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RESEARCH

Exploring the Middle Stone Age lithic technology at DGS, Olduvai Gorge, Tanzania

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Abstract

Olduvai Gorge, nestled between the East African Rift Valley and the Mozambique Belt, is key to understanding human evolution. Even though extensive archaeological and palaeoanthropological findings have been unearthed here since the 1930s, the Middle Stone Age in this area has nonetheless received less attention than the Oldowan or the Acheulean. This paper presents the lithic technology analysis of Dorothy Garrod Site (DGS), a newly-documented MSA site located at the junction of the main gorge and the side gorge at Olduvai. DGS provides valuable additional knowledge to our understanding of the MSA groups that inhabited the region, offering insights into the mobility and settlement patterns of human groups in East Africa during MIS 4. This study focuses on the techno-typological characterization of the DGS lithic assemblage through an analysis of the raw material management strategies and knapping methods employed. The presence of discoid and Levallois methods, as well as single platform methods shows DGS to be a 'typical' MSA archaeological site, together with its associated fauna. The retouched pieces are scarce and characterized by a high presence of denticulates, retouched flakes and notches, as well as by the low presence of heavy-duty tools and total absence of points. All of these features make of DGS an exceptional MSA site at the heart of Olduvai.

Keywords Dorothy Garrod Site · Ndutu Beds · Middle Stone Age · Lithic technology · Olduvai Gorge · Tanzania

Introduction

Olduvai Gorge, in northern Tanzania and east of the Serengeti, is geologically located between the *great East African Rift Valley* and the Mozambique Belt (Holmes 1951; Hay 1976). It is a unique enclave, representing one of the key regions for the study of human evolution. Within it we find a sedimentary sequence around 100 m thick dating between 2.1 mya to the Holocene (Hay 1976; Uribelarrea 2017). Hans Reck (1914) was the first to study the geology of the Gorge, but it was Richard Hay (1976) who would go on to fully define it. The geological sequence of Olduvai Gorge was divided into four Beds (I, II, III, IV, from oldest to youngest) and other more modern units, the Masek, the Ndudu, and the Naisiusiu (Hay 1976; Skinner et al. 2003).

Since the first archaeological works carried out by the Leakey family in the 1930s, Olduvai Gorge has produced a multitude of archaeological and palaeoanthropological finds, especially in Beds I-IV dated between 2.1 and 0.8 mya. Numerous lithic assemblages classed as Early Stone Age (ESA), both Oldowan and Acheulean, have been

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found in these Beds (Leakey 1971a; Díez-Martín et al. 2016; Sánchez-Yustos et al. 2019; de la Torre et al. 2021). Some of these sites, such as FLK West or TK, have led to a paradigm shift on the origins of the Acheulean technocomplex and hominid behaviour in relation to the environment and the use of lithic tools (Díez-Martín et al. 2016; Bello-Alonso et al. 2021). All of these sites have also provided important palaeoanthropological information thanks to the *Homo habilis*, the *Paranthropus (Zinjanthropus) boisei* and the *Homo erectus/ergaster* remains found within them (Leakey 1959, 1961; Leakey 1971a, b; Leakey and Leakey 1964; Leakey et al. 1971; Johanson et al. 1987; Blumenschine et al. 2003; Domínguez-Rodrigo et al. 2013).

Less attention has been paid to the Middle Stone Age (MSA) in the area. This period, characterized by the presence of prepared cores, points and showing evidence of modern human behaviour (p. e. McBrearty and Brooks 2000; Foley and Lahr 2003; Coulson et al. 2011; Conard 2015; Scerri and Will 2023), has hardly been looked at in the Gorge (Leakey et al. 1972; Mabulla 1990; Eren et al. 2014). Given the small number of archaeological works, the MSA lithic technology emerging from excavated and well-dated levels at Olduvai Gorge is still rare (Maíllo-Fernández et al. 2019a, 2022).

In this paper we present a detailed techno-typological analysis of level 3 at the Dorothy Garrod Site (DGS) in Olduvai Gorge. Fully understanding the techno-typological composition of an archaeological assemblage enables us to delve deeper into the behaviour and economy of MSA groups. This provides us with the necessary data to place DGS within its northern Tanzanian MSA context.

The Middle Stone Age at Olduvai

The MSA at Olduvai is linked to the Ndutu Bed. This Bed is composed of tuffaceous, aeolian, fluvial, and colluvial sediments (Hay 1976; Manega 1993; Maíllo-Fernández et al. 2019a). This Bed was subdivided into two levels by Hay: the oldest level, termed Lower Ndutu, and the more recent Upper Ndutu (Hay 1976:152). The chronology of this Bed is currently under debate. Hay dated the Ndutu Bed indirectly, concluding that the Lower Ndutu was 400-60 ka and the Upper Ndutu between 60 and 32 ka. Manega (1993), by means of the Single Crystal Laser Fusion technique (SCLF), obtained a chronological span between 450 and 210 ka, and of 549–260 ka using bone aminoacids. Deino et al., (2021) applied 40Ar/39Ar dating, magnetostratigraphy, tephrostratigraphy and Bayesian stratigraphic age models and suggested a 50 ± 4 ka date for the Ndutu package. A recent luminescence study, however, has dated the Upper Ndutu Bed between 117.1 ± 17.9 and 45.3 ± 4.2 ka, which, when applying Bayesian statistical modelling, yields a 125.9 ± 26.5 and 45.8 ± 8.2 ka date (Smedley et al. 2023).

Additionally, Ndutu Bed has yielded modern human fossil remains. Several *Homo sapiens* cranial remains have been found associated with various fossils: OH-11, found close to DK site (Leakey 1971a), and OH-83 near PLK site (Reiner et al. 2017). Unfortunately, there are no dates available for these fossils at present.

Mary Leakey and colleagues were the first to identify two MSA sites in the Ndutu Bed at Olduvai, east of the Second Fault, to be more precise (Leakey et al. 1972). Not much is known about these two sites as specific locations were not provided in the publication. However, according to Hay (1976:159), these two sites could be those labelled 4b and 26 by him. A total of 120 pieces were collected, among them prepared cores (discoid and Levallois), flakes with faceted platforms, and several retouched pieces such as scrapers (Leakey et al. 1972: 333). In the early 1990s, Mabulla and his team carried out several surveys in the Gorge, documenting a total of five MSA sites (Mabulla 1990). Three of the sites were found in the main gorge (HdJe 1, HdJe 2, HdJe 3) and two in the side gorge (HdJe 4 and HdJe 5) (Mabulla 1990). Lithics (discoid and Levallois cores) and fauna were found on the surface in both.

Years later, in 2013, Eren and colleagues surveyed the Gorge more intensively. At least 72 localities with MSA surface materials were documented, although none were excavated (Eren et al. 2014). Since 2016, the Ndutupai team is working in the area searching for sites that will provide more information on the MSA groups that inhabited Olduvai Gorge. In 2019, we therefore presented Victoria Cabrera Site (VCS), the first site with MSA material with a clear stratigraphic and chronological context excavated at the heart of the Gorge (Maíllo-Fernández et al. 2019a).

VCS comprises five excavated levels where MSA lithics and fauna were found. The site was dated by means of Infrared Luminescense (IRSL) between 86 and 75 ka BP (Maíllo-Fernández et al. 2019a). There are few well-dated MIS 5 sites in eastern Africa; VCS therefore provides valuable information on the mobility and settlement patterns of human groups in this region of Africa. 400 m north of VCS we find Dorothy Garrod Site (henceforth DGS), the lithic industry study of which we present here.

Dorothy Garrod Site (DGS)

Dorothy Garrod site is an MSA site found in the northern part of Olduvai Gorge (Fig. 1) (Maíllo-Fernández et al. 2022), between the main and side gorges, 200 m west of the KK fault. The archaeological assemblage was recovered during three field seasons in an excavation area approximately 28 m^2 (Fig. 2). The site is geologically

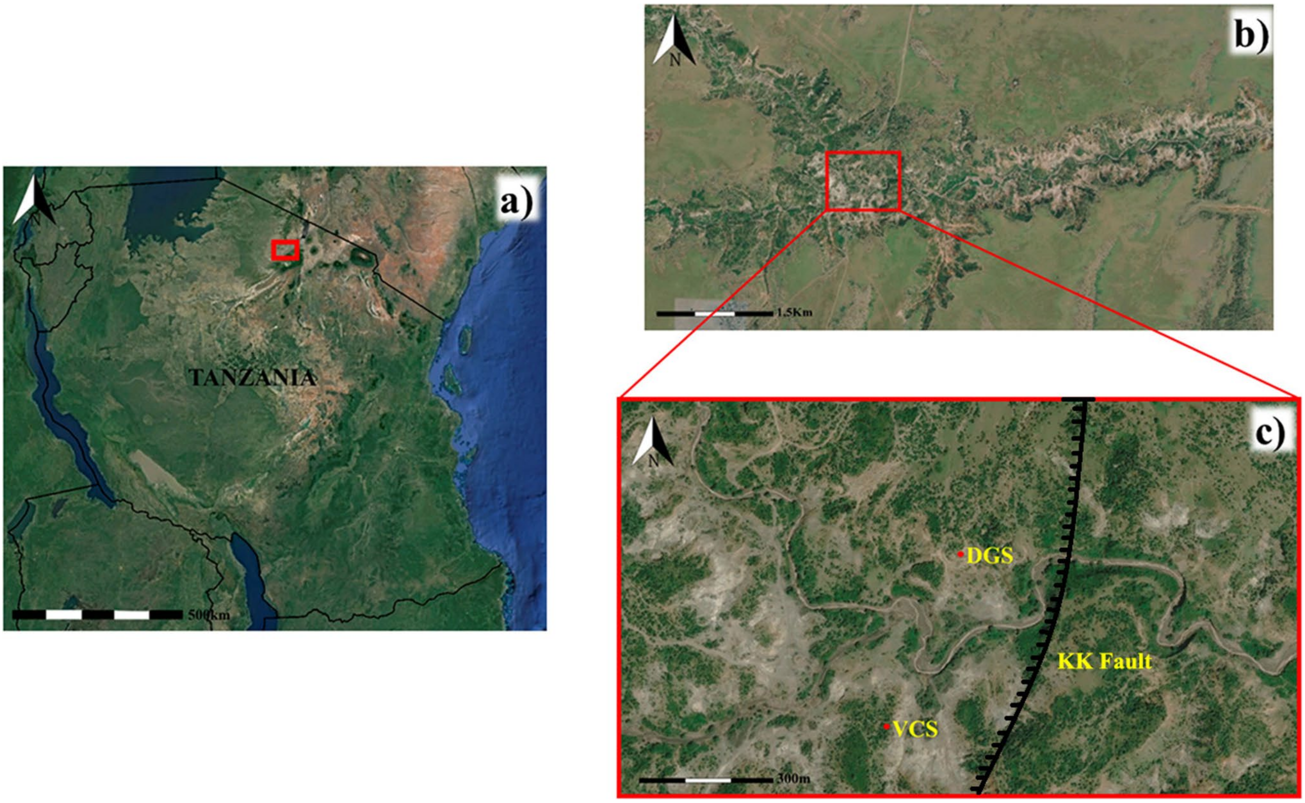


Fig. 1 Map showing the location of DGS in relation to VCS site

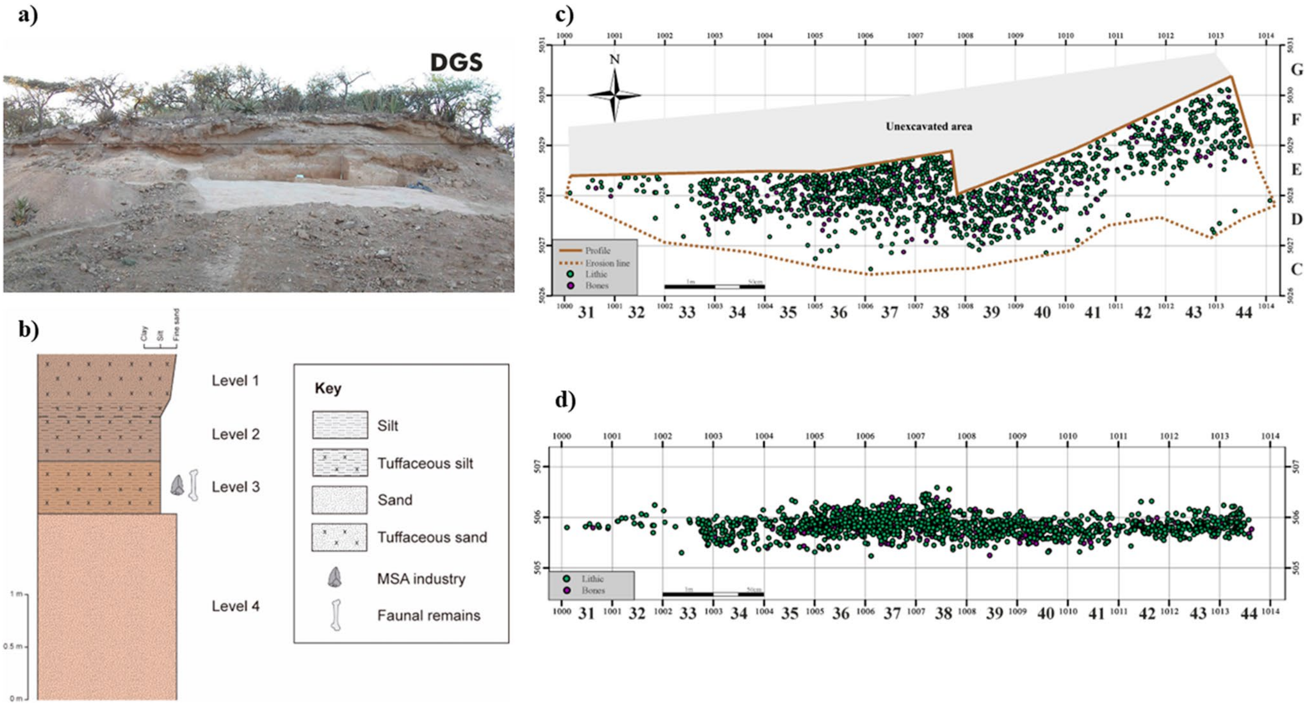


Fig. 2 **a** DGS site, **b** DGS stratigraphic column, **c** Spatial distribution of the DGS archaeological remains (bones and lithics); **d** Profile distribution of the archaeological material in Level 3

found within the Ndutu Formation. The sedimentological composition and aeolian facies pertain more specifically to the Upper Ndutu Formation, although at present there are no radiometric dates for these levels. Although previously thought otherwise (Maíllo-Fernández et al. 2022), DGS appears to be younger than VCS (75–86 ka BP, Maíllo-Fernández et al. 2019a) mainly due to its position and stratigraphic correlation within the Gorge and with VCS. Studies to confirm this hypothesis and to establish a precise chronology are still ongoing.

