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Evidence of Levallois strategies on cores at Guanyindong cave, Southwest China during the Late Middle Pleistocene

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A B S T R A C T

The discovery of early Levallois stone-tool technology at 170 ka at Guanyindong cave, Southwest China, has raised questions about the validity and characters of Levallois strategy at this site. To address these questions, we present a detailed technological analysis that primarily focuses on the Levallois cores, along with Levallois flakes and by-products. These analysis include analytical descriptions, technological illustrations, worldwide inter-site comparisons, and quantitative analysis, providing extended and substantial evidence of the usage of Levallois strategy at Guanyindong cave, and indicating highly technological variability and likely convergent technological evolution during Late Middle Pleistocene in East Asia.

1. Introduction

The Levallois strategy, the representative technology of lithic mode 3, is significant for marking technical innovations and apparent shifts from biface manufacture to flake-based industries. It is one form of prepared-core reduction strategies that commonly appeared in Middle Palaeolithic assemblages in western Eurasia and Africa. Explanations for its omnipresence in different regions include either archaic *Homo* populations dispersal or technological convergence (Adler et al., 2014; Tryon et al., 2005; Foley and Lahr, 1997). Despite its broad geographical distribution in the western hemisphere, it has been generally regarded as absent in East Asia before Marine isotope stage (MIS) 3 (Bar-Yosef and Belfer-Cohen, 2013; Li et al., 2018). Recently, this view was challenged by a discovery of a set of Levallois stone artifacts from Southwest China dated back to 170–80 ka (Hu et al., 2019a).

This claim has inspired discussions on the validity of application of Levallois stone-tool technology in East Asia during Late Middle Pleistocene (LMP, Li et al., 2019a; Li et al., 2019b; Hu et al., 2019b; Li et al., 2020). To advance these discussions, here we extend this issue by supplementing more pertinent data and more analytical comparisons for further inspecting the usage of this technology.

2. Materials and method

Our analysis here focus on 45 stone artifacts (cores = 11, flakes = 30, retouched flakes = 4) that are identified as resulting from Levallois strategies, and relevant by-products. At the time of our analysis these materials are housed at Institute of Vertebrate Paleontology and Paleoanthropology. The identification of Levallois strategies on cores at Guanyindong is principally on the basis of the volumetric method developed by Boëda (1995). This reduction sequence concept permits a large variety of cores and flakes. Meanwhile, we integrate this concept with more recent applications in Africa and Europe (White and Ashton, 2003; Scott, 2006; Bolton, 2015), which, rather than matching the Mousterian typology and similarly precise and delicate pieces, embraces localized convergences on Levallois technology that have no historical connection to the Bordesian core area of Levallois.

The recognition of debitage pieces resulting from Levallois strategies is harder, compared with the identification of cores (Boëda, 1995; Van Peer, 1992; Shimelmitz and Kuhn, 2013). Ideally, the identification of

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Levallois flakes would be based on refitting to Levallois cores. Unfortunately, this analysis was not possible at Guanyindong due to the small sample size. Instead, we employed several criteria to avoid arbitrariness and improve the reproducibility of our analysis. These criteria include a clearly organized scar pattern which indicates the predetermined process, the angles between the striking platform and debitage surfaces to monitor the percussion angle of the flake, and morphological symmetry (Debénath and Dibble, 1993).

3. Results

3.1. Levallois reduction strategy in the Guanyindong assemblage

We previously introduced the stratigraphy and dating of the archaeological deposits at Guanyindong, but only briefly described the Levallois lithic technology in the assemblage (Hu et al., 2019a). Here we expand on this with additional metrical descriptions, diacritical sketches, reduction schemes, analytical photos, and diagrams for Levallois cores (Figs. 1–8, Tables 1–2). Three preparation methods were applied to produce the cores: centripetal, bidirectional, and unidirectional. Both preferential and recurrent approaches were exploited to produce predetermined blanks. However, the dominant method was centripetal preferential (55 %, Table 1). The preparation intensity of striking platforms and peripheral convexities varies depending on each core reduction scenario with some closer to proto-Levallois, whereas some resemble late Mousterian techniques such like Nubian-Levallois. The predetermined blanks were produced by parallel or sub-parallel removal, with respect to the intersection plane, using hard hammer percussion.

Many flakes have facetted platforms (Fig. 18), an important detail confirming the preparation of striking platforms, and the dorsal scar patterns display earlier lateral and distal convexity management, as well as previous predetermined removals. The convexity removals indicate that the main production method was also centripetal preferential method. Preceding predetermined removals are displayed by invasive central scars (Fig. 18).

3.1.1. Individual analytical inspections and technological descriptions of cores

In this section we present the analytical illustrations (Figs. 1–8) of Levallois cores in the Guanyindong assemblage. We narrate specific analysis for each core.

Specimen P15948 (Fig. 1), speculating from the cortex on the lower surface, is a core whose original size could not be reduced too much, yet the initial morphology of the nodule probably had been altered repeatedly after frequent recycling exploitation and eventually ending up with a slab shape. Two distinct hierarchically related surfaces can be readily identified. The creation of lateral convexities was via a few preparatory flakes and an orthogonal elimination to determine the distal side. The main volume of this surface was possibly peeled off during recurrent re-preparations of convexities. The parallel preparatory and predetermined flakes (the dotted plane in the figure indicates the intersection plane of upper and lower surface) sustain the continuity of configuration process by avoiding the increasement of flaking surface convexity. At the final stage, the last desired product is hinged, then, the exploitation was terminated. For the lower surface, the remaining bulk of cortex is dedicated to striking platforms with both plain and facetted preparation. This core yielded two predetermined blanks. Please see 3D image for this core on page 52 in SI from Hu et al. (2019a).

Specimen P15226 (Fig. 2) is a centripetal preferential Levallois core made on a cortical chert nodule. Two surfaces are distinct and hierarchized. The lateral and distal convexities were maintained by centripetal peripheral removals. The right-side convexity was controlled by one débordant removal. The striking platform surface was partially

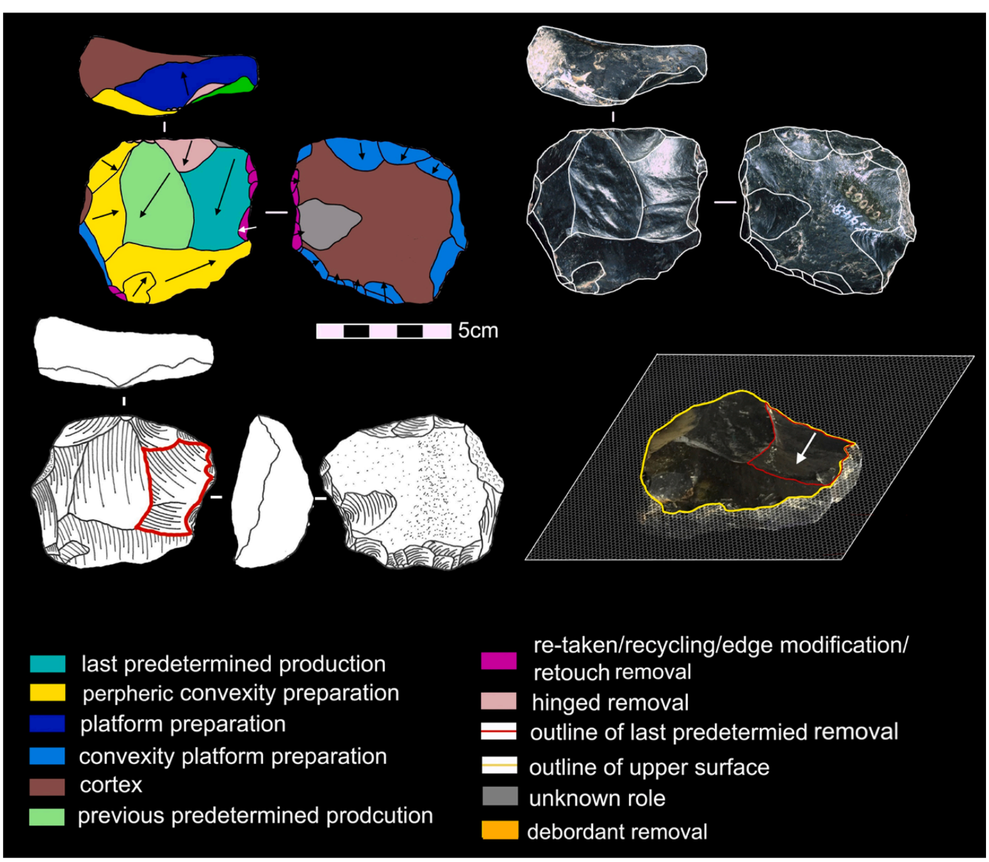

Fig. 1. Recurrent Levallois core made on a black chert nodule.

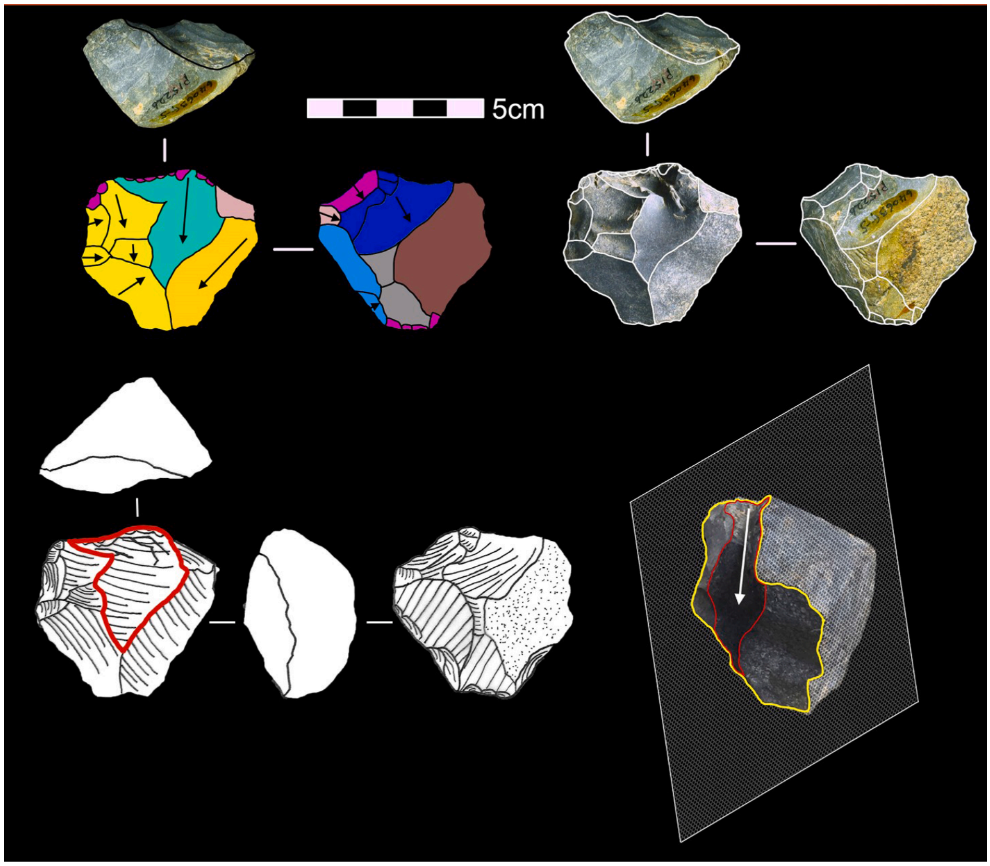

Fig. 2. Centripetal preferential Levallois core made on a cortical chert nodule.

