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Early *Homo* and associated artefacts from Asia

Huang Wanpo*, Russell Ciochon†‡, Gu Yumin*, Roy Larick§, Fang Qiren‖, Henry Schwarcz¶, Charles Yonge#, John de Vos☆ & William Rink¶

* Institute of Vertebrate Paleontology and Paleoanthropology, Academia Sinica, Beijing 100044, China
† Departments of Anthropology and Pediatric Dentistry, The University of Iowa, Iowa City, Iowa 52242, USA
§ Department of Anthropology, University of Massachusetts, Amherst, Massachusetts 01003, USA
‖ Chongqing Museum of Natural History, 72 Loquat Hill Park Street, Chongqing, Sichuan 630013, China
¶ Department of Geology, McMaster University, Hamilton, Ontario L85 4M1, Canada
# Department of Physics & Astronomy, University of Calgary, Calgary, Alberta T2N 1N4, Canada
☆ National Museum of Natural History, Post Office Box 9517, 2300 RA Leiden, The Netherlands

THE site of Longgupo Cave was discovered in 1984 and excavated in 1985–1988 by the Institute of Vertebrate Paleontology and Paleoanthropology (Beijing) and the Chongqing National Museum (Sichuan Province). Important finds include very archaic hominid dental fragments, *Gigantopithecus* teeth and primitive stone tools. Palaeomagnetic analysis and the presence of *Ailuropoda microta* (pygmy giant panda) suggested that the hominid-bearing levels dated to the earliest Pleistocene[1]. In 1992, joint Chinese–American–Canadian geochronological research corroborated the age using electron spin resonance (ESR) analysis. We report here that the hominid dentition and stone tools from Longgupo Cave are comparable in age and morphology with early representives of the genus *Homo* (*H. habilis* and *H. ergaster*) and the Oldowan technology in East Africa. The Longgupo dentition is demonstrably more primitive than that seen in Asian *Homo erectus*. Longgupo's diverse and well preserved Plio-Pleistocene fauna of 116 species provide a sensitive contextual base for interpreting the early arrival of the genus *Homo* in Asia.

‡ To whom correspondence should be addressed.

Longgupo Cave or, as known in Chinese, the 'Wushan Hominid Site' lies 20 km south of the Yangtze River near the eastern border of Sichuan Province (Fig. 1). The cave infilling comprises two major units: an upper cave breccia with few fossils, and an underlying poorly cemented fossiliferous unit with three depositional zones (Fig. 2). The middle zone (excavation levels 2–12) has a clay facies localized along the north and south cave walls in longitudinal channels 2–3 m wide. Two hominid dental fragments and two stone artefacts derive from these channels. The middle zone yields 68 mammalian genera including *Procynocephalus* and *Macaca* as well as *Gigantopithecus* and *Homo*[1]. The presence of *Sinomastodon*, *Nestoritherium*, *Equus yunnanensis*, *Ailuropoda microta* and Cricetinae indeterminate (with molar structure similar to *Sinocricetus* and *Nannocricetus*) suggests a late Pliocene to earliest Pleistocene age[1–3]. The occurrence of *Mimomys peii* places this zone within the Dachaian (mammal neogene reference level 17 (MN 17)) age of north China (late Pliocene)[4,5].

Basic taphonomic observations suggest how the fauna accumulated within the middle zone channels. About 750 large mammal long bones derive from the channels, usually without surface erosion and sometimes as complete limb elements. Many shafts are punctured, split or shattered to indicate processing by *Pachycrocuta* or *Homotherium*, and many long bones were also gnawed, probably by *Hystrix* and smaller rodents while fresh. *Pachycrocuta* is the most common carnivore at Longgupo, and numerous hyaenid-sized coprolites suggest the cave occasionally served as a lair. Two accumulation processes are therefore possible. The large scavengers/carnivores may have brought carcasses into a horizontal passage, eventually to be interred by gentle fluvial action. Alternatively, the representation and condition of the Longgupo fossils also recall the assemblages from Yanjinggou (about 50 km NW), where carcasses accumulated in vertical passages, the result of predation and falls[6,7].