The site, 3.5 m thick, comprises four levels, (Fig. 2b). Level 1 is archaeologically sterile and represents a deposit of very fine tuffaceous sand. Level 2 is made up of a tuffaceous silt package and is also archaeologically sterile. Level 3, comprising tuffaceous silt, formed due to aeolian processes, and is the only level with archaeological material. Lastly, Level 4 represents the base of the sequence. It is also sterile and is made up of sands originating from aeolian processes.

The spatial anisotropy of the DGS archaeological assemblage indicates that there is no preferential positioning of the pieces at the site. The stereogram and rose diagram analyses carried out show that the assemblage has not undergone processes that could have modified the position of the remains. They present independent positions to each other, indicating that the assemblage has not suffered significant displacement and can be safely assumed to be in primary position (Maíllo-Fernández et al. 2022).

A total of 1459 archaeological remains have been found, 280 of which are faunal remains, and 1179 are lithic pieces (Fig. 2c and d). The faunal assemblage at DGS comprises 247 bone remains, 27 tooth fragments and whole pieces, 2 ostrich eggshell and 4 terrestrial mollusc fragments (Maíllo-Fernández et al. 2022:6). Although the faunal remains were very fragmented, Equidae and bovids (Hippotragini and Alcelaphini) have been identified among them. The faunal remains show anthropogenic alterations, such as bone breakage and burning, linking faunal remains to human activity. This allows us to learn about the food consumption, prey selection, and landscape use patterns of *Homo sapiens* at Olduvai Gorge.

Materials and methods

The archaeological assemblage was recovered from Level 3 only (Fig. 2b). A total of 1179 lithic blanks were excavated over three consecutive field seasons conducted between 2018 and 2019. The assemblage has been analyzed using taphonomic and techno-typological criteria (following Maíllo-Fernández et al. 2019a; Supplementary Information 1–4).

Taphonomic analysis

For archaeologists to fully understand and interpret sites, knowledge of post-depositional processes is essential. A taphonomic analysis allows archaeologists to identify and correlate archaeological assemblages with anthropic actions or natural processes. The most common modifications observed in the DGS lithic industry are: pseudo-retouch, cemented sediment and erosion (Maíllo-Fernández et al. 2022).

Pseudo-retouch affects stone tool surfaces through mechanical processes. This modification may arise as a result of anthropic (trampling) or natural (wind and/or water) processes from the movement and contact of the pieces with the sediment (Stapert 1976). Pseudo-retouch at DGS has been recorded as 'marginal', 'deep', or 'very deep' depending on the extent of the alteration to the edge of the piece.

Cemented sediment arises when the mineral components of the sediment become attached to a piece. Cementation represents a build-up process given that mineral substances external to the elements become attached. This modification results in the new minerals adhering to the surface pieces through the existing interstices and pores on the raw material, giving rise to a partial or total cementation of the pieces (Fernández-López 2000).

Erosion represents a mechanical alteration that triggers the loss of small particles of the raw material from which the piece is made. Natural processes linked to weathering (Hiscock 1985) represent the main cause behind these alterations.

Other taphonomic changes observed in the assemblage, although much less frequently, are: rounding, double patina, burning, and white patina.

Technological analysis

The techno-typological study has been carried out to define the techno-economic processes that took place at the site to: 1. learn about and define the lithic production methods used—the *chaîne opératoire* is used to examine the technical actions and reduction phases; and 2. learn about the management and use made of the different raw materials (Geneste 1991; Karlin 1992; Inizan et al. 1995; Bar-Yosef and Van Peer 2009; Audouze and Karlin 2017).

During the MSA, hominins applied different knapping methods, the main purpose of which was to obtain a high flake predetermination. Understanding the causes that gave rise to the technological variations observed at these sites is important to determine the significance and the reason behind the use of each method (Schiffer 1992). Generally, these groups used discoid, Levallois and bifacial shaping, among others (McBrearty and Brooks 2000; Basell 2013). At DGS, the most used knapping methods were the discoid, Levallois and single platform and, to a lesser extent, the centripetal, Kombewa, polyhedral and opportunistic methods (Supplementary Information 4).

Discoid methods are one of the most used in MSA lithic assemblages (Schmidt 2011; Bahra et al. 2020; Staurset et al. 2023). As defined by Boëda (1993), in discoid knapping methods the non-exclusively hierarchical relationship of the surfaces and the secant direction of the production allow for a less rigid configuration of the core volume and, therefore, greater flexibility when producing flakes (Boëda 1993, 1995; Terradas 2003; Mourre 2003). Using discoid methods, it is possible to obtain different products such as chordal and centripetal flakes, and pseudo-Levallois points (Boëda 1993; Mourre 2003). Discoid methods are especially noteworthy at DGS, being the most abundant amongst the predetermined methods.

Levallois methods emerged during the Final Acheulean and are one of the most characteristic methods of the MSA (Tryon et al. 2005). They centre around the classification of the core's surfaces and a well-defined volumetric conditioning that allow for specifically-shaped flakes to be obtained (Boëda et al. 1990; Boëda 1993, 1994). Levallois methods are less abundant at DGS compared to their discoid counterparts.

The products obtained by means of single platform knapping are also noteworthy here. These methods show short operational schemes in which the shape of the nodules is taken advantage of, quickly adapting a flake exploitation method (Delagnes and Roche 2005). Some of these methods could be classed as opportunistic given that, in general, they represent an immediate and quick use of the nodules found in the nearby landscape.

Centripetal knapping methods are those whose conceptual scheme is structured around two secant planes and whose exploitation takes place from the crest of the core’s contour in a centripetal direction (Fuertes Prieto 2004, 2006). It is true that the cores from this kind of methods, as well as their products, can be mistaken with discoid methods, especially in the final stage of exploitation (Boëda et al. 1990). Centripetal flakes have triangular and trapezoidal sections, whereas the previous negatives of the dorsal surface are centripetal or sub-centripetal in direction (Wadley et al. 2016).

The Kombewa knapping method entails the removal of flakes from the convexity of the ventral surface of a flake used as a core, thus giving rise to flakes with two bulbar surfaces (Owen 1938; Balout et al.1967; Tixier et al. 1980; Boëda 2013). These methods have been observed as far back as the ESA and during the MSA (de Lumley et al. 2004; Douze et al. 2021).

Typological analysis

The typological analysis has been carried out in a general way given the absence of a standard typology for the study of the African MSA, as noted previously by other authors (Clark and Kleindienst 2001; Douze 2012; Will et al. 2019a, Maíllo-Fernández et al. 2019b; Shea 2020; Solano-Megías et al. 2020; Scerri and Will 2023). Therefore, we have chosen to carry out the analysis following a general typology comprising large groups of retouched pieces that will allow us to compare different sites in the future.

Results

The assemblage comprises 827 débitage artefacts (flakes, blades and bladelets), 60 cores, 64 chunks, 60 chips, 6 hammers, 1 anvil, etc. (Table 1). 40 retouched pieces have been identified within the assemblage. Unfortunately, it has not been possible to study 113 of the pieces due to the presence of cemented sediment, so a full technological reading has not been possible.

Taphonomic analysis

In Level 3 at DGS, various preferential—yet very marginal—orientations have been noted, which, together with the presence of various taphonomic modifications (Table 2) suggest that during the formation of the level, low-energy transport and movement took place. This indicates that the site is found practically in primary position, as previously noted (Maíllo-Fernández et al. 2022).

The most common modification in the assemblage is pseudo-retouch, which has been identified and described according to its intensity. Of the 1179 pieces found in the assemblage, 615 show pseudo-retouch, representing 52.16% of the total (Table 2). Of these 615 pieces, 524 (44.44%) show marginal pseudo-retouch, 33 (6.53%) deep pseudo-retouch, and 14 (1.19%) very deep pseudo-retouch. This pseudo-retouch only affects the edges marginally and discontinually, with the interior crests of the pieces remaining undisturbed. This modification normally arises due to trampling, although in this particular case we must bear in mind the knapping processes undergone by Naibor quartz, which fractures easily, leaving behind dented and fractured edges.

Likewise, it is important to note that, of the 1179 pieces, 728 are fractured (Table 3). Hyaline quartz and Naibor quartz are the most fractured type of raw material, representing 78,57% hyaline quartz, followed by Naibor quartz (73.55%), phonolite (52.03%) and basalt (51.35%) (Table 3). The fracture percentages coincide also with the use frequencies for the raw materials noted at the site. Of the 728 pieces showing fractures, 155 have diametrical fractures produced during the knapping process, of which 92.9% have been made on Naibor quartz. This indicates that these fractures were produced during the knapping process due to excessive force being applied during percussion, coupled with the fracture characteristics of rocks such as Naibor quartz.

Table 1 Lithic assemblage classified by category and raw material. Pieces without complete data are in brackets

	Basalt	Fine-grained quartzite	Chert	Gneiss	Hyaline quartz	Naibor Quartz	Phonolite	Quartz	Sandstone	Sandstone/Tuff	Indet	Total
Cobble	2					1						3
Cobble Fragment				1		7	0 (1)		1			10
Totally cortical flake	1					21						22
Totally cortical blade						1						1
Cortical flake with no cortical platform						14						14
Cordal flake	1					27	4		3			35
Kombewa flake						1						1
Lateral cortical flake						2						2
Core tablet						3						3
Debordant flake	2					2			1			5
Striking platform preparation flake	4					19	4					27
Pseudolevallois point						2	2					4
Ordinary flake	8		1		6	340	37	1	35			428
Indet. flake	2					13	2		2			19
Single platform flake	1				2	32	3					38
Bidirectional flake	1				1	6	1					9
Bipolar flake						1						1
Discoid flake	2	1				162	12		6			183
Preferential Levallois						3						3
Unidirectional recurrent Levallois	3					2	2					7
Bidirectional recurrent Levallois						1						1
Centripetal recurrent Levallois	4				2	8	6		2			22
Indet. Levallois						1						1
Blade			1									1
Core			1		2	56					1	60
Chunck	4		1		1	51	3		3		1	64
Chips	1					20	5		4			30
Indet						1			1		1	3
Other						9	1		2			12
Hammer						6						6
Anvil	1											1
No modified									1		1	2
No data						2	41 (112)		5	1		161
Total	37	1	4	1	14	813	123 (113)	1	66	1	4	1179

Table 2 Taphonomic alterations

Taphonomic alteration	N	% each alteration	% total collection
Marginal pseudoretouch (PY)	524	85,20%	44,44%
Deep pseudoretouch (PM)	77	12,50%	6,53%
Very deep pseudoretouch (PR)	14	2,30%	1,19%
Total pseudoretouch	*615*	*100%*	*52,16%*
Cemented sediment	156	100%	-
Total cemented sediment	*156*	*100%*	*13,23%*
Degraded	134	100%	-
Total degraded	*134*	*100%*	*11,37%*
Weight loss	61	100%	-
Total weight loss	*61*	*100%*	*5,17%*
Marginal rounding (RD1)	5	83,34%	0,42%
Deep rounding (RD2)	0	-	-
Very Deep rounding (RD3)	1	16,66%	0,08%
Total rounding	*6*	*100%*	*0,51%*
Double patina	5	100%	-
Total double patina	*5*	*100%*	*0,42%*
Burnt	4	100%	-
Total burnt	*4*	*100%*	*0,34%*
Marginal white patina (DS1)	0	-	-
Deep white patina (DS2)	3	100%	0,25%
Very deep white patina (DS3)	0	-	-
Total piece white patina (DS4)	0	-	-
Total white patina	*3*	*100%*	*0,25%*

Cemented sediment is the second most common modification at DGS. A total of 156 pieces have cemented sediment, which represents 13.23% of the total assemblage. The blanks are covered to some extent by cemented sediment (Table 2). This modification is more pervasive in two raw materials: Naibor quartz and phonolite.

The third most common modification is erosion, found on 134 pieces, representing 11.37% of the total (Table 2). Naibor quartz is the raw material that erodes the most, which leads it to break up into smaller pieces. This is followed by sandstone/tuff, a thick-grained and porous raw material, which makes the pieces degrade both externally and internally.

Lastly, there are other types of modifications that are present very marginally, such as: rounding, double patina, burning, and white patina (the latter only present on chert pieces) (Table 2).

Technological analysis

The most used raw material is Naibor quartz (68.97%), followed by phonolite (20.02%), sandstone (5.34%), and basalt (3.15%), among others (Table 4) (Fig. 3a). All of them were local in origin: Naibor quartz comes from the Naibor soit hills, 2 km north; phonolite originates in the Engelosen volcano, 7 km north; and the basalt from the Lemagrut volcano, approximately 10–12 km from DGS. The remaining raw materials can all be found in the Olduvai riverbed (Hay 1976; Jones 1994; Tarriño et al. 2023; Maíllo-Fernández et al. 2022).

From a spatial point of view, we observe a uniform distribution of the raw materials, especially along the excavated surface (Fig. 3a). Naibor quartz is the most used raw material at the site, so a more homogeneous distribution is observed across the surface (Fig. 3b). Phonolite (Fig. 3c) is the second most abundant raw material. It is found throughout the whole excavated surface although to different degrees. There are two focal points in the central area where most of the pieces made using this raw material can be found. These concentrations could be indicating that more activities involving phonolite took place here.

