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New Evidence of Human Occupation in Southwest China Since 44,800 Years ago

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ABSTRACT

Since marine isotope stage 3 (MIS3), major alternations in global climate, population dynamics, and human behavioral patterns have taken place in many regions of the world. In China, ambiguity in modern human evolutionary trajectories, variation in lithic industries, and limited previous investigations into archeological sites confound our understanding of Upper Paleolithic human species and technological trajectory in East Asia. To address this issue, we present a newly excavated cave site in southwest China, Zhaoguodong Cave, whose occupation spans the start of the Upper Paleolithic to the Holocene. Our study shows that behavioral patterns, including lithic production, organic tools, and pyro-technologies at Zhaoguodong Cave have not undergone substantial overturns over the past 45 thousand years. This finding implies an adaptive optimum and a consistent cultural framework in southern China that may be attributed to modern humans.

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Lithic industry; Upper Paleolithic; Holocene; modern human; southwest China

Introduction

In East Asia, the appearance of *H. sapiens*, documented in paleoanthropological and archeological records, reveals that they were present in northern Asia at least 45,000 years ago (Hu et al., 2009; Li et al., 2013; Rybin et al., 2023; Wang et al., 2022; Yang et al., 2017; Zwyns, 2021; Zwyns et al., 2019). Likewise, both genetic and fossil data support the entry of AMHs around MIS 3 across modern-day China (Li et al., 2010, 2018; Shang et al., 2007; Yang et al., 2017; Zhang et al., 2004, 2022). However, human activities in southern China are more complicated, as fossils assigned to *H. sapiens* have been successively found within a larger period, with morphological variances and other unknown species. Such intricacy is also reflected by complex cultural trajectories in southern China during the Upper Paleolithic period (Bar-Yosef & Wang, 2012). In northern China, blade and microlithic industries, personal ornamentations, and the symbolic uses of ocher have been frequently discovered since 45 ka (Li et al., 2018; Wang et al., 2022; Yang et al., 2017, 2024a). However, in contemporary southern China, the technological changes are relatively less pronounced, primarily characterized by a diverse collection of pebble/cobble tools, core-flake tools, and micro-flake tools across various sites and periods (Cao et al., 2024; Li et al., 2019, 2023; Qu et al., 2013; Zhou et al., 2022, 2024). Moreover, most industries exhibit either incomplete sequence or interrupted technocomplex. The scarcity of continuous deposits from this period hinders our ability to gain insights into the coherent development of technological evolution in southern China.

In this study, we present a study of the lithic assemblage of Zhaoguodong cave in southwest China, where sedimentary accumulation occurred from 44,800 to 7,000 years ago, with no major identifiable interruptions in chronology and cultural behaviors. The site, therefore, provides a valuable opportunity to explore an undisturbed sequence from the Late Pleistocene to the Holocene period in southwest China.

Geographic Background and Excavation

Zhaoguodong Cave (N26°32′22.83″, E106°27′00.02″, 1280 m a.s.l.), 20 m wide and 25 m in length is located in Yankong village, Guizhou Province, in Southwest China (Figure 1). It was developed in limestone mountains, where a wide distribution of karst is found. In the middle of these mountains is a north–south

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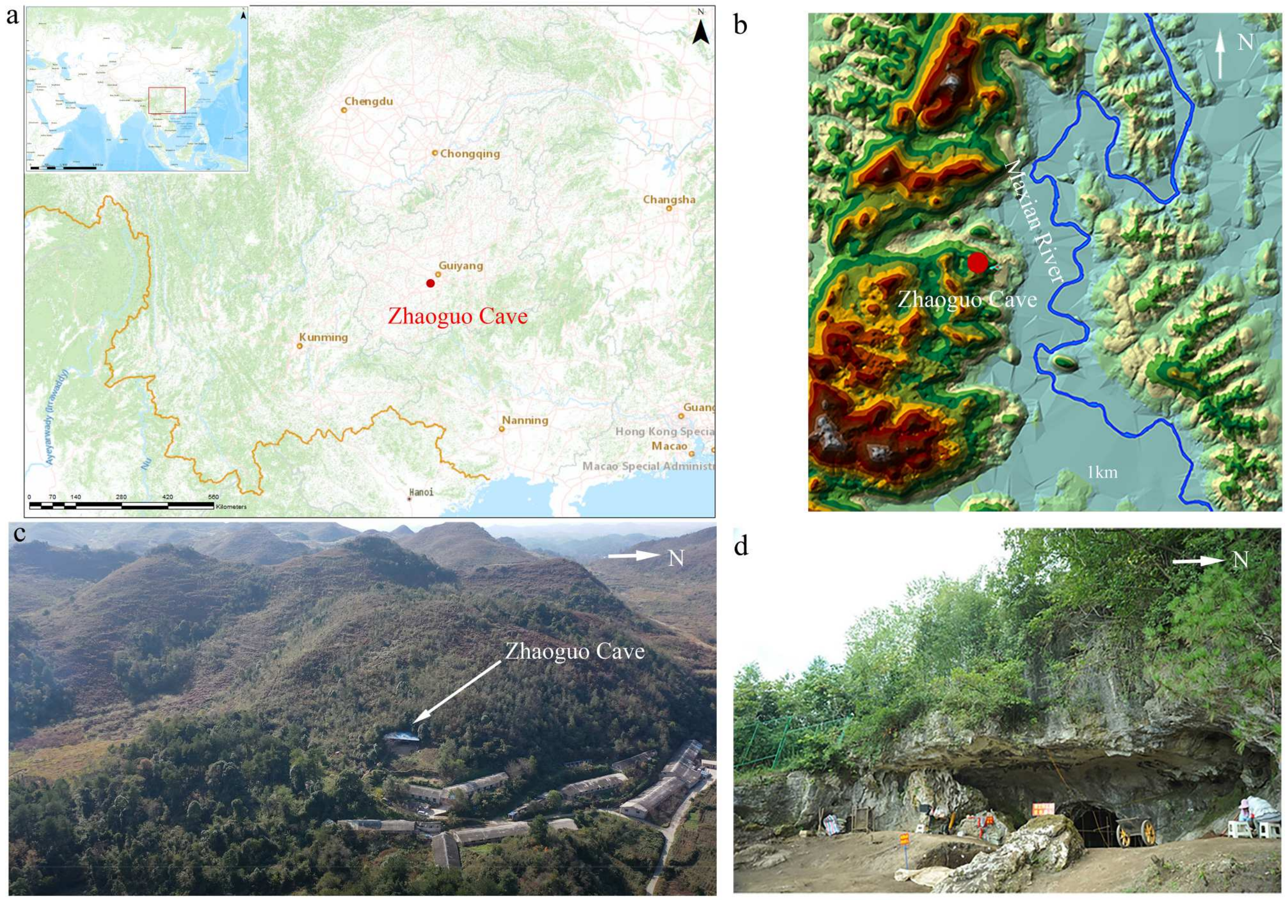


