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Knocking on Acheulean’s door. DK revisited (Bed I, Olduvai, Tanzania)

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ABSTRACT

The Douglas Korongo (DK) holds the earliest archaeological evidence documented in Olduvai Gorge to date. This ~1.9 Mya site, excavated by M. Leakey during the early 1960s, has become an iconic site within studies on the origins of human behaviour. The objective of the present paper is to test the hypothetical presence of derived techno-typological traits in this later Oldowan assemblage. We have undertaken an exhaustive technological and statistical analysis and the results confirm the presence of the following derived traits: flaked cores with platform preparation; discrete technological processes geared to producing tools with different size, shape and mass; a high frequency and diversity of retouched flakes; the production and shaping of large blanks (*ca.* 10 cm); and the emergence of morpho-types. We conclude that the DK knappers displayed the necessary technological know-how from which the Acheulean could emerge and, therefore, the transition from the Oldowan to the Acheulean was more gradual and complex than previously thought.

1. Introduction

The Douglas Korongo (DK) has provided one of the earliest archaeological assemblages as an Olduvai Gorge (Tanzania). This site is located in the main gorge about 5 km downstream from the junction (Fig. 1). It lies above the Bed I lavas dated in 1.95 Mya and is overlain by Tuff IB dated in 1.84 Mya (Stanistreet et al., 2018). It was located at a lake margin-distal fan that flooded and dried out in response to lake transgressions and regressions (Hay, 1976). Mary Leakey excavated this site in the early 1960 s, opened 521.66 m^2 in four trenches, and recognised three artefact yielding levels all of which are clay horizons distinguished from one another by colour and texture (Leakey, 1971). She discovered a paleo-surface with a high concentration of fossils and artefacts and an enigmatic stone circle at the bottom of Level 3. M. Leakey interpreted the paleo-surface as an occupation floor, the stone circle as a hominin-constructed shelter, and the industry recovered along the sequence as “typical of the Oldowan” (Leakey, 1971: 23). A partial *Homo habilis* skull (OH 24) and other skull fragments from the same taxon (OH 56) were found in 1968 and 1977 respectively, adjacent to the site but slightly above Leakey’s sequence (Stanistreet et al., 2017).

DK has played a remarkable role in the understanding of early hominin behaviour. Numerous researchers have revisited its fossil record (Potts, 1983, 1988; Bunn, 1986; Shipman, 1986; Blumenschine and Peters, 1998; Egeland, 2007) and lithic assemblage (Bower, 1977; Wynn, 1981, 1989; Willoughby, 1987; Sahnouni, 1991; Ludwig, 1999; Kimura, 2002; de la Torre and Mora, 2005; Reti and Petraglia, 2016; Proffitt, 2018; this work). Special attention was paid to site formation processes (Potts, 1988; Benito and de la Torre, 2011; Stanistreet et al., 2017). More currently, new trenches (n = 25) were excavated below Tuff IB, adjacent to Leakey’s excavation area (Masao et al., 2012; Albert et al., 2015; Stanistreet et al., 2017).

The main conclusions reached after decades of research in DK may be summarised in the following points: (i) water disturbance and rearrangement is recognized in some lithics and fossils, but the dispersed materials seem to be relatively close to their original location (e.g., Benito-Calvo and de la Torre, 2011; Stanistreet et al., 2017); (ii) hominin activity was focused on a basalt ridge promontory, represented by the position of the stone circle, and located close to a fresh-water pool (e.g., Potts, 1988; Stanistreet et al., 2017); (iii) hominids played a marginal role in the modification of the fossil assemblage and large felids and hyenas were the most important agent of accumulation (e.g., Bunn, 1986; Shipman, 1986; Blumenschine and Peters, 1998; Egeland, 2007); (iv) the industry is typical of the “classic” Oldowan in techno-typological terms and the frequency of stone tools made from volcanic rocks is higher than at any other sites in Bed I or II (e.g., Leakey, 1971; Ludwig, 1999; Kimura, 2002; Reti and Petraglia, 2016; Proffitt, 2018).

However, DK seems to show unusual elements for a “classic” Oldowan assemblage. Some authors noted core-preparation in the Leakey DK lithic collection (de la Torre and Mora, 2005). Others have found a few proto-bifaces and proto-picks in the current excavations carried out in the DK area (Masao et al., 2012; Albert et al., 2015). Unfortunately, further technological description of these artefacts was not provided and

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their significance was not discussed. This is important since the presence of such presumed derived techno-typological elements in a later Oldowan assemblage (<2 Mya) would affect our current knowledge about the Oldowan-Acheulean transition.

We have revisited the Leakey DK lithic assemblage given such a research gap. Our objective was to test the presence of derived techno-typological traits in it and, if so, discuss their significance. The results confirm the presence of derived traits in DK. The conclusion that follows from it is that the transition from the Oldowan to the Acheulean was more gradual and complex than previously thought.

2. Materials and method

The Leakey DK lithic collection was initially formed by 1,198 objects (Leakey, 1971). This collection is currently curated in the National Museum of Tanzania at Dar es Salaam and now consists of 1,190 objects. Those authors that revisited the whole Leakey DK lithic collection before us reported a smaller number of items (Table 1), and none of them divided the collection into levels (Potts, 1988; Kimura, 2002; de la Torre and Mora, 2005). We have not done it either because our research objective was not to reconstruct the integrity of the operative sequences and a large proportion of the artefacts correspond to Level 3 (Leakey, 1971).

The number of items according to artefact categories is presented in Table 2 sorted by raw material. The technological analysis presented here is only focused on cores and flakes since are the most appropriate categories to achieve our objective. We included fragmented flakes or flake fragments within the category of waste, together with other fragmented objects, debris or chunks. It is necessary to highlight that the number of cores and flakes reported by those scholars who studied these materials before us shows discrepancies between them (Table 1). The differences are significant in many cases and cannot be explained according to the approach adopted by each author. We cannot claim what is the final reason that may explain it. We can just suggest that lithic analysis and classification has an important subjective component, more evident in collections like this, with great antiquity, performed in raw materials of poor quality (porous volcanic materials) and with a low degree of plan-form design and standardization. We support our techno-typological study on an exhaustive statistical analysis. We first examined the normal and homoscedastic distribution of the numerical variables statistically analysed (see SI. Table 1), and the p-value of the univariate tests undertaken can be consulted in SI. Table 2.

Table 1
Number of items from DK lithic collection studied by each author (*Included choppers, discoids, polyhedrons and subspheroids; **Included light-duty scrapers, sundry-tools and utilized light-duty flakes; ***Included cores and incidental cores; ****Included retouched flakes and edge-damage flakes).

N° Total	Core-forms	Whole flakes	Retouched flakes	References
1198	113*	242	65**	Leakey, 1971
1163	148***			Potts, 1988
1134	182	401	59****	Kimura, 2002
1180	69	115	10	de la Torre & Mora, 2005
	106			Reti and Petraglia, 2016
	61			Proffit, 2018
1190	136	242	60	This work

Table 2
Count of the lithic material sorted by artefact category and raw material.

	Basalt	Phonolite	Lava	Quartzite	Other	N°./%
Hammers	34	9	2	1	0	46/3.86
Chopper-cores	10	4	0	0	0	14/1.17
Flaked-cores	85	23	8	6	0	122/10.25
Plain whole flakes	156	65	5	15	1	242/20.33
Retouched flakes	28	14	3	15	0	60/5.04
Waste	413	123	7	161	2	706/59.32
N°./%	726/61	238 /20	25/2.1	198/16.36	3/0.25	1190/100

We divided cores into the following groups according to the presence or absence of macro traces of edge damage (e.g., blunted, chipped, jagged or fractured): chopper-cores show edge damage and flaked-cores do not do it. The presence of edge damage could interpret it as utilization (e.g., Leakey, 1971), but it does not exclude that the function of chopper-cores may change over time and different production processes (*façonnage* and *debitage*) may interplay in their reduction. By contrast, we assume that flaked-cores are mostly geared to detach flakes (*debitage*). We recorded the following variables in both core-types: raw material, typometry, weight, faciality (unifacial, bifacial and trifacial), edge angle,

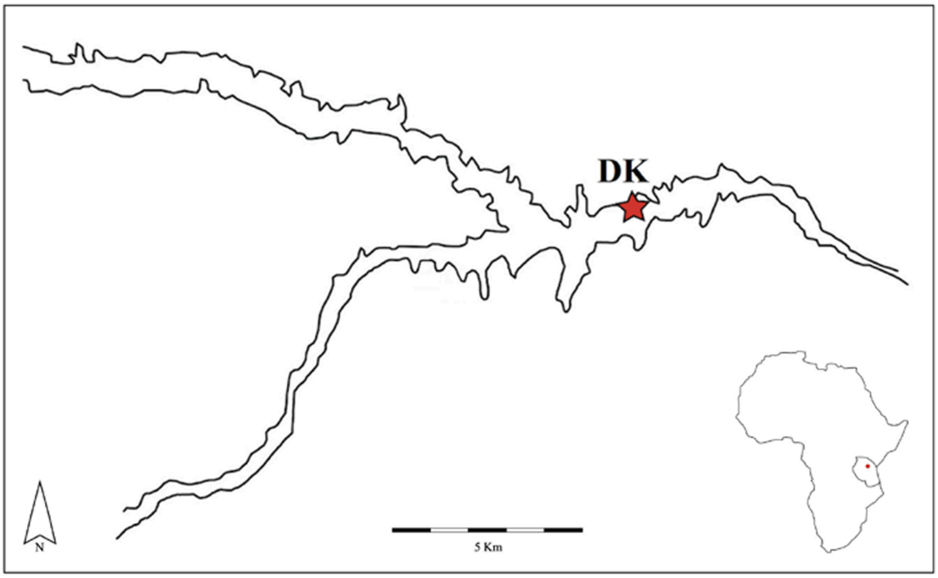

Fig. 1. Location of DK site in Olduvai Gorge.

flaked perimeter index (the perimeter of the flaked area of the core divided by its whole perimeter), scar number, and presence of overlapping flake-series and cortical butt opposite to the edge.