The flakes linked to the first knapping and cortical removal stages are scarce (22.14%, n = 261), of which 6.37% (n = 75) are fully cortical. Non-cortical flakes, linked to a full production in the *chaîne opératoire*, predominate in the assemblage (63.61%, n = 750) (Table 4). Naibor quartz is the raw material presenting the greatest number of cortical pieces (20.1%, n = 237), whereas, for the remaining raw materials, the number of pieces showing cortical is minimal (Table 4). This indicates that the

Table 3 Fracture and non-fractured pieces by raw material. *In the phonolite we calculated non fracture pieces, fracture pieces and the percentages without the 113 cemented pieces because we have no information

	Basalt	Fine-grained quartzite	Chert	Gneiss	Hyaline quartz	Naibor Quartz	Phonolite	Quartz	Sandstone	Sandstone/Tuff	Indet	Total
Total pieces	37	1	4	1	14	813	123 (113) *	1	66	1	5	1179
Non fracture pieces	18 (48,65%)	0 (0%)	4 (100%)	1 (100%)	3 (21,43%)	215 (26,45%)	59 (47,97%) *	0 (0%)	37 (56,06%)	0 (0%)	5 (100%)	338 (28,67%)
Fractured pieces	19 (51,35%)	1 (100%)	0 (0%)	0 (0%)	11 (78,57%)	598 (73,55%)	64 (52,03%) *	1 (100%)	29 (43,94%)	1 (100%)	0 (0%)	728 (61,75%)

Table 4 Pieces with presence of cortex depending on the raw material. I = A whole dorsal surface with cortex; IIa = 2/3 dorsal surface with cortex; IIb = between 2/3 and 1/3 dorsal surface with cortex; IIc = less than 1/3 dorsal surface with cortex; III = dorsal surface with cortex

	Basalt	Fine-grained quartzite	Chert	Gneiss	Hyaline quartz	Naibor Quartz	Phonolite	Quartz	Sandstone	Sandstone/Tuff	Indet	Total
I	4			1		65	3		2			75 (6,37%)
IIa						25	1					25 (2,12%)
IIb	1		1			42	1		1			46 (3,9%)
IIc	1					105	3	1	5			115 (9,75%)
III	31	1	3		14	572	75		53		1	750 (63,61%)
Indet*						1	1			3	2	7 (0,6%)
No data**						3	153		2	1	2	161 (13,65%)
Total	37 (3,14%)	1 (0,08%)	4 (0,34%)	1 (0,08%)	14 (1,20%)	813 (68,97%)	236 (20,02%)	1 (0,08%)	63 (5,34%)	4 (0,33%)	5 (0,42%)	1179 (100%)

[*] Indet = pieces with the entire dorsal surface with cemented sediment and it was not possible to determine the presence or absence of cortex

[**] No data. Cemented pieces that could not be analyzed

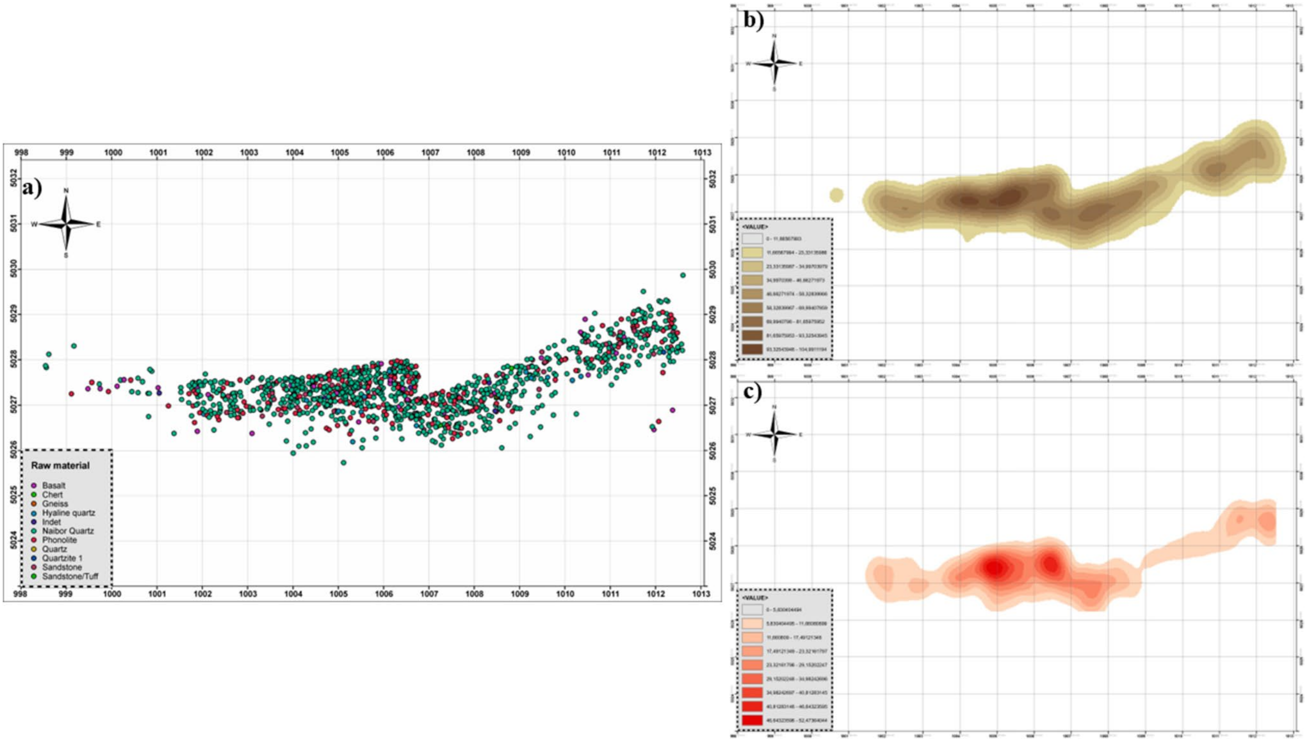


Fig. 3 **a** Spatial distribution of lithic pieces by raw material, **b** Spatial distribution of pieces made of Naibor quartz, **c** Spatial distribution of pieces made of phonolite

pieces made on these latter raw materials were brought to the site already knapped.

The technological analysis of the assemblage has enabled us to learn which were the main knapping methods used. As a result, we have been able to reconstruct the various operational schemes used at the site. The most common knapping methods are the discoid, Levallois and the single platform. To a lesser extent, the use of centripetal and Kombewa methods has also been noted (Table 5).

- Discoid methods.

This is the most abundant method at the site, with 248 pieces, representing 21.03% of the total assemblage. Of these 248 pieces, 26 are cores and 222 are flakes (Table 5; Fig. 4).

Among the 26 discoid cores, 16 were exploited unifacially (15 knapped on Naibor quartz and one on chert), whereas the other 10 were knapped bifacially (all on Naibor quartz) (Table 5; Fig. 4). The unifacial discoid cores were produced on two different types of blanks: pebbles (n = 11) and plaquettes (n = 1). On the four remaining cores, it was not possible to identify the type of blank. Among the cores, three do not have cortical, nine show it marginally and four have a fully cortical surface (Table 6). 12 unifacial cores show prior preparation of the striking platforms by means of removals and abrasion. The four remaining cores do not present prior preparation given that the angular relationship allowed for an exploitation of the blank to be made without it. The number of removals from the cores varies, ranging from 2–7 to 10. The reasons for abandonment of the unifacial discoid cores are mainly due to exhausting the core, although other causes such as bad angulation and stepped scars that prevented knapping from going forward have also been noted.

The bifacial discoid cores (n = 10) were also made on two different types of blanks: pebble (n = 3) and plaquette (n = 1). In the remaining cores (n = 6), it was not possible to identify the blank. In terms of the cortical, seven do not have cortical and three show it partially. Preparation of the striking platform by means of removals and overhang abrasion has been noted on nine cores, whereas one core does not show any prior preparation. The number of removals from the bifacial discoid cores is slightly greater than on their unifacial counterparts: between 3 and 10 removals in the case of the latter, and between 4–8, 12 and 17 in the case of the former. The main reason why these cores were abandoned was due to exhaustion, fracture or stepped scars.

On the other hand, 222 discoid flakes have been identified, of which 35 are chordal flakes (15.77%); four are pseudo-Levallois points (1.8%), and 183 are centripetal

Table 5 Raw material in different methods *chaîne operatoires*

	Basalt	Fine-grained quartzite	Chert	Gneiss	Hyaline quartz	Naibor Quartz	Phonolite	Quartz	Sandstone	Sandstone/Tuff	Indet	Total
Discoid material												
Cordal flake	1					27	4		3			35 (14,11%)
Pseudo-Levallois point						2	2					4 (1,61%)
Centripetal flake	2	1				162	12		6			183 (73,8%)
Unifacial discoid core			1			15						16 (6,45%)
Bifacial discoid core						10						10 (4,03%)
Total	3 (1,21%)	1 (0,4%)	1 (0,4%)	0 (0%)	0 (0%)	216 (87,1%)	18 (7,26%)	0 (0%)	9 (3,63%)	0 (0%)	0 (0%)	248 (100%)
Levallois material												
Débordant flake	2					2			1			5 (12,2%)
Levallois indeterminate flake						1						1 (2,44%)
Preferential levallois flake						3						3 (7,32%)
Unidirectional levallois flake	3					2	2					7 (17,07%)
Bidirectional levallois flake						1						1 (2,44%)
Recurrent centripetal levallois flake	4				2	8	6		2			22 (53,66%)
Levallois recurrent centripetal core					1	1						2 (4,87%)
Total	9 (21,95%)	0 (0%)	0 (0%)	0 (0%)	3 (7,32%)	18 (43,9%)	8 (19,51%)	0 (0%)	3 (7,32%)	0 (0%)	0 (0%)	41 (100%)
Single platform material												
Single platform flake	1				2	32	3					38 (97,44%)
Single platform core						1						1 (2,56%)
Total	1 (2,56%)	0 (0%)	0 (0%)	0 (0%)	2 (5,13%)	33 (84,62%)	3 (7,69%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	39 (100%)
Bipolar material												
Bipolar flake with cortical						1						1 (11,11%)
Bipolar flake without cortical	1				1	5	1					8 (88,89%)
Total	1 (11,11%)	0 (0%)	0 (0%)	0 (0%)	1 (11,11%)	6 (66,67%)	1 (11,11%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	9 (100%)
Centripetal cores	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	7 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	7 (100%)
Kombewa material												
Kombewa flakes						1						1 (20%)
Kombewa cores						4						4 (80%
Total	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5 (100%)
Total by raw material	14 (4%)	1 (0,29%)	1 (0,29%)	0 (0%)	6 (1,72%)	285 (81,66%)	30(8,6%)	0 (0%)	12 (3,44%)	0 (0%)	0 (0%)	349 (100%)

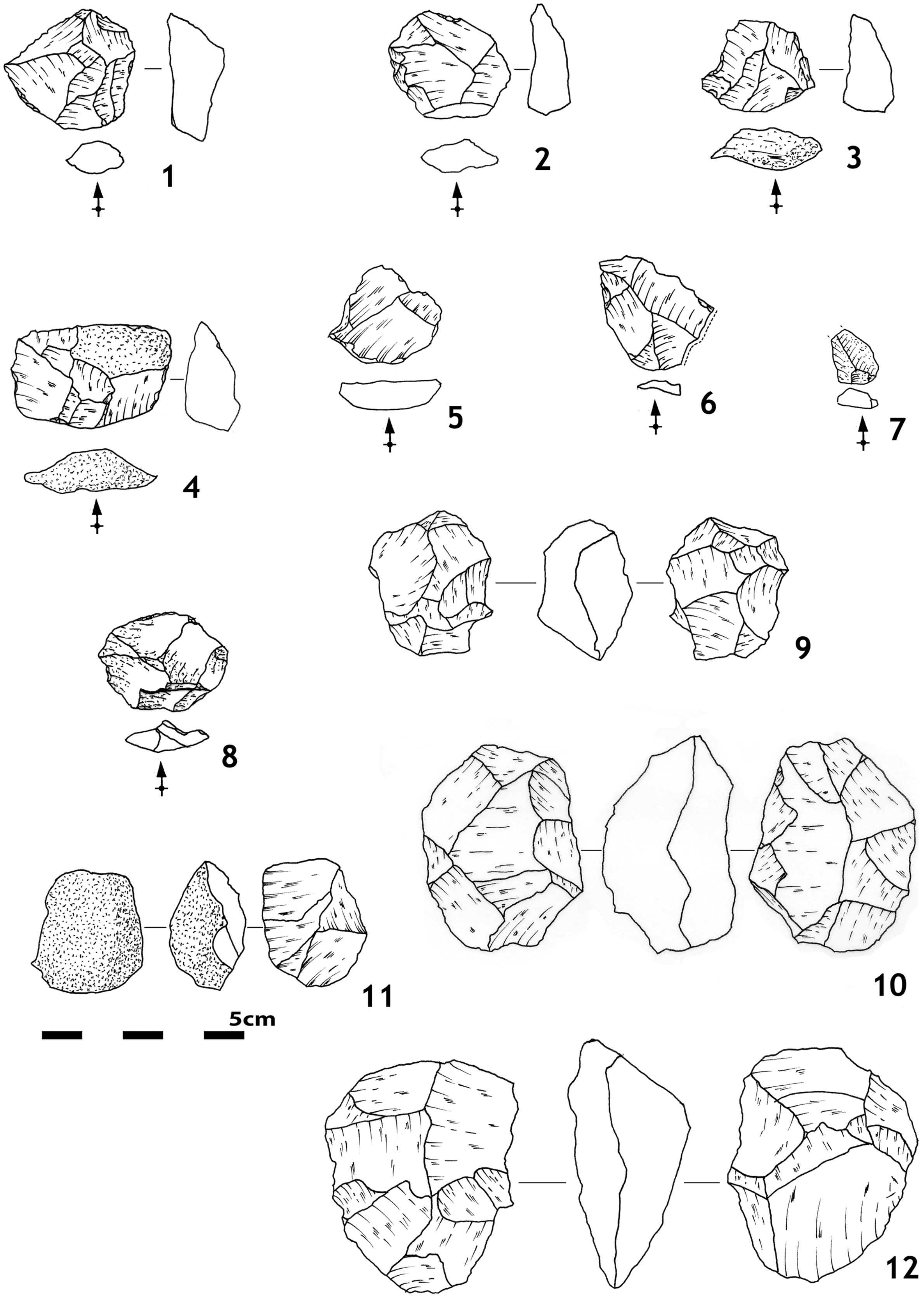


Fig. 4 Discoid-method pieces. 1, 2, 3, 4 and 5: Discoid flakes; 6 and 7: Pseudo-Levallois point; 8: Centripetal flake; 9 and 10: Bifacial discoid cores; 11 and 12: Unifacial discoid core. Raw material: 1–5, 6, 9–12: Naibor quartz; 7: Basalt; 8: Phonolite

Table 6 Presence of cortical in different methods. The pieces where it has not been possible to determine the presence of cortical or not (indet) are not included

	I	IIa	IIb	IIc	III	Indet	Total
Discoid blanks-cores							
Cordal flake	1			7	27		35
Pseudo-Levallois point					4		4
Centripetal flake			5	22	156		183
Unifacial discoid core	4	4	3	2	3		16
Bifacial discoid core	1	1		1	7		10
Total discoid blanks-cores	6 (2,41%)	5 (2,02%)	8 (3,23%)	32 (12,9%)	197 (79,44%)	0 (0%)	248 (100%)
Levallois blanks-cores							
Débordant flake					5		5
Levallois indeterminate flake					1		1
Preferential levallois flake					3		3
Unidirectional levallois flake				1	6		7
Bidirectional levallois flake					1		1
Recurrent centripetal levallois flake				2	20		22
Levallois recurrent centripetal core					2		2
Total Levallois blanks-cores	0 (0%)	0 (0%)	0 (0%)	3 (7,32%)	38 (92,68%)	0 (0%)	41 (100%)
Single platform material							
Single platform flake		1	5	10	22		38
Single platform core				1			1
Total	0 (0%)	1 (2,56%)	5 (12,82%)	11 (28,21%)	22 (56,41%)	0 (0%)	39 (100%)
Bipolar blanks							
Bipolar flakes				1	8		9
Total bipolar flakes				1 (11,11%)	8 (88,89%)		9 (100%)
Centripetal cores	1 (14,29%)	0 (0%)	1 (14,29%)	4 (57,13%)	1 (14,29%)	0 (0%)	7 (100%)
Kombewa blanks-cores							
Kombewa flakes		1					1
Kombewa cores	1	1	1		1		4
Total	1 (20%)	2 (40%)	1 (20%)	0 (0%)	1 (20%)	0 (0%)	5 (100%)
Total blanks and cores by cortical	8 (2,29%)	8 (2,29%)	15 (4,3%)	51 (14,62%)	267 (76,5%)	0 (0%)	349 (100%)

flakes (73.8%) (Table 5; Fig. 4). The most used raw material is Naibor quartz (86.04%), followed by phonolite (8.11%), sandstone (4.05%), and basalt (1.35%). Among the discoid flakes, 84.24% do not present cortical, whereas 15.76% do show it to different extents (Table 6). The most common platforms are flat (26.58%), although there is a large number showing broken ones (27.93%) or none due to proximal fractures (21.17%) (Table 7). The discoid flakes have between two and five previous scars (Table 8) in centripetal (65.32%), proximal (14.86%) and proximo-lateral (8.56%) directions (Table 9).

