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What comes after the Developed Oldowan B debate? Techno-economic data from SHK main site (Middle Bed II, Olduvai Gorge, Tanzania)

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ABSTRACT

The Oldowan-Acheulean transition shows remarkable variability in Olduvai Bed II. To explain this, M. Leakey formulated a cultural model whose most distinctive contribution was the introduction of two cultural traditions (Developed Oldowan A and B) between the Oldowan and the Acheulean. This model has been discussed for the last fifty years, giving rise to the "Developed Oldowan B debate". SHK is one of the very few sites that M. Leakey employed to characterize this cultural tradition. We present here a techno-economic analysis of the lithic assemblage recovered in a current excavation at this site that positively provides evidence of structured and complex techno-economic behavior. The results are consistent with the current and uncontested consensus about the Acheulean nature of the Developed Oldowan B. These results may also fuel a newly established debate.

1. Introduction

The Oldowan-Acheulean transition displays significant lithic assemblage variability in Olduvai Bed II. M. Leakey brilliantly encoded it in her cultural model, whose most distinctive contribution was the "Developed Oldowan" concept that she divided into two discrete cultural traditions, the "Developed Oldowan A" (DOA) and the "Developed Oldowan B" (DOB) (Leakey, 1967, 1971). The DOB contains primitive and derived traits inherent to the DOA and Early Acheulean (EA) respectively. M. Leakey provided phylogenetic reasons in her "dual parallel phyla model" to explain this admixture (Leakey, 1967, 1971, 1975). Accordingly, the Oldowan is an indigenous phylum associated with *Homo habilis* which evolved into the DOA in Lower-Middle Bed II. Conversely, the Acheulean is an intrusive phylum associated with *Homo erectus* who imported this tradition to Olduvai in Upper-Middle Bed II. As a result of the contact between both populations, the DOA evolved into DOB due to an acculturation process by which *Homo habilis* adopted the manufacture of handaxes.

Although both cultural traditions, the DOB and EA, contain handaxes, M. Leakey pointed out significant differences in their frequency and formal appearance and gave them a taxonomic value. She incorporated the criterion previously suggested by M. Kleindienst (1961) by which a given Stone Age assemblage is classified as Acheulean if handaxes represent ≥40% of the tool-types (Leakey, 1971). Subsequently, M. Leakey introduced a significant taxonomic readjustment (Leakey, 1975). She considered that the formal differences of handaxes in the two traditions reflect the lack of expertise of the DOB knappers (i.e. *Homo habilis*) to produce large flakes and refined handaxes and, for this reason, EA handaxes are mostly made on flakes and are more symmetrical. The introduction of this stylistic proxy implied that two assemblages initially classified as DOB (i.e. MNK main site and TK upper floor) were later re-classified as EA. The three sites that remained within the DOB after this readjustment were SHK, FC, and BK.

Soon after M. Leakey formulated her model, an intense polemic arose in Paleolithic literature known as the "Developed Oldowan B debate" (see Semaw et al., 2009 for a review). In a few words, it is a taxonomic debate on the status of those assemblages in which handaxes and other LCTs are rare soon after the Acheulean emergence (here called DOB assemblages). Many archaeologists supported the distinction between DOB and EA in Bed II and other East African and Middle East sites for decades (e.g. Mason, 1976; Bower, 1977; Davis, 1980; Chavaillon et al., 1979; Clark and Kurashina, 1979; Bar-Yosef and

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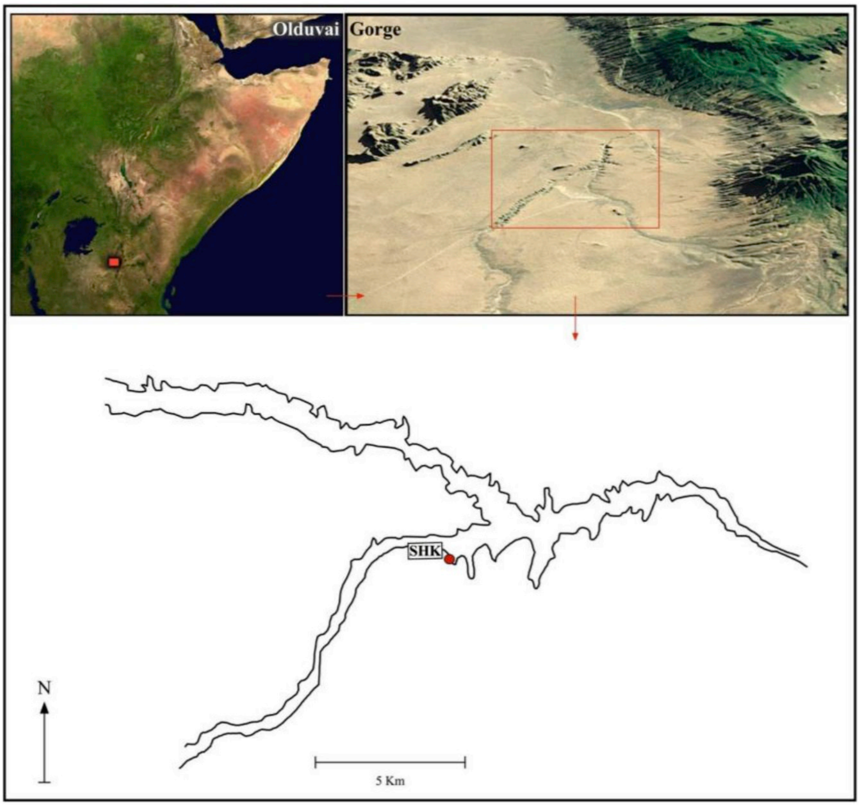

Fig. 1. Location of SHK into its geographical context.

Goren-Inbar, 1993; Callow, 1994; Roe, 1994; Kimura, 1999, 2002; Piperno et al., 2004a, 2004b). However, critics of M. Leakey's model have been claiming for the last fifty years that the techno-typological differences between the DOB and EA reflect eco-functional and techno-economic factors rather than cultural or biological factors (e.g. Isaac, 1969, 1971; Stiles, 1977, 1979, 1980, 1991; Gowlett, 1986, 1988; Bar-Yosef and Belfer-Cohen, 2001; de la Torre and Mora, 2005, 2014; Semaw et al., 2009; de la Torre, 2011; Diez-Martín and Eren, 2012; Gallotti, 2013; Gallotti and Mussi, 2018; Sánchez-Yustos et al., 2016, 2017a, 2017b, 2018, this work).

We present here a techno-economic approach to study the new lithic collection recovered during the current excavations carried out in SHK. It is the first time that this approach is applied to this site, which plays a critical role in the DOB debate. The main objective of our work is to assess to what extent the distinction between DOB and EA are supported by significant techno-economic differences.

