).

The collagen was combusted into CO₂ by an elemental analyzer (Yoneda et al., 2004). Carbon and nitrogen content during extraction was monitored by elemental analysis (EA). Trapped CO₂ was reduced to graphite by using hydrogen and iron catalysis (Kitagawa et al., 1993). A graphitization system designed for micro-scale (< 100 μg) samples was used for this sample (Uchida et al., 2004) because the extracted matter was as small as 0.03 mgC.

Produced graphite was measured by NIES-TERRA, an AMS at the National Institute for Environmental Studies, Tsukuba, Japan (Tanaka et al., 2000). Each target was measured for 30 min (10 min × 3). The bone sample (630.5 mg) produced a 0.2 mg extraction, the yield of which was 0.03%. The empirical criteria for collagen yields in isotopic analysis are greater than 1% (Ambrose, 1990; Van Klinken, 1999), which shows the poor status of ‘collagen’ in this sample. Other parameters suggested a bad preservation status as well. Although the carbon and nitrogen content in well-preserved collagen are generally expected to be larger than 40%
and 10%, respectively (Ambrose, 1990), the extracted matter (0.131 mg) contained 23.1% carbon and 1.36% nitrogen. Furthermore, the atomic ratio of carbon and nitrogen (C/N ratio) is the most reliable indicator for collagen preservation (DeNiro, 1985). The biological samples given by DeNiro (1985) display C/N ratios between 2.9 and 3.6, but this sample had a C/N ratio at 14.6, which is clearly at variance with the background ratios.

A small graphite sample (27 μg) was reduced from CO2 trapped by EA by using the micro-scale graphitization system (Uchida et al., 2000). The measurement of the 13C/12C ratio was conducted with standard materials, NBS SRM-4990c oxalic acid (HOxII) and IAEA-C6 sucrose. The size of the standards was matched to the sample: 27 μg of HOxII and 28 and 29 μg of IAEA-C6, respectively. The background level was corrected by a 14C-dead standard, IAEA-C1. The 14C-free graphite (29 μg) was produced from IAEA-C1 by reaction with 100% phosphoric acid. Exact matching between samples and standards is very important for micro-scale 14C measurement, especially for samples smaller than 350 μg (Yoneda et al., 2004). Two results of IAEA-C6 at 153.0 ± 2.1 and 151.3 ± 1.9 pMC (percent modern carbon) showed good agreement with consensus values at 150.61 ± 1.1 pMC. The background sample corresponds to 1.0 ± 0.1 PMC (37014 years BP). Graphitization and AMS measurement of smaller samples, around 27 μg, provide reasonable results in this study.

The conventional radiocarbon age of this sample is 9259 ± 206 years BP, which was calibrated using a δ13C isotopic fractionation value of −33.4 ± 1.3‰. It cannot be ruled out that the isotopic value was somewhat influenced by diagenetic effects, nevertheless the age of the human remains from the Hang Cho site is not inconsistent with the time-frame of the Hoabinhian lithic assemblage. Although the diagenetic effects seem not to be serious, we shall discuss this problem, including the integrity of "collagen" elsewhere. As shown in Figure 7, the conventional age corresponds to the calibrated age from 10,750 to 10,150 cal years BP (68.2%), or from 11,150 to 9,750 cal years BP (95.4%). The calibration was conducted using OxCAL 3.10 (Ramsey, 1995) with a calibration dataset INTCAL 04 (Reimer et al., 2004).

**Description of the Human Skeleton**

The Hang Cho individual was estimated to be an old, mature female based on the pelvic features, extent of tooth attrition, cranial suture closures, pubic symphysisal face morphology, and severity of osteoarthritis. Descriptions of the preservation and the morphological features of Hang Cho skeleton, including the determination of sex and estimate of age at death, are provided bellow.

**Cranium and teeth**

Figure 8 displays various aspects of the reconstructed Hang Cho skeleton, and Table 1 gives the cranial measurements taken following Martin’s definitions (Bräuer, 1988). Facial flatness measurements and indices were taken after Yamaguchi (1973).

Although the cranium was fragmented by crushing in situ, almost all parts of the specimen were reconstructed. Missing portions were the greater and lesser wings of the sphenoid bone. The facial skeleton lacks the nasal bones and some parts of the maxilla and palatine bones. Other missing portions include the ethmoid and lachrymal bones, and the inferior conchae and vomer, which together form the inside of the orbits and the inner portion of the nasal cavity.

