Journal of Paleolithic Archaeology (2024) 7:4
https://doi.org/10.1007/s41982-024-00170-6

RESEARCH

Nubian Levallois Technology During MIS 5: Refitted Lithic Sequences and OSL Ages of Dimona South, Israel, and Their Broader Implications

Maya Oron[1,2] · Erella Hovers[2,3] · Naomi Porat[4] · Joel Roskin[5] · Talia Abulafia[1]

Accepted: 10 January 2024

Abstract
The site of Dimona South is a knapping locality in the Negev desert of Israel, situated at the raw material source. A test excavation followed by a salvage excavation conducted during 2020 revealed a partly buried archaeological layer that was exposed over an area of ~ 40 m^2 and yielded a well-preserved lithic assemblage. Optically stimulated luminescence (OSL) ages of sediments within and above the archaeological layer fall within MIS 5. With a lithic assemblage dominated by Nubian Levallois technology, this site provides a rare opportunity for analysis of a well-dated, in situ Nubian assemblage. A refitting study in combination with an attribute analysis of the whole assemblage allowed the reconstruction of the Nubian reduction sequence. Our analyses indicate that a specifically pre-planned Nubian point production system existed at the site. It is characterized by the early preparation of an acute distal ridge and its careful maintenance throughout the reduction process until the cores were exhausted. These characteristics stand out from most Levantine Middle Paleolithic assemblages.
The discovery of Dimona South allows us to revisit some of the technological issues at the heart of debates about Levallois Nubian technology that could not be addressed from analyses of partial surface assemblages. These new data from a secure and dated context are crucial to the inter-site and regional technological comparisons, informing our views of the Nubian technology and its role in the Middle Paleolithic world of eastern Africa, Arabia and the Levant.

Keywords Nubian Levallois · Middle Paleolithic · Negev desert · MIS 5 · Refitting

Introduction

Nubian Levallois technology was first recognized as a techno-typological component of several lithic industries in the Nile Valley and Nubia (Guichard & Guichard, 1965; Marks, 1968; Seligman, 1921; Van Peer, 1992). Later, it was suggested that these industries could be integrated into a single techno-complex named the Nubian Complex (Van Peer, 1998, 2001; Van Peer & Vermeersch, 2000). The presence of Nubian cores was also reported from other areas in North and Eastern Africa (Foley et al., 2013; Tryon et al., 2012; Wendorf & Schild, 1974). Interest in Nubian Levallois lithic technology was renewed due to its discovery in the Arabian Peninsula (Crassard & Hilbert, 2013; Hilbert et al., 2017; Rose et al., 2011; Usik et al., 2013), when it was suggested that this technological attribute might have been a cultural marker for the dispersal of *Homo sapiens* out of Africa or even from Arabia into north-eastern Africa (Marks & Rose, 2014; Rose et al., 2011; Usik et al., 2013; Van Peer & Vermeersch, 2007). In recent years, Nubian Levallois technology was reported also from the Negev in the southern Levant (Goder-Goldberger et al., 2016, 2017), South Africa (Hallinan & Shaw, 2015, 2020; Will et al., 2015) and possibly India (Blinkhorn et al., 2013, 2015). These new data challenged the restriction of Nubian phenomenon to a geographically and chronologically defined techno-complex as well as its association to a single

Maya Oron and Talia Abulafia contributed equally.

✉ Maya Oron
mayaoron@gmail.com

1 Israel Antiquities Authority, Nahman Avigad 1, 9370726 Jerusalem, Israel

2 Institute of Archaeology, The Hebrew University of Jerusalem, Mt. Scopus, 91905 Jerusalem, Israel

3 Institute of Human Origins, Arizona State University, 777 East University Drive, Tempe, AZ 85287-8404, USA

4 Geological Survey of Israel, 32 Yesha'ayahu Leibowitz St., 9692100 Jerusalem, Israel

5 Department of Geography and Environment, Bar-Ilan University, Ramat-Gan, Israel

Published online: 01 February 2024

human expansion out of Africa (Groucutt, 2020; Hallinan et al., 2022b). More recently, the debate has shifted from the focus on the role of the Nubian technology as a cultural marker for human expansions to challenging its existence as a defined technological phenomenon (e.g., Groucutt, 2020; Blinkhorn et al., 2021; Hallinan et al., 2022a; Blinkhorn et al., 2022; but see Groucutt & Rose, 2023).

The uncertainties and the debate revolving around the Nubian technology can be partly attributed to the fact that stratified and securely dated archaeological contexts that bear Nubian components are rare. The few radiometric dated contexts suggest that the Nubian technology is associated with MIS 5 in Arabia and the horn of Africa, and comes from MIS 5 and MIS 4 contexts in the Nile Valley and the Egyptian deserts (Table 1). Other, undated sites in Egypt and Sudan as well as nearly all the sites in Arabia were assigned to MIS 5 based on geographical and paleoclimatic considerations (Chiotti et al., 2009; Crassard et al., 2013; Mercier et al., 1999; Scerri et al., 2014; Usik et al., 2013; Van Peer, 1998; Van Peer et al., 2010; Vermeersch & Van Peer, 2002).

Cores bearing characteristics of Nubian Levallois technology were mentioned as sporadic finds in earlier studies of Levantine Middle Paleolithic (MP) assemblages (Munday, 1976; Ronen, 1974). Their presence in several localities in the Central Negev highlands was established recently by the work of Goder-Goldberger et al. (2016) who assigned them to MIS 5 based on paleoenvironmental considerations. Additional Nubian cores were reported from several other surface assemblages in the southern Negev (Goder-Goldberger et al., 2017). These data show that Nubian Levallois technology is present, in small frequencies, in surface collections usually adjacent to raw material sources, where non-Nubian Levallois cores are also present.

While the notion of Nubian technology as a marker of a clearly defined techno-typological complex should probably be re-evaluated (Hallinan et al., 2022b and references within), a better technological definition would help in building more explicit inter-site and inter-region comparisons. The well-dated and well-preserved assemblage from Dimona South (DS) allows us to reconstruct the full reduction sequence of the Nubian Levallois technology knapped on-site and to test the technological definition suggested by Hallinan et al. (2022b), who refined the scheme previously suggested by Usik et al. (2013). Therefore, this study makes a contribution toward a resolution of the ongoing debate about the nature of the Nubian. Specifically, we can now address two questions:

a) Is the Nubian a distinct technological Levallois variant or a by-product of other Levallois flaking modes?

b) Is the Nubian technology a case of cultural convergence or does its occurrence bear implications for demic dispersal or ideational diffusion of technological concepts?

Table 1 Nubian Levallois reported from dated contexts

Site	Region	Assemblage	Chronology	References
Gademotta, ETH-72-6	Ethiopia	Nubian cores in an MSA assemblage	Younger than 183 ka and older than 105 ka (Ar/Ar ages of volcanic ash layers)	Morgan & Renne, 2008; Brown et al., 2012
Sai Island	Nile Valley, Sudan	Thin bifacial foliates and Nubian and discoidal Levallois reduction strategies	Later than 152 ± 10 due to OSL date underlying layer	Van Peer et al., 2003
BP177	Nile Valley, Sudan	Lithic assemblages that contain abundant Nubian Levallois cores and bifacial foliates	OSL ages of ca. 27–17 ka for upper horizon, and ca. 65–25 ka for lower horizons	Masojć (2010), Masojć et al. (2017)
Taramsa 1	Nile Valley, Egypt	Burial associated with the Nubian complex (Phase III)	68.6 ± 8 ka to 78.5 ± 5.6 ka OSL dates from the burial	Van Peer et al., 2010
Sodmein Cave	Eastern Desert, Egypt	A Nubian core and a fragmented thinly flaked bifacial	Two series of TL ages of 109 ± 8 ka to 127 ± 10 ka and 86.9 ± 9.4 ka to 121.2 ± 14.8 ka	Mercier et al., 1999; Schmidt et al., 2015
Mata'na G, Kharga	Western Desert, Egypt	Lithic assemblage that includes some Nubian Levallois forms	U-series estimates on tufa deposits give a minimum age of 103 ± 14 ka, underlying maximum age of 127.9 ± 13 ka	Caton-Thompson (1952); Smith et al., 2004, 2007
Aybut Al Auwal	Njed Plateau, Oman	Mostly surface collection dominated by Nubian Levallois. One Nubian core found in the dated unit C	OSL age of 106.6 ± 6.4 ka below the Nubian core in unit C	Rose et al., 2011

Technological Definition

Current knowledge of the Nubian technology is based in many cases on finds from surface collections. This definition of Nubian technology focuses on cores, due to the rarity of in situ assemblages where the whole Nubian reduction can be analyzed such that debitage can be linked technologically to cores or to end-products (i.e., pointed item) (but see exceptions in Van peer, 1992; Usik et al., 2013). The definition of the Nubian reduction sequence has been revised several times (Bordes, 1988; Chiotti et al., 2009; Crassard & Hilbert, 2013; Rose et al., 2011; Usik et al., 2013; Van Peer, 1992, 1998) since its early definition by Seligman (1921) and Guichard and Guichard (1965). Recently, debates about the Nubian have been renewed, when the definition of Nubian technology was widened to the point where it cannot be separated from other Levallois reduction sequences, as a result of which its status as a defined technological phenomenon has been challenged (e.g., Blinkhorn et al., 2021; Groucutt, 2020).

In the present paper, we follow the definition of Nubian Levallois cores as refined and stated explicitly by Hallinan et al. (2022b). We support the notion that the Nubian reduction sequence is a variant of the Levallois reduction system; hence, it complies with the basic 'recipe' for Levallois flaking as defined by Boëda (1988, 1995) and Van peer (1992): (a) the volume of the core is formed of two sub-parallel surfaces converging at a plane of intersection, (b) the surfaces are hierarchically related with defined and non-changeable roles as preparation and production surfaces, and (c) the aim of reduction is to produce a predetermined product, achieved through the management of lateral and distal convexities. Following from this, we acknowledge the specific characteristics of the Nubian reduction within the Levallois system (Hallinan et al., 2022b; Usik et al., 2013): (a) The existence of a steep ridge (with an angle of 90° or less) at the distal end of the core (the median distal ridge—MDR), formed by two or more intersecting scars. (b) The presence of a distal platform for preparation removals, serving an alternate role to the proximal platform from which preferential removals are struck. (c) Core maintenance is focused on the preparation of the MDR, using the distal platform and/or steep lateral removals mostly at the distal part of the core. (d) The overall morphology of the core is pointed, occurring in a variety of convergent shapes. (e) Reduction is aimed at producing pointed end-products.

The Site of Dimona (South)

The site of DS is a knapping locality situated in the northeastern Negev Highlands of Israel (Fig. 1), at a flint source of cobbles originating mainly from Miocene conglomerates from the Hazeva Group (Zilberman & Calvo, 2013, see the Supplementary Information for additional information on region Geology). A test excavation followed by a salvage excavation were conducted during 2020 and revealed a partly buried archaeological layer, and a lithic assemblage dominated by Nubian Levallois technology. The layer was excavated over an area of ~ 40 m^2 and yielded a well-preserved lithic assemblage, allowing a detailed analysis, refitting and radiometric dating.

Materials and Methods

Dating

Samples for optically stimulated luminescence (OSL) dating were collected from the excavated sediment sections above, within and below the buried archaeological horizon. Given that DS is close to the site of Nahal Yitnan 7, situated in a similar landscape and within similar geological environment with similar quartz particle sources, OSL field sampling, sample preparation, dose rate evaluation and luminescence measurements closely followed the protocols used for Nahal Yitnan 7 (Oron et al., 2023). Briefly, equivalent doses (De) values were measured on the purified quartz using the OSL signal and the single aliquot regenerative dose (SAR) protocol (Murray & Wintle, 2000). Fifteen aliquots (2 mm) were measured for each sample, and the average De and errors were calculated using the central age model (CAM, Galbraith & Roberts, 2012). Dose rates were calculated from the concentrations of the radioactive elements U, Th and K, measured on the additional sample by ICP-MS (U&Th) or ICP-OES (K). Moisture contents were estimated at $5 \pm 3\%$, as appropriate for this arid region, and the cosmic dose was evaluated from current burial depths.

Lithic Analysis

The main goal of this work was to reconstruct the full reduction sequence of the Nubian Levallois technology knapped in DS, as a tool for understanding knappers' decision making and for placing the assemblage in the regional context (Boëda, 1995; Soressi & Geneste, 2011). The small size of the DS assemblage and the good preservation of the artifacts render this assemblage optimal for refitting (see Goring-Morris et al., 1998; Laughlin & Kelly, 2010), which was therefore chosen as a main tool to achieve these goals. Refitting was attempted for the entire lithic assemblage, resulting in a total of 136 refitted items (11% of the lithic artifacts) rejoined into 42 sequences. Some of the sequences are nearly complete, from the stage of decortication to the discarded core. The physical reconstruction of these sequences resulted in valuable information about the different stages of the

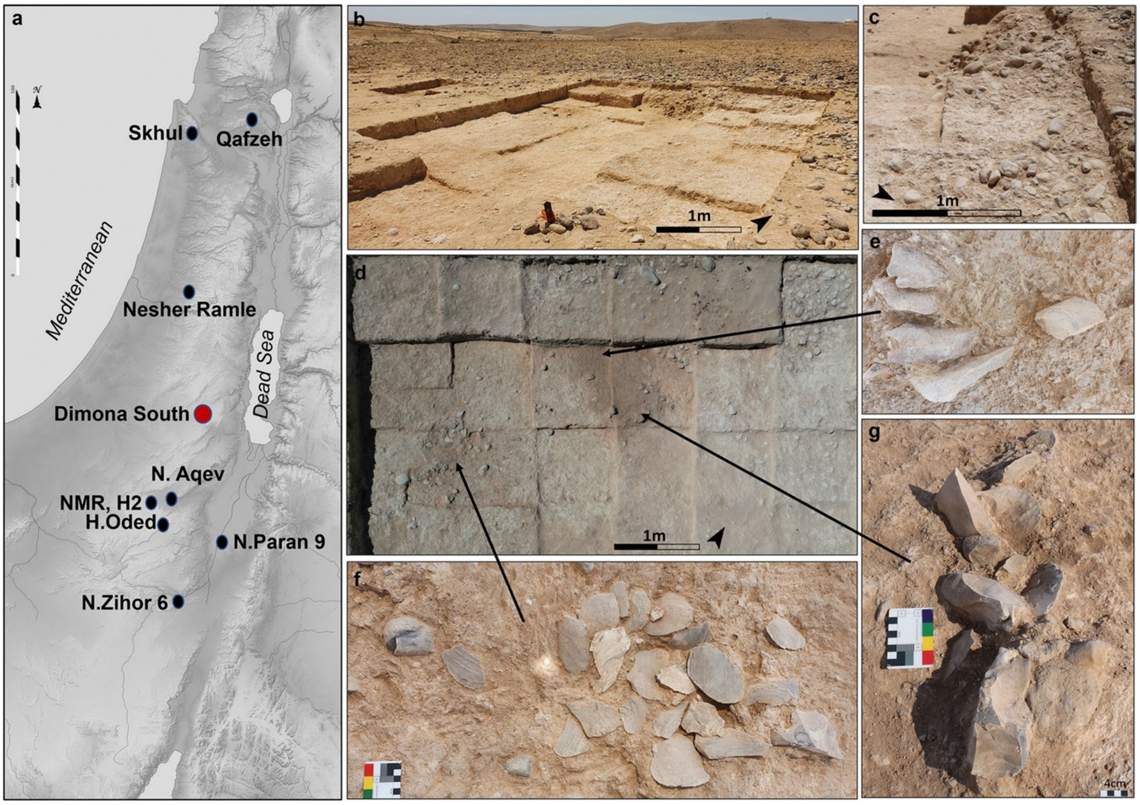


Fig. 1 (**a**) The location of DS and other MIS 5 sites in the southern Levant. (**b**) The excavated area in DS. (**c**) The conglomerate slope underlying the archaeological layer, partly cemented by calcrete. (**d**) An aerial view of the main lithic concentrations during the excavation. (**e**–**g**) Lithic artifacts as found in situ and their location in the excavation area (marked by arrows)

chaîne opératoire, from the choice of pebble to sequence initiation onto the production stage and core maintenance.

