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Huanglong Cave: A Late Pleistocene human fossil site in Hubei Province, China

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ABSTRACT

This contribution discusses recent paleoanthropological findings from Huanglong Cave, a Late Pleistocene human fossil site from Yunxi County, Hubei Province, China. Three excavations in the Huanglong Cave from 2004 to 2006 yielded seven human teeth, some stone and bone tools, possible burnt sediment and other evidence possibly related to hominin activities. Based on the presence of extinct faunas (20% of total taxa identified), the deposits dated to the Late Pleistocene. Electron spin resonance (ESR) and uranium-series (U-series) dating analyses on associated teeth and speleothems have resulted in divergent chronometric ages (ESR: 44–34 ka; U-series: 103–79 ka). Analysis indicates: (1) most of the morphological and metric features of the human teeth from Huanglong Cave fall within the range of variation of modern Chinese, but a few characters may still link them to more archaic hominins; (2) some activity-induced abrasion and other tooth use-marks were identified, including pronounced tooth chipping and interproximal grooves on the anterior teeth; (3) the sample of blackened deposit has a high carbon content (over 70%), experienced high temperatures, and likely was of cultural origin and not natural; (4) the mammal fossils represent the "Ailuropoda-Stegodon" faunal unit which lived in southern China throughout the Pleistocene. Synthesizing all of these findings, especially the human teeth that display modern human characteristics, Huanglong Cave will offer some new insights into various issues currently being debated in Late Pleistocene human evolutionary research.

1. Introduction

Based on a series of new fossil discoveries and an improved dating framework, the earliest anatomically modern humans or early modern humans currently appear in East Africa (White et al., 2003; McDougall et al., 2005; Grine et al., 2007). In contrast, to the African record, the nature of early modern humans in East Asia is more debated (Shen, 2004; Shang et al., 2007). Currently, Late Pleistocene hominin fossils have been found in more than 40 sites in China (Wu and Poirier, 1995; Wu and Wu, 1999) (Fig. 1). However, most of the fossils are very fragmentary, hindering detailed morphological studies. In addition, most of the Late Pleistocene hominin fossils found in China date to within 30 ka (Wu and Poirier, 1995) (Table 1). A recent discovery and related research show that the mandible and postcrania from Tianyuan Cave near Zhoukoudian, China, which have direct AMS ^{14}C dates of ∼35 ka may represent the oldest modern human fossils from mainland East Asia (Tong et al., 2004; Shang et al., 2007). Nonetheless, there have been claims that the earliest modern humans in China can be traced back to 50 ka or even earlier (e.g., Shen et al., 2002, 2005; Shen, 2004). However, either because of stratigraphic uncertainties or lack of reliable dating, all of the evidence which support such claims is weak (Wu and Poirier, 1995). Two key barriers in China have been the lack of accurately dated hominin fossils from between 100 ka and 50 ka (Shang et al., 2007) and the paucity of more detailed studies of the morphological variation in Chinese Late Pleistocene hominins. With this background in mind, more fossil discoveries of early modern humans from China are required to explore various issues related to the emergence and spread of modern humans in East Asia. This paper reports a newly discovered Late Pleistocene human fossil site from central China: Huanglong Cave.

2. Background

Huanglong Cave (Huanglongdong) is located in Yunxi County, Hubei Province, China (33°07′62.8″N; 110°13′04.3″E) (Fig. 2). The huge cave has a northeast facing opening and is 598 m above sea

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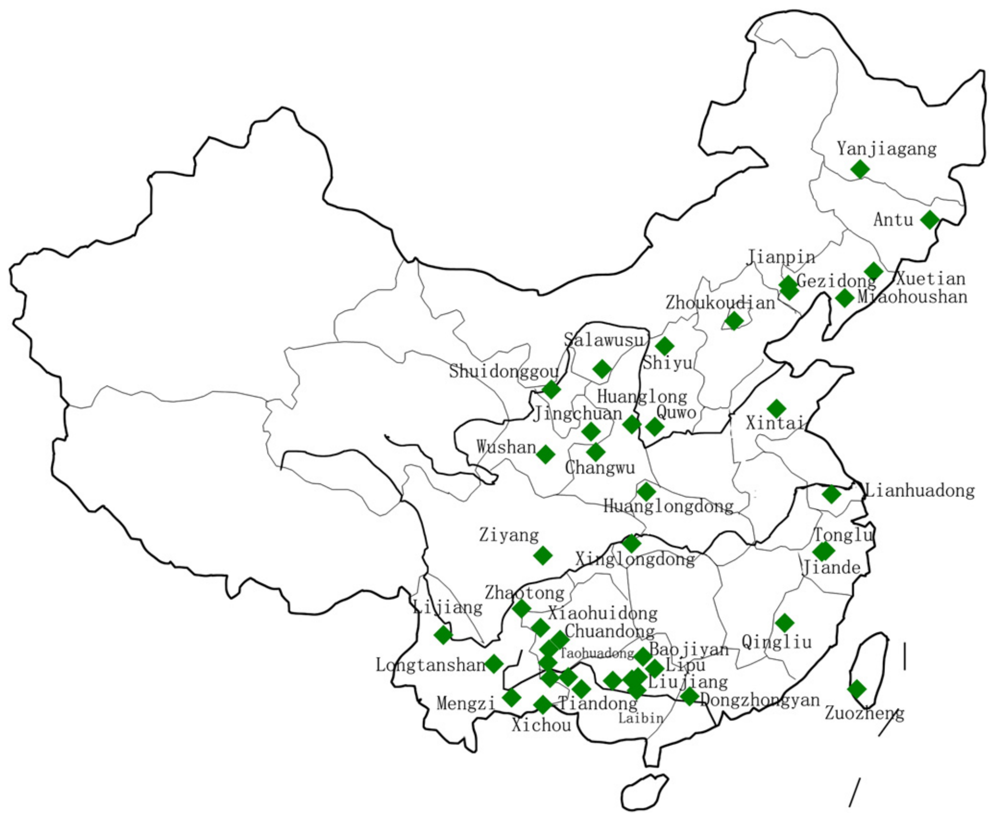

Fig. 1. The late Pleistocene hominin fossil sites in China.

level. In May 2004, during a field survey conducted as part of local highway construction, some mammal fossils were discovered in the cave. Three archaeological excavations were conducted in 2004, 2005 and 2006 by the Hubei Province Institute of Archaeology and the Institute of Vertebrate Paleontology and Paleoanthropology. The three excavations resulted in the discovery of seven human teeth, some stone and bone artifacts, and evidence of fire use (Wu et al., 2006, 2007a; Pei et al., 2008; Wang et al., 2008; Liu et al., 2009a,b).

The main axis of the cave is in a northeast–southwest direction with its entrance width of 27.8 m and height of 11 m. About 50 m in front of the site is the Dashui River, a branch of the Hanjiang River. The entrance of the cave is about 7.8 m above the current river level. Huanglong Cave extends more than 400 m (the end has not been reached). Within the cave, five regions were mapped, and four of the regions were excavated (see Fig 3). The excavations in Region 1, Region 2, Region 4, and Entrance were of varying sizes. Excavations in the four regions indicate that the stratigraphy is similar

Table 1
The main late Pleistocene hominin fossil and their chronological dates in China.

Sites	Province	Main specimens	Chronological Dates or Geological Epoch	References
Upper Cave	Beijing	3 crania and bone fragments	34–29 ka (AMS)	Wu and Poirier, 1995
Liujiang	Gaungxi	1 cranium and 4 bone fragments	67 ka? (U)	Wu and Poirier, 1995
Ziyang	Sichuan	1 cranium	30 ka (^{14}C)	Wu and Poirier, 1995
Tianyuan Cave	Beijing	1 mandible, several limb bones, both scapulae and some hand and foot bones	42–39 ka (^{14}C)	Tong et al., 2004; Shang et al., 2007
Chuandong	Guizhou	2 skulls	Late Pleistocene	Wu and Poirier, 1995
Jianping	Liaoning	1 humerus	Late Pleistocene	Wu and Poirier, 1995
Lijiang	Yunnan	A cranium	Late Pleistocene	Wu and Poirier, 1995
Miaohoushan	Liaoning	2 parietal fragments and 1 radius	28 ka (^{14}C)	Wu and Poirier, 1995
Salawusu	Inner Mongolia	1 parietal and 2 frontal fragments, 1 child mandible, 2 femurs, 1 tibia and 1 incisor	50–37 ka (U) 35.3–19 ka (^{14}C)	Wu and Poirier, 1995
Huanglong	Gansu	1 skull cap preserving most frontal and anterior part of parietal bones	Late Pleistocene	Wu and Poirier, 1995
Jingchuan	Gansu	A cranium without facial and basal portion	48–15 ka (OSL)	Wu and Poirier, 1995; Liu et al., in press
Shiyu	Shanxi	A occipital fragment	28.9 (^{14}C)	Wu and Poirier, 1995
Wushan(Yuanyang)	Gansu	A skull cap including a complete frontal bone, two parietals and parts of nasal and sphenoid bones	38.4 (^{14}C)	Wu and Poirier, 1995
Laibin	Guangxi	A cranial base	Late Pleistocene	Wu and Poirier, 1995
Mengzi	Yunnan	4 fragmentary crania	Late Pleistocene?	Wu and Poirier, 1995
Huanglong Cave	Hubei	7 teeth	103–44 ka (U and ESR)	Wu et al., 2006