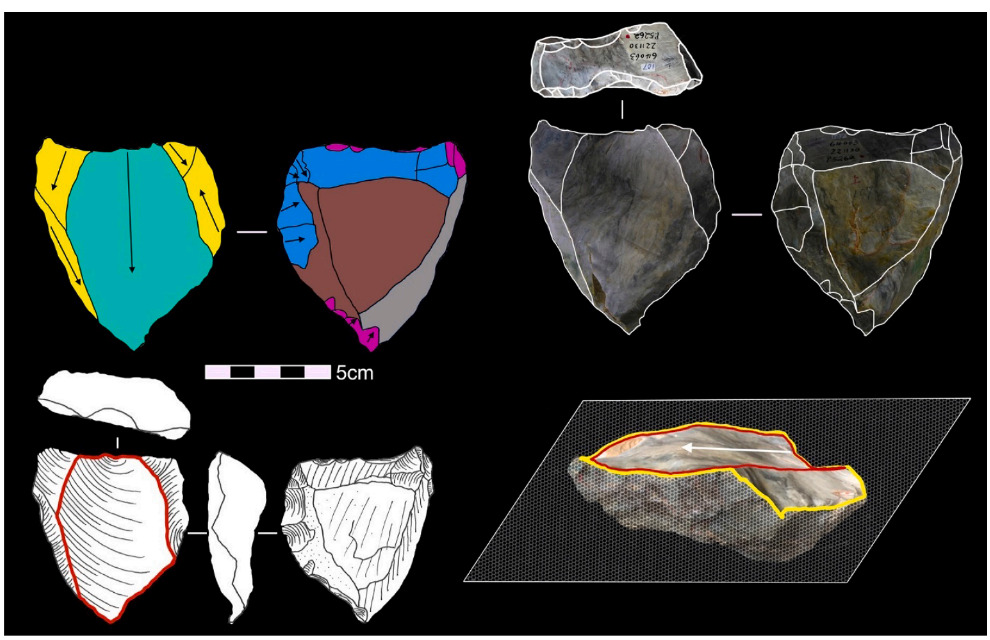

Fig. 3. Preferential Levallois core.

prepared. The predetermined and last flake was removed after all the stage of preparation. All the flaking fractures of predetermining and predetermined flakes are parallel or sub-parallel to the plane. re-taken/ edge modification scars are visible on the platform edge. Although parallel planes exploitation was utilized, this core shows a reversed trapezoidal cross-section, which is commonly considered as Levallois in some literature (see also Section 3.2.6 below), yet some regard it as only partially prepared (Carmignani et al., 2017).

Specimen P5262 (Fig. 3) is a preferential Levallois core prepared by bidirectional removals. The core volume is divided into two hierarchical surfaces, a 3D image for this core is available on page 51 in SI from Hu et al. (2019a). The upper surface is a dedicated flaking surface, where an

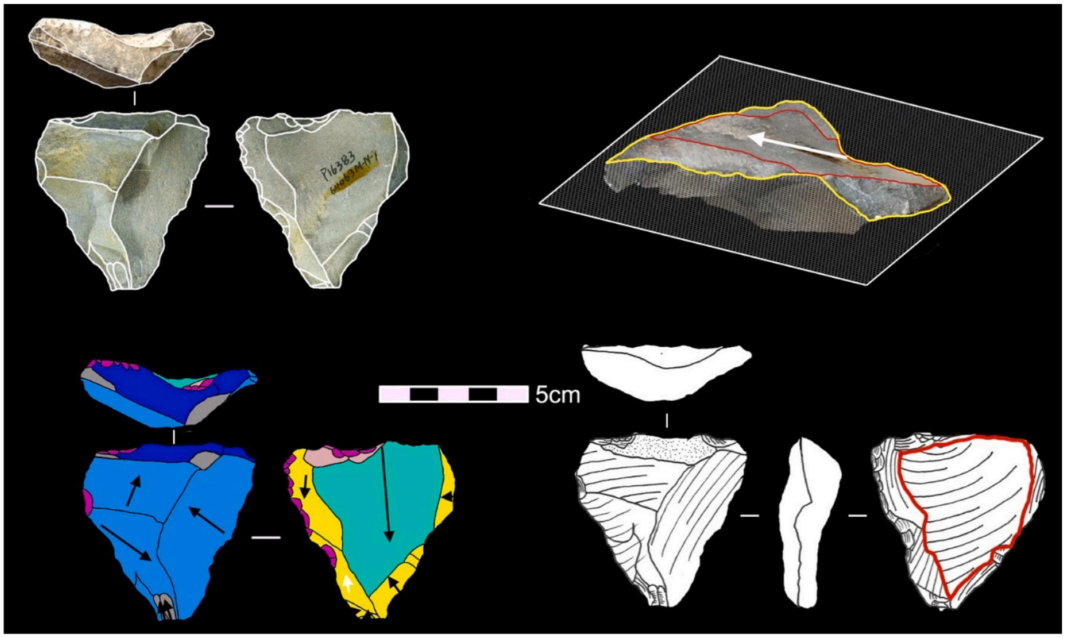

Fig. 4. Preferential Levallois core which is Nubian-like.

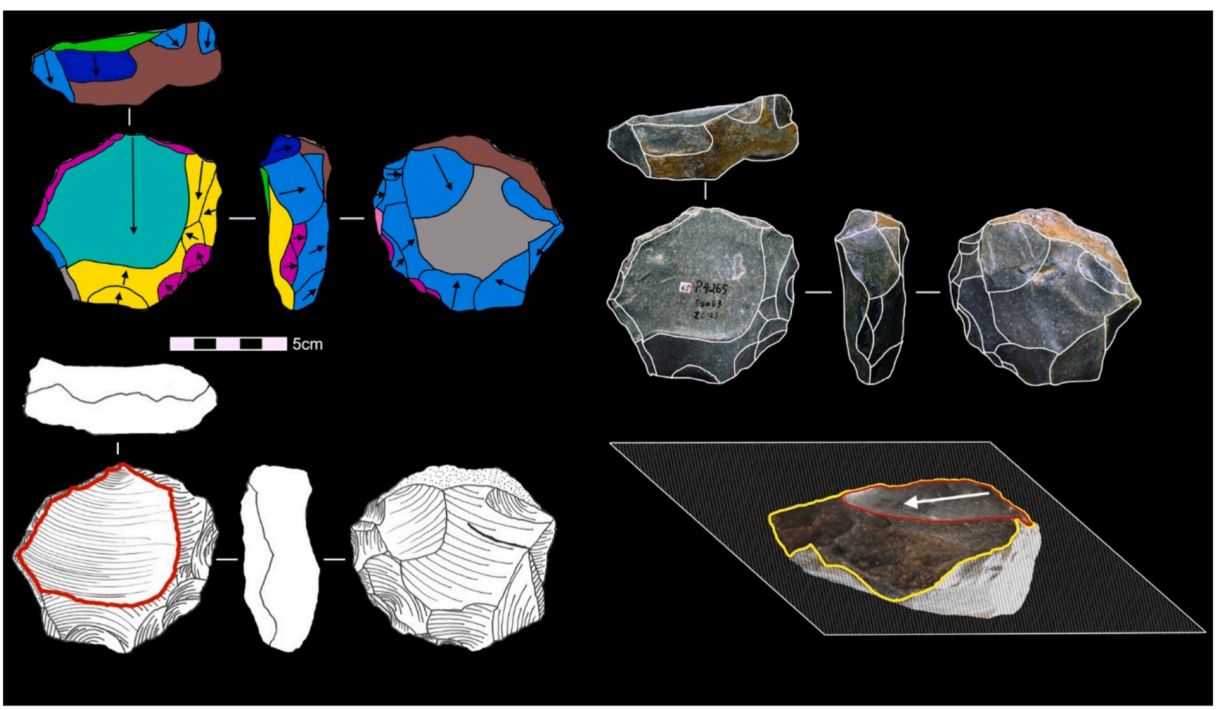

Fig. 5. Preferential Levallois core made on a cortical nodule.

overpassed oriented flake was detached. Signs of management of lateral convexities by core débordant flakes and peripheral removals are visible on both the right and left. However, the distal side was eliminated by a final overshot flake removal. Owing to the ridges of preparatory convexity removals, the final detachment is invasive and covers most part of flaking surface. The lower surface, a devoted surface of striking platforms, was roughly prepared. Li et al. (2019b) claim that except for several scatter edge modification removals, the core is made on naturally flat slab. However, we dispute this claim due to the complete removal of cortex from the upper surface, and major traces of convexity management. In addition, the 'oriented flake' is extracted successfully in a way that not only the hinge of the striking platforms and the flaking surfaces are perpendicular to the flaking axis, but also the flaking fracture is parallel to the plane that divides the two surfaces. Overshot flakes are common in Levallois technology (e.g. (Hallinan and Shaw, 2020), see example and discussions in Section 3.2.6 and Fig. 15), so the last flake from the relatively broader face of this core meets the requirements for a basic Levallois flake (Dibble, 1985; Sandgathe, 2004; Schlanger, 2008; Eren et al., 2011).

Specimen P16383 is a Nubian-like preferential Levallois core (Fig. 4) whose preferential flake removal was guided by the preparation of a steep medial-distal ridge through either distal divergent or lateral

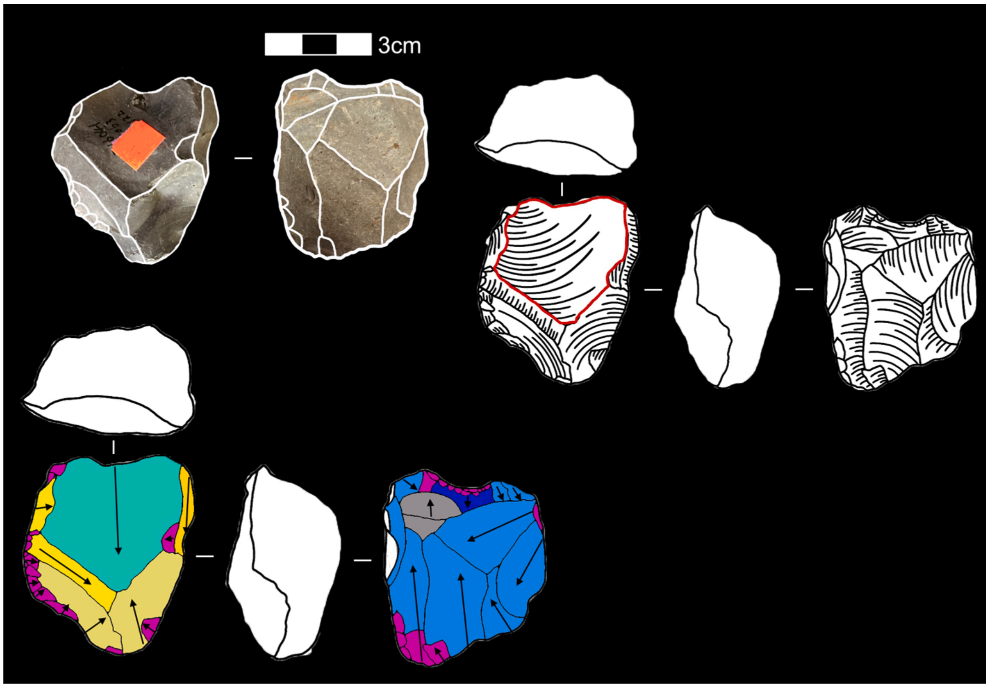

Fig. 6. Preferential centripetal Levallois core which is recycled in later phases.

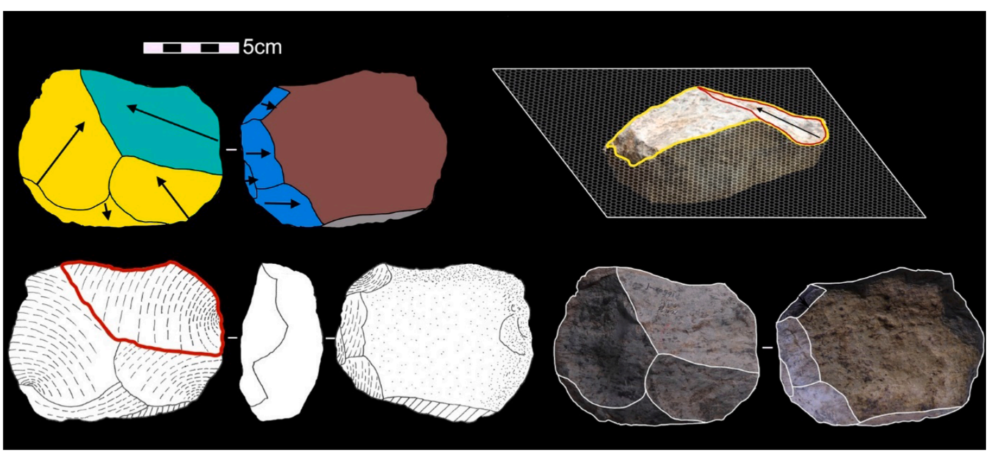

Fig. 7. Preferential centripetal Levallois core.

removals (Guichard, 1965). Likewise, this core shows precise preparation of the distal and lateral convexities with the last preferred removals all extending over the middle point of the flaking surface without increasing the middle point of the flaking surface, even when approaching the core's exhausting stage. The lower surface was maintained by three large detachments for creating peripheral platforms. The platform of the predetermined flake is prepared roughly, associated with a percussion angle that is around 80°. Debitage removal likely stopped because it was too flat without potential volume for further exploitation.