Information yielded from the refitting was combined with the data from attribute analysis. All artifacts larger than 2 cm were described for their techno-typological aspects according to a list of qualitative and quantitative attributes, under the accepted methodology used in previous research of the Levantine MP (Bar-Yosef et al., 1992; Boëda et al., 1990; Bordes, 1980; Goren-Inbar, 1990; Hovers, 1997, 2009) and adapted to quantify some of the specified attributes of the Nubian technology (Hallinan et al., 2022b; Usik et al., 2013).

Results

Stratigraphy and Chronology

The archaeological horizon, rich with well-preserved lithic artifacts, was buried under a loess cover (see the Supplementary Information for additional information). The scatter of flint artifacts on the slope above the excavation area showed generally the same typo-technological attributes, and several items found on the surface were indeed refitted to items in the buried layer. Hence, most of the surface finds had probably been part of the archaeological layer but had been exposed by erosion and continuously spread on the surface above the loess cover, due to the active slope process.

All the squares exposed in the excavated area showed the same stratigraphy, with differences in depth due to the slope (Figs. 1, 2). The lowermost part of the section, representing the paleo surface at the time of human occupation, is composed of two parts: a conglomerate built of pebbles sloping from north to south (Fig. 2a) and changing into sandy sediments mixed with pebbles that appear on the bottom of the section sloping gently to the south (Fig. 2b). This basal unit is partly covered with patchy calcrete and carbonates consolidating the pebble and sand unit (Fig. 2c). The archaeological material is found above the consolidated conglomerate and calcrete cover (Fig. 2d) and covered with loessal sediments (Fig. 2e). A few high-density artifact concentrations stand out against a background of low-density scatters across the excavated area (Fig. 3a,b). The archaeological unit is approximately

20 cm deep at most. The depth of the archaeological layer beneath the surface changes according to slope erosion and the inclination of the basal conglomerate and sandy units underneath (see the Supplementary Information for additional information on Geological background and sedimentology).

OSL Age

The layer overlying the artifacts was dated by OSL to 85 ± 7 ka, giving a minimum age for the level. The artifact level was dated to 111 ± 11 ka and 116 ± 8 ka, and the underlying layer to 124 ± 14 ka (Table 2 and Fig. 2). The suggested age

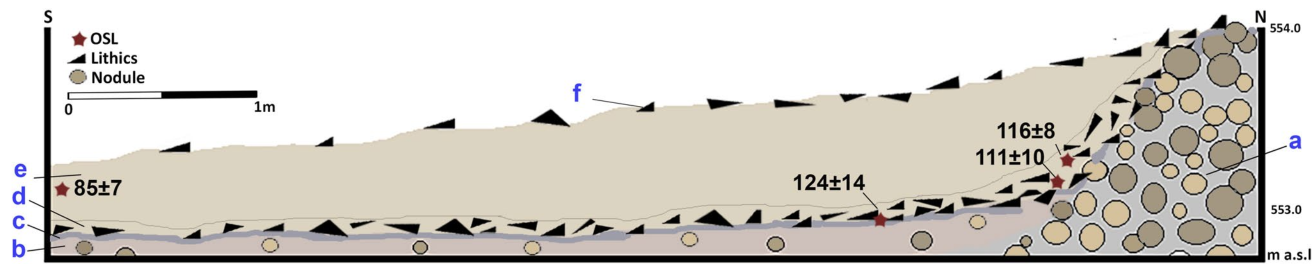


Fig. 2 A schematic south north section of the excavation area showing the main stratigraphic elements: (**a**) the conglomerate sloping from north to south, (**b**) sandy sediments mixed with pebbles, (**c**) patchy calcrete cover of units a and b, (**d**) the buried archaeological layer, (**e**) the loess sediments covering the layer, (**f**) flint pebbles and artifacts scattered on the surface. OSL ages (in ka) are shown next to each sample

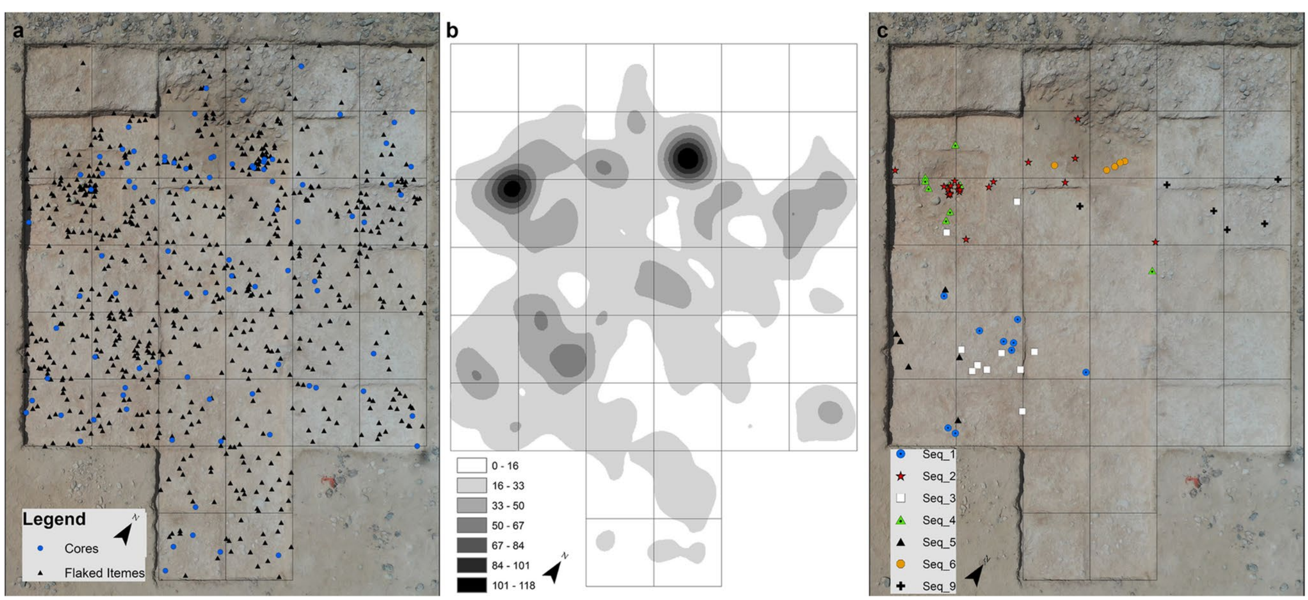


Fig. 3 Spatial distribution of lithic artifacts. (**a**) The distribution of all lithic artifacts in the excavated area (artifacts from mixed contexts are excluded). (**b**) Kernel density estimate of lithic artifacts in the excavated area (0.5 m search radius). (**c**) Spatial distribution of the main refitted sequences discussed in the text

Table 2 The location of each sample within the site layout and stratigraphy (see also Fig. 2). For full analytical details see Table S2

Sample code (DPV)	Location	Sediment	Burial depth (m)	Age (ka)
8	Above artifacts level (Fig. 2e)	Soft calcified loam	0.22	85 ± 7
3	Within artifact level (Fig. 2d)	Consolidated calcified loam	0.30	116 ± 8
2	Within artifact level (Fig. 2d)	Consolidated calcified loam	0.4	111 ± 11
5	Bottom of the Artifact level (Fig. 2c and d contact)	Soft calcified loam	0.3	124 ± 14

of ~ 115 ka for the archaeological level places it securely within the earlier part of MIS 5.

The Lithic Assemblage of DS

The lithic assemblage is small (*n* = 1196, Table 3). Due to the nature of the archaeological layer and site stratigraphy (see above), the assemblage derives from both an in situ context (*n* = 695) and from surface collection (*n* = 501). Although most of the items probably originated from the same short-term event, the excavated and surface material are presented separately, to ensure we maximize the reliability of our analysis and interpretations.

The assemblage shows the general characteristics of a knapping site that is adjacent to raw material source (Barkai et al., 2006; Binford, 1979; Hovers, 2009; Kuhn, 1995), i.e., a significant number of primary elements (> 50% cortex cover of the dorsal face; *n* = 284, 24%) and cores (*n* = 102, 9%) and relatively few retouched items (*n* = 12, 1%).

Twelve categories of cores were recognized typologically (Table 4). The cores derive from at least three technological modes of reduction, with a clear dominance of Nubian technology, accompanied by cores-on-flakes (COF) and few cores representing other Levallois production modes. The largest core category is that of the Nubian cores (*n* = 23) accompanied by exhausted cores that preserve the Nubian characteristics (4 overshot cores and 7 exhausted Nubian cores). Together, these groups comprise 33% of all cores. Cores from non-Nubian reduction types include other Levallois reduction modes (*n* = 13), COF (*n* = 5) and single platform cores (*n* = 3). Non-Nubian cores are less frequent in the in situ excavated layer than in the surface collected material (10% as opposed to 34%, respectively). Levallois cores indicating a centripetal reduction mode were found only within the surface material, whereas Levallois cores from the in situ context bear unidirectional convergent and bidirectional scar patterns. The remaining cores are highly reduced (*n* = 14), cores in the initial stage of reduction (*n* = 25) or broken items (*n* = 8), most of which cannot be assigned to a specific reduction mode.

The composition of the assemblage presented here, alongside the refits, suggests that Nubian production was the main aim of the knapping activity on site, accompanied by few items from other Levallois sequences (i.e., Levallois point and flake production) and by some expedient short reduction sequences (mostly the production of small flakes from large cortical flakes).

The Nubian Levallois Reduction System in DS

Choice of Nodules

The site is located at an outcrop of a fluvial conglomerate composed mostly of transported flint pebbles of the Hazeva Group, with additional local flint redeposited from the local Meshash Formation. The Hazeva Group includes a series of conglomerates, relicts of Miocene age fluvial systems (Zilberman & Calvo, 2013), that are characterized by rounded flint pebbles mostly 10–30 cm in diameter. It is often used as raw material for knapping in the MP and other periods. The size

Table 3 Composition of the lithic assemblage of DS

Type	In situ		Mixed with surface		Total	
	N	**%**	**N**	**%**	**N**	**%**
Primary flakes	159	23	125	25	284	24
Primary blades	10	1	11	2	21	2
Flakes	210	30	190	38	400	33
Blades	19	3	12	2	31	3
Levallois flake	23	3	18	4	41	3
Levallois point	13	2	12	2	25	2
Levallois blade	2	0	10	2	12	1
CTE	29	4	15	3	44	4
NBK	45	6	22	4	67	6
Total debitage	**510**	**73**	**415**	**83**	**925**	**77**
Chunks	16	2	27	5	43	4
Chips	96	14	6	1	102	9
Total debris	**112**	**16**	**33**	**7**	**145**	**12**
Cores	64	9	48	10	112	9
Tools	7	1	5	1	12	1
Hammerstone	2	0	0	0	2	0
Total	**695**	**100**	**501**	**100**	**1196**	**100**

Total counts for lithic categories are highlighted by bold

Table 4 Breakdown of core types in DS

Type	In situ		Mixed with surface		Total	
	N	**%**	**N**	**%**	**N**	**%**
Levallois Nubian	14	24	9	20	23	23
Nubian overshot	2	3	2	5	4	4
Exh. Nubian	5	9	2	5	7	7
Total Nubian	**21**	**36**	**13**	**30**	**34**	**33**
Levallois Unidirectional Convergent	1	2	2	5	3	3
Levallois Bidirectional	1	2	7	16	8	8
Levallois Centripetal	0	0	2	5	2	2
Core on flake	4	7	1	2	5	5
Single platform core	0	0	3	7	3	3
Total non-Nubian	**6**	**10**	**15**	**34**	**21**	**21**
Exh. Hierarchical surface	9	16	5	11	14	14
Core Preform	11	19	3	7	14	14
Tested Nodule	6	10	5	11	11	11
Broken/Indet	5	9	3	7	8	8
Total early/unidentifiable	**31**	**53**	**16**	**36**	**47**	**46**
Total	**58**	**100**	**44**	**100**	**102**	**100**

Total counts for lithic categories are highlighted by bold

distributions of the nodules in refitted sequences (when refitted to the full nodule size) and of the tested nodule categories (e.g., nodules showing up to 3 removals that were not further utilized for lithic production) show a clear difference between the two groups (Fig. 4). The average length of all selected nodules is 13 cm (range 5–25 cm). However, the refitted nodules tend to be larger than the tested nodules in all metric attributes, suggesting that larger nodules were selected for reduction.

Reduction Initialization

Based on the appearance of both the refitted sequences and tested nodules, most knapping sequences were initiated by using a natural break or angle of the pebble and then removing a single flake (Fig. 5a and c, Fig. 6) that enabled continued decortication of the pebble. One exception for this method is seen in refitted sequence #2 (Fig. 7a), where an exceptionally large nodule was used. The nodule was split into two along its middle and its reduction continued as two separate sequences. These two reduction initiations are demonstrated in the schematic illustration in Fig. 5d1.

The decortication stage was operationalized by removing a series of large flakes, creating a core preform with a triangular section, as seen in all the refitted sequences, regardless of their stage of discard (see preform in Fig. 5a–c, schematic illustration in Fig. 5d, and dashed sections illustrated

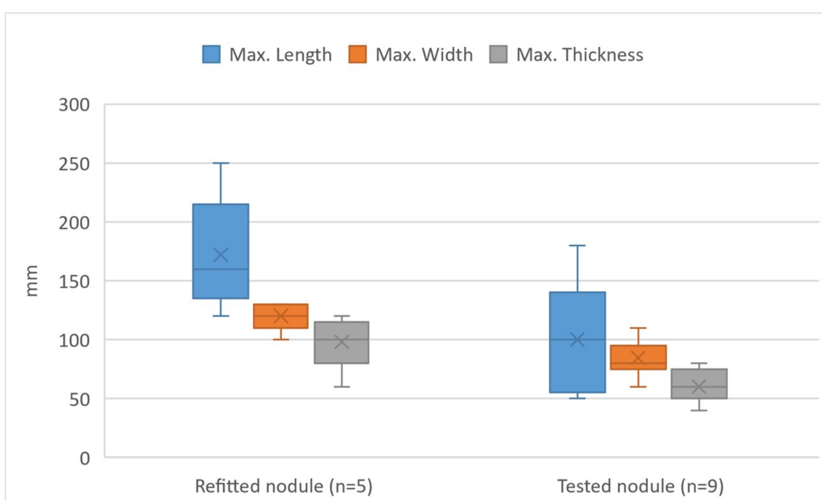


Fig. 4 Comparison of the metric attributes of tested and (refitted) knapped nodules in the DS assemblage (median value shown by a line and mean by x, as for all box plots below). See text for details