The cranial shape is ovoid in superior view. The cranial vault is dolichocephalic (cranial index 71.9). The external occipital protuberance is not prominent. The superior nuchal line is moderately developed, but the nuchal plane is smooth. The temporal line, to which the temporal muscles attach, is marked in the frontal region but becomes weak towards the posterior end of the temporal bones.

The glabella region is prominently protruding compared with the majority of modern East Asian females, although the superciliary arch is relatively flat. The frontal bone is perpendicularly elevated. The facial skeleton is low and wide (Virchow’s index 64.2). The orbital margins are relatively straight, while the nasal root is slightly concave. The coronal, sagittal, and lambdoidal sutures are completely fused ecto- and endocranially. The mandible expresses weak alveolar prognathism. Frontal nerve incisures and superior orbital foramina exist on either side of the frontal bone. The supramastoid crest is well developed, while the mastoid process is moderate in size.

The mandibular body is relatively small and low, while the muscle attachments are well developed. The mental eminence is weakly projected. The mylohyoid line is well angulated. The mandibular ramus is wide with a deeply concaved mandibular notch. The preangular incisula is shallow and the mylohyoid line is moderately developed, but the nuchal plane is smooth. The temporal line, to which the temporal muscles attach, is marked in the frontal region but becomes weak towards the posterior end of the temporal bones.

The following teeth are present in the maxilla and mandible.

| M3 | M2 | M1 | P2 | P1 | C | I1 | I2 | P2 | P1 | P2 | M1 | M2 | M3 |
|----|----|----|----|----|---|----|----|----|----|----|----|----|----|----|
|    |    |    |    |    |   |    |    |    |    |    |    |    |    |    |

X = tooth lost antemortem and alveolus remodeled.
O = tooth lost postmortem and alveolus not remodeled.
/ = tooth lost postmortem and alveolus damaged.
The mandible lacked the right second incisor, left first premolar, and both first molars antemortem. The occlusal surfaces of the remaining teeth were heavily worn, representing the 7th grade of the Smith system (Smith, 1984), where enamel remains only on the outer rim, the entire occlusal surface of the crown being lost and secondary dentine visible on every tooth. The right maxillary first molar and right mandibular second molar exhibit open dental pulp chambers on the occlusal surfaces. The crown of the right mandibular third molar was chipped off at the mesial, buccal, and distolingual corners. The alveolus of the left lower third molar was eroded by an abscess or granuloma.

High rates of interstitial wear reduced the mesiodistal crown diameters and only the buccolingual diameters were recorded (see Table 2). Unfortunately the heavy wear precluded extensive morphological study of the tooth crowns.

Infra-cranial skeleton

The following section summarizes the preservation and morphological observations of the infra-cranial remains. Both scapulae were fragmented and only the glenoid cavity, acromion, and lateral margin were preserved. Both humeri survive, except for the proximal heads. The right humerus has a well-developed deltoide tuberosity (Figure 9, No. 1), greater tubercle crest (Figure 9, No. 2), and a clear groove for the radial nerve. Both left and right radii and ulnae were well preserved and almost complete. The supinator crest is pronounced in the ulnae, especially the right ulna (Figure 9, No. 3). The ulnar tuberosity for both sides is very rough and prominent (Figure 9, No. 4). The radial tuberosity of the
right radius is prominent and exhibits an enthesophyte at the insertion of biceps brachii (Figure 9, No. 5), while the left radius is free of musculo-skeletal stress markers. Measurements recorded for the arm bones are given in Table 3. The stature of the Hang Cho individual, using Sjovold’s (1990) sex- and race-independent formula on the left radius, is estimated to be 162.5 ± 5 cm.

The carpals, including the right capitate, hamate, scaphoid, pisiform, left hamate, and trapezium, are preserved. All the right metacarpals are preserved, while only the 2nd and 5th left metacarpals are present. All proximal phalanges except the 1st, all middle phalanges, and the distal right 2nd, 4th, 5th, and left 5th phalanges were preserved in situ.

The right os coxa preserves only as a portion of the acetabulum and a part of the iliac blade. On the left side, the iliac, ischial, and pubic body are preserved, but the pubis is separated from the other parts. The greater sciatic notch forms an obtuse angle, suggesting the sex is female. Although the symphysial surface of the pubis is roughened and has a clear ventral outline with slight osteophytes, the dorsal

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<th>Table 1. Cranial and mandibular measurements (mm) of the Hang Cho skeleton</th>
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( ): estimated value; NPH, OBB: Howell’s definitions of measurements (Howell, 1989).