We classified flaked-cores according to the following reduction models: Multifacial, Unifacial, Bifacial Alternating, Bifacial Alternate and Bifacial Continuous. We presented the criteria and features that define these five reduction models in previous work (Sánchez-Yustos et al., 2017a). Fig. 2 shows the type of core rotation that characterizes the bifacial reduction models. We introduced here another reduction model called Splitting. It consists of splitting natural blanks by perpendicular percussion which generates a core with adjacent large right-angle planes. We complemented the analysis of flaked-cores with other variables: type of reduction (Fig. 2); scar organization (Fig. 2); type of percussion (Fig. 2); flake size production, it is related to the length of the scars; and type of blank: spherical or rounded (cobbles and pebbles), split blanks, and flake.

We divided flakes into whole and retouched flakes, and the variables employed in their analysis were: the Toth́s flake types (Toth, 1982), size (small: 20–49 mm; medium: ≥50 – 99 mm; large: ≥100 mm), butt type (cortical, plain and faceted), number of dorsal scars and dorsal scar pattern (linear, opposed, orthogonal, centripetal), edge angle and type of retouch (i.e. morphotype). We followed a conservative approach in the identification of flake retouching giving the friable nature of the Olduvai quartzite and the number of taphonomic circumstances that may generate “pseudo-retouches” (e.g., use, trampling, sediment pressure or fluvial action).

3. Results

3.1. Cores

We identified 136 cores, most of which are flaked-cores (n = 122), and just a few are chopper-cores (n = 14). The former core-type is mostly made on volcanic rocks, but some on quartzite, while the latter is exclusively made on volcanic rocks (Table 2). Chopper-cores are only made on cobbles (n = 5) and blocks (n = 9), but flaked-cores show a greater variety of blanks (Table 3).

We first assessed to what extent the distinction between both core-types is statistically supported. Flaked-cores made on volcanic rocks were included in this analysis since all chopper-cores are made on this material. We looked for any significant differences according to size (length, width and thickness) and weight, and the results indicated that the mean rank of these variables was significantly different between core-types (SI. Table 2). Chopper-cores tend to be larger and heavier (Fig. 3). The mean number of flake-scars registered is not significantly different between core-types (SI. Table 2) and, therefore, this variable cannot explain such differences. Although core-types did not show significant differences in the number of flake-scars, two features indicate that their reduction was managed differently. First, the flaked perimeter index is significantly higher in chopper-cores (i.e., peripheral knapping), whereas the presence of overlapping flake-series is statistically more significant in flaked-cores (i.e., percussion platform recurrence) (SI. Table 2). Second, all chopper-cores show a cortical butt opposite the knapped area, but only some flaked-cores possess one (13,1%). The knapped angles of core-types did not present significant differences (SI. Table 2), the mean in both is close to 90°. We can conclude the distinction between core-types is statistically supported by differences observed in blank selection and reduction, and it thus suggests possible differences in function.

Table 3
Count of the blank types of the flaked cores sorted by raw material (Indeterminate = Indet.).

Raw material	Cobble	Block	Flake	Frag.	Split blank	Indet.	Total
Basalt	21	41	2	3	9	9	85
Phonolite	12	4	0	0	1	6	23
Lava	3	5	0	0	0	0	8
Quartzite	0	2	0	0	2	2	6
Total	36	52	2	3	12	17	122

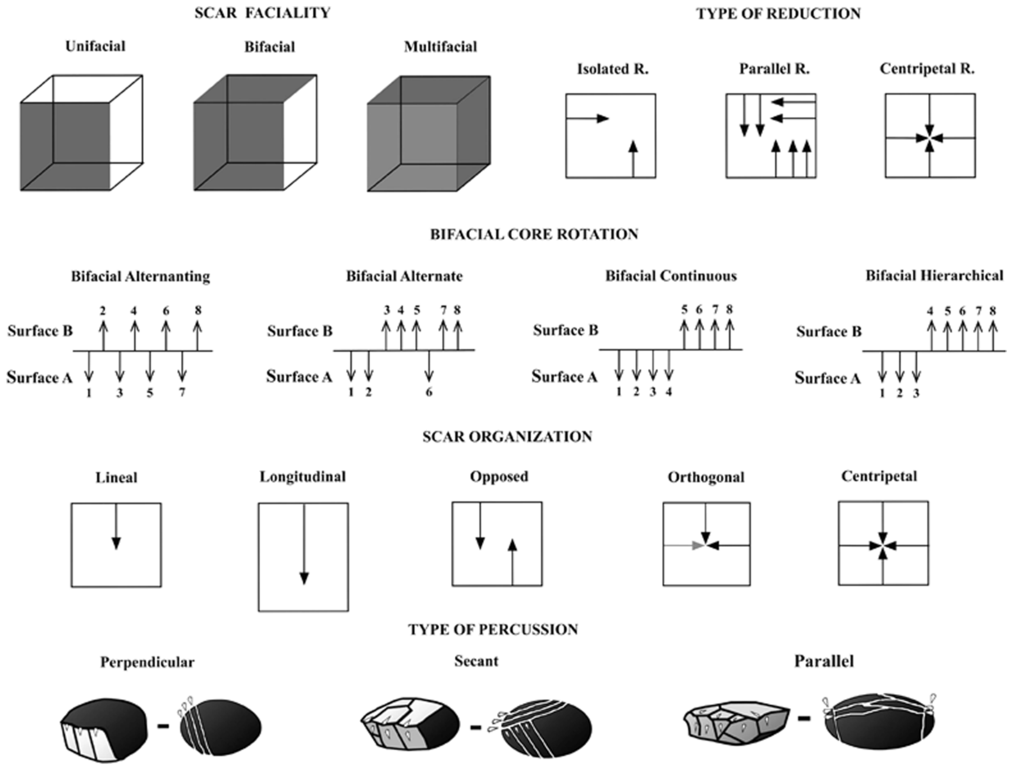

Fig. 2. Technical variables employed for flaked-cores analysis (R = removal) (Modified from Sánchez-Yustos, et al. 2017a).

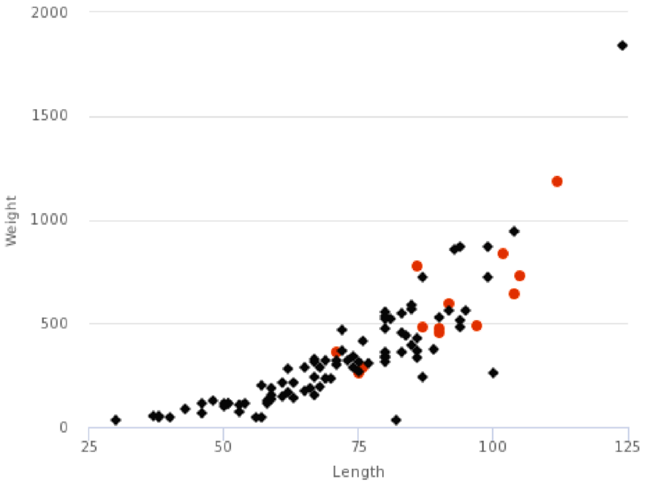

Fig. 3. Scatter plot length (mm) and weight (g) grouped by core-type (chopper-cores in red and flaked-cores in black).

Most chopper-cores show very similar volume reduction, a distal and straight edge bifacially shaped. However, there are two that present a different reduction: one shows lateral bifacial edges that converge in a distal tip, and is 104 mm in length and weighs 641 g; the other presents bifacial edges that converge forming a convex distal edge, and is 90 mm in length and weighs 454 gr (Fig. 4.1). According to M. Leakeýs classification system (1971), both artefacts could potentially be considered as "proto-biface".

On the other hand, we carried out a battery of statistical tests to assess if the reduction models in flaked-cores have a technological sense, and if it is possible to discover reduction patterns or, conversely, if they are artificial groups. Our first statistical analysis addressed the relationship between reduction models and raw material, size and weight. According to the results, there are no statistical differences (SI. Table 2). However, we found a strong correlation between reduction models and those variables related to core reduction management (i.e., blank type, scar number, flake-size production, type of reduction, type of percussion and scar organisation) (SI. Table 2). It supports the technological integrity of the reduction models. The strong correlation between reduction models and scar number is a clear indicator that the number of flaking surfaces and how the knapper rotates these surfaces is geared towards increasing productivity. In this regard, it is worth highlighting that the most productive reduction models are also the most represented (SI. Fig. 1).

The most prominent technological features of the reduction models identified here are presented below (see SI. Table 3). Bifacial Alternate is the most widespread reduction model in the studied sample (30.3%). It is mostly focused on the production of micro and small flakes through isolated and parallel reduction and perpendicular percussion, and their most flaked surface often displays a linear and orthogonal scar pattern. The multifacial reduction is also frequently performed by hominins in DK (28.6%). Its reduction sequence is characterised by the production of small flakes through isolated and disorganised removals flaked by perpendicular percussion, sometimes combined with short series of parallel removals. The Bifacial Continuous reduction plays a minor role according to its representation (15.5%). Core reduction is carried out by different modes, but parallel reduction is predominant, although perpendicular percussion and linear scar pattern are also employed. Five Bifacial Continuous flaked cores show platform preparation. The first knapped face has an isolated scar (i.e., preparatory removal) employed as a striking platform from which a parallel series was detached on the opposite face (Fig. 5). Platform preparation was a very convenient way to create a flat surface or rectify the natural angle of the blank. Unifacial cores also played a minor role (14.7%). This core reduction is aimed at producing small flakes through parallel series that show a linear scar pattern, knapped by perpendicular percussion. Bifacial Alternating reduction is infrequently represented (6.5%) but exhibits a quite invariable technical principle: production of small flakes carried out by isolated reduction and secant percussion which generate flaked surfaces with linear scar pattern. The splitting reduction model is reported in five flaked cores all on volcanic rocks. The use of split blocks as blanks in unifacial cores (27,7%) suggests that the target of this reduction model would be to produce suitable blanks for knapping.

The technological description presented here allows us to appreciate the core reduction skills shown by DK hominins. They carried out different and simple solutions (e.g., split block and preparatory removals) to overcome constraints imposed by initial blank shape, generating proper striking angles and platforms or knappable blanks. We have not recorded any evidence of flaking surface preparation through latero-distal convexity. However, DK hominins managed peripheral convexity successfully towards production maintenance. This technical competence is particularly evident in the six centripetal cores documented in this study (Fig. 6).