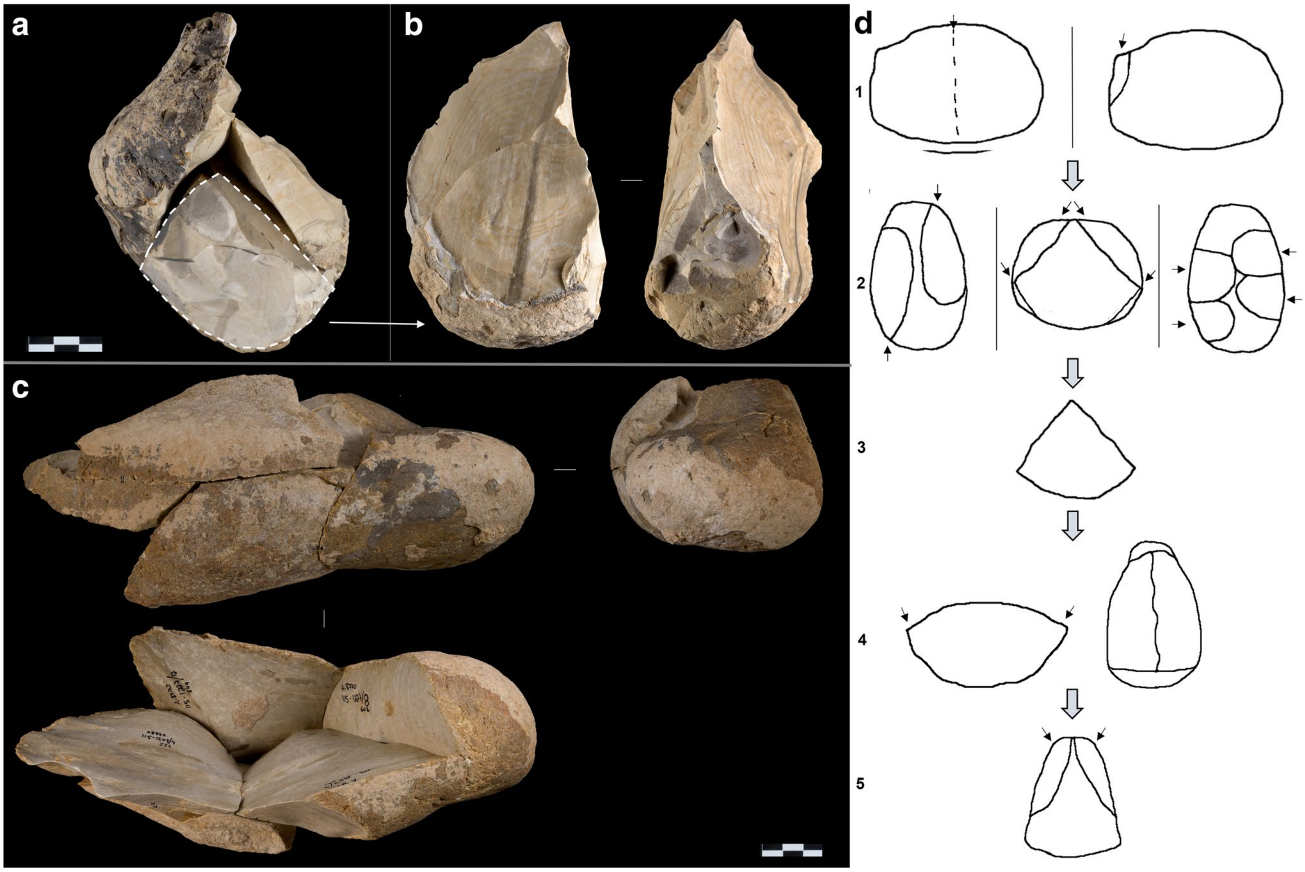


Fig. 5 Refitted sequences demonstrating the initialization stage: (**a**) sequence #1: a core preform abandoned after the first stage of decortication (marked with dashed line) creating a triangular section and a ridge, (**b**) the abandoned pick-like preform of sequence #1, (**c**) refitted sequence #6: a series of large cortical flakes creating a ridge (the core was not found/refitted), (**d**) a schematic demonstration of core initialization stage: the two options for sequence initialization explained in the text (1), followed by the formation of a ridged preform using bi-lateral and parallel removals (2–3), the opening of opposed striking platforms (4) and the creation of the MDR (5)

in sequences #3 — Fig. 6c, and #2 — Fig. 7a). The ridge created in this initial stage as part of the triangular section was later transformed, by removals from the distal platform, into the MDR, the main characteristic of Nubian Levallois cores, and maintained through the whole reduction.

Following decortication, two opposed striking platforms were created at the two ends of the preform, and a final preparation of the distal ridge was carried out using the distal (opposed) striking platform. This systematic initialization resulted in the preparation of a median ridge but in some cases also in characteristic bi-lateral scar pattern on the back of the cores (see back of cores illustrated in Fig. 8b,d), and some centripetal-like scarring on the lateral edges of the core flaking surface (Fig. 8a,d; Fig. 9b).

The Nubian Cores

Nubian Levallois cores ($N=23$) are the dominant group within the core assemblage of DS. Other cores that cannot be assigned morphologically to the category (following the accepted definition: Hallinan et al., 2022b; Usik et al., 2013), may also be related to the Nubian reduction sequence. For example, exhausted cores that show clear attributes of the reduction sequence, such as MDR, and core preforms showing the same initialization as the Nubian cores.

Scar patterns on the flaking surface of the Nubian Levallois cores show that all cores were exploited using a preferential reduction concept, with a scar of a dominant point or a pointed flake in most cases. Most cores show bidirectional scar patterns, but a large group of the Nubian cores (26%, $n=6$) bear centripetal scar patterns, a result of some of the core maintenance (see further discussion of core maintenance below) but also of core initialization (remnants from the core preform stage Fig. 9a,b). More than half of the Nubian cores ($n=13$) show additional preparation of the core, mainly the MDR, after the last dominant scar removal, but were discarded without further production.

The Nubian cores from DS are fairly standardized in size. Length ranges between 8 and 10.5 cm long and 6 to 8 cm

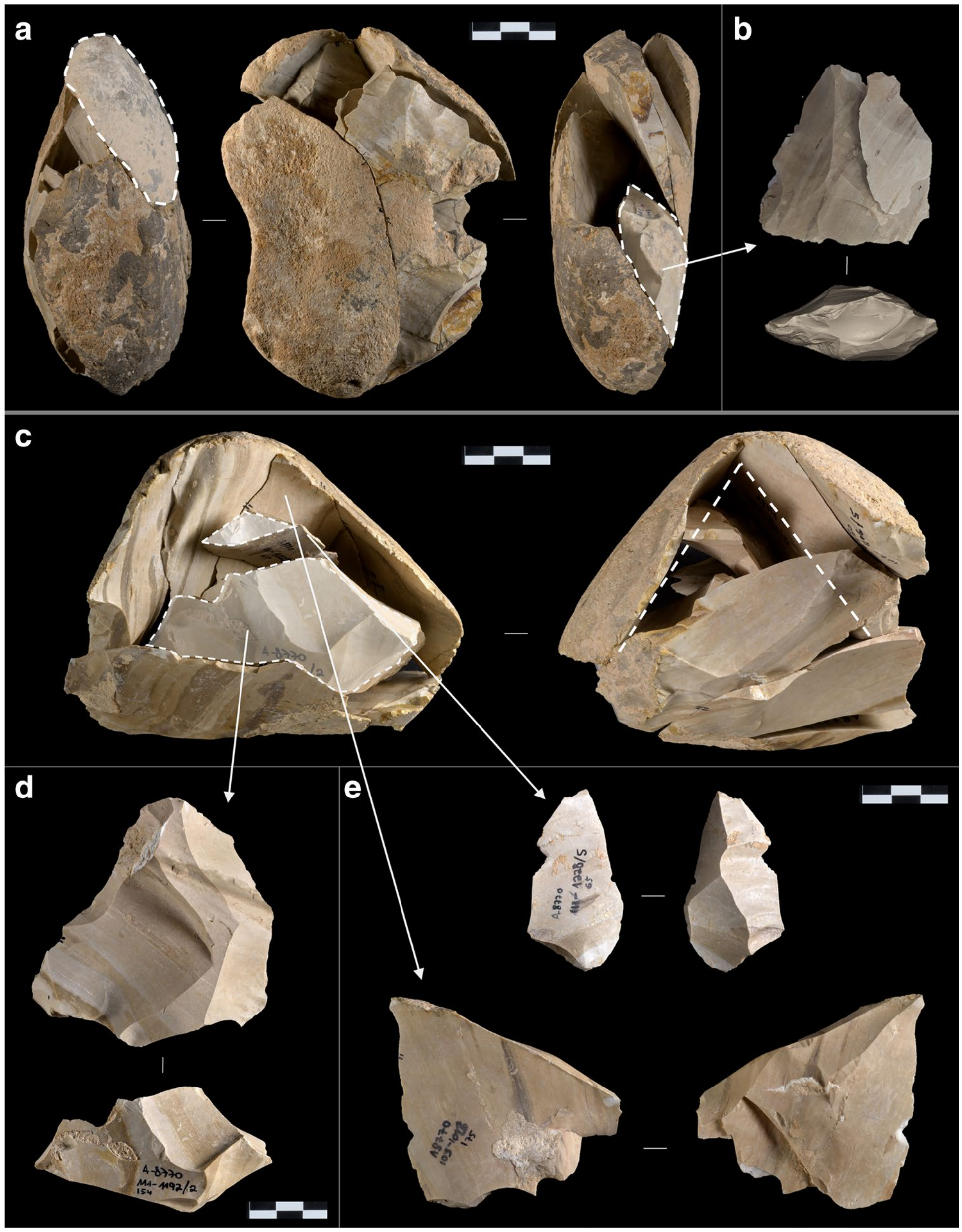


Fig. 6 Complete refitted sequences from DS: (**a**) refitted sequence #4 initiated by a single cortical flake removal (marked with dashed line) using the natural shape of the pebble. Continued to the decortication shaping a triangular section for the core and a short production stage. (**b**) The exhausted core of sequence #4 with a refitted flake from MDR maintenance, (**c**) refitted sequence #3: a complete sequence demonstrating the core initialization and a short production stage. (**d**) The core from sequence #3 with one potential end product scar, discarded with a hinge mistake. (**e**) A possibly unsuccessful point removed at the beginning of the reduction and a flake from shaping the MDR of sequence #3

wide. Exhausted cores that show technological characteristics of Nubian Levallois reduction are smaller on average but their size range overlaps with Nubian core metrics (Fig. 10a).

All Nubian cores have two opposed striking platforms. The main striking platform is usually dihedral ($n = 16$) or faceted ($n = 7$), and its shape is convex ($n = 18$), strait ($n = 2$) or irregular ($n = 3$). The distal platform has a characteristic pointed steep shape due to the MDR and is restricted to the distal half of the core. In most cases ($n = 15$), the distal platforms extend up to 24% of core circumference, but in some cases they may be up to 50% ($n = 6$) or even 75% of core circumference ($n = 2$), when cores show more lateral preparation (Fig. 8a,d). The angles of the striking platforms of the Nubian cores are maintained fairly steep, with the distal platform angle being generally steeper and more variable (Fig. 10d).

All Nubian cores show clear and steep MDR on the distal end of the core flaking surface. The MDR's angle measurements fall within the range of 40–92° (Fig. 10b, steep and semi-steep after Usik et al. (2013). Within this range, the largest group ($n = 10$) falls in the range of 60–70°, seemingly being intentionally maintained by the knappers within this range of acute angles. The variation of angle values is due to differences in the specific stage of preparation or production before discard. All Nubian cores show generally elongated and pointed shapes, variable between triangular (most

Fig. 7 (**a**) Refitted sequence #2 demonstrating initialization by splitting the pebble in its middle and then creating two preforms with triangular sections. (**b**) Sequence #2b an exhausted core from sequence #2 with a refitted partial debordant flake. (**c**) Sequence #2c; an exhausted core with a series of three refitted flakes from decortication to MDR maintenance preserving the acute angle. The core discarded without a MDR after an overpass removal

frequent), cordiform, pitched and one oval-shaped core (Fig. 8, 10c).

The exhausted Nubian cores in the assemblage ($n=7$) show very similar attributes to the Nubian cores. All except one still show a clear MDR with angle measurements that fall within the range of the Nubian cores (40–80°). Six out of the seven cores show two opposed striking platforms, in most cases with dihedral preparation and convex or irregular in shape. The main difference between this group and the Nubian cores is the irregular shapes, smaller size (Fig. 10a) and the more diverse scar patterns, all related to the continuous reduction before discard.

Core Maintenance and Debitage

Refitted sequences from DS show that after the cores were shaped, the production stage was generally short, and each core was used in order to produce 2–3 target items. Core preparation/modification between removals of the target items was minimal and consisted mainly of reshaping of the MDR and of the striking platforms. Therefore, the majority of debitage in the assemblage probably derived from the stage of core initialization. Out of all complete detached items in the assemblage ($n=350$), 75% bear cortex on the dorsal face, with more than a third (36%) showing > 50% cortex cover (Fig. 11a). This flaking system also resulted in

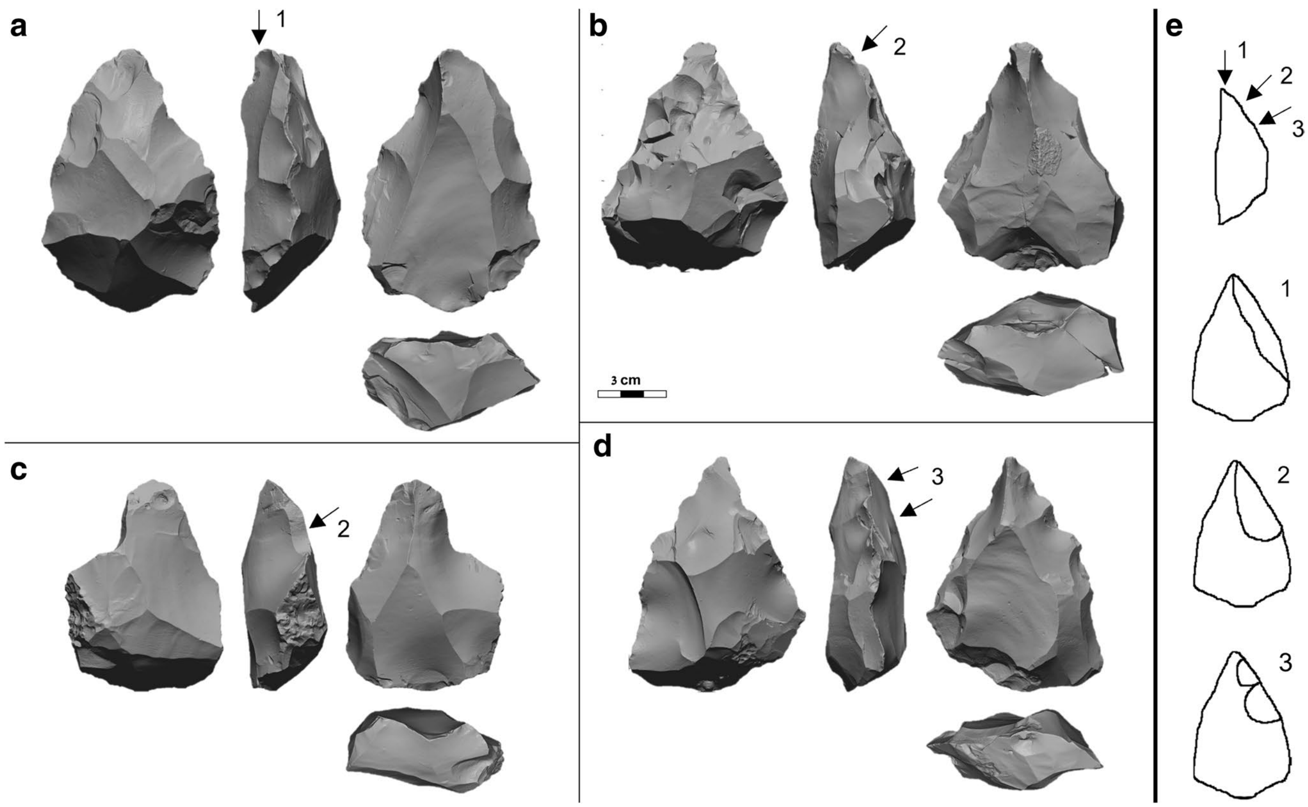


Fig. 8 (**a**)–(**d**) Nubian cores from DS showing scars of MDR renewal flakes/blades (shown by arrows), using different parts of the distal platform. (**e**) A schematic illustration of the different parts of the distal platform used for the removal of flakes/blades in MDR maintenance and the typical scars left on the core surface

a low number of dorsal scars, with most items (58%) bearing up to 3 scars (Fig. 11b), and in the dominance of plain butts (Fig. 11c).

The preparation of the MDR was done by both the removal of elongated debitage diverging from the tip of the core, as reported in previous studies (Fig. 8a, b; Van peer, 1992; Chiotti et al., 2007, 2009; Usik et al., 2013), as well as by the removal of flakes, using the lateral part of the distal platform—further down from the core tip (Fig. 8c, d). This is well attested in the debitage and refitted sequences. Blade and flake removals were applied alternately during the reduction, resulting in a variety of scar patterns on the core's flaking surface that range between exclusively bidirectional patterns to a combination of opposed and lateral scars.