- Levallois Methods

The pieces linked to Levallois methods are the second most abundant at DGS, with a total of 41 pieces (3.48% of the total assemblage). Of these, two are recurrent centripetal Levallois cores, and 39 are flakes (Table 5; Fig. 5).

The two recurrent centripetal cores were knapped on Naibor quartz and hyaline quartz. The blank used to knap these cores has not been identified and does not present cortical (Table 6; Fig. 5). The preparation of the débitage surface in both was done by removing small centripetal negatives prior to knapping. The number of removals on the débitage surface is five and six, respectively. Both cores were exhausted.

Of the flaking products, a total of 39 flakes were recorded, of which 22 are recurrent centripetal (56.41%); seven are unidirectional Levallois flakes (17.95%); five are débordant flakes (12.82%); three are preferential Levallois flakes (7.7%); one is a bidirectional Levallois flake (2.56%); and one is an indeterminate Levallois flake (2.56%) (Table 5; Fig. 5). The Levallois flakes are made on Naibor quartz (43.59%); basalt (23.08%); phonolite (20.51%); sandstone (7.69%) and hyaline quartz (5.13%). 92.31% of Levallois flakes lack cortical, whereas 7.32% preserve it very marginally, with less than a third of the cortical dorsal surface

Table 7 Platform type in DGS blanks

Flake type/Platform type	Cortical	Dihedral	Rectilinear facetted	Convex facetted	Concave facetted	Plain	Indeterminate	Broken	Delete	No platform	Total
Discoid material											
Cordal flake	2	4	5	3		15		3		3	35
Pseudo-Levallois point				1		2		1			4
Centripetal flake with cortical	9	3				9		4		2	27
Centripetal flake without cortical		9	5	11	1	33		54	1	42	156
Total	11 (4,95%)	16 (7,21%)	10 (4,5%)	15 (6,76%)	1 (0,45%)	59 (26,58%)	0 (0%)	62 (27,93%)	1 (0,45%)	47 (21,17%)	222 (100%)
Levallois material											
Débordant flake				1		3				1	5
Levallois indeterminate flake								1			1
Preferential levallois flake				1				1	1		3
Unidirectional levallois flake			3	1		1		1		1	7
Bidirectional levallois flake			1								1
Recurrent centripetal levallois flake		4	5	5		5		3			22
Total	0 (0%)	4 (10,26%)	9 (23,08%)	8 (20,51%)	0 (0%)	9 (23,08%)	0 (0%)	6 (15,38%)	1 (2,56%)	2 (5,13%)	39 (100%)
Single platform material											
Single platform flake	5 (13,16%)	2 (5,26%)	6 (15,79%)	0 (0%)	0 (0%)	8 (21,05%)	0 (0%)	12 (31,58%)	0 (0%)	5 (13,16%)	38 (100%)
Bipolar material											
Bipolar flake with cortical						1					1
Bipolar flake without cortical						3		3		2	8
Total	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	4 (44,45%)	0 (0%)	3 (33,33%)	0 (0%)	2 (22,22%)	9 (100%)
Kombewa material											
Kombewa flake	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (100%)	0 (0%)	0 (0%)	1 (100%)
Total platform type	16 (5,18%)	22 (7,12%)	25 (8,1%)	23 (7,44%)	1 (0,32%)	80 (25,89%)	0 (0%)	84 (27,18%)	2 (0,65%%)	56 (18,12%)	309 (100%)

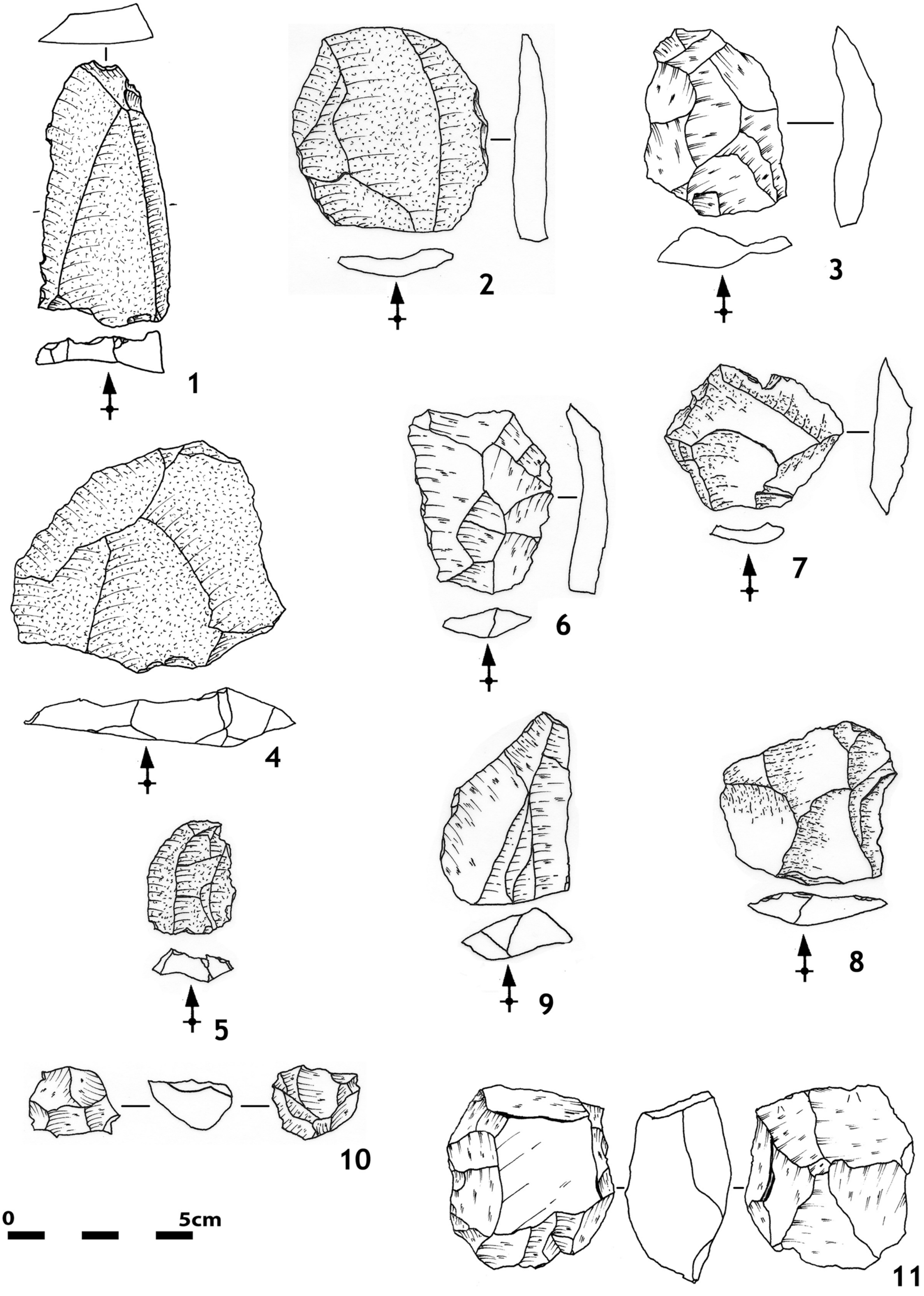
Table 8 Dorsal scar number in DGS blanks

Flake type/Scar number	1	2	3	4	5	6	7	8	9	11	13	Total
Discoid material												
Cordal flake	7	8	4	8	4	2	2					35
Pseudo-Levallois point			1	2	1							4
Centripetal flake with cortical		7	10	6	1	2	1					27
Centripetal flake without cortical	3	17	54	43	20	11	4	2	2			156
Total	10 (4,5%)	32 (14,42%)	69 (31,08%)	59 (26,58%)	26 (11,71%)	15 (6,76%)	7 (3,15%)	2 (0,9%)	2 (0,9%)	0 (0%)	0 (0%)	222 (100%)
Levallois material												
Débordant flake		1	1		1	1			1			5
Levallois indeterminate flake					1							1
Preferential levallois flake			1		1					1		3
Unidirectional levallois flake			1	2	3	1						7
Bidirectional levallois flake				1								1
Recurrent centripetal levallois flake			4	4	6	2	5		1			22
Total	0 (0%)	1 (2,56%)	7 (17,95%)	7 (17,95%)	12 (30,77%)	4 (10,26%)	5 (12,82%)	0 (0%)	2 (5,13%)	1 (2,56%)	0 (0%)	39 (100%)
Single platform material												
Single platform flake	2	13	9	8	3	1	1				1	38
Total	2 (5,26%)	13 (34,21%)	9 (23,7%)	8 (21,05%)	3 (7,89%)	1 (2,63%)	1 (2,63%)	0 (0%)	0 (0%)	0 (0%)	1 (2,63%)	38 (100%)
Bipolar material												
Bipolar flake with cortical					1							1
Bipolar flake without cortical		1	2	5								8
Total	0 (0%)	1 (11,11%)	2 (22,22%)	5 (55,56%)	1 (11,11%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	9 (100%)
Kombewa material												
Kombewa flake	1											1
Total	1 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (100%)
Total scar number	13 (4,21%)	47 (15,21%)	87 (28,16%)	79 (25,57%)	42 (13,59%)	20 (6,47%)	13 (4,21%)	2 (0,65%)	4 (1,29%)	1 (0,32%)	1 (0,32%)	309(100%)

Table 9 Dorsal scar direction in DGS blanks

Flake type/ Scar direction	Centripetal	Proximal	Convergent	Lateral	Proximo-lateral	Proximo-distal	Lateral-proximal	Indet	Total
Discoid material									
Cordal flake	13	8	1	2	6	4		1	35
Pseudo-Levallois point	1	2		1					4
Centripetal flake with cortical	16	6			4	1			27
Centripetal flake without cortical	115	17		1	9	12	1	1	156
Total	145 (65,32%)	33 (14,86%)	1 (0,45%)	4 (1,8%)	19 (8,56%)	17 (7,66%)	1 (0,45%)	2 (0,9%)	222 (100%)
Levallois material									
Débordant flake	2			1		2			5
Levallois indeterminate flake	1								1
Preferential levallois flake	2	1							3
Unidirectional levallois flake		6				1			7
Bidirectional levallois flake						1			1
Recurrent centripetal levallois flake	20		1			1			22
Total	25 (64,1%)	7 (17,95%)	1 (2,56%)	1 (2,56%)	0 (0%)	5 (12,83%)	0 (0%)	0 (0%)	39 (100%)
Single platform material									
Single platform flake		33			2	3			38
Total	0 (0%)	33 (86,84%)	0 (0%)	0 (0%)	2 (5,26%)	3 (7,9%)	0 (0%)	0 (0%)	38 (100%)
Bipolar material									
Bipolar flake with cortical						1			1
Bipolar flake without cortical		1			1	6			8
Total	0 (0%)	1 (11,11%)	0 (0%)	0 (0%)	1 (11,11%)	7 (77,78%)	0 (0%)	0 (0%)	9 (100%)
Kombewa material									
Kombewa flake		1							1
Total	0 (0%)	1 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (100%)
Total scar direction	170 (55,02%)	75 (24,27%)	2 (0,65%)	5 (1,62%)	22 (7,12%)	32 (10,35%)	1 (0,32%)	2 (0,65%)	309 (100%)

showing it (Table 6). The platforms of the Levallois flakes are rectilinear-facetted (23.08%); plain (23.08%); convex-facetted (20.51%); and dyhedral (10.26%). 15.38% of the flakes have broken platforms (Table 7). The flakes show between three and five previous scars (Table 8), and are centripetal (64.1%), proximal (17.95%) and disto-proximal (12.83%) in direction (Table 9). This assemblage is compatible with a recurrent centripetal exploitation.


1
2
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◂**Fig. 5** Levallois-method pieces. 1 and 2: Levallois recurrent unidirectional flakes; 3: Levallois preferential flake; 4–8: Levallois recurrent centripetal flake; 9: Levallois recurrent bidirectional flake; 10–11: Levallois recurrent centripetal cores. Raw material: 1, 2, 4, 5: Basalt; 3, 6, 9, 11: Naibor quartz; 7–8: Phonolite; 10: Hyaline quartz

- Centripetal methods

Related to the previous methods, we have identified some cores with centripetal directional débitage, but which do not follow the characteristics of either the Levallois or Discoid methods. The centripetal sensu lato methods have been documented from seven cores, all on Naibor quartz (Table 5). Different blanks were used to knap them: four cores were knapped on pebble, and one on plaquette, whereas it was not possible to identify the blank on two of the cores. Only one centripetal core does not show cortical (14.29%); four have cortical residually (57.13%), and the other two cores have cortical to different degrees (Table 6). Cores were abandoned for several reasons: they were exhausted, had poor angles or showed fractures. There is a clear relationship between the type of blank used as core and the type of débitage. There is no general core preparation and few flakes are obtained per core, so we can class them as ‘opportunistic’.

- Single platform method

Single platform methods are the third most common in this assemblage, represented by a total of 39 pieces (3.22% of the total). Of the pieces, one is a core and 38 are flakes (Table 5) (Fig. 6).

