BRILL

JOURNAL OF AFRICAN ARCHAEOLOGY 23 (2025) 205–228

JAA

brill.com/jaa

Technological Variability at Mochena Borago Rockshelter, Ethiopia: a Contribution to Understanding MIS 3 Cultural Change in the Horn of Africa

Hannah Rohringer | ORCID: 0000-0001-7526-8376
Austrian Archaeological Institute, Austrian Academy of Sciences, Wien, Austria
Institute of Prehistoric Archaeology, University of Cologne, Köln, Germany
Corresponding author
hannah.rohringer@oeaw.ac.at

Steven A. Brandt
College of Liberal Arts & Sciences, University of Florida, Gainesville, FL, USA
sbrandt@ufl.edu

Elisabeth A. Hildebrand | ORCID: 0000-0002-4071-6068
Department of Anthropology, Stony Brook University, Stony Brook, NY, USA
elisabeth.hildebrand@stonybrook.edu

Ralf Vogelsang | ORCID: 0000-0001-7280-5324
Institute of Prehistoric Archaeology, University of Cologne, Köln, Germany
r.vogelsang@uni-koeln.de

Received 26 July 2024 | Accepted 28 October 2025 | Published online 16 December 2025

Abstract

Non-Levallois core reduction strategies for producing elongated flakes or blades appear early in the African Middle Stone Age (MSA) but have rarely been studied in detail. In this paper we present a detailed comparative analysis of non-Levallois lithic technologies at Mochena Borago Rockshelter, SW Ethiopia, from strata dating to around 46 to 36 ka, with a focus on the technological solutions and quality of blade production. Although there is an increase in the frequency of laminar production as well as improved technological capabilities over time, the numerical importance of laminar products remains small. Only the youngest assemblages (~39–36 ka) show the beginning of a technological transformation, with clear features of intentional blade production. Several factors may explain this transformative process: functional changes in tool production, raw material availability, climatic change, cultural developments and/or population movements.

Keywords

Ethiopia – Middle Stone Age – Levallois – MIS 3 – blade production – out of Africa

1 Introduction

The Late Pleistocene in eastern Africa is a crucial time period concurring with the major dispersals of *Homo sapiens* through and out of Africa (Richter et al. 2012). Yet very little is actually known about this enigmatic timeframe, partially due to a scarcity in sites, but also due to a scarcity of in-depth technological studies of available lithic inventories (Leplongeon et al. 2023). The Middle Stone Age in general is defined by the presence of Levallois stone artifacts (Phillipson 1990). Levallois cores are biconvex with flat, often facetted platforms which allow the reduction of predetermined flakes, points, or blades. Different sub-techniques are known to either reduce preparation effort or create different final products (Boëda 1995). Levallois technology is a staple in the MSA and as

Published with license by Koninklijke Brill BV | DOI:10.1163/21915784-BJA10051
 | ISSN: 1612-1651 (print) 2191-5784 (online)

FIGURE 1 The rockshelter of Mochena Borago as seen from the north
CREDIT: H. ROHRINGER

a defining criterion it should be present at all MSA sites. Yet towards the end of that timeframe the dominance of the Levallois concept fades. The few studies available note a decrease in Levallois technology and an increase in backed items (Tryon & Faith 2013), yet those studies often offer very little data on the non-Levallois stone industries present at these sites.

The development of non-Levallois core reduction concepts in Africa over the last 200 ka (kilo annum = thousand years) offers many interpretive avenues for clarifying human behavioral change: Which non-Levallois core reduction strategies were present at different periods in different regions? How and why did they emerge? Did they change the tool spectrum? Might they have played a role in the development of the later Upper Palaeolithic industries that emerge outside of Africa?

This present work gives a detailed overview of non-Levallois core reduction strategies at Mochena Borago Rockshelter, Wolaita, Ethiopia (Fig. 1) during Marine Isotope Stage (MIS) 3 and attempts to investigate possible root causes for a development away from the long-standing, successful Levallois concept. Rockshelters, such as Mochena Borago, are particularly suitable for the discovery of stratified deposits that can clarify behavioral change. Although MSA surface sites are common in Ethiopia (de la Torre 2007; Vogelsang 2023: 76, 87), post-depositional processes such as displacement and redeposition can undermine the contextual integrity and chronological attribution of finds. Furthermore, open-air archaeological sites in the Horn of Africa are often problematic due to strong erosion by overuse of the soil, strong seasonal rainfall, and tectonic activity. Rockshelter sites avoid many of these problems, but stratified deposits dated to the MIS 3 are comparatively rare (Leplongeon et al. 2020). To date, only five rockshelters in Ethiopia are known to have extensive, artifact-bearing deposits from MIS 3: Porc Epic and Goda Buticha overlook the Afar Triangle in eastern Ethiopia (Leplongeon 2014, 2017), Mochena Borago (Brandt et al. 2012, 2017) just west of the Main Ethiopian Rift (MER), Gorgora Rockshelter at the northern shores of Lake Tana (Sahle et al. 2024), and Fincha Habera in the Bale Mountains (Ossendorf et al. 2019). Due to the strong taphonomic overprint stratified in situ open-air sites are even more rare and only the Bulbula sites (Ménard et al. 2014; Ménard & Bon 2023), Gotera GOT 10 (Spinapolice et al. 2017; Fusco et al. 2021, 2022) and Shinfa SM1 (Kappelman et al. 2024; Loewy et al. 2020) can be named in this context. All rockshelters are in high-altitude regions, whereas the open-air sites are in fluvial environments (Richter et al. 2024).

Mochena Borago Rockshelter offers ideal conditions for a diachronic study of late MIS 3 technological change due to its large number of lithic artifacts and clear stratigraphic demarcations.