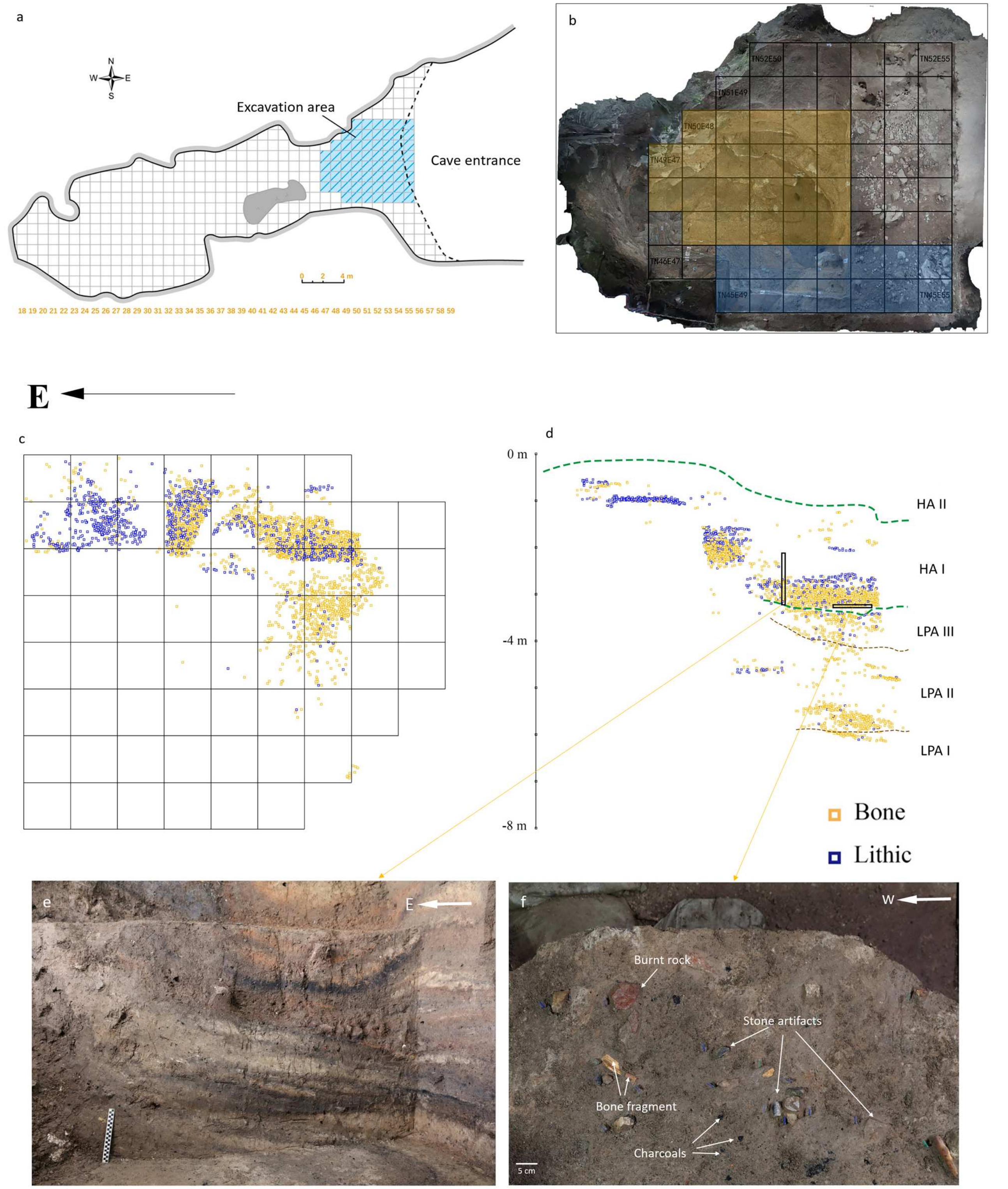
Figure 1. (a) Location of Zhaoguodong cave (ZGD cave). (b) Topography near the cave. (c) Bird's-eye view of the cave entrance. (d) Close look of the cave entrance.

extended basin formed by the Maxian River, 300 m from the cave and 30 m lower in elevation. The cave is situated west of the basin, with an entrance facing east. The mountain's carbonate rocks were formed as part of the Middle Carboniferous Huanglong Group with a major component of sparry limestone and coarse-grained dolomite. When buried in sediment, the water flowing from underground and ground seepage dissolves the rocks. It gradually formed the cave's main chamber through the downward flow of the groundwater (the Maxian River), and the mountain's elevation stopped the cave's horizontal extension. Today, except for temporary sheet flow concentrated along fractures and the cave roof, the cave has basically dried up, with secondary calcium carbonate precipitates forming stalagmites at the end of the chamber.

The cave was discovered in March 2016 during an archeological survey led by the Guizhou Institute of Cultural Relics and Archaeology, Sichuan University, and the Chengdu Institute of Cultural Relics and Archaeology (Zhang et al., 2024). A trench with an approximate area near 70 m^2 by 8 m deep was unearthed near the entrance over five excavation seasons (Figure 2a). Research on archeological materials recovered from 2016 to 2019 is still ongoing. In this paper, we focus only on the materials unearthed during the 2020 excavation, where the complete archeological sequence of the cave was unearthed (Figure 2b).

Stratigraphy

A complex depositional process was observed in the cave. A doline is situated in the southern part of the excavation area, resulting in gravitational collapse at the southwestern corner. This collapse has caused a southwest-ward inclination in the stratigraphy. Meanwhile, vertical variations are evident as yellow sandy clay dominates the lower sections of the profile, while white and black interbedding characterizes the upper portions. Given the complex sedimentary process, a universal lithostratigraphy for all the sections was impractical. The southern wall of pits N46E47–N46E50 exhibits the most integrated archeological units within the excavation area, with a maximum depth of 8 m observed. This particular profile section was also excavated in 2020 when the archeological materials studied in this



*Please note that some lithics and bones are not recorded in the Neolithic layers due to their small sizes and large quantity.

Figure 2. (a) A plane view of the cave (a total of 64 formally excavated pits). In (b) the blue area indicates the new pits of 2020, and the yellow area indicates subsequent excavations in 2020 that follow on layer 19. Horizontal (c) and vertical (d) plots of the 2020 excavation area. (e) Vertical view of overlap combustion features; (f) photography of excavation plane (TN46E49–TN46E50).

paper were recovered. Therefore, we utilize this representative profile section to illustrate the stratigraphic characteristics of the cave (Figure 3). Except for the doline-caused subsidence and sporadic animal burrows, the lithostratigraphic units were successive and not disturbed by major erosion or significant disturbances. Combustion features were identified where ash, charcoal grains, and burnt materials appeared in high concentrations without necessarily exhibiting a formal hearth structure. Edges of most stone artifacts are fresh and sharp, showing little or no traces of post-depositional process or hydraulic impact. Stone artifacts with heavy abrasion only account for a small proportion (0.2%), indicating most artifacts were buried quickly without long-distance transport by natural process. According to experimental flaking studies, ratio of small, detached pieces against the assemblage can be an important proxy for site integrity (de la Torre et al., 2018; Kuman, 2003; Petraglia & Potts, 1994). The low ratio (2.98%) of cores to small flaking debris suggests an in-situ reduction sequence. Figure 2f shows artifacts and bones of varying sizes were excavated simultaneously from the same lamina of a layer. A total of 25 sedimentary units were identified, primarily based on lithological changes (Figure 3).

Methods

All the excavation areas were explored following a standard procedure. The excavation area was framed by a 1 m^2 grid pit. Each pit was dug down vertically 5 cm at a time within an intact natural layer. Recognizable mammal bones, artifacts, and combustion features were documented within their original context on the working surface. The corresponding sediment was collected for flotation using a 0.2 mm screen to catch the light fraction and a 1 cm screen to catch the heavy fraction. After all the individual pits reached the same level, photographs were taken, and a 3D model was created using PhotoScan (https://www.agisoft.com/pdf/photoscan_presentation.pdf). Context information, including the layers, attribution (e.g. stone artifact, bone, pottery sherds, and carbonate), and three-dimensional coordinates, were recorded by a total station Leica TS02 equipped with newplot 2.0 (https://www.oldstoneage.com/osa/tech/plot/), which simultaneously generated an identification barcode (Figure 2c, d).

A total of 13 ^{14}C accelerator mass spectrometry (AMS) dates were obtained from the bottom to the top of the profile. Most samples were bone fragments collected during the excavation and charcoals recovered from combustion features. They were prepared and measured by the BETA lab. Calibrations were conducted using both Bchron (Haslett & Parnell, 2008) and OxCal 4.4 software (Bronk Ramsey, 2009). The IntCal20 atmospheric calibration curve (Reimer et al., 2020) was employed for this process. The calibrated results against MIS and profile are presented in Figure 3. The lithic study followed the established lithic analytic methods and concepts outlined in relevant literature, such as (Andrefsky, 1998; Debénath & Dibble, 1994; Inizan et al., 1999). The recognition of chaîne opératoire (Bar-Yosef & Van Peer, 2009; Geneste, 2010; Pelegrin et al., 1988; Sellet, 1993) includes the investigation of raw materials, understanding core reduction strategies, as well as analyzing retouched or unretouched products including flakes, flake fragments, debris, and artificial chunks. In the paper, debris refers to fragmentary flakes without a proximal end and any retouching or measuring less than 20 mm in size, while artificial chunks denote stone artifacts lacking ventral surfaces and showing no evidence of retouching.