The only identified core is a blade single platform core (Fig. 6). The core was produced on a non-identifiable blank on Naibor quartz. Cortical has been observed on one of its surfaces, although residually. The striking surface was prepared by means of various flakes to create a surface with a suitable angle for knapping, from which at least three removals were obtained from the débitage surface. The reason for its abandonment has not been established.

Among the 38 flakes, the most common raw material is Naibor quartz (84.21%), followed, at a great distance, by phonolite (7.9%), hyaline quartz (5.26%) and basalt (2.63%) (Table 5; Fig. 6). 57.89% of flakes do not present cortical, whereas 26.32% show it residually. 13.16% of the flakes show half cortical on some of their surfaces, and 2.63% have more than a third on some of its surfaces with cortical (Table 6). The most common platforms are plain (21.05%), followed by the rectilinear facetted (15.79%), and the cortical (13.16%) (Table 7). However, many pieces show broken (31.58%) or missing (13.16%) platforms due to fractures. The flakes from this kind of methods present between two and four previous scars (Table 8), the majority proximal in direction (86.84%) (Table 9).

- Other operational schemes

In the DGS assemblage we have also noted the presence of other types of cores, such as polyhedral (n = 7) and opportunistic (n = 15) or Kombewa (n = 5; four cores and one flake) (Tables 5 and 10 and Fig. 6).

Both the polyhedral and the opportunistic cores are knapped without a preconceived scheme in mind and take advantage of the favourable angles arising during the knapping process. The seven polyhedral cores were knapped on Naibor quartz, whereas in terms of the opportunistic cores, 13 were knapped on Naibor quartz, one on hyaline quartz, and on one it was not possible to determine the raw material used. All cores were abandoned due to poor angulation, knapping accidents or for unknown reasons.

From a typometric point of view (Fig. 7), we observe that the length of the unretouched pieces is similar, except in the case of the Levallois flakes, which are clearly greater when considering the median (22.5–25 mm *versus* 49 mm). The width of the blanks does not appear to be very different among the various methods nor between the unretouched and retouched flakes, except in the case of simple retouched flakes, which are slightly wider (Fig. 7b). Lastly, thickness is greater in the retouched (12–15 mm) than in the unretouched flakes (7–10 mm, Fig. 7c). In general, in Fig. 7a tendency to retouch the longer and thicker pieces can be noted.

In terms of the raw materials, in Fig. 8a and b the longest and widest pieces are those knapped on basalt, with a 49 mm median. The pieces produced on sandstone/tuff, chert and Naibor quartz, have medians of 27.5, 26.5 and 25 mm, respectively. The pieces produced on phonolite and sandstone present a median length of 21 mm. In terms of the width, (Fig. 8b), the widest pieces have also been made on basalt, with a median of 46 mm, followed by pieces produced on phonolite (median = 32.5 mm); the pieces knapped on sandstone are the narrowest. Lastly, there is no great difference in terms of the thickness of the pieces in relation to the raw materials used (Fig. 8c). It appears that the humans occupying DGS had a clear preference for longer, wider, and thicker pieces, especially on basalt.

Typological analysis

The lithic assemblage at DGS comprises 1179 pieces, of which only 40 are retouched (Table 11), representing 3.39% of the total. The most used raw material on the retouched blanks is Naibor quartz (80%), followed by phonolite (7.5%) (Table 11). Again, we can observe how the most retouched raw materials continue to be those that are most abundant at the site (Fig. 9).

In terms of the knapping methods linked to the retouched pieces, ordinary flakes are the most retouched (55%), followed by discoid flakes (32.5%), whereas single platform flakes and the Levallois flakes are hardly retouched (Table 12) (Fig. 10).

Fig. 6 Other methods. 1–2: Recurrent unidirectional flakes; 3: Recurrent unidirectional core; 4: Kombewa core; 5: Opportunistic core. Raw material: 1, 3–5: Naibor quartz; 2: Basalt

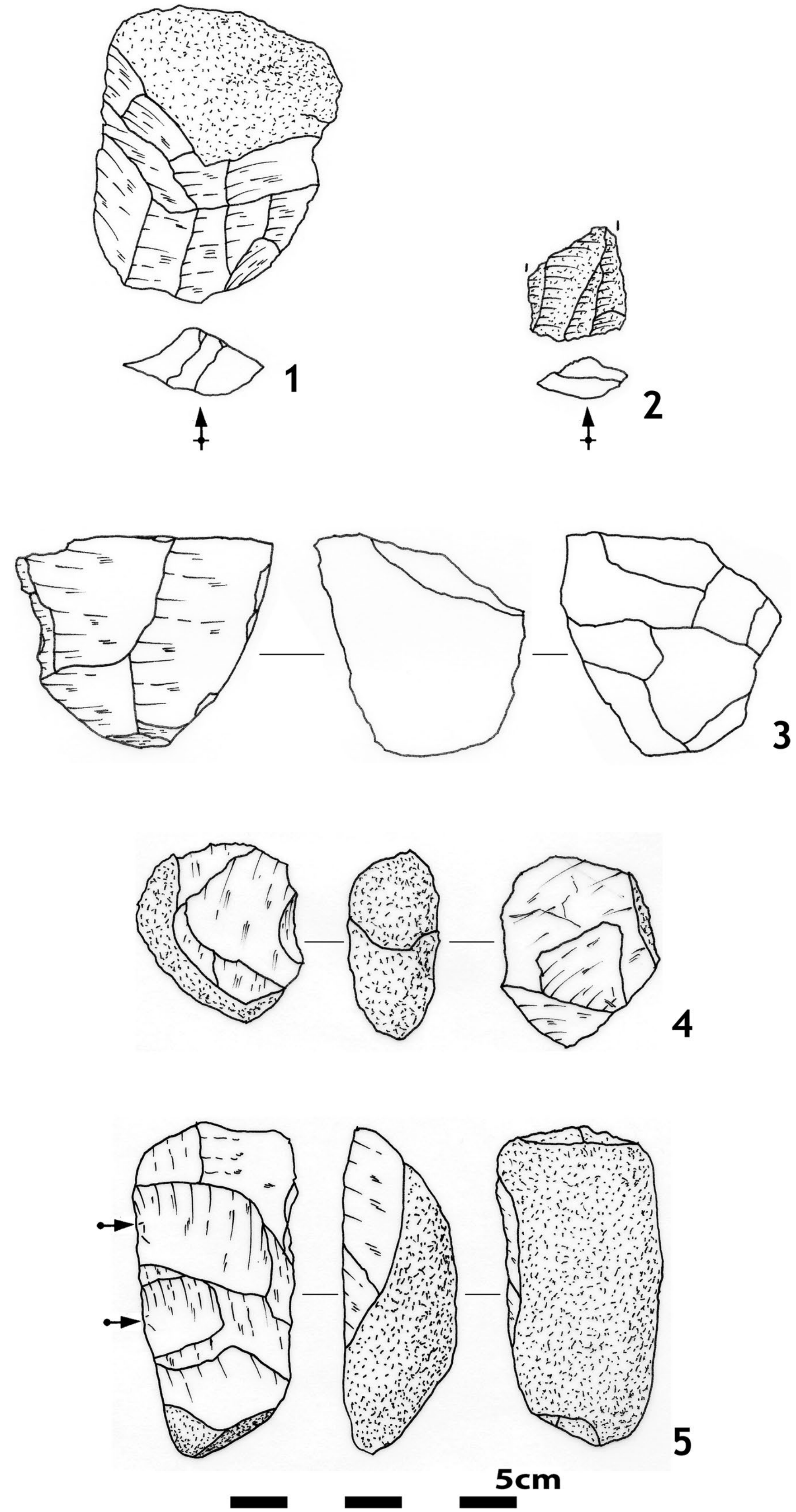

Table 10 Other operational schemes by raw material

Core types / Raw material	Hyaline quartz	Naibor Quartz	Indet	Total
Oportunistic	1	13	1	15
Polyhedral		7		7

The retouched piece assemblage comprises denticulates (n = 14), retouched flakes (n = 13), sidescrapers (n = 4), simple notches (n = 4), a double notch (n = 1), a bec (n = 1) and a double tool (sidescraper + denticulate) (Table 11) (Fig. 10). There are only two heavy duty (one bifacial and one transversal sidescraper), and there are no points of any kind.

As noted earlier, (Fig. 7), from a typometric point of view, there is a preference for longer and thicker pieces for retouching.

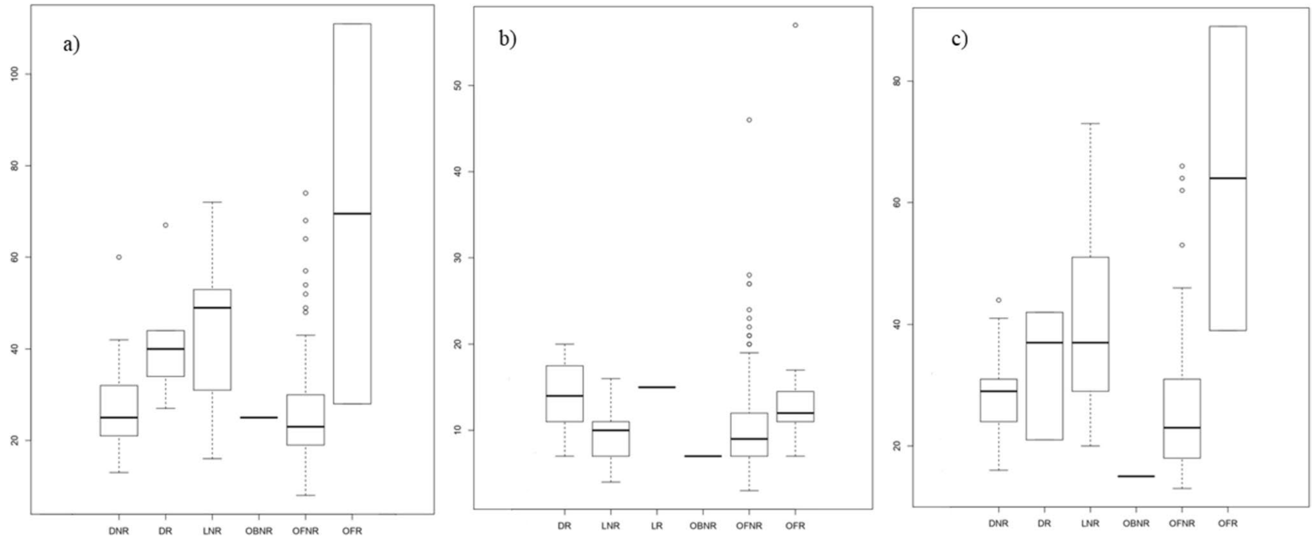

Fig. 7 Typometries. **a** Length vs. knapping method; **b** Width vs. knapping method; **c** Thickness vs. knapping method. CODES: DNR = Discoid non-retouched; DR = Discoid retouched; LNR = Levallois non-retouched; LR = Levallois retouched; OBNR = Single platform blade non-retouched; OFNR = Single platform non-retouched flake; OFR = Single platform retouched

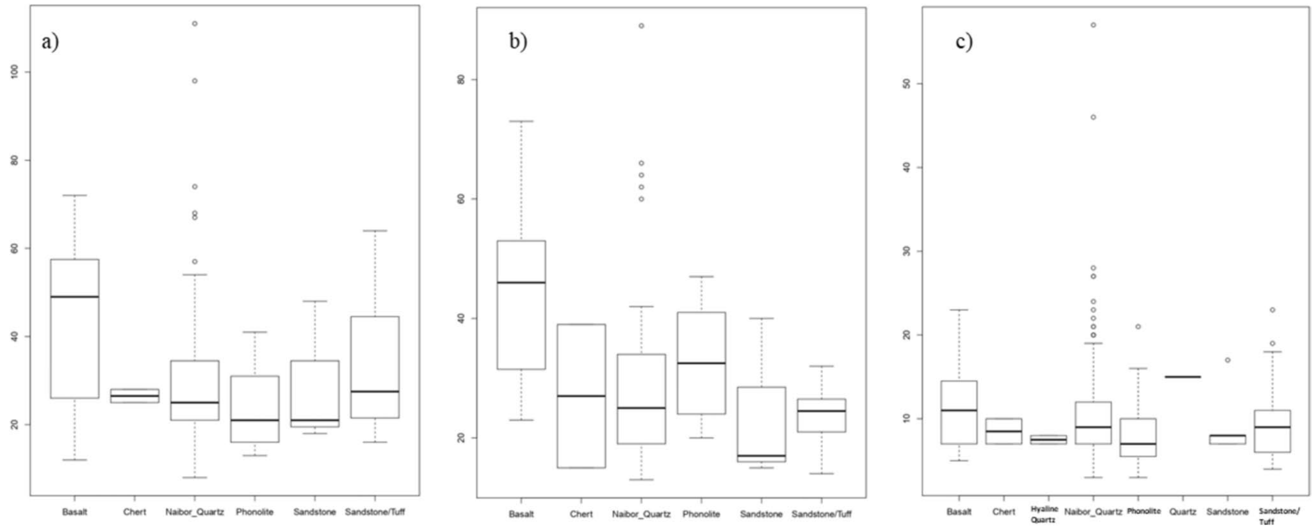

Fig. 8 Typometries. **a** Length vs. raw material; **b** Width vs. raw material; **c** Thickness vs. raw material

Table 11 Retouched blanks by raw material

Type	Basalt	Chert	Hyaline quartz	Naibor Quartz	Phonolite	Quartz	Total
Bec				1			1
Denticulate		1		12	1		14
Heavy-duty (*bifacial*)				1			1
Heavy-duty (*transversal sidescraper*)				1			1
Notch				4			4
Notch (double)				1			1
Sidescraper				3	1	0	4
Sidescraper + denticulate						1	1
Retouched flake	1		2	9	1		13
Total	1 (2,5%)	1 (2,5%)	2 (5%)	32 (80%)	3 (7,5%)	1 (2,5%)	40 (100%)

Fig. 9 Bar chart showing retouched and unretouched pieces in relation to the raw materials found at DGS

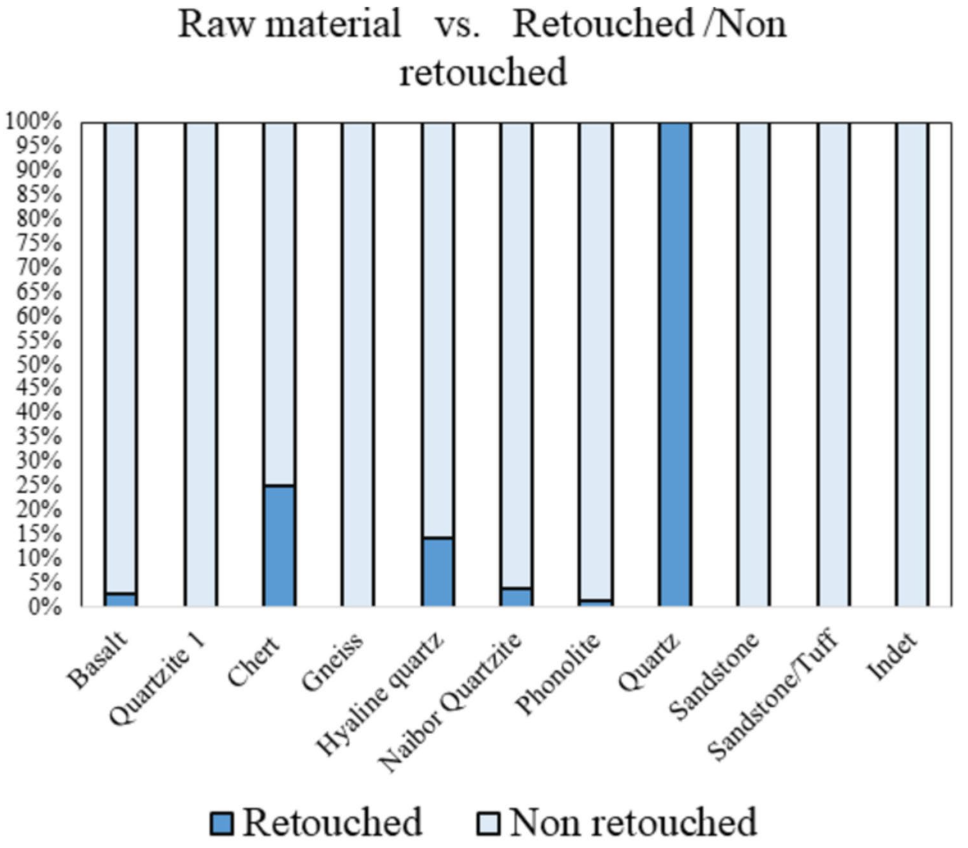

Fig.6. Bar diagram showing retouched and unretouched pieces in relation to the raw materials found in DGS.