2. SHK excavations and geology

The SHK (Sam Howard Korongo) site is in the right bank of the Side Gorge, about 2 km from the junction area (Fig. 1). S. Howard discovered this archaeological outcrop during the 1935 expedition, but excavations took place between 1953 and 1957 in two different localities, the main site (SHK MS), located at the point where the gully opened to the Side Gorge, and the annex site (SHK AS), about 90 m from the main site. M. Leakey interpreted both localities as pene-contemporaneous occupations that represented two complementary environmental situations (i.e. fluvial channel and alluvial plain) (Leakey, 1971). She placed SHK in the upper part of Middle Bed II, directly below Tuff IIC (~1.5 Mya). More recently, we (The Olduvai Paleoanthropological and Paleoecological Project, TOPPP) opened a large-scale excavation area in SHK MS (~40 m2). We have already published details of the excavation process, geological and sedimentological study, taphonomic and micro-spatial interpretation and a detailed reconstruction of the flake production processes (Diez-Martín et al., 2014; Domínguez-Rodrigo et al., 2014; Sánchez-Yustos et al., 2017a). We have also published an infant *Homo erectus* skull fragment recovered in 2009 (Domínguez-Rodrigo et al., 2012).

The stratigraphic sequence (Fig. 2) documented at SHK MS by TOPPP (Diez-Martín et al., 2014) is consistent with the sequence presented by M. Leakey (1971). We identified and excavated three archaeological levels: two (Level A and B) associated with a paleochannel and covered by Tuff IIC, while the other (Level C) is above Tuff IIC. From a geological perspective, both Level A and B are pene-contemporaneous as they are related to the same paleosurface, a seasonal channel (Level A) and the adjacent left side overbank (Level B). Fluvial impact on the lithic assemblage composition of both levels is smaller than the depositional environment might suggest (Diez-Martín et al., 2014; Domínguez-Rodrigo et al., 2014). Water disturbance played a minor role in the Level B assemblage, but a moderate disturbance likely occurred in the Level A assemblage with size sorting (debris sweeping) and re-deposition of a few allochthonous materials.

3. Materials and method

We retrieved a total sample of 1916 lithic artefacts, sorted by levels as follows: Level A, 1418 objects (74%); Level B, 355 objects (18.52%); and Level C, 143 objects (7.46%). We have only included here the lithics from Level A and B (n = 1773), studying them as a single sample since both levels are contemporaneous and distinctive features of the same landscape and, in turn, constitute different fractions of the same occupation event (Diez-Martín et al., 2014). We divided the studied sample into the following artefact categories: unmodified elements (cobbles), percussion elements (hammerstones, modified battered blocks, and anvils), chopper cores, large cutting tools (LCTs), flaked cores, flakes, retouched flakes, and waste. The numerical variables of these categories analyzed statistically were first examined to determine whether they showed a normal distribution (see Supplementary Material, Table 1).

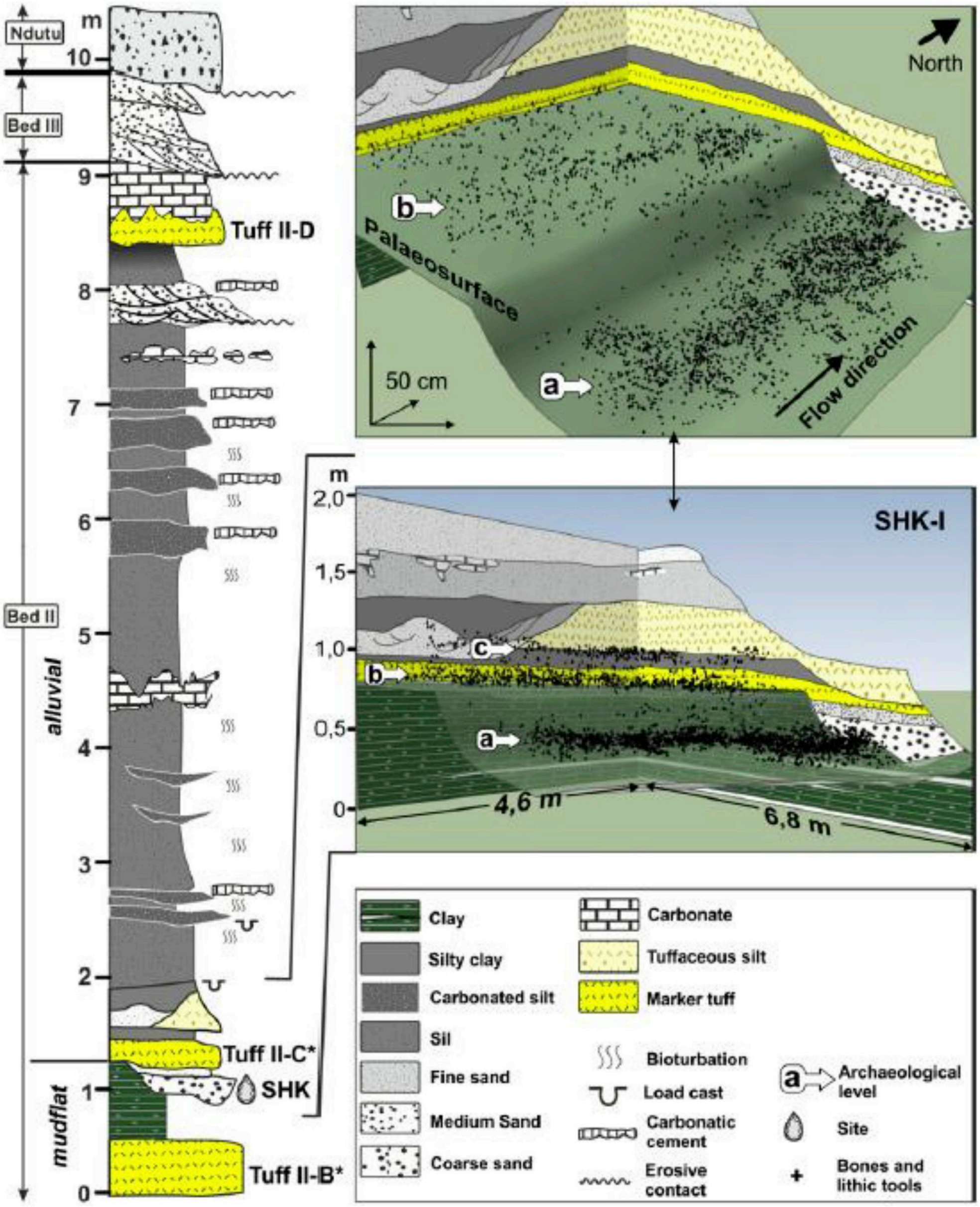

Fig. 2. Stratigraphic column of Bed II at SHK MS and stratigraphic section of the archaeological levels projected in 3D (Modified from Diez-Martín et al., 2014).