Palaeomagnetic data also suggest great antiquity for the middle zone clay facies where 100 sediment samples were taken in overlapping columns. Sample natural remanent magnetization was determined after thermal demagnetization to 700 °C. Sediment at the top of the lower unit is magnetically reversed, indicating an age of at least 0.78 million years (Myr). There are 7 magnetic reversals between levels 1 and 20 with magnetic normal sediment sections thinner (about 1–2 m) then reversed sections (about 3–4 m) (Fig. 2). Thermal demagnetization properties are similar in normal and reversed sediments, suggesting both remanence types are of the same (detrital) origin. Although we do not have sufficient rock magnetic data to exclude completely the possibility that selective remagnetization may have lead to a spurious magnetostratigraphy, we do not believe that this is likely. We therefore assign the magnetically normal hominid-bearing levels 7–8 to the Olduvai event that spans the interval 1.96 to 1.78 Myr[8,9]. A few depositional breaks (such as at the 13/12 boundary) may correspond to lengthy time gaps in which further reversals could have occurred. Therefore this is a minimum age estimate for the hominids.

Electron spin resonance (ESR) analysis of tooth enamel further constrains the age of the middle zone channels. This method has been successfully applied to fossils older than 2 Myr[10,11]. From level 4, a large cervid premolar fragment (recovered within the sediment-filled interior of a long bone) yields about 400 mg of enamel and dentine, containing 0.85 and 39 p.p.m. uranium, respectively. External gamma dose-rates were estimated from U, Th and K contents of sediment adhering outside the long bone; beta dose-rates alone were determined from sediment within the long bone cavity. Age calculation depends on an assumed uranium uptake history of the tooth: early uptake gives a minimum age of 0.75 ± 0.09 Myr; a linear uptake model, which generally has given ages close to independent estimates, yields 1.02 ± 0.12 Myr[11]. The linear uptake age places the level 4 sediment within the Matuyama reversed mag-

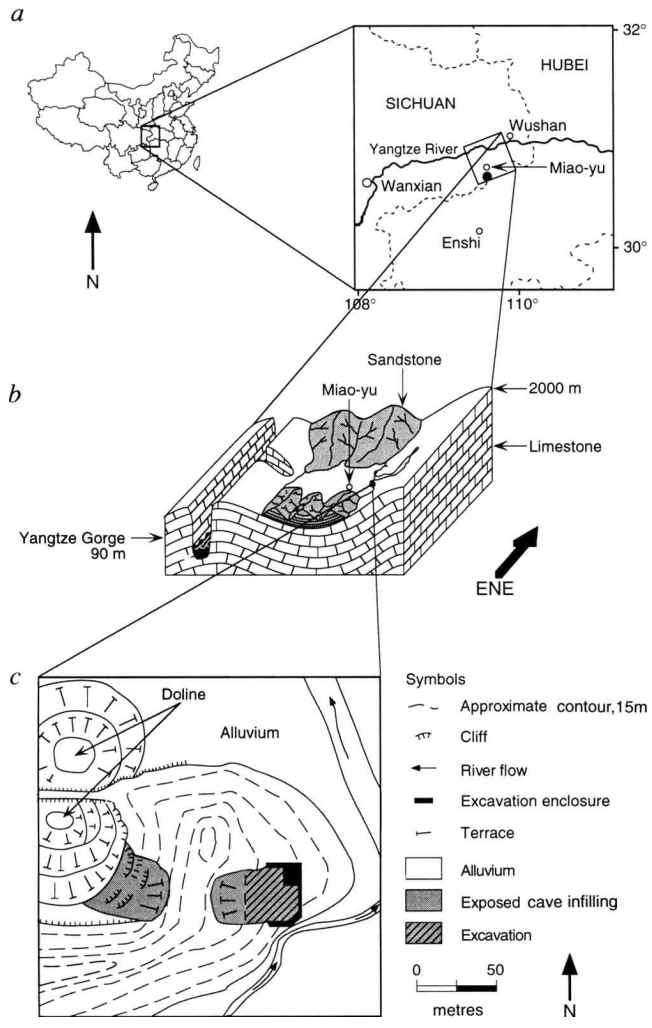

FIG. 1 Longgupo Cave. *a*, Location in Sichuan Province, Wushan County (109° 40′ E, 30° 50′ N). *b*, Regional geology has massive Triassic limestones and intercalated sandstones. The primary local geomorphic feature is an E–W-trending syncline that exposes carbonates on its limbs and silicates within. The limbs are karstic and the consequent drainage forms a polje around Miao-yu village. Longgupo Cave is a remnant of this drainage that has been eroding the polje's southern margin since Miocene times. *c*, The cave presents an infilled east–west passage, bi-truncated to leave its floor 130 m long and its vault 25 m long. Vertical passages are also common within the local complex. Just northwest of the Longgupo site, a lower north–south passage retains an even shorter vault between two dolines.

netic chron, consistent with the palaeomagnetic interpretation for levels 7–8.