Specimen P4265 (Fig. 5) is a preferential Levallois core made on a cortical nodule, a 3D image for this core is on page 50 of the SI of Hu et al. (2019a). The lateral and distal convexities were configured mainly by bidirectional flakes parallel to the direction of the flaking production. The management of convexities enable the final desired flake to spread to most parts of the upper surface. This is comparable with the observations on flakes, whose dorsal surfaces are often covered by large unidirectional negative removals (see examples in Fig. 18). The platform surface was also carefully prepared, mainly by vertical removals along the contour. The only coarse preparation of striking platform is where the predetermined flake detached. However, the minimal preparation did not impede the final flake detaching along the flaking axis perpendicular to the line of intersection of the two surfaces and parallel to the intersection plane. Li et al (2019b) disputed the Levallois character of this core because of several recycling removals, which we named 're-taken flakes.' These kinds of removals are commonly observed in Levallois assemblages and are referred by diverse terms, including "re-taken/recycling/edge modification/retouch" (e.g. Moncel et al., 2020). Although exact role of those removal is unknown, perhaps due to taphonomy, retouch, or recycling, the predetermined management of the core is recognizable.

Specimen P16041 (Fig. 6) is a preferential centripetal Levallois core. A hierarchical division of the core volume separates flaking and preparing surfaces. The preparing surface served as striking platforms and they were mostly plain. The lateral convexity was maintained by convergent unidirectional removals and core débordant. Two convergent removals were struck obliquely with respect to the intersection plane from opposite determined the distal side. A big invasive preferential blank was removed that truncated the bulk of upper volume of the

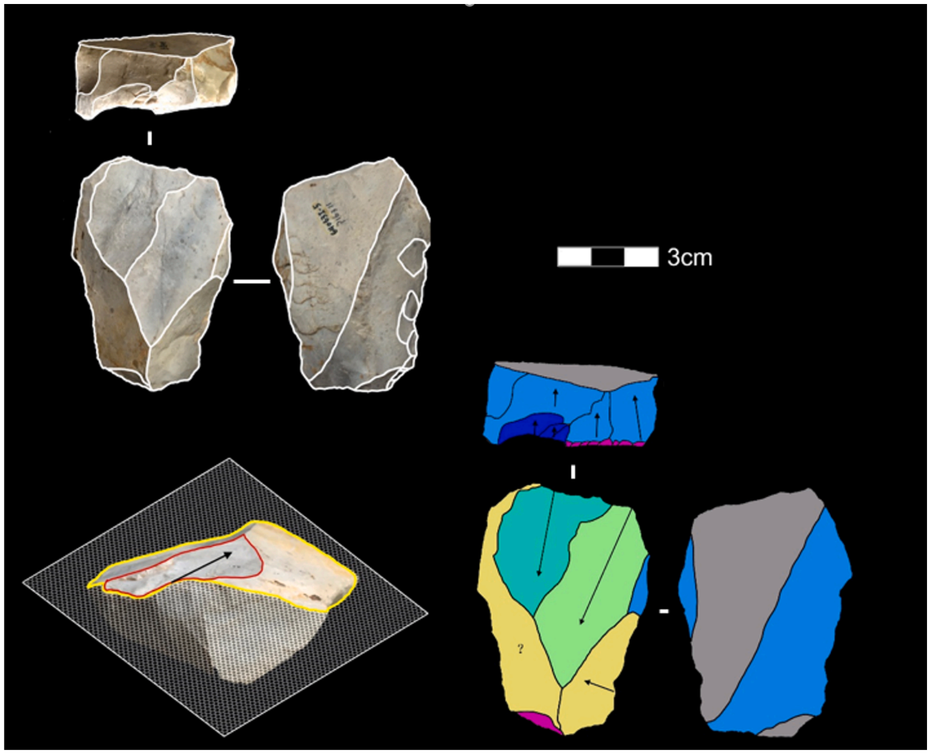

Fig. 8. Recurrent unidirectional Levallois core with less preparation.

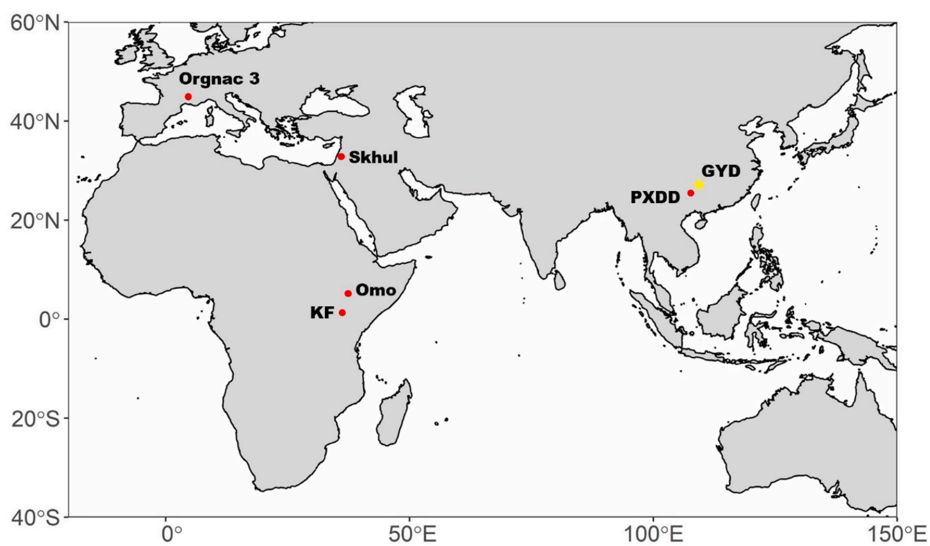

Fig. 9. .Locations of compared sites. Omo stands for Omo Kibish Formation; KF stands for Kapthurin Formation; PXDD stands for Panxian Dadong cave; GYD stands for Guanyindong cave.

core. The Levalloisian production is possibly-one episode of the reduction sequence for this core. A series of small final removals/re-taken flakes on the platform, as well as the core periphery, indicate this core was perhaps recycled as a tool. This fragmentation of the reduction sequence is also observed elsewhere (see example in Fig. 14C).

Specimen P16502 (Fig. 7) is the only Levallois core in this assemblage made on a cortical nodule that is less fine-grained. This probably also contributed to its relatively simple preparation. However, both convexity management and platform preparation can still be observed and reveal a predetermined core configuration. The upper surface and the opposite surface are divided by a plane, where two distinct concepts of exploitation are separated. The original chunk of upper surface was reduced through several centripetally invasive removals, in order to create a convexity for guiding the detachment of a larger preferential flake. The lower surface has a much steeper manner for forming a platform for subsequent parallel predetermined flake removals.

Specimen P16311 (Fig. 8) is recurrent unidirectional Levallois core made on nonhomogeneous chert chunk. The core's volume is divided by two convex asymmetrical faces that are hierarchically ordered and defining a plane of intersection. Both convexities of upper face and lower face were simply prepared with inclined removals, whereas the striking platform for the predetermined flakes was trimmed, increasing the flaking angle for parallel removals. Although each phase of preparation and production is represented on hierarchically organized

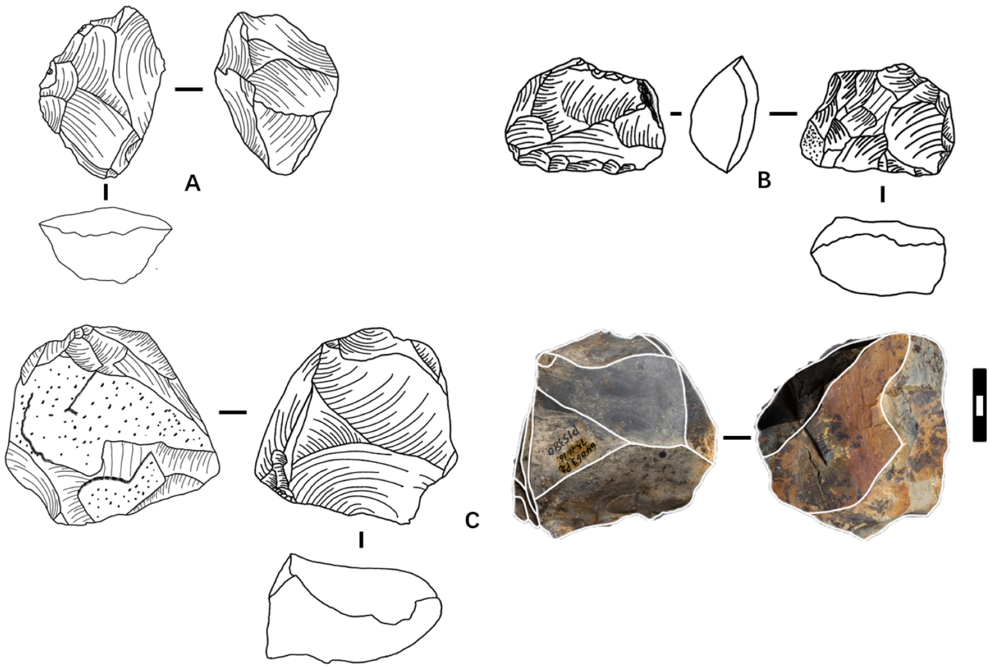

Fig. 10. Hierarchical cores from Guanyindong showing the hierarchical structure of upper surface and lower surface.

surfaces, the cores interpreted here are similar to a 'proto-Levallois/ simple prepared core' (whose Levallois attribution is debated depending on whether either a stricter or a broader concept is adopted) defined by White and Ashton (2003), for showing less intensive maintenance of peripheral convexities (see more discussion in Section 3.2.6 and Fig. 16).

3.1.2. Summary of methods and traits of Levallois cores at Guanyindong

Overall, the Levallois approach at Guanyindong is characterized by centripetal preferential methods. The preparations of platform, peripheral convexities, and parallel (uni- and bidirectional) exploitation are well-presented on cores. They are very different from other types of cores from the site and there is little chance of confounding with other core technologies. That is because, like some sites in other regions (Moncel et al., 2020; Wiśniewski, 2014; Koulakovska et al., 2010), Levallois production exists here without a bifacial tradition (only one isolated handaxe is identified), excluding the misreading of bifaces with large thinning removal as Levallois cores. Other core reduction methods, such as discoidal or polyhedral types, depend on the natural convexity and geometry of the original blanks and migrating episodes with no sign of management of the convexities. In those other methods, since no efforts were made for creating new convexities and maintaining the core volume, cores are abandoned after the natural convexity disappears, even if the core is far from exhausted. The appearance of Levallois flakes with corresponding dorsal scars confirm the presence of Levallois strategies at Guanyindong in terms of the upper surface of flake production, management of core surface convexities, percussion with hard hammer as well as the usage of diverse methods (Fig. 18). The question of whether Levallois strategies at Guanyindong were persistent or opportunistic requires future work at similarly aged deposits in the region.

We speculate that the development and use of Levallois strategies at Guanyindong occurred in parallel with behavioral shifts such as mobility, hunting strategy, cognitive abilities, cultural and social life. However, many of these shifts are difficult to identify directly from Guanyindong based on the evidence currently available. The origin of Levallois at Guanyindong is unclear; we have not identified a sequence of technological evolution through the stratigraphy. Nevertheless, the onset of the Levallois strategy suggests an important turning point in Southwest China during LMP.

3.2. Inter-site comparison of Levallois core technology

In this section, we compared the Levallois assemblage at Guanyindong with five well-dated sites associated with the Levallois concept to contextualize the core strategy with contemporary lithic prepared-core technologies (Fig. 9). Because the advent of Levallois is scattered compared with well documented MSA assemblages (Klein, 1999; McBrearty and Brooks, 2000), we selected two of the earliest MP/MSA sites from Europe (Organc 3) (Moncel et al., 2020; Moncel et al., 2011; Moncel et al., 2012; Fontana et al., 2013) and Africa (Kapthurin formation), (Tryon et al., 2005; Tryon, 2006; McBrearty and Tryon, 2006; Tryon and McBrearty, 2006; Tryon and Faith, 2013). In addition, three roughly contemporary sites, Skhul (PRM sample) (Shea, 2003; Shea and Bar-Yosef, 2005; Groucutt et al., 2019) in Levant, Lower Omo Valley Kibish Formation (Shea, 2003; Shea et al., 2007; Shea, 2008) in East Africa and Panxian Dadong (Huang et al., 2012; Otte et al., 2017) in China, were also selected for peer comparison. More specific qualitive comparisons among these sites and other related sites are presented afterwards (Section 3.2.6).

3.2.1. Orgnac 3

The raw material of Orgnac 3 is dominated by local (2–5 km) gathered flint slabs (90 % for lower levels and 99 % for upper levels). A variety of other raw materials used less common were also collected, including quartz, quartzite, limestone, basalt, hornfels, pebbles, etc. Most of them are collected from very local area as well (Moncel et al., 2012) (Table 1).