Table 1
Count of the lithic material, sorted my artefact category and raw material. Fragmented artefacts are in brackets.

	Quartzite	Basalt	Phonolite	Others	Total
Unmodified cobble	6	194	19	5	224
Hammerstone	25 (13)	124 (43)	2 (2)	–	151 (58)
MBB	19	–	–	–	19
Anvil	2	1	–	–	3
Chopper core	5	6	–	–	11
LCT	–	2	–	–	2
Flaked core	149	85	9	–	243
Flake	459 (156)	76 (10)	1 (1)	–	536 (167)
Retouched flake	72	6	1	–	79
Waste	443	56	4	2	505
Total nº/%	1180/66.55	550/31.02	36/2.03	7/0.39	1773/100

Table 2
Mean of scars per flaked core faciality and raw material (Standard deviation = Std).

	Quartzite		Volcanic rocks	
	Mean	Std	Mean	Std
Unifacial	5.076	1.998	3.478	1.620
Bifacial	7.072	2.348	7.529	3.694
Multifacial	8.297	3.332	5.529	3.318

Regarding percussion elements, the main difference between hammerstones and modified battered blocks (MBB) is based on both the blank and raw material employed. The former are volcanic cobbles, and the latter are diverse angular blanks of quartzite such as natural blocks, block fragments or blocks split by bipolar technique (i.e. bipolar cores) whose identification is problematic in those blanks intensively modified through percussion (Sánchez-Yustos et al., 2016). Using an experimental program we developed (Sánchez-Yustos et al., 2015), we proved that bipolar technique is a suitable technical solution to split quartzite tabular blocks into more easily-handled fragments employed in percussion tasks, while the quartzite angular blanks employed in battering tasks (i.e. MBB) suffer a progressive shape transformation that goes from cubic to spherical morphologies. Accordingly, we have included within this category those angular blanks that show different degrees of modification through percussion. We have also subsumed within the term MBB the spherical and subspherical pieces that show percussion damage to avoid the equifinality issue that often accompanies the term of "spheroid" and "sub-spheroid". M. Leakey, who coined the MBB concept, precisely pointed out that these artefacts do not show a clear demarcation with subspheroids and spheroids (Leakey, 1971).

The distinction between chopper cores (i.e. cores with cutting edge) and flaked cores (i.e. cores without cutting edge) could be problematic (see Toth, 1982; Isaac, 1986). The ascription of artefacts to the former category should be thus cautious and restrictive, paying special attention to specific attributes. We employed the following criteria developed by Leakey (1971) and Chavaillon and Chavaillon (1973) to characterize these tools, namely: acute angle ($< 75°$), overlapping series for secondary trimming, or edge-damage (e.g. battered or micro-scars). We follow Kleindienst's (1962) definition of LCT, and use it as a synonym for handaxe, as shaped or retouched tools with a length or width > 10 cm.

We arranged flaked cores according to scar faciality (unifacial, bifacial, and multifacial) and scar organization (lineal, opposed, orthogonal, and centripetal) of the most exploited surface. These variables allow the recognition of reduction schemes which complement the reconstruction of flake production processes already published (Sánchez-Yustos et al., 2017a). We classified flakes according to the six flake categories proposed by Toth (1982) on the basis of the occurrence of cortex on the platforms and dorsal surfaces and used as evidence of reduction stages. Other variables considered in flake analysis were size (small: < 50 mm; medium: ≥ 50 and < 100 mm; large: ≥ 100 mm), type of butt (cortical, plain, and faceted), dorsal scar pattern (linear, orthogonal, centripetal, and unorganized), presence of retouch and type of retouch (i.e. morphotype). We followed a conservative approach in the identification of retouched artefacts given taphonomic problems associated with the creation of "pseudo-retouch" often caused by use, trampling, sediment pressure, or fluvial action. Furthermore, the coarse-grained crystalline structure of the Olduvai quartzite favors unintentional chipping of edges that could be confused with retouch.

We included different types of residues within the category of waste: fragments of other categories (e.g. hammerstones, cores, or flakes), indeterminate positives, and debris (< 20 mm items). We also included bipolar artefacts within this category as we considered that they are by-products resulted from fracturing quartzite blocks with the bipolar knapping technique (Sánchez-Yustos et al., 2015). Bipolar artefacts show the main features associated with this technique in Bed II assemblages, such as opposite platforms with percussion wear (e.g. impact-fractures, cracks, pits, notches, or crushing and plunging ridges) and irregular fracture planes tending toward 90° (Diez-Martín et al., 2011; Sánchez-Yustos et al., 2015).

4. Results

The raw material most employed is quartzite ($n = 1180$ or 66.55%), followed by basalt ($n = 550$ or 31.02%). Other materials such as phonolite, chert, or gneiss contribute with very marginal percentages (Table 1). The SHK channel was the main procurement source for basalt and quartzite cobbles and, perhaps, also for a few quartzite rounded blocks. Many of the knapped quartzite blocks documented in the studied sample were quarried close to quartzite outcrops as they still exhibit tabular morphology. To date, three quartzite outcrops are known in Olduvai Gorge; the Precambrian formations of Naibor Soit inselberg (3.7 km away), Kelogi inselberg (7 km away), and Naisiusiu inselberg (12 km away). However, a closer quartzite source may have been available during the formation of Bed II, but current sediments may be covering it.

There is a strong statistical correlation between tool categories and raw materials (p.value= < 0.0001, Chi-squared test). The correspondence analysis (CA) carried out is able to cluster quartzite with MBBs, flakes (plain and retouched), waste, anvils, and flaked cores and, on the other hand, basalt with LCTs, unmodified cobbles, hammerstones, and chopper cores (SI. Fig. 1A). Although the strength of these relationships may be nuanced in some cases (i.e. flaked cores and chopper cores), the correlation between tool categories and raw materials indicated that SHK MS hominins understood the physical properties of different lithotypes and recurrently selected them for different purposes. We present below the results of the analysis of each tool category.

4.1. Percussion tools

4.1.1. Hammerstones

These percussion tools are the most numerous ($n = 151$) and many are broken ($n = 58$). They are formed by rounded or oval cobbles whose percussion damage is mostly located on the perimeter and seldom on the center of the piece. The percussion wear tends to be concentrated and connected, generating rough and battered surfaces with a frosted appearance (Fig. 3). The mean rank of the metrical values and weight is significantly higher in hammerstones than in unmodified cobbles (p.value = < 0.0001, Kruskal-Wallis test). We can thus infer that hominins preferentially quarried large and heavy cobbles from the SHK MS conglomerate (Level A) where most of the unmodified cobbles included here were naturally deposited ($n = 224$, or 12.63% of the studied sample). We cannot rule out that some unmodified cobbles were involved in percussion tasks that do not leave macro percussion wear (Sánchez-Yustos et al., 2015).