1.1 *Environmental Context*

Mochena Borago Rockshelter is located on the southwestern flank of Mount Damota, an inactive stratovolcano 320 km south of Addis Ababa (Fig. 2). Rising to 2980 m above sea level, Mt. Damota lies on the eastern edge of the southwest Ethiopian highlands and overlooks Lake Abaya in the MER. Mochena Borago lies high on the southwestern

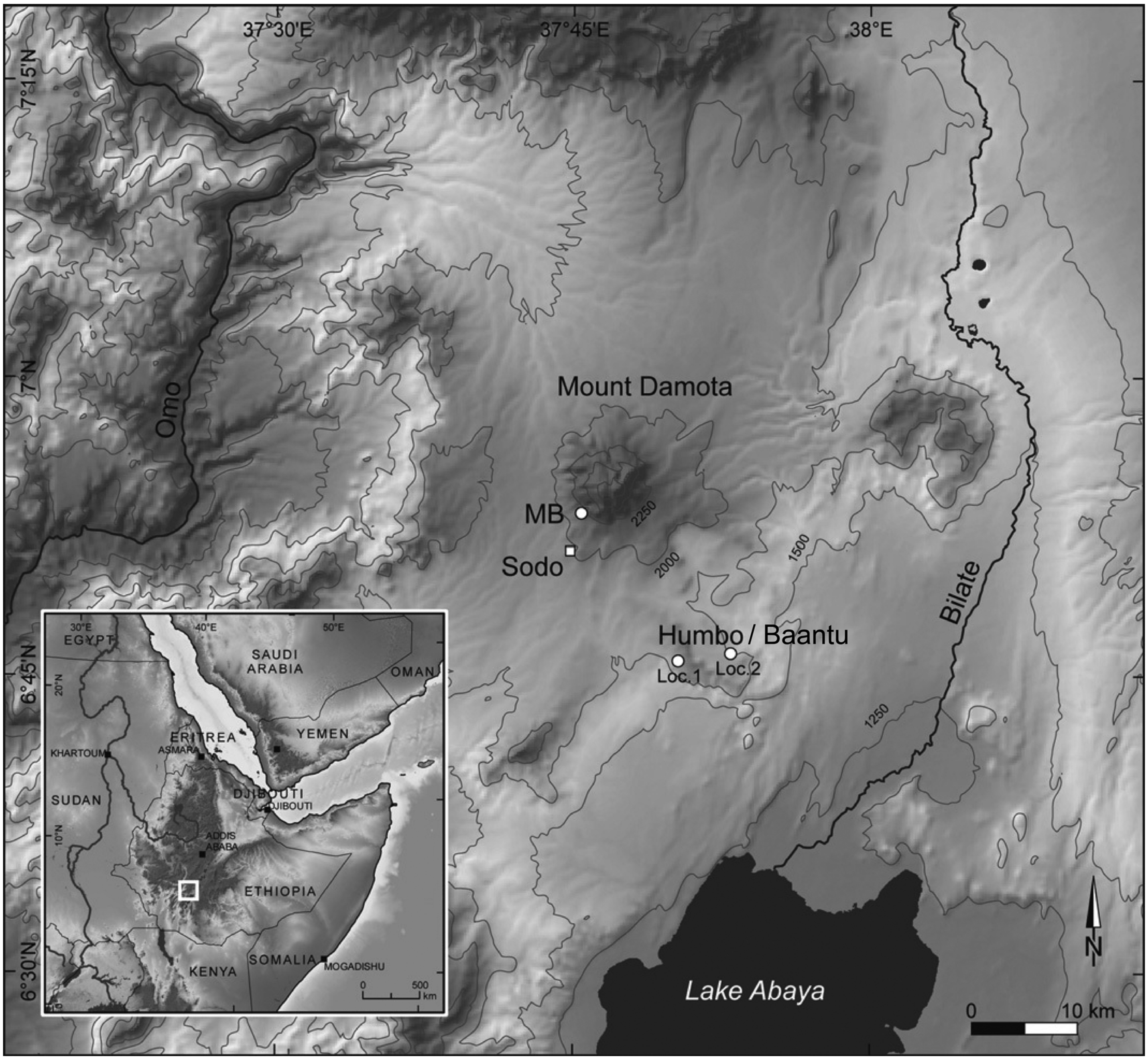

FIGURE 2 Location of Mochena Borago (MB) and the obsidian flows of Baantu/Humbo
CREDIT: ANDREAS BOLTEN, CRC806

side of the mountain at 2214 m above sea level in an area of steep slopes and highly variable topography. The rockshelter is more than 70 m wide, 12 m high and 20 m deep with a floor that is mostly flat except for occasional large boulders resulting from roof fall of unknown age (Brandt et al. 2012, 2023).

Due in part to the orographic effects of Mt. Damota, the area around Mochena Borago today receives annual precipitation of ~1400 mm/a (per annum), but rainfall decreases in the surrounding lowlands to about 750 mm/a (Brandt et al. 2012: 41–42).

Rainwater on Mount Damota drains into a complex system of ravines that have eroded the volcano's basaltic lava flows. Mochena Borago is positioned midway up a cliff at the head of one of these ravines. The rockshelter floor is 13 m above the ravine base, and 14 m below the cliff top. A seasonally variable stream flows over the cliff top in the form of a waterfall. Most of its water cascades several meters beyond the front of the rockshelter. The resulting trickle – or torrent – lands near the cliff base below and then flows down the ravine. During the rainy season and windy episodes, gusts may carry limited amounts of spray to the very front of the rockshelter, dampening the floor a meter or so near the edge.

Population pressure, intensive agriculture and severe erosion have degraded the natural landscape around MB