The first levels with Levallois are Levels 4b-4a (MIS 9). Towards the upper levels Levallois production increases with widespread finds of core-on-flake also (Figure 11C). At the first stage Levallois cores were mainly exploited by unidirectional methods, which was replaced by centripetal in the following upper levels (3–1) (Figure 14C). These variations are probably related to MP type behaviors that changed gradually at the end of MIS9. This technique seems rooted in MIS12 at Cagy la Garenne where 'pre-Levallois' was identified (Moncel et al., 2012). The preferential flake method is quite frequent, with the occasional application of uni- and bipolar for the latter can usually produce flakes without reworking optimizing the convex surface. At Guanyindong, both centripetal preparation and preferential methods are

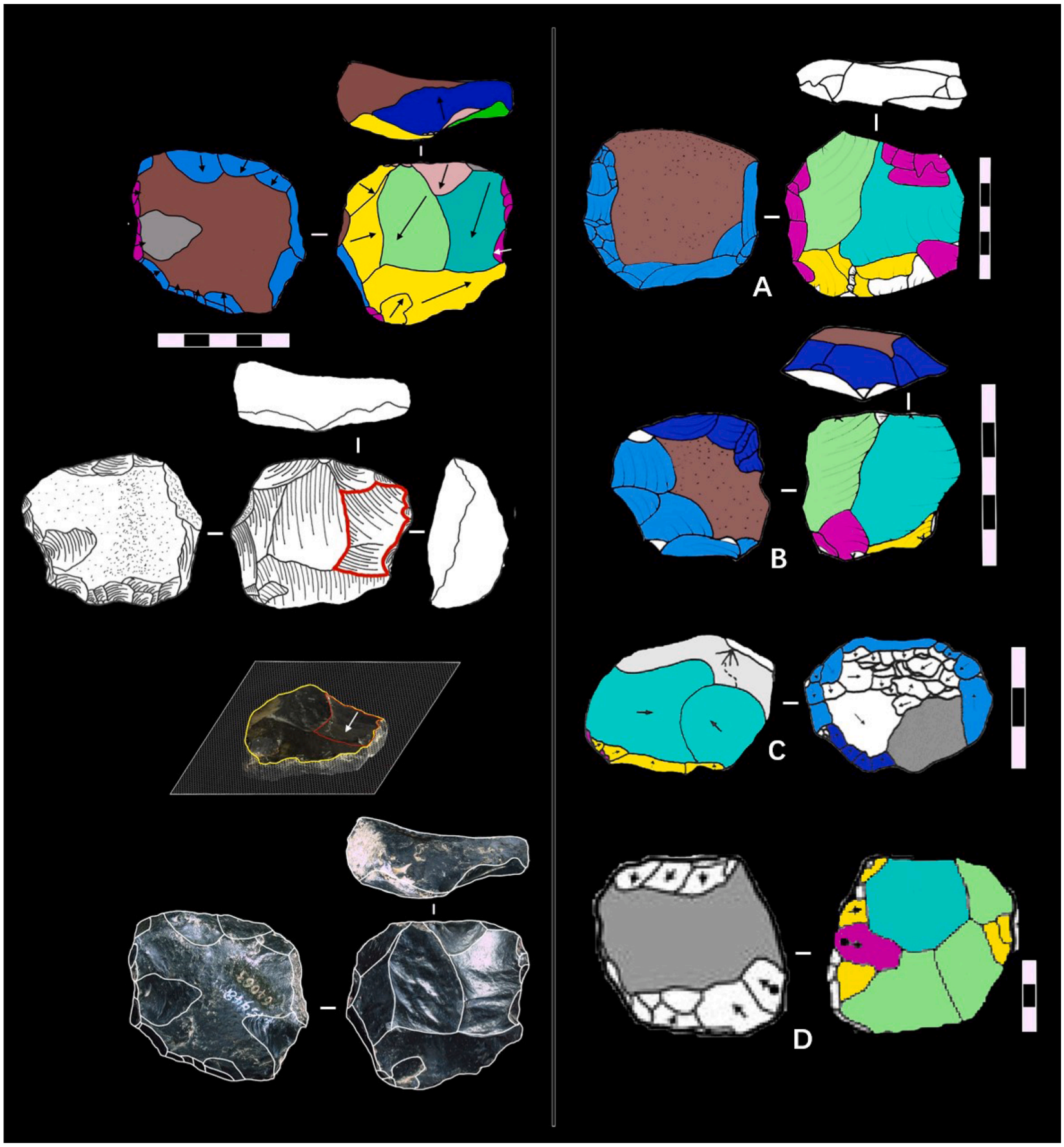

Fig. 11. Core configural comparison between recurrent Levallois cores from Guanyindong (left) and other sites (right). (A, B) BNS (Shea, 2008); (C) Orgnac 3, layer 1 (Fontana et al., 2013); (D) KL1 (Kenya) (Tryon et al., 2005). Please note that the filled color of cores from other sites are done by us based on descriptions in published papers and our own reading.

prominent. Similar with the upper levels of Orgnac 3, these Levallois products are associated with common core-on-flake strategies. Also, Levallois operation is associated with discoidal production at Orgnac 3, as at Guanyindong. And compared with level 5b and 5a (lower levels) of Orgnac 3, the ratio of Levallois product frequency is parallel between two sites, but at level 5b and 5a, cores are mostly unidirectional, bidirectional recurrent (Moncel et al., 2020), meanwhile preferential centripetal was dominant at Guanyindong throughout. However, at Orgnac 3, the Levallois technology gradually evolved and dominated during two phases, indicating an in situ development (Moncel et al., 2012). In contrast, at Guanyindong, such conclusion cannot be drawn owing to incomplete provenance information.

One difference between Guanyindong and Orgnac 3 is the use of big flakes (Mathias, 2016; Mathias and Bourguignon, 2020). A large quantity of Levallois cores were made on flakes that have a naturally convex surface that can be utilized as a peripheral convexity (Fig. 11C). However, there are no Levallois cores made on flakes at Guanyindong. Instead, big flakes are usually ramified into core-on-flakes by truncating the distal and proximal end. Re-taken/recycling flakes found on Orgnac 3 Levallois cores are small removals and on more than half of cores indicates a deliberation of small flake products (Fig. 14C in (Moncel et al., 2020), whereas those removals on Levallois cores at Guanyindong are less continuous and partially confined (e.g., Fig. 5).

The main range of flint core lengths is 40–50 mm, while for Guanyindong the core length range is around 50–100 mm (maximum length) (Table 1). At Orgnac 3, Levallois flakes almost fall in the same range (30–50, 65–70 mm) as Guanyindong (30–80 mm). In level 4a and 4b of Orgnac 3, flakes never cover the flaking surface (Fontana et al., 2013), whereas Levallois flakes that cover a large portion of flaking surface are common. Part of the production at Orgnac 3 level 1 can be classified as microlithic for small cores (15–20 mm) and flakes (<15 mm). This kind of small flake production can be also observed on core-on-flake pieces at Guanyindong.

At Orgnac 3, Levallois flake platforms are 30 % facetted, 10 % dihedral, while at Guanyindong striking platform are usually plain (44 %), followed by facetted (11 %) (see examples in Fig. 18) and dihedral (10 %). Chapeaux de gendarme found at Orgnac 3 are absent at Guanyindong.

With respect to Levallois frequency, the ratio of Levallois in the upper layers of Orgnac 3 is obviously higher than Guanyindong. But,

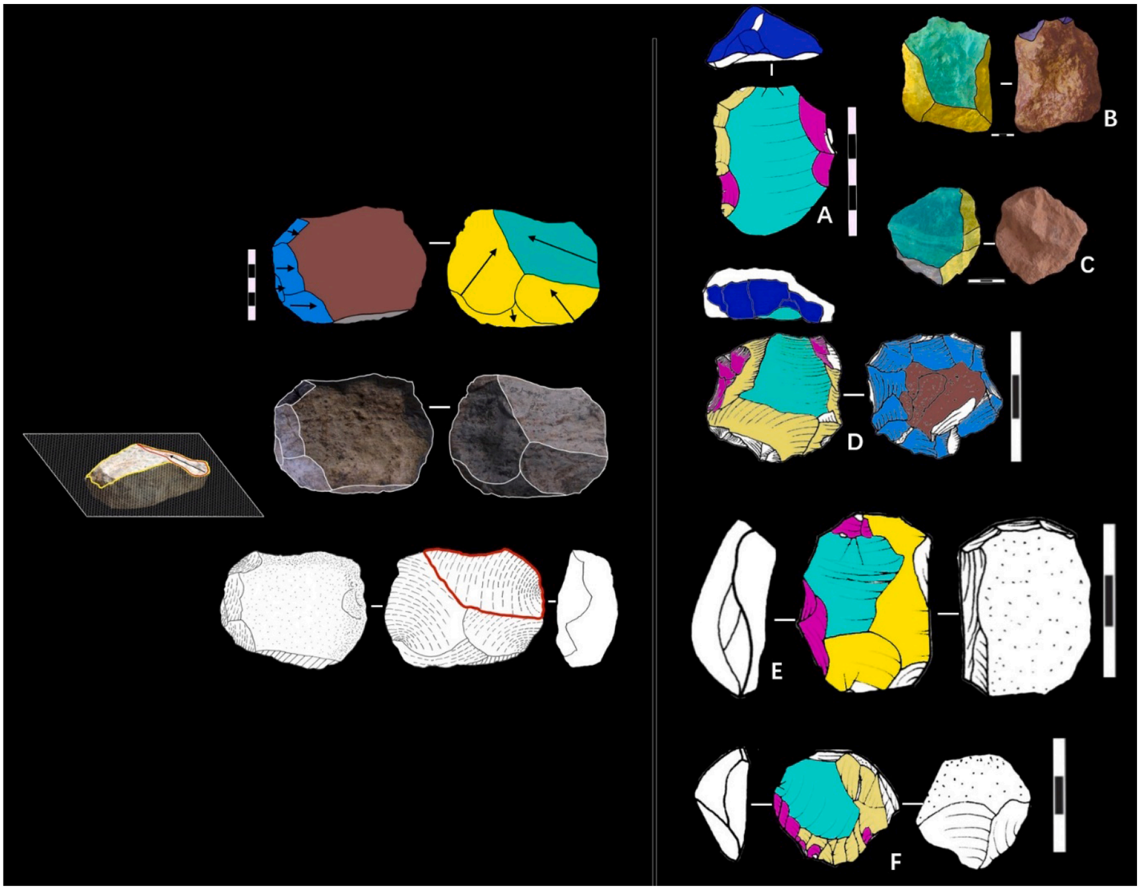

Fig. 12. Core configural comparison between preferential centripetal cores from Guanyindong (left) and other sites (right). (A, F) AHS (Shea, 2008); (B, C) Panxian Dadong (Huang et al., 2012); (D) KHS (Shea, 2008); E) BNS (Shea, 2008).

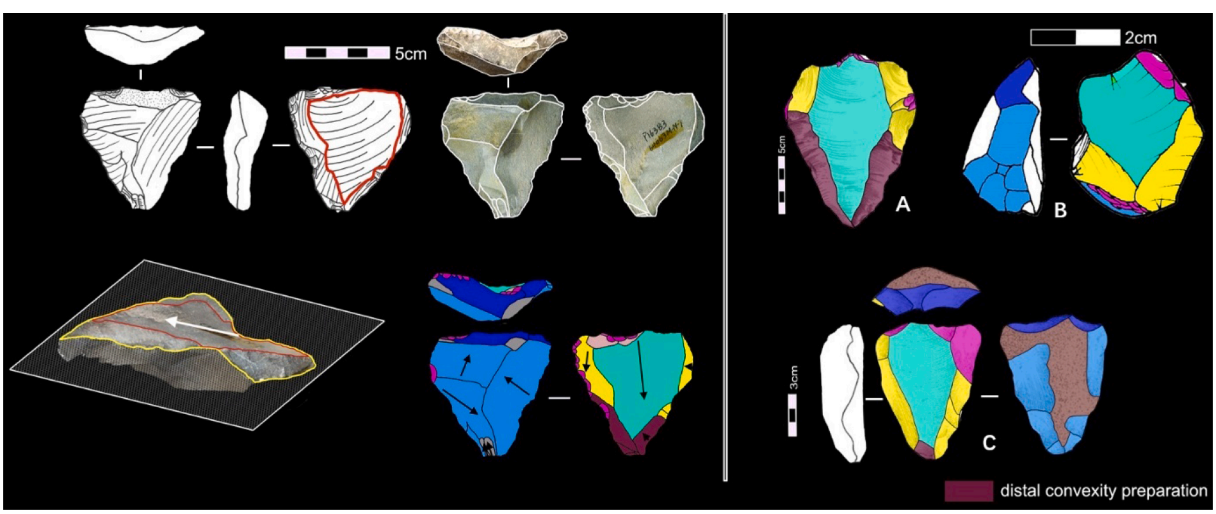

Fig. 13. Core configural comparison between Levallois core from Guanyindong (left) and Nubian, Levallois point cores from other sites (right). (A) Dhofar, southern Oman (Usik et al., 2013); (B) BNS, Levallois point core (Shea, 2008); (C) Central Arabia (Crassard and Hilbert, 2013).

since similar methods are used (centripetal preferential), flakes with an invasive scar on the dorsal surface became more common on upper levels at Orgnac 3 (Moncel et al., 2012), likewise this kind of flake is extensively presented at Guanyindong (Fig. 18), which is unusual at contemporary sites in East Asia.