Discussion

Fully understanding the techno-typological composition of an archaeological assemblage enables us to delve deeper into the behaviour and economy of MSA groups. This is the reason behind our techno-typological analysis of DGS.

From a taphonomic point of view, the archaeological level at DGS presents some alterations, such as pseudo-retouch or fracturing on the pieces. At first, this could be thought to be due to post-depositional processes. However,

Table 12 Retouched blanks and blanks type (discoid, Levallois, single platform and ordinary flakes)

Type	Discoid	Levallois	Single platform flakes	Ordinary flakes	*Total*
Bec				1	1
Denticulate	4	1	1	8	14
Heavy-duty (*bifacial*)				1	1
Heavy-duty (*transversal sidescraper*)				1	1
Notch (simple)	2		1	1	4
Notch (double)	1				1
Sidescraper	2			2	4
Sidescraper + denticulate				1	1
Retouched flake	4	1	1	7	13
Total	13 (32,5%)	2 (5%)	3 (7,5%)	22 (55%)	40 (100%)

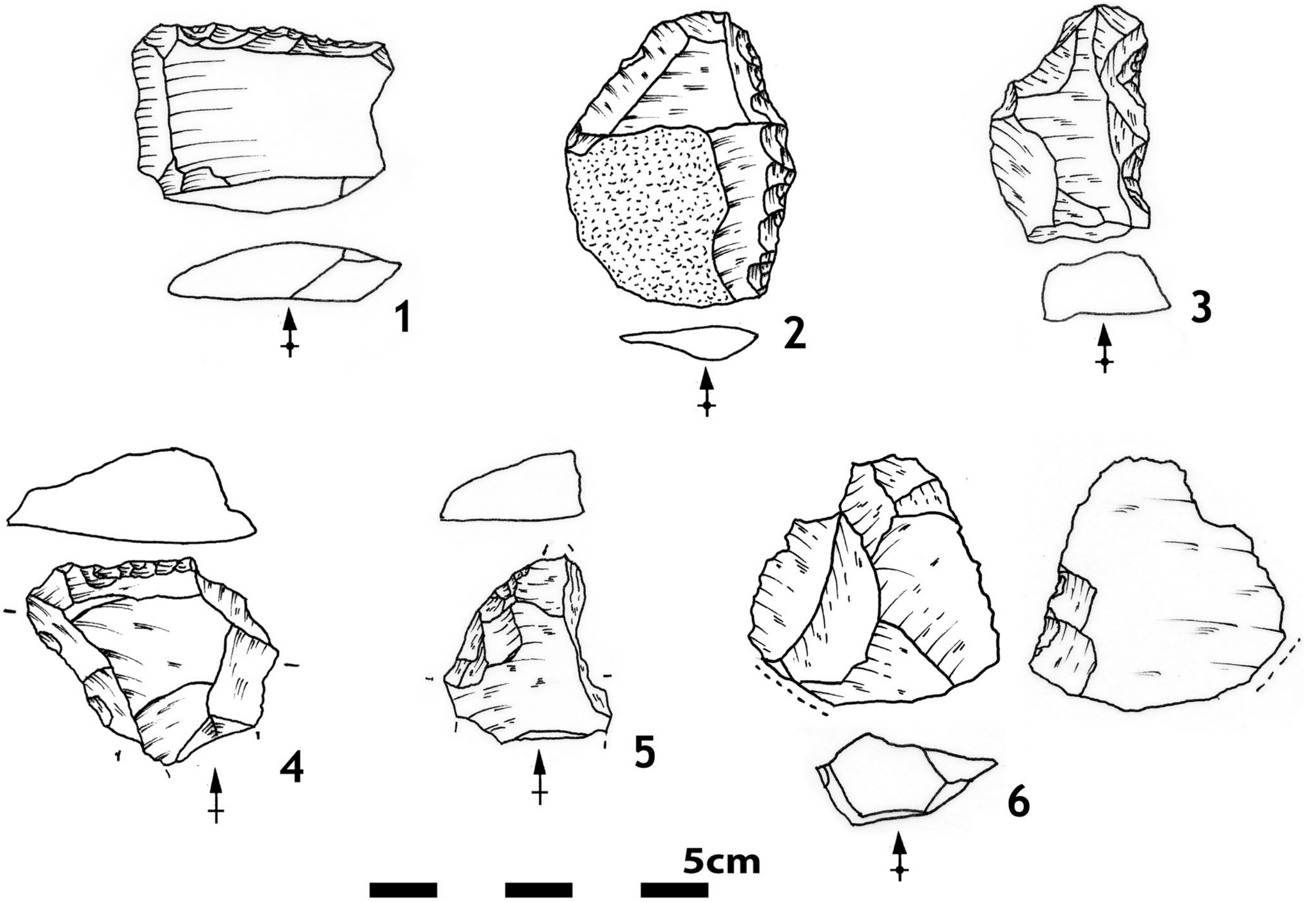

Fig. 10 Retouched pieces. 1: Denticulate on ordinary flake; 2: Denticulate on discoid flake; 3: Denticulate on ordinary flakes; 4: Sidescraper on discoid flake; 5: Sidescraper on ordinary flake; 6: Retouched flake on chordal flake. Raw material: 1: Chert; 2–6: Naibor Quartz

the non-preferential orientation of the pieces, together with the raw materials used, lead us to a different conclusion. Most of the pseudo-retouch (85%) is marginal, hardly constant and is found on the edges of the pieces, distancing it from any kind of pseudo-retouch known to be produced by movement (McBrearty et al. 1998). On the other hand, fracturing is found on more than 82% of Naibor quartz pieces. This raw material, and quartz in general, presents internal fissures that trigger the fracturing of the pieces when knapping takes place (Tallavaara et al. 2010; Will 2021). Additionally, 21% of the fractured pieces noted for all raw materials are due to diametrical fracturing, which arises during knapping as a result of excessive force. This is a very common characteristic found in quartz knapping (Mourre 1996). Therefore, these fractures cannot be linked to post-depositional processes. Having said this, trampling cannot be ruled out completely in terms of the pseudo-retouch, although, if it was the case, it would not be strongly linked to a significant post-depositional movement of the pieces.

The raw materials used at DGS are local in origin as they can be sourced from within a 10–12-km radius from the site (sensu Geneste 1991; Kuhn 2020). The most abundant raw material found is Naibor quartz, representing nearly 69% of the total. Naibor quartz is found in primary position two kilometers north of the site, and in secondary form in the Olduvai River itself, a few tens of meters away (Hay 1976; Tarriño et al. 2023). The closest phonolite source is found in Engolesen, around 7 km north of DGS (Hay 1976; Jones 1994). Sandstone is present in Beds I and II and in the Lower Ndutu of the Gorge itself (Hay 1976). Lastly, basalt, the fourth most-used raw material, is found in primary position in Mount Lemagrut, 10–12 km south of DGS and in the Lower Beds, as well as in the paleochannels from Lemagrut to Olduvai Gorge in secondary from (Jones 1994).

The assemblage, as previously noted (Maíllo-Fernández, et al. 2022), shows a predominance of discoid methods (unifacial and bifacial) and, to a lesser extent, of Levallois and single platform methods. The finding of many cores termed ‘opportunistic’ is worth highlighting, from which a series of flakes are obtained, one flake in some cases. The raw material fragments used offer appropriate morphological and angular characteristics for knapping to take place with little to no preparation. Some researchers term this approach as the ‘path of least resistance’ (Vaquero and Rogmanoli 2018), and which here can also be linked to the kind of raw material used, especially Naibor quartz and its internal fissuring. This ‘opportunistic’ composition, especially with quartz, has been observed at various MSA sites such as Etemba 14 in Namibia or Mumba VI-B in Tanzania (Schmidt 2011; Solano-Megías et al. 2024), and in the European Middle Paleolithic (Daffara et al. 2021).

Analyzing the raw materials and technology together, we can observe a débitage economy linked to phonolite and Levallois débitage (sensu Perlès 1991). We believe that this preferential selection of this raw material for Levallois débitage is not linked to the quality of the grain, but rather to the homogeneity of the raw material itself. The fact that phonolite does not present fractures like Naibor quartz does, makes it a more suitable raw material for the development débitage like the Levallois, which requires a more complex preparation to avoid knapping accidents triggered by the properties of the raw material. Naibor quartz was used in a general way in the discoid methods, the most numerous kinds at the site. It was used due to its greater availability in the site surroundings, because this method allows for a simpler reconditioning to be carried out should knapping accidents occur, and because less preparation is required to produce a greater number of predetermined products (Bourguignon et al. 2006). A similar behavior was noted by Eren and his team during a systematic survey of the end of Olduvai Gorge, in which it was found that all Levallois cores were knapped on basalt, a raw material that behaves similarly to phonolite and which presents bigger cobbles (Eren et al. 2014).

In terms of the quartz, the versatility of this raw material is also worth noting. It is usually linked to ‘simple’ operational schemes where there is an adaptation between the raw material, its morphology and the débitage used, as noted at various African sites (Schmidt 2011; Will 2021; Maíllo-Fernández et al. 2019b; Díez-Martín et al. 2009; Shipton et al. 2021) and the European Middle Paleolithic (e.g. Daffara et al. 2021, 2019; Lombera-Hermida et al. 2011). However, the versatility of this raw material has also been observed in more elaborate débitages such as in laminar prismatic methods (de la Peña and Wadley 2014), or in the making of microliths or bifacial pieces of the Howiesons Poort industry (Douze et al. 2018; de la Peña et al. 2013).

At DGS we observe an adaptation of the quartz to opportunistic and discoid débitages, as is also the case at Mumba or Nasera, whereas at other regional sites the knapping of quartz is linked to the bipolar method, as is the case at Loiyangalani (Maíllo-Fernández et al. 2019b). This allows for functional or cultural explanations to be put forward to explain this behavior.

The retouched assemblage is scarce ($n = 40$) and is predominated by denticulates, notches and retouched blanks (Table 11). The lack of any kind of point is noteworthy. Which leads us to ask the following questions: why is there such a small number of retouched pieces? And why are there no points?

The absence of retouched pieces in eastern African MSA assemblages, especially at open-air sites, appears to be a trend (Tryon and Faith 2016; sensu Will 2021), with percentages rarely surpassing 10–12% of the total assemblage. Recently studied sites in northern Tanzania (Mumba, Nasera, VCS and DGS) follow this trend, but the same cannot be said for Loiyangalani in the Serengeti, which has more than 21% of retouched pieces (Maíllo-Fernández et al. 2019b). These two observations can be considered in two ways. We agree with Tryon and his team that the quality of the raw material is essential for the retouched material (Tryon et al. 2008; Tryon and Ranhorn 2020), but not only the quality of the grain, but also its homogeneity, the absence of internal fractures, the size of the cobbles, etc. This provides an explanation for the preferential phonolite Levallois débitage economy at DGS and the high number of retouched pieces at Loiyangalani, where the most-used raw material is fine-grained quartzite. This raw material allows for the development of prepared methods such as the discoid or the Levallois, and in which 44% of pieces from both methods are retouched (Maíllo-Fernández et al. 2019b).

In terms of the absence of points at DGS, we can put forward a similar explanation, in line with the opinion of various colleagues (Tryon et al. 2008). The quality and homogeneity of the grain can be key in the lack of lithic point production, as evidenced by sites with high-quality materials like Gademotta, Kulkuletti (Douze 2012) and Aduma (Yellen et al. 2005), all three in Ethiopia, or Loiyangalani in the Serengeti, in which eight of its nine points are retouched on quartzite and one on chert (Maíllo-Fernández et al. 2019b).

This trend can be observed, at least in a general sense, can also be observed in northern Tanzania, but not exclusively. The characterization of the MSA in northern Tanzania was put forward by M. Mehlman (1989). He divided the MSA into various industries which, from oldest to youngest, are: Njarasa (~ 200 ka BP), Sanzako (131–109 ka BP) and Kisele (108–50 ka BP), the latter the only industry characterized by a large percentage of points. The Loiyangalanian (Bower et al. 1985) and the sites of VCS (75–86 ka BP) and DGS are later additions, all contemporaneous with the Kisele industry. In all the assemblages, with the exception of Kisele, points are produced on good quality and homogeneous raw materials (quartzite or chert). However, in Kisele, the re-examined industry containing the most points, points are produced widely on quartz, not following the dynamics presented so far (Table 13). The reason for this may lie in the fact that at Nasera and at Mumba, the closest chert is found more than 30 km away, making it not readily accessible.