3.2. Flakes

We documented 302 flakes (25.3% of the sample), many of them on volcanic rocks, mostly basalt (Table 2). Almost one in five flakes is retouched, and one in four retouched flakes is made on quartzite. The abundance of quartzite retouched flakes explains why there is a significant statistical difference between flake types (i.e., whole plain flakes and retouched flakes) and raw material (SI. Table 2). The statistical analysis conducted also identified a strong correlation between flake types and their typometry, weight, number of dorsal scars and edge length (SI. Table 2). The results indicate that the retouched flakes are larger and heavier (Fig. 7), exhibit longer edges and their dorsal face present more scars than whole plain flakes (SI. Table 4).

The whole plain flakes are quite homogeneous since their typometry, weight, Toth's flake type, scar number, scar pattern and edge length do not present significant differences when they are sorted by raw material (SI. Table 2). Retouched flakes are more heterogeneous than whole plain flakes. They show significant differences in typometry, weight and edge length according to raw material (SI. Table 2). The retouched flakes made on lava or basalt are larger and heavier (SI. Fig. 2) and possess longer edges than those made on phonolite and quartzite (SI. Fig. 3). Greater availability of large blocks and cobbles derived from the nearby volcanic Bed I outcrop may explain why the DK hominins used this raw material preferentially to produce larger and heavier retouched flakes.

There is a group of retouched flakes that show relatively high typometrical and weight values (Fig. 8). For instance, the typometrical and weight values of 16 items are all above the mean of the retouched flakes (Table 4 see*). Accordingly, we can divide the retouched flakes into two groups: the small and light retouched flakes, those below the mean values (Table 4 see*); and the large and heavy retouched flakes, those above the mean values (Table 4 see*). These groups also show clear statistical differences according to their raw material, edge length and morphotype (SI. Table 2).

The small and light retouched flakes are larger and heavier than the whole plain flakes (Table 4). It suggests a size selection within small-sized flakes to be retouched. These retouched flakes show a high variety of morphotypes, being scrapers, sundry-tools, denticulates and awls the most represented in that order (Table 5; Figs. 9 and 10). On the contrary, it is difficult to identify discrete morpho-types within the large and heavy retouched flakes because they are less formally worked. We cannot classify these artefacts as handaxes or Large Cutting Tools (LCTs) as they do not meet all techno-typological requirements proposed by Kleindienst (1959), Isaac (1977) or Gowlett (2006).

Five large and heavy retouched flakes show lateral edges bifacially shaped that converge distally forming convex or pointed tips that present macro traces of damage (Fig. 4.2; Fig. 11.2), but one shows a distal cleaver-like edge. The bifacial detachments modified the edge rather

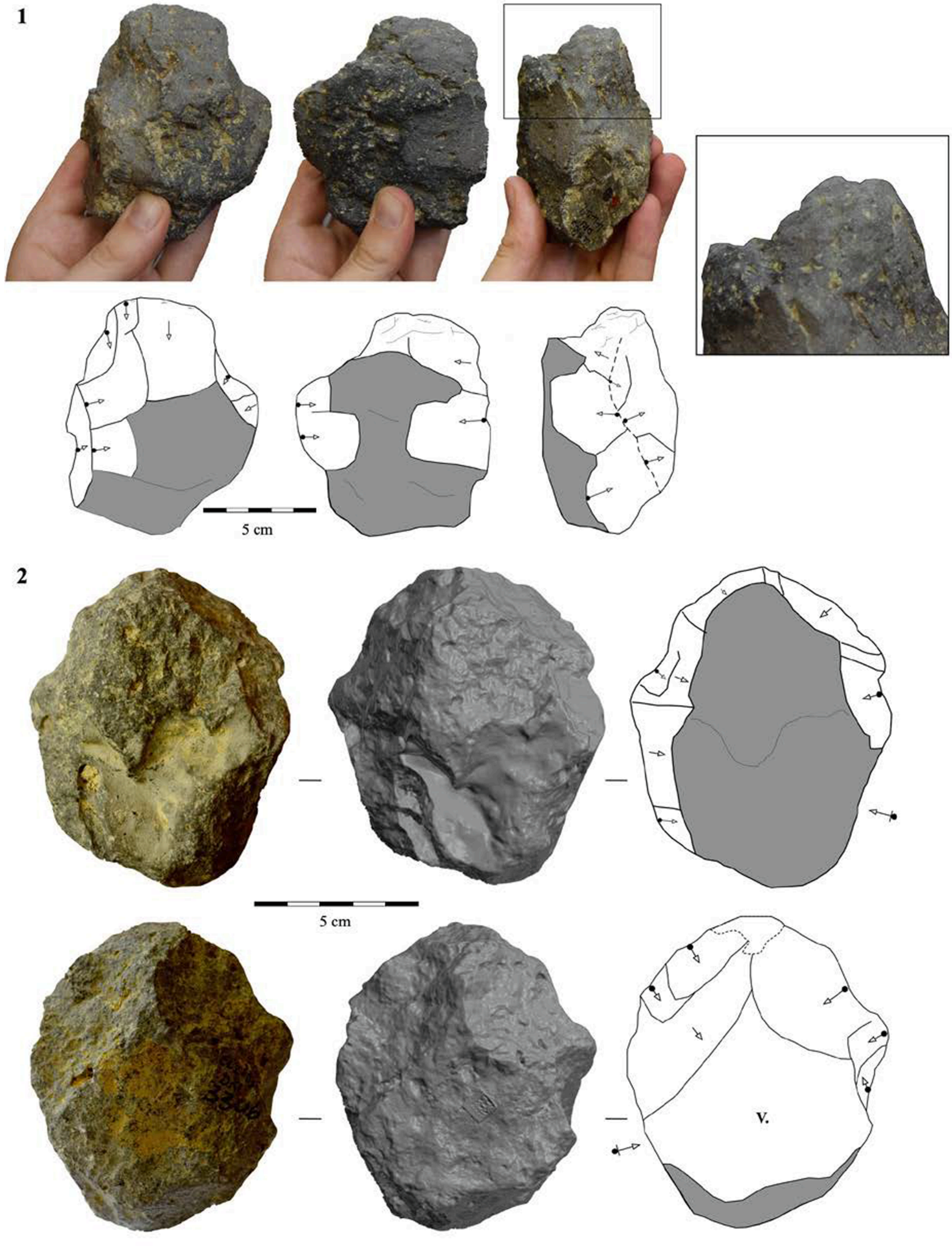

Fig. 4. Large and heavy artefacts. Artefact 1 is made on a cobble and its distal region is blunted; Artefact 2 is made on a thick flake and its distal region is broken (ventral face = V), see its 3D model in Supplementary Information Video Fig. 4.2.

than the volume of the blank which is consistent with the lack of a clearly defined plan-form and the difficulties in managing thick volumes that evidence their knappers. It is interesting to stress that three of them show a discrete trihedral bifacially shaped in one of their lateral edges (Fig. 4.2; Fig. 11.2). These artefacts are performed on thick flakes and their length and mass are: 89 mm and 563 g.; 97 mm and 739 g; 101 mm and 354 g; 104 mm and 471 g; and 105 mm and 541 g. In typological terms, these artefacts could potentially be considered as “proto-biface” according to M. Leakeýs definition (1971). We have statistically compared the proto-biface-like artefacts (included the two made on cobbles) with the bifacial flaked-cores (SI. Table 2). The results indicated that the artefacts of the former group are significantly larger and

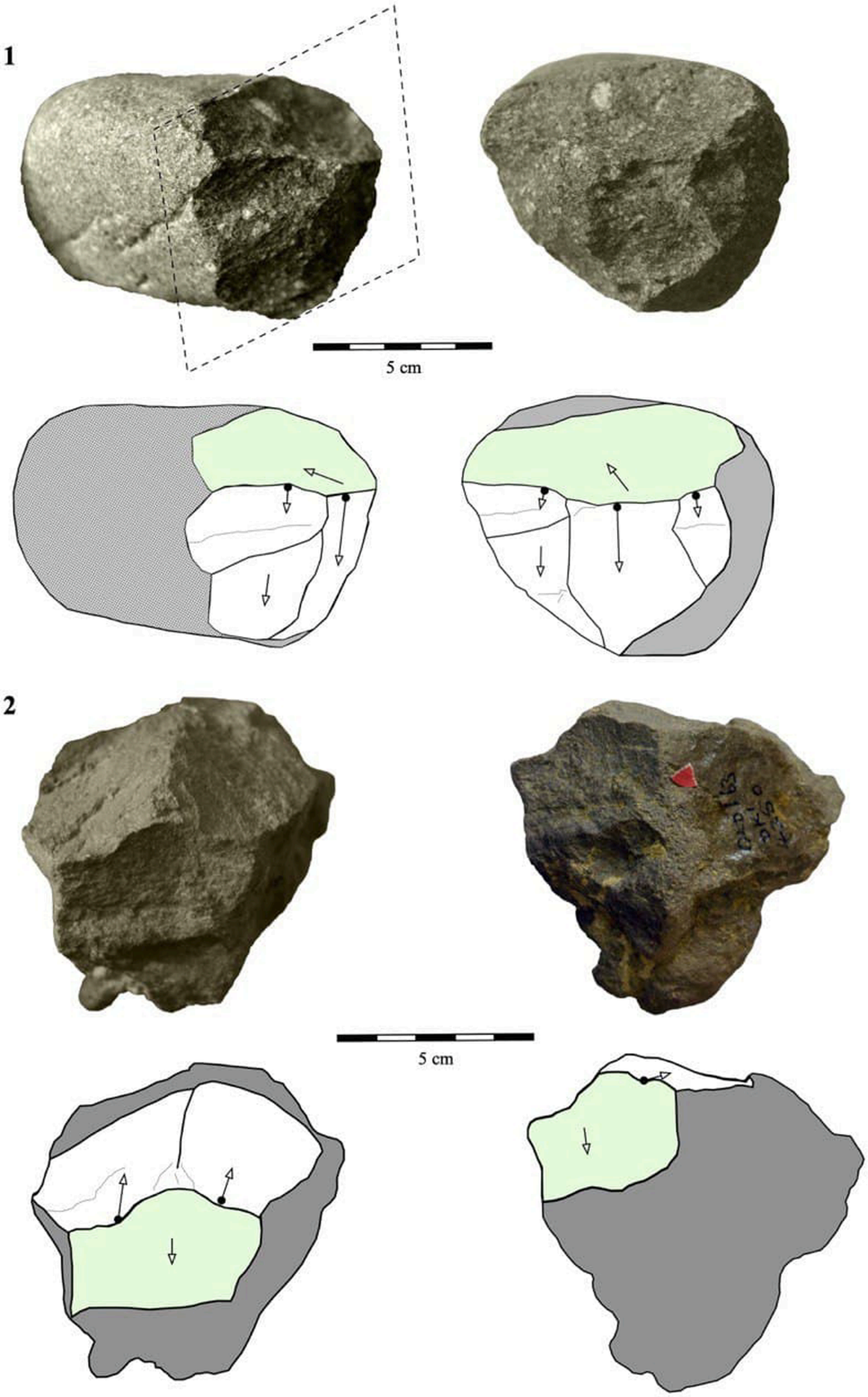

Fig. 5. Flaked-cores with platform preparation (the green colour represent the preparatory removal).

heavier and present more extractions, but there are no differences in the flaked perimeter area. It suggests possible differences in function between both artefact groups.