4.1.2. Modified battered blocks (MBB)

MBBs display a modest representation ($n = 19$). They are exclusively made on angled blanks of quartzite that exhibit battering on ridges or/and flat surfaces (Fig. 4). These artefacts show different stages of transformation related to battering intensity (Sánchez-Yustos et al., 2015). We identified two stages of transformation: Stage 1 ($n = 15$), blocks with battered areas that very often generate rounded ridges or

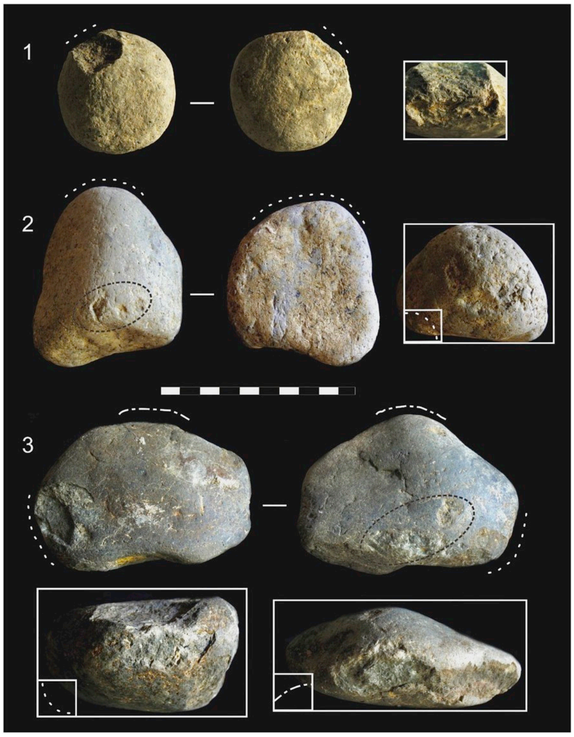

Fig. 3. Hammerstones made on basalt cobbles (dotted lines indicate areas with percussion damage).

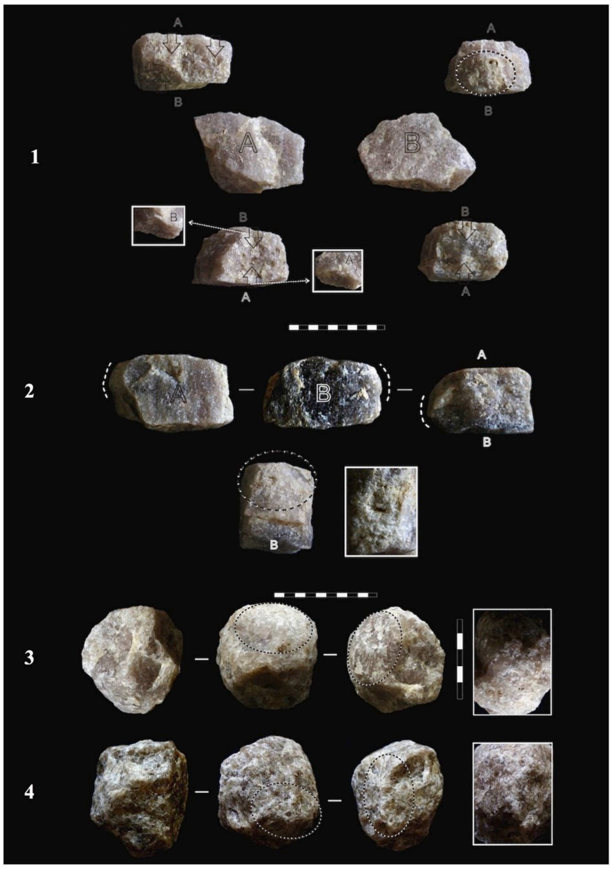

Fig. 4. Different stages of modified battered blocks (dotted lines indicate areas with percussion damage; A-B and arrows indicate fracture planes knapped by bipolar technique).

surfaces, but it is still possible to distinguish their blank type (natural block, n = 5; block fragment, n = 4; bipolar core, n = 3; indet, n = 3) (Figs. 4.1–2); Stage 2, blocks which have lost their original cuboid-shape, show rounded battered surfaces and their blank type is unclear (Figs. 4.3–4). The mean rank of weight between MBB and hammerstones is not statistically different (p.value = 0.1871, Kruskal-Wallis test).

4.1.3. Anvils

The three anvils identified are made on angular blocks of quartzite (n = 2) or a basalt boulder (n = 1), all are heavier than 2000 kg. The percussion damage is centered around the flat surfaces and rarely on the edges. They do not exhibit detached fragments, and percussion wear tends to be loose and separated, generating no rough or deeply battered percussion surfaces.

4.2. Chopper cores and LCTs

There are eleven chopper cores, both unifacially (n = 5) and bifacially shaped (n = 6) (Fig. 5.1) Most are shorter than 100 mm in length (n = 10), and their working edge is about 25% of their perimeter (n = 9). We also documented two LCTs, a handaxe made on gneiss with a broken tip and several bifacial shaping episodes (140 × 77 × 50 mm and 496 gr) and a handaxe made on a basalt flake (109 × 148 × 54 mm and 1153 gr) with a retouched transversal cutting edge (Figs. 5.2–3).

4.3. Flaked cores

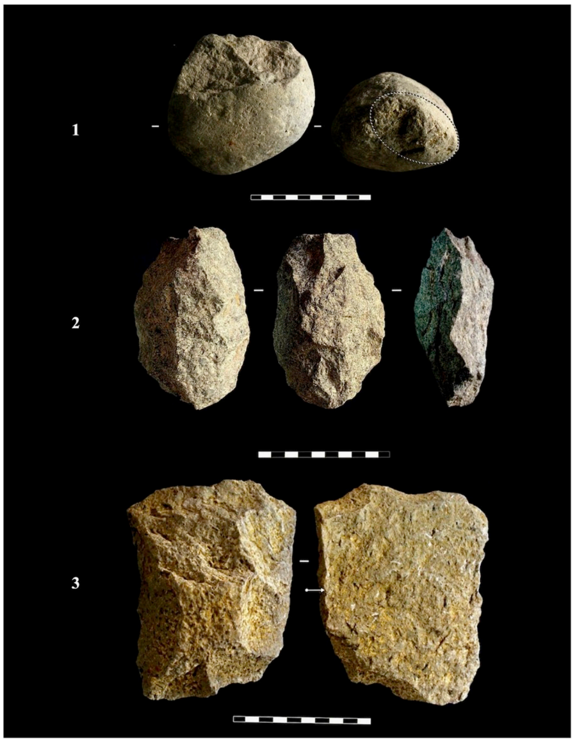

Fig. 5. Large and heavy-duty tools: 1) Chopper core with percussion damage made on a basalt cobble; 2) Handaxe with a broken tip made on a gneiss blank (probably a flake); 3) Handaxe with a retouched transversal cutting edge made on a basalt flake.