Within the middle zone channels, levels 7–8 yield two hominid dental fossils, a fragmentary left mandible (with P_4, M_1 and M_2 alveolus) and a right upper lateral incisor (Fig. 3). These specimens were originally described as a new subspecies of *Homo erectus*, *H. e. wushanensis*[1], but joint reanalysis demonstrates morphology different from and sometimes more primitive than Asian *H. erectus*. The Longgupo dentition exhibits affinities with representatives of East African early Pleistocene *Homo*, including *H. ergaster* and *H. habilis* (Fig. 3 legend). For the mandibular teeth, relevant features include, for P_4: cusp placement and inflection, relationship between cusps and talonid, and root morphology; and for M_1: cusp number and spatial relationship, enamel surface thickness, and surface texture. Basic dimensions of the Longgupo mandibular corpus, P_4 and M_1 (Fig. 3 legend) are very small. These fall outside the lower range for Zhoukoudian (G1, H1, 29, 30, 34, 89–93, 96–102)[12] and Sangiran (1b, 9) specimens[13,14], while lying near the lower limit for any East African Plio-Pleistocene hominine (such as OH 7, OH 13, OH 16, ER 992 and WT 15000)[14–16]. I^2 crown shape index (BL/LL × 100) also distinguishes Longgupo from Asian *H. erectus*. The Longgupo index (116) is quite high compared with Zhoukoudian 6 and 7 (101), but falls within the range for OH 6, OH 16, OH 39 and ER 1813 (*H. habilis*) (96−127 (mean = 109))[15]. Finally, the shovel-shaped character of the Longgupo

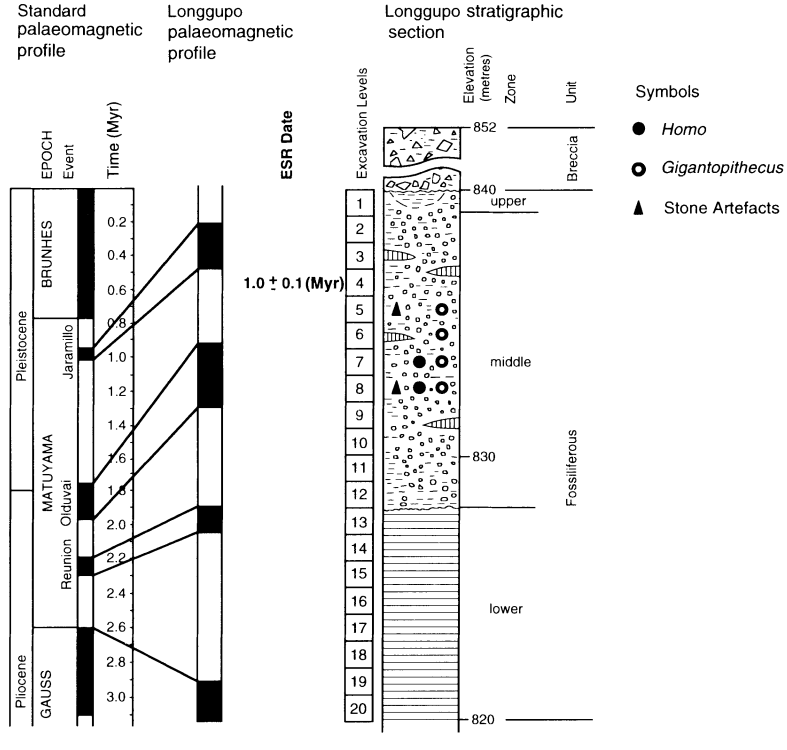

FIG. 2 Longgupo Cave stratigraphy and suggested age. The upper sedimentary unit is a 12-m-thick fossil-poor cave breccia where clasts range to 50 cm × 90 cm within a highly cemented sandy clay. The underlying poorly cemented fossiliferous unit has three depositional zones excavated in 1 m levels. The upper zone (within level 1) consists of a few spatially discrete sandy clay lenses with some gravels and localized areas of calcite concretion. The middle zone (levels 2–12) has a clay facies localized along the north and south cave walls in longitudinal channels (2–3 m wide), while a gravel facies occupies the passage centre. Clast size ranges to 2 cm × 3 cm in the clay facies and to 10 cm × 20 cm in the gravels with limestone clasts dominating shale and mudstone. The lower zone (levels 13–20) has primarily silts in parallel horizontal beds that indicate stagnant fluvial or lacustrine environments.