Concerning the techno-typological features of the rest of large and heavy retouched flakes, we identified an item that could be classified as proto-pick since its volumetric structure consisting of a distal trihedral unifacially shaped with a broken tip, a proximal trihedral with three shaped faces, and a lateral dihedral bifacially shaped (100 mm and 397 g). Ten large and heavy flakes show a lateral or distal continuous retouching edge, seven are unifacial and three bifacial. These objects could be classified without much difficulty as scrapers or bifacial scrapers (Table 5). The length and thickness of the unifacial scrapers (with one exception: 104 mm and 438 g, Fig. 12.2) are significantly less than the other large and heavy retouched flake (SI. Table 6; SI. Fig. 3).

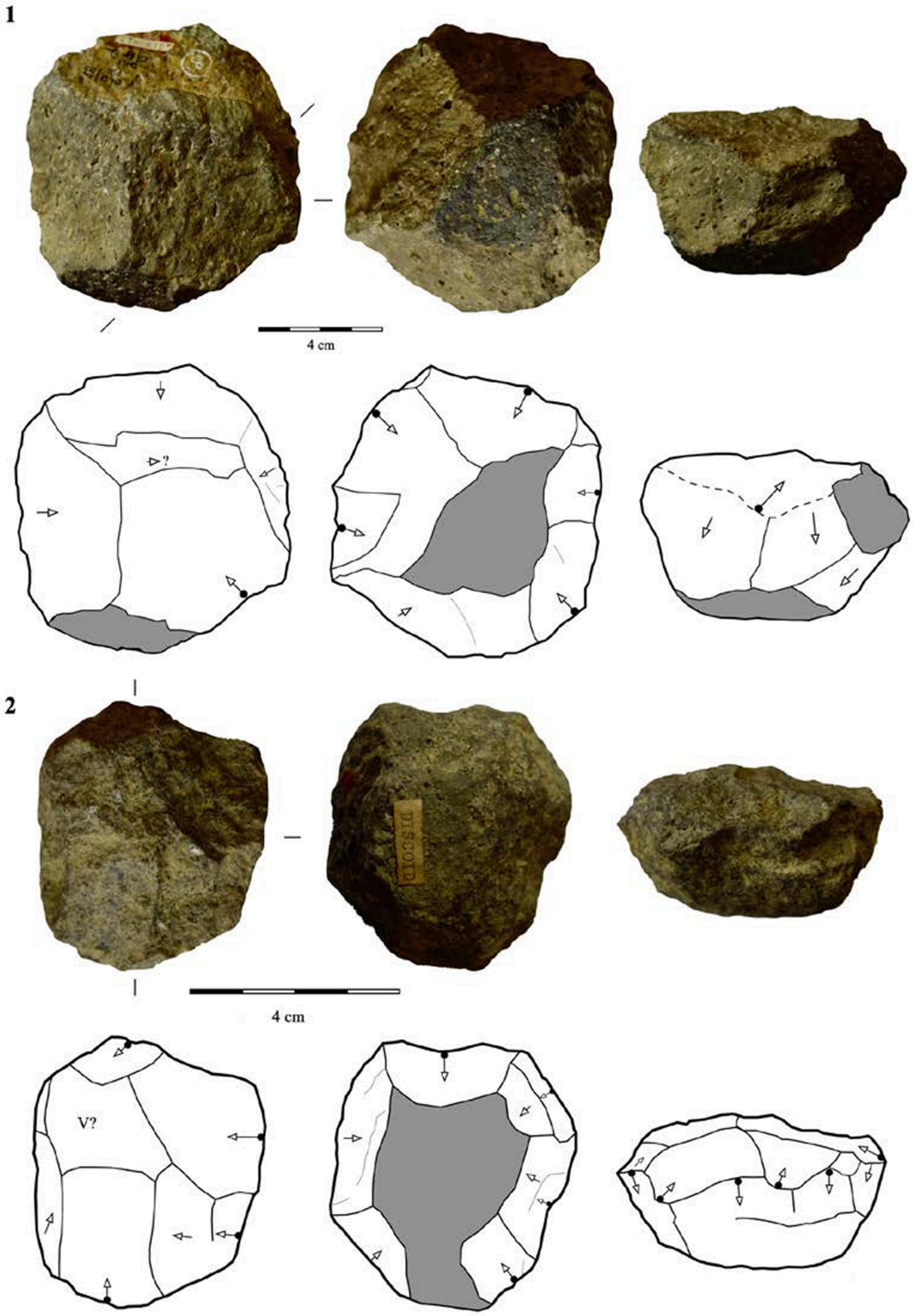

Fig. 6. Bifacial centripetal flaked-cores. The blank of Artefact 2 could be a flake (ventral face = V.). See the 3D model of artefact 1 in Supplementary Information Video Fig. 6.1.

The length and weight of the three bifacial scrapers are 84 mm and 326 g, 99 mm and 563 g, and 115 mm and 530 g (Fig. 12.1).

4. Discussion

4.1. *Distinctive features of the M. Leakey DK lithic assemblage*

The results of our study definitely confirm the statement of some archaeologists about the presence of flaked-cores with striking platform preparation and artefacts that may fall into the category of proto-bifaces in DK (de la Torre and Mora, 2005; Masao et al., 2012; Albert et al., 2015). We add other derived techno-typological traits to the technological behaviour of the DK knappers such as a significant frequency and diversity of retouched flakes which show a certain degree of plan-form standardization, the production and shaping of large blanks and the diversification of production processes geared to producing tools with different size, shape and mass. Although all these traits also appear in a few later Oldowan sites cited below, they are often considered as a threshold within the Oldowan-Acheulean technological gradient (e.g., Gallotti, 2013; de la Torre, 2016; Toth and Schick, 2018).

It is worthwhile focusing on the presence of large artefacts in the studied assemblage due to the critical implication it plays in the

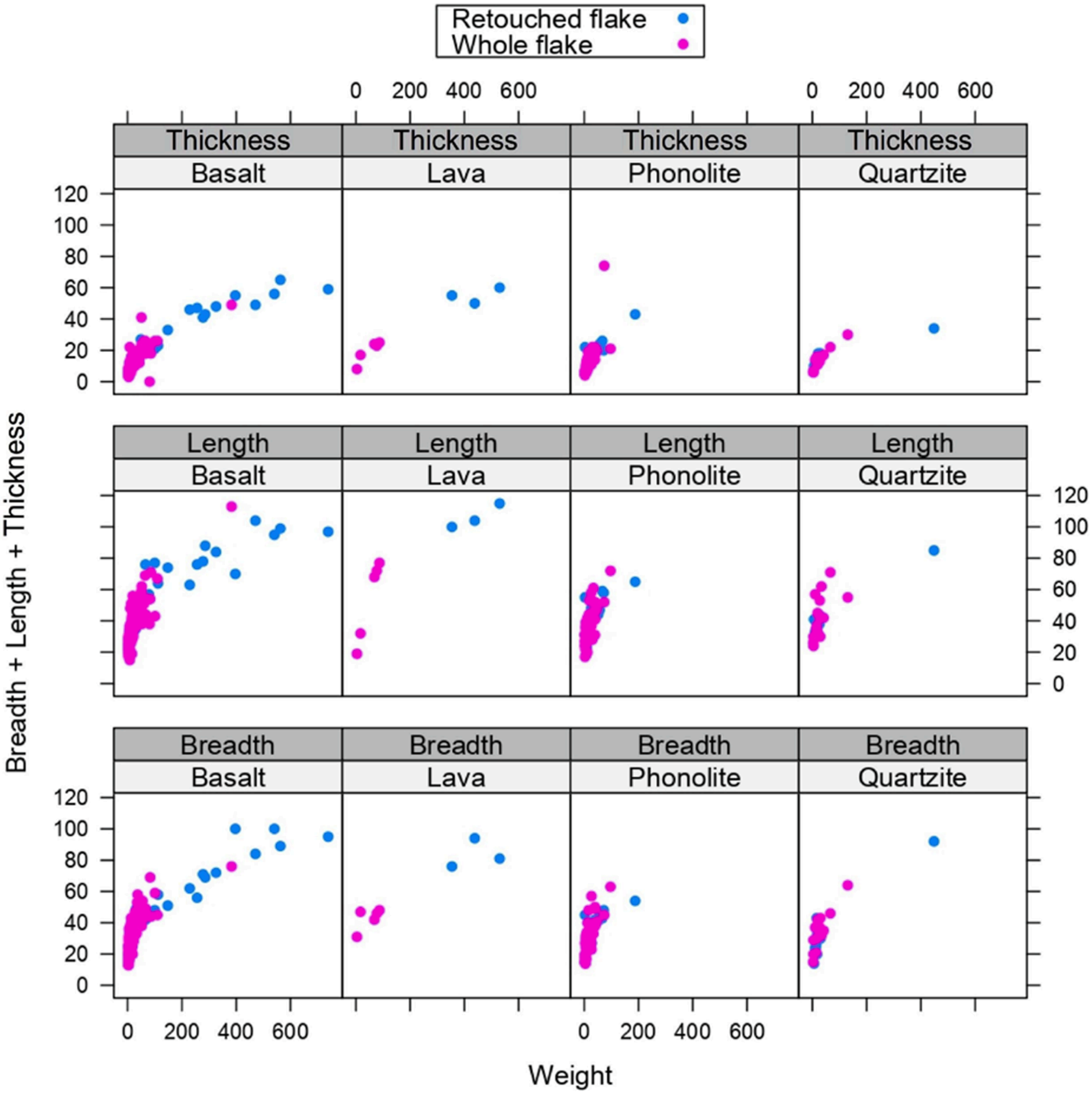

Fig. 7. Scatter plot length (mm), breadth (mm), thickness (mm) and weight (g) grouped by raw material and flake types (whole and retouched flakes).