Olduvai Gorge could be an exception to this trend for the simple reason that there are no points at neither VCS nor DGS. Points are also not referenced in Leakey's excavations (Leakey et al. 1972). However, in the surveys carried out by M. Eren, 10 pointed flakes (none retouched) were identified, of which seven were knapped on basalt and one on phonolite (Eren et al. 2014), following the trend previously noted. In addition, the size of the "good quality" raw material cobbles should also be taken into account, given that at Olduvai chert can be found in relative abundance (Hay 1976:76), but in the shape of small and morphologically-irregular cobbles. This prevents the methods employed in the MSA to produce points from developing; however, these are later used abundantly during the Later Stone Age, when pieces are smaller in size (Leakey et al. 1972). However, both phonolite and basalt occur in sizes larger than a decimeter, which would, in theory, allow for point production.

Then, if raw materials suitable for point knapping are available, why are there no points at the excavated sites? The reasons to explain the absence of a certain type of tool at a site, points in this case, can be varied: they are not produced because they are not needed; they were knapped, but they were taken elsewhere; or they were made on perishable material. The first option indicates a specific functionality of the site, where the points are not necessary; the second, an economic aspect of the site which cannot be argued clearly because there is not a lithic production of points. The points

Table 13 MSA sites and industries in the Northern Tanzania región

Site	Retouched %	Retouched (n)	Point (%)	Point (n)	Point raw material (%)	Industry	Date (ka BP)	Reference
Nasera 12–17	7.1	61	18	11	Ch (72.7), Q (27.3)	Kisele	108–50	Mehlman 1989 Bushozi et al. 2020
Nasera 18–25	5.2	188	13.3	25	Q (56), Ch (44)	Kisele		
Mumba VI-A	13.8	202	13.8	27	Q (44), Qe (44)	Kisele		
Mumba VI-B Up	4.4	125	1.6	2	Q (100)	Sanzako	131–109	Solano-Megías et al. 2024 Mehlman 1989
Mumba VI-B Mid	8.8	40	5	2	Qe (100)	Sanzako		
DGS	3.4	40	0	0		-	-	This study
VCS*	0–12.5	10	0	0			75—86	Maíllo-Fernández et al. 2019a
Loiyangalani	21.4	173	5.2	9	Qe (88.9), Ch (11.1)	Loiyangalanian	64	Maíllo-Fernández et al. 2019b Bower and Mabulla 2012
Eyasi shore	4.7	25	0	0		Njarasa	± 200	Mehlman 1989

may have been taken elsewhere, but evidence of their making would remain at the site. This is not the case at DGS, where the discoid débitage is not favorable to producing points. And, in any case, pseudo-Levallois points, which are obtained in discoid methods (Faivre et al. 2017), are not abundant in the assemblage. The third option would be a plausible one at DGS and VCS, and links it to the first explanation in terms of a cultural sphere as opposed to an economic one.

In addition, as noted by J. Shea (2006), it could be that the hafted stone points for hunting activities were not needed because there was not high demographic pressure or an increased competition for resources. This hypothesis is also plausible in the context of DGS and the MSA of northern Tanzania.

Therefore, we consider as a hypothesis that the absence of points at the excavated sites in Olduvai Gorge is linked more to the functionality of the site or to cultural traditions than to the restrictions of the raw material used. The functionality cannot be tested without a use-wear analysis and, therefore, should not be ruled out. However, the absence of points could be a cultural and identity response within the MSA of northern Tanzania, as has been suggested for other regions of East Africa like Karonga in Malawi, among others (Trimbell et al. 2023; Thompson et al. 2017).

Of the levels analyzed, (Table 13) Nasera 12–17, 18–25 and Mumba VIA correspond to the Kisele industry, which is characterized, among other things, by the abundant number of points within its collection (Mehlman 1989). However, in the rest of the assemblages the role played by points is much smaller, both in chronologically earlier industries like Sanzako represented by Mumba VIB (Mehlman 1989), like in assemblages contemporary with the Kisele of DGS and VCS in Olduvai. Only Loiyangalani, also contemporary with Kisele, has a relatively high percentage of points, but it shows techno-typological differences that set it apart from this industry.

Therefore, as a hypothesis, the absence of points at Olduvai should be understood as a functional response or a cultural element.

Conclusion

The Middle Stone Age in northern Tanzania is known thanks to sites such as Mumba and Nasera rockshelter, where most of the chronological periods of the African Stone Age are represented (Mehlman 1989). However, the open-air settlement dynamics of the MSA are different and show instances of shorter occupations, meaning that often only a single level of MSA occupation is found, as is the case at DGS, Loiyangalani or Ngaloba Beds (Maíllo-Fernández et al. 2019b, 2022; Mabulla 2015; Masao and Kimambo 2022).

At Olduvai, so far two stratigraphic open-air sites have been documented: VCS and DGS, which share several techno-typological features. At DGS, the discoid, Levallois and single platforms are the most common methods employed. Among the retouched pieces, there is a prevalence of denticulates, retouched flakes, notches and sidescrapers, with hardly any points.

While it is true that great technological variability has been observed throughout the MSA in the various regions of the African continent (Scerri et al. 2018; Will et al. 2019b; Scerri and Will 2023), shared technological traits have also been noted in small, particular areas. That is, in northern Tanzania discoid methods are commonly employed, likely linked to the raw material available in the area. At DGS, Naibor quartz, tabular in shape, was used in knapping methods involving little prior preparation, less organizationally complex, and therefore, more useable, as is the case with the discoid and single platform methods.

Although we believe that the regional proposal put forward by Mehlman (1989) is still valid, the analysis of new sites using new methodologies, such as Loyangalani, VCS and DGS, allows for previously excluded areas such as Olduvai Gorge or the Serengeti to provide additional data to his proposal, enhancing our knowledge of human occupations during the MSA in northern Tanzania.

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Declarations

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References

Audouze F, Karlin C (2017) La chaîne opératoire a 70 ans : Qu'en ont fait les préhistoriens français. J Lithic Stud 4(2):1–69. https://doi.org/10.2218/jls.v4i2.2539

Bahra N, Djerrab A, Ruault-Djerrab M, Semiane K, Zedam R (2020) Middle Stone Age technology in Algeria: A techno-economic approach case study of the Oued Bousmane site (Djebel Dyr). Quatern Int 555:33–46

Balout L, Biberson P, Tixier J (1967) L'Acheuléen de Ternifine (Algérie), gisement de l'Atlanthrope. L'anthropologie 71(3–4):217–237

Bar-Yosef O, Van Peer P (2009) The chaîne operatoire approach in Middle Paleolithic archaeology. Curr Anthropol 50(1):103–131. https://doi.org/10.1086/592234

Basell L (2013) The Middle stone age of eastern Africa. In: Mitchel P, Lane P (eds) The Oxford Handbook of African Archaeology. Oxford University Press, Oxford, pp 387–401

Bello-Alonso P, Ríos-Garaizar J, Panera J, Rubio-Jara S, Pérez-González A, Rojas R et al (2021) The first comprehensive micro use-wear analysis of an early Acheulean assemblage (Thiongo Korongo, Olduvai Gorge, Tanzania). Quatern Sci Rev 263(3):106980

Blumenschine RJ, Peters CR, Masao FT, Clarke RJ, Deino A et al (2003) Late Pliocene Homo and hominid land use from Western Olduvai Gorge, Tanzania. Sci 299(5610):1217–1221. https://doi.org/10.1126/science.1075374

Boëda E (1993) Le débitage discoïde et le débitage Levallois rècurrent centripète. Bull Soc Prehist Fr 90:392–404

Boëda E (1994) Le concept Levallois : variabilité des méthodes. Monographie du C.R.A, Paris

Boëda E (1995) Caractéristiques techniques des chaînes opératoires lithiques des niveaux micoquiens de Külna (Tchécoslovaquie). Paléo, Supplément 1(1):57–72

Boëda E, Geneste JM, Meignen L (1990) Identification de chaînes opératoires lithiques du Paléolithique ancien et moyen. Paléo 2:43–80

Boëda E (2013) Techno-logique & Technologie. Une paléo-histoire des objets lithiques tranchants. Prigonrieux : Archeo-editions

Bourguignon L, Delagnes A, Meignen L (2006) Système de production lithique, gestion des outillages et territoires au Paléolithique moyen : où se trouve la complexité. In: Astruc L, Bon F, Léa V, Milcent P.-Y, Philibert S. (eds.). Normes techniques et pratiques sociales. De la simplicité de soutillages pré- et protohistoriques, XXVIe rencontres internationales d'archéologie et d'histoire d'Antibes, APDCA, Antibes, pp 75–86

Bower JRF, Gifford D, Livingstone D (1985) Excavations at the Loiyangalani site, Serengeti National Park, Tanzania. Nat Geogr Soc Res Rep 20:41–56

Bower JRF, Mabulla A (2012) Setting In: Evidence of territorial exclusion in the late Middle Stone Age of Nothern Tanzania. Studies in the African Past, 1: 7–24

Bushozi PM, Skinner A, de Luque L (2020) The Middle Stone Age (MSA) technological patterns, innovations, and behavioral changes at bed VIA of Mumba Rockshelter, Northern Tanzania. Afr Archaeol Rev 37:293–310

Clark JD, Kleindienst MR (2001) The Stone Age cultural sequence: terminology, typology and raw material. In: Clark JD (ed) Kalambo Falls Prehistoric site, volumen III. Cambridge University Press, Cambridge, pp 34–65

Conard N (2015). Cultural Evolution During the Middle and Late Pleistocene in Africa and Eurasia. In: Henke W, Tattersall I. (2015). Handbook of Paleoanthropology. 2nd Edition

Coulson S, Staurset S, Walker N J (2011) Ritualized behaviour in the Middle Stone Age: evidence from Rhino Cave, Tsodilo Hills, Botswana. PaleoAnthropology, 18–61

Daffara S, Borel A, Moncel M-H (2019) Conditioning of the raw materials on discoid exploitation strategies during the Early Middle Palaeolithic: the example of Payre level D (South-East France). Archaeol Anthropol Sci 11(9):4681–4695. https://doi.org/10.1007/s12520-019-00823-6

Daffara S, Gabriele S, Berruti LF, Arzarello M (2021) Expedient behaviour and predetermination at the Ciota Ciara cave (north-western Italy) during Middle Palaeolithic. Quatern Int 577:71–92

de la Peña P, Wadley L (2014) Quartz knapping strategies in the Howiesons Poort at Sibudu (KwaZulu-Natal, South Africa). PLoS Once 9(7):e101534. https://doi.org/10.1371/journal.pone.0101534

de la Peña P, Wadley L, Lombard M (2013) Quartz bifacial points in the Howiesons Poort of Sibudu. S Afr Archaeol Bull 68:119–136

de la Torre I, Benito-Calvo A, Martín-Ramos C, McHenry L, Mora R et al (2021) New excavations in the MNK Skull site, and the last appearance of the Oldowan and Homo habilis at Olduvai Gorge, Tanzania. J Anthropol Archaeol 61:101255

Deino AL, Heil C Jr, King J, McHenry LJ, Stanistreet IG, Stollhofen H, Njau J, Mwankunda J, Schick KD, Toth N (2021) Chronostratigraphy and age modeling of Pleistocene drill cores from the Olduvai Basin, Tanzania (Olduvai gorge coring Project). Palaeogeogr Palaeoclimatol Palaeoecol 571:109990

Delagnes A, Roche H (2005) Late Pliocene hominid knapping skills: The case of Lokalalei 2C, West Turkana, Kenya. J Hum Evol 48(5):435–472

Díez-Martín F, Domínguez-Rodrigo M, Sánchez P, Mabulla AZP, Tarriño A et al (2009) The Middle to Later Stone Age technological transition in East Africa. New data from Mumba rockshelter Bed V (Tanzania) and their implications for the origin of modern human behavior. J Afr Archaeol 7(2):147–173

Díez-Martín F, Sánchez P, Uribelarrea D, Baquedano E, Mark D, Fraile C, Duque J, Díaz I, Pérez-González A, Yravedra J, Egeland C, Organista E, Domínguez-Rodrigo M (2016) The origin of the Acheulean: The 1.7-Million-year-old site of FLK West. Olduvai Gorge. Nat Sci Rep 5:17839. https://doi.org/10.1038/srep17839

Domínguez-Rodrigo M, Pickering T, Baquedano E, Mabulla A, Mark D, Musiba C et al (2013) First Partial Skeleton of a 1.34-Million-Year-Old Paranthropus boisei from Bed II, Olduvai Gorge, Tanzania. PLoS ONE 8(12):e80347. https://doi.org/10.1371/journal.pone.0080347

Douze K, Delagnes A, Wurz S, Henshilwood CS (2018) The Howiesons Poort lithic sequence of Klipdrift Shelter, southern Cape, South Africa. Plos ONE 13(11):e0206238. https://doi.org/10.1371/journal.pone.0206238

Douze K, Lespez L, Rasse M, Tribolo C, Garnier A, Lebrun B, Mercier N, Ndiaye M, Chevrier B, Huysecom E (2021) A West African Middle Stone Age site dated to the beginning of MIS 5 Archaeology, chronology, and paleoenvironment of the Ravin Blanc I (eastern Senegal). J Hum Evol 154:102952

Douze K (2012) Le Early Middle Stone Age d'Éthiopie et les changements technoéconomiques. La période de l'emergence des premiers Homo sapiens. Dissertation, Université de Bordeaux I

Eren M, Durant ME, Prendergast M, Mabulla AZP (2014) Middle stone age archaeology at Olduvai gorge, Tanzania. Quatern Int 322–323:292–313

Faivre JP, Gravina B, Bourguignon L, Discamps E, Turq A (2017) Late Middle Palaeolithic lithic technocomplexes (MIS 5e3) in the northeastern Aquitaine Basin: Advances and challenges. Quaternary International 433:116–131

Fernández-López SR (2000) Temas de Tafonomía. Universidad Complutense de Madrid, Dpto. de Paleontología

Foley R, Lahr MM (2003) On Stony Ground: Lithic Technology, Human Evolution, and the Emergence of Culture. Evol Anthropol 12:109–122

Fuertes Prieto N (2004) Estudio tecnológico de las industrias líticas del Paleolítico Superior y del Epipaleolítico en la Cuenca del Duero. Tesis Doctoral, Universidad de León

Fuertes Prieto N (2006) Las cadenas operativas de lascas en el yacimiento mesolítico de "El Espertín". In: Maíllo-Fernández JM, Baquedano E (eds.) (2006) Miscelánea en homenaje a Victoria Cabrera. Zona Arqueológica, 7, vol I, pp 552–561

Geneste JM (1991) Systèmes techniques de production lithique : variations technoéconomiques dans les processus de réalisation des outillages paléolithiques. Tech Cult 17(18):1–35