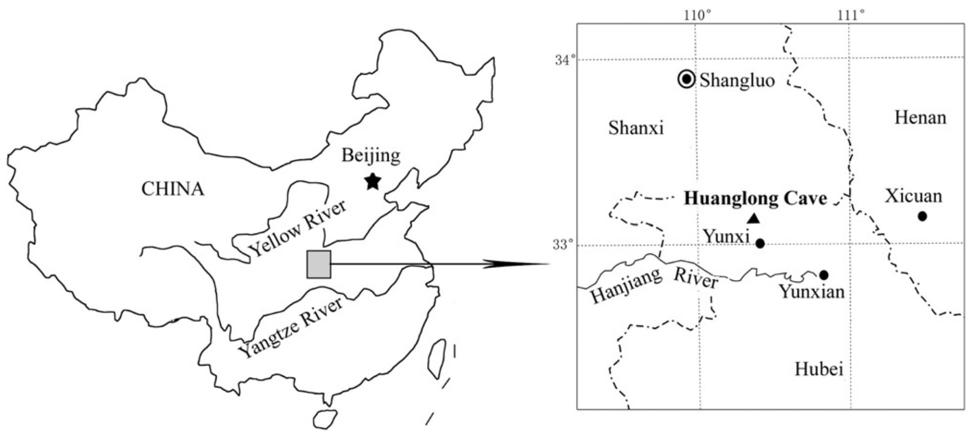

Fig. 2. The location of Huanglong Cave and its horizontal profile.

throughout the surveyed areas with five stratigraphic layers identified (Fig. 4):

(1) *Capping flowstone layer (2–28 cm)*: Milk-white or brown-yellow layer widely developed in the cave and most of the layer has a pure and dense structure.
(2) *Silt clay–sandy gravel layer (1–201 cm)*: Silty clay and sandy gravel are in the same layer but in different levels the deposit of the layer near the entrance comprises mainly gravels bedded in a clay matrix. The gravels decrease in both density and size gradually when moving toward the interior of the cave. In the deeper areas of the cave the deposit becomes silty clay.
(3) *Red silt clay layer (58–101 cm)*: Two thin flowstone layers developed with a break. Below the flowstone layers there are isolated stalagmites which have no direct connection with the flowstone layer.
(4) *Mantle limestone layer (41–66 cm)*: Loose layer mainly composed of mantled limestone breccia and clay matrix residue.
(5) *Brown-red silt clay layer (18–26 cm)*: It has a dense structure without embodied materials.

All of the human fossils and most of the animal fossils were excavated from Region 1. A few animal fossils were found in Region 2. No fossils were found in Region 4 and the Entrance region. In Region 1, about 50 m^2 were excavated. The 2004 and 2005 excavations are represented by the white area in Fig. 4, and the dark area indicates the 2006 excavation. Among the seven human teeth

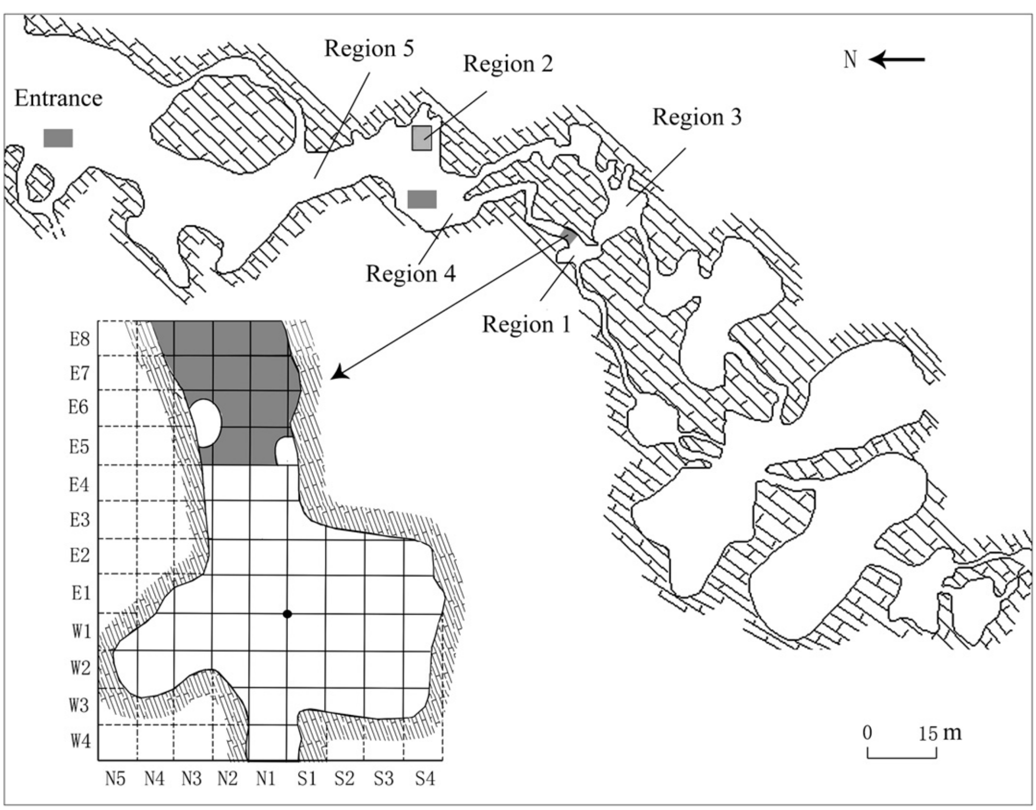

Fig. 3. The plan view of the Huanglong Cave and the excavation area (modified after Wu et al., 2007a).

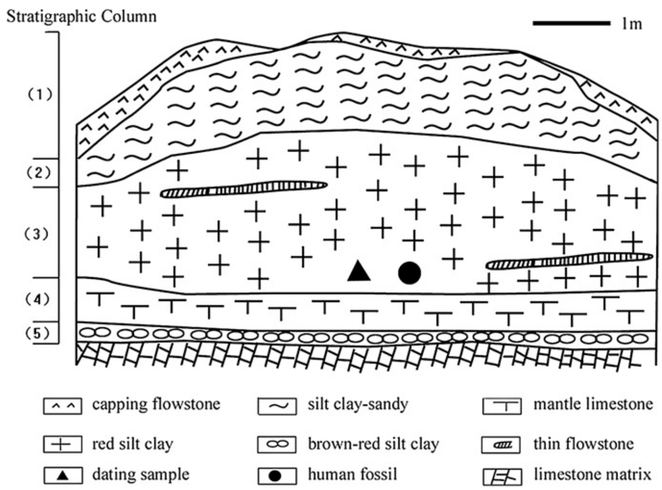

Fig. 4. Stratigraphic context of the Huanglong Cave deposits (from Wu et al., 2006).

unearthed from Huanglong Cave, five of them were found during the 2004–2005 excavations in square zones N1W2, N1W3, N3E1, N2W1 and N1W3. The other two human teeth were found during the 2006 excavation in square zones N2E6 and N1E7. All the seven hominin teeth, all the stone artifacts and most of the animal fossils are derived from Layer 3. The hominin teeth and stone artifacts were found at the bottom of the layer, in association with the stalagmites.

During the excavations, the fossil yielding layer was carefully examined to ascertain if there is any possible evidence indicating the fossils and artefacts were transported, sorted or redeposited. For the following reasons, the materials are considered to have been buried rapidly. First, Layer 3 is comprised of sharp-edged breccia. Little evidence of fluvially transported sediment is present. No horizontally or cross-bedded sediment was observed in the deposit. Second, the faunal assemblage contains different species of varying sizes with no evidence of apparent sorting. Both intact complete small mammal bones and limb bones of large animals are well preserved. Third, evidence of human fire use, which will be discussed below, is distributed in multiple spots. If there had been a flow of water, then no evidence of fire would be anticipated. However, the influence of rodents cannot be completely ruled out (see below).