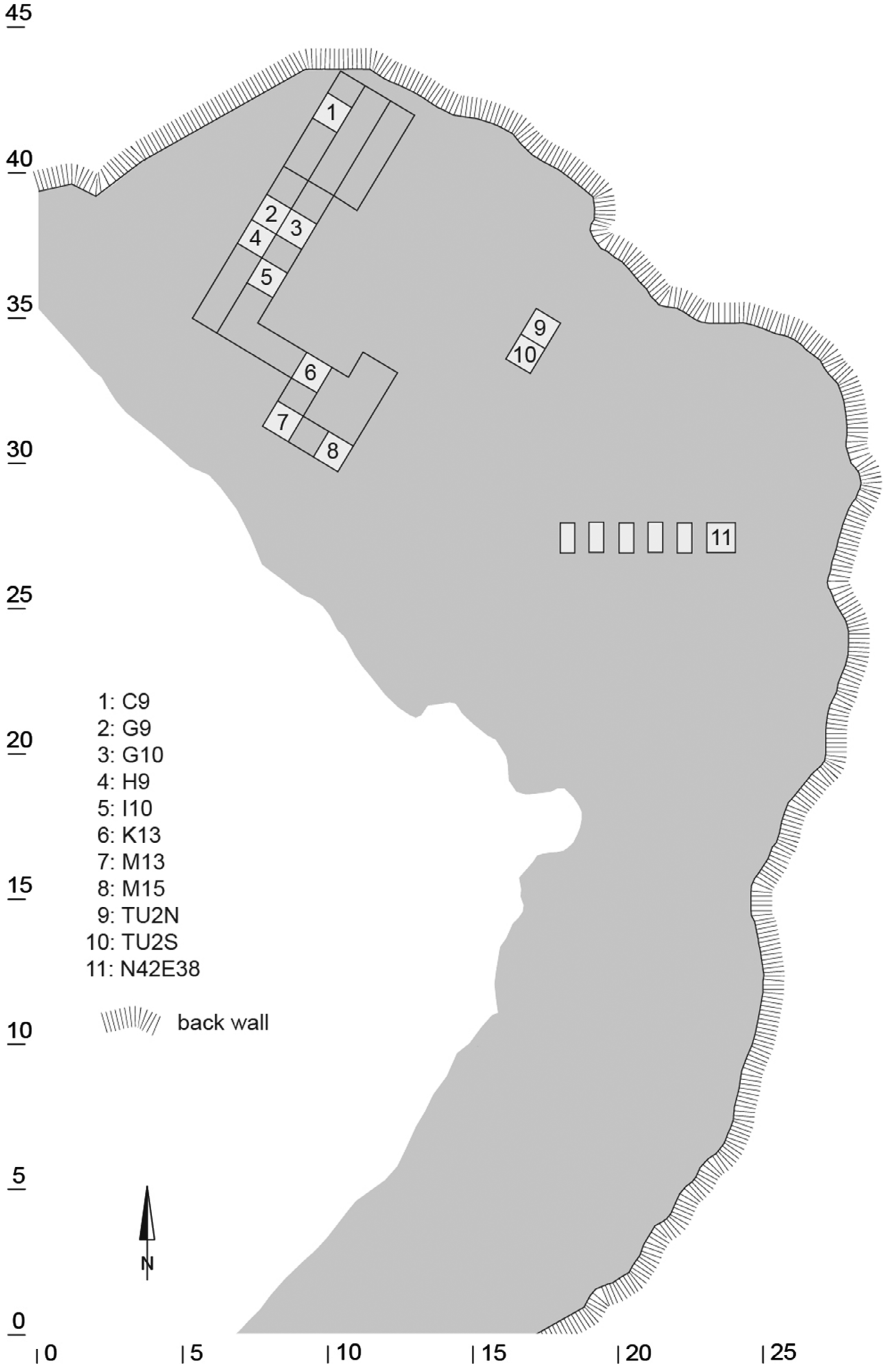

FIGURE 3 Site plan of Mochena Borago with the location of H9 (4). Depicted are all areas excavated prior to 2014.
CREDIT: R. VOGELSANG

during the past 50 years. Only the steepest slopes and deep canyon bottoms, unsuitable for agriculture, harbor natural vegetation characterized as Dry Afromontane Forest (Friis et al. 2011). Nearby lowland vegetation remnants include *Combretum-Terminalia Woodland*, and farther east in the MER one can find *Acacia-Commiphora Woodland & Bushland*. These three potential vegetation zones meet in mixed ecotonal areas, and in the past, they would have moved depending on climate shifts. One can conclude that people using Mochena Borago would have had access to a wide range of environments and plant and animal species within a day's walk (Friis et al. 2011).

1.2 *History of Excavations*

Since its initial archaeological discovery in 1995 by R. Joussaume, Mochena Borago has been investigated by two teams with different research aims. The Groupe pour l'Étude de la Protohistoire de la Corne de l'Afrique (GEPCA) focused on the study of early food production in Ethiopia (Gutherz 2000; Gutherz et al. 2002). From 2000–2002 they excavated 36 m² at four different locations (Fig. 3) in the rockshelter now labelled MB1–MB4, providing evidence of 3 m of stratified late Pleistocene and Holocene deposits. The late Pleistocene deposits drew the interest of the Southwest Ethiopian Archaeological Project (SWEAP) under the direction of S. Brandt (University of Florida) and E. Hildebrand (Stony Brook University) who carried out further excavations from 2006–2008 at MB1–MB4. From 2010–2014 SWEAP excavations were conducted in areas MB1–MB4 and MB6 in collaboration with R. Vogelsang (University of Cologne) as part of the CRC806 "Our Way to Europe." From 2015 to the present, SWEAP has continued investigations at Mochena Borago (Brandt et al. 2017, 2023).

2 Stratigraphy and Dating

Mochena Borago was formed through water percolation and retroactive erosion of a softer rock layer by the waterfall. The softer rock is possibly a non-welded ignimbrite, enclosed by harder layers, which are probably basaltic (Brandt et al. 2012: 44). Sedimentation processes within the rockshelter are complex, locally distinct, and not yet fully understood. Area MB1 (formerly the "Block Excavation area" or BXA), is the most securely dated archaeological sequence and covers most of MIS 3: > 50 ka to ~36 ka, as can be seen in the western wall of Square H9 (Fig. 4). The lowest excavated stratum in the MB1 sequence is a hard, yellowish-brown lahar, which is archaeologically sterile and at least one meter thick. Above this, three lithostratigraphic groups rich in archaeological material (T-Group, S-Group and R-Group) are separated by sterile volcanic tuffs and a lahar.

The work presented here is restricted to lithic assemblages from S-Group and R-Group, representing palimpsests of multiple occupations and geomorphological events. The S-Group deposits overlie the YBT tuff and encompass multiple layers of clayey silts about 30 cm thick. A fluvial influence is observable in the formation of one channel in square G10. S-Group layers have dense concentrations of stone artifacts, natural and processed ochre, charcoal, and poorly preserved faunal remains (Brandt et al. 2012). Bayesian analysis of a large number of charcoal radiocarbon dates shows that deposition of S-Group began sometime between 44.2 and 42.8 ka and ended between 44.0 and 41.9 ka (Brandt et al. 2017).