There are few cases with predetermination of knapping strategies as at Orgnac 3 during MIS 8–9 in SE France, representing a beginning phase of extension of a prepared core strategy (Picin et al., 2013). Similarly, Guanyindong is one of the isolated and early sites to use prepared-core technology in East Asia. This innovation seems be related to higher quality raw material, mobility strategies, and other factors of behavior adaption during the Early MP. To sum up, Guanyindong and Orgnac 3 have similarities in local raw materials, preparation and production methods, core and flake sizes, flake characters and a variety of methods for diverse blanks.

Table 1
Main attributes of Levallois products of the compared sites. RM = Raw Material; prefer = preferential; recur = recurrent; cent = centripetal; uni,bi,cov = unidirectional, bidirectional, convergent; dihedral, plain refer to flake platform types.

Site	Layer	Region	Date(ka)	Method	Reference	Majorrawmaterial	RMprocurement	Coreno.	Core%	Flakeno.	Flake%	Allartifacts	Prefer	Recur	Cent	uni, bi, cov	Scarsize(mm)	Flakesize(mm)	Coresize(mm)	Facettedflake%	Dihedral%	Plain%
Orgnac 3	1	France	MIS8			flint	2–5 km	540	1.03	1676	3.20	52,315			more	less	30–70		40–50	30	10	
	2		<302.9	Ar/Ar, U/Th	(Michel et al., 2013)			138	1.63	434	5.12	8483			more	less						
	3		MIS9					58	1.44	152	3.77	4029			more	less						
	4a							8	0.38	64	3.00	2133	more	less	less	more						
	4b							11	0.33	37	1.13	3285	more	less	less	more						
	5a		288–374	ESR, U/Th, Ar/Ar	(Michel et al., 2011, Masaoudi, 1995)			3	0.06	14	0.29	4759	less	more	less	more						
	5b							4	0.08	54	1.1	4931	less	more	less	more						
KF	LHA	Kenya	284–509	Ar/Ar	(Deino and McBrearty, 2002)	fine-grained lava	local	4	0.26	18	1.17	1536	more	less	more	less	130–150					
	FS							6	1.06	1	0.18	567	more	less	more	less						
	KL1		200–250	Tephrostratigraphic correlation	(Tryon and McBrearty, 2006)			7	0.16	11	0.25	4033	similar?	similar?	more	less						
	KL2											343	similar?	similar?	more	less						
Omo	KHS	Ethiopia	195 ± 5	Ar/Ar	(McDougall et al., 2005)	fine-grained cryptocrystalline silicate rocks	Kibish Member I	10	2.92	12	3.5	343			more	less		<50	<30			
	AHS					chert most common, followed by phyolite and shale		4	0.052	46	0.59	7737			more	less		30	30			
	BNS		>104 ± 1			fine-grained and highly siliceous rocks		8	0.42	33	1.7	1924						30	40			
Skhul	PRM	Israel	100–130	TL, U-series/ESR	(Grün et al., 2005, Mercier et al., 1993)	chert	very close	48	17.78	85	31.48	270	more	less	more	less						
Panxian Dadong		China	130–360	OSL, ESR	(Jones et al., 2004, Zhang et al., 2015)	chert, basalt, limestone	local	5	<0.25	15	<0.75	greater than2000	more?	less?	more	less						
Guanyindong		China	170–80	OSL, U/Th	(Shen and Jin, 1992, Hu et al., 2019, Yuan et al., 2000)	chert	2–6 km	11	0.49	34	1.5	2270	7	4	8	3	30–80	30–70	50–100	11	15	44

Table 2
Statistic comparison between Skhul (PRM) and Guanyindong Levallois cores. Min = minimum; max = maximum; dim = dimension; tech = technological.

	Mass (g)		Max dim (mm)		Max thick (mm)		Tech length (mm)		Tech width (mm)	
Site	PRM	GYD	PRM	GYD	PRM	GYD	PRM	GYD	PRM	GYD
Min	15.5	41	31	46.5	11.3	21	22.7	32.1	31.6	41.6
Max	397.2	383	109.7	104	52.6	51	100.9	101	108.2	89
Mean	74.3	147.5	57.3	75.8	22.7	31.4	51.1	62.8	53.2	66.3
Sd	77.8	110.1	15.6	20.4	9.5	11	15.5	25.5	14.3	14.7

*Max thick for Guanyindong is based on oriented thickness.
PRM stands for Skhul (PRM), GYD stands for Guanyindong.

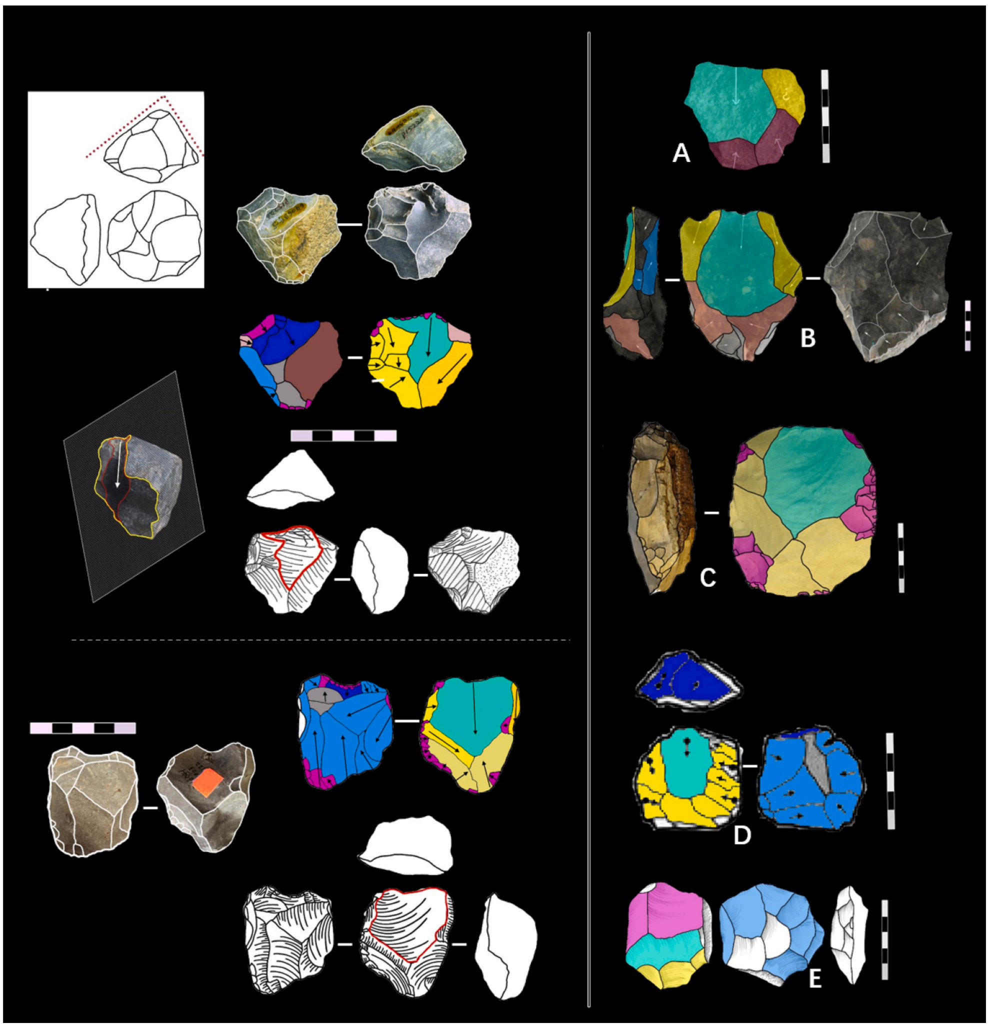

Fig. 14. Core configural comparison between preferntial centripetal cores from Guanyindong (left) and other sites (right). Sketech in white box is recurrent centripetal Levallois core from Central Arabia showing reversed trapezoidal cross-section (Crassard and Hilbert, 2013). (A) The Jebel Katefeh-1 (Arabia) (Groucutt et al., 2015); (B) Zwochau (Germany) (Picin, 2018); (C) Orgnac 3, layer 2 (Mathias, 2016); (D) KL1 (Kenya) (Tryon et al., 2005); (E) Panxian dadong (Otte et al., 2017).

3.2.2. *Kapthurin formation*

In the Kapthurin Formation (KF), the earliest African MSA assemblage (McBrearty and Tryon, 2006), Levallois products from four sites, namely Leakey Handaxe Area (LHA), Factory Site (FS, 284–509 ka), Koimilot Locus 1 (KL1), and Locus 2 (KL2, 200–250 ka) (Tryon et al., 2005) are compared here.

At LHA and FS, the raw materials are mainly local fine-grained phonolitic lava in the forms of rounded cobbles and boulders. At KL1 and KL2 a greater variety of similar fine-grained lava, which resemble European flints, was also utilized (Table 1).

The patterns on flake dorsal surfaces and core flaking surfaces suggest a majority exploitation of centripetal method (Fig. 11D, Fig. 14D, Fig. 16E), associated with one bidirectional core and flake. This is similar with Guanyindong. The same patten is also observed at KL1, where all Levallois cores and flakes are centripetal. Other than centripetal, flakes from KL2 also indicate unidirectional and convergent removal pattern. However, convergent preparation has not been found at Guanyindong. '*Éclats débordants*' (débordant) for lateral and distal convexities are traced on a core and five flakes (Tryon et al., 2005). As for Guanyindong, they are found on both cores (Fig. 2, Fig. 3 and Fig. 6) and a small number of flakes. All the platforms of KF Levallois flakes are facetted, whereas for Guanyindong only so are for 11 % of them. Hard hammer percussion is the exclusive technique used at both KF and Guanyindong. Overshot knapping accident on one core at KF terminated

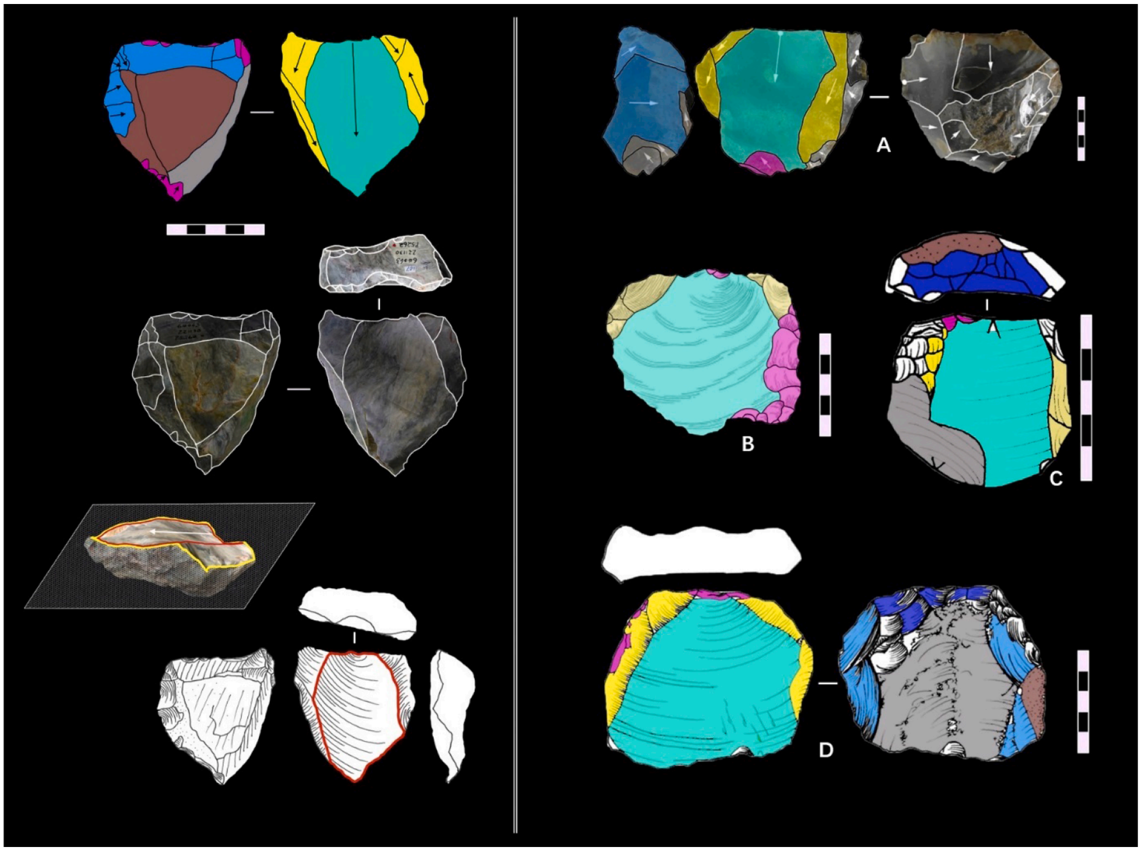

Fig. 15. Core configural comparison between preferential Levallois cores (overshot) from Guanyindong (left) and other sites (right). (A) Zwochau (Germany) (Picin, 2018); (B) Skhul (Groucutt et al., 2019); (C) BNS (Shea, 2008); (D) Nor Geghi 1 (Armenia) (Adler et al., 2014).

the reduction. Likewise, overshot removal combined with the depletion of volume also stopped the Levallois debitage on some cores at Guanyindong (Fig. 3).