^{14}C (AMS) Dating Results

According to the ^{14}C AMS dates, the human occupation spaned from the Late Pleistocene to the Holocene period (Figure 3). The lowest sample, taken from HT51, is dated back to 44,881–43,086 cal. BP. The result is close to the limit of radiocarbon dating and may be potentially underestimated. However, this sample represented the earliest record of human activity in the cave. The surface layer dates back to 7934–7752 cal. BP, signifying the uppermost extent of this profile. Based on the radiocarbon dating results, we assigned the cultural remains into two archeological assemblages (Figure 3): the Late Pleistocene assemblage (LPA; Layer 25-9; 44,881–11,251 cal. BP) and the Holocene assemblage (HA; Layer 8-1; 10,430–7752 cal. BP). Within LPA, three phases were divided according to lithological/sedimentary facies and abundance of cultural remains. They are LPA I (Layer 25-21), LPA II (Layer 20-17), LPA III (Layer 16-9). Likewise, HA is also divided into two phases: HA I (Layer 8-2) and HA II (Layer 1).

Lithic Assemblage

Raw Material Acquisition

Black chert in small nodule forms with existing internal joints was consistently used for stone-tool making. In later phases, a diverse range of raw material is increasingly evident, but they only make up a small proportion. According to the geological structure of the cave and field surveys, these raw materials were provenanced outside the cave. Within the cave and its immediate

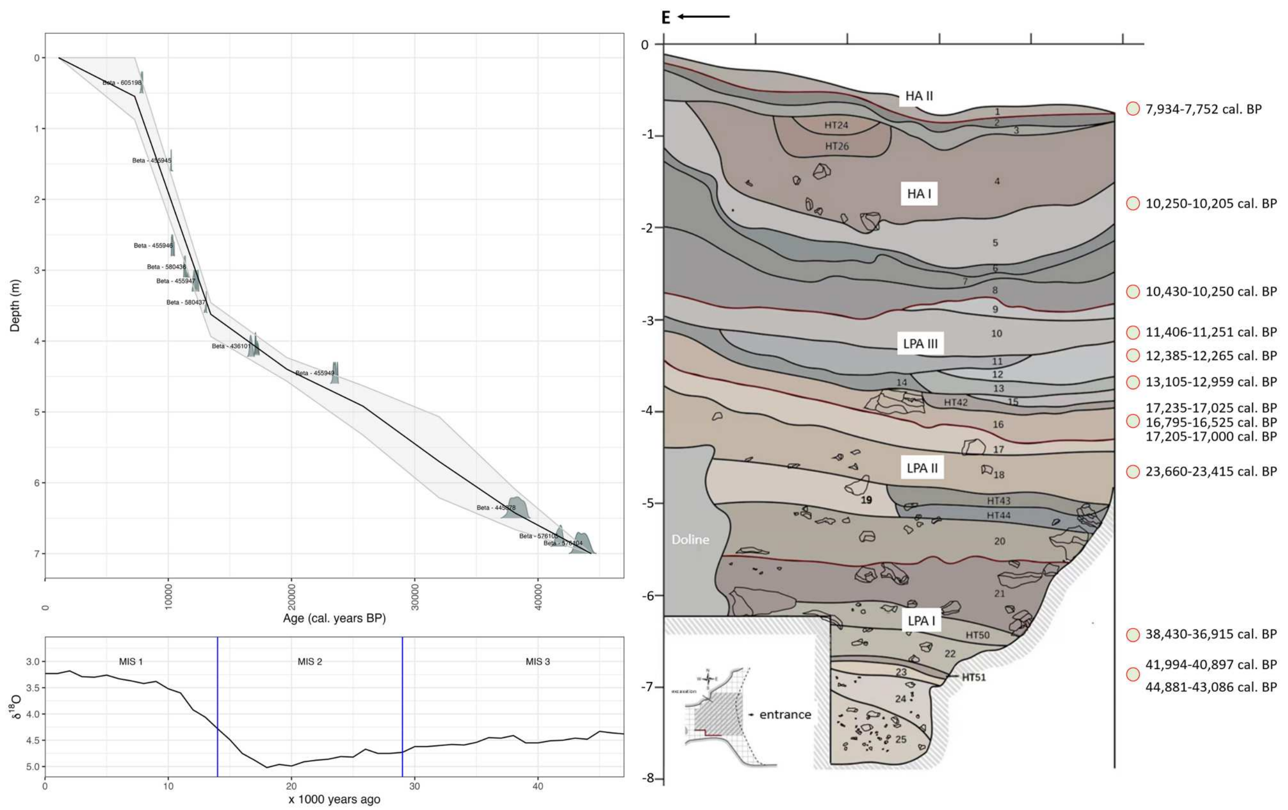


Figure 3. From left to right, respectively. The age-depth plot of calibrated radiocarbon dates for Zhaoguodong cave and the corresponding MIS stage. Calibrations were computed using Bchron (Haslett & Parnell, 2008) and the IntCal20 atmospheric curve (Reimer et al., 2020); the stratigraphical profile of Zhaoguodong cave; red circle denotes the depth of samples and their corresponding results of AMS dating results; red lines on the profile indicate the boundaries of the archeological phases.

environs of the carboniferous limestone mountains, only limestone and dolomite can be found (Figure 4). Natural rocks embedded in layers associated with stone artifacts and bones are mainly clastic limestone, dolomite, and stalactite, probably originating from the cave roof and wall. No chert vein is found inside the cave or near the cave entrance. The nearest chert resource was found in the bedrock at the foot of the mountain, located 500 meters north of the cave (Figure 5e and f). Another chert intrusion where more abundant and stable black chert is available was found 1 km away from Zhaoguodong cave (Figure 5a–c). Given that no riverbed sediments in the nearby modern landscape are exposed and accessible (Figure 5d), black chert and other types of cherts were provenanced from surrounding mountains where outcrops could be easily found.

The Late Pleistocene Assemblage

A total of 1,783 stone artifacts composed of various knapping elements were recovered (Figure 6a), namely, cores, flakes, retouched tools, and abundant debitages (Table 1), alongside other lithic materials associated with human activities, such as burnt stones and few minerals that may have been used for pigment.

Phase LPA I lies on top of the bedrock and contains three combustion features and five sedimentary units. Most of the stone artifacts, charred bone, and bone tools (n = 3, osseous awl) were recovered from the combustion features. Though burnt rocks and charred bones were found in small quantities, they confirm the use of fire when hominins first arrived at the cave. The overall low density of archeological materials in LPA I implies this spot was not preferred for intensive occupation and was only used occasionally over time. Black chert is the main raw material, with a small amount of limestone (Figure 6b). The stone artifacts are generally smaller than 50 mm (Figure 7). Debris and artificial chunks dominate the assemblage (Figure 6a). According to the core configurations, unidirectional percussion without preparation appeared to be the only knapping strategy when producing flakes. The reduction sequence was short, with one or two series that yielded a few successful debitages, yielding flakes with various morphologies. Flake detachments were usually interrupted by the heterogeneity of the raw materials. Complete flakes are predominantly characterized by side flakes,