3. Dating

Chronometric dating analysis for the layer yielding the human teeth (Layer 3) was carried out in three different laboratories. The first Uranium-series (U-series) dating on two rhinoceros teeth was analyzed at the Laboratory of the Institute of Karst Geology, Chinese Academy of Geological Sciences. An age range of $94.7 \pm 12.5 - 79.4 \pm 6.3$ ka (Table 2) was derived (Wu et al., 2006, 2007a).

The second dating attempt, again using U-series, was made on a pure and dense stalagmite sample collected from the same horizontal level that yielded the human fossils. The speleothem sample was analyzed at the TIMS Laboratory in the Department of Geology and Geophysics, University of Minnesota. Two small pieces from the stalagmite sample were taken out and tested separately. The results indicated an age range of $103{,}739 - 103{,}119 \pm 1616 - 1348$ years (Table 3).

To further assess the age of the hominin tooth layer, electron spin resonance (ESR) dating on a rhinoceros tooth was conducted. The rhinoceros tooth was analyzed at the State Key Laboratory of Earthquake Dynamics, Institute of Geology, China Earthquake Administration, resulting in an age of $44{,}180 - 34{,}780 \pm 3280 - 4540$ years (Table 4), which is much younger than the dates from the U-series studies.

Among the three dating procedures for Layer 3, the two U-series dates give an age range between 79,400 and 103,739 years. The ESR date is much younger, between 44,180 and 34,780 years. Because the exact provenience of the speleothem sample and its relationship with the human fossils need further verification, more detailed study of the stratigraphy and context from which the samples were derived are necessary. In particular, if the speleothem overlies the human fossil layer, the age of the human fossils could be older than 103 ka. However, if the stalagmite underlies the human fossil layer, then the hominin deposition could be much younger. In order to attempt to narrow the age range of the deposit, AMS ^{14}C analysis will be conducted on associated bones. If the AMS dates fall outside the accepted range (>50 ka), it would lend support for the older U-series dates. If the AMS dates are younger than or around 40 ka, it would support the ESR date. At this point, it is believed that the age of the Huanglong Cave hominin teeth can be conservatively bracketed between 100 ka and 34 ka.

Although questions still exist about the chronometric age of the human fossils, based on the biostratigraphy, it can be minimally concluded that the deposits are Late Pleistocene and clearly not Holocene. The animal fossils from Huanglong Cave were classified into 91 taxa (Wu et al., 2006, 2007a), representing a mixed assemblage comprising extinct (e.g., *Macaca robustus*, *Cricetinus varians*, *Crocuta ultima*, *Ailuropoda melanoleuca baconi*, *Ursus thibetanus kokeni*, *Stegodon orientalis*, *Rhinoceros sinensis*, *Megatapirus augustus*), and extant species (e. g., *Neofelis nebulosa*, *Cuon alpinus*, *Canis lupus*, *Arctonyx collaris*, *Paguma larvata*, *Sus scrofa*, *Rusa unicolor*, and *Cervus nippon*). Among the 91 identified taxa found in the Huanglong Cave, 20% are extinct species (see Table 5 for details).

The Huanglong Cave faunal assemblage is typical of the Oriental biogeographic region (Norton et al., in press). The faunal composition indicates both tropical and subtropical forest environments. For example, *Neofelis nebulosa* is the representative taxa of tree living animals in subtropical forests (Sheng, 1994), and *Belomys pearsoni* lives in the evergreen broadleaved forest (Corbet and Hill, 1980). There are also many fossils of *Rhinolophus*, an animal normally living in broad forest environments. The Huanglong Cave fauna also includes animals that typically exist in the Qinling Mountains. These animals include *Capricornis sumatraensis*, *Naemorhedus goral*, and *Caryomys ineg*. The faunal composition reflects its geographic location in the southern part of the Qinling Mountains, and its border position separating the Palearctic and Oriental biogeographic zones.

4. Hominin paleontology

The seven human teeth found in the Huanglong Cave were identified as upper central and lateral incisors, upper canine, upper third molar, lower lateral incisor, lower second and third molars (see Fig. 5 and Table 6).

4.1. Age and individuals

According to the occlusal wear and root formation, the ages of the individuals were estimated. Six teeth were estimated to be from adults between 20 and 45 years of age, and only one tooth may

Table 2
U-series analysis and age result for the Huanglong Cave rhinoceros teeth.

Sample No.	Uranium content (Ug/g)	$^{234}U/^{238}U$	$^{230}TH/^{234}U$	Age (Ka)	Corrected age (ka)
020	1.445	1.553	0.576	85.3 ± 6.9	79.4 ± 6.3
021	1.583	1.469	0.595	92.4 ± 12.1	94.7 ± 12.5

Table 3
The U-series analysis and age results for the Huanglong cave stalagmite.

Sample Number	^{238}U (ppb)	^{232}Th (ppt)	^{230}Th / ^{232}Th (atomic $\times 10^{-6}$)	δ^{234}U[a] (measured)	^{230}Th / ^{238}U (activity)	^{230}Th Age (yr) (uncorrected)	^{230}Th Age (yr) (corrected)	$\delta^{234}U_{Initial}$[b] (corrected)
HL-1	146.0 ± 0.2	18922 ± 58	113 ± 1	379 ± 2	0.8903 ± 0.0051	106267 ± 1009	103739 ± 1616	508 ± 4
HL-2	141.8 ± 0.2	14132 ± 38	147 ± 1	384 ± 2	0.8880 ± 0.0048	105049 ± 949	103119 ± 1348	514 ± 4

$\lambda_{230} = 9.1577 \times 10^{-6}\ y^{-1}$, $\lambda_{234} = 2.8263 \times 10^{-6}\ y^{-1}$, $\lambda_{238} = 1.55125 \times 10^{-10}\ y^{-1}$.
[a] $\delta^{234}U = ([^{234}U/^{238}U]_{activity} - 1) \times 1000$.
[b] $\delta^{234}U_{initial}$ was calculated based on ^{230}Th age (T), i.e., $\delta^{234}U_{initial} = \delta^{234}U_{measured} \times e^{\lambda 234 \times T}$. Corrected ^{230}Th ages assume the initial $^{230}Th/^{232}Th$ atomic ratio of $4.4 \pm 2.2 \times 10^{-6}$. Those are the values for a material at secular equilibrium, with the bulk earth $^{232}Th/^{238}U$ value of 3.8. The errors are arbitrarily assumed to be 50%.

represent a sub-adult less than 20 years old (see Table 6 for details). From the occlusal views of these teeth (see Fig. 5), very different wear patterns can be observed. Thus, the seven teeth came from multiple individuals. Currently, with just these isolated teeth, the sex of the individuals cannot be determined.

4.2. Research method

The morphology of the human teeth was assessed by referring to the methods described by several authors (e.g., Weidenreich, 1937; Turner et al., 1991; Irish, 1998; Irish and Guatelli-Steinberg, 2003; Bailey et al., 2008). Other studies (e.g., Wolpoff, 1979; Bermudez de Castro, 1988, 1993) were also consulted. The Arizona State University Dental Anthropology System (ASUDAS) (Turner et al., 1991) was used to grade some morphological features. Dental metric analysis followed the descriptions by Bermudez de Castro (1986, 1993), the mesiodistal (MD) and buccolingual (BL) dimensions of the Huanglong Cave teeth were recorded to the nearest 0.1 mm. The crown base area (CBA = MD × BL) and crown shape index (CSI = BL × 100/MD) were calculated from these tooth dimensions. For those teeth which have light interproximal wear, original borders were estimated by referring to overall crown shape and the buccolingual extent of the wear facet (Bailey, 2004).

4.3. Comparative samples

The comparative samples include Chinese (*Homo erectus*, archaic *Homo sapiens*, Late Pleistocene humans and recent Chinese populations), Neandertals, European Middle Pleistocene humans (Krapina and Atapuerca SH), European Late Pleistocene humans, modern Europeans and the early modern humans of Skhul and Qafzeh (Weidenreich, 1937; Wolpoff, 1971, 1979; Brace, 1976; Frayer, 1977; Brace et al., 1984; Bermudez de Castro, 1993; Liu and Yang, 1999; He, 2000).

Table 4
The ESR analysis and age result for the Huanglong Cave rhinoceros tooth.

Lab Number	5103
Sample Number	N1W2:59
Enamel thickness (mm)	2.1
Thickness of removed enamel (mm)	0.1
Dose (Gy)	56.16 ± 2.38
U-enamel (ppm)	2.81
U-dentine (ppm)	5.05
U-sediment (ppm)	2.10 ± 0.10
Th-sediment (ppm)	7.05 ± 0.35
K-sediment (%)	1.52
EU (Gy/ka)	1.673 ± 0.142
LU (Gy/ka)	1.316 ± 0.124
EU age (ka)	34.78 ± 3.28
LU age (ka)	44.18 ± 4.54

The following paragraphs describe the morphology and metric features of the Huanglong Cave human teeth (see also Liu et al., 2009a; Liu et al., 2009c).