There are 243 flaked cores (13.7% of the sample). Many of them show percussion damage (n = 71) which demonstrates their use as percussion tools. Quartzite is the raw material most employed to produce flakes (Table 1). The flaked cores made on quartzite blanks are significantly more productive than those made on volcanic rocks (i.e. basalt and phonolite) (p.value = 0.0009, Kruskal-Wallis test). There is no statistical relationship between raw material and core faciality (p.value = 0.2545, Chi-squared test). Both core faciality and number of scars are statistically related (p.value= < 0.0001, Kruskal-Wallis test). This means that the more faces that are flaked, the more flakes are detached (Table 3). However, the number of flaked faces is not related with core length (p.value = 0.388, Anova), but it is with their weight (p.value = 0.0173, Kruskal-Wallis test), as multifacial cores are the heaviest cores (Table 4), not because the production of large-sized flakes would preferentially associate with these cores. Of the nine cores that show large detachments, six are made on basalt and the others on quartzite and they are evenly distributed among the three groups of core faciality. Their reduction mimics the schemes identified in the production of small and medium-sized flakes. The reduction schemes identified on the studied cores are described below according to both faciality and scar pattern.

Table 3
Counts of flaked cores, sorted by reduction scheme, raw material, and scars mean.

	Quartzite	Basalt	Phonolite	Total No./ %	Scars mean
Unifacial lineal	29	24	3	56/23.04	3.88
Unifacial orthogonal	4	2		6/2.46	6.14
Bifacial lineal	18	22	2	42/17.28	6.54
Bifacial orthogonal	36	10		46/18.93	7.55
Bifacial centripetal	6	3		9/3.7	9.33
Multifacial	56	24	4	84/34.55	9.43
Total No./%	149/61.31	85/34.97	9/3,7	243/100	7.15

Table 4
Typometrical values of the flaked cores, sorted by reduction schemes: Unifacial lineal (Uf. lin.), Unifacial orthogonal (Uf. ort.), Bifacial lineal (Bf. lin.), Bifacial orthogonal (Bf. ort.), Bifacial centripetal (Bf. cnt.), Multifacial (Mf) (Standard deviation = Std).

Reduction scheme		Minimum	Maximum	Mean	Std
Uf. lin. (n = 56)	Length	35	144	74.13	21.59
	Width	29	115	61.62	19.37
	Thickness	15	442	58.39	13.16
	Weight	27	1846	392.55	123.94
Uf. ort. (n = 6)	Length	61	118	94.25	21,12
	Width	57	100	81.37	14.58
	Thickness	47	78	63.50	10.45
	Weight	246	1066	655.12	286.63
Bf. lin. (n = 42)	Length	27	167	85.37	29.08
	Width	26	135	70.92	14.58
	Thickness	21	135	53.35	11.42
	Weight	20	2575	522.73	480.21
Bf. ort. (n = 46)	Length	32	112	68.80	18.63
	25	25	94	58.62	11.41
	Thickness	15	75	44.77	9.43
	Weight	12	1019	290.13	90.77
Bf. cnt. (n = 9)	Length	35	102	59.83	20.95
	Width	30	84	51.41	18.06
	Thickness	3	59	37.83	16.70
	Weight	29	693	208.75	207.57
Mf. (n = 84)	Length	36	147	75.01	24.41
	Width	30	121	64.32	21.88
	Thickness	28	118	58.05	20.29
	Weight	40	3373	527.86	628.75

4.3.1. *Unifacial lineal*

This is one of the best-represented schemes (n = 56, or 23.04%), but it is the least productive (3.8 flakes per core). Quartzite (n = 29) and basalt (n = 24) are the materials most often used, while phonolite (n = 3) is used marginally (Table 3). This scheme is characterized by a short series of parallel removals that exploit the volume generally by flaking a reduced portion of the perimeter of the piece (about 25%) (Fig. 6.1). However, the exploitation is maximized in those cases in which a broad and flat surface (i.e. tabular blocks of quartzite) allows the flaking perimeter to be extended following a semi-circular (n = 3) or circular (n = 8) reduction.

4.3.2. *Unifacial orthogonal*

This scheme is the least common reduction pattern in the studied sample (n = 6). It is characterized by the exploitation of a single flaking surface and two or more striking platforms that show an orthogonal arrangement. Thereby the exploitation is maximized by elongating the perimeter of the flaked surfaces through the use of different striking platforms.

4.3.3. *Bifacial lineal*

This reduction model is the least productive within the bifacial schemes, but it is well represented (Table 3). This type of production is characterized by the use of the removals detached on the other surface as striking platforms (Fig. 6.2). The production is often geared to the production of a short series of parallel removals that exploit a reduced portion of the perimeter of the piece (about 25%). The exploitation is maximized by core rotation. The raw material selected for carrying out this reduction model is preferentially basalt (n = 22), followed by quartzite (n = 18) and phonolite (n = 2). There are three quartzite blanks reduced by this model with hierarchy between surfaces since they exhibit striking platform preparation (see Sánchez-Yustos et al., 2017a).

4.3.4. *Bifacial orthogonal*

This scheme is the most common scheme among bifacial cores (Table 3). The technical actions carried out to maximize production are core rotation and elongation of the perimeter of the flaked surface by using different striking platforms that generate orthogonal crossing series of removals in the most exploited flaking surface (Fig. 6.3).

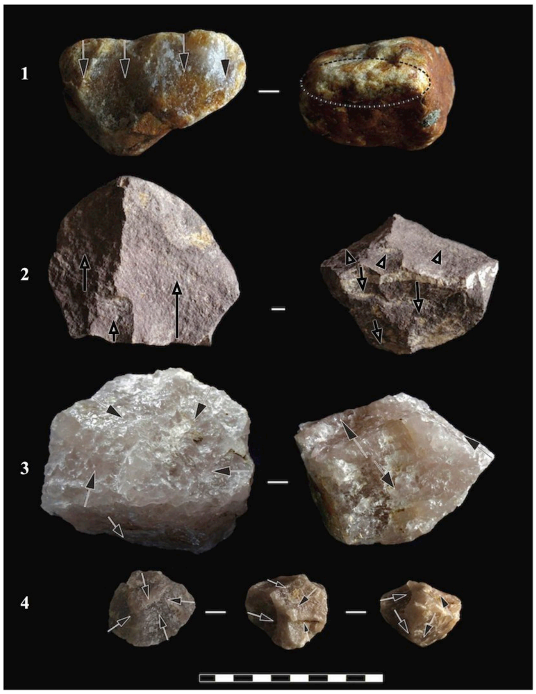

Fig. 6. Flaked cores: 1) Unifacial lineal reduction scheme on a quartzite cobble; 2) Bifacial lineal reduction scheme on a basalt cobble; 3) Bifacial orthogonal reduction scheme on a quartzite block; 4) Bifacial centripetal reduction scheme on a quartzite blank (possibly a flake).