S-Group deposits are capped by the YBS lahar that underlie another ~30 cm of clay/silt layers forming the R-Group. Red to dark brown in color, these layers have variable frequencies of rounded to subrounded pebbles and contain high amounts of archaeological material. Micromorphological investigations point to the existence of small, shallow, often tranquil pools. Bayesian analysis of radiocarbon dates indicates R-Group deposition began between 41.2 and 40.0 ka and ended between 37.7 and 34.6 ka (Brandt et al. 2017). The R-Group represents the end of the Pleistocene sequence as it is unconformably overlain by an early Holocene tephra (BWT) indicating a major erosional phase more than 30,000 years in age.

3 Surface Condition of Lithics

While excavating S-Group and R-Group deposits, an unusually high proportion of abraded lithics intermixed with unabraded ones were observed in deposits that, at least in part, appeared to be in primary context. This interpretation is supported by features such as an intact, well-preserved hearth, and *in situ* lithics in close proximity that could be directly refitted. Consequently, all artifacts were initially classified into four types of preservation: "fresh," "rolled," "chipped," and "chipped and rolled" (Table 1). However, as analyses proceeded, it quickly became apparent that for analytical purposes the lithics would most effectively be divided into two groups: "fresh" and "damaged" (Fig. 5). Fresh artifacts included all of those with unabraded sharp edges and ridges, as well as those with minor modifications such as: 1) fresh surface scratches likely from recent excavations or transport; 2) slightly rounded edges possibly caused by chemical weathering; 3) minor chipping along the edge(s) which may have

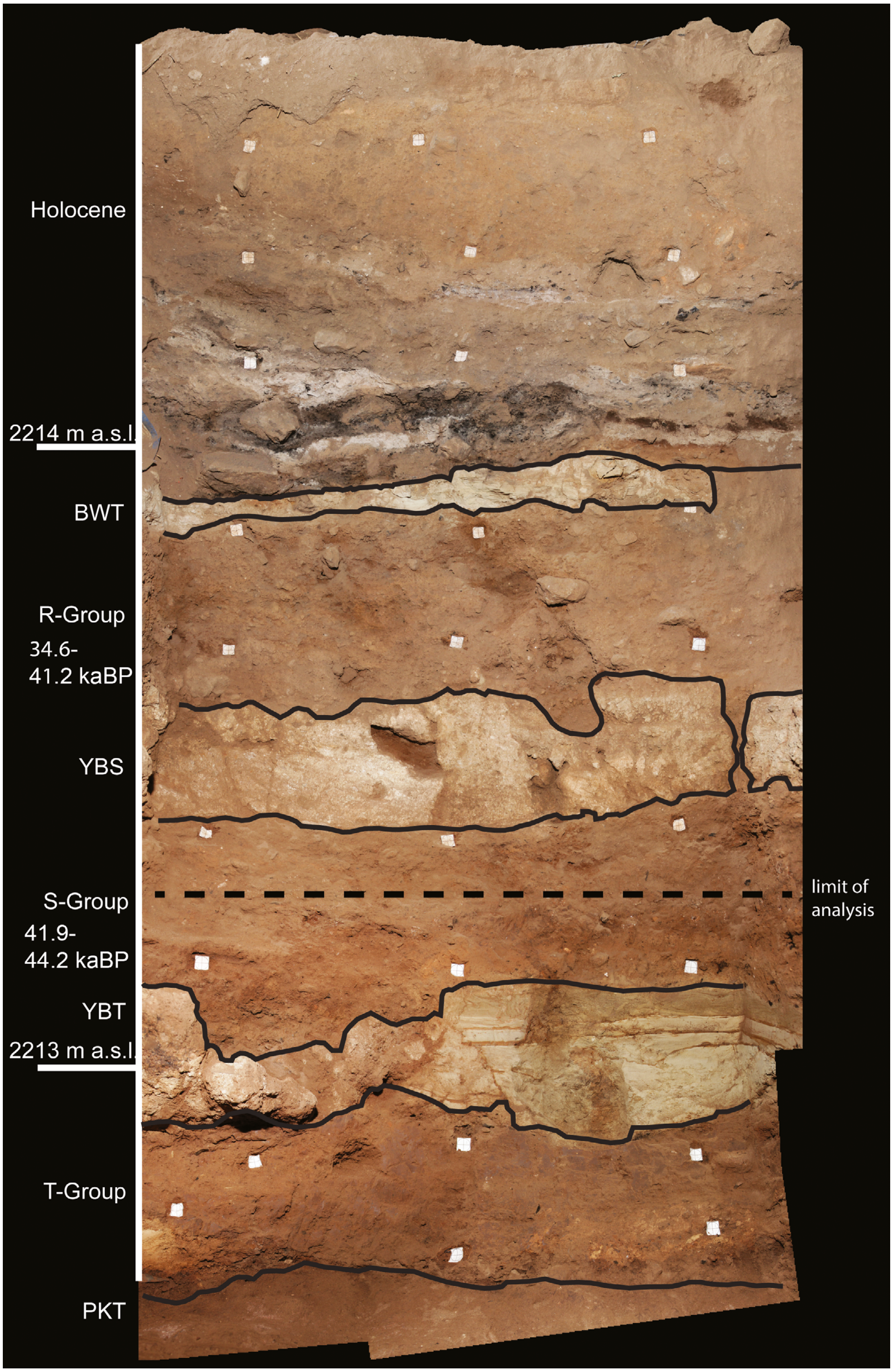

FIGURE 4 Stratigraphy of square H9. The lower dotted line represents the lower limit of the sample from S-Group.
CREDIT: H. ROHRINGER

resulted from trampling; and 4) a frequently observed thin patina possibly caused by the high acidity of the volcanic sediments. Damaged artifacts included all other forms of modification including rounded/abraded or irregularly chipped edges or dorsal ridges and strongly weathered surfaces. Almost half of all the obsidian lithics from S-Group (40%) and R-Group (45%) samples were subsequently categorized as "damaged" (Table 1).

TABLE 1 Surface condition of obsidian artifacts in H9

	R-Group		S-Group	
	n	%	n	%
Total assemblage	2544	100	1655	100
Fresh	1369	53.8	979	59.2
Chipped	611	24	405	24.5
Rolled	143	5.6	97	5.9
Rolled & chipped	391	15.4	167	10.1
Indeterminate	21	0.8	5	0.3
Unworked nodules	10	0.4	3	0.2
Total damage	1145	45	669	40.4

The origin(s) of the damaged lithics remains unclear, especially as the damaged lithics co-occur with unabraded "fresh" lithics in primary context. Furthermore, the distinctive patina observed on fresh and damaged lithics, indicates that both have experienced similar forms of weathering. Fluvial events are suspected as one causal mechanism, as are anthropogenic activities, such as trampling.