Table 4
Typometrical (mm) and weight (g) values of whole and retouched flakes. The mean of the retouched flakes (*) is employed to divide these artefacts into two size and mass groups: small and light retouched flake (SL-RF) and large and heavy retouched flake (LH-RF) (Standard deviation = Std).

		Minimum	Maximum	Mean	Std
Plain whole flakes (n = 242)	Length	15	113	35.98	12.84
	Width	13	76	30.98	10.68
	Thickness	1	74	12.11	7.09
	Weight	1	383	20.63	31.30
Retouched flakes (n = 60)	Length	23	115	54.66*	23.41
	Width	14	100	45.86*	22.62
	Thickness	10	65	24.96*	15.79
	Weight	3	739	12.93*	179.04
SL-RFs (n = 44)	Length	23	77	42.79	11.32
	Width	14	58	34.22	9.34
	Thickness	10	27	16.22	4.42
	Weight	3	112	31.0	24.60
LH-RFs (n = 16)	Length	63	115	87.37	15.87
	Width	51	100	77.87	16.51
	Thickness	33	65	49	9.05
	Weight	148	739	387	158.8

Acheulean emergence. One may firstly wonder why DK hominins would produce large blanks to be knapped when they could directly knap large cobbles or blocks. We can tentatively suggest that DK hominins had noticed the technical and formal advantages offered by a flake over a core. It is well known that a flake mitigates the inherent difficulty entailed in the reduction of thicker blanks and it allows more control over the initial shape and size of the blank (Sharon, 2007). However, the DK knappers evidence difficulties in reducing thick volumes and the result is the poor formal and technological standardization that evidence these artefacts. Their reduction and shape were likely subordinated to functional parameters rather than structured plan-forms or mental templates. This is what is expected during a tool-kit genesis (Sánchez-Yustos et al., 2017b). At a later stage, the consolidation of functional contexts and, in turn, the tool functioning patterns would promote a positive selection of specific volumetric constructions and the consequent emergence of structured plan-forms and the standardisation of their production processes as, for instance, it is observed in the early Acheulean assemblages at Olduvai (Sánchez-Yustos et al., 2016, 2017b, 2019; de la Torre and Mora, 2018a). Furthermore, some archaeologists have stressed that the design form of bifaces developed gradually in Bed

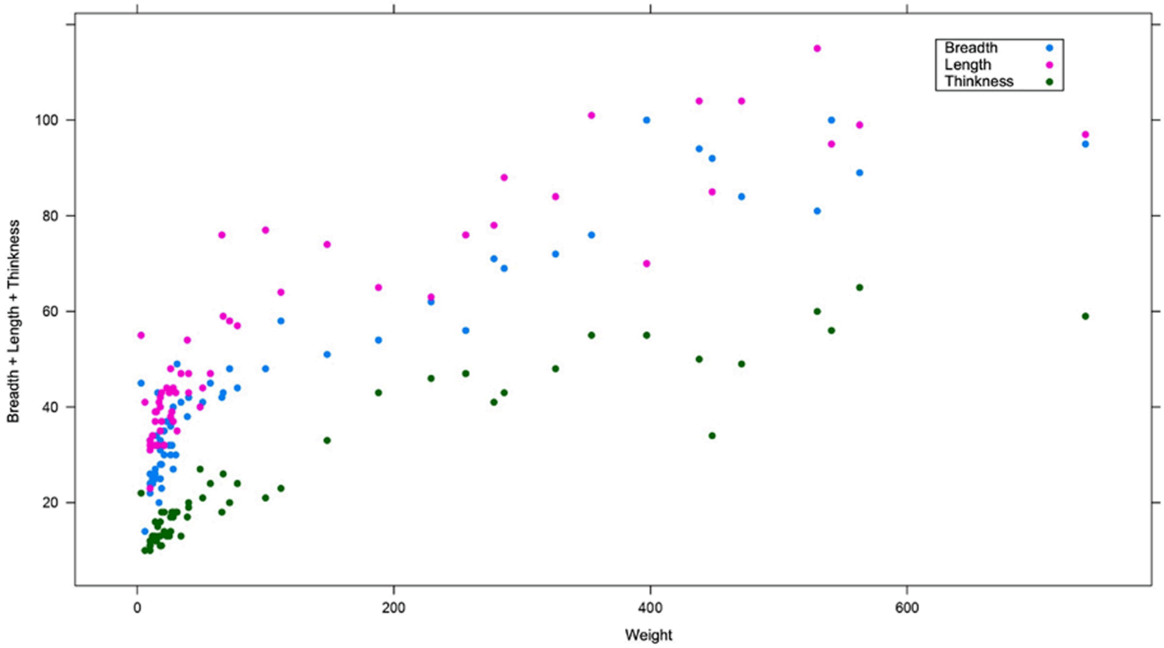

Fig. 8. Scatter plot length (mm), breadth (mm) and thickness (mm) sorted by weight (g).

Table 5
Count and percentage of the retouched flake morphotypes sorted by size and mass groups: small light retouched flake (SL-RF) and large and heavy retouched flake (LH-RF).

Morphotype	SL-RF N°/%	LH-RF N°/%
Proto-biface	–	5/31,25
Proto-pick	–	1/6,25
Bifacial scraper	1/2,32	3/18,75
Scraper	7/16,27	4/25
Scraper-Scraper	3/6,97	1/6,25
Scraper-sundry	1/2,32	2/12,5
Scraper-denticulate-spine	1/2,32	–
Scraper-Scraper-awl	1/2,32	–
Scraper-Scraper-notch	1/2,32	–
Denticulate	4/9,3	–
Denticulate-spine	1/2,32	–
Denticulate-Awl-sundry	2/4,65	–
Spine	4/9,3	–
Awl	3/6,97	–
Awl-Awl	1/2,32	–
Awl-sundry	2/4,65	–
Notch	1/2,32	–
Point	1/2,32	–
Sundry	9/20,93	–
Total	43/100	16/100

II at Olduvai, becoming more elaborate and sophisticated as time went by (Leakey, 1951; de la Torre and Mora, 2005; but see Leakey, 1971; Diez-Martín et al., 2019). The presence of proto-biface-like artefacts in Oldowan Bed I and II assemblages (Leakey, 1971; Masao et al., 2012; Albert et al., 2015; de la Torre and Mora, 2018b; this work) would intensify the sensation that the design of this iconic stone tool experiences a gradual development. A progressive evolutionary trend to perform more refined bifaces is also reported in other sequences from East Africa (Beyene et al., 2013; Gallotti and Mussi, 2017). The main contribution of the present work to this issue is the statistically significant differences noted between proto-biface-like artefacts and flaked-cores (particularly, bifacial flaked-cores). It likely confirms that a *façonnage* process may operate in the reduction of the proto-biface-like artefacts and, although *debitage* may also do it in some cases or reduction stages, they are thus not mere bifacial flaked-cored used in certain tasks.

Be that as it may, we shall conclude that the production of large blanks (*ca.* 100 mm) seems to be a technical solution adopted by DK hominins ~ 1.9 Mya to overcome the shape and size constraints imposed by the natural blanks available in the DK area. Equally important is that such production reveals an emergent demand for larger and heavier artefacts likely aimed to perform heavy-duty tasks (Sánchez-Yustos et al., 2017b). In other words, a demand determined by functional needs related to how resources are acquired, transformed and/or consumed creates the incentive for producing a tool-kit to satisfy it (i.e., demand creates supply). This might seem obvious, but it really is not. For instance, some archaeologists consider that the earliest Acheulean forms created the incentive for performing new tasks (i.e., supply creates demand) (e.g., Semaw et al., 2009).

Unfortunately, the information about the Oldowan stone tools function cannot contribute to elucidate this issue because it is scarce and limited to very few sites in which have studied reduced samples that have provided few positive evidence (Keeley and Toth, 1981; Sussman, 1987; Sahnouni et al., 2013; Lemorini et al., 2014, 2019). The functional analyses performed are mostly focused on flakes and the use-wear identified were attributed to processing both animal and plant tissues. However, reliable positive evidence of use-wear on cores is limited to three artefacts from Kanjera South (Kenya) dated ~ 2 Mya and associated with plant tissues processing (Lemorini et al., 2014, 2019). These cores are significantly smaller than the large and heavy artefacts studied here.

4.2. *Progressive model vs stasis model*

In the last decades, a consensus has emerged among Paleolithic archaeologists about the internal variability of the Oldowan industry (for a review, see Hovers 2012). Variability refers to the disparity of techno-economic traits such as raw material management, knapping techniques, structure of knapping sequences, or production objectives and processes. The subject of debate is whether this variability followed a progressive evolutionary trend.