4.3.5. *Bifacial centripetal*

This reduction model is not well represented despite being one of the most productive (Table 3). These cores present the lowest typometrical values (Table 4) which could reflect the maximization of production and the use of flakes as blanks (n = 3) (Fig. 6.4). Its high productivity is the result of employing core rotation and several striking platforms. The production is articulated either by isolated flakes or series of parallel removals that very often generate a peripheral convexity that promotes production maintenance. However, a basalt cobble seems to exhibit a more complex technical procedures in its reduction process, such as the preparation of both striking platform and flaking surface (i.e. convexity management) and, therefore, both surfaces are hierarchically related (see Fig.9B in Sánchez-Yustos et al., 2017a).

4.3.6. *Multifacial*

This reduction scheme is commonly known as “polyhedrons” in classic ESA typologies (Leakey, 1971). It constitutes the most abundant reduction scheme (35.5%). Quartzite is the most employed raw material, followed by basalt and phonolite (Table 3). These cores are characterized by three or more flaking surfaces often exploited from multiple directions that result in intensive exploitation of the blanks. The maintenance of production is carried out by continuous core rotation, flaking new planes or repeatedly using scars as striking platforms. The perimeter of the flaked surface was extended by using multiple platforms, generating multiple flaking surfaces consisting of a single removal.

4.4. *Flakes*

Flakes represent 30.23% of the studied sample (n = 536), most

Table 5
Counts of flakes, sorted by size, type of flake, and raw material.

	Plain flakes		Retouched flakes		Total No./%
	Quartzite	Basalt	Quartzite	Basalt	
Small-sized	240	38	53	1	332
Medium-sized	61	25	18	5	109
Large-sized	2	3	–	–	5

Table 6
Typometrical values of the flakes, sorted by type and raw material (Standard deviation = Std).

Plain flakes		Minimum	Maximum	Mean	Std
Quartzite (n = 303)	Length	14	89	36.53	19.25
	Width	14	113	32.86	21.78
	Thickness	4	47	14.45	12.17
	Weight	2	380	32.79	89.39
Basalt (n = 66)	Length	17	142	49.15	22.34
	Width	15	129	47.46	19.68
	Thickness	4	63	17.37	11.37
	Weight	2	1284	91.84	168.45
Retouched flakes		**Minimum**	**Maximum**	**Mean**	**Std**
Quartzite (n = 71)	Length	20	92	41.57	19.26
	Width	17	81	33.91	18.35
	Thickness	8	45	17.15	15.21
	Weight	5	446	44.15	231.91
Basalt (n = 6)	Length	4	91	64.86	13.22
	Width	37	61	48.5	9.41
	Thickness	17	27	2133	11.86
	Weight	42	129	90.66	17.20

Table 7
Counts of Toth's flake type (Tp), sorted by type of flake and raw material.

Toth's flake types	Plain flakes		Retouched flakes	
	Quartzite	Basalt	Quartzite	Basalt
Tp 1	4	9	2	–
Tp 2	41	18	–	–
Tp 3	33	5	1	–
Tp 4	12	5	1	1
Tp 5	73	17	11	4
Tp 6	293	22	28	1

Table 8
Counts of flakes, sorted by dorsal pattern, type of flake, and raw material.

Dorsal patterns	Plain flakes		Retouched flakes	
	Quartzite	Basalt	Quartzite	Basalt
Lineal	187	29	31	4
Orthogonal	51	13	7	–
Centripetal	2	–	–	–
Unorganized	37	1	4	–

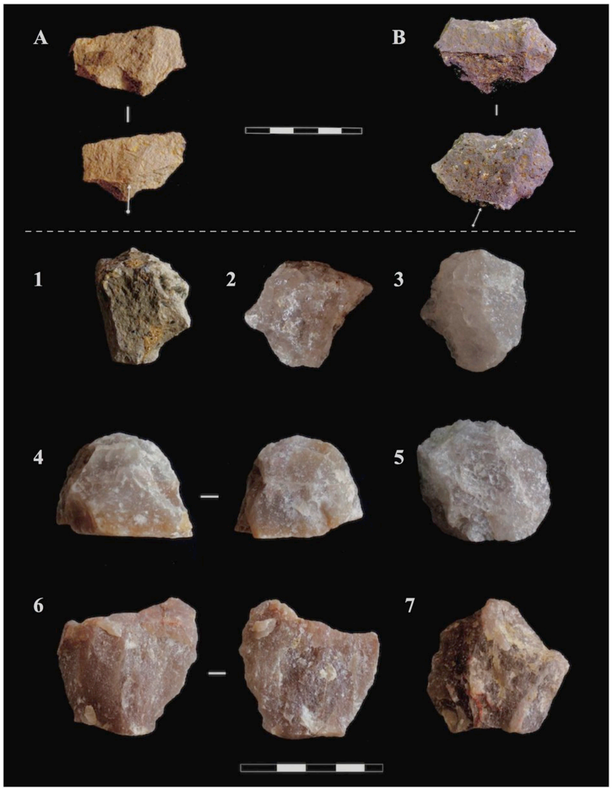

Fig. 7. LCT maintenance flakes (A–B) and retouched flakes (denticulates, 1–3; scrapers 4–6).

made on quartzite (Table 1). The percentage of fragmented flakes is much higher in quartzite (33.89%) than basalt (13.15%) due to the breaking properties of quartzite. Most of the flakes are small-sized (74.43%), while medium-sized flakes play a secondary role and large-sized ones are poorly represented (Table 5). Five basalt small-sized flakes correspond to LCT maintenance (Fig. 7A–B).

There is a significant statistical correlation between the size (length and width) and weight of flakes and their raw material (p.value= < 0.0001, Kruskal-Wallis test), as the basalt flakes are larger and heavier than the quartz ones (Table 6). Likewise, the variables flake size-type and raw material also show a strong correlation (p.value= < 0.0001, Chi-squared test). The CA carried out indicates that small-sized flakes are strongly related to quartz, while large-sized flakes are strongly related to basalt (SI. Fig. 1C).

We also observed that the variables of Toth's flake-type and raw material are significantly correlated (p.value= < 0.0001, Chi-squared test) (Table 7). The results of the CA reveals that the basalt flakes are primarily associated with those types in which the cortical regions have a greater extension (Types 1, 2 and 4), and precisely the opposite happens with quartzite flakes (SI. Fig. 1B). This fact reinforces the trend, previously observed in cores, that unifacial reduction is more abundant in basalt flakes (42.1%) than in quartzite flakes (17.64%). However, it has no impact on the dorsal pattern (Table 8), as the two raw materials do not show significant differences (p.value = 0.08117, Chi-squared test). We can thus conclude that production sequences were more extended in quartzite than in basalt, and the flaking schemes were more productive in quartzite than in basalt.