Three-dimensional plotting of all lithics recovered from the two groups by their degree of surface modification does not appear to show any significant differences in planar (Figs. 6–7) nor profile (Fig. 8) views. In planar view, both fresh and damaged lithics lie intermingled. Kernel density plots only show slight differences in both groups. In profile view, four different layers are visible: the lowermost layer forms the S-Group, while the upper three layers are combined to form the R-Group. The topmost R-Group layer includes the majority of the lithics and other finds, while the lower two layers are thinner and have lower find numbers. The lower layers include a slightly higher percentage of damaged lithics. Therefore, it is possible that several depositional events of sediments that included those damaged lithics are interstratified with deposits from occupational activity that produced the fresh lithics.

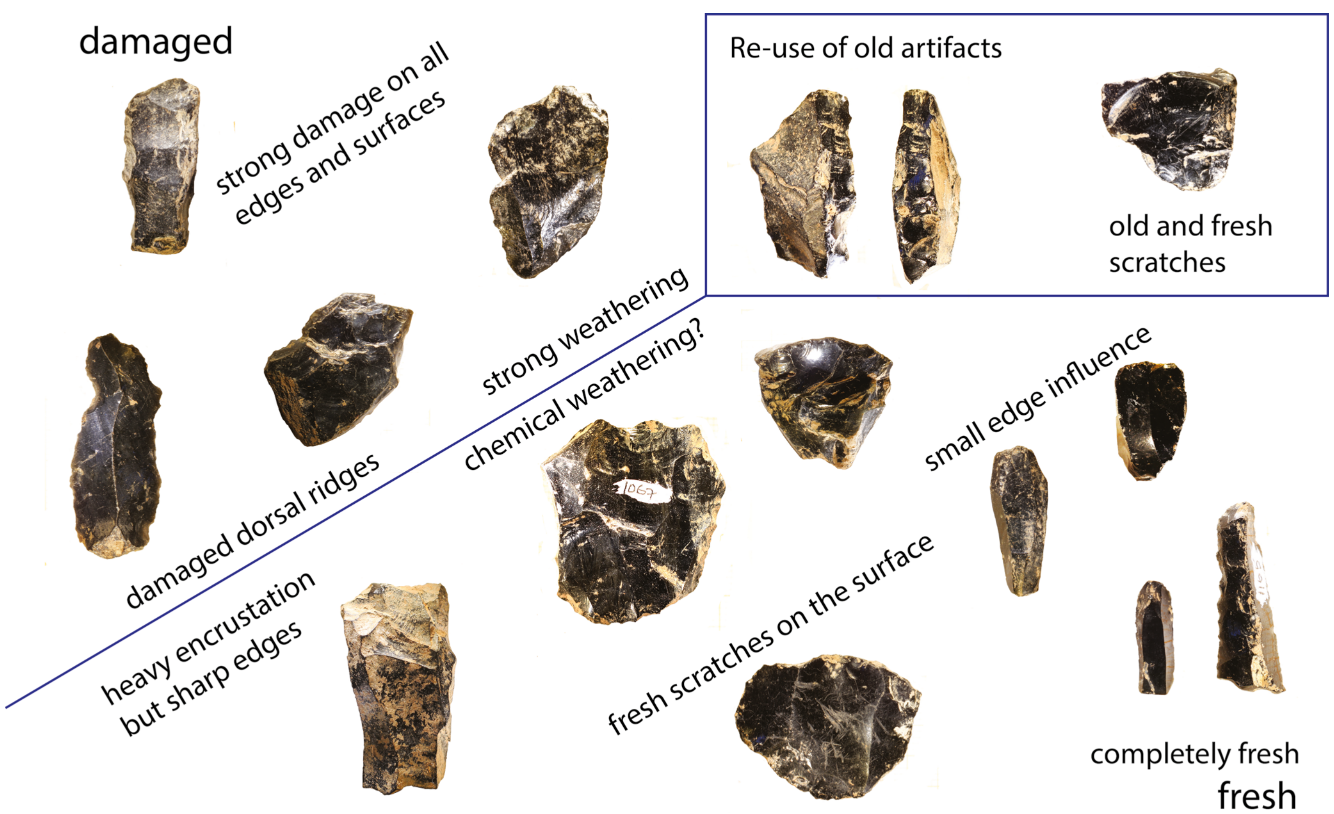

FIGURE 5 Variables used to differentiate "fresh" from "damaged" obsidian artifacts from Mochena Borago (photos not to scale)
CREDIT: H. ROHRINGER