The supporters of the “Stasis Model” argue that the rate of innovation was maintained throughout the Oldowan (e.g. Semaw, 2000; Stout et al., 2010). The Oldowan stasis does not refer to a stationary techno-

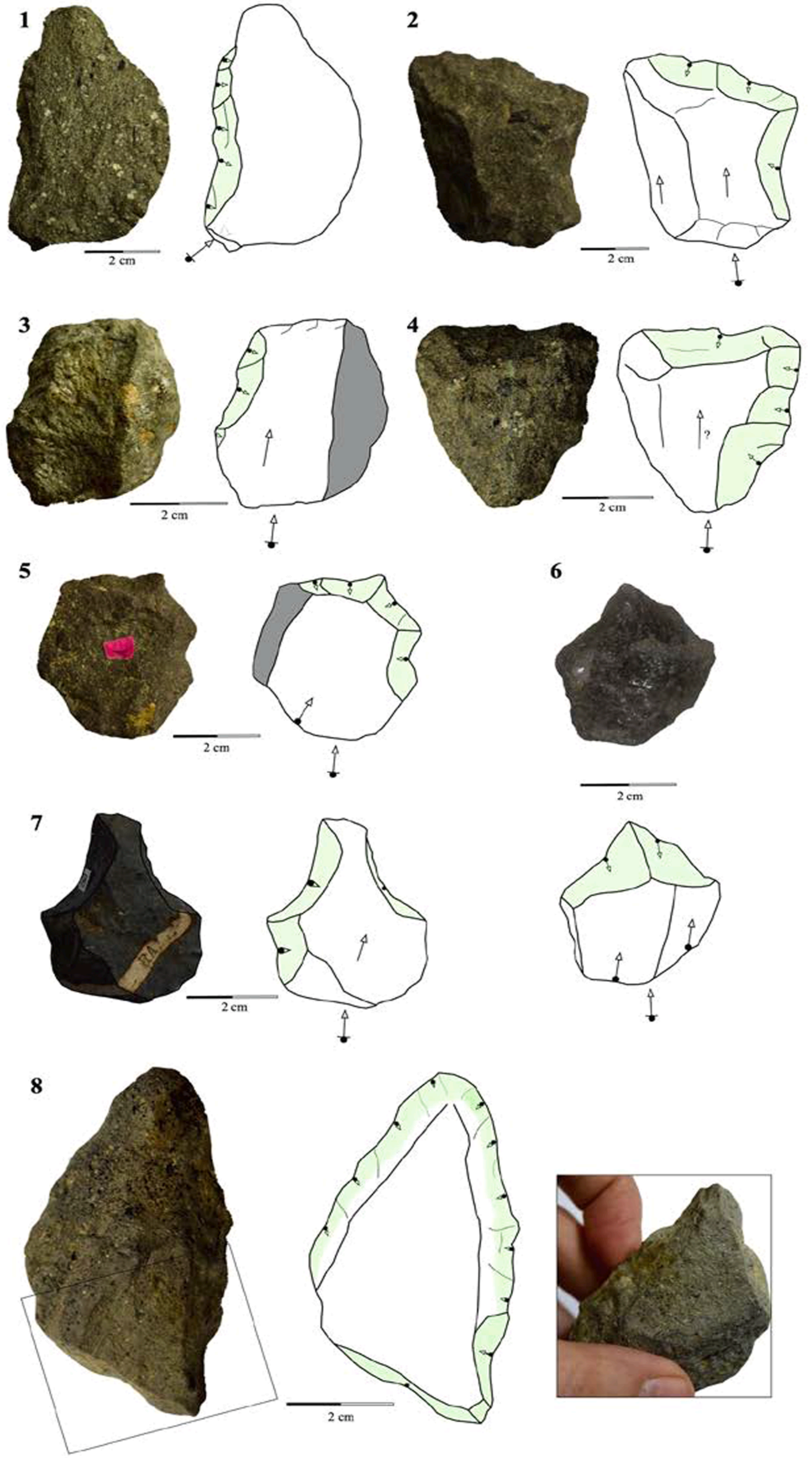

Fig. 9. Small and light retouched flakes: scrapers (1–4), spines (5–7) and scraper plus awl (8) (the light green colour represents the retouched areas).

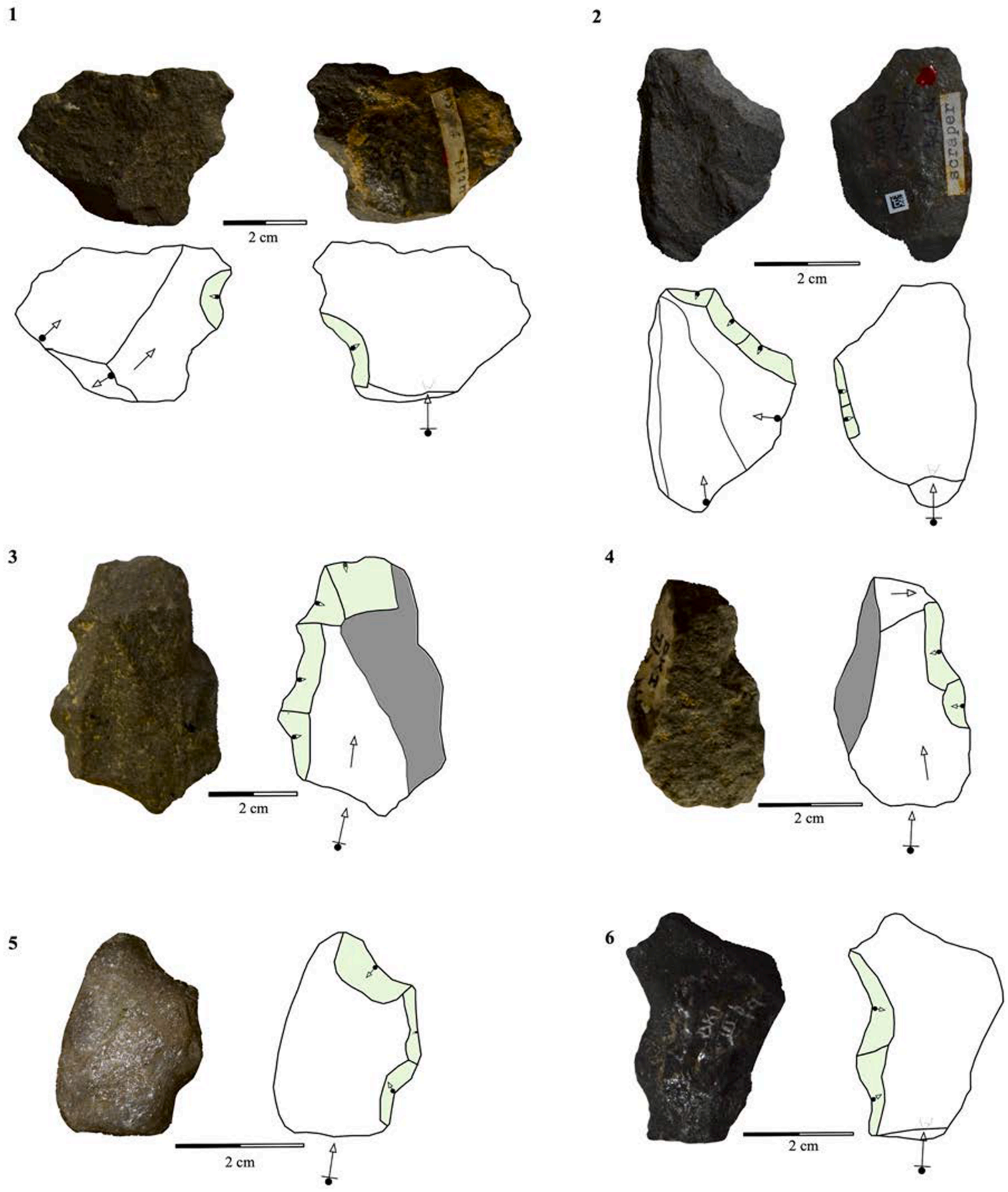

Fig. 10. Small and light retouched flakes: denticulates (1–6) (the light green colour represents the retouched area).

economic behaviour, but stationary technical competences. It is widely accepted that the range of technical solutions and procedures of the Oldowan knappers were limited and constrained by the natural properties of raw materials (e.g., Plummer, 2004; Delagnes and Roche, 2005; Schick and Toth, 2006; Hovers, 2012). Within this interpretative framework, the inter-site technological variability noted in the Oldowan is explained as a response to raw material constraints (e.g., availability, quality, knapping suitability, size and shape) and/or occasional functional needs which evidence the plasticity of the techno-economic behaviour of the Oldowan knappers (e.g. de la Torre and Mora, 2005; Delagnes and Roche, 2005; BRAUN et al., 2009; Braun et al., 2008, 2009b; Rogers and Semaw, 2009; Goldman-Neuman and Hovers, 2012; Gallotti et al., 2015; Proffitt, 2018). Some archaeologists also suggest that the variability observed would include different material culture expressions that likely respond to hominin diversity and/or group tradition differences (e.g. Roche, 2000; Hovers, 2012; de la Torre and Mora, 2018b; Roche et al., 2018).

On the contrary, some archaeologists have recognized growing complexity within the later Oldowan (≤2 Mya) that would reflect a progressive evolutionary trend towards a new technological organisation. Based on this assumption, de Lumley et al. (2009) suggested using the term "Pre-Oldowan" or "Archaic Oldowan" for > 2 Mya sites. It is interesting to recall the critical role played by DK in the foundation of the "Progressive Model". Gowlett (1986) pointed out that, conceptually speaking, the key artefacts within the Oldowan-Acheulean transition are the "discoids" from the DK (here called bifacial centripetal flaked-cores, see Fig. 6), as they show evidence of dexterity, practical skill, conceptual grasp of three-dimensional form and imposed form. However, the lack of