The variability of scar patterns has led to the classification of a number of Nubian core types (e.g., types 1, 2 and type 1/2; Guichard & Guichard, 1965). The refit analysis and technological study of the DS assemblage indicate, however, that types 1 and 1/2 in the assemblage did not derive from discrete reduction sequences. These "types" are based on differences in scar patterns that resulted from the last preparations before the core was discarded, reflecting the use of one or alternative options for MDR maintenance. Because the two preparation types were used alternately during the reduction of the same core and are not related to a specific stage of the reduction, they are not associated with significant differences in core size. Exhausted Nubian cores are indeed smaller, as would be expected (Fig. 12).

The refitted sequences from DS show that some lateral scars seen on the flaking surface of the core are remnants of the core initialization stage, while the flaking related to the maintenance of the ridge is only concentrated on the distal half of the core. A common outcome of the MDR maintenance described above are large, mostly asymmetrical flakes, removed from the lower part of the distal platform transversally or obliquely to the axis of the MDR. These flakes are sometimes similar to partial debordant flakes, which are typical of the Levallois production systems. In the DS assemblage, two items that were typed as partial debordant flakes were recognized as MDR maintenance flakes when refitted.

Apart from the MDR maintenance, the reduction sequences include the renewal of the striking platform and shaping it by removing small flakes, and some removals from the main striking platform to preserve the convexity

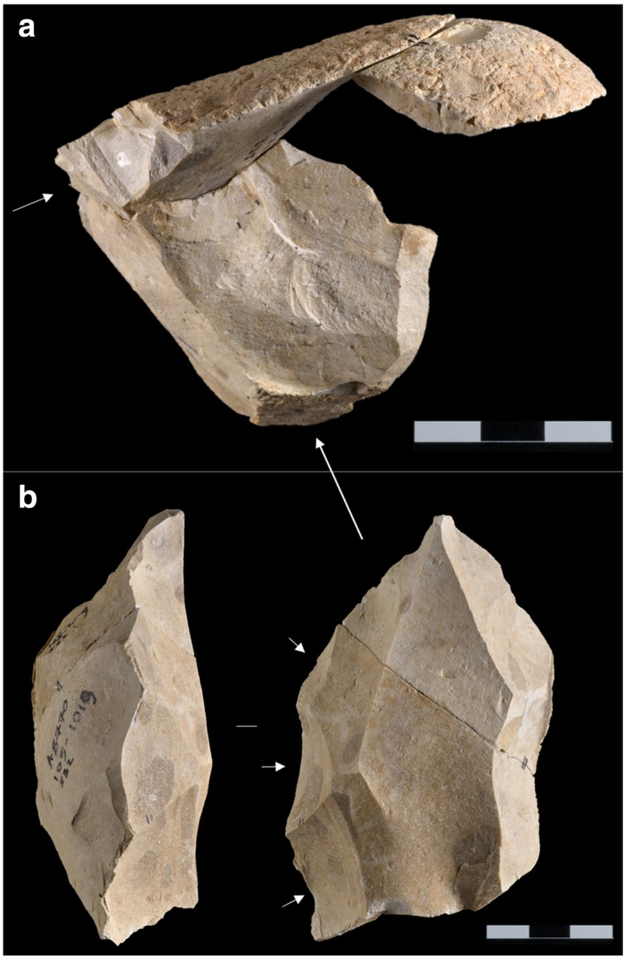


Fig. 9 A short refitted sequence showing two flakes from the decortication stage refitted on a core (**a**), resulting in a centripetal-like scar pattern on the core (**b**) shown by arrow

of the core's flaking surface in the proximal part of the core, similar to other Levallois reduction sequences (Fig. 7b).

End Products

The assemblage from DS includes a group of Levallois Items ($n=54$) that can be considered as the target items of the production on site. Of these, 20 items show clear pointed morphology (Fig. 13). Some of these pointed items refitted onto Nubian cores ($n=3$; Fig. 13a). In most cases, the pointed Levallois items are either broken or did not have a pointed tip due to overpass knapping mistakes. One such knapping mistake is an overpassed removal, due to which part of the MDR was removed inclusive of some of the core's distal part, as observed by Chiotti et al. (2009). Only a few items in the assemblage can be considered complete Levallois points. We therefore suggest that these items in the DS assemblage may not truly represent the target items of the Nubian Levallois reduction of DS, but rather the unsuccessful items left behind.

The maximum axis length of complete pointed Levallois items ($n=13$) is 78 mm in average (range 41–98, SD = 16), maximum axis width is 45 mm in average (range 30–59, SD = 9) and maximum thickness (measured at the thickest part) is 10 mm in average (range 6–16, SD = 3). These measurements are similar to those of the complete point scars on the Nubian cores (Fig. 14a, $n=7$), suggesting that pointed items were the target items of this reduction. The other items in the assemblage identified as Levallois products are much shorter and thinner (Fig. 14a) and most likely were the result of core maintenance and not target items.

Other attributes of the pointed Levallois items in DS include the prepared striking platforms, high frequency of chapeau de gendarme (Fig. 14b) and dominance of the bidirectional dorsal scar pattern (Fig. 14c). Most of the complete items of this group show a convex-concave profile ($n=8$) and others convex-strait ($n=5$).

Discussion

The search for archaeological evidence for the expansion of anatomically modern humans (AMH) from Africa into Eurasia became a central goal for many in the last few decades, led by the desire to link biological and cultural evolution (Klein, 2009). Different migration routes were suggested based on the fragmentary paleoanthropological and archaeological evidence as well as the paleoclimatic record (Armitage et al., 2011; Bar-Yosef, 1987; Derricourt, 2005; Frumkin et al., 2011; Lahr & Foley, 1994; Richter et al., 2012; Rose, 2007; Vaks et al., 2010, 2013). Against this background, the Nubian Levallois techno-complex, where the Nubian Levallois technology is one typo-technological feature associated with several different industries (e.g. Nubian MSA, Nubian Mousterian, Khormusan and Aterian), was associated with the expansion of AMH out of Africa (Marks & Rose, 2014; Rose et al., 2011; Usik et al., 2013; Van Peer & Vermeersch, 2000, 2007).

Rose and Marks (2014) correlated the archaeological data with paleoclimatic evidence in order to explain the typo-technological similarities between the Arabian record and neighboring regions. They suggest that during MIS 5, the Nubian reduction strategy spread from its geographic center in the Egyptian Middle Nile Valley and its hinterlands, reaching as far south as the Ethiopian Rift and east into the Arabian Peninsula. Following earlier works, they posit that such movements capitalized on the "greening" of the Saharo-Arabian phytogeographic zone (e.g., Drake et al., 2013; Parker & Rose, 2008; Rosenberg et al., 2011; Vaks et al., 2010, 2013). According to their model, over tens of thousands of years, up until the MP-UP transition,

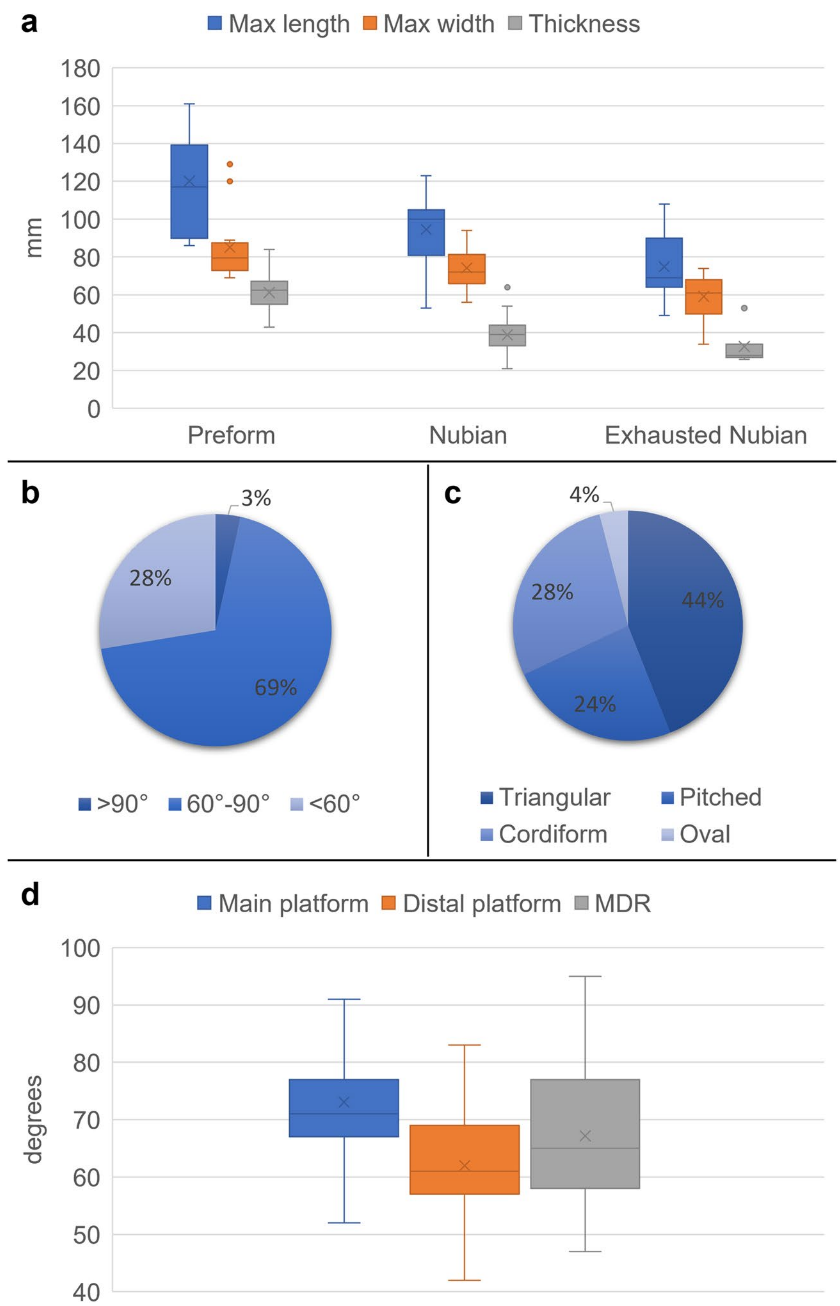


Fig. 10 Attributes of Nubian cores from DS; (**a**) Metric attributes of cores, comparing different stages of the reduction sequence. (**b**) Frequncies of the MDR angle. (**c**) Shapes of the Nubian cores. (**d**) Angles of the striking platforms and MDR's of Nubian cores

genetic and/or cultural information was transmitted across expanding and contracting "contextual areas" (in the sense of Richter et al., 2012) in Arabia and the southern Levant and maybe back into Africa, driven by climate patterns. Within this suggested model, the dominance of the Nubian Levallois technology in Dhofar, and its local technological changes, make it central within this continuous regional process. Similar suggestions of movement of people and ideas within one interaction sphere during MIS 5 explain the presence of Nubian cores in different parts of the Arabian Peninsula and the southern Levant (Goder-Goldberger et al., 2016, 2017; Hilbert et al., 2017).

The notion of a Nubian techno-complex has been questioned on both technological and cultural grounds. Recently discovered occurrences of Nubian Levallois technology were reported from several new regions — South Africa (Hallinan & Shaw, 2015, 2020; Will et al., 2015) and India (Blinkhorn et al., 2013, 2015) as well as a controversial study in the southern Levant (Blinkhorn et al., 2021; Hallinan et al., 2022a) — and challenged the view of the Nubian technology as a geographically and chronologically discrete phenomenon (Groucutt, 2020; Hallinan et al., 2022b). Groucutt (2020) argued that these new discoveries supported an explanation of Nubian technology occurrences as instances

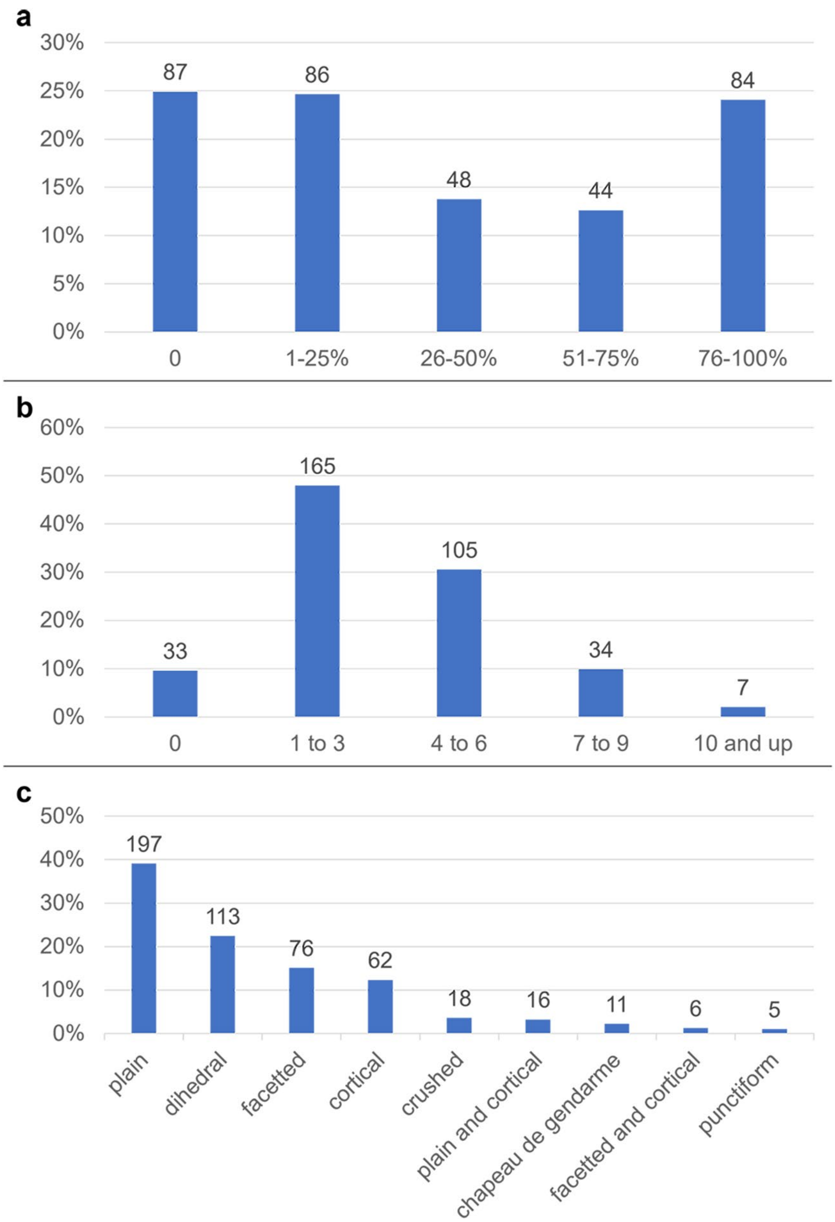


Fig. 11 Attributes of complete detached items (debitage and retouched); (**a**) amount of cortex on the dorsal face, (**b**) number of dorsal scars. (**c**) Butt types (the *n* for each category is shown at the top of each column)

of convergent evolution rather than as markers of human dispersals or indications of cultural transmission. In fact, due to the rare occurrence of Nubian technological features within well-constrained, comparable assemblages, the debate has shifted from a focus on the role of the Nubian technology as a cultural marker for human expansions to challenging its existence as a defined technological phenomenon (e.g., Blinkhorn et al., 2021, 2022; Groucutt, 2020; Hallinan et al., 2022a).

Regardless of their interpretations of the Nubian as a marker of demic dispersals or information transmission vs. convergent evolution, all researchers agreed that detailed, quantitative technological analyses and comparisons were necessary to further distinguish between these two options (e.g., Crassard & Thiébaut, 2011; Douze & Delagnes, 2016; Groucutt, 2020; Hallinan et al., 2022a, 2022b; Scerri et al., 2014). Importantly, if the Nubian Levallois technology could be shown to be a discrete and recognizable technological system, then its role as a potential cultural marker of dispersal would remain a valid hypothesis.