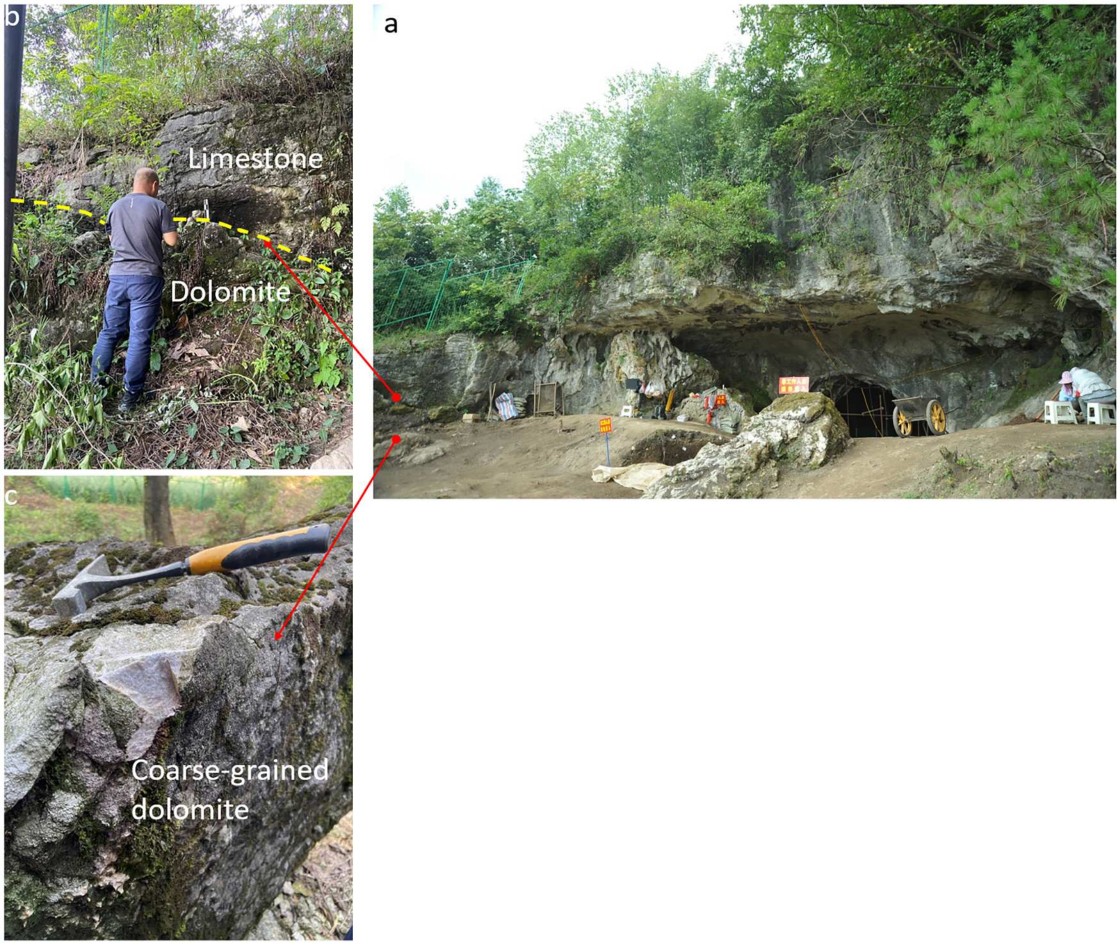


Figure 4. (a) East entrance of Zhaoguodong cave; (b) boundary between limestone and dolomite layers; (c) close view of coarse-grained dolomite in front of the cave entrance.

which are defined as having a width greater than their length (width > length). They display similar patterns to the cores, including few dorsal scars (n = 2–6) and unprepared platforms (Figure 8a, b). Cortex is uncommon. Initial flakes with full cortical dorsal surfaces are missing. Given that the majority of chert specimens can be sourced from outcrops of veins near the site where chert with little cortex is abundant, the scarcity of cortical flakes does not necessarily indicate off-site initial reduction. Scrapers are the most frequently retouched tools made from flakes (complete or incomplete) and chunks (Figure 8c, d). Isolated points exhibiting convergent retouched lateral sides at the tip are also evident. Retouches are restrained and informal, usually only on one edge. Interestingly, the retouched tools are generally larger than the unretouched flakes and cores. It is likely that such flakes were produced outside the cave or deliberately selected from larger flakes for tool manufacture.

Phase LPA II is 2 m thick and composed of five layers, seven combustion features, and a substantially greater density of artifacts than LPA I. Petrographic is characterized by yellow coarse-grained silt embedded with large fallen rocks. More than 400 stone artifacts, including all the elements of the reduction sequence (Figure 6a), were recovered (though mostly debris and chunks). They are associated with countless bone fragments and burnt materials and four osseous awls. Although raw materials are still dominated by black chert, the diversity of raw materials increased to six types of rocks (Figure 6b). Unidirectional and bidirectional strategies were utilized when knapping cores (Figure 8e). While the proportion of cortical and joint platforms (the flake was detached from the natural joint surface) on the cores decreased, plain platforms increased. Likewise, the number of reduction sequences demonstrates an increasing trend, as does the number of removals detached from each reduction sequence. The cores were made only of chert, but the raw materials of the flakes included a few exotic types, such as opal and crystal quartz. Flake platforms are predominated by plain platforms, according with schemes

Figure 5. (a, b) Chert intrusion (yellow dashed box) showing on the cave wall 1 km south of Zhaoguodong cave; (c) black chert collected from the chert intrusion; (d) modern landscape of the Maxian River; (e, f) chert vein at the foot of the Zhaoguodong mountain and black chert obtained from the vein.

observed on cores (Figure 8f, j). The flakes show some morphological variations, and side flakes are also the aimed products. Dorsal scar patterns are more complex and show, on average, four scars. Only one initial flake was found. Unlike cores and flakes, retouched tools, most of which (75%) are modified from broken flakes and natural chunks, are only made on black chert. The retouching approach is still simply working on one edge, and the most favored tool type remains scrapers (Figure 8h), although other tools, such as denticulates and notches, also occur (Figure 8i).

Although techniques are slightly altered, one important shift that makes LPA II distinct from LPA I is the appearance of exotic raw materials (Figure 6b) It possible due to an expansion of the cave users' foraging range or trading activity. Meanwhile, there is a greater diversity of raw materials found in flakes than in cores, suggesting that some flakes were brought into the cave. Consequently, we hypothesize that the bulk of the products took place outside the cave, indicating sporadic and transient occupation patterns within this cave environment. Fire usage in LPA II is accompanied by charred bones and more charcoal layers. The increased number of combustion features suggests a more frequent exploitation of the cave compared to LPA I. The lowest trace of using fire in LPA II is evidenced by two circular features (Figure 10d), one containing visible charcoals.

Phase LPA III consists of six archeological units. There are no sterile sediments separating LPA II and III; however, unlike the last two phases, the petrology of LPA III changes dramatically from laminar yellow sandy silt to fine gray-brown horizontal cross bedding mixed with mass charcoal grains, burnt red particles, and strips of white ash. The thickness is uneven, ranging from 20 to 120 mm. Besides, LPA III is marked by a substantial increase in mammal bones and stone artifacts (n = 1381). Siliceous rocks (black chert, colored black chert, gray chert, and stripe chert) are still the most common raw material, although sedimentary and metamorphic rocks were also identified (limestone, sandstone, quartzite, and opal, Figure 6b). The cores demonstrate a variety of morphologies (Figure 9a, b). This may be because the diverse raw material required different skills to knap, and different knapping techniques and strategies generate amorphous outcomes. Multidirectional and bipolar percussion are present in the core reduction system for the first time. The presence of continuously small flakes along the platform edge on a core, referred to as "frame management/taphonomic breaks" (Figure 9a), may indicate an alternative approach to