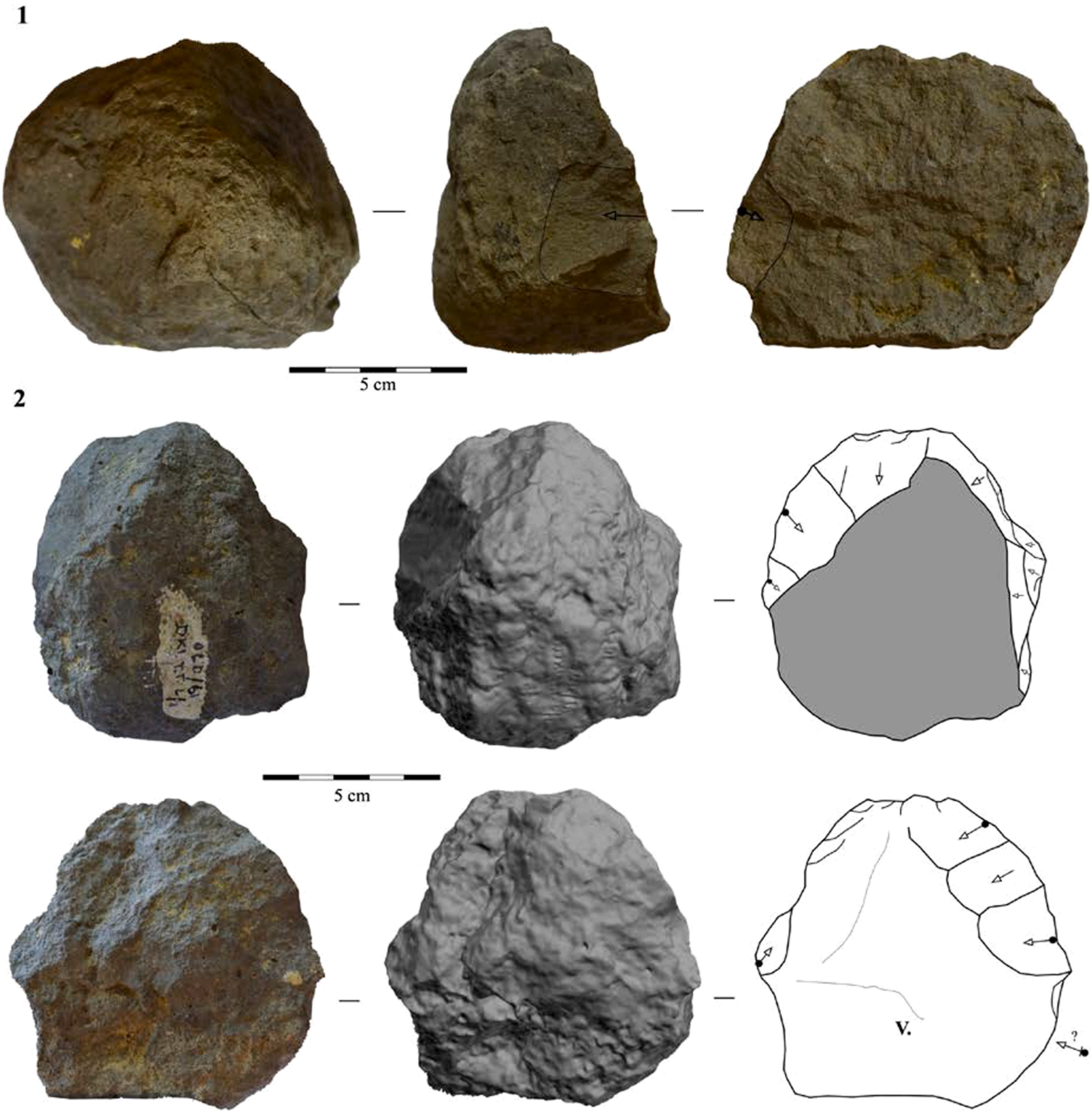

Fig. 11. Large and heavy flakes: Artefact 1 is a thick flake with isolated detachments; Artefact 2 is a shaped flake classified as a proto-biface-like artefact (ventral face = V.), see its 3D model in Supplementary Information Video Fig. 11.2.

elongation prevented Gowlett labelling these discoid artefacts as "Acheulean" tools. Likewise, according to Carbonell et al. (2009), Carbonell et al. (2016) the later Oldowan assemblages from East Africa, in which DK also plays a crucial role, are dotted with key technological developments (such as extensively practised bifacial knapping geared to both *façonnage* and *debitage*, multiplatform cores, retouching and the appearance and diversification of morpho-types) that announce a technological change whose milestone would be the development of edge transformation as the epicentre of the lithic technological behaviour.

Other authors have pointed out that the later Oldowan site of Kokiselei 5 (KS5) dated *ca.* 1.79 My exhibits transitional features to the Acheulean (Texier et al., 2006; Harmand, 2009). KS5 is very close in time and space to Kokiselei 4 (KS4) that contains the earliest Acheulean tools (Lepre et al., 2011). The flaking strategies documented in KS5 is less limited by the initial morphology of the raw materials, and the knappers display the ability to modify their initial morphology by preparing striking platforms. Furthermore, two types of production are identified, small-and-light flakes and heavy-duty tools, each of them performed on different sizes of clasts quarried at nearby streams. According to these features, Texier et al. suggested that "the knappers from KS5 possessed both the conceptual and technical background necessary to evolve towards the Acheulean technology" (Texier et al., 2006: 11).

Likewise, the results presented here are consistent with the Progressive Model. We have demonstrated that DK knappers performed different technical innovations and developed imaginative solutions to overcome the morphological constraints of the local raw material available. Indeed, DK would exhibit the earliest evidence of flaked-cores with striking platform preparation, but it is also documented in other later Oldowan assemblages (e.g., Texier, 1995; de la Torre et al., 2003). The presence of a flake-core reduction mode that uses the convexity of dorsal surfaces of large flakes in Kanjera South also leads to interesting implications (Braun and Plummer, 2013). These technological improvements are absent in those early Oldowan assemblages that provide evidence of controlled and structured flake production through constant technical rules resulting in high productivity (e.g., Delagnes and Roche, 2005; Stout et al., 2010).

An equidistant position between both models has recently been

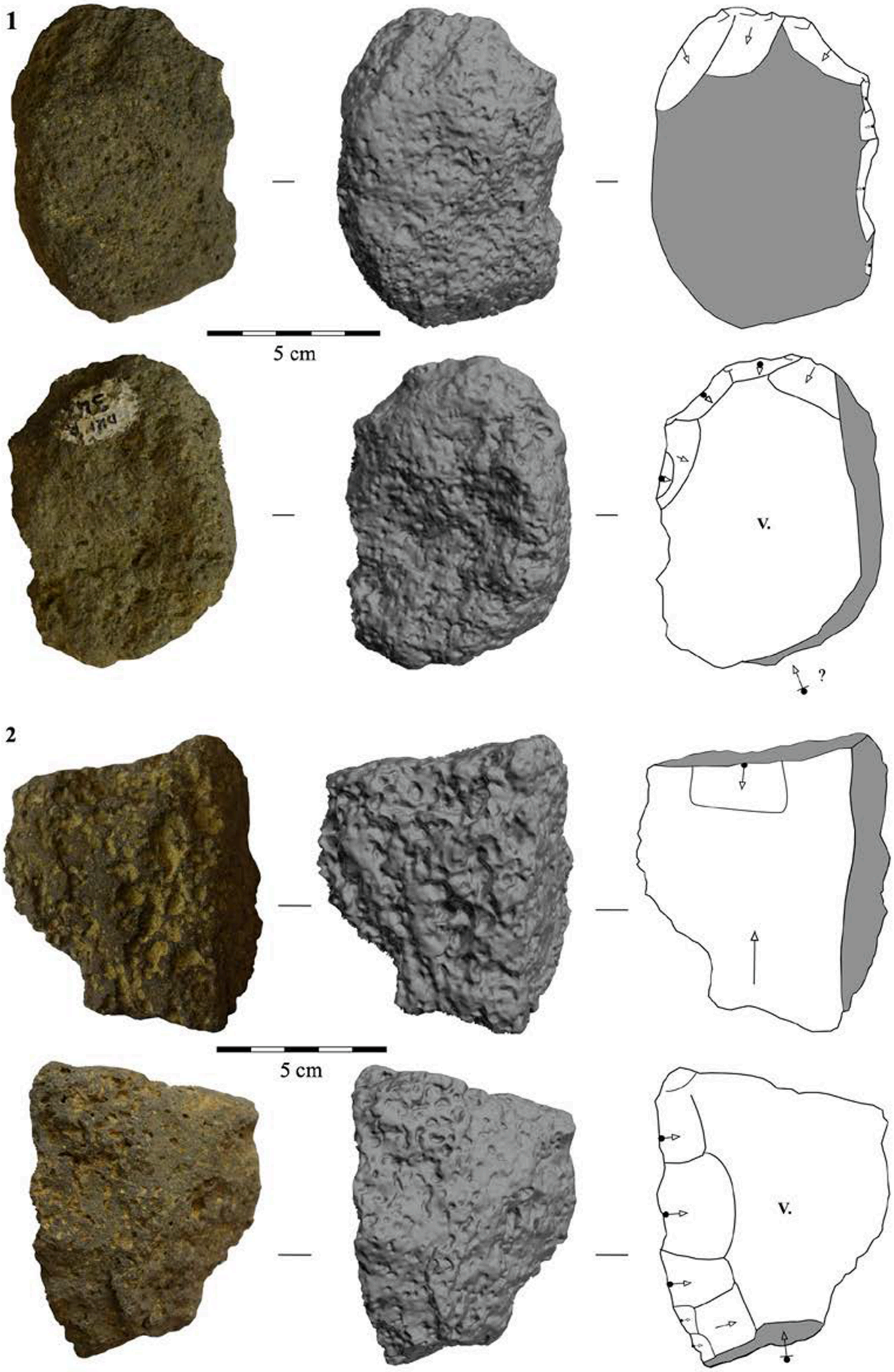

Fig. 12. Large and heavy retouched flakes: Artefact 1 is a thick retouched flake classified as a heavy-duty scraper with a bifacial latero-distal retouching, see its 3D model in Supplementary Information Video Fig. 12.1: Artefact 2 is a retouched flake classified as a heavy-duty scraper with a unifacial lateral retouching, see its 3D model in Supplementary Information Video Fig. 12.2.

formulated by de la Torre and colleagues who suggested that it is possible to observe a "true behavioural difference between the classic and the later Oldowan at Olduvai" (de la Torre and Mora, 2018b: 271), but its "distinctiveness does not herald the technological change brought about with the Acheulean" (de la Torre et al., 2018: 4). The difference these authors refer to are a few retouched pieces from HWK EE (Lower-Middle Bed II, Olduvai) dated to ~ 1.7 Mya that could be potentially considered as proto-bifaces according to them, some made on large blanks, and would evidence intentional shaping of points and the existence of discrete plan-forms (de la Torre and Mora, 2018b: 271). Standardized small flake retouching was also reported in a ~ 1.7 Mya Oldowan assemblage from Melka Kunture (Ethiopia) (Gallotti and Mussi, 2015). In this regard, DK would represent an early departure point towards the imposition of shape and, therefore, the design of volumetric constructions with different functional scopes.

The growing complexity noted within the later Oldowan assemblages seems to be part of a broader transformative process. Different lines of evidence have concluded that, beyond the changes in technological behaviour commented above, a substantial change occurred in hominin adaptive strategies after 2.0 Mya and before the Acheulean appearance. This change is materialised in the following issues: geographic expansion of archaeological occurrences; raw material selection criteria become more complex; raw material transport distances increase which widens the landscape use; spatial organisation of resources in the landscape; growing tendency to link certain raw materials to the production of certain tool forms; convincing evidence for intentional clustering of different types of lithic and subsistence resources; more habitual tool use for processing animal tissue; increased exploitation of faunal foods; advance carcass foraging; and diet diversification and dietary niche broadening (e.g., Braun, 2012; Hovers, 2012; Goldman-Neuman and Hovers, 2012; Plummer and Bishop, 2016; Domínguez-Rodrigo and Pickering, 2017). In light of this evidence, it is legitimate to wonder whether "the putative Oldowan typo-technological stasis may mask important changes in the adaptive strategies and social relationships of early hominin groups" (Goldman-Neuman and Hovers, 2012: 363). Other authors have also noted that the current taxonomic classification is not able to account the complexity and diversity observed in the so-called Oldowan assemblages (Delagnes and Roche, 2005; de Lumley et al., 2009).