We posit that the new data from DS, suggesting that Nubian Levallois constitutes such a discrete technological behavior, reopens the discussion, even more so considering the well constrained dates of the assemblage. In the following section, we discuss the contribution of our results to the understanding of the Nubian Levallois technology, and how these new insights fit within the regional framework.

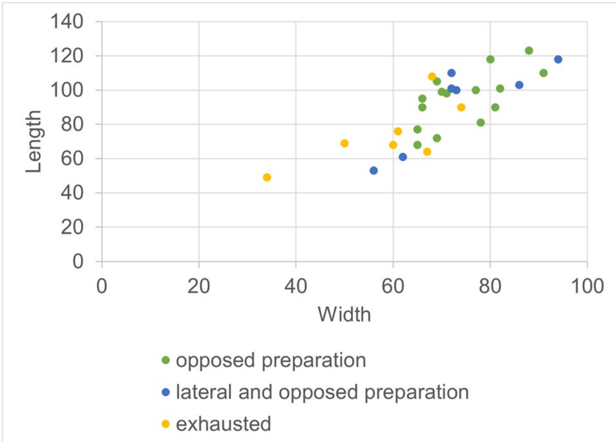


Fig. 12 Width and length ratio for Nubian cores showing different preparation and exhausted. All values in mm

New Insights on the Nubian Levallois Technology

The Levallois reduction system is a dominant technological feature of MP and Middle Stone Age (MSA) lithic assemblages, found across vast geographic and temporal spans and within different environmental conditions (Goren-Inbar & Belfer- Cohen, 1998; Shea, 2003; Villa et al., 2005; Hovers, 2009). This may be due in part to its recognizable features, making it easily visible in the assemblages (Otte, 1995). While following a basic common technological 'recipe' (Boeda, 1988; 1995), the Levallois reduction system is comprised of different variants, resulting in three main morphotypes as end products: flakes, points and blades (Van Peer, 1992), which are pre-determined by the organization of core geometry and topography of the core flaking surface. Assemblage variability in the MP is manifested by the frequency of combinations of different knapping methods (i.e., unidirectional, bidirectional or centripetal flaking) and modes (preferential, recurrent) of Levallois reduction, which has led to significant behavioral and cultural inferences (Hovers, 2009; Hovers & Belfer-Cohen, 2013; Zaidner et al., 2021).

The Nubian reduction sequence was initially defined and acknowledged as a variant of the Levallois technology by Seligman (1921). This definition, mainly based on core morphology, has since been debated and revised

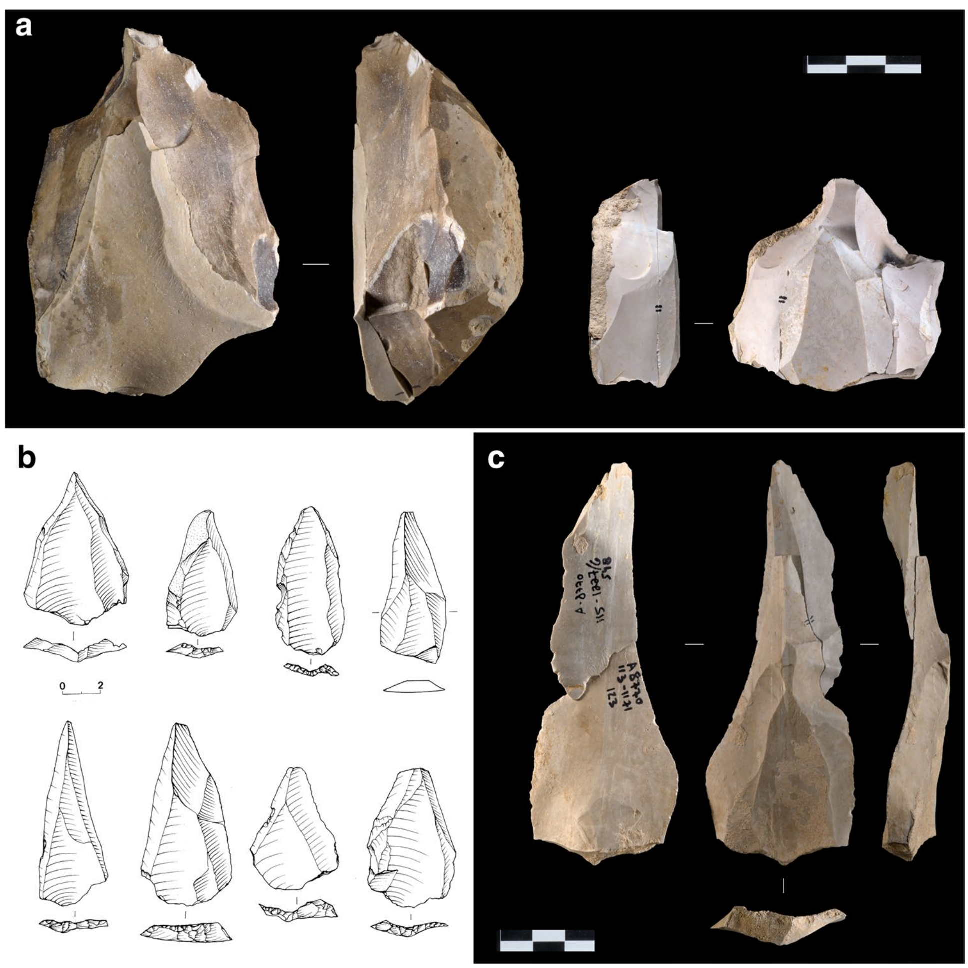


Fig. 13 (**a**) Pointed Levallois items refitted on a Nubian core and an exhausted Nubian core. (**b**) Pointed Levallois items from DS. (**c**) A pointed Levallois item refitted to a typical MDR maintenance flake

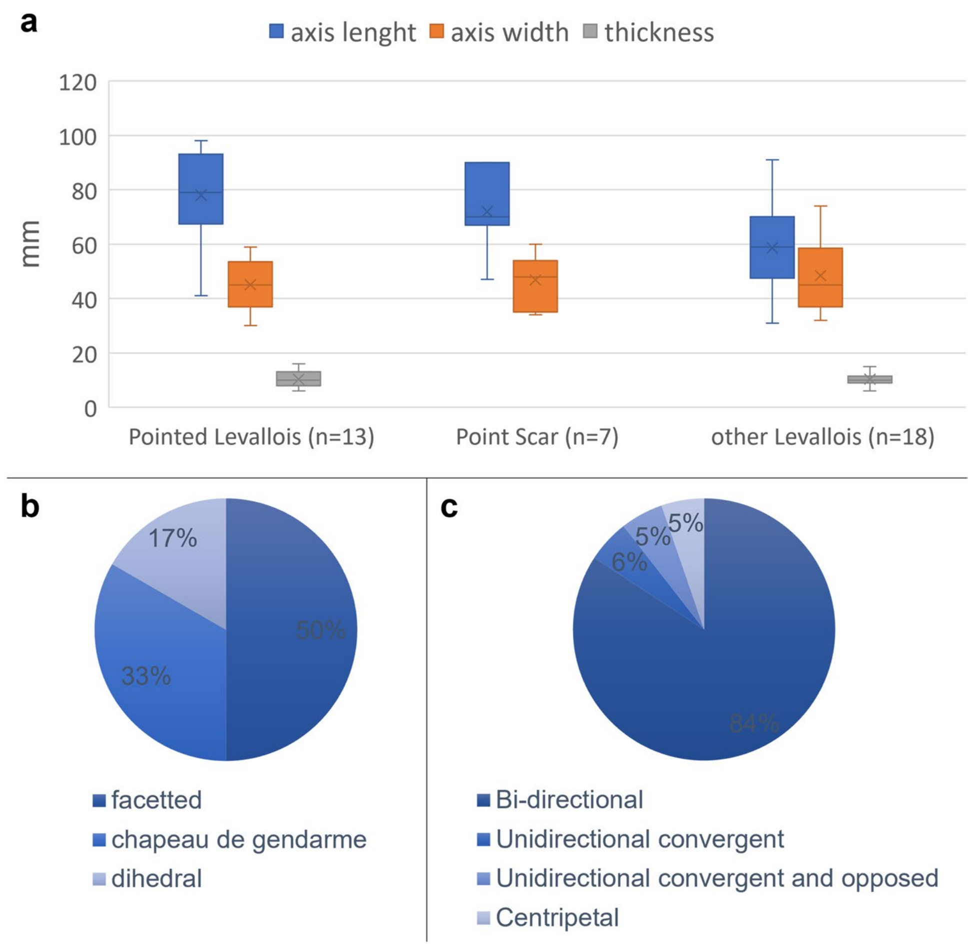
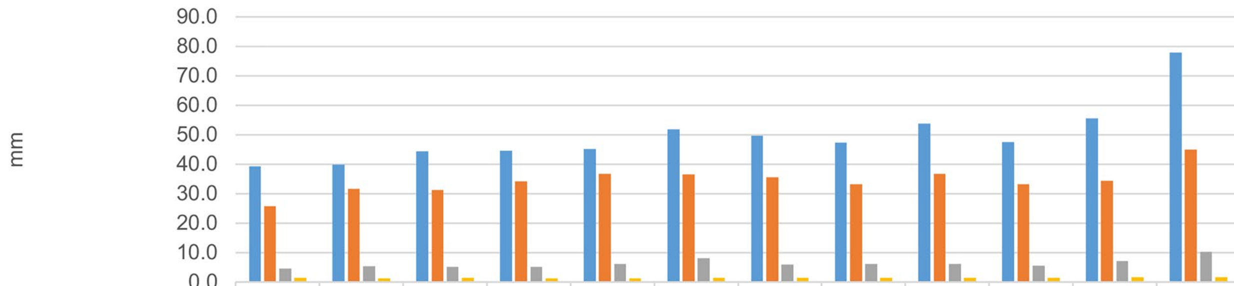


Fig. 14 Attributes of Pointed Levallois items; (**a**) Metric attributes compared with metric attribute of preferential point scars on Nubian cores and to other Levallois Items in the assemblage. (**b**) Frequencies of butt types; (**c**) frequencies of dorsal scar patterns

several times (Chiotti et al., 2009; Crassard & Hilbert, 2013; Guichard & Guichard, 1965; Rose et al., 2011; Usik et al., 2013; Van Peer, 1992, 1998), leading some authors to claim that it cannot be clearly separated from other Levallois reduction sequences. Groucutt (2020) stressed that since Nubian cores are distinguished from other Levallois cores only by the presence of a MDR, they cannot represent a particular Levallois method but one which overlaps and blends into other Levallois technologies. He therefore regards Nubian Levallois as a sub-type of preferential Levallois reduction with centripetal preparation. Similarly, a morphometric comparison of arguably Nubian cores with points from Shukbah cave with other Levallois items from the same site as well as other occurrences led Blinkhorn et al. (2021) to suggest that the observed variability largely overlaps between the two groups. In both papers, however, the definitions of Nubian technology do not incorporate key technological elements suggested by Usik et al. (2013), particularly the acute angle of the MDR, which casts doubts on their conclusions (Hallinan et al., 2022a). The emerging contradictory views underline the importance of the technological definition (see also Hallinan et al., 2022b).

The analysis of the DS assemblage shows that the Nubian reduction sequence at the site was consistent and systematic, starting from the choice of the nodule and sequence initialization, through the creation of a preform with a triangular section already at the decortication stage (Figs. 4, 5, 6), continued to the shaping of the MDR and its consistent maintenance throughout the reduction (Fig. 8), and the production of elongated pointed target items with traits that do not overlap with those of Levallois points (Figs. 14–15).

The reconstruction of the reduction sequence from DS is consistent with other reconstructions offered previously from North Africa (for example Chiotti et al., 2007, 2009) and Arabia (Crassard & Hilbert, 2013; Usik et al., 2013) and underscores strong similarities to these studies, while at the same time offering a broader technological perspective. It is also in agreement with the recent results showing intra assemblage consistency in the attributes of Nubian cores in Dhofar (Groucutt & Rose, 2023). Our analyses indicate that the Nubian Levallois production system in DS was a stand-alone, specifically pre-planned and consistent technological strategy. Although the production on-site is non-economical to some degree, “wasting” most of the pebble volume in decortication and ending up with a fairly short production



	Amud B1 (n=47)	Amud B2 (n=92)	Amud B4 (n=80)	Keb X (n=132)	Keb XI (n=43)	Tor Faraj (n=59)	NRQ IIB (n=85)	NRQ IIA (n=15)	NRQ I (n=19)	NRQ III (n=67)	NAQ 7,11 (n=26)	DS (n=13)
Flaking length	39.2	40.0	44.4	44.6	45.2	51.9	49.6	47.4	53.8	47.5	55.5	78.0
Flaking width	25.7	31.7	31.3	34.2	36.7	36.6	35.6	33.3	36.8	33.3	34.5	45.0
Maximum thickness	4.6	5.4	5.1	5.3	6.1	8.2	6.0	6.2	6.2	5.6	7.1	10.3
Length/width	1.5	1.3	1.4	1.3	1.2	1.4	1.4	1.4	1.5	1.4	1.6	1.7

Flaking length Flaking width Maximum thickness Length/width

Fig. 15 Metric attributes of Levallois points from sites in the southern Levant (Centi & Zaidner, 2021; Henry, 2003; Krakovsky, 2017; Prévost & Zaidner, 2020). *NAQ data were not previously published

stage for each core (Figs. 5, 6), it is carried out accurately and consistently. We show that the acute angle of the MDR is not a random feature that appears on some cores when discarded but reflects the most central technological decision of the knappers in core preparation and maintenance and separates it clearly from other Levallois variants.

Based on the reconstructed reduction sequence of DS, and on its similarity to previously identified Nubian cores within and outside the Levant, our analyses identify the Nubian Levallois reduction as a separate variant within the Levallois production system rather than an unintended outcome of the centripetal preferential Levallois reduction. The fact that these different stages are all seen in a single assemblage forming a cohesive technological strategy may render elements of the Nubian technology — other than the iconic cores — indicative of its existence in other sites.

Further, the analysis of the DS assemblage provides insights about the distinctions between Nubian core types and their shaping, another point of debate in the pertinent literature. For example, it refutes the existing classification to types 1 and 2 and shows that these are the result of different preparation choices that can be used alternately on the same core (Figs. 8, 12). Another clear feature seen in DS is the change in core shape as it transitions throughout the reduction sequence from preforms to exhausted core. Core preforms have a triangular section and sometimes resemble large picks (Fig. 5b), while exhausted cores usually preserve the pointed shape and, in many cases, also a steep distal ridge (Fig. 6b).

An intriguing question regarding the Nubian Levallois technology concerns the characteristics of the end-products that led to the use of Nubian reduction over other methods for producing points/pointed items in specific sites or regions (Hallinan et al., 2022b). Given their morphology, Nubian and Levallois points were assumed to have similar functions, and technological resemblances (mainly intensively prepared striking platforms, usually faceted and in some cases shaped as *chapeau de gendarme*) were noted. Still, two main differences were emphasized. First, in the shapes of the items, given that a Nubian point is a pointed elongated flake and not necessarily a broad-based triangular flake. A second difference in production is attested in the dorsal scar pattern, which is typically bidirectional rather than unidirectional convergent as in most Levallois points (Usik et al., 2013; Van peer, 1992). The former is clearly related to Nubian Levallois reduction sequence and is very different from the "classic" unidirectional convergent point production (see for example the refitted sequences from Tor Faraj, Demidenko & Usik, 2003). The number of potential target items in the DS collection is small and include many broken items or ones that attest to knapping accidents/mistakes. Because of the proven technological integrity of the assemblage, we can argue that the resemblance in metric attributes of these pointed Levallois items to those of the dominant preferential scars on the cores suggests that the discarded items found in DS fall well among the intended target items of the Nubian reduction. Therefore, they present a rare opportunity to discuss characteristics of the end products.