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<th>Table 2. Buccolingual crown diameters (mm) of the Han Cho skeleton</th>
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* Average: right and left sides
one is not distinct. The auricular surface is uneven and appears porotic. In the anteroinferior position of this surface there is a clear pre-auricular sulcus (Figure 9, No. 6).

No femoral, tibial, or fibular elements were preserved due to possible postmortem/post-interment disturbance. The preserved foot bones include the right calcaneus, left talus, cuboid, navicular, and all cuneiforms, and the following tubular bones: right 3rd, left 1st, and 2nd metatarsals; left 1st, 2nd, 5th proximal, 2nd, 3rd, 5th middle, and 1st, 2nd distal phalanges. The talus shows the extension of the medial malleolar surface and medial portion of the superior surface in the anterior direction (Figure 9, Nos. 7 and 8). According to the definition of Barnett (1954), these features are identified as squatting facets. Identifiable vertebrae consist of cervical spines and the sacrum, while preserved ribs are all highly fragmented.

Morphometric Comparisons

Comparative samples

Cranial and dental measurements from representative late Pleistocene and Holocene human specimens from the East/Southeast Asian and Southwest Pacific regions were used as a basis for comparison with the Hang Cho skeleton. A list of comparative cranial and dental samples and data sources is given in Table 4.

Skeletal remains from three late Pleistocene sites were used for craniometric comparisons of the cranial metric data. The first is a female individual from Moh Khiew Cave, Kra-bi Province, southern Thailand, dated to 25800 ± 600 years BP (Pookajorn, 1991, 1994; Matsumura and Pookajorn, 2005). Unfortunately the poor condition of the cranium meant that only dental data can be utilized for comparisons. The second comparative specimen is the Liujiang cranium, Guanxi Zhuang Autonomous Region, southern China (Woo, 1959). We treated the Liujiang cranium as female (after Wu and Poirier, 1995; Wolpoff, 1999), although it has also been sexed as male (e.g. Woo, 1959). The Liujiang dentition was not used for comparison due to the lack of mandibular teeth. The third late Pleistocene specimen used comparatively is the Coobool Creek sample, Coobool Crossing on the Wakool River, South Australia (Brown, 1989), dated to c. 14000 years BP.

The only early Holocene female sample is the Mai Da Dieu specimen, which is a nearly complete skull of the late Hoabinhian period (c. 8000 years BP) excavated from the Mai Da Dieu rock shelter in Thanh Hoa Province, northern Vietnam (Cuong, 1986).

Middle Holocene samples consist of five series, including those from the Neolithic period. The Middle Holocene Flores specimens, all from pre-ceramic contexts and dated from c. 7000 years BP to c. 4000 years BP (Jacob, 1967), came from Liang Momer, Liang Toge, Liang X, and Gua Alo. The Guar Kepah series, discovered in a shell midden in Lenggong district, Peninsular Malaysia (Callenfels, 1936; Mijsberg, 1940). Only the dental samples were utilized from above Flores and Guar Kepah series due to the poor skeletal preservation of female crania. Man Bac is a late Neolithic (c.
3500–3800 years BP) or Phung Nguyen period (Cuong, 2001; Phung, 2001; Hiep and Phung, 2004; Matsumura et al., 2008) cemetery site in Ninh Binh Province, northern Vietnam. In the Man Bac series, only the cranial measurements were recorded by one of us (H.M.). The Japanese sample is represented by a Jomon series which represents early hunter-gatherers that lived in the Japanese archipelago from c. 13000 years BP to 2300 years BP (Akazawa and Aikens, 1986). The samples used here are of the middle to final Jomon phases (c. 4000–2300 years BP). In China a Neolithic rice-farming sample from Weidun, south of the Yangtze River, Jiangsu Province, dates from c. 7000–5000 years BP (Hudson, 1990). Data recorded for several modern samples (see Table 4) were also used for the cranial and dental comparisons.