4.4. Upper central incisor (I^1)

The crown lingual surface is shovel-shaped. There is a weakly developed basal prominence, but no finger-shaped projection can be identified. The whole crown labial surface bulges slightly. Both the mesial border and distal border at the labial side display marked projections, which makes the whole crown labial surface depressed and flat. Because both the lingual and buccal surfaces of the crown are shovel-shaped, this upper central incisor has the double shovel-shaped feature. According to ASUDAS, the degrees of shoveling and double-shoveling are 4 and 3 respectively. The root is awl-shaped. From the cervical region to the root tip, the root gradually thins.

Previous studies of upper central incisors of Pleistocene hominins found in China indicate that there are some morphological features shared by the Chinese archaic hominins (Weidenreich, 1937; Wu et al., 1989). These features are pronounced labial bulging, pronounced basal tubercle with finger-shaped projections extending toward the incisal edge, the crown and root are not in the same long axis, and the root is robust and awl-shaped. These morphological features cannot be identified in the Huanglong Cave upper central incisor. The crown lingual surface of the Huanglong Cave upper central incisor is very flat and smooth. Its crown labial surface is not only less bulging but shows obvious depressions. Both the MD and BL diameter are within the modern human ranges, and smaller than those of Chinese *Homo erectus* and archaic *Homo sapiens*, and also smaller than Middle and Late Pleistocene hominins in other regions of the world (see Table 7 for details). The long axis of the crown and root of the Huanglong Cave upper central incisor is not in the same line and the crown is inclined toward the direction making a slight angle between the crown and root. These morphological features indicate the upper central incisor is more like modern humans. However, the robust root of the Huanglong Cave specimen differs from that of modern humans, and resembles that of earlier fossil hominins. The CSI is 76.5, which is closer to the average of the same index of *Homo erectus* (75.7), and smaller than those of archaic *Homo sapiens* and other Late Pleistocene humans and modern humans (see Table 7).

4.5. Upper lateral incisor (I^2)

The crown lingual surface is shovel-shaped (grade 3 of ASUDAS). The crown lingual surface is flat without a basal tubercle and a finger-shaped projection. The root is slender, flat and awl-shaped. The crown mesiodistal and labiolingual dimensions fall within range of modern humans, although the labiolingual dimension is relatively large (see Table 7). In general, the labiolingual dimension of modern humans' upper lateral incisors is smaller than *Homo erectus* and other Pleistocene humans. With the latter groups, CSI

Table 5
Fauna compositions of the Huanglong Cave.

	Order/genus /species	Extinct	Extant
Lamellibranchia	Eulamellibbanchia		△
Gastropoda	Order stylommatophora		△
Malacostraca	*Somanniathelphusa zhongshiensis*		△
Osteichthyes	*Diptychus kaznakovi*		△
	Mylopharyngodon piceus		△
	Elopichthys bambusa		△
Amphibia	*Rusa* sp.		△
Reptilia	Boidae		△
Mammalia	*Homo sapiens*		△
	Macaca robustus	▲	
	Macaca mulatta		△
	Rhinopithecus iantianensis	▲	
	Trachypithecus phayrei		△
	Hylobates sp.		△
	Erinaceus sp.		△
	Chimmarogale sp.		△
	Anourosorex squamipes		△
	Soriculus leucops		△
	Uropsilus soricipes		△
	Megaderm lyra		△
	Hipposideros pratti		△
	Hipposideros armiger		△
	Rhinolophus ferrumequinum		△
	Rhinolophus pearsoni		△
	Rhinolophus macrotis		△
	Rhinolophus cornutus		△
	Murina leucogaster		△
	Myotis formosus		△
	Myotis daubentoni		△
	Myotis sp.		△
	Tylonycteris pachypus		△
	Miniopterus schreibersi		△
	Scotomanes emarginatus		△
	Pipistrellus coromandra		△
	Ochotona thibetana		△
	Ochotona huangensis		△
	Collosciurus erythraeus		△
	Sciurotamias forreti		△
	Belomys pearsoni		△
	Petaurista xanthotis		△
	Petaurista alborufus		△
	Caryomys inez		△
	Leopoldamys edwardsi		△
	Niviventer andersoni	▲	
	Niviventer fulvescens		△
	Niviventer confucianus		△
	Mus sp.		△
	Hapalomys sp.		△
	Hystrix magna	▲	
	Hystrix subcristata		△
	Atherurus macrourus		△
	T.cf. fasciculata		△
	Rhizomys sinensis		△
	Rhizomys sp.		△
	Stegodon orientalis	▲	
	Cuon javanicus antiquus	▲	
	Canis variabilisb	▲	
	Crocuta ultima	▲	
	Selenarctos thibetanus	▲	
	Helarctos malayanus		△
	Ailuropoda melanoleuca baconi	▲	
	Mustela kathiah		△
	Arctonyx collaris		△
	Herpestes urva		△
	Lutra lutra		△
	Viverra zibetha		△
	Paguma larvata		△
	Felis sinensis	▲	
	Neofelis nebulosa		△
	Panthera tigris amoyensis		△
	Rhinoceros sinensis	▲	
	Dicerorhinus kirchbergensis	▲	
	Megatapirus augustus	▲	
	Sus scrofa		△
	Sus xiaozhu	▲	
	Moschus moschiferus plicodon	▲	
	Muntiacus muntjak		△
	Muntiacus reevesi		△
	Elaphoudus cephalophus		△
	Rusa unicolor		△
	Hydropotes inermis		△
	Budorcas cf. *taxicolor*		△
	Capricornis sumatraensis		△
	Naemorhedus goral		△
	Bubalus bubalis	▲	
	Leptobos sp.	▲	
Aves	*Aviceda jerdoni*		△
	Cygnus		△
	Ciconia boyciana		△
	Phasianidae indet		△
	Scolopacidae indet		△
Total	91	18 (20%)	73(80%)

range between 92.9 and 97.2; the range of the same index in Neandertal, European Middle Pleistocene humans, and modern Europeans are 100.0–106.4 and 89.5–98.5 respectively. The data indicate that both the shape and CSI of the Huanglong Cave upper lateral incisor are more robust than modern humans.

4.6. *Upper canine (C)*

The tooth is robust. The crown and the root are at the same longitudinal axis with only the root tip bending toward the distal direction. The crown labial surface bulges in both horizontal and longitudinal directions, more pronounced in the former direction. Because of advanced wear, most of the crown's morphological features are absent. On the preserved portion, basal parts of mesial and distal marginal ridges are well developed, and the lingual basal prominence is complete. The basal prominence is partly separated from the lingual surface and forms a weakly developed basal tubercle. There is also a small finger-like projection coming from the lower end of the basal prominence. Because of the severe crown wear, the length and shape of the projection cannot be determined. Both the crown MD and LL dimensions of the Huanglong Cave upper canine are smaller than Chinese *Homo erectus* and archaic *Homo sapiens*, but greater than those of Late Pleistocene and Holocene Chinese populations (see Table 7).

The upper canines of Zhoukoudian *Homo erectus* are very robust in both their crown and root morphology. The crowns are relatively low and broad. There is a pronounced cingulum at the cervical region and triangular prominence at the crown mesial and distal sides. The structure of the crown lingual surface is complicated with well developed basal tubercle and finger-shaped projections. The labial surface bulges strongly in the horizontal direction. The roots are big and robust with the root tip blunt. All dimensions of Zhoukoudian *Homo erectus* upper canines are larger than modern humans (Weidenreich, 1937). The morphology of Chinese archaic *Homo sapiens* upper canines resembles that of Zhoukoudian specimens in many aspects (Jia et al., 1979; Wu, 1984). Although not well studied (Li et al., 1984), the upper canine morphological features of Late Pleistocene Chinese resemble those of modern Chinese. The crowns of Late Pleistocene hominins thus far found in China are robust with their CSI scores exceeding even Zhoukoudian *Homo erectus* (see Table 7). The European Middle and Late Pleistocene hominins share many upper canine feature patterns with Zhoukoudian *Homo erectus*. However, the European hominin upper canines have greater size variation (Wolpoff, 1979; Bermudez de