Compared with Guanyindong, the core mass (3 kg) and flake removal size (130–150 mm) (Table 1) at KF are much larger. Maximum lengths of Levallois flakes from KF range from 40 to 180 mm (KL2 around 100 mm, KL1 around 50 mm, LHA all larger than 100 mm) (Tryon et al., 2005). While for Guanyindong the dimensions of flake removals on cores are between 30 and 70 mm and flake sizes range from 30 to 70 mm (Table 1, about 50 mm on average), End-struck (length > width) is the only flake type for all KF flakes, side-struck are rare (n = 1?). For Guanyingdong, Levallois flakes with lengths larger than their width (end-struck) are in the majority (67 %). As with Guanyindong, both preferential and recurrent methods are presented at KL1 (Fig. 11D, Fig. 14D). Some of those flakes (all from Acheulian sites: LHA and FS) were recycled by thinning on the ventral face or retouched along the edges. So do Levallois flakes at Guanyindong, as many of them exhibit the trace of recycling but not for thinning pieces since bifaces are almost absent at Guanyindong. Demand for larger flakes at LHA and FS was probably one of the reasons for the larger Levallois flakes and exclusive usage of preferential, while the dominance of preferential flakes at Guanyindong reflects the technological choices there.

Overall, the Levallois features among Acheulian (LHA and FS) and EMSA (KL1, KL2) are similar, though important difference are shown (KL 1 and KL2 smaller in size, lower in recycling ratio and more productive preparing methods, (Tryon et al., 2005)), probably due to the shifts from large cutting tools to flake-based tools as smaller blanks and more effective (recurrent) methods are favored. The shapes from EMSA sites are more diverse than Acheulian, with an increase in triangular flakes. Triangular flakes are common at Guanyindong, but most of them were not made using Levallois methods. Another characteristic shared between Guanyindong and Kapthurin Formation assemblage are the majority of discoidal and opportunistic knapping on single and multiple platform cores (McBrearty and Tryon, 2006).

3.2.3. Skhul

In Levant MP assemblages, Levallois assemblages always dominated, and there are high proportions of recurrent Levallois production in MIS 5 (Shea, 2003; Hovers, 2009; Meignen, 1995; Petraglia et al., 2012; Groucutt et al., 2015a, 2015b). Unidirectional-parallel and bidirectional-parallel preparation was the dominant recurrent Levallois technology in Early Levantine Mousterian. Levallois points are very common. High quality raw materials are locally available within 10 km, (Shea, 2003).

The Skhul assemblage was initially analyzed by Garrod before dispensed to different institutions. The assemblage discussed here are those stored at Pitt Rivers Museum (PRM), which includes 270 Levallois products, as a sample of the entire Skhul assemblage (Groucutt et al., 2019). We consider this representative of the assemblage's technological performance and frequency of key forms. As described by Garrod (1937), Skhul cores were also dominated by Levallois cores for producing broad flakes. The size of cores varied, but smaller cores are more standardized. Cores and flakes get smaller in the lower layers, and a high frequency of triangular Levallois flakes are found in the lowest layer. Levallois points and retouched points appeared in a larger quantity.

All the artifacts are made on local high-quality chert, and non-Levallois products are few (Table 1). Contrasting with the prominent recurrent method at other Levantine MP sites, centripetal preferential core are predominant at Skhul (Groucutt et al., 2019; Crew, 1975) (Fig. 16B, Fig. 17A). Recurrent centripetal products are present in small numbers, and isolated bidirectional recurrent pieces were found as well. The preparation and production patterns are similar with Guanyindong

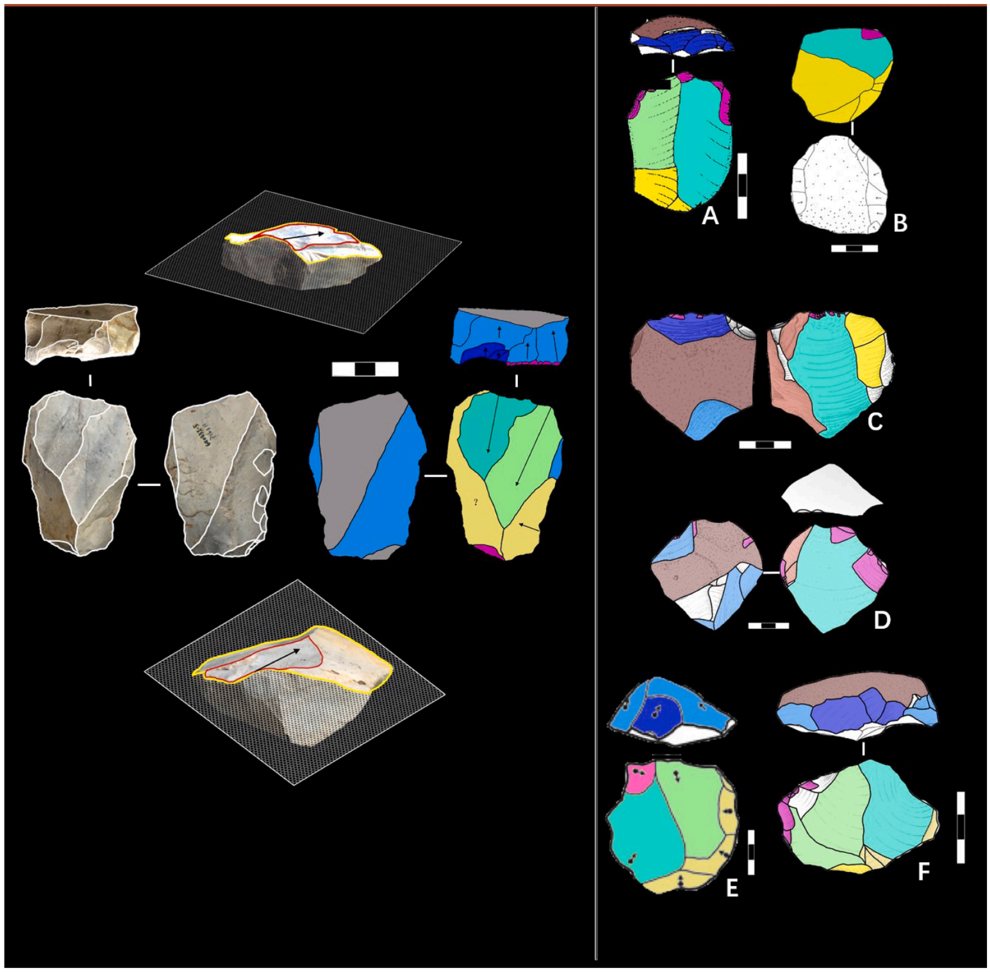

Fig. 16. Core configural comparison between recurrent cores from Guanyindong (left) and other sites (right). (A) Ar Rasfa (Jordan) (Shea, 1998); (B) preferential Levallois core from Skhul (Groucutt et al., 2019); (C, D) 'proto-Levallois' cores from Acheulo-Yabrudian layers of Tabun Cave (Shimelmitz et al., 2016); (E) KL2 (Kenya) (Tryon et al., 2005); (F) Guado San Nicola (France) (Moncel et al., 2020).

as centripetal preferential dominated, occasional use of recurrent and bidirectional.

While the shape of Levallois cores varied at Guanyindong, the morphologies of Levallois cores of Skhul (PRM) are homogeneous. Elongated preferential cores have a pointed shape that was prepared by elongated débordant removals from the distal end, whereas rounded cores have oval preferential scars. The former is considered as a tendency towards Nubian-like reduction (Fig. 17A). The core (Fig. 4, Fig. 13) alike Nubian found at Guanyindong also has the similar scars at the end to ensure the distal convexity. Given that the reliability of Nubian as indicator to population event is under debate (Crassard and Hilbert, 2013; Groucutt, 2020; Blinkhorn et al., 2021), the Nubian-like core at Guanyindong might be 'opportunistic' when the hominids applying various methods of Levallois production.

Most of the Skhul cores are between 65 and 40 mm in maximum dimension, 60–40 mm in width and 30–15 mm in maximum (Groucutt et al., 2019). Guanyindong Levallois core sizes are larger than Skhul (PRM) cores. Table 2 shows the principle statistical data of cores from Guanyindong and Skhul (PRM). The larger size of Guanyindong is evident on mass, max dimension, max thickness, technological length. From the illustrations of several Levallois cores, Skhul cores (Groucutt et al., 2019), either preferential or recurrent, exhibit much more convexity preparation, such as 'classic' centripetal which is rare at Guanyindong. But for preferential preparation, the convexity maintenance shows a variant, either simple or careful, that occurs at both sites.

No Levallois points were found at Guanyindong, but nearly half of Skhul (PRM) Levallois debitage are Levallois points. Similarly, the centripetal dorsal scar pattern dominated, and they are very thin (<20 mm on average) and light (75 % weigh < 30 g) (Groucutt et al., 2019). Although Guanyindong Levallois flakes also show somehow regularity, being relatively flat (mean thickness is 12 mm) and light (mean weight is 27.8 g), flakes of Skhul (PRM) are more homogeneous with respect to width, length and thickness and more dorsal scars number (5–7). More than 80 % of Levallois flake platforms are finely facetted, plain only accounts for 2 % (Groucutt et al., 2019). This is in contrast with Guanyindong, where plain platforms are found in larger numbers, with the facetted platforms infrequent (Fig. 18). Unidirectional and bidirectional are the main patterns of the Levallois dorsal scar, whereas centripetal only appears in low frequency. Conversely, at Guanyindong, centripetal dorsal scars dominate.