Hay RL (1976) Geology of the Olduvai Gorge: A Study of Sedimentation in a Semiarid Basin. University of California Press, Berkeley

Hiscock P (1985) The need for a taphonomic perspective in stone artefact analysis. Queensland Archaeol Res 2:82–97

Holmes A (1951) The sequence of Pre-Cambrian orogenic belts in south and central Africa. 18th International Geological Congress. Great Britain Part 1:254–269

Inizan ML, Reduron M, Roche H, Tixier J (1995) Technologie de la Pierre taillée. C.R.E.P, Paris

Johanson D, Masao F, Eck G, White T, Walter R et al (1987) New partial skeleton of Homo habilis from Olduvai Gorge, Tanzania. Nature 327:205–209. https://doi.org/10.1038/327205a0

Jones PR (1994). Results of experimental work in relation to the Stone industries of Olduvai Gorge. In: Leakey, M. (Ed.), Olduvai Gorge. 5. Excavations in Beds III, IV and the Masek Beds, 1968–1979. Cambridge University Press, Cambridge, pp 254–298

Karlin C (1992) Connaissances et savoir-faire : comment analyser un processus tecnique en Préhistoire Introduction. Treballs d'Arqueología 1:99–124

Kuhn S L. (2020). Moving on from Here: Suggestions for the Future of "Mobility Thinking" in Studies of Paleolithic Technologies. J Paleolit Archaeol 3664–681 https://doi.org/10.1007/s41982-020-00060-7

Leakey LSB (1959) A New Fossil Skull from Olduvai. Nature 184(4685):491–493

Leakey L (1961) New Finds at Olduvai Gorge. Nature 189:649–650. https://doi.org/10.1038/189649a0

Leakey M (1971b) Discovery of Postcranial Remains of Homo erectus and Associated Artefacts in Bed IV at Olduvai Gorge, Tanzania. Nature 232:380–383

Leakey L, Leakey M (1964) Recent Discoveries of Fossil Hominids in Tanganyika: At Olduvai and Near Lake Natron. Nature 202:5–7. https://doi.org/10.1038/202005a0

Leakey M, Clarke R, Leakey L (1971) New Hominid Skull from Bed I, Olduvai Gorge, Tanzania. Nature 232:308–312. https://doi.org/10.1038/232308a0

Leakey M, Hay R, Thurber D, Protsch R, Berger R (1972) Stratigraphy, archaeology, and age of the Ndutu and Naisiusu Beds, Olduvai Gorge, Tanzania. World Archaeol 3:328–341

Leakey M (1971a) Olduvai Gorge: Volume 3, Excavations in Beds I and II, 1960–1963. Cambridge University Press, Cambridge

Lombera-Hermida A, Rodríguez XP, Fábregas R, Moncel M-H (2011) La gestion du quartz au Pléistocène moyen et supérieur. Trois exemples d'Europe Méridionale. L'anthropologie 115:294–33

de Lumley H, Beyene Y, Barsky D, Byrne L, Camara A, Cauche D, Celiberti V, Fournier A, Pleurdeau D (2004) L'industrie lithique préoldowayenne du site de Fejej FJ-1. In: de Lumley H., Beyene Y. (eds.). Les sites préhistoriques de la région de Fejej, sud-Omo, Ethiopie, dans leur contexte stratigraphique et paléontologique. Édition Recherche sur les Civilisations, 391–563

Mabulla A (1990) Preliminary report on an archaeological survey of the Ndutu beds, Olduvai gorge, Tanzania. Nyame Akuma 33:20–25

Mabulla A (2015) Middle Pleistocene lithic industry and hominin behavior at Laetoli. Afr Stud 24(1):13–32

Maíllo-Fernández JM, Marín J, Solano-Megías I, Uribelarrea D, Martín-Perea DM, Aramendi J, Medialdea A, Arteaga C, Pernas-Hernández M, Gidna A, Neogi S, Baudot E, Narváez C, Mabulla AZP (2019a) Victoria Cabrera site: a Middle Stone Age site at Olduvai Gorge, Tanzania. Quatern Int 526:129–154. https://doi.org/10.1016/j.quaint.2019.07.032

Maíllo-Fernández JM, Solano-Megías I, Mabulla A, Arriaza MC, Bower JFR (2019b) Lithic technology at Loiyangalani, a Late Middle Stone Age site in the Serengeti, Tanzania. Afr Archaeol Rev 36:291–315. https://doi.org/10.1007/s10437-019-09340-2

Maíllo-Fernández JM, Marín J, Martín-Perea DM, Uribelarrea D, Solano-Megías I, Asiaín R, Baquedano E, Domínguez-Rodrigo M, Gidna A, Medialdea A, Mwamakimbula SH, Haruni Chilonzi D, Arteaga C, Mabulla AZP (2022) The Dorothy Garrod Site: a new Middle Stone Age locality in Olduvai Gorge, Tanzania. Archaeol Anthropol Sci 14:177. https://doi.org/10.1007/s12520-022-01644-w

Manega . (1993) Geochronology, geochemistry, and isotopic study of the Plio-Pleistocene hominid sites and the Ngorongoro volcanic highlands in northern Tanzania. Ph.D. Dissertation, University of Colorado at Boulder

Masao F, Kimambo J (2022) Further Notes on the Ngaloba Industry, a Middle Stone Age Assemblage Directly Associated with Early Homo in the Greater Laetoli, Northern Tanzania. In: Fortes-Lima C, Mtetwa E, Schlebusch C (eds) Cultural and biological approaches to uncover African diversity, Brill, pp 43–60. https://doi.org/10.1163/9789004500228_004

McBrearty S, Bishop L, Plummer T, Dewar R, Conard N (1998) Tools underfoot: Human trampling as an agent of lithic artifacts edge damage. Am Antiq 63(1):108–129

Mcbrearty S, Brooks AS (2000) The revolution that wasn't: A new interpretation of the origin of modern human behavior. J Hum Evol 39(5):453–563

Mehlman MJ (1989) Later Quaternary archaeology sequences in northern Tanzania. Ph.D dissertation, University of Illinois

Mourre V (1996) Les industries en quartz au Paléolithique. Terminologie, méthodologie et technologie. Paléo 8:205–223

Mourre V (2003) Discoïde ou pas discoïde ? Réflexions sur la pertinence des critères techniques définissant le débitage discoïde. In: Peresani M (ed.) Discoid Lithic Technology: Advances and Implications. British Archaeological Reports, International Series 1120. Archaeopress, Oxford, pp 1–18

Owen WE (1938) The Kombewa culture. Kenya Colony Man 38(218):203–205

Perlès C (1991). Économie des matières premières et économie du débitage: deux conceptions opposés? In Juan-les- Pins (Ed.), 25 Ans d'études technologiques en Préhistoire: Bilan et perspectives, Actes des XI" rencontres inter nationales d'Archéologie et d'Histoire d'Antibes, 18–20 octobre 1990, Valbonne: APDCA, pp. 35–45

Reck H (1914) Erste vorläufige Mitteilung über den Fund eines fossilen Menschenskelets aus Zentral-afrika. Sber Ges nartuf Freunde Berl 3:81–95

Reiner WB, Masao F, Sholts SB, Songita AV, Stanistreet I, Stollhofen H, Taylor RE, Hlusko LJ (2017) OH 83: a new early modern human fossil cranium from the Ndutu beds of Olduvai Gorge, Tanzania. Am J Phys Anthropol 164(3):533–545

Sánchez-Yustos P, Díez-Martín F, Díaz I, Fraile C, Urribelarrea D et al (2019) What comes after the Developed Oldowan B debate? Techno-economic data from SHK main site (Middle Bed II, Olduvai Gorge, Tanzania). Quatern Int 526:67–76

Scerri EML, Will M (2023) The revolution that still isn't: The origins of behavioral complexity in Homo sapiens. J Hum Evol 179:103358

Scerri EML, Thomas MG, Manica A, Gunz P, Stock J, Stringer C, Grove M, Groucutt HS et al (2018) Did our species evolve in subdivided populations across Africa, and why does it matter? Trends Ecol Evol 33:582–594

Schiffer MB (1992) Technological Perspectives on Behavioral Change. University of Arizona Press, Tucson

Schmidt I (2011) A Middle Stone Age Assemblage with Discoid Lithic Technology from Etemba 14, Erongo Mountains, Northern Namibia. J Afr Archaeol 9(1):85–100

Shea JJ (2006) The origins of lithic projectile point technology: evidence from Africa, the Levant, and Europe. J Archaeol Sci 33:823–846

Shea JJ (2020) Prehistoric stone tools of Eastern Africa. A guide. Cambridge University Press, Cambridge

Shipton C, Blinkhorn B, Archer W, Kourampas N, Roberts P, Prendergast M, Curtis R, Herries AIR, Ndiema E, Boivin N, Petragli MD (2021) The Middle to Later Stone Age transition at Panga ya Saidi, in the tropical coastal forest of eastern Africa. J Hum Evol 153:102954

Skinner AR, Hay RL, Masao F, Blackwell BAB (2003) Dating the Naisiusiu Beds, Olduvai Gorge, by electron spin resonance. Quat Sci Rev 22:1361–1366

Smedley RK, Fenn K, Stanistreet IG, Stollhofen H, Njau JK, Shick K, Toth N (2023) Age-depth model for uppermost Ndutu Beds constrains Middle Stone Age technology and climate-induced paleoenvironmental changes at Olduvai Gorge (Tanzania). J Hum Evol 186:103465

Solano-Megías I, Maíllo-Fernández JM, Marín J, Martín-Perea DM, Mabulla AZP (2020) Lithic Technology in the Earliest Later Stone age at Nasera Rockshelter (Tanzania). Lithic Technol 46(1):60–79. https://doi.org/10.1080/01977261.2020.1832180

Solano-Megías I, Maíllo-Fernández JM, Mabulla AZP (2024) Deciphering Middle Stone Age Technological Behaviors: An Analysis of the Lithic Technology from Level VI-B at Mumba, Tanzania. Afr Archaeol Rev 41:205–237. https://doi.org/10.1007/s10437-024-09582-9

Stapert D (1976) Some natural surface modifications on flint in the Netherlands. Palaeohistoria, XVIII, 7–41

Staurset S, Coulson SD, Mothulatshipi S, Burrough SL, Nash DJ, Thomas DSG (2023) Making Points: The Middle Stone Age lithic industry of the Makgadikgadi Basin, Botswana. Quat Sci Rev 301:107823

Tallavaara M, Manninen MA, Hertell E, Rankama T (2010) How flakes shatter: a critical evaluation of quartz fracture analysis. J Archaeol Sci 37:2442–2448

Tarriño A, Ábalos B, Puelles P, Eguiluz L, Díez-Martín F (2023) The Crystalline Quartz-rich Raw Material from Olduvai Gorge (Tanzania): Why is it called quartzite when it should be called quartz? Archaeol Anthropol Sci 15:78. https://doi.org/10.1007/s12520-023-01774-9

Terradas X (2003) Discoid flaking method: Conception and technological variability. In: Peresani M (ed.). Discoid Lithic Technology: Advances and Implications. British Archaeological Reports, International Series 1120. Archaeopress, Oxford, pp 19–20

Thompson JC, Mackay A, Nightingale S, Wright D, Choi J-H, Welling M, Blackmore H, Gomani-Chindebvu E (2017) Ecological risk, demography and technological complexity in the Late Pleistocene of northern Malawi: implications for geographical patterning in the Middle Stone Age. J Quat Sci 33(3):261–284

Tixier J, Inizan ML, Roche H (1980) Préhistoire de la pierre taillée I, Terminologie et technologie. Meudon: CREP

Trimbell L, Habte B, Tefera Y, Maroma Ch, Ndiema E, Plomp K, Blinkhorn J, Grove M (2023) Stone point variability reveals spatial, chronological and environmental structuring of eastern African Middle Stone Age populations. Azania: Archaeol Res Afr 59(1):111–139

Tryon CA, Faith T (2016) A demographic perspective on the Middle to Later Stone Age transition from Nasera rockshelter, Tanzania. Philos Trans R Soc Lond B Biol Sci 371(1698):20150238

Tryon CA, McBrearty S, Texier P-J (2005) Levallois lithic technology from the Kapthurin formation, Kenya: Acheulian origin and Middle Stone Age diversity. Afr Archaeol Rev 22(4):199–229. https://doi.org/10.1007/s10437-006-9002-5

Tryon CA, Roach NT, Logan AV (2008) The Middle Stone Age of the northern Kenyan Rift: age and context of new archaeological sites from the Kapedo Tuffs. J Hum Evol 55:652–664

Tryon CA, Ranhorn KL (2020) Raw material and regionalization in stone age eastern Africa. In: Groucutt, H. (eds.) (2020). Culture History and Convergent Evolution. Vertebrate Paleobiology and Paleoanthropology. Springer, Cham, 143–156

Uribelarrea D (2017) Geología en la Cuna de la Humanidad. Cómo trabaja un geólogo en los yacimientos de la garganta de Olduvai (Tanzania). Enseñanza de las ciencias de la tierra, 25 (1): 74–81

Vaquero M, Romagnoli F (2018) Searching for Lazy People: the significance of expedient behavior in the Interpretation of Paleolithic assemblages. J Archaeol Method Theory 25:334–367

Wadley L, Murungi ML, Witelson D, Bolhar R, Bamford M, Sievers C, Val A, de la Peña P (2016) Steenbokfontein 9 Kr: A Middle Stone Age spring site in Limpopo, South Africa. S Afr Archaeol Bull 71(204):130–145

Will M (2021) The role of different raw materials in lithic technology and settlement patterns during the Middle Stone Age of Southern Africa. Afr Archaeol Rev 38:477–500. https://doi.org/10.1007/s10437-021-09446-6

Will M, Tryon C, Shaw M, Scerri EM, Ranhorn K, Pargeter J, McNeil J, Mackay A, Leplongeon A, Groucutt HS, Douze K, Brooks AS (2019a) Comparative analysis of Middle Stone Age artifacts in Africa (CoMSAfrica). Evol Anthropol 28(2):57–59. https://doi.org/10.1002/evan.21772

Will M, Conard NJ, Tryon CA (2019b) Timing and trajectory of cultural evolution on the African continent 200,000–30,000 years ago. In: Sahle Y, Reyes-Centeno H, Bentz C (eds) Modern Human Origins and Dispersal. Kerns Verlag, Tübingen, pp 25–72

Yellen J, Brooks A, Helgren D, Tappen M, Ambrose S, Bonnefille R et al (2005) The archaeology of Aduma Middle Stone Age sites in the Awash Valley, Ethiopia. Paleoanthropology 10:e100