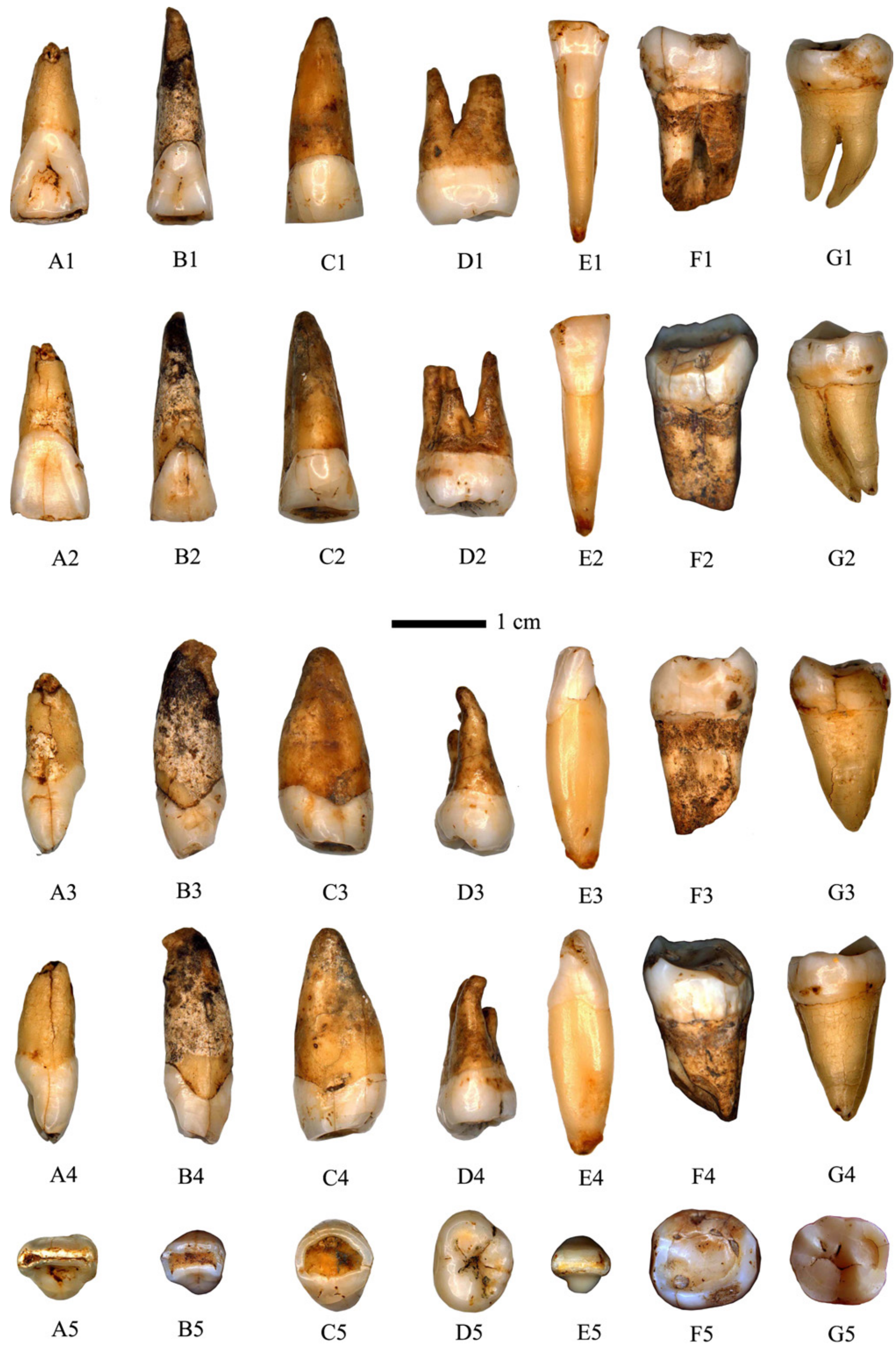

Fig. 5. The human teeth found in the Huanglong Cave (from Liu et al., 2009a,b) (A: right I^1; B: Left I^2; C: Left UC; D: left M^3; E: Right I_2; F: right M_2; G: left M3 Lingual, buccal, mesial, distal sides, and occusal surface are represented from 1 to 5 respectively) (from Liu et al., 2009a).

Castro, 1986, 1988, 1993). Compared with the Pleistocene hominins mentioned above, the Huanglong Cave upper canine looks robust and possesses some primitive features of archaic hominins. Taking crown area (CBA) as the tooth size, the Huanglong Cave upper canine is smaller than the averages of Chinese *Homo erectus* and archaic *Homo sapiens*, but lager than the averages of Chinese Late Pleistocene hominins and modern Chinese. The CSI of the Huanglong Cave canine is close to those of nearly all Late Pleistocene hominins and modern humans. In modern humans, both the crown and roots of the canines are gracile with the bulging of the crown labial surface not pronounced. All dimensions of the upper canines in modern humans are small. The root is short relative to the crown. The root length (from cervical line to root tip) is 56.3% of the whole tooth length in the canines of modern Chinese, while this measure is 62.5% in the Huanglong Cave upper canine, which is very close to 62.0% of Zhoukoudian *Homo erectus* (Liu and Yang, 1999).

Table 6
List of isolated hominin teeth from the Huanglong Cave.

Specimen No.	Tooth	Side	Wear category	Estimated age (years old)
Upper				
N2E6:X34	I1	R	2–3	20–30
	I2	L	4	30–40
	C	L	5	30–40
	M3	L	1	<20
Lower				
	I2	R	3	20–25
	M2	R	5	35–45
	M3	L	2	20–30

Tooth wears were graded after Smith (1984); Aging was made with methods provided by Alt et al. (1998) and Hillson (1996).

4.7. Upper third molar (M^3)

The crown is triangular-shaped with its base long in the mesial side. Among the four cusps of paracone, metacone, protocone and hypocone on the occlusal surface, the paracone is the largest followed by the protocone and metacone, with hypocone the smallest. The tooth has three roots diverging at about 3 mm from the cervical region. All of the roots have not fully developed with their root canals open at the tips. Around the root canals, the cement is fused with the surface flat; thus indicating the roots were still developing. Thus, this tooth is from a sub-adult. All of the crown dimensions of the Huanglong Cave upper third molar are smaller than those of Pleistocene hominins in both China and other regions of the world. Compared with the upper third molars of archaic hominins, the Huanglong Cave upper third molar has simple crown occlusal patterns and lacks the features often present in Pleistocene hominins upper M3, such as wrinkles and oblique ridges. The paracone and protocone are similar in size. Compared with the other cusps, the metacone is a little smaller. All of the tooth dimensions of the Huanglong Cave upper third molar are within the range of modern human humans. The roots of the Huanglong Cave upper M3 are substantially branched, which is different from the modern human pattern.

4.8. Lower lateral incisor (I_2)

A weak shovel-shaped lingual side (equal grade 1–2 of ASUDAS) is present. The lingual surface of the crown is very smooth. The region bordering the crown base and root slightly bulges, but no obvious tubercle-like structure is present. The whole crown labial side is flat and inclines toward the lingual direction. Compared with the crown, the root looks slender. Among the lower lateral incisors of modern Chinese, the shovel-shaped crown lingual sides are more obvious than the Huanglong Cave specimen. Compared with Pleistocene hominin lower lateral incisors, the morphological patterns of the Huanglong Cave specimen more resembles modern humans because of the following characteristics: gracile tooth; less bulged labial surface; the longitudinal groove occurred in only one side of the root and smaller dimensions. All of the crown dimensions of the Huanglong Cave lower lateral incisor are smaller than those of Chinese *Homo erectus* and archaic *Homo sapiens*, and also smaller than those of the early modern humans of Skhul and Qafzeh and European Pleistocene humans (see Table 7). However, the root tip of the Huanglong Cave specimen is rounded, which differs from modern humans.

4.9. Lower second molar (M_2)

Because of the occlusal wear, nearly all of the morphological features are missing. The maximum BL dimension is located at the slightly mesial to the middle part of the crown, indicating that the trigonid is bigger than the talonid. Judging from the remaining occlusal profile, there appears to be five cusps on the occlusal surface. The hypoconid and hypoconulid are much smaller than the other three cusps. The dimensions of the Huanglong Cave lower second molar are smaller than those of Chinese *Homo erectus*, and also smaller than those of Krapina and the Neandertals. But the tooth dimensions of the Huanglong Cave specimen is larger than those of Atapuerca SH and European Late Pleistocene hominins, and closer to those of the Near East early modern humans from Skhul. Compared with both Chinese and European modern humans, all of the dimensions of the Huanglong Cave lower second molar are larger (see Table 7). In most cases, the lower second

Table 7
Tooth measurements of the Huanglong Cave hominin and comparative samples (mm).