4.4.1. *Retouched flakes*

Retouched flakes represent 4.45% (n = 79) of the studied sample; 91.13% are made on quartzite and the rest on volcanic rocks (Table 1). The flake retouched ratio indicates that retouching is much more extended in quartzite than basalt (Table 9). According to the typometrical and weight values of plain and retouched flakes (Table 6), there is a recurrent selection of larger, thicker, and heavier flakes to be retouched in both quartzite and basalt (see statistical results in the Supplementary Materials, Table 2). The comparison of Toth's flake-type in plain and retouched flakes indicates that, just as in the case of basalt, there is a systematic selection of flakes to be retouched derived from advanced stages of the production sequences (p.value= < 0.0001, Chi-squared test). As in the case of the plain flakes, the dorsal pattern preferentially tends to show a linear arrangement, but orthogonal and unorganized patterns are also recorded (Table 8).

Retouching often occurs along one of the edges and consists of a single row, or at the very most two rows, of continuous retouch scars that can be either direct or inverse. These are not deep, sometimes

Table 9
Flaking and retouching ratios sorted by raw material: mean of scars per core (chopper cores and flaked cores); core-flake ratio, considered as the number of flakes (whole, fragmented and retouched flakes) divided by the number of cores (chopper cores and flaked cores); retouched flake ratio, considered as the number of retouched flakes divided by the number of whole flakes.

	Quartzite	Basalt
Mean scars per core	7.01	5.81
Core-flake ratio	3.44	1.08
Retouched flake ratio	0.21	0.08

Table 10
Counts of retouched flakes, sorted by morphotypes.

Morphotypes	Nº	%
Denticulate	30	37.97
Denticulate + Scraper	2	2.53
Scraper	14	17.72
Awl	7	8.86
Awl + scraper	1	1.26
Awl + denticulate	1	1.26
Diverse	24	30.37

slightly invasive and not very regular, resulting in a cutting edge with a sinuous and often denticulated shape. In typological terms, the most common morphotype is the denticulate, followed at a distance by scrapers and awls (Table 10). However, many retouched flakes only exhibit partial and slight modification of the edge (diverse order) (Fig. 7).

4.4.2. Waste

This group consists of different residues generated by percussion and knapping through hand-held and bipolar techniques (Table 11). Its abundance here (28.42%) is mostly related to the higher representation of quartzite in this category (88.88%) and the friable nature of this raw material. It is well known that the use of quartzite blanks for knapping and percussion generated a vast amount of waste in Bed II assemblages (e.g. Diez-Martín et al., 2011; Sánchez-Yustos et al., 2015).

5. Discussion

SHK MS has provided the first direct association between a DOB assemblage and a *Homo erectus* fossil (Domínguez-Rodrigo et al., 2012). This evidence refutes the phylogenetic relationship between *Homo habilis* and DOB proposed by M. Leakey (1971, 1975). Although *Homo erectus* very likely performed both DOB and EA assemblages, it does not necessarily invalidate their distinction as discrete cultural entities. This conclusion, or the contrary, should necessarily be discussed from techno-economic data.

The techno-economic analysis presented here allows us to identify the main production objectives, patterns, and sequences performed by the SHK MS knappers. The production and use of three different tools structured this assemblage: percussion tools, small and light-duty tools (SLD tools), and large and heavy-duty tools (LHD tools). The production of percussion tools is associated with MBB (n = 19) and bipolar fragments (n = 19). We have experimentally proved that bipolar technique was employed to split quartzite tabular blocks into more easily handled fragments (Sánchez-Yustos et al., 2015). These fragments were very often used as pounding tools (i.e. MBBs) as confirmed by the MBBs with bipolar fracture planes identified here and elsewhere in Bed II (Sánchez-Yustos et al., 2016). However, these pounding tools represent a small fraction of the set of artefacts related with percussion tasks identified in SHK MS (151 hammerstones, 3 anvils and 71 flaked cores with percussion damage). The differences between hammerstones and MBBs in terms of raw material and blank may suggest differences in use; the former would likely be employed preferentially for knapping and the latter for pounding organic materials (Sánchez-Yustos et al., 2015; Arroyo and de la Torre, 2018). Either way, the abundance and diversity of percussion tools is a clear indicator of the importance of percussion tasks in the formation of the SHK MS assemblage. Unlike "classic" Oldowan Bed I assemblages, DOA and DOB assemblages also contain abundant and diverse percussion tools (de la Torre and Mora, 2005; Diez-Martín et al., 2009; Sánchez-Yustos et al., 2016; Arroyo and de la Torre, 2018).

Table 11
Counts of waste types, sorted by raw material.

Waste	Quartzite	Basalt	Others
Debris	165	14	2
Frag. of hammerstones	1	8	–
Flakes of hammers	2	13	–
Anvil fragments	2	–	–
Core fragments	69	9	2
Indeterminate positives	165	12	2
Bipolar elements	39	–	–

The production of SLD tools (i.e. small and medium-sized flakes) is the primary objective identified here. The production processes of these tools exhibit great technological homogeneity, including the presence of striking platform preparation in a few cores. Several lines of evidence (see mean scars per core and core-flake ratio in Table 9, Toth's type flakes in Table 7, and debris representation in Table 11) suggest that the production sequences of quartzite SLD tools are quite complete and occurred on-site, but we can exclude fluvial disturbance, importation and exportation of end-products, and off-site core testing. The same proxies indicate that there is a significant deficit of basalt flakes and debris, but the initial flaking would frequently occur on-site as suggested by Toth's type flakes and the immediate availability of basalt cobbles in the SHK-MS channel. In the light of the low reduction intensity reported on basalt cores, the exportation of end-products is the most plausible scenario to explain this mismatch between cores and flakes, but fluvial disturbance and importation of already-flaked cobbles may also have occurred. This differentiated techno-economic behavior between quartzite and basalt, as well as some technical solutions (i.e. striking platform preparation) and reduction schemes applied to the production of SLD tools, have also been reported in DOA and DOB assemblages (Sánchez-Yustos et al., 2016; Torre and Mora, 2018a).

We have pointed out that quartzite is the foremost material used for the production of SLD tools and their flaked cores are more productive than the basalt ones. The reasons that may explain the preference of quartzite for SLD tool production is the broader availability of striking platforms and flaking surfaces of their blanks and the greater durability of the cutting edges of the flakes made on this raw material (Sánchez-Yustos et al., 2016). A demand for greater amounts of small sharp edges is probably the most parsimonious scenario to explain why the production of SLD tools is preferentially carried out on quartzite. In this regard, it is worth highlighting that several authors have observed in Middle and Upper Bed II assemblages (i.e. DOA, DOB and EA) a significant increase in the production of SLD tools, largely linked to the preference of quartzite for their production, in contrast to the Oldowan Bed I assemblages (e.g. Leakey, 1971; Kimura, 2002; de la Torre and Mora, 2005, 2018a; Sánchez-Yustos et al., 2016, 2018; Proffitt, 2018). These Bed II sites also have in common with our assemblage a significant increase in flake retouching and a recurrent selection of larger flakes to be retouched.