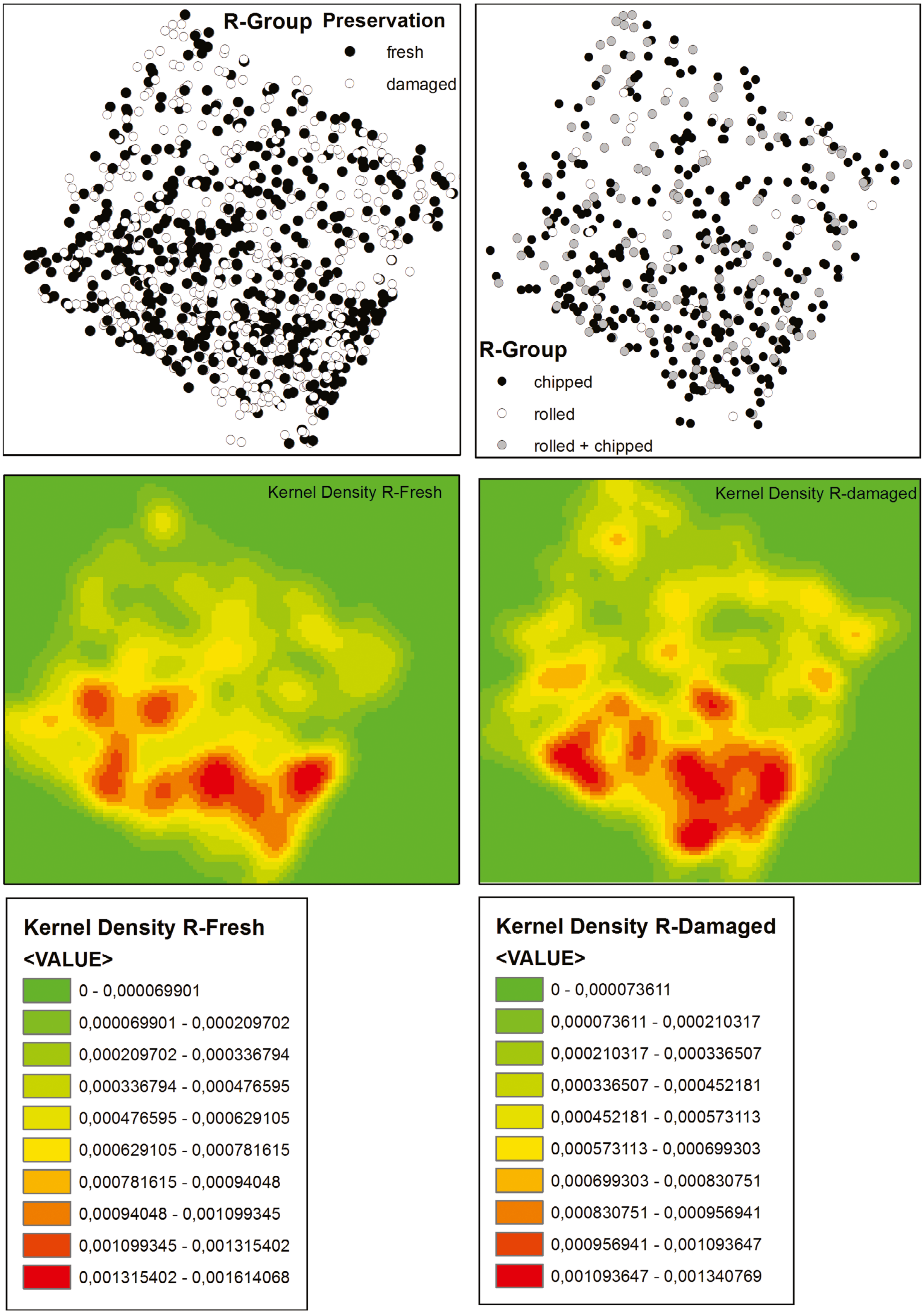

FIGURE 6 Spatial and kernel density plots for the distribution of R-Group material
CREDIT: H. ROHRINGER

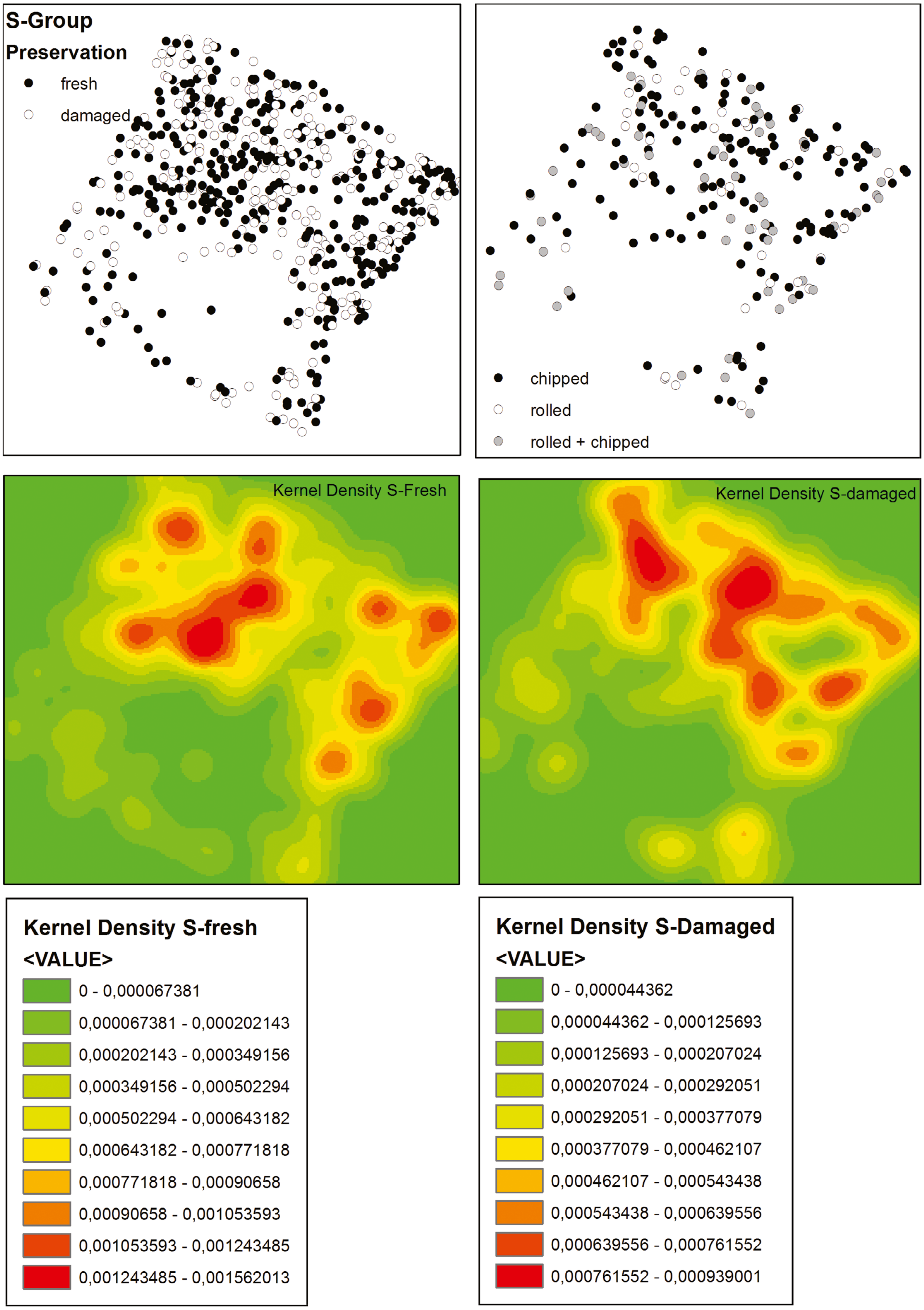

FIGURE 7 Spatial and kernel density plots for the distribution of S-Group material
CREDIT: H. ROHRINGER