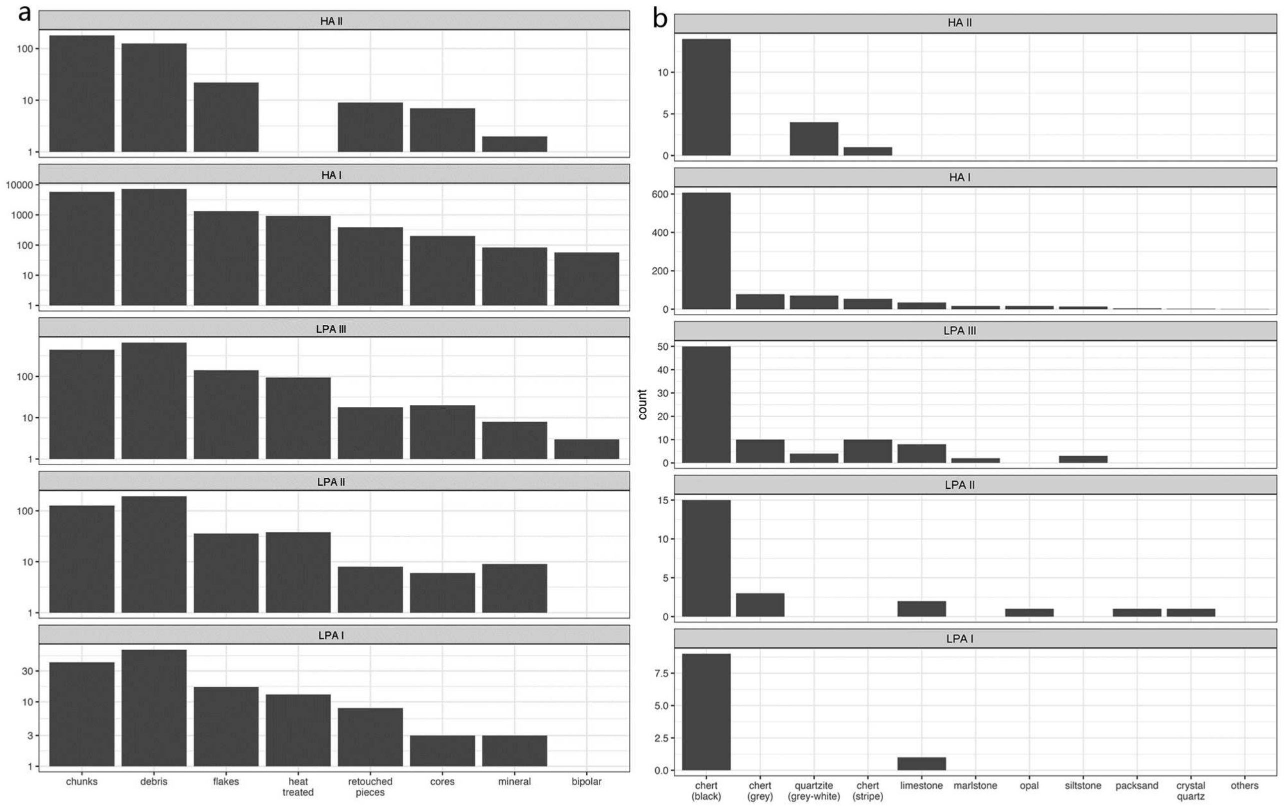


Figure 6. Counts of assemblage components (cores, flakes, retouched tools, debris, chunks, burnt rocks, and minerals) for each phase.

platform preparation, tool curation or could be attributed to post-depositional influences. Most cores are small, with an average length of less than 5 cm.

There are 17 hard-hammer percussion cores, twelve of which are unidirectional cores. Unidirectional cores are mostly made of chert, with one exception, which is made of limestone. Unidirectional cores are smaller than bidirectional and multidirectional cores (mean length = 2.4 cm), and they are exploited with minimal preparation on the platform or working surfaces. Although successful removals were made, only one knapping series can be identified on almost all the unidirectional cores. Bidirectional and multidirectional cores display analogous patterns, such as non-preparation and few reduction phases, but platform angles increase to 80°. Bipolar cores are mostly made from

Table 1. Categories of stone artifacts from three different levels.

		Late Pleistocene					
Category	Type	LPA I	LPA II	LPA III	Holocene I	Holocene II	Total
Core	Single-platform	3	2	12	79	7	258
	Double-platform		4	2	67		
	Multi-platform			3	26		
	Bipolar			3	50		
Flake	Completed flake	10	23	87	926	22	1644
	Flake fragment	7	15	54	493		
	Bipolar flake				7		
Retouched tool	Scraper	6	4	12	297	9	486
	Notch	1		2	41		
	Clactonian notch		2	2	8		
	Denticulate		2	2	79		
	Point	1			17		
	Burin				1		
Chunk		41	127	442	6224	180	7014
Debris		64	192	658	7530		8444
Burnt rock		13	38	94	980		1125
Mineral stone		3	9	8	101	2	123
Total		**149**	**418**	**1381**	**16926**	**220**	**19094**

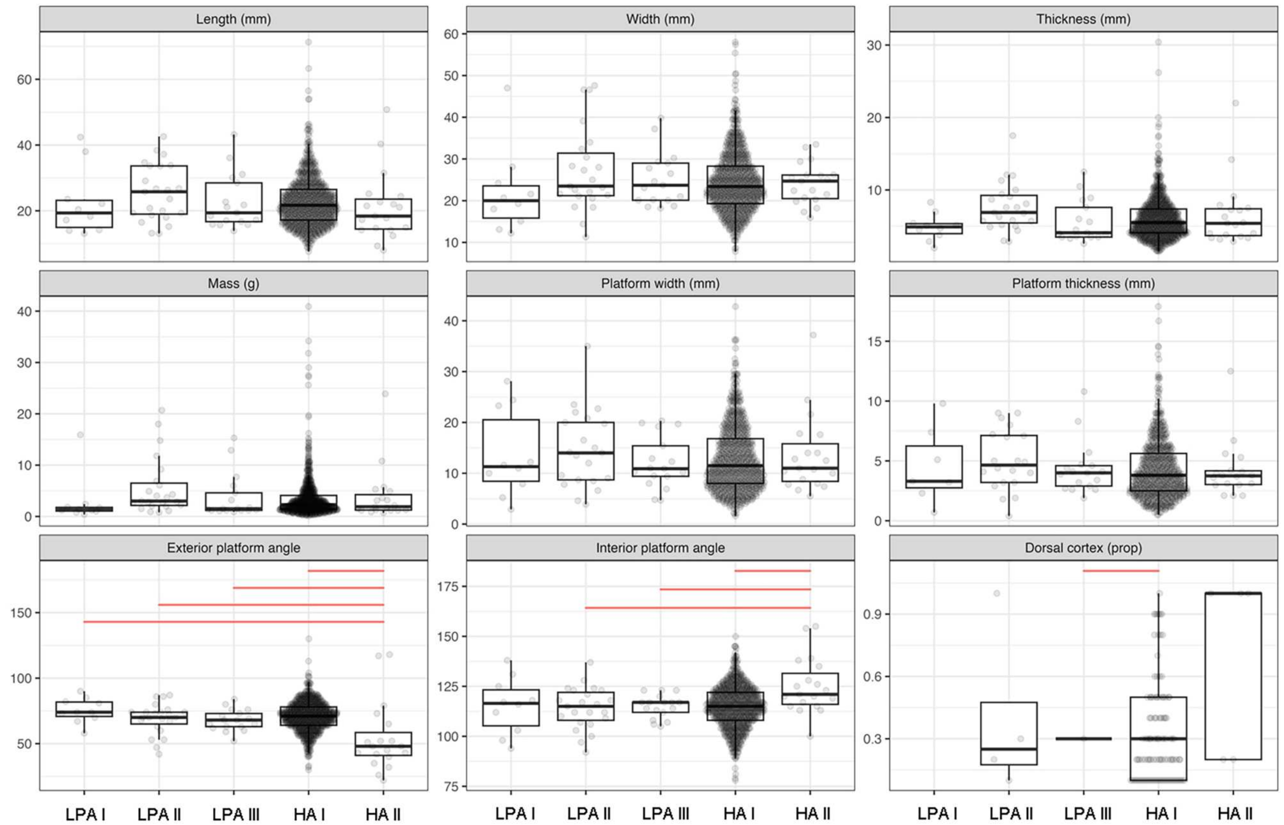


Figure 7. Boxplots summarizing variation in flake dimensions and technological attributes. The horizontal red lines in the upper part of some panels indicate statistically significant differences ($p < 0.05$) in metrics between phases, computed by ANOVA.

chert and are elongated, with an average size of 2.5 × 2.7 × 1.5 cm (Figure 9b).