		China						Neanderthals	Skhul	Qafzeh	Herto	European Early UP	European Later UP	Atapuerca SH	Modern Europeans
		HC	*H. erectus*	Archaic *H. sapiens*	Late Pleistocene	Neolithic moderns	Living moderns								
I^1	MD	8.5	10.7	9.8	8.2	8.6	8.6	9.3	9.4	9.9		9.3	8.7	9.6	7.8
	LL	6.5	8.1	8.0	7.2	7.3	7.3	8.2	8.0	8.1		7.5	7.5	7.7	6.6
	CSI	76.5	75.7	81.8	87.8	84.8	84.8	87.3	85.7	81.8		80.6	86.2	80.5	84.6
I^2	MD	7.3	8.3	7.9	7.1	7.1	6.9	7.8	7.0	8.0		7.6	7.1	7.9	6.2
	BL	7.0	8.1	7.6	6.9	6.6	6.5	8.3	7.3	7.7		6.8	6.6	7.9	6.0
	CSI	95.3	97.5	95.8	97.2	93.0	94.2	106.4	105.5	96.3		89.5	93.0	100.0	96.8
UC	MD	9.0	9.4	9.5	8.0	7.9	7.9	8.2	8.5	8.6	7.0	8.0	8.0	8.6	7.4
	BL	9.8	10.2	9.6	8.9	8.4	8.3	9.5	9.1	9.5	9.0	9.0	8.8	9.7	8.2
	CSI	108.9	108.5	103.9	111.3	106.3	106.4	115.9	107.6	110.5	120.0	112.5	110.0	112.8	110.8
M^3	MD	8.5	9.6	8.5	9.4	9.0	8.9	9.6	9.9	9.8	8.6	9.5	9.0	8.7	8.5
	BL	11.2	11.9	9.9	11.0	10.8	10.9	12.0	11.7	12.6	11.9	11.4	11.4	11.7	10.5
	CSI	131.8	121.1	116.5	117.0	120.0	122.5	125.0	119.8	128.6	138.4	120.0	126.7	134.5	123.5
I_2	MD	6.1	6.9			6.0	6.0	6.7	6.5	6.8		6.4	5.6	6.6	5.8
	LL	6.0	7.1			6.3	6.3	7.8	7.4	7.2		7.0	6.5	7.3	6.3
	CSI	98.4	102.9			105.0	105.0	116.4	112.9	105.9		109.4	116.0	110.7	108.6
M_2	MD	11.0	12.6	11.2	11.4	10.9	10.9	12.0	10.9	11.4		11.3	10.9	11.0	10.8
	BL	11.0	12.7	10.1	10.7	10.7	10.4	11.1	10.9	11.7		10.8	10.7	10.2	10.3
	CSI	100.0	100.8	90.2	93.9	98.2	95.4	92.5	100.4	102.6		95.6	98.2	93.3	95.3
M_3	MD	10.0	11.7		10.9	10.7	10.7	11.7	10.9	12.6		11.1	10.6	11.3	10.8
	BL	10.5	11.2		10.4	10.3	10.1	10.9	10.3	11.5		10.7	10.4	9.9	10.2
	CSI	105.0	95.7		95.4	96.3	94.4	93.2	94.2	91.3		96.4	98.1	87.9	94.4

Table 8
The main diagnostic morphological features of the Huanglong Cave hominin teeth, which share with modern humans and similar to archaic hominins.

Tooth	Features shared with modern humans	Features similar to archaic hominins
I^1	The crown lingual surface is smooth without basal tubercle and linger-shaped projection. Both the lingual and labial sides are shovel-shaped. All the crown dimensions are within the modern human ranges.	The MD diameter is relatively big with CSI as 76.5 close to archaic hominins. The root is a little robust.
I^2	The main morphology and metric dimensions are within the variation ranges of the modern humans. The structure of crown lingual surface is simple and smooth without basal tubercle and finger-shaped projection. The bulging of crown labial surface is not obvious. The root is gracile with its long axis meeting the crown in an angle.	The crown looks robust with its labiolingual diameter relatively big and CSI closer to archaic hominins.
UC	The crown dimensions and CSI are closer to modern humans.	The whole tooth looks robust with its crown and root in the same axis. The crown labial surface bulges pronouncedly. The crown lingual surface has well developed basal tubercle and finger-shaped projection. The root tip is blunt. The tooth dimensions are bigger than the average of modern humans.
M^3	The pattern of occlusal surface is simple without wrinkles. The paracone and protocone are similar in size. Metacone does not reduce very much. All the metric dimensions are within the variation ranges of modern humans.	The root bifurcates pronouncedly, which is different from the fusing trend of modern humans.
I_2	The whole tooth looks gracile. The crown lingual surface is concave and smooth slightly with marginal ridges weakly developed and no basal tubercle. The crown labial surface is flat and inclines lingually. There is a vertical groove at one side of the root. All the tooth dimensions are small and within the variation ranges of modern humans.	The root tip is blunt.
M_2	The structure of the crown occlusal surface is simple.	The trigonid is bigger than telanid. Root is robust. Tooth dimensions are bigger than the average of modern humans.
M_3	The pattern of occlusal surface is simple lacking the accessory ridge and fissures. The tooth dimensions are closer to those of modern humans. Enamel extension is identified.	The crown is low. There are six cusps. The reduction of telanid is not obvious. The two roots separate.

molars of modern humans are more gracile with simple occlusal structure and much smaller dimensions. Both the length and breadth of the trigonid decrease in modern human lower second molars, while the talonid increases to be comparable to the trigonid. The occlusal pattern tends to be simple and the cusp surface is flat and smooth lacking the accessory ridges. There are only four or five cusps in modern human lower second molars. Modern Chinese lower second molars are round–square-shaped with four cusps. Based on these comparisons, the Huanglong Cave specimen resembles modern humans in most of the features, but still preserves some primitive morphological features of Late Pleistocene hominins.

4.10. *Lower third molar (M_3)*

The occlusal surface is square-shaped with its four corners blunt. The crown MD dimension is greater than the BL dimension. The crown has pronounced bulges on all sides. There is an obvious enamel extension at the crown buccal side that reaches the roots branching region (Fig. 5). Among the six cusps on the occlusal surface, the protoconid, endoconid and metaconid are similar in size and much larger than the hypoconid, hypoconulid and endoconulid. Except for the cusps and grooves mentioned above, there are no other minor groove, fissure or accessory ridges on the occlusal surface. Thus, the occlusal structure is simple. The Huanglong Cave lower third molar has two roots on the mesial and distal sides. The two roots become narrower and sharper toward the tips.

The morphology of the Huanglong Cave lower third molar is characterized by a lower crown, six cusps, decreased talonid and separate roots. Although these characteristics are not specific to modern humans, the variation in the lower third molar morphology in modern humans is quite large. Thus the pattern in the Huanglong Cave specimen can also be found in modern humans. Additional features that align the Huanglong Cave specimen with modern humans include a simple crown structure, lack of accessory ridges and grooves on the occlusal surface, and overall tooth size that is smaller than fossil hominins and within range of

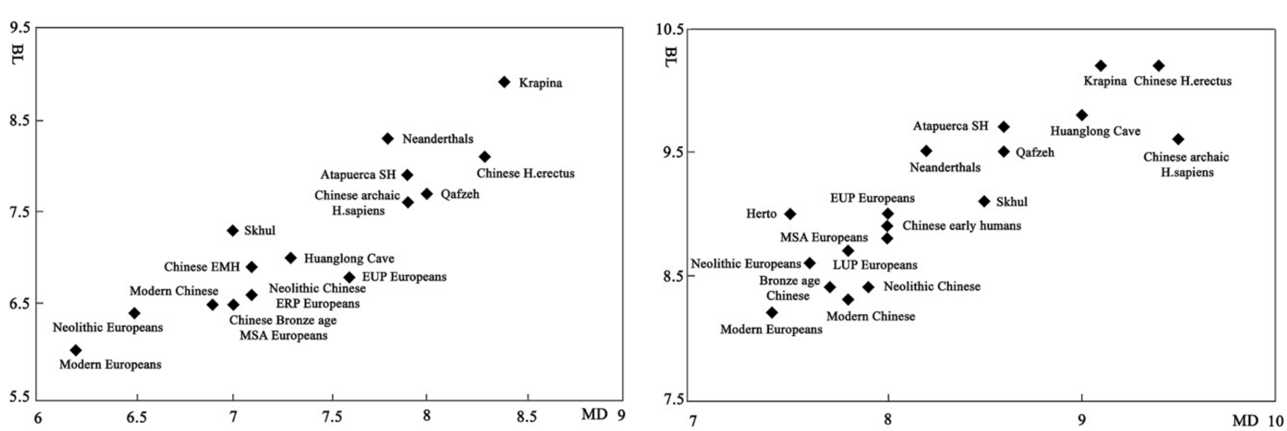

Fig. 6. Scatter plots of the UI2 and UC crown MD and BL dimensions. Left: UI2; right: UC.