There are discrepancies in the measurement systems of upper facial height and orbital breadth between Howell’s (1989) data and that of other researchers. Howell’s upper facial height (NPH) is measured at the anatomical point of prosthion, while others use the alveolar point according to Martin’s method (M48). Dodo (2001) noted an average discrepancy of approximately 2 mm in his studies of various female cranial samples. As for the orbital breadth, Howell used dacryon (OBB) while others use the maxillofrontale (M51). Data using both methods, recorded for Japanese female samples (Hanihara, 2002), indicate an average difference of 2.7 mm. Brown (1989) also adopted Howell’s method of utilizing either upper facial height or orbital breadth. Because of these measurement differences, all the comparative data, except for Howell’s and Brown’s, were corrected by subtracting 2 mm from the upper facial height and 2.7 mm from the orbital breadth measurements. The upper facial height and orbital breadth after Howell’s method were originally provided in Table 1.

### Craniometric multivariate analysis

In order to confirm impressions of craniofacial proportions recorded in the previous skeletal descriptions, four representative indices based on the above cranial measurements are compared between Hang Cho and other samples. Figure 10 plots the averages of the cranial indices (M8/M1), upper facial indices (NPH/M45), orbital indices (M52/OBB) and nasal indices (M54/M55). The cranial index of the Hang Cho specimen is low due to its dolichocranic shape, which is comparable to prehistoric and modern Aboriginal Australians. With regard to the upper facial index, the Hang Cho skull is characterized by a relatively low and broad face. The nasal and orbital indices suggest that the Hang Cho specimen has a low and wide orbital shape and relatively low and broad nasal shape. Overall, the Hang Cho cranium shares closer similarities to Australian specimens such as those from Coobool Creek and Tasmania, as well as to the Tolai Melanesians and Liujiang specimen.

The morphological affinities between the Hang Cho skull and comparative samples were also explored using Mahalanobis’ generalized distance and Q-mode correlation coefficients (Sneath and Sokal, 1973). Both procedures indicate the likelihood of similarities in proportion or shape of the cranial morphology between samples, with the advantages that Mahalanobis’ generalized distances take the inter-correlation of measurements into account, and the Q-mode correlation coefficients entirely eliminate the overall absolute size factor. Contrasting the results from these two techniques will help us to interpret the estimates of sample affiliations.

To calculate these values, nine cranial measurements, available for the Hang Cho skeleton and the published female series listed in Table 4, were selected. That is, maximum cranial breadth (M1) and length (M8), cranial height (M17), bizygomatic breadth (M45), upper facial height (NPH), orbital breadth (OBB) and height (M52), and nasal breadth (M54) and height (M55). The variance and covariance matrix used in this calculation of Mahalanobis’ generalized distances was derived from Howell’s data set.

To aid in the interpretation of the intersample phenetic af-
finities, cluster analyses using the unweighted pair-group method (UPGMA) (Sneath and Sokal, 1973) were applied to the Mahalanobis' distance matrix and Q-mode correlation coefficient matrix computed using the nine cranial measurements.

Figure 11 represents two dendrograms resulting from a cluster analysis applied to the Mahalanobis' distance and Q-mode correlation coefficients respectively. Two major clusters were drawn in both dendrograms, in which the late Pleistocene Liujiang and Coobool Creek, and the modern Australian, Tolai Melanesian, and Tasmanian Aboriginal samples form one major cluster to which Hang Cho specimen also clusters. The late Neolithic Man Bac and early Bronze Age Dong Son specimens, despite being from neighboring regions in northern Vietnam, were clearly separated from the cluster that include the Hang Cho specimen. These later period Vietnamese samples belong to another major cluster formed by the remaining Neolithic to modern samples from Southeast Asia, Southern China, and Japan.

**Dental metric multivariate analysis**

As noted, dental metric comparisons were made for buccolingual crown diameters only due to extreme interproximal wear which had reduced the mesiodistal diameters. For the Hang Cho data given in Table 2, average buccolingual diameters of the right and left side were used for statistical comparisons where teeth and their antemeres were present. Data from the third molars were not used in this analysis because of the lack of data from comparative specimens.

Figure 12 represents the summation of ten buccolingual diameters of the comparative samples, and although tooth size alone does not imply population relationships, it is possible to compare the degree of absolute largeness of Hang Cho teeth to other modern and prehistoric samples. The late Pleistocene Moh Khiew specimen is marked by the largest total crown size. The tooth size of the Coobool Creek sample is next largest, followed by the modern Australian Aboriginal and Middle Holocene Flores samples. The overall tooth size of Hang Cho is comparable to the average size of these samples.