4.3. *Gradual model vs abrupt model*

At present, the hegemonic position about the Oldowan-Acheulean transition is the "Abrupt Model", perfectly summed up in Glynn Isaac's statement: "The Oldowan and Acheulean entities appear to have been separated by a comparatively rapid change dependent on a single technical step which by its very nature could not have been taken gradually" (Isaac, 1969: 21). This step would be the production of large flakes (>100 mm), but subsequently Isaac introduced two additional technical innovations: the shaping of large flakes and the imposition of specific mental templates over such blanks (Isaac, 1986). These innovations are highly cognitively demanding as entail planning sequence, hierarchical actions and envisioning the toolmaking outcome, competencies that the Oldowan knappers presumably lacked (Wynn, 1989; Stout et al., 2015). Following this reasoning, the appearance of a hominin with higher cognitive skills (i.e., *H. erectus*) stimulated technological innovations brought together in the early Acheulean tool-kit and, in turn, the performing of new tasks (i.e., supply creates demand).

The Earliest Acheulean sites nuance the picture portrayed by Isaac since LCTs are performed on different blanks and the iconic Acheulean morphotypes show poor formal and technological standardization (Beyene et al., 2013; Diez-Martín et al., 2015; Lepre et al., 2011; but see Diez-Martín et al., 2019). However, the short chronological gap between KS5 and KS4, and the apparent absence of both transitional tools and industry would strengthen the idea of an abrupt appearance of the Acheulean after a temporally rapid transition from the Oldowan (Semaw et al., 2009; de la Torre, 2016). In sum, according to the Abrupt Model, the critical innovation that would trigger the abrupt appearance of the Acheulean was the manufacture of LCTs on different blanks. Thereby the presence or absence of LCTs becomes the main marker to define the taxonomic limit between the Oldowan and Acheulean. However, some archaeologists have identified alternative taxonomic markers such as core preparation, diversification and spatiotemporal fragmentation of production processes, and emergence and diversification of morphotypes (de la Torre and Mora, 2005; de la Torre, 2011; Gallotti, 2013; Sánchez-Yustos et al., 2016, 2017a, 2019).

The discovery of FLK West site (Lower-Middle Bed II, Olduvai) is also challenging the Abrupt Model (Sánchez-Yustos et al., 2018). This site dated between 1,69 Mya and 1,66 Mya provides the earliest Acheulean evidence in Olduvai and, furthermore, the earliest evidence in the archaeological record where LCT and non-LCT bearing assemblages are interstratified in the same sequence. All assemblages share significant techno-economic similarities and the differences they show in the absence/presence and frequency of LCTs likely respond to occupation differences. Consequently, we concluded they were performed by the same hominin group or taxon (i.e., early *H. erectus*) and represent different expressions of the same economic structure. It is relevant to dwell on this conclusion, as it entails a complex transitional scenario, less dependent on a single and dramatic technological step, and closer to a process that gradually developed a novel economic structure (Fig. 13). It would imply dietary diversification and the introduction of new feeding patterns supported on new strategies and solutions related to how resources were acquired, transformed and/or consumed. On one hand, we suggested that the Acheulean appearance was supported on a new economic structure rather than on novel, isolated and punctuated technical innovations derived from the Oldowan technological knowhow. On the other hand, we proposed that the Acheulean should be re-defined as an economic structure rather than an immutable cultural tradition supported on nineteenth-century postulates (Sánchez-Yustos et al., 2018, 2019).

The distinctive features of the M. Leakey DK lithic assemblage are also in conflict with the Abrupt Model, but supports a "Gradual Model". This ~ 1.9 Mya assemblage exhibits a crude and early version of the three critical technical innovations proposed by Isaac to characterize the Acheulean emergence. DK is not far from KS5 in terms of technical innovations and conceptual background and, as a result, the cognitive gap between their knappers does not seem significant. The same applies if we compare KS5 with KS4. However, DK shows a critical difference with KS4. It is not a typological issue but is a matter of size. The artefacts from DK do not show the forward extension that the earliest Acheulean tools clearly show. Although DK presents compelling evidence of the production and configuration of large-size blanks (~100 mm), the LCTs from the Earliest Acheulean sites are larger and heavier and therefore provide higher working loads (Beyene et al., 2013; Diez-Martín et al., 2015; Lepre et al., 2011). We have proposed that the economic mechanism governing the manufacture of the earliest Acheulean LCTs was a significant increase in the loading levels of tools (Sánchez-Yustos et al., 2017b) which is critical to successfully perform heavy-duty tasks (Key and Lycett, 2014; Key, 2016). In other words, forward extension was a critical improvement in tool design intended for performing heavy-duty tasks more efficiently.

On the other hand, the presence of other technological improvements (e.g., core preparation, diversification of production processes and objectives, and emergence of morpho-types), regularly associated

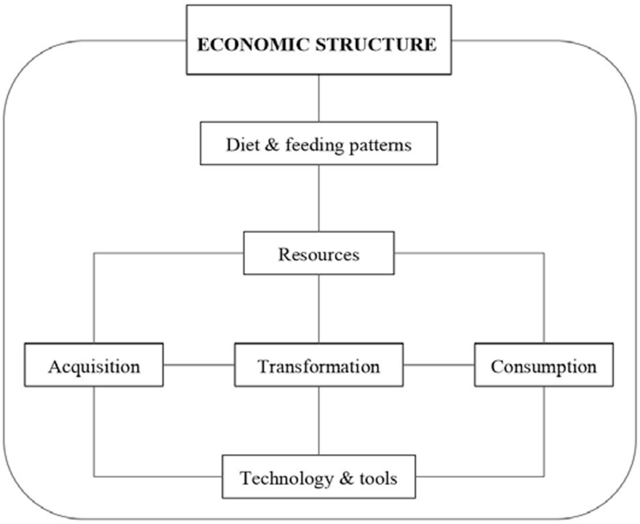

Fig. 13. Main elements that form an Early Stone Age Economic Structure.

with Early Acheulean assemblages, also challenges the classification of the M. Leakey DK lithic assemblage, whereas the absence of true LCTs prevents label it as an Acheulean. This assemblage also occupies an intermediate position in techno-economic terms. It does not show a well-structured spatiotemporal fragmentation of production processes often noted in Middle and Upper Bed II assemblages at Olduvai that suggests an advanced spatial organisation of resources in the landscape (e.g., Sánchez-Yustos et al., 2016, 2018, 2019). Despite that, the DK knappers were able to modulate the production efficiency to the procurement cost of the utilized materials (Reti and Petraglia, 2016). A quite similar techno-economic behaviour was reported in Kanjera South also associated with the increase of raw material transport distances and the subsequent widening of the landscape use (Braun and Plummer, 2013). The production efficiency in the early Oldowan assemblages is subordinated to other raw material constraints (e.g., shape, size and quality) rather than the procurement cost (Delagnes and Roche, 2005; Stout et al., 2010).

5. Conclusion

The DK knappers displayed the necessary technological know-how from which the Acheulean could emerge. This is a further argument in favour of the idea that changes took place in the hominin economic structure after 2 Mya and before the appearance of true LCTs in the African archaeological record. However, the technological improvements reported in some ≤ 2 Mya Oldowan assemblages (Texier, 1995; de la Torre et al., 2003; Braun and Plummer, 2013; Gallotti et al., 2015; de la Torre and Mora, 2018b; this work) contrasts with the stationary technological competences seen in other later Oldowan assemblages (e.g., de la Torre and Mora, 2005; Diez-Martín et al., 2010; Proffitt, 2018; Roche et al., 2018).

The high hominin taxonomic diversity observed in the African paleoanthropological record during this period could explain the disparity of technical competences (Domínguez-Rodrigo et al., 2015; Herries et al., 2020), but the techno-economic behaviour of the same taxon could also concurrently exhibit internal variability. The current occurrence of early *Homo erectus* at ~ 2 Mya (Herries et al., 2020) makes this taxon the most qualified actor to be responsible for the new adaptive strategies and solutions observed in the African archaeological record shortly after its appearance.

According to the inferential line followed here, the DK assemblage epitomises the formative or experimental phase of a new economic structure (Fig. 13). This phase corresponds to a period in which some hominin groups or taxa formulate and experience new adaptive strategies and solutions to acquire, transform and/or consume resources. The production of artefacts likely aimed to perform heavy-duty tasks appeared on the hominin technological behaviour in this context. These early artefacts seem to be not very efficient in production and performing terms, but a subsequent innovation (i.e., forward extension) would suppose a breakthrough in their design, efficiency, development and generalization. We thus understand the technological behaviour displayed by DK hominins as an adaptive response to the subsistence behaviour changes occurred ≤ 2 Mya and before the emergence of LCTs.

The most critical shift in the hominin subsistence sphere presumably operated in the predatory/meat-eating behavioural module (Domínguez-Rodrigo and Pickering, 2017). The significant increase in faunal foods consumption followed by advanced carcass foraging and processing and more habitual tool use that, ultimately, implied diet diversification and dietary niche broadening as Oldowan hominins also consumed a variety of high-quality plant foods (Lemorini et al., 2014, 2019). DK would represent, along with other East African sites as Kanjera South, the earliest archaeological expression of "a shift towards the tool-dependent foraging of high-quality foods within a cooperative group context" (Plummer and Bishop, 2016: 36).

We finally conclude that the Oldowan and Acheulean are not discrete entities separated by a rapid change dependent on punctuated technical innovations, but they are connected by a long-lasting transitional process that marks a rise in the complexity of human behaviour. It takes human tool use from a simple extension of primitive skills in the primate behavioural package to a technology grounded on a complex set of adaptive strategies and solutions. To explain such a complex process (i.e., the Oldowan-Acheulean transition) through just a single element (i.e., technology and tools), omitting the rest of the elements involved in and their interactions (see Fig. 13), could overemphasize the significance of this element, imply an oversimplification and cause the false sensation of a sudden shift leading to radical change.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2020.102763.

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