Flakes were made on more varied raw materials, such as sandstone and quartzite, although black chert still represents more than 50%. Flakes show some morphological variations (Figure 9c, d), but most have a width longer than their length. It seems cores from the whole Late Pleistocene level aim to obtain small side flakes, mainly by simple production systems like unidirectional or bidirectional knapping. Cores were abandoned after a short reduction process. This could be attributed to raw materials whose homogeneity is largely compromised by internal joints, leading them unsuitable for further reduction. Plain platforms are common (72.4%), without showing facetted preparation. The number of dorsal scars increased to an average of 4–5 among the 87 completed flakes, and the patterns are also more diverse. Most flakes have a non-cortical dorsal surface, and initial flakes are absent.

A total of 18 retouched pieces were found in LPA III, most of which were modified chunks. Scrapers remained the main tool type (Figure 9e, f), while denticulates and notches only represent a small proportion of the find. The average size of chunk tools, 2.8 × 3.5 × 3.1 cm, parallels the cores and flakes. The retouching strategy was to work on mostly one edge, 2–3 occasionally, with simple, separated, marginal scars left on the edge. Flake tools are somewhat larger than chunk tools, with a mean size of 3.7 × 2.9 × 1.1 cm, and the retouching is more successive compared to the chunk tools. Another latent variation from earlier stages (LPA II and LPA I) is the retouching approach transferred from ventral-dorsal to alternation manners.

Three combustion features (HT40, 41, 42) were sequentially excavated without stratigraphic separation of their contents and sediments in the field. Given their non-typical circular outlines and varying depths, we assigned them as three distinct units. However, it should not be ruled out that they may belong to a major fire-use event or were used within a short period (Figure 10a). A thick layer of burnt red soil, lying underneath and aligned with a black and gray ash sub-circle, indicates that HT41 might have been the center of this event (Mallol et al., 2013). A combination of many bone fragments, various formally polished bone tools (n = 31, Figure 10b2, please see more details in Yang et al., 2024b), rocks, and burnt

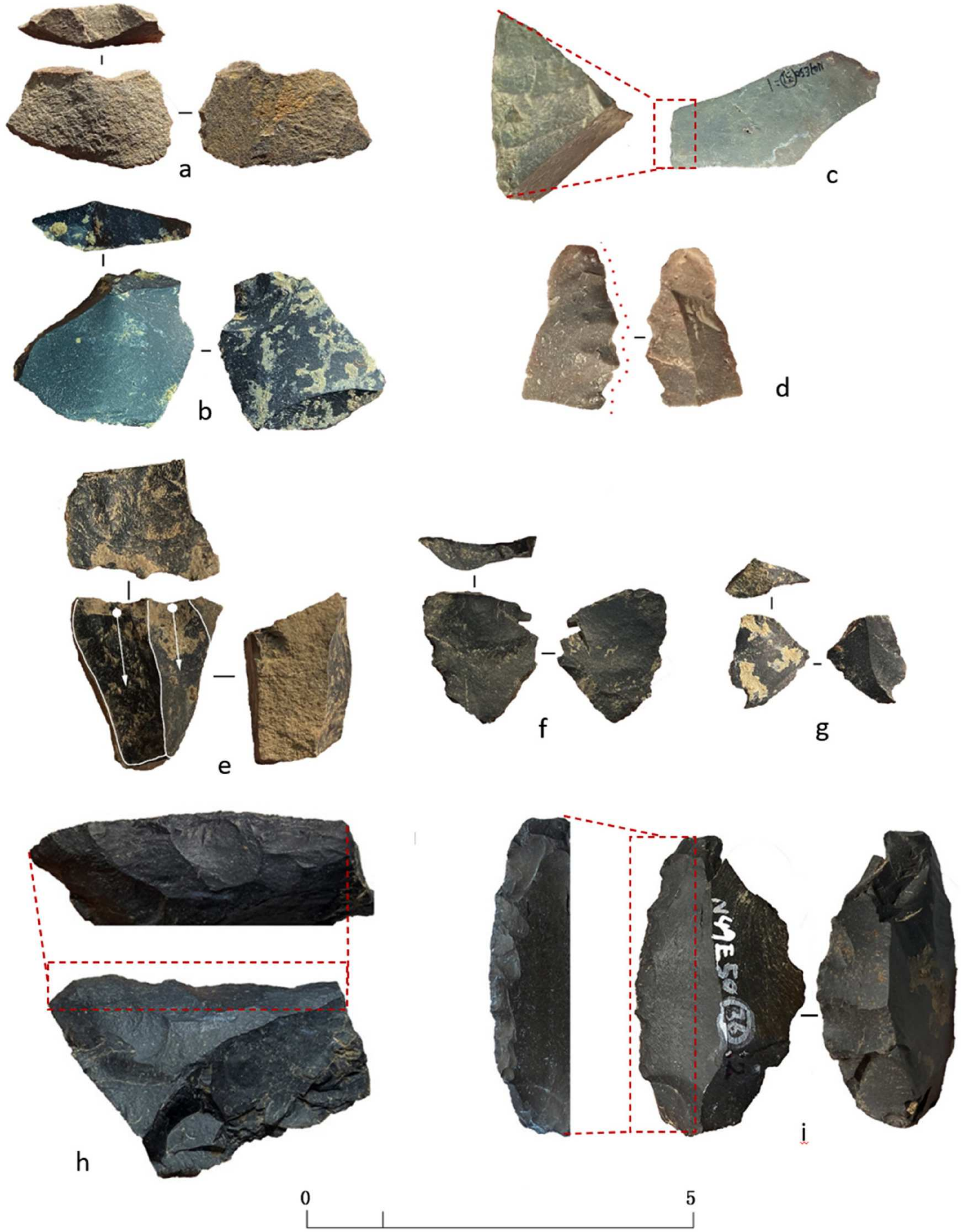


Figure 8. Upper: Selected stone artifacts from LPA I (a, b flakes; c end-scraper; d denticulate). Lower: Selected stone artifacts from LPA II (e single platform core; f, g flakes, h scrapper; i denticulates).

stone artifacts were distributed within the combustion features. Although the scale of this event is not beyond earlier combustion features, the transition from yellow sandy clay to thick white ash and a black layer, along with an abundance of charcoals and reddened grains, suggests a more frequent utilization of fire during this stage. Additionally, the increased presence of stone artifacts and bones indicates a more intensive occupation in the cave.

Holocene Assemblages

Based on chronological order and sedimentary characteristics, the Holocene assemblage is divided into two

Figure 9. Selected stone artifacts from LPA III (a single platform core; b bipolar core; c, d flakes; e, f scrapers).

phases: HA I (10,430–10,205 cal. BP) and II (7,934–7,752 cal. BP). In many regions around the world, the commencement of the Holocene marked the start of the Neolithic period, characterized by the presence of polished stone, grinding tools, ceramics, and agriculture (Gibbs & Jordan, 2016; Weisdorf, 2005). Direct evidence of agriculture, such as rice and soybeans, has been found in both northern and southern China (Cohen, 2011; Jones & Liu, 2009). However, in Southwest China, the Neolithic period is characterized by a protracted series of developments other than incipient cultivation and agriculture (Chi & Hung, 2008; Zhang, 1998). Apart from the presence of a limited quantity of pottery fragments and ground stone artifacts (Zhang et al., 2024), the technological behaviors of Zhaoguodong Cave remain broadly consistent with previous periods, characterized by the dominance of knapped stone artifacts associated with bone tools and frequent use of fire.