I^2 is also found in OH 6 and OH 16 (*H. habilis*)[15], and WT 15000 (*H. ergaster*)[16] as well as at Zhoukoudian[12]. Indeed, Tobias concludes that "shovelling is a virtually universal feature of all early hominids up to *Homo erectus*" (p. 614)[15].

Sixteen teeth of *Gigantopithecus blacki* come from levels 5–8 (Fig. 2): one C_1, three P_3, one P^3, four P_4, three P^4 and four M_{1-2}. In size and morphology the Longgupo teeth match the >900 isolated teeth from Liucheng Cave, Guangxi, China[17,18], where amino-acid racemization measurements suggest an age greater than 1.2 Myr[19]. The Longgupo *Gigantopithecus* teeth, like those of Liucheng, exhibit high sexual dimorphism, lower molars with a distinctive accessory internal tubercle between metaconid and entoconid and very thick enamel (5–6 mm). Nearly all of the roots show evidence of rodent gnawing, probably by *Hystrix*. Longgupo marks the northernmost extent of *Gigantopithecus* in China. It also represents the third east Asian cave where *Gigantopithecus* and *Homo* lie within the same stratigraphic interval. The others are Tham Khuyen Cave, Lang Son, Vietnam dated to 0.475 Myr[20], and at Jianshi Cave, Hubei, China, where the co-occurrence remains undated[21]. With the Longgupo date indicating the earliest presently known association, *Gigantopithecus* and *Homo* evidently coexisted for more than 1 Myr in east Asia.

Two items from the clay facies show three characteristics of early stone artefacts (Fig. 4). They have exotic petrological composition (andesite–porphyrite), they are twice the size of the largest normal deposit clasts, and they exhibit surface damage inconsistent with natural cause. The closest primary outcrops for andesite–porphyrite rocks lie 130 km ENE and 150 km NNW. Derived sources occur within the non-carbonate sediments of the Miao-yu polje, a function of pre-Yangtze Valley (Pliocene and earlier) fluvial systems. Potential sources are to be found about 2 km downstream from Longgupo, but andesite–porphyrite remains undocumented. As both objects are more than twice as large as the largest clay facies clasts, fluviatile transport does not explain their presence. Assuming artefact status, these specimens recall the Oldowan technology of early Pleistocene East Africa[22] in two ways. First, they were chosen