The production of LHD tools (i.e. LCTs) plays a secondary role in the composition of the present assemblage. The production of large quartzite blanks occurs on-site. There are three flaked cores with large detachments and the two large flakes that corroborate it. However, we cannot confirm that these large blanks were shaped, used, and maintained on-site since we did not record any LCTs made on quartzite. In contrast, all stages of LCT production on basalt are presented here (i.e. blank production, blank shaping, use, maintenance and discard). Different lines of evidence seem to converge on the fact the production of large basalt blanks would occur on-site: namely, six flaked cores with large detachments, three large flakes and the tendency of the basalt flakes to be larger than the quartzite ones. Nonetheless, we should be cautious with this assumption since it is supported on a scarce number of artefacts. On the other hand, different reasons suggest that the early stages of LCT production on basalt (i.e. blank production and shaping) are underrepresented. First, the significant deficit of basalt flakes, which could be even more dramatic if we include the production and shaping of large blanks. Secondly, the match between basalt flakes and flaked cores in terms of low-intensity reduction. Despite the underrepresentation of the early production stages, already-shaped blanks were maintained (5 flakes) and discarded (a handaxe) on-site. In sum, the LCT production on basalt is composed of different and disconnected knapping stages, unevenly developed and spatially and temporally fragmented. Likewise, the presence of a handaxe made on gneiss and the absence of flaked cores and flakes in this material confirm that it is an imported artefact. We can thus conclude that LCTs engaged in active transport routines and their production sequences show systematic spatiotemporal fragmentation.

Summarizing, the most relevant feature that shapes the studied assemblage is the standardization (i.e. technological homogeneity), diversification, and spatiotemporal fragmentation of production processes. The SHK-MS knappers also exhibited advanced technological competencies such as the production of large blanks and core preparation (i.e. platform preparation, convexity management and hierarchy between flaking surfaces). All of these features and competences, which illustrate highly structured and complex techno-economic behavior of the SHK knappers, have been identified as distinctive innovations of the Acheulean (i.e. taxonomic markers), recognized in Developed Oldowan assemblages in Olduvai and other East Africa sites and, ultimately, employed to justified the Acheulean nature of those assemblages (e.g. de la Torre and Mora, 2005; de la Torre, 2011; Gallotti, 2013; Sánchez-Yustos et al., 2016, 2017a). Another remarkable singularity of our assemblage is the abundance and diversity of percussion tools and the massive production of SLD tools which contrasts with the limited production of LCTs. The spatiotemporal fragmentation of the LCT production sequences and the consequent active transport routines in which these tools participated would explain the low frequency of LCTs. Some assemblages from Middle and Upper Bed II (FLK W5 and BK4b) also exhibit this behavioral pattern: a low frequency of LCTs and fragmentation of their production sequences (Sánchez-Yustos et al., 2016, 2018). However, other assemblages from Middle and Upper Bed II (i.e. FLK W6, EF-HR, and TK UF) show the opposite pattern: a higher frequency of LCTs and on-site production sequences (Sánchez-Yustos et al., 2017, 2018; de la Torre and Mora, 2018b; Santonja et al., 2018). In sum, the frequency of LCTs in Bed II, so critical to differentiate between the DOB and the Early Acheulean in M. Leakey's cultural model (1971), is largely linked to spatiotemporal fragmentation of LCT production. It is also important to highlight, in connection with their taxonomic value subsequently attributed by M. Leakey (1975), that refined handaxes are rare in both types of assemblages.

6. Conclusions

The results of the research that we have undertaken at SHK MS confirm that DOB and EA assemblages share significant techno-economic, typological, and stylistic features and their distinction as discrete cultural traditions is thus an unrealistic scenario. Our research also evidences that the taxonomic markers employed by M. Leakey to differentiate between the two assemblages lack empirical support. Nowadays there is an uncontested consensus, forged in the last decades (e.g. de la Torre and Mora, 2005, 2014; Semaw et al., 2009; Gallotti, 2013; Sánchez-Yustos et al., 2016, 2017a), around the conclusions achieved in this work. It appears that the DOB debate is definitively closed in favor of the Acheulean nature of the DOB assemblages, which implies accepting internal variability of the EA.

Despite this consensus, EA variability is still restricted to the presence of handaxes and, in turn, the absence/presence of this techno-typological innovation still marks the limit between the Oldowan and EA. However, new archaeological evidence from FLK W (Lower-Middle Bed II) is challenging this cultural-history premise (Sánchez-Yustos et al., 2018). This site has provided DOA, DOB, and Acheulean assemblages (according to M. Leakey's nomenclature) inter-stratified in the same sequence. These assemblages show significant techno-economic similarities that suggest that the same group or taxon (i.e. *Homo erectus*) may have produced them (Sánchez-Yustos et al., 2018). In this regard, it is worth recalling that the assemblage presented here and DOA assemblages (i.e. core-and-flake assemblages from Lower-Middle Bed II) share an important number of techno-economic features and, therefore, the possibility that the same taxon produced them cannot be ruled out. Likewise, other researchers considered that the techno-typological singularities displayed by DOA assemblages represent a departure from earlier classic Oldowan (de la Torre and Mora, 2018a; but see Proffitt, 2018). Be that as it may, the affinities currently noted between DOA and DOB assemblages (i.e. spatio-temporal, techno-economic and quite likely the authorship) de-emphasize the prominent role given to the absence/presence of handaxes as the foremost cultural marker to establish the limit between the Oldowan and the Acheulean.

The rejection of the taxonomic markers traditionally employed to explain assemblage variability during this period would imply the assumption of the following scenarios once the Acheulean appeared in East Africa (i) core-and-flake assemblages (i.e. Oldowan): and assemblages with handaxes (i.e. Acheulean) could be performed by the same group or taxon; (ii) core-and-flake assemblages could be performed by different hominin groups or taxa (Sánchez-Yustos et al., 2018). Thereby, we consider that the center of gravity of the discussion of how to interpret assemblage variability during the Oldowan-Acheulean transition has started to shift from the EA nature of the DOB assemblages to reassess the nature of the EA itself. In other words, what comes after the DOB debate is the reformulation of the taxonomical limits between the Oldowan and EA beyond typological postulates and, ultimately, the redefinition of the Acheulean as a concept beyond cultural-history postulates.

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Appendix A. Supplementary data

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