Figure 10. (a) Plane view of combustion feature HT40; (b) Selected bone tools from Zhaoguodong cave (1 awl; 2 bone spatula; and 3 antler spatula); (c) Plane view of stone floor HDM8; (d) photographs of HT 46 and HT47 showing circular features; and (e) selected ground stone tools.

A total of 16,926 stone artifacts were found from **HA I**, more than 80% of which are chunks and debris (Table 1, Figure 6a). Ground and polished stone tools were also found for the first time, although only in a small amount (Figure 10e). The most used technology remains hard hammer percussion skills, with a growth of bipolar technique application. Bone tools with delicate manufacture techniques (n = 274) were also more abundant during this period (Yang et al., 2024b) (Figure 10b-1,3). The use of fire in the HA I exhibits different structural attributes from those in the earlier phases. They appear to be more fixed and overlapped (Figure 2e). However, to further substantiate the assumptions regarding fire use, additional analytical approaches such as micromorphology, mineral magnetic parameters, archaeomagnetic analysis, and organic petrology (e.g. Goldberg et al., 2017; Herrejón-Lagunilla et al., 2024; Stahlschmidt et al., 2015) are necessary. Although these analyses are not included in the current study, future research will aim to integrate these methods to provide more comprehensive insights. Except for combustion features, pottery sherds were also found to be associated with stone artifacts and bones; however, most pieces are heavily weathered fragments.

A large variety of raw materials – up to 10 categories – were identified for knapping stones, including chert with different tones, quartzite, limestone, opal, chalcedony, and crystal quartz (Figure 6b). As in the underlying sequence, chert is still the predominant raw material. More than 70% of the cores were reduced by hard-hammer percussion, and about 27% are bipolar cores (Figure 11a). Regardless of the techniques used, the overall dimensions remain small. Subtle discrepancies can be found among the different raw materials: for

Figure 11. Selected stone artifacts from the HA I (a bipolar core; b multiple-platform core; c core with discoidal reduction; d, e, and f flakes; g, i scraper; h denticulate). The red dotted line indicates the area of retouches for "g", while the red dotted boxes indicate the zoomed-in areas for "h" and "i".

instance, the cores made of chert are usually smaller than those made of limestone. Another latent impactor of size may come from techniques. Bipolar cores are slightly smaller than percussion cores. For percussion cores, the reduction strategy is primary unidirectional and double-directional exploitation, with discoidal reduction occasionally present (Figure 11c). Multidirectional cores are less common (please refer to the example provided by Figure 11b). For most cores, further reductions were possible as refelcted by small platform angles (minimum = 42°) and proper convexities. While sequences on percussion cores were terminated quickly, bipolar cores were exhausted when abandoned.

Debitages from percussion cores predominated the flake cluster (99%), and their width was usually larger than their length. The number of bipolar flakes is disproportional to their cores (20%). Only seven of them, all of which were black chert, are recognizable. Unlike the percussion flakes, bipolar flakes have a thin, elongated, and narrow outline. Other flakes are obtained by the unifacial knapping of minimally prepared cores. As a result, the majority of flakes have plain platforms (Figure 11d–f). This suggests an expedient core reduction strategy. Most of the completed flakes fall in the 1–4 cm range, which might reflect a high incidence of internal fracture due to raw material flaws. The rarity of flakes exhibiting a complete cortical dorsal side suggests that, apart from the nearby resource, the raw materials might be subjected to brief reduction prior to their introduction into the cave.

A third of the complete and fragmentary flakes, as well as chunks, were then retouched into tools. Denticulate edges and side scrapers predominate the batch of tools (Figure 11g, h). An inclination to use certain raw materials to produce special tool types is not evident. However, quartzite was frequently retouched into convex side-scrapers, and points were often made using opal. Likewise, the retouch strategy also exhibits expedient and elementary traits. The retouching removals are marginal, confined, and irregular. The sizes of tools are mostly under 4 cm. For completed flakes, about 59% only have one side modified. Tools with more than one edge tend to be made with larger flakes (Figure 11i). The retouching directions are varied, with most of the modification removals on the dorsal surface. As flakes from this period tend to have a greater width than length, retouched flakes are found in a higher proportion of modified flakes that possess a longer length than width. This tendency is related to the method used for retouching. Modifications on both the left and right sides of these tools are more prevalent than those done on proximal and distal ends, resulting in a reduction in blank width and an increase in length-to-width ratio for stone tools. This inclination suggests an intentional selection of long blanks for tool-making and a preference for lateral retouching over end-retouching.

In total, 220 stone artifacts were found from **HA II** (Table 1). This is the surface layer where Neolithic materials, as well as a small intrusion of historic and modern waste, were found. Black chert still predominates (Figure 6b; 71.4%), with occasional use of quartzite and limestone (Figure 12). Unidirectional, bidirectional, multidirectional, and bipolar knapping without preparation remain the chief reduction approaches (Figure 12a, b). Flakes with cortical platforms and dorsal surfaces increased, indicating they came from early production stages. Interior and exterior platform angles (IPA and EPA) were significantly lower in HA II, compared to flakes from earlier periods. It is the only technological variable significantly different across all phases (Figure 7). While experimental research has demonstrated that EPA is directly influenced by the knappers (Dibble, 1997), and influences both flake size and flake morphology (Dibble & Rezek, 2009), the absence of significant changes in flake size observed here suggests that EPA may not have an impact on flake size. Therefore, the decrease in EPA is unlikely to be related to the substantial technological change in HA II (Figure 11c, d). Scrapers, denticulates, notches, and points, made on fragmentary flakes are the most common tool types (Figure 12e, f). Modifications frequently made on one edge with simple and basic retouches. The stone artifacts are still small (3–4 cm). No cobble tools were found, grinding and polishing stone artifacts are also absent.

Distinct from the simple lithic manufacturing processes, Finely made formal bone tools include bone/antler shovels, awls, needles, arrows, and an awl present. Their blanks were deliberately selected from limbs, scapula, ribs, and antlers. Most pieces are either polished at the end/tip, or elaborately polished entirely. But the majority of them are broken, with only tips or ends identifiable. A total of 164 and 28 pottery sherds were recovered from HA II and I, respectively. Technologically, their manufacturing process was simple and more concerned with functionality and practicability. Due to the absence of intact pieces, esthetic characteristics are reflected merely on the emblazonries on the outer surfaces, which are dominated by rope figures (68%) and blanks (24%), with grate patterns, wave patterns, stamped circles appearing occasionally.

Discussion and Conclusion

Behavioral Patterns Over Time at Zhaoguodong Cave

The initial occurrence of stone artifacts at Zhaoguodong is characterized by their limited quantity and simplicity in reduction and retouches. Debris and chunks are the most found types in the lithic assemblage. Black chert with internal fractures was the only raw material exploited. The evidence suggests hominins arrived at

Figure 12. Selected stone artifacts from the HA II (a single platform core; b bipolar core; c, d flakes; e denticulate; f scraper).

the landscape of the cave and visited it with a low frequency. The fragmentary reduction sequence also supports this hypothesis, suggesting that many lithic activities occurred outside the cave. The cave's low level of human occupation could be attributed to the topographical characteristics of the cave, such as poor accessibility, as indicated by the large accumulations of limestone rocks found in our excavations when reaching the deepest horizons. Being confronted with random falling bedrock clasts and limited space for habitation made the cave inhospitable to humans at the time of their first appearance here at 45 ka. Apart from the subtle growth in fire usage and lithic quantity, no remarkable changes in lithic strategies and behavioral patterns appeared until the end of LPA II.