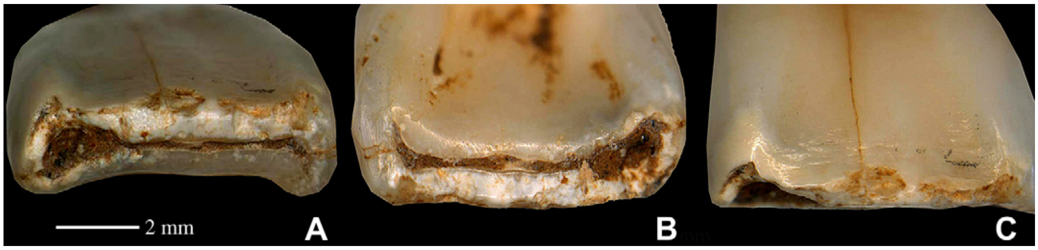

Fig. 7. The tooth wear and chippings of upper incisor from the Huanglong Cave hominin. A: incisal view; B: lingual view; C: labial view.

modern humans. Perhaps most importantly, the enamel extension is widely regarded as a modern human feature (Turner, 1990; Turner and Scott, 1997).

Based on all of these morphological and metric observations (see Table 8 for a summary), all of the Huanglong Cave hominin teeth most closely align with modern humans. However, analysis indicates that the Huanglong Cave teeth retain a few symplesiomorphic features that characterize Late Pleistocene hominins (see Table 8 and Fig. 6).

The Huanglong Cave anterior teeth display some evidence of activity-induced patterns of dental abrasion including obvious enamel chipping along the incisal region (Fig. 7), interproximal grooves, and damage on the labial surface of the lateral upper incisor. These unusual patterns of tooth use-marks suggest the Huanglong Cave humans frequently used their anterior teeth for non-masticatory utilization (see Larsen, 1997 for discussion of this). The interproximal grooves on the upper anterior teeth suggest the Huanglong Cave humans often practiced tooth-pickings. Considering these observations, the Huanglong Cave humans used their teeth to perform a series of work-related activities (e.g., holding skin with their teeth during skin preparation), similar to what Neandertals may have been doing (Wallace, 1975; Bermudez de Castro et al., 1988). Thus tooth morphology may be related to the functional adaptation of the anterior tooth use.

5. Archaeology

5.1. Evidence for fire use

During the 2006 excavation, in the same layer as the human teeth, a few patches of black material were identified embedded in the deposit. To explore the possibility that the materials were the remains of fire, comparative laboratory analyses of these black patches were conducted, along with samples taken from several other places in the cave. A variety of methods were used: micromorphology; element content determination; and deposit temperature analysis. The results indicate that the carbon content in the black deposit ranged between 64.59 and 73.29%, which was much greater than the 5.82–9.49% derived from the comparative samples (Table 9). The micromorphology analysis on the black deposit samples reveals plant structures like *axial parenchyma*, fibrocyte, uniseriate ray and vessel (Fig. 8). Deposit temperature analysis confirms that the blackened materials were the result of a high temperature event. Based on the result of these lab analyses, the black patches are the remains of fire.

5.2. Artifacts

The artifact assemblage is comprised of lithic and bone implements [representative samples are shown in Fig. 9; detailed descriptions and analysis of the artifacts can be found in Pei et al., 2008]. The lithic assemblage includes thirty-six artifacts: two stone hammers, one core, eight flakes, fourteen retouched artifacts, four block fragments, five waste flakes (debris) and two bipolar cores. Many of the stone artifacts (78%) were manufactured using the local vein quartz embedded in the Upper Sinian limestone and marlite from which the cave developed. Only 22% of the lithic artifacts were made on pebbles available from the ancient riverbeds outside the cave. The hominins probably knapped inside the cave, as deduced from the different lithic types identified. In general, the artifacts were detached by direct hard-hammer percussion, though the existence of two bipolar (one core and one flake) indicates that the bipolar technique was also used. Knapping strategies were simple, flakes show plan rather than cortical butts, and dorsal scars are parallel to the flake extraction axis, which indicates unidirectional knapping.

Stone tools with secondary retouch include scrapers, picks, chopper-chopping tools, a burin and an awl. Six scrapers, made of quartz and flint, represent the greatest percentage of stone tool types. All of the scrapers display retouch on the flakes. Three picks, made of silicarenite, volcanic rock, and quartzite were identified. The blanks for the picks are pebbles. One finished pick has a thick and blunt point at one end, which may have been used for digging. Two of the three picks exhibit deliberate and standardized modification: a pointed end was carefully produced from the original curved surface of the pebble and the other end was purposely

Table 9
The element content analysis of the Huanglong Cave samples (wt%).

Specimen No.	C	O	Cu	Na	Mg	Al	Si	P	K	Ca	Ti	Fe
HLD 1(1)	73.29	23.99	/	/	0.88	0.05	0.06	0.09	0.06	1.58	/	/
HLD 1(2)	71.62	23.03	0.51	/	1.19	0.49	0.16	0.09	/	2.91	/	/
HLD 1(3)	70.75	25.79	/	/	0.92	/	/	0.07	/	2.47	/	/
HLD 1(4)	72.02	22.13	0.28	/	1.24	0.42	0.12	0.11	/	3.69	/	/
HLD 1(5)	62.44	25.41		/	1.13	/	/	0.56	/	10.47	/	/
HLD 2	64.59	29.35		/	0.60	0.67	0.96	0.89	/	2.94	/	/
HLD 3	9.49	48.38		0.69	1.96	7.76	20.13	/	1.57	4.24	/	5.78
HLD 4	5.82	43.75		2.10	8.29	22.09	1.18	/	1.69	4.94	1.28	8.87
HLD 5	6.52	44.42		1.51	1.90	7.84	23.59	/	1.69	2.72	/	9.82
HLD 6	5.82	46.83		1.06	2.03	8.43	25.66	/	2.32	0.97	/	6.86

HLD 1: sample of black layer.
HLD 2–6: comparative samples taken from other parts of Huanglong Cave.

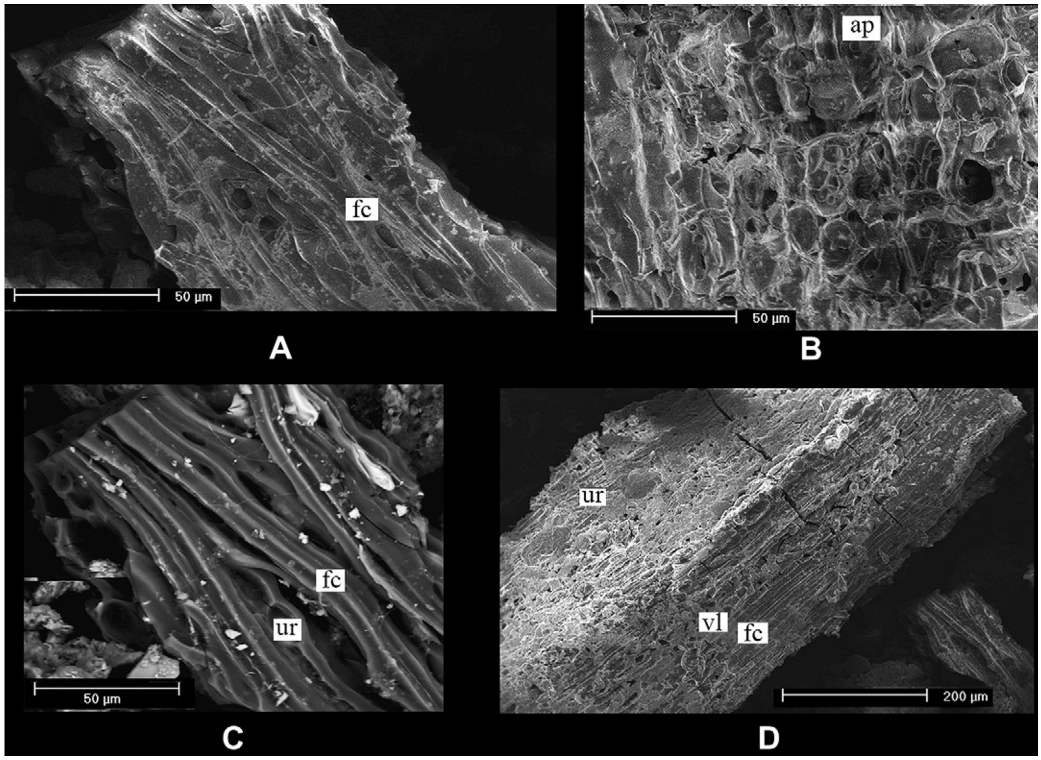

Fig. 8. The SMC picture of charcoal from the Huanglong Cave black layer shows plant structure (ap: axial parenchyma; fc: fibrocyte; ur: uniseriate ray; vl: vessel) from Liu., et al, 2009b.