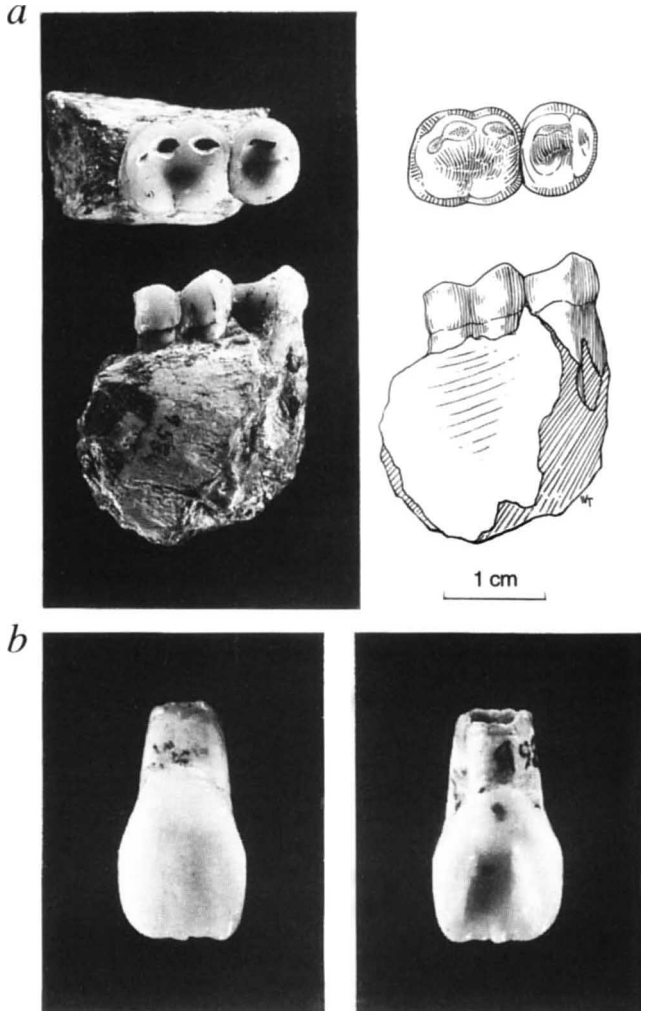

FIG. 3 Longgupo Cave hominids. *a*, Left mandible fragment (CV.939.1, level 8), occlusal (top) and lingual views. The mandibular corpus is nearly complete directly below M_1, where the inferior margin is damaged. The buccal and lingual faces bulge little and remain parallel as they descend to the inferior margin. Behind M_1, the buccal face begins to thicken. Below M_1, corpus height is 21 mm and width is 13.5 mm. For the limited morphology preserved, the Longgupo mandibular corpus is gracile compared with Asian *H. erectus* (Zhoukoudian G1, H1; Sangiran 1b, 9)[12–14], and more closely resembles specimens of early Pleistocene East African *Homo* such as KNM-WT 15000, KNM-ER 730 (*H. ergaster*) and OH 13 (*H. habilis*)[14–16]. P_4 (mesio-distal (MD) = 7.4, buccal–lingual (BL) = 9.1): The crown is slightly subcircular with a buccal–lingual long axis. No cingulum is present. The cusps are placed mesially and inflected centrally to be separated only by a central sagittal groove, while a long, wide talonid, with no cusps or ridges, occupies the distal two-thirds of the tooth. The neck is constricted, and a long robust root bifurcates for 2/3 of its length. In comparison, the seven Asian *H. erectus* P_4 from Zhoukoudian (29, 30, 89–93) have an obliquely oval crown with the greatest diameter running mesio-buccally to distal-lingually, with distinct buccal and lingual cusps, and with a small talonid having numerous short accessory ridges and wrinkles. The buccal surface of these teeth has a well developed cingulum and the root structure shows a single tapering root that is compressed mesio-distally. In the Longgupo P_4, the buccal–lingually expanded crown resembles ER 992 (*H. ergaster*), the position of the mesial cusps and large talonid compares with OH 7 and OH 13 (*H. habilis*), and the bifid root is like ER 992 (*H. ergaster*) and to a lesser extent OH 13 (*H. habilis*). M_1 (MD = 11.0, BL = 10.1): The tooth is low-crowned and possesses two strong roots and five cusps. In occlusal view the crown is sub-rectangular with rounded corners. The metaconid is larger than entoconid and is the highest cusp. The enamel is relatively thin and uncrenulated; perforations expose dentine at the protoconid, hypoconid and hypoconulid. In comparison, the seven *in situ* M_1 of *Homo erectus*, as well as Black's type specimen (Zhoukoudian 96–102, 34)[12] exhibit six cusps (including tubercle 6), thickened enamel, cusps covered by wrinkles, furrows and accessory ridges, and larger size. The cusp arrangement and size of the Longgupo M_1 may be likened with ER 992 (*H. ergaster*) and OH 13 (*H. habilis*). *b*, Right I^2 (CV.939.2, level 7) labial (left) and lingual views (×1.5 the scale of *a*). This isolated tooth is complete and unerupted with the root intact (MD = 8.1, labio-lingual (LL) = 7.0, crown height (CH) = 10.3). In lingual view, the mesial and distal marginal ridges are both high and well defined. A small tubercle is present at the base of the lingual surface where the mesial and distal marginal ridges converge upward to meet. The lingual surface is concave and quite shovel-shaped. A central ridge runs from the tubercle to the occlusal edge and divides into two branches at the middle of its crown. The labial surface is moderately convex. A mamelonated incisal ridge shows that the tooth was never in occlusion. The Longgupo I^2 differs from Zhoukoudian 6 and 7 (ref. 12) in its significantly lower crown height, less buccal–lingual expansion of the crown, significantly thicker mesial and distal marginal ridges, and a less wedge-shaped appearance when viewed from the lingual side of the occlusal surface. These features are variably expressed in the OH 6, 16, 39, ER 1813 (*H. habilis*)[15] and WT 15000 (*H. ergaster*)[16].