Generally speaking, the difference between Levallois assemblage found at Guanyindong and Skhul is noticeable. One of the prominent differences is proportions of Levallois products is much larger at Skhul than at Guanyindong. Levallois production at Skhul is undoubtedly the first choice for hominis there, while Guanyindong hominins tended to take is as an option in daily knapping activity. In this case, Skhul cores are more homogeneous in both morphology and technology, while Guanyindong cores appear with large variation due to less preparations and less efforts on convexity maintains. This directly generate less standardized final products at Guanyindong, such like the absence of Levallois points and small amount of Levallois flakes. However, at the conceptual level, we believe that these disparities of the two Levallois

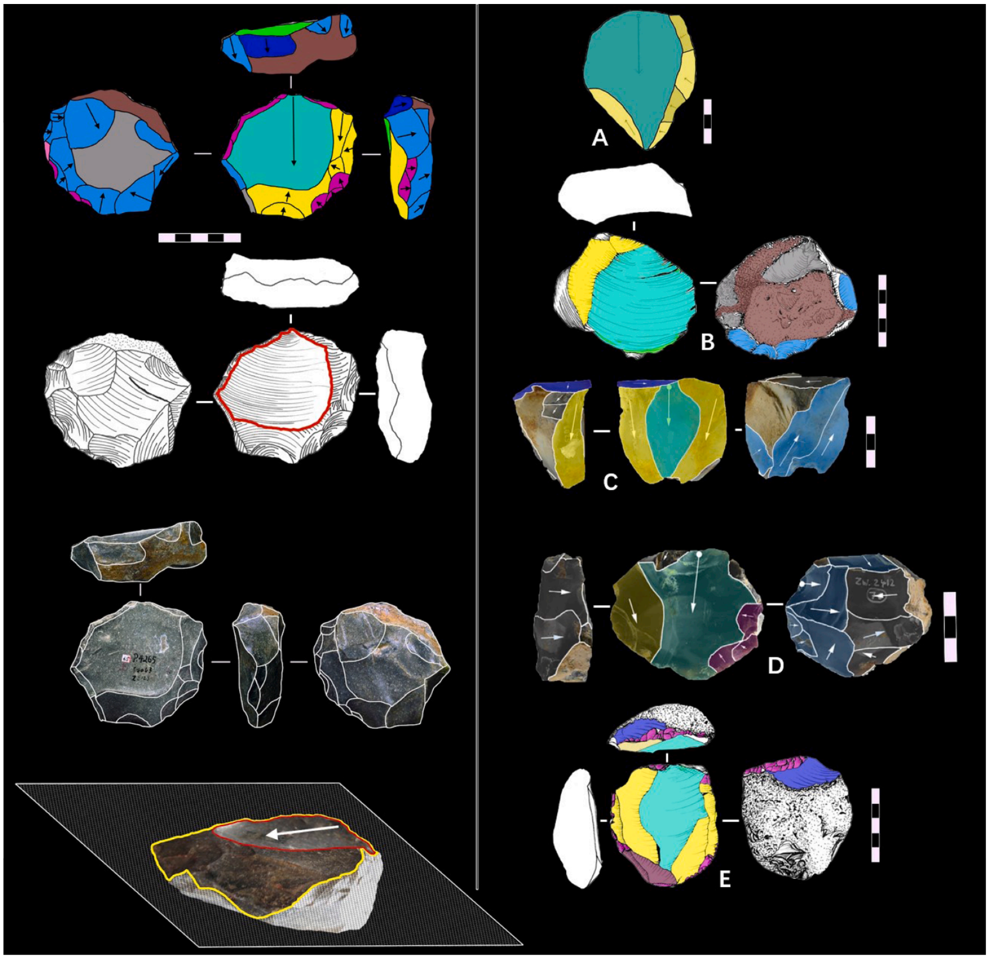

Fig. 17. Core configural comparison between preferential Levallois cores from Guanyindong (left) and other sites (right). (A) Skhul beaked-Levallois technological core (Groucutt et al., 2019); (B) Nor Geghi 1 (Armenia) (Adler et al., 2014). (C, D) Zwochau (Germany) (Picin, 2018); (E) Nor Geghi 1 (Armenia) (Adler et al., 2014).

assemblage are quantitative and qualitative, rather than essential.

3.2.4. Omo Kibish formation

There are three main archaeological sites at Omo Kibish Formation: Kamoya's hominid site (KHS), Awoke's hominid site (AHS), The Bird's Nest Site (BNS) (Shea, 2008). Artifacts from these sites collected both in situ and surface collection are treated equally.

3.2.4.1. KHS. The dominant raw materials at KHS are fine-grained cryptocrystalline silicate rocks, jasper, chalcedony and chert (Table 1). Other coarse-grained raw materials are less common (Shea, 2008). Raw materials from Guanyindong are similar, but the quality of chert or other silicate rocks is not as good as KHS. Almost half of cores are Levallois cores that are mainly prepared centripetally and <30 mm and are abandoned after a single central or overshot removal (Fig. 12). Levallois cores from Guanyindong are fewer, larger and some are more exhausted. At KHS complete flakes are dominated by Levallois products (flakes, blades) and core trimming elements (mostly overshot Levallois flakes, pseudo-Levallois points) while at Guanyindong they only account for 13 % (Levallois flakes and débordants). According to the cortex on flake and refitting, the original blank are pebble and cobble (this number of Guanyindong is less as cortex indicating the original forms on lower surfaces are only found on half of Guanyindong Levallois cores; Fig. 1, Fig. 2, Fig. 3, Fig. 5, Fig. 7). Levallois production was started by unilinear and then replaced by centripetal removals. We observed that larger Guanyindong Levallois recurrent cores have relatively less preparation (for example Fig. 8), but the correlation with earlier stages of core exploitation is not yet clear.

3.2.4.2. AHS. The raw materials used at AHS are more varied, among them chert is the most common (43 %), followed by rhyolite and shale. According to the cortical flakes, raw materials are local cobbles. Stone artifacts are smaller, with mean dimension is around 30 mm. The assemblage is discoidal method dominated, with a high ratio of discoid cores and discoidal-linked products (pseudo-Levallois points). Levallois cores for flakes (only typical Levallois flakes are counted) detached by preferential methods are the most typical ones (Fig. 12A, F). While for Guanyindong, both Levallois and discoidal production are not the dominant approach, and the sizes of cores and flakes are much larger (Table 1). Preferential method is the prominent mode of Levallois production at both sites.

3.2.4.3. BNS. Asymmetrical discoids (69 %) are the most common core type at BNS (Shea, 2008), Levallois cores also present. Both 'Asymmetrical discoids' and Levallois cores belong to the 'formal cores' cluster and these cores, in addition to 'core-on-flake' show a hierarchical configuration (Shea et al., 2007; Shea, 2008). Cores are around 40 mm, flakes are around 30 mm. In contrast, the numbers at Guanyindong are 70 and 50 mm respectively (Table 1). Levallois flake and pseudo-Levallois points, which are obtained by recurrent centripetal (pseudo-Levallois points) (Fig. 11A, B) and large preferential removals (Levallois flakes) (Fig. 12E, Fig. 13B), are the prominent components among the non-cortical debitage. Levallois points are found on surfaces, as well as other pointed artifacts. At Guanyindong, Levallois cores are less

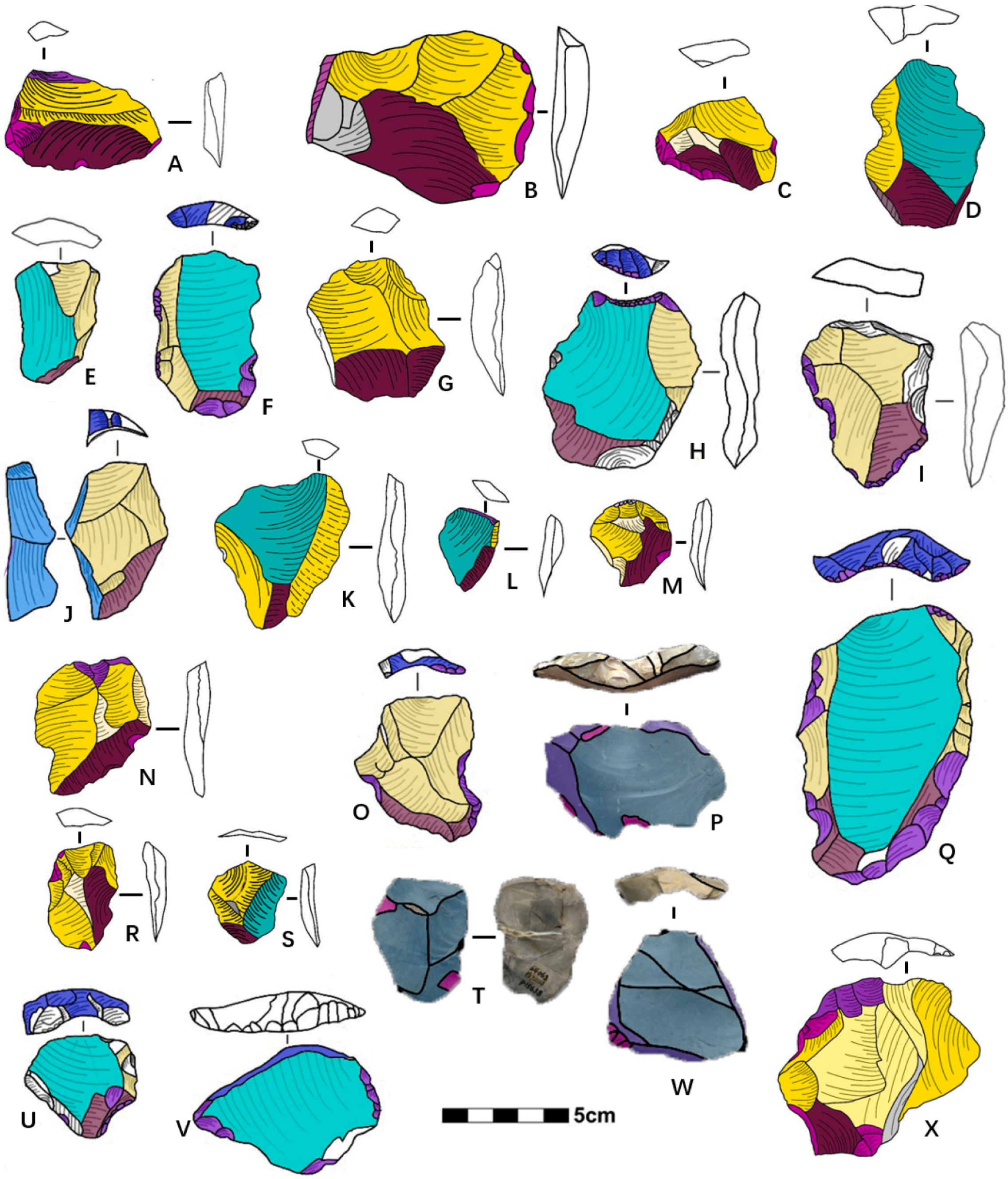

Fig. 18. Illustrations of flake from Guanyindong. (A, B) bidirectional preferential Levallois flake (purple red showing the distal convexity maintenance); (C, G, I, M, N, O, R, S, and X) centripetal Levallois flake; (D) bidirectional recurrent Levallois flake (lake blue showing the previous predetermined removal); (E, F, H, K, and L) centripetal Levallois flake with previous predetermined removal remains on the dorsal surface; P, Q, U, V, and W are flake with a big invasive scar covers on almost the entire of dorsal surface. (J) débordant, which has previous core edge left on lateral side; (T) centripetal flake.

common. But hierarchical cores other than Levallois also present, termed 'hierarchical core' in this paper (Fig. 10). This kind of core at Guanyindong are featured by the division of two hierarchical related surfaces. The upper surface is for production, and the lower surface is striking platform surface. They are different from Levallois cores mostly for either less paralleled fracture planes or a lack of convexity preparation. Core rejuvenation is limited suggesting high thresholds for core discard. Guanyindong also has low frequency of core trimming elements (n = 26). The scarcity of core trimming elements probably is results of stone tools imported under a high mobility strategy.

Generally, the core technologies patterns at three sites from Omo Kibish Formation suggest high residential mobility (Shea, 2008). All the cores are smaller, probably due to their initial natural forms (like small pebbles) and Levallois ratios are much higher than Guanyindong as well as standardization, despite that similar preparation and production methods were applied.

3.2.5. *Panxian Dadong*

Chert, basalt and limestone, available locally (Miller-Antonio et al., 2004), were the main raw materials used to produce predetermined blanks. All components of the Levallois strategy are present at Panxian Dadong, including cores, flakes, tools, facetted platforms, débordants (Otte et al., 2017). Based on the description of flake dorsal scar patterns, the preparation is mainly centripetal, and the production method is preferential according to our reading of the photography (Fig. 12A, C, Fig. 14E) (Huang et al., 2012). Recurrent bidirectional exploitation is occasionally used, and the production patterns are consistent with Guanyindong. The core sizes range from 55 to150 mm, which is generally larger than Guanyindong. Most Levallois cores show less control over the core, and therefore 'mask the skills of the Panxian Dadong knappers' (Fig. 12C) (Otte et al., 2017). In contrast, Levallois points appeared in a small number and some of them were resharpened to other type of tools (Otte et al., 2017). Compared with Guanyindong, the Levallois cores at Panxian Dadong seem to be less developed. The mechanism leading to this disparity is still unknown, but we consider that it represents an initial phase of the Levallois strategy in Southwest Asia.

3.2.6. Qualitative comparison

This section provides analytic illustration and corresponding interpretation of comparisons among Levallois cores from Guanyindong with those selected from the foregoing sites and other similar sites. To avoid reiterate with above sections, the selected Levallois cores are not necessarily typical.