Pointed Levallois items are generally less common in MIS 5 assemblages in the southern Levant (Centi & Zaidner, 2021; Hovers, 2009; Meignen, 1998; Prévost &

Zaidner, 2020). They are more frequent in the Early MP assemblages, where many of them tend to have blade proportions (Meignen, 2011; Shimelmitz & Kuhn, 2018; Zaidner & Weinstein-Evron, 2020) and are considered a prevalent component of many Late MP assemblages (Bar-Yosef, 1998; Meignen, 1995, 2019). Levallois points are characterized by a base that is the broadest part of the item; there is a tendency for prepared striking platforms (more prominent in the Late MP); and the unidirectional convergent dorsal scar pattern is dominant. Another characteristic trait of Levallois points are convex-concave or *concord* profiles, but this data is unavailable for many of the relevant assemblages in the southern Levant.

Aside from the general pointed aspect, two characteristics of DS pointed items are similar to Levallois points in Levantine sites dated from MIS5 and later. The first is in the striking platform preparation, which in most cases in faceted or shaped as *chapeau de gendarme*. Secondly, 61% of the Levallois pointed items from DS show convex-concave profile, similar to the percentages reported from Amud units B1 and B4 and Kebara units X and XI (Krakovsky, 2017) as well as to the lower units of Nahal Aqev (units 7,11).

Other comparisons underscore the differences between DS and other assemblage. The pointed Levallois items from DS are larger and show slightly more elongated proportions (Fig. 15). Moreover, in 42% of the cases, the maximum width of the item is near the base but not at the striking platform itself. Most of the items (89%) show a bidirectional dorsal scar pattern, with only one showing a unidirectional convergent pattern, almost the opposite of scar pattern distributions in most southern Levantine assemblages (Centi & Zaidner, 2021; Henry, 2003; Hovers, 1998; Meignen, 2019; Prévost & Zaidner, 2020).

Within some late MP assemblages, the "classic" broad-based Levallois points appear alongside other pointed elongated Levallois flakes and blades, separated typologically since their widest part is not always at the base (Goder-Goldberger & Bar-Matthews, 2019; Henry, 1995; Hovers, 1998; Sharon & Oron, 2014). The general description for these items suggests some similarities to the Nubian target items from DS, but since these Late MP pointed items are not considered a distinct typological group, it is hard to assemble their metric and technological characteristics and compare them thoroughly. Recent use-wear analysis of such items from the Late MP site of NMO, interpreted as a hunting and butchering locality, suggested that some of them were used as butchering knives (Martin-Viveros et al., 2023). Interestingly, these items from NMO show metric attributes closer to the DS pointed items than to those of the Levallois points presented above (average length 71 mm, width 35 mm, thickness 11 mm). As suggested in the past, the elongated proportions (allowing more cutting edge) and the more robust structure of the Nubian target items compared with Levallois points, may have made these items more efficient in a curated, highly mobile toolkit (Groucutt, 2020; Hallinan & Shaw, 2020).

DS in its Regional and Chronological Frameworks of the Southern Levantine MIS 5

Most of the currently known assemblages with Nubian Levallois technology are found in arid environments, and many of them are associated with knapping activities adjacent to raw material sources. The partial record makes it hard to discuss the adaptive role of the technology. The location of DS in the Negev desert, with geographic proximity to the southern Levantine Mediterranean environment and its rich MP archaeological record, emphasizes the tethering of the technology to arid environments. This common environmental background has been suggested to promote a toolkit geared to high mobility (Groucutt, 2014, 2020; Hallinan & Shaw, 2020). The possibility of recognizing the Nubian target items, and not Nubian cores alone (see above) may contribute to further discussion of these behavioral aspects.

As demonstrated above, the Nubian cores from DS show the same traits as other Nubian cores reported from surface collections in the Negev and from different parts of the Arabian Peninsula, the Nile valley and Nubia. Nubian Levallois is almost the only reduction sequence knapped in DS, and it is even more prominent when considering only the in situ material (see above). Its secure dating to early MIS 5 supports previous claims, based on paleoclimatic inferences (Goder-Goldberger et al., 2016) that Nubian Levallois technology was present in the Negev during the last interglacial, broadly contemporaneous with dated assemblages in eastern Africa, the Nile Valley and Arabia (Table 1). Further afield, MIS 5 assemblages in the Mediterranean zone of the Levant are characterized by the prominence of centripetal Levallois reduction methods (see discussion in Hovers, 2009; Prevost & Zaidner, 2020). Other than isolated items in some of the of assemblages, there is no clear evidence for Nubian technology north of the Negev.

The assemblages from layers 7 and 11 of Nahal Aqev, dated 131 ± 23 and 117 ± 7–134 ± 7, respectively (Barzilai et al., 2022), are of interest here. Located only 25 km southwest of DS, the lithic assemblages are dominated by centripetal Levallois technology with no evidence for Nubian Levallois reduction (Barzilai et al., 2022). This underlines the lack of inherent contextual dependence between the occurrence of Nubian Levallois and centripetal Levallois technologies (and see Goder-Goldberger et al., 2016). This comparison between the two sites also bears some broader implications. The resemblance in the environmental background for Nubian technology (see above) was used to promote convergent evolution as the parsimonious explanation of its wide geographic range (Groucutt, 2014, 2020; Hallinan & Shaw, 2020). Such an argument is now undermined by the data from Nahal Aqev and DS.

The clear typo-technological differences between Nahal Aqev and DS may suggest that different human groups with different technological and adaptive preferences existed in the Negev during MIS 5. This in turn might imply movements of people or of technological ideas (or both) within this interaction sphere. While the centripetal Levallois technology may be associated with northern groups, the appearance of the Nubian Levallois knapping system in the Negev during MIS 5 could represent interactions with southern areas (Arabia and the Nile Valley) (Goder-Goldberger, 2014; Goder-Goldberger et al., 2016).

In the different regions of their occurrence, Nubian cores appear with centripetal Levallois cores, DS and the site from the Dhofar region being the exceptions (Fig. 16a). As many of these assemblages are surface collections, each may represent palimpsests of occupations by groups using different Levallois reduction systems.

There is clear similarity in shape and technological traits between the Nubian cores from Negev, Arabia, Egypt and Sudan. Metric attributes (Fig. 16b) suggest some intra-region homogeneity. For example, the Negev cores, and the cores from some of the Dhofar sites, tend to be longer in average than those from other regions. The cores from Dhofar also tend to have more elongated proportions than the cores from other regions, especially compared with the Egyptian assemblages. The Central Arabian sites seem to show more inter-regional variability. These differences may reflect localized knapping traditions but can also be highly affected by raw material availability, shape, and quality in the different regions (Hilbert et al., 2016). Given the paucity of detailed technological data

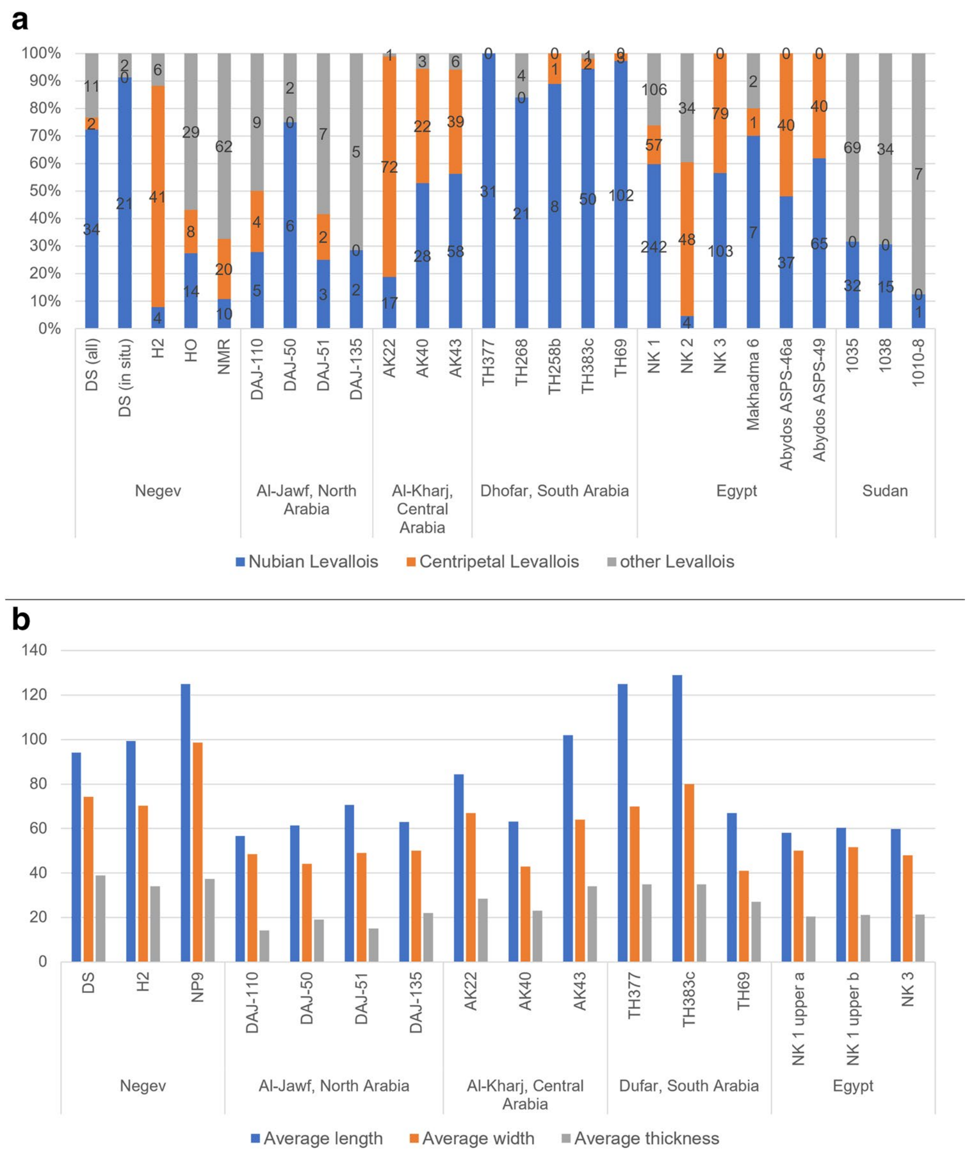


Fig. 16 (**a**) Frequencies of Levallois core types in assemblages that include Nubian cores by region (Marks, 1968; Van Peer, 2000; Vermeersch, 2002; Olszewski et al., 2010; Usik et al., 2013; Goder Goldberger et al., 2016; Hilbert et al., 2016, 2017). (**b**) Average metric attributes (in mm) of Nubian Levallois cores from different regions (Van Peer, 2000; Vermeersch, 2002; Goder Goldberger et al., 2016; 2017; Hilbert et al., 2016, 2017). *Information on the frequencies of Centripetal Levallois cores is missing for the Sudan sites

and comparisons, these suggestions are best viewed as working hypotheses for future research.

In the Dhofar region of Oman, Nubian cores are dominant in all the reported assemblages, stimulating discussions of its place as a core area for the appearance and development of this technological phenomenon (Rose, 2022; Rose & Marks, 2014). In addition to technological similarities between DS and assemblages from Arabia and Northeast Africa, the dominance of Nubian Levallois technology in DS draws another line of resemblance between this site and the assemblages from the Dhofar region. Combined with the MIS 5 dates for the Nubian in both regions, this supports the scenario for the existence of an interaction sphere in this part of the world during the last interglacial. The early MIS 5 dates for DS suggest that the appearance of Nubian technology in the Negev may in fact be earlier than some of the Nile Valley sites. This early appearance may suggest a scenario of the Negev, being a geographical bridge between Africa and Asia, becoming a hub for the movement of people and ideas back and forth between the Arabian Peninsula, the Levant and Northeast Africa.

Importantly, a 'culture-history' scenario does not necessarily exclude convergence of Nubian morphological characteristics in later assemblages in distant areas — and vice versa. In our view, while the Nubian technology in the southern Levant, Arabia and northeast Africa is more likely explained by the human interaction, its later appearance in South Africa is most likely convergence (as suggested by Hallinan & Shaw, 2020). This may be the case for Nubian Levallois technology in India as well, but the evidence at this time is very limited, and further information on the technological traits and their context may help to test this explanation in the future. As site integrity and dating possibilities can be monitored by researchers to varying degrees (e.g., Oron et al., 2023), detailed technological analyses can now be used to empirically assess the parsimony of each of these two contradicting hypotheses.

Nubian Levallois Technology and the Middle to Upper Paleolithic (MP-UP) Transition

Much of the interest of Paleolithic researchers in the question of the Nubian has stemmed from suggestions that technological similarities could be identified between the Nubian Levallois technology and the bidirectional point production from the site of Boker Tachtit (levels 1–3), a key site for discussion of the Middle to Upper Paleolithic transition in the southern Levant (Belfer-Cohen & Goring-Morris, 2007, 2009; Clark, 1988; Van Peer, 2004). On this basis, different scenarios of incoming populations and/or the diffusion of technologies were suggested, both from Arabia (Rose & Marks, 2014) and the Nile Valley (Wurz & Van Peer, 2012). Alternatively, the claim for technological similarity between Boker Tachtit assemblages and the Nubian Levallois was used as an example for convergent evolution of the Nubian phenomenon, due to the different chronology of the two (Groucutt, 2020). More recent studies demonstrate that the technological shift seen in Boker Tachtit reflects technological continuity from the Late MP in the southern Levant possibly coupled with local innovation and development (Belfer-Cohen & Goring-Morris, 2007, 2009; Goder-Goldberger, 2020; Goder-Goldberger et al., 2020, 2023; Meignen, 2012).

The results of the current study are directly relevant for testing the competing hypotheses. The refitted sequences and technological analysis of the DS Nubian Levallois, compared to the studied sequences of Boker Tachtit (Goder-Goldberger et al., 2023; Marks & Kaufman, 1983; Volkman, 1983), show that the two reduction sequences are significantly different. The MDR, being the most prominent and defining attribute of the Nubian reduction from initiation to discard, is completely absent in the Boker Tachtit reduction strategy. On the other hand, there is no evidence for the use of crested blades in the DS assemblage, while they are an important aspect of the point production in Boker Tachtit. Unlike the Boker Tachtit reduction strategies, the hierarchy between the surfaces is maintained in the DS reduction and the core's narrow face is never used for blank production. Apart from the focus on the MDR, core maintenance in DS resembles other contemporaneous and later Levallois reduction sequences more than it does the reduction sequences encountered in Boker Tachtit.

Thus, the detailed technological analysis of the DS assemblage undermines the hypothesis of cultural convergence. The dates assigned to the assemblage are consistent with the time span of MIS 5 already suggested tentatively for the Nubian phenomenon in the Negev. The DS chronology aligns with the notion of a long temporal gap between occurrences of Nubian technology in the region and the time of Boker Tachtit, recently re-dated to 50–44 ka (Boaretto et al., 2021). Given the data in the current paper as well as early and recent studies of Boker Tachtit lithic technology (Goder-Goldberger et al., 2023) and its relation to the late MP in the Negev (Goder-Goldberger & Malinsky-Buller, 2022), the suggestion that Boker Tachtit technological affinities are associated with Nubian ones seems tenuous.

Conclusions

Nubian Levallois technology has been at the center of many recent debates about the movements of hominins across the southern Levant and Arabia specifically, and about explanation of the archaeological record in general.

It has been heralded as a marker of AMH out of Africa movements during MIS 5 or alternatively, as a product of Levallois technology inevitably associated with centripetal Levallois technology, or as a case of convergent cultural evolution. The debates remained inconclusive due to the paucity of in situ, well dated assemblages. The assemblage from the site Dimona South, dominated by Nubian cores and dates securely to early MIS 5, provides an opportunity to conduct a detailed technological analysis combined with refitting studies of the Nubian Levallois technology from a secure context. The analysis demonstrates that the Nubian constitutes a stand-alone, planned and systematic knapping system for the production of pointed target items and should not be perceived as a by-product of other Levallois reduction systems. The robust dating of the assemblage to early MIS 5 supports earlier claims for the age of other Nubian occurrences in the Negev region of Israel, which up to now could not be substantiated by absolute chronology. We posit that the contemporaneity of this defined technological system in several neighboring regions (e.g., northeast Africa, the Arabian Peninsula and the Negev), is most parsimoniously explained by the movement of ideas and maybe also people within one interaction sphere. Our data suggest that ideas that Nubian technology played a role in the shift from the Middle to the Upper Paleolithic in the southern Levant should be critically evaluated.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s41982-024-00170-6.