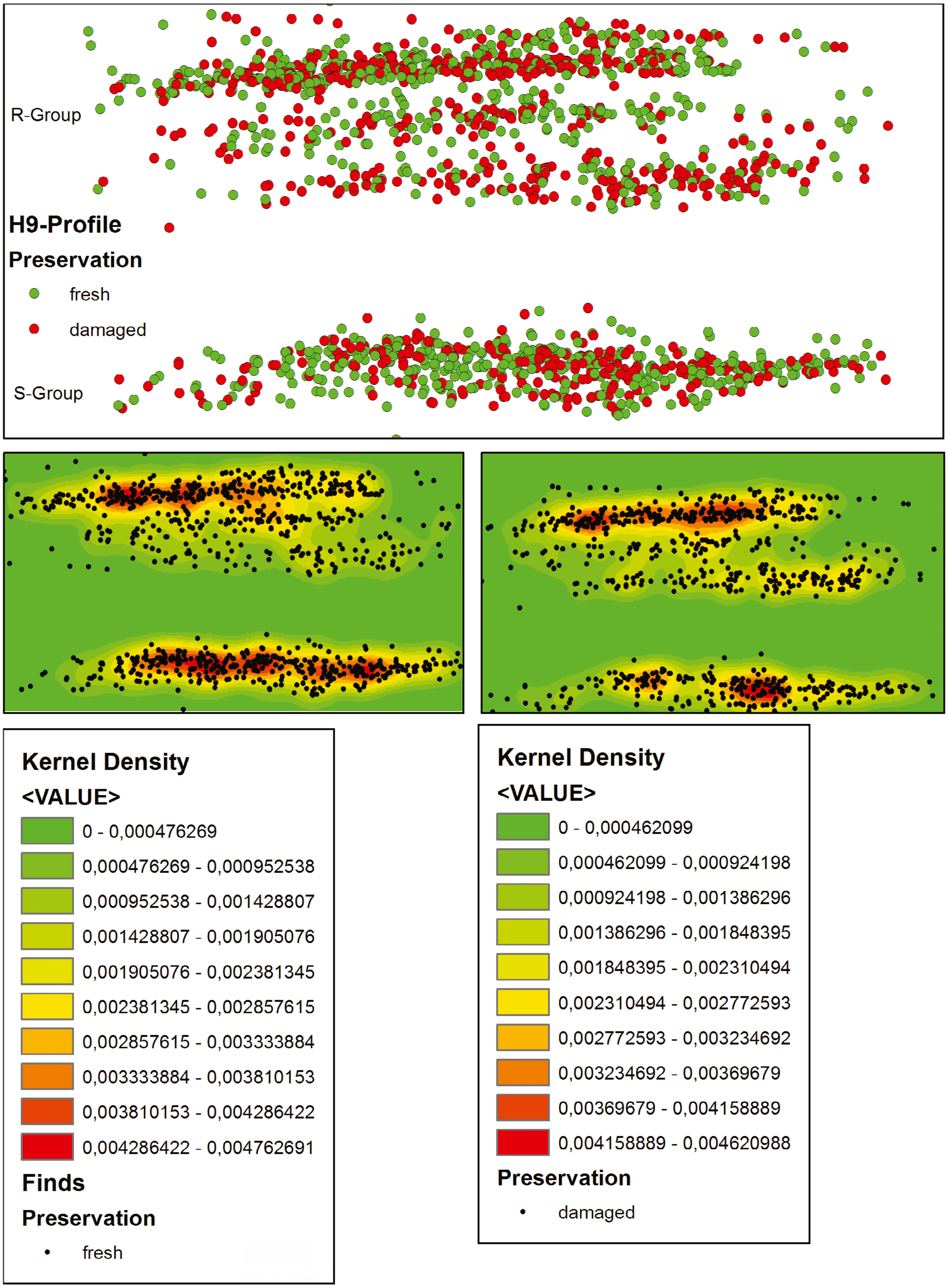

FIGURE 8 Spatial and kernel density profile plots for the distribution of R and S-Group lithics
CREDIT: H. ROHRINGER

An intensive lithic refitting study is likely to shed more light on this topic but was beyond the scope of this work. A separation of the three R-Group layers for the technological analysis was dismissed due to small sample sizes from the lower two layers and the unclear taphonomical processes that have led to this picture.

4 Lithic Techno/Typological Analytical Methods

Excavations of all three lithostratigraphic units in MB1 were confined to four 1 m² excavation units (G9, G10, H9, H10 – Fig. 3), yielding more than 40,000 lithics. Detailed analyses of T-Group lithics are ongoing (Brandt et al. 2017, 2023). Fisher (2010) reported on a small sample of S- and R-Group lithics from G10, while Bermensolo (2013) analyzed a sample from the G9 S- and R-Groups. This present study focuses upon lithic samples from unit H9 undertaken during 2012 at the Ethiopian National Museum (Parow-Souchon 2013). This study includes all lithics from R-Group deposits (n = 2544), but only those from the uppermost 20 cm of the S-Group sediments (n = 1655) due to lab time constraints (Figs. 3–4, Table 2). Although MB1 excavators recognized multiple stratigraphic layers within S-Group and R-Group, these were usually subtle and difficult to discern during excavation. Therefore, in this analysis we do not attempt to differentiate artifact assemblages from these smaller stratigraphic units, even though differentiations clearly exist. Our emphasis is rather on evaluating lithic techno/typological changes over time in lithics recovered from S-Group and R-Group units. The distinctions between these larger stratigraphic units are clear as they are separated by an archaeologically sterile volcanic layer, and the total number of lithic samples from each Group provide a better overall sample for statistical analysis and comparison.