Qualitative comparisons are demonstrated on the basis of Figs. 11–17, respectively (Note that different colors symbolize different functions as listed in Fig. 1. The filled color of cores from other sites are *done by us* based on descriptions in published papers and our own reading, therefore might be biased). In Fig. 11, we can see that all presented cores show the recurrent production of the upper surface. Their striking platforms are prepared, as well as the peripheral convexities. All the lower surfaces have cortex remaining. The upper surfaces and lower surfaces exhibit a hierarchical relation. Because of successive production, some of cores (A, B, C) only have distal convexities visible. Retaken/edge modification flakes can be observed on either proximal, lateral or distal end (Guanyindong, A, B, D). C is a Levallois core exploiting the natural convexity of flake ventral surface, showing less convexity preparation.

Fig. 12 shows comparison between preferential centripetal cores from Guanyindong and other sites. All the presenting cores applied the preferential method by centripetal preparation (except A, C). Preparation of A and C is unexaminable for the last predetermined removal is overshot (A) and little information can be extracted from the photograph (C). Most of those cores have cortex remaining on the lower surface. B, D, E and the Guanyindong cores exhibit similar preparation intensities while convexity of F is more carefully prepared.

Fig. 13 shows a Nubian-like core from Guanyindong, while the cores from right side are similar to Nubian cores from Arabia. Except for the common Levallois features, A, C and Guanyindong core show distal convexity management by the opposite detachment (colored in purple red). B is Levallois point core from Africa, which show opposite and lateral preparing removal. The last determined flake on all the cores appears to have been a point.

Some of the Levallois cores show a reversed trapezoidal cross-section (Fig. 14 showing preferntial centripetal Levallois cores, where the reversed trapezoidal cross-section of a Levallois core from Central Arabia site is also shown in a white box). The aim is to form inclined striking platforms on both sides for creating the convexity on the flaking surface. The shown cores are centripetal prepared with preferential exploitation, although for E, the upper surface seems to be truncated. The last preferred removals all extend over the middle point of the flaking surface owing to the elaborated lateral and distal convexity preparation. Débordant removals are shown on Guanyindong cores when maintaining lateral convexity. The lower Guanyindong core and C have a lot of re-taken flakes, probably recycled into tools. While the flaking surface of E is less instructive for re-taken detachments, striking platform preparations are noticeable.

Fig. 15 shows cores all have an overshot scar remaining on the flaking surface (preferential). Lateral convexities are still evident on the edge of cores. Their striking platforms were prepared with cortex left on the lower surface (except B, which has no lower surface information). The configurations of D and Guanyindong are similar and both show a final shape of slab form. Re-taken flakes are noticeable on B probably indicating resharpening. B, D and the Guanyindong core have similar core size, while A is much larger.

All the cores from Fig. 16 are recurrent cores, exhibiting the preparation of striking platforms on the lower surface. The core sizes and shapes vary from one to others. A, C, E and the upper Guanyindong core are technologically alike, showing somewhat lateral and distal convexity maintenance. The lower Guanyindong core is 'proto-like', showing coarsely convexity management, resembling C, D, where convexity preparations are minimal. All the recurrent cores have two desired detachments, some are unidirectional (A, F, and Guanyindong cores), while some were orthogonally exploited (E).

In Fig. 17 preferential cores are shown, where A, E and Guanyindong core are prepared by centripetal removals, while, B, C, D seem to be unidirectional preparation. All the removals are invasive, covering the major (A, C, E, and Guanyindong core) or entire (B, D) area of flaking surface. Lower surfaces of most of them are cortical. D and Guanyindong core have re-taken flakes on the margin, probably for second preparing phase, while the re-taken flakes on E are located on the platform, perhaps being part of platform preparation for next sequence.

3.2.7. Summary of inter-site comparison of Levallois core technology

In summary, comparison of Levallois strategies at the sites discussed above and Guanyindong reveals interesting patterns of similarities and differences. The analyzed sites show an exploitation of high quality local raw materials, such as chert, fine-grained Lava and flint, and show considerable variability in Levallois technology. However, preferential production and centripetal preparation was the major Levallois reduction strategy used among these sites. With respect to Levallois proportions, Skhul (PRM), KHS, layers 1–3 of Orgnac 3 show a much higher ratio compared to Guanyindong, whereas Levallois products from lower layers of Orgnac 3, AHS, BNS, and Guanyindong account for a similar percentage of their assemblage. The ratios at KF and Panxian Dadong are lower.

As for core and flake sizes, except for KF and Panxian Dadong, Guanyindong falls in a similar range to the rest of analyzed sites. Bifacial tools and tools curation are less emphasized at these comparative sites. However, in some assemblages, such as the upper layers of Orgnac 3, KHS, and PRM, Levallois cores are more developed, with more preparatory removals from the lateral margins and more homogeneous, and facetted platforms are much more common. Typical Levallois points, which are absent at Guanyindong, dominate the products at PRM, confirming the high standardization of Levallois core technology in that assemblage. The Levallois core technology of Guanyindong is generally more skilled than Panxian Dadong, much closer to the Early MP/MSA found in Europe and Africa, less similar with the later phases.

At most sites, Levallois core technologies were commonly associated with other production methods. The co-occurrence in MP assemblages of various methods such as discoidal, core-on-flake, laminar has been widely observed elsewhere (Hérisson et al., 2016) including some of the sites described above. We combined the published diagrams and sketches with detailed information on the layout of negative scars and core preparation removals to provide more information on degree of convexity management, platform preparation and core configuration. However, we acknowledge that the comparison is based on broad technological features, given the constraints of the available information and the total amount of Levallois artifacts in different assemblages varies significantly, therefore our comparison is necessarily limited. Nevertheless, based on the results, we believe that Levallois strategies is present at Guanyindong as an important flake production method. A productive direction for future comparative work like this would be a quantitative genetic approach, which may help to explain variation patterns in terms of socially learnable and transmittable factors (Lycett and von Cramon-Taubadel, 2015). The statistical analysis of artefact-level measurements required for a quantitative genetic approach was unfortunately not possible in our case because artefact-level data was not openly available to us for the assemblages in our comparison, except for Guanyindong. We recommend that future work on LMP assemblages provide artefact-level data at the time of publication, in addition to the traditional practice of assemblage-level summaries, to advance debates about the origin and distribution of Levallois strategies, and facilitate richly informative comparative analyses.

4. Discussion

The LMP was a period that witnessed multiple transitions in human evolution and cultural behaviors. In terms of human evolution, many major processes first occurred in this time span, including the appearance of anatomically modern humans and their migrations, the ubiquity of Neanderthals in Europe and north Africa, the occupations of Denisovans in Siberia and China, and frequent gene flows between each population. With respect to human cultures and society, the lithic productions switch from large cutting tools to flake and flake-tools, diverse flake-oriented technology such like Levallois, the cognitive improvement reflected by lithic manufactory, hunting strategies, and potential social structure changes.

Evidence of these revolutions has primarily been found in western Eurasia and Africa, while such changeover in East Asia is less striking. This inconformity is hard to explain, with scholars proposing demography, raw material, environment, population, and geographic boundaries as factors responsible for the relatively low rate of change during the LMP in East Asia, though a consensus has not been reached (Foley and Lahr, 1997; Dennell and Roebroeks, 2005; Lycett and Norton, 2010; Bar-Yosef and Wang, 2012). Our study here helps to address this puzzle by presenting details of a technology analogical to Levallois that appearing in East Asia during LMP. The appearance of this technology at Guanyindong is a starting point for redirecting the debate away from hypothesizing why the Levallois is absent, towards considering competing hypotheses of sporadic population dispersal events, technological convergence or adaptive peaks to explain its presence.

The question of dispersal requires substantially additional work to be answered satisfactorily. The geographically closest assemblages to Guanyindong that have Levallois core technology, aside from for Panxiandadong, are Shuidonggou (MIS3), and Jinsitai (MIS3). The straight-line distance between these sites is about 1500 km and the Guanyindong assemblage was produced at least 40,000 years before them. This implies that the human group made those tools had a distinct original source of the technological strategy, and a diverse diffusion process. If we took distance and age in consideration, Ust'-Izhul (125 ka, Chlachula et al., 2003) and Denisova Cave (220–280 ka, Derevianko et al., 2003; Jacobs et al., 2019) are most likely the last geographical points of cultural diffusion before Panxiandadong and Guanyindong. It is, however, tenuous to link the Levallois assemblage in southwest China to Altai region without catenating assemblages between them. Investigating the contents of LMP assemblages located between these regions should be a priority for future research to evaluate the hypothesis of a technological dispersal of Levallois strategies from Altai to southwest China.

An alternative hypothesis to dispersal of Levallois strategies is technological convergence. Convergence means the technology was developed independently and locally. Claims of isolated technological convergences on Levallois strategies in the western hemisphere have been proposed based on evidence of Levallois technology evolving from local practices of bifacial or large flake production (Adler et al., 2014; Tryon et al., 2005; White and Ashton, 2003; Foley and Lahr, 2003). Assemblages with bifaces or large cutting tools in East Asia rationalizes the expectation of Levallois core technology date to LMP, but the relationship between these two technologies is still debated. The convergence hypothesis is compelling for explaining the appearance of Levallois at Guanyindong because it is simple and largely satisfied with the available evidence. However, it does not satisfactorily explain why the character of Levallois at Guanyindong has differences from many other LMP sites.

The adaptive peak hypothesis is a useful alternative to simple convergence because it may help to explain why the character of Levallois at Guanyindong is distinctive, and why the assemblage has relatively few Levallois pieces overall. This hypothesis proposes that Levallois strategies represent an adaptive 'peak' on a wider 'landscape' of various lithic technologies. In many locations around the world where distantly related and geographically isolated hominin groups used Levallois strategies, it may have been because those strategies conferred functional and economic benefits under similar selective pressures (Eren and Lycett, 2012; Lycett and Eren, 2013a; Lycett and Eren, 2013b; Eren and Lycett, 2016; Brantingham and Kuhn, 2001). In the case of Guanyindong, the adaptive peaks hypothesis shifts the debate from a focus on simple presence/absence of Levallois, to a discussion of the extent to which Guanyindong was approaching the Levallois adaptive peak. Our analysis presented here demonstrates that the occupants of Guanyindong did indeed approach this adaptive peak.

The adaptive peak at Guanyindong is represented by the inter-related preparatory steps, the deliberate usage of entire core's volume, the discrete core production concept differing from other core reduction schemes, and the diverse and complete methodological pattern. The rarity of Levallois pieces at Guanyindong can be interpreted as the adaptive peak at Guanyindong not having reached the same height as at other sites, for example in the western hemisphere. This may due to small, low-density populations in the Guanyindong region, with weak and/or irregular patterns of social interconnectedness in this region, and less strong ecological and social selective pressures on technological strategies. Under these conditions, technological innovation, 'peakness', transmission and persistence would have been rarer at Guanyindong. Nevertheless, the low frequency is not extraordinary compared with western assemblages (see examples in Table 1). As is shown in Table 1, Guanyindong is not the only site where have Levallois products were not dominant. The ratios between Levallois cores at the given sites to the whole assemblage mostly range from 0.05 to 1 %, which is close to Guanyindong (0.5 %).

5. Conclusion

Given the functional and adaptive advantage of Levallois strategies, we expect that future work will reveal more LMP assemblages found with Levallois, Levallois-like pieces or other parallel optima in this region. The observational and descriptive results from Guanyindong presented in this paper are a starting point for more in-depth quantitative studies of Levallois strategies in southwest China. Future studies that involve more inter-site comparison, open sharing artefact-level data and experimental knapping are needed to discern between the competing hypotheses for the origin and spread of Levallois in East Asia. In particular, systematic quantitative studies on the Levallois products, especially cores, should be studied against the non-Levallois products. Furthermore, raw-material controlled knapping experiment using preferential and recurrent Levallois methods should be conducted to model the recovered specimens. Experimental methods simulating discoid, multidirectional or other analogous core reduction strategies are needed be used to investigate the null hypothesis of 'opportunistic' and 'accidental'. If specific quantitative data of other Levallois assemblages were available, inter-site morphometric comparisons can examine the coefficients of variance of Levallois cores and explore to which degree the variance was tolerated. Finally, a quantitative genetic approach (Lycett and von Cramon-Taubadel, 2015) may also help understand the sources of variation in terms of raw materials efficiency, causes of variation, discrepancy of Levallois and non-Levallois, and, hence, benefit tremendously any inter-site comparisons between Guanyindong and other sites of interest.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Author contributions

B.L., Y.H., Y.-M.H., and W.-W.H. conceived and coordinated the study. Y.H., B.L. and Y.-M.H. conducted the fieldwork. Y.H., B.M., Y.-M. H., and H.-L.L. conducted the stone artefact analysis. Y.H., B.M., and H.-L.L. wrote the manuscript, with contributions from the other authors.

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