Figure 13 displays the results of a cluster analyses applied to the Mahalanobis’ distance and the Q mode correlation coefficients computed using the ten buccolingual crown diameters. In both dendrograms Hang Cho is connected with a cluster containing the Middle Holocene Flores, Moh Khiew Cave, and Australian samples, which is distinct from another separate cluster joining the Neolithic to modern samples from East/Southeast Asia.

**Discussion**

New radiocarbon dates for the Hang Cho skeleton provide a calibrated age of $10450 \pm 300$ years BP (68.2%) or $10450 \pm 700$ years BP (95.4%), suggesting that this material belonged to the terminal Pleistocene. This estimated date is within a range determined by AMS dating using freshwater
shell mounds formed in the main chamber (14100 ± 300 years BP at the lowest layer to 9710 ± 50 years BP at the top: Seonbok et al., 2004). Furthermore, this date is consistent with the Hoabinhian material cultural complex uncovered surrounding the burial of the Hang Cho skeleton. In Vietnam, only a few skeletal remains are known from the pre-ceramic level at Dong Can (c. 16000 years BP: Cuong, 1986), Mai Da Dieu, and Mai Da Nuoc (c. 8000 years BP: Cuong, 1986). The Dong Can specimen is missing more than half of one side of the cranium, and these pre-ceramic skeletal series lack post-cranial elements. The Mai Da Dieu and Mai Da Nuoc series include nearly complete skulls belonging to the later stage of the Hoabinhian period. Accordingly, the Hang Cho skeleton is very important in terms of its good, including post-cranial, preservation and sound dating, indicating an early Hoabinhian period origin.

The Hang Cho skeleton, dated to the terminal Pleistocene, may represent one of the early indigenous settlers of this region. Multivariate analyses of cranial and dental data, making large-scale comparisons with Northeast/Southeast Asian and Pacific groups, demonstrates close affinities between Hang Cho and Australo-Melanesian samples.

Beyond Vietnam’s borders a considerable number of prehistoric human remains have been recovered in various regions of Southeast Asia (see Tayles and Oxenham, 2006, for an overview). As far as the pre-ceramic culture sites are concerned, most of the skeletal remains are found in Malaysia and Indonesia. Several sites in the north of Peninsular Malaysia have produced Hoabinhian (Tampanian) human skeletons, such as Gua Kajang, Gua Kerbau, and Gua Cha. From the western part of Flores Island some human remains associated with Hoabinhian period artefacts have been recovered from Liang Momer, Liang Toge Liang X, Gua Alo, Gua Nempong, and other sites. Among these sites, well-preserved skeletal individuals are unearthed from only a few sites such as Gua Cha, Liang Momer, and Liang Toge. Although many of these skeletal remains from pre-ceram-
ic contexts are fragmented, a number of earlier analyses frequently described morphological features akin to those of Australian Aboriginal or Melanesian people, citing their dolichocranic skulls with protruding glabella regions, massive jaws with relatively large teeth, alveolar prognathism, and long gracile limbs (e.g. Evans, 1918; Duckworth, 1934; Mijsberg, 1940; Trevor and Brothwell, 1962; Jacob, 1967; Bulbeck, 2000). They were all associated with pre-ceramic levels and so-called ‘Sumatralith’ pebble tools (oval unifacs), hammer stones, and slabs, and were thus all said to belong to the late Hoabinhian period.

Tracing back to the late Pleistocene and early Holocene periods, several sets of human remains have been discovered in Southeast Asia. In east Malaysia, Niah Cave in Sarawak is the site of the earliest well-dated modern human remains in Southeast Asia. The so-called ‘Deep Skull’ from Niah Cave has an associated radiocarbon date of c. 40000 years BP (Kennedy, 1977; Barker et al., 2007). In mainland Malaysia, the excavation of Gua Gunung Runtuh revealed a 10000–11000 years BP primary burial of an adult male (Zuraina, 1994, 2005). Tabon Cave on Palawan Island is a well-known site which has produced the oldest human skeletal remains in the Philippines, consisting of a frontal bone and two mandibular fragments and a tibia. The mandibular fragment has been AMS dated to c. 30000 years BP (Dizon et al., 2002). From southern Thailand, a late Pleistocene human skeleton was excavated at the Moh Khiew Cave in Krabi Province (Pookajorn, 1991, 1994). An adult female buried in the pre-Neolithic cultural level has been AMS dated to 25800 ± 600 years BP. The Wajak skulls from central Java in Indonesia (Dubois, 1922; Weidenreich, 1945; Wolpoff et al., 1984) have long been regarded as late Pleistocene, but AMS dating of the skeleton indicates that a middle Holocene date (c. 6500 years BP) may be more appropriate (Storm, 1995).