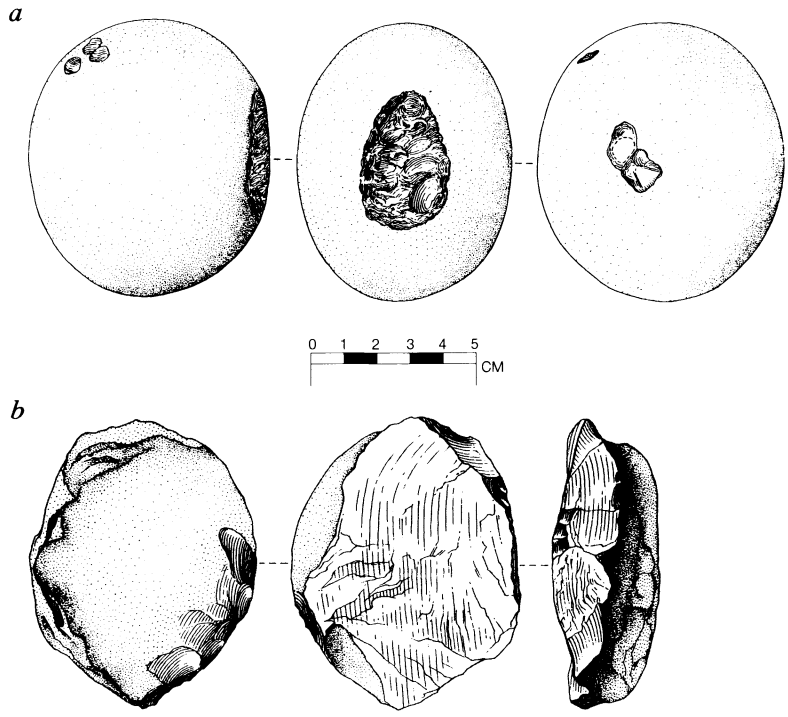

FIG. 4 Longgupo Cave andesite/porphyrite stone artefacts. *a*, The elongated, spherical cobble (P.6524, level 5) has a heavily weathered cortical surface. Three relatively discrete areas (left, centre and right) have reweathered crushing and pitting. The area at centre has a concentrated pattern of pits (4 mm depth) that suggest repeated battering. *b*, The lenticular flake (P.6523, level 8) represents a larger cobble that has split near a natural waist. The heavily abraded and weathered ventral surface consists of a few large scars (centre). The dorsal surface (left) shows two stages of weathering: rough, highly pitted areas confined to recesses, and smoother crests and convexities covering most of the surface. The dorsal surface recurves onto the ventral surface to indicate the waist in the original cobble (right). Heavily weathered crest damage occurs (left) clockwise from bottom centre at 0°–85° and at 180°–270°. The dorsal faceting at 270°–350° also has heavy crest damage.

from the natural environment for inherent qualities of raw material and morphology and thus used with little modification[23]. The andesite–porphyrite raw material is resilient to repeated battering, and both implements fit within the hand to offer numerous surfaces and edges for use. Second, the tightly patterned distribution of surface and edge damage indicates deliberate and consistent gestures of use[24]. If, eventually, andesite–porphyrite cobbles prove unavailable within several kilometres of the Longgupo cave site, curation may distinguish this potentially earliest Asian technology from its African contemporaries.

We have estimated the age of the Longgupo hominid specimens and artefacts in three ways. The co-occurrence of *Sinomastodon*, *Nestoritherium*, *Equus yunnanensis*, *Ailuropoda microta* and *Mimomys peii* place the middle zone clay facies in the late Pliocene and earliest Pleistocene. Palaeomagnetic data then bracket levels 7–8 within the Olduvai chron, 1.96 to 1.78 Myr. Finally, the ESR determination of 1.02 ± 0.1 Myr, on material from level 4 (3 m above levels 7–8), constrains and reinforces these interpretations. The Longgupo specimens are therefore older than any reported for China and at least as old as Indonesian *Homo erectus*[25]. The Longgupo specimens closely resemble East African fossils representing the earliest species of the genus *Homo*. They share few characters in common with Asian *Homo erectus*. As their incompleteness precludes designating a new species, we assign the Longgupo hominids to *Homo* species indeterminate, while noting affinities with *H. habilis* and *H. ergaster*. The stone tools are consistent with this interpretation. Given the early date and primitive morphology for the Longgupo specimens, and the older age estimates for *H. erectus* in Java[25], we must recognize more than one Plio-Pleistocene hominid species in east Asia. The new evidence suggests that hominids entered Asia before 2 Myr, coincident with the earliest diversification of genus *Homo* in Africa[26,27]. Clearly, the first hominid to arrive in Asia was a species other than true *H. erectus*, and one that possessed a stone-based technology. A pre-*erectus* hominid in China as early as 1.9 Myr provides the most likely antecedents for the *in situ* evolution of *Homo erectus* in Asia[27–29]. □

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