Acknowledgements The excavation was conducted on behalf of the Israel Antiquities Authority (IAA) who granted us permission to use all figures of the excavations and finds from the site. We thank the workers and volunteers as well as the Israel Antiquities Authority (IAA) Southern district crew for their support and much needed help in the carrying out field work during the 2020 pandemic. Field documentation, drone photos were done by Emil Aladjem (IAA). Artifacts were photographed by D. Gazit, drawn by M. Smilansky and scanned by A. German-Levanon, all from the IAA. We thank O. Barzilai, E. Boaretto and G. Sharon for allowing us to use unpublished metric data of the points from NAQ and NMO.

Author Contribution (T.A. and M.O. led the field work and conducted the artifact refitting. J.R. did the geomorphological and sedimentological field work and analysis. N.P. did the OSL analysis. M.O. did the lithic and GIS analysis and prepared the illustrations in the manuscript. M.O. and E.H. wrote the main manuscript text. All authors reviewed the manuscript.

Funding Open access funding provided by {institution name}. Maya Oron has been supported by the Israel Antiquities Authority scholarship program and by the Institute of Archaeology of the Hebrew University through its Ruth Amiran Fund for Archaeological Research in Israel.

Data Availability The Lithic analysis data will be available by request from the corresponding author.

Declarations

Competing Interests The authors declare no competing interests.

References

Armitage, S. J., Jasim, S. A., Marks, A. E., Parker, A. G., Usik, V. I., & Uerpmann, H.-P. (2011). The southern route "out of Africa": Evidence for an early expansion of modern humans into Arabia. *Science, 331*(6016), 453–456.

Barkai, R., Gopher, A., & LaPorta, P. C. (2006). Middle Pleistocene landscape of extraction: Quarry and workshop complexes in northern Israel. In N. Goren-Inbar & G. Sharon (Eds.), *Axe Age: Acheulian Toolmaking-from Quarry to Discard* (pp. 7–44). Equinox Publishers.

Bar-Yosef, O. (1987). Pleistocene connexions between Africa and Southwest Asia: An archaeological perspective. *African Archaeological Review, 5*(1), 29–38.

Bar-Yosef, O. (1998). The chronology of the Middle Paleolithic of the Levant. In T. Akazawa, K. Aoki, & O. Bar-Yosef (Eds.), *Neandertals and Modern Humans in Western Asia* (pp. 39–56). Plenum Press.

Bar-Yosef, O., Vandermeersch, B., Arensburg, B., Belfer-Cohen, A., Goldberg, P., Laville, H., et al. (1992). The excavations in Kebara Cave, Mt. Carmel. *Current Anthropology, 33*(5), 497–550.

Barzilai, O., Oron, M., Porat, N., White, D., Timms, R., Blockley, S., et al. (2022). Expansion of eastern Mediterranean Middle Paleolithic into the desert region in early marine isotopic stage 5. *Scientific Reports, 12*(1), 1–13.

Belfer-Cohen, A., & Goring-Morris, A. N. (2007). From the beginning: Levantine Upper Palaeolithic cultural change and continuity. In P. Mellars, K. Boyle, O. Bar-Yosef, & C. Stringer (Eds.), *Rethinking the human revolution* (pp. 199–205). McDonald Institute for Archaeological Research.

Belfer-Cohen, A., & Goring-Morris, A. N. (2009). The shift from the Middle Palaeolithic to the Upper Palaeolithic: Levantine perspectives. In M. Camps & C. Szmidt (Eds.), *The Mediterranean from 50 000 to 25 000 BP: Turning Points and New Directions* (pp. 89–100). Oxbow Books.

Binford, L. R. (1979). Organization and formation processes: Looking at curated technologies. *Journal of Anthropological Research, 35*(3), 255–273.

Blinkhorn, J., Achyuthan, H., Petraglia, M., & Ditchfield, P. (2013). Middle Palaeolithic occupation in the Thar Desert during the Upper Pleistocene: The signature of a modern human exit out of Africa? *Quaternary Science Reviews, 77*, 233–238.

Blinkhorn, J., Achyuthan, H., & Ajithprasad, P. (2015). Middle Palaeolithic point technologies in the Thar Desert, India. *Quaternary International, 382*, 237–249.

Blinkhorn, J., Zanolli, C., Compton, T., Groucutt, H. S., Scerri, E. M., Crété, L., et al. (2021). Nubian Levallois technology associated with southernmost Neanderthals. *Scientific Reports, 11*(1), 1–13.

Blinkhorn, J., Zanolli, C., Compton, T., Groucutt, H. S., Scerri, E. M., Crete, L., et al. (2022). Reply to: 'No direct evidence for the presence of Nubian Levallois technology and its association with Neanderthals at Shukbah Cave.' *Scientific Reports, 12*(1), 1–4.

Boaretto, E., Hernandez, M., Goder-Goldberger, M., Aldeias, V., Regev, L., Caracuta, V., et al. (2021). The absolute chronology of Boker Tachtit (Israel) and implications for the Middle to Upper Paleolithic transition in the Levant. *Proceedings of the National Academy of Sciences, 118*(25), e2014657118.

Boëda, E. (1988). Le Concept Levallois et évaluation de son champ d'application. *L'homme De Néandertal, 4*, 13–26.

Boëda, E., Geneste, J. M., & Meignen, L. (1990). Identification de Chaine Opératoires lithique du Paleolithic Ancient et Moyen. *Paleo, 2*, 43–80.

Boëda, E. (1995). Levallois: A volumetric construction, methods, a technique. In Dibble H.L & Bar-Yosef O (Eds.), *The definition and interpretation of Levallois technology* (Vol. 23, pp. 41–65). Madison: Prehistory Press.

Bordes, F. (1980). Le débitage Levallois et ses variants. *Bulletin De La Société Préhistorique Francaise, 77*(2), 45–49.

Bordes, F. (1988). *Typologie du Paléolithique ancien et moyen*. Presses du CNRS.

Brown, F. H., McDougall, I., & Fleagle, J. G. (2012). Correlation of the KHS Tuff of the Kibish Formation to volcanic ash layers at other sites, and the age of early Homo sapiens (Omo I and Omo II). *Journal of Human Evolution, 63*(4), 577–585.

Caton Thompson, G. (1952). *Kharga Oasis in Prehistory*. Athlone Press.

Centi, L., & Zaidner, Y. (2021). The Levallois flaking system in Nesher Ramla Upper Sequence. *Journal of Paleolithic Archaeology, 4*(2), 9.

Chiotti, L., Dibble, H. L., Olszewski, D. I., McPherron, S. P., & Schurmans, U. A. (2009). Middle Palaeolithic lithic technology from the western high desert of Egypt. *Journal of Field Archaeology, 34*(3), 307–318.

Chiotti, L., Olszewski, D. I., Dibble, H. L., McPherron, S. R., Schurmans, U., & Smith, J. R. (2007). Paleolithic Abydos: reconstructing individual behaviors across the high desert landscape. In Z. A. Hawass & J. Richards (Eds.), *The Archaeology and Art of Ancient Egypt: Essays in Honor of David B. O'Connor* (pp. 169–183). Supreme Council of Antiquities Press (distributed by American University in Cairo Press).

Clark, J. D. (1988). The Middle Stone Age of East Africa and the beginnings of regional identity. *Journal of World Prehistory, 2*, 235–305.

Crassard, R., & Hilbert, Y. H. (2013). A Nubian Complex site from central Arabia: Implications for Levallois taxonomy and human dispersals during the Upper Pleistocene. *PLoS ONE, 8*(7), e69221.

Crassard, R., & Thiébaut, C. (2011). *Levallois points production from eastern Yemen and some comparisons with assemblages from East-Africa*. Presses Universitaires de Liège.

Crassard, R., Petraglia, M. D., Drake, N. A., Breeze, P., Gratuze, B., Alsharekh, A., et al. (2013). Middle Palaeolithic and Neolithic occupations around Mundafan palaeolake, Saudi Arabia: Implications for climate change and human dispersals. *PLoS ONE, 8*(7), e69665.

Demidenko, Y. E., & Usik, V. I. (2003). Into the mind of the maker: Refitting study and technological reconstruction. In D. O. Henry (Ed.), *Neanderthals in the Levant: Behavioural Organization and the Beginnings of Human Modernity* (pp. 107–155). Continuum.

Derricourt, R. (2005). Getting "Out of Africa": Sea crossings, land crossings and culture in the hominin migrations. *Journal of World Prehistory, 19*, 119–132.

Douze, K., & Delagnes, A. (2016). The pattern of emergence of a Middle Stone Age tradition at Gademotta and Kulkuletti (Ethiopia) through convergent tool and point technologies. *Journal of Human Evolution, 91*, 93–121.

Drake, N. A., Breeze, P., & Parker, A. (2013). Palaeoclimate in the Saharan and Arabian Deserts during the Middle Palaeolithic and the potential for hominin dispersals. *Quaternary International, 300*, 48–61.

Foley, R. A., Maíllo-Fernández, J. M., & Lahr, M. M. (2013). The Middle Stone Age of the central Sahara: Biogeographical opportunities and technological strategies in later human evolution. *Quaternary International, 300*, 153–170.

Frumkin, A., Bar-Yosef, O., & Schwarcz, H. P. (2011). Possible paleohydrologic and paleoclimatic effects on hominin migration and occupation of the Levantine Middle Paleolithic. *Journal of Human Evolution, 60*(4), 437–451.

Galbraith, R. F., & Roberts, R. G. (2012). Statistical aspects of equivalent dose and error calculation and display in OSL dating: An overview and some recommendations. *Quaternary Geochronology, 11*, 1–27. https://doi.org/10.1016/j.quageo.2012.04.020

Goder-Goldberger, M. (2020). The Middle to Upper Palaeolithic transition as seen from Far'ah II and Boker Tachtit, Israel. In A. Leplongeon, M. Goder-Goldberger, & D. Pleurdeau (Eds.), *Not just a corridor: Human occupation on the Nile Valley and neighbouring regions between 75,000 and 15,000 years ago* (pp. 221–237). Publications scientifiques du Muséum national d'Histoire naturelle Paris.

Goder-Goldberger, M. (2014). Lithic variability along the Middle Paleolithic dispersal routes of modern humans' Out of Africa' (Unpublished doctoral dissertation). Hebrew University of Jerusalem.

Goder-Goldberger, M., & Bar-Matthews, M. (2019). Novel chronocultural constraints for the Middle Paleolithic site of Rosh Ein Mor (D15), Israel. *Journal of Archaeological Science: Reports, 24*, 102–114.

Goder-Goldberger, M., Gubenko, N., & Hovers, E. (2016). "Diffusion with modifications": Nubian assemblages in the central Negev highlands of Israel and their implications for Middle Paleolithic inter-regional interactions. *Quaternary International, 408*, 121–139.

Goder-Goldberger, M., Ginat, H., Ragolski, G., Seri, G., & Abadi, I. (2017). Middle Palaeolithic find spots with Nubian cores from the Southern Negev and the Arava, Israel. *Journal of Lithic Studies, 4*(1). https://doi.org/10.2218/jls.v4i1.1688

Goder-Goldberger, M., Crouvi, O., Caracuta, V., Horwitz, L. K., Neumann, F. H., Porat, N., et al. (2020). The Middle to Upper Paleolithic transition in the southern Levant: New insights from the late Middle Paleolithic site of Far'ah II. *Israel. Quaternary Science Reviews, 237*, 106304.

Goder-Goldberger, M., Barzilai, O., & Boaretto, E. (2023). Innovative technological practices and their role in the emergence of initial Upper Paleolithic technologies: A view from Boker Tachtit. *Journal of Paleolithic Archaeology, 6*(1), 11.

Goder-Goldberger, M., & Malinsky-Buller, A. (2022). The Initial Upper Paleolithic and Its Place Within the Middle-to-Upper Paleolithic Transition of Southwest Asia: What Hides Behind the Curtain of Taxonomies? *Journal of Paleolithic Archaeology, 5*(1), 2.

Goren-Inbar, N., & Belfer-Cohen, A. (1998). The technological abilities of the Levantine Mousterians. In T. Akazawa, K. Aoki, & O.

Bar-Yosef (Eds.), *Neandertals and Modern Humans in Western Asia* (pp. 205–221). Plenum Press.

Goren-Inbar, N. (1990). The lithic assemblages. In N. Goren-Inbar (Ed.), *Quneitra: A Mousterian Site on the Golan Heights* (vol. 31, pp. 61–149). Institute of Archaeology, The Hebrew University of Jerusalem.

Goring-Morris, A. N., Marder, O., Davidzon, A., & Ibrahim, F. (1998). Putting Humpty together again: Preliminary observations on refitting studies in the eastern Mediterranean. In S. Milloiken (Ed.), *The organization of lithic technology in late glacial and early postglacial Europe* (pp. 149–182). Archaeopress.

Groucutt, H. S. (2014). Middle Palaeolithic point technology, with a focus on the site of Tor Faraj (Jordan, MIS 3). *Quaternary International, 350*, 205–226.

Groucutt, H. S., & Rose, J. I. (2023). Standardization of Nubian Levallois Technology in Dhofar, Southern Arabia. *Lithic Technology, 48*(4), 1–15. https://doi.org/10.1080/01977261.2023.2211878

Groucutt, H. S. (2020). Culture and convergence: The curious case of the Nubian Complex. In H. S. Groucutt (Ed.), *Culture History and Convergent Evolution: Can we Detect Populations in Prehistory?* (pp. 55–86). Springer.

Guichard, J., & Guichard, G. (1965). The Early and Middle Palaeolithic of Nubia: A preliminary report. In F. Wendorf (Ed.), *Contributions to the prehistory of Nubia* (pp. 57–116). Fort Burgwin and Southern Methodist University Press.

Hallinan, E., & Shaw, M. (2015). A new Middle Stone Age industry in the Tanwka Karoo, Northern Cape Province. *South Africa. Antiquity Project Gallery, 89*, 344.

Hallinan, E., & Shaw, M. (2020). Nubian Levallois reduction strategies in the Tankwa Karoo. *South Africa. Plos One, 15*(10), e0241068.

Hallinan, E., Barzilai, O., Bicho, N., Cascalheira, J., Demidenko, Y., Goder-Goldberger, M., et al. (2022a). No direct evidence for the presence of Nubian Levallois technology and its association with Neanderthals at Shukbah Cave. *Scientific Reports, 12*(1), 1–8.

Hallinan, E., Barzilai, O., Beshkani, A., Cascalheira, J., Demidenko, Y. E., Goder-Goldberger, M., et al. (2022b). The nature of Nubian: Developing current global perspectives on Nubian Levallois technology and the Nubian complex. *Evolutionary Anthropology, 31*(5), 227–232.

Henry, D. O. (1995). The influence of mobility levels on Levallois point production, Late Levantine Mousterian, Southern Jordan. In H. L. Dibble & O. Bar-Yosef (Eds.), *The definition and interpretation of Levallois technology* (pp. 185–200). Prehistory Press.

Henry, D. O. (2003). Human behavior and the Stone Tools from Tor Faraj. In D. O. Henry (Ed.), *Neanderthals in the Levant: Behavioural organization and the beginnings of human modernity* (pp. 60–85). Continuum.

Hilbert, Y. H., Crassard, R., Rose, J. I., Geiling, J. M., & Usik, V. I. (2016). Technological homogeneity within the Arabian Nubian Complex: Comparing chert and quartzite assemblages from central and southern Arabia. *Journal of Lithic Studies, 3*(2), 411–437.

Hilbert, Y. H., Crassard, R., Charloux, G., & Loreto, R. (2017). Nubian technology in northern Arabia: Impact on interregional variability of Middle Paleolithic industries. *Quaternary International, 435*, 77–93.