The majority of analyses of Pleistocene and early Holocene East/Southeast Asian material demonstrate Australo-Melanesian characteristics in the skeletal and dental morphology, despite issues with using subadult or poorly preserved material (Brothwell, 1960; Macintosh, 1978; Cuong, 1986; Jacob and Soepriyo, 1994; Matsumura, 1995; Matsumura and Zuraina, 1995, 1999; Matsumura and Pookajorn, 2005). However, both Jacob (1967) and Storm (1995) have identified so-called ‘Mongoloid’ features in the Wadjak specimens.

Based on these earlier findings, as well as more recent discoveries of preceramic period skeletons, it has been argued that Southeast Asia was occupied by an indigenous population, sometimes referred to as ‘Australo-Melanesian’, before immigrants from East Asia dispersed widely into this region (e.g. Callenfels, 1936; Mijsberg, 1940; Barth, 1952; von Koenigswald, 1952; Coon, 1962; Jacob, 1967, 1975; Brace, 1976; Howells, 1976; Brace et al., 1991; Matsumura and Hudson, 2005). This population history scenario for Southeast Asia is known as the ‘Two Layer’ or ‘Immigration’ model. This ‘Two-Layer’ hypothesis is supported by a wide range of genetic, linguistic, and archaeological evidence, which has linked the pre-modern expansion of the Austronesian and Austroasiatic language families with the dispersal of rice-cultivating populations during the Neolithic period (Renfrew, 1989, 1992; Bellwood, 1991, 1993, 1996, 1997;

There are, however, different interpretations regarding these peoples based on recent studies of dental and cranial morphology. Studies by Turner (1987, 1989, 1990, 1992) based on nonmetric dental traits suggested that both early and modern Southeast Asians display the so-called ‘Sunda-dont’ dental complex. Turner concluded that early Sunda-dont populations migrated into Northeast Asia and evolved into ‘Simodont’ populations. Cranial studies by Hanihara (1993, 1994) advocated that Proto-Malays, similar to the present-day Dayaks, widely inhabited Southeast Asia during the late Pleistocene. Hanihara (1993) regards Proto-Malay as an original source for present-day Southeast Asians. Pietrusewsky (1992, 1994, 1999) analyzed a number of large-scale craniofacial data sets from Southeast Asia and argued for regional continuity in Southeast Asia and relatively close affinities between modern East and Southeast Asians, coupled with a distinct dissimilarity to Australo-Melanesians. However, these studies did not include extensive Hoabinhian period samples from Southeast Asia. In terms of dental morphology, Lauer (2002) and Matsumura and Hudson (2005) have analyzed data from combined Hoabinhian period specimens, and demonstrated their close affinity with Australo-Melanesian samples. Bulbeck (2000) has discussed at length some of the interpretive problems resulting from the scarcity of pre-Neolithic materials in Turner’s Southeast Asian samples. Turner (1987) himself presumed that further sampling, particularly of older remains, may show the ancient presence of Australo-Melanesians in Southeast Asia.

Our new discovery of the early Hoabinhian Hang Cho skeleton is of crucial importance in resolving the issue under debate here. Our skeletal and dental morphometric analyses demonstrate that the Hang Cho remains share a number of similarities with early Australian or Melanesian samples, demonstrating the possibility that the first modern human colonizers of mainland Southeast Asia and the Australian subcontinent were ancestors of modern-day Australo-Melanesians in the region. The antiquity of this early colonization event is clearer for Australia where the earliest human occupation dates back to approximately 50,000 years ago (Bowdler, 1992). Australian teeth, which are most like those of the early Southeast Asians (Hanihara, 1992; Turner, 1992; Matsumura, 1995), suggest a Sundaland (mainland Southeast Asia for the most part) origin of the first Australians. Along with the above-mentioned late Pleistocene and early Holocene fossils from Southeast Asia, such as the Niah, Tabon, Moh Khiew and Gua Gunung Runtuh Cave sites, the Hang Cho remains can be regarded as descending from late Pleistocene Sundaland populations, which, in turn, may share a common ancestry with present-day Australian Aboriginal and Melanesian people. Some craniodental traits exhibited by the Pleistocene founding populations in the region were retained in Southeast Asia peoples, represented by Hoabinhians, until the early Holocene at least.

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