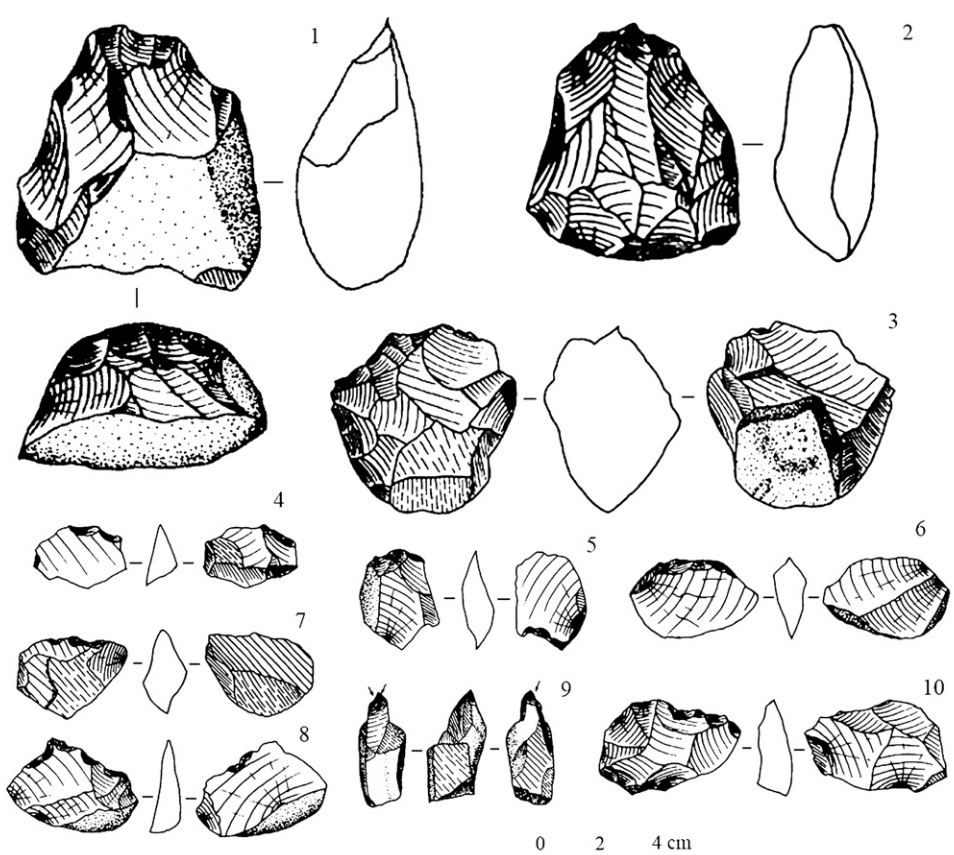

Fig. 9. Some stone and bone tools found in Huanglong Cave 1 Bone unifacial spade; 2 Bone point; 3 Bone scraper; 4 Bone point; 5 Flake; 6 Pick; 7 Pick; 8 Burin; 9 Core from Pei., et al, 2008.

blunted, making it comfortable to be held. One stone awl, made of vein quartz, has two sharp edges that meet each other to form a short and blunt point edge. One stone burin, made of vein quartz, displays unidirectional retouch. Three chopper-chopping tools, two made of vein quartz and one made of jasper, have been retouched on several edges. In addition, one stone hammerstone has a depressed region with small pits. The depression developed over time through consistent breaking of nuts. In the third excavation, six bone artifacts were found, which include three bone points, two bone scrapers and one bone unifacial spade.

5.3. *Bone surface modifications*

Although a complete taphonomic study utilizing modern methodologies has yet to be undertaken, evidence of butchering was found on forty of the 3000 bones. Cut marks, percussion marks, and scraping marks were identified, primarily on the long bones. Cut marks and scraping marks are usually considered to be evidence of defleshing activities (Lyman, 1994). Percussion marks on long bone midshafts are the result of marrow processing (Norton and Gao, 2008a). Based on the current evidence, butchered bones are present in the cave, a case not unlike that at Zhoukoudian Upper Cave (Norton and Gao, 2008b). Huanglong Cave differs from Zhoukoudian Upper Cave, however, because roughly 50% of the former faunal assemblage displays evidence of rodent gnawing. More detailed taphonomic studies should clarify the formation of the Huanglong Cave faunal assemblage.

6. Discussion and conclusions

Because of the age disparity between the U-series (103–79 ka) and ESR (44–37 ka) analyses, the chronometric dates of the Huanglong Cave should be interpreted cautiously. At the minimum, based on the biostratigraphy, the age of the Huanglong Cave deposits is Late Pleistocene. Further detailed dating analysis will hopefully give a more exact age for the Huanglong Cave hominin occupation. Because of the paucity of reported early modern human fossils from East Asia (Shang et al., 2007), the Huanglong Cave human fossils could be of potential importance to addressing issues related to the emergence and dispersal of early modern humans in East Asia.

This analysis indicates that most of the morphologic and metric features of the seven Huanglong Cave human teeth resemble those of modern *Homo sapiens*. Generally speaking, the Huanglong Cave human teeth look gracile and lack the archaic features usually identified on Middle and Late Pleistocene humans. Furthermore, this study also indicates that the Huanglong Cave human teeth already possess some dental features of modern East Asian populations. Studies of worldwide dental collections indicate there are eight major dental morphological features that characterize modern East Asian human populations (Turner, 1990). These eight features have higher frequencies and pronounced expressions in modern East Asian Sinodont populations (Turner, 1990). Three of these traits (shovel-shaped incisors, double shovel-shaped upper central incisors, and enamel extension of the upper molars) were identified in the Huanglong Cave human teeth. However, the Huanglong Cave human teeth still retain a few features of Late Pleistocene humans (mainly the robust upper anterior teeth) (see Table 8 for summary).

The intentional production and controlled use of fire is one of the most important events in human evolution. However, the advent and nature of fire use by Pleistocene hominins has been strongly debated for many decades (James, 1989). To date, the evidence of fire use by Pleistocene hominins in China is limited to reports from Zhoukoudian Locality 1, Lantian, Xihoudu, Yuanmou and Jinniushan. Among these sites, only the sediment from Zhoukoudian locality 1 has undergone lab analysis, the results of which cast doubt on controlled use of fire there (Weiner et al., 1998). More recently, new methods of lab analyses have been applied to examine the evidence of fire use, including element analysis, micromorphology analysis, and high temperature of deposit analysis (Hrouda et al., 2003; Goren-Inbar et al., 2004). In the analysis of the fire use by the Huanglong Cave humans, all three methods were used (Liu et al., 2009b). The results indicate: 1) that carbon contents in the samples from the black deposit are over 64%, much higher than those of the comparative samples which are less than 10%; 2) micromorphology analysis shows the plant structure suggesting the black deposit layer is the charred remains of plants; and 3) the deposit experienced high temperatures. The results of the three lab analyses indicate that fire did occur in the cave. To determine whether it is a natural fire or human-induced fire, further research is necessary. Indirect evidence of a human-induced fire may be from the location of the charred sediment, which is found about ~100 m inside the cave. Natural fire is nearly impossible to occur so deep within a cave (Wu et al., 2007b).

The Huanglong Cave stone tools were primarily produced with local vein quartz, sandstone, and flint. The main stone tools are scrapers and picks, which were made by hard-hammer direct percussion. Both large and small lithics are represented in the tool assemblage. Although at present the number of stone artifacts found in Huanglong Cave is insufficient to reconstruct the whole picture of hominin behavior, the Huanglong Cave hominins used both direct hammerstone percussion and bipolar flaking to produce flakes and other stone tools. The existence of hammerstones, cores, flakes and debitage further suggests that stone knapping activities occurred inside the cave. Butchered bones found in association with the lithics are suggestive of what the stone tools may have been used for.

In the west Hubei and Three Gorge region, where Huanglong Cave is located, several hominin fossil sites ranging from Early to Late Pleistocene have been discovered. These include the Yunxian *Homo erectus* crania, Meipu *Homo* sp. teeth in Yunxian, *H. erectus* teeth from Bailong Cave in Yunxi, early *Homo sapiens* teeth from Xinglong Cave in Fengjie, the newly found early *Homo* sp. teeth from Jianshi, and the debated mandible from Longgupo in Wushan (Wu et al., 1989; Li and Etler, 1992; Huang et al., 1995; Gao et al., 2004; Zhang et al., 2004; Liu et al., 2006). The Huanglong Cave human teeth contribute to this growing list of Pleistocene hominin fossils from this region. Ongoing and future multi-disciplinary research at Huanglong Cave will serve to determine the role the site and materials play in any reconstructions of human evolution from this time period and geographic region.

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