Compared to subsequent phases, the cave experienced low visitation rates during LPA I and II. At the onset of LPA III (around 13-12 ka), there was a substantial surge in lithic abundance and notable changes in sedimentary facies, coinciding with the outset of Younger Dryas (Björck et al., 1996; Cheng et al., 2020; Rasmussen et al., 2006; Shen et al., 2006; Wang et al., 1994; Wünnemann et al., 2018). Periods of episodic visits to the cave were replaced by longer and more regular occupation events. Massively dispersed ash in the sediments associated with abundant charred bones, heated artifacts, rocks, and redden grains indicate intensive fire use. Meanwhile, the rate of angular block roof-fall decreased, allowing the chamber of the cave to become a more amiable site for a stable shelter. Organic tools, awls, and needles made from animal bones and antlers likely facilitated adaptations. They contributed to the persistence of people at the site throughout the sudden falloff in temperature and available food resources. Nevertheless, the lithic industry remained unified with the preceding small flakes and tools made by simple approaches on chert. Slight core reduction shifts did take place, such as the addition of new raw materials and the application of bipolar techniques. These shifts are additive rather than transformative of the local lithic technologies.

The end of LPA III, the last stage of the cave's Late Pleistocene occupation, ceased at 11.4–11.2 ka. The overlying levels bearing HA materials are homogeneous both in sedimentary series and entities within LPA III. However, changes in adaptive strategies and technological innovations are evident. The emergence of pottery, the intensified utilization of formal bone tools, and the presence of ground stone artifacts signify the transformation in subsistence strategies. Combustion features associated with charred bones, bone tools, artifacts, and redden rocks of variable sizes, along with ash that make up the principal components of the sediment, embody a heightened utilization and control of fire. Next to the concentration of combustion features, a dozen rockpiles formed by roughly uniform-sized stones (either burnt or unburned), inlaid with stone artifacts and bones, superimposed consecutively (see Figure 10d). However, the functions of these rockpiles need further investigation. The quantity of flaked stone artifacts in this period increased substantially to 16,000 pieces. The diversity of raw materials, especially exotic raw materials, points to more regular and extensive excursions across the landscape, possibly involving trade. However, the technological characteristics of the flaked stone during the HA appear to have been directly inherited from earlier periods. Cores continue to be small and reduced by simple unifacial blows without preparation to the core platform and volume. Tools were not extensively maintained; most were made expediently. No blade technology products have been found.

Implications for Human Behaviors in Southern China

Given that the ^{14}C dates might be underestimated, the deepest horizontal layers of Zhaoguodong cave were dated back to at least 45 ka. The Upper Paleolithic levels lasted until around 11,000 cal. BP and the following Neolithic levels ended around 10,000 cal. BP until covered by a layer of 7,000 years old. This timespan witnessed the most far-reaching cultural evolutions in human history. However, in terms of lithic industry, the essential strategies from the onset of the Upper Paleolithic to the Neolithic period seem to be monotonous without substantial technological breakthroughs such as blade or microlithic, and prepared core technology. Grinding stone tools were present alongside in later periods and are relatively in smaller numbers and were roughly made.

Except supplemented by Neolithic implements such as pottery invention and grinding tools, the homology in the lithic techno-complex from the later Late Pleistocene to Neolithic may reflect a stabilizing selection of lithic technological strategies (cf. Finkel & Barkai, 2021). The core-flake industry strategy that successfully persisted through generations was locally optimized for the specific forager niche in the Zhaoguodong environs. Furthermore, bone pieces with anthropic modification were recovered in all levels of occupation periods.

At present, we may picture a rough scenario of the adaptive strategy at Zhaoguoodong, which is characterized by simple flaked-based lithic production accompanied by evolutions of bone/antler tools, ground stone artifacts, and potteries. The process of lithic production took place from both off-site and on-site, aiming at obtaining small flakes and replenishing the toolkit quickly by the "least effort approach" (Reti, 2016). In contrast with the "expedient" manner of lithical material, knappers tend to make organic materials with complex technologies, probably profiting from their physical properties (O'Connor et al., 2014). These technological innovations undoubtedly facilitated survival through the LGM and Young Dryas period. Meanwhile, this overall pattern interestingly parallels the Southeast

Asia records such as stable lithic technocomplexes (Fuentes et al., 2019; Marwick et al., 2016; Patole-Edoumba et al., 2012; Van Tan, 1997) and the development of performance in bone/antler tools, symbolic ornamentation, art, specialized hunting strategies (Aubert et al., 2014; Boulanger et al., 2019; Brumm et al., 2017; O'Connor et al., 2017). However, this consistency resulted from either local inventions or as a part of the toolkit along the first colonization of modern humans in the region still needs more investigation. Considering the lithic industries reported in southern China, and modern human fossils records, we suggest that indigenous innovations is highly plausible. In comparison with the technological shifts that frequently happened in other regions, Zhaoguodong cave exhibits a unique and relatively stable adaptive strategy across the Late Pleistocene to the Holocene. We propose that the differences may be interpreted as different local technological optima that have found different positions within an adaptive zone.

This concept of technological consistency as a local adaptive optimum may be helpful beyond Zhaoguodong for understanding Late Pleistocene sequences throughout South China. Due to the warmer climates in the greater southern China region, blade and microlithic techniques have not been found extensively. Xiaodong site, dated back to 43.5 ka, in the south China region is associated with the oldest Hòabìnhian pebble and flake tools in Southwest China, which continued until 24.5 ka (Ji et al., 2016). Other major assemblages during this period are mainly characterized by the small-flake and cobble tool industry, such as Bailian phase 1 (Jiang, 2006), Ma'anshan (Hu & Gao, 2022), Chuanfandong lower level (Chen et al., 2001). Bailian and Chuanfandong were dominated by small flakes but were interrupted by cobble tools in a later phase. Ma'anshan (dated to 31–15 ky by ^{14}C; Zhang et al., 2009), dominated by limestone and chert, shares most common with Zhaoguodong. The stone artifacts from lower levels (56 ka, Wang et al., 2023) at the Chuandong cave site also exhibit a prevalence of small flakes and cores, which were produced through hard hammer percussion and bipolar technology on chert (Zhang, 1995). Subsequently, following a period of sterility, the lithic industry was superseded by larger tools made on basalt flakes and cobbles that were associated with the explosion of finely made bone tools (Mao & Cao, 2012; Zhang, 1995) between 15 and 11 ka (Wang et al., 2023). During the terminal Late Pleistocene period, the number of sites in the southern region increased significantly, especially sites from the late LGM period. However, these assemblages are characterized by fragmentary use of small-flake and cobble tools, such as Niupodong sites (Fu et al., 2017), Maomaodong (Zhou et al., 2022) and Bailian phase 2 (Jiang, 2006; Zhou et al., 2019). A recent study at Sandinggai (in Hunan Province, south China; Li et al., 2022) reported a gradual lithic technological shift from earlier LCTs reliance to later small flakes dominance, suggesting a relative continuity in lithic technology and continuous human occupation since 100–113 ka.

Current research, including genetic, and archeological material, suggests that anatomically modern humans (AMHs) from Africa dispersed into Asia around 65–45 ka (Demeter et al., 2017; Westaway et al., 2017) and several associated with the Neolithic period (Curnoe et al., 2015; Kong et al., 2011; McColl et al., 2018; Zhong et al., 2011) occurred within East Asia. However, in terms of technological perspective, little archeological evidence from the early Upper Paleolithic (40–30 ka) in south China has been found to confirm the "southern route" dispersal model (Jiang, 2006; Mao & Cao, 2012; Zhou et al., 2019). At Zhaoguodong, human fossils were found from the upper layers in 2016 that undoubtedly attribute the specie to modern human (~10 ka). They have a close relationship with Southern Chinese Neolithic specimens (Zhang et al., 2021). Despite the absence of direct evidence of modern human fossils in the earlier phases, the enduring continuity of multiple human behavioral patterns until the Holocene at Zhaoguodong since 45 ka, coupled with the current evidence suggesting an extremely low likelihood of co-existence of multiple *Homo* species in the region (Zhang et al., 2022). Southern China, and in particular southwest China, as one possible departure point to Southeast Asia and Sahul, is of great importance for understanding modern human dispersal, and behaviors. Unfortunately, modern human remains with secure chronology dating back to MIS 3 and consecutive archeological sequences are rare, making reconstructions in this region difficult. Therefore, Zhaoguodong cave presents a rare and valuable data point for investigating the occupation of modern human and their behaviors in Southwest China.

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