Hovers, E. (1998). The lithic assemblage of Amud Cave, implications for understanding the end of the Mousterian in the Levant. In T. Akazawa, K. Aoki, & O. Bar-Yosef (Eds.), *Neandertals and modern humans in western Asia* (pp. 143–163). Plenum Press.

Hovers, E. (2009). *The lithic assemblages of Qafzeh Cave*. Oxford University Press.

Hovers, E., & Belfer-Cohen, A. (2013). On variability and complexity: Lessons from the Levantine Middle Paleolithic record. *Current Anthropology, 54*(S8), S337–S357.

Hovers, E. (1997). *Variability of lithic assemblages and settlement patterns in the Levantine Middle Paleolithic: Implications for the development of human behavior* (Unpublished doctoral dissertation). The Hebrew University of Jerusalem.

Klein, R. G. (2009). *The human career: Human biological and cultural origins* (3rd ed.). University of Chicago Press.

Krakovsky, M. (2017). *Decision making process and technology: Is there a "traditional" operational sequence?* The Hebrew University of Jerusalem, Jerusalem.

Kuhn, S. L. (1995). *Mousterian lithic technology: An ecological perspective*. Princeton University Press.

Lahr, M. M., & Foley, R. (1994). Multiple dispersals and modern human origins. *Evolutionary Anthropology: Issues, News, and Reviews, 3*(2), 48–60.

Laughlin, J. P., & Kelly, R. L. (2010). Experimental analysis of the practical limits of lithic refitting. *Journal of Archaeological Science, 37*(2), 427–433.

Marks, A. E. (1968). The Mousterian industries of Nubia. In F. Wendorf (Ed.), *The Prehistory of Nubia* (Vol. I, pp. 194–314). Fort Burgwin and Southern Methodist University Press.

Marks, A. E., & Kaufman, D. (1983). Boker Tachtit: The artifacts. In A. E. Marks (Ed.), *Prehistory and Paleoenvironments of the Central Negev, Israel* (Vol. III, pp. 69–126). Southern Methodist University (SMU) Press.

Marks, A. E., & Rose, J. I. (2014). A century of research into the origins of the Upper Palaeolithic in the Levant. In M. Otte (Ed.), *Neandertal/Cro-Magnon La rencontre* (vol. 111, pp. 221–266). Errance.

Martin-Viveros, J. I., Oron, M., Ollé, A., Chacón, M. G., & Sharon, G. (2023). Butchering knives and hafting at the Late Middle Paleolithic open-air site of Nahal Mahanayeem Outlet (NMO), Israel. *Scientific Reports, 13*, 112. https://doi.org/10.1038/s41598-022-27321-5

Masojć, M., Kusiak, J., Standzikowski, K., Paner, H., Kuc, M., Parafiniuk, M., & Szmit, M. (2017). OSL/IRSL estimation for Nubian Complex Middle Stone Age settlement from Bayuda Desert in Sudan. *Journal of Archaeological Science: Reports, 16*, 391–396.

Masojć, M. (2010). First note on the discovery of a stratified Palaeolithic site from the Bayuda Desert (N-Sudan) within MAG concession. Der Antike Sudan. *Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e. V., 21*, 63–70.

Meignen, L. (1995). Levallois lithic production systems in the Middle Paleolithic of the Near East: The case of the unidirectional method. In H. L. Dibble & O. Bar-Yosef (Eds.), *The definition and interpretation of Levallois technology* (pp. 361–380). Prehistory Press.

Meignen, L. (1998). Hayonim Cave lithic assemblages in the context of the Near Eastern Middle Paleolithic. In T. Akazawa, K. Aoki, & O. Bar-Yosef (Eds.), *Neandertals and modern humans in Western Asia* (pp. 165–180). Plenum Press.

Meignen, L. (2012). Levantine perspectives on the Middle to Upper Paleolithic "transition." *Archaeology, Ethnology and Anthropology of Eurasia, 40*(3), 12–21.

Meignen, L. (2019). The Mousterian lithic assemblages from Kebara cave. In O. Bar-Yosef (Ed.), *The Middle and Upper Paleolithic Archaeology, Part II* (pp. 1–147). Peabody Museum Press.

Meignen, L. (2011). The contribution of Hayonim cave assemblages to the understanding of the so-called Early Levantine Mousterian. In J.-M. L. Tensorer, R. Ragher, & M. Otte (Eds.), *The Lower and Middle Paleolithic* in *the Middle East and neighboring regions* (Vol. 126, pp. 85–100). Liège: ERAUL.

Mercier, N., Valladas, H., Froget, L., Joron, J.-L., Vermeersch, P. M., Van Peer, P., & Moeyersons, J. (1999). Thermoluminescence dating of a middle palaeolithic occupation at Sodmein Cave,

Red Sea Mountains (Egypt). *Journal of Archaeological Science, 26*(11), 1339–1345.
Morgan, L. E., & Renne, P. R. (2008). Diachronous dawn of Africa's Middle Stone Age: New 40Ar/39Ar ages from the Ethiopian Rift. *Geology, 36*(12), 967–970.
Munday, F. C. (1976). Intersite variability in the Mousterian occupation of the Avdat/Aqev area. In A. E. Marks (Ed.), *Prehistory and Paleoenvironments of the Central Negev, Israel, Vol. I, The Avdat/Aqev Area. Part 1.* (Vol. 1, pp. 57–68). Dallas, Texas: Southern Methodist University Press.
Murray, A. S., & Wintle, A. G. (2000). Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. *Radiation Measurements, 32*(1), 57–73. https://doi.org/10.1016/S1350-4487(99)00253-X
Olszewski, D. I., Dibble, H. L., McPherron, S. P., Schurmans, U. A., Chiotti, L., & Smith, J. R. (2010). Nubian Complex strategies in the Egyptian high desert. *Journal of Human Evolution, 59*(2), 188–201.
Oron, M., Roskin, J., Avni, Y., Porat, N., Aladjem, E., Yegorov, D., Vardi, J., & Hovers, E. (2023). A conceptual model of multiscale formation processes of open-air Middle Paleolithic sites in the arid Negev desert, Israel. *Quaternary Research, 116*, 162–180. https://doi.org/10.1017/qua.2023.31
Otte, M. (1995). The nature of Levallois. In H. L. Dibble & O. Bar-Yosef (Eds.), *The Definition and Interpretation of Levallois Technology* (pp. 117–123). Prehistory Press.
Parker, A. G., & Rose, J. I. (2008). Climate change and human origins in southern Arabia. *Proceedings of the seminar for Arabian studies, 38*, 25–42.
Prévost, M., & Zaidner, Y. (2020). New insights into early MIS 5 lithic technological behavior in the Levant: Nesher Ramla, Israel as a case study. *PLoS ONE, 15*(4), e0231109.
Richter, J., Hauck, T., Vogelsang, R., Widlok, T., Le Tensorer, J.-M., & Schmid, P. (2012). "Contextual areas" of early Homo sapiens and their significance for human dispersal from Africa into Eurasia between 200 ka and 70 ka. *Quaternary International, 274*, 5–24.
Ronen, A. (1974). *Tirat-Carmel: A Mousterian open-air site in Israel*. Institute of Archaeology, Tel-Aviv University.
Rose, J. I., & Marks, A. E. (2014). "Out of Arabia" and the Middle-Upper Palaeolithic transition in the southern Levant. *Quartär, 61*, 49–85.
Rose, J. I., Usik, V. I., Marks, A. E., Hilbert, Y. H., Galletti, C. S., Parton, A., et al. (2011). The Nubian complex of Dhofar, Oman: An African middle stone age industry in southern Arabia. *PLoS ONE, 6*(11), e28239.
Rose, J. (2007). The Arabian Corridor Migration Model: archaeological evidence for hominin dispersals into Oman during the Middle and Upper Pleistocene. *Proceedings of the Seminar for Arabian Studies, 37*, 219–237.
Rose, J. I. (2022). Out of Arabia (70–50 Ka). In J. I. Rose (Ed.), *An Introduction to Human Prehistory in Arabia: The Lost World of the Southern Crescent* (pp. 213–229). Springer. https://doi.org/10.1007/978-3-030-95667-7
Rosenberg, T. M., Preusser, F., Fleitmann, D., Schwalb, A., Penkman, K., Schmid, T. W., et al. (2011). Humid periods in southern Arabia: Windows of opportunity for modern human dispersal. *Geology, 39*(12), 1115–1118.
Scerri, E. M., Drake, N. A., Jennings, R., & Groucutt, H. S. (2014). Earliest evidence for the structure of Homo sapiens populations in Africa. *Quaternary Science Reviews, 101*, 207–216.
Schmidt, C., Kindermann, K., Van Peer, P., & Bubenzer, O. (2015). Multi-emission luminescence dating of heated chert from the Middle Stone Age sequence at Sodmein Cave (Red Sea Mountains, Egypt). *Journal of Archaeological Science, 63*, 94–103.
Seligman, C. G. (1921). The older Palaeolithic Age in Egypt. *The Journal of the Royal Anthropological Institute of Great Britain and Ireland, 51*, 115–153.
Sharon, G., & Oron, M. (2014). The lithic tool arsenal of a Mousterian hunter. *Quaternary International, 331*, 167–185.
Shea, J. J. (2003). The middle paleolithic of the east Mediterranean Levant. *Journal of World Prehistory, 17*(4), 313–394.
Shimelmitz, R., & Kuhn, S. L. (2018). The toolkit in the core: There is more to Levallois production than predetermination. *Quaternary International, 464*, 81–91.
Smith, J. R., Giegengack, R., Schwarcz, H. P., McDonald, M. M., Kleindienst, M. R., Hawkins, A. L., & Churcher, C. S. (2004). A reconstruction of Quaternary pluvial environments and human occupations using stratigraphy and geochronology of fossil-spring tufas, Kharga Oasis. *Egypt. Geoarchaeology: An International Journal, 19*(5), 407–439.
Smith, J. R., Hawkins, A. L., Asmerom, Y., Polyak, V., & Giegengack, R. (2007). New age constraints on the middle stone age occupations of Kharga Oasis, Western Desert. *Egypt. Journal of Human Evolution, 52*(6), 690–701.
Soressi, M., & Geneste, J.-M. (2011). The history and efficacy of the chaîne opératoire approach to lithic analysis: studying techniques to reveal past societies in an evolutionary perspective. *Paleo-Anthropology, 2011*, 334–350. https://doi.org/10.4207/PA.2011.ART63
Tryon, C. A., Peppe, D. J., Faith, J. T., Van Plantinga, A., Nightingale, S., Ogondo, J., & Fox, D. I. (2012). Late Pleistocene artefacts and fauna from Rusinga and Mfangano islands, lake Victoria. *Kenya. Azania, 47*(1), 14–38.
Usik, V. I., Rose, J. I., Hilbert, Y. H., Van Peer, P., & Marks, A. E. (2013). Nubian Complex reduction strategies in Dhofar, southern Oman. *Quaternary International, 300*, 244–266.
Vaks, A., Bar-Matthews, M., Matthews, A., Ayalon, A., & Frumkin, A. (2010). Middle-Late Quaternary paleoclimate of northern margins of the Saharan-Arabian Desert: Reconstruction from speleothems of Negev Desert, Israel. *Quaternary Science Reviews, 29*(19), 2647–2662.
Vaks, A., Woodhead, J., Bar-Matthews, M., Ayalon, A., Cliff, R. A., Zilberman, T., et al. (2013). Pliocene-Pleistocene climate of the northern margin of Saharan-Arabian Desert recorded in speleothems from the Negev Desert, Israel. *Earth and Planetary Science Letters, 368*, 88–100.
Van Peer, P. (1992). The Levallois reduction strategy. *Monographs inWorld Prehistory, 13*, 92–94.
Van Peer, P. (1998). The Nile corridor and the out-of-Africa model. *Current Anthropology, 39*, 117–140.
Van Peer, P. (2000). Makhadma 6, a Nubian complex site. In P. M. Vermeersch (Ed.), *Palaeolithic Living Sites in Upper and Middle Egypt* (pp. 91–100). Leuven University Press.
Van Peer, P. (2001). The Nubian complex settlement system in Northeast Africa. In N. J. Conard (Ed.), *Settlement Dynamics of the Middle Paleolithic and Middle Stone Age* (pp. 45–63). Kerns Verlag.
Van Peer, P. (2004). Did Middle Stone Age moderns of sub-Saharan African descent trigger an Upper Paleolithic revolution in the lower Nile Valley? *Anthropologie (1962-), 42*(3), 215–226.
Van Peer, P., & Vermeersch, P. M. (2000). The Nubian Complex and the dispersal of modern humans in North Africa. In L. Krzyzaniak, K. kroeper, & M. Kobusiewicz (Eds.), *Recent Research into the Stone Age of Northeastern Africa* (vol. 7, pp. 47–60). Poznań Archaeological Museum.
Van Peer, P., & Vermeersch, P. M. (2007). The Place of Northeast Africa in the early history of modern humans: New data and interpretations on the Middle Stone Age. In P. Mellars, K. Boyle, O. Bar-Yosef, & C. Stringer (Eds.), *Rethinking the Human*

Revolution (pp. 187–198). McDonald Institute for Archaeological Research.

Van Peer, P., Fullagar, R., Stokes, S., Bailey, R. M., Moeyersons, J., Steenhoudt, F., et al. (2003). The Early to Middle Stone Age transition and the emergence of modern human behaviour at site 8-B-11, Sai Island, Sudan. *Journal of Human Evolution, 45*(2), 187–193.

Van Peer, P., Vermeersch, P. M., & Paulissen, E. (2010). *Chert quarrying, lithic technology and a modern human burial at the Palaeolithic site of Taramsa 1*. Leuven University Press.

Vermeersch, P. M. (2002). *Palaeolithic quarrying sites in Upper and Middle Egypt*. Leuven University Press.

Vermeersch, P. M., & Van Peer, P. (2002). Conclusions on Palaeolithic chert extraction in Egypt. In P. M. Vermeersch (Ed.), *Palaeolithic quarrying sites in Upper and Middle Egypt* (pp. 353–359). Leuven University Press.

Villa, P., Delagnes, A., & Wadley, L. (2005). A late middle stone age artifact assemblage from Sibudu (KwaZulu-Natal): Comparisons with the European middle Paleolithic. *Journal of Archaeological Science, 32*(3), 399–422.

Volkman, P. (1983). Boker Tachtit: Core reconstructions. In A. E. Marks (Ed.), *Prehistory and Paleoenvironments of the Central Negev, Israel* (Vol. III, pp. 127–190). Southern Methodist University (SMU) Press.

Wendorf, F., & Schild, R. (1974). *Middle Stone Age Sequence from the Central Rift Valley, Ethiopia*. Warsaw: Institute of the History of Material Culture, Polish Academy of Sciences.

Will, M., Mackay, A., & Phillips, N. (2015). Implications of Nubian-like core reduction systems in southern Africa for the identification of early modern human dispersals. *PLoS ONE, 10*(6), e0131824.

Wurz, S., & Van Peer, P. (2012). Out of Africa, the Nile Valley and the Northern route. *The South African Archaeological Bulletin, 67*(196), 168–179.

Zaidner, Y., & Weinstein-Evron, M. (2020). The emergence of the Levallois technology in the Levant: A view from the Early Middle Paleolithic site of Misliya Cave. *Israel. Journal of Human Evolution, 144*, 102785. https://doi.org/10.1016/j.jhevol.2020.102785

Zaidner, Y., Centi, L., Prévost, M., Mercier, N., Falguères, C., Guérin, G., et al. (2021). Middle Pleistocene Homo behavior and culture at 140,000 to 120,000 years ago and interactions with Homo sapiens. *Science, 372*(6549), 1429–1433.

Zilberman, E., & Calvo, R. (2013). Remnants of Miocene fluvial sediments in the Negev Desert, Israel, and the Jordanian Plateau: Evidence for an extensive subsiding basin in the northwestern margins of the Arabian plate. *Journal of African Earth Sciences, 82*, 33–53.