All fresh cores, blades, core trimming elements and tools (S-Group n = 303, R-Group n = 579) were subjected to a detailed attribute analysis. Fresh flakes, chips, angular waste, and nodules were only sorted and counted by their raw material and condition of preservation. Debitage categories were defined as follows: flake proportions L/W 1:2, blade L/W 2:1, chip > 5 mm, core: minimum of three negatives, angular waste: no ventral face, no core. Blade cores in the sense of this study are dominated by blade negatives on their reduction surface, flake cores likewise by flake negatives. Levallois core determination followed Boëda (1995). Additionally, cores on flakes were recognized via the core blank. Residual cores were determined on size in relation to the other core types, multidirectional "all around" reduction and a breaking up of the conceptual characteristics of the other core types. The analysis of knapping characteristics followed Soriano and colleagues for Rose Cottage Cave, South Africa (Soriano et al. 2007), while the designation "used hammer" was based upon Pelegrin (2000). The detailed results of the attribute analysis are recorded in the supplementary tables. All illustrated lithics are also available as supplementary plates.

TABLE 2 Inventory composition of the H9 S and R-Group lithics

	R-Group		S-Group	
	n	%	n	%
Blades	73	5.3	41	4.2
Flakes	260	19	155	15.8
Cores	50	3.7	16	1.6
Flake fragments	322	23.5	253	25.8
Blade fragments	141	10.3	122	12.5
Chips	495	36.2	360	36.8
Angular waste	27	2	32	3.3
Indeterminable fragment	1	0.1		
Total	1369	53.8	979	59.2
Unworked nodules	10	0.4	3	0.2
Indeterminable	20	0.8	4	0.2
Grand total	1399		986	

4.1 *Raw Materials*

By far the dominant raw material in both stratigraphic groups is obsidian of a very fine grained, highly usable quality (Table 3). Only single pieces of obsidian show inclusions or a coarser crystalline structure. Fine-grained, homogeneous, greyish or reddish chert is rare with R-Group and absent from the S-Group sample. Whereas burning is very hard to detect on obsidian and usually only visible after exceeding the melting point (pers. observation), nearly half of the chert pieces show considerable signs of burning and suggest strong post-discard fire impact.

Portable X-Ray Fluorescence (pXRF) studies to determine the source of the obsidian show a uniform chemical signature of nearly all artifacts sampled and identify the rich obsidian flows of Baantu (formerly Humbo), about 20 km southeast of Mochena Borago (Fig. 2), as the major source region for MB1 lithics (Warren 2010; Smith et al. 2024). It is striking that despite the proximate raw material source most artifacts are extremely small, nodules are

TABLE 3 Raw material use in H9

	R-Group		S-Group	
	n	%	n	%
Obsidian	2523	99.2	1654	99.9
Chert	20	0.79	0	0
Quartz	1	0.04	0	0
Indeterminate	0	0	1	0.1
Total	2544	100	1655	100
Quality				
Microcrystalline obsidian	549	93.1	301	97.1
Coarse obsidian	15	2.7	3	1
Obsidian with inclusions	18	3.3	4	1.3
Fine grained chert	20	0.79	0	0
Total	602		308	
Burning				
Burned obsidian	4	0.7	1	0.3
Burned chert	9	45	0	0
Total	13		1	

TABLE 4 Size, cortical coverage, and set-up of the cores

	R-Group		S-Group	
Average size in mm length × width × thickness (median)	25.5 × 16.5 × 11		21 × 18 × 9	
Average weight	5g		2g	
Cortex	n	%	n	%
No cortex	16	32	7	43.8
Cortex coverage 0–1/3	21	42	6	37.5
Cortex coverage 1/3–2/3	11	22	3	18.8
Cortex coverage 2/3–3/3	2	4		
Core type	n	%	n	%
Blade cores	26	52	5	31.25
Flake cores	16	32	7	43.75
Residual cores	2	4		
Cores on flakes	2	4	2	12.5
Levallois cores	3	6	2	12.5
Indeterminate	1	2		
Total	50	100	16	100

extremely exploited, and even artifacts are reused (Fig. 5). Intensive geomorphological surveys are needed to map all obsidian sources around Mount Damota and to identify the impact of climatological, sedimentological and volcanological events on their visibility and accessibility during MIS 3 (Hensel et al. 2019; Smith et al. 2024).

4.2 *S-Group and R-Group Lithic Techno/Typological Characteristics*

In total 1,655 stone artifacts were analysed from the S-Group, of which 979 (59.2%) did not undergo visible post-depositional alterations (Table 1). The inventory is dominated by flake production in cores and debitage, and numerous chips indicate little post-depositional disturbance (Table 2). The small spatial sample only yielded 16 cores for analysis, all showing an exceptionally advanced stage of reduction (Fig. 9, Table 4, Suppl. Tables 1–8). The blade cores are very small (less than 25 mm in greatest length) and are reduced unidirectionally from either plain or facetted platforms (Suppl. Table 9). A predominance of unidirectional reduction is also attested by the dorsal negatives of the blades (Suppl. Table 27). Flake production shows an even stronger size reduction (Suppl. Table 4) and a dominant concept of bidirectional reduction from facetted platforms (Suppl. Table 9). The Levallois concept is only represented by two cores and thus represents a small percentage of total cores (Table 4; Suppl. Tables 5, 9). Two further unidirectional cores on flake are present. The remaining length of the last preserved negatives can give indication about the lower tolerance limits for debitage product size. Blade (17 mm) and flake (11 mm) cores are thus more intensively exploited than Levallois cores (27 mm).

Core preparation and maintenance (Table 5) focuses on the correction of the platform and the distal curvature of the cores. Initial core preparation is attested by two bilateral primary and secondary (Suppl. Plate XVI.5) crested blades (Fig. 10.1, Suppl. Plate XVI.6; Suppl. Table 15). Cross blanks can be used to shape the distal part of the core (Suppl. Plate XIV.3). A secondary crested blade fragment still measures 42 mm (Suppl. Plate XVI.5), thus indicating the former size of the nodules. Core tablets (Fig. 10.2, Suppl. Plate XVI.1) and neocresting blades (Fig. 10.4–6; Suppl. Tables 15–16; Suppl. Plate XVI.2–7) indicate a volumetric approach to core conception. Neocresting blades are easily recognizable core trimming elements: unilateral retouch at the distal margins of the core creates a crest to guide the detachment. Many of the resulting, mostly plunging, blades are twisted and curve around the lateral margins towards the back of the core. Secondary flaking characteristics (Suppl. Table 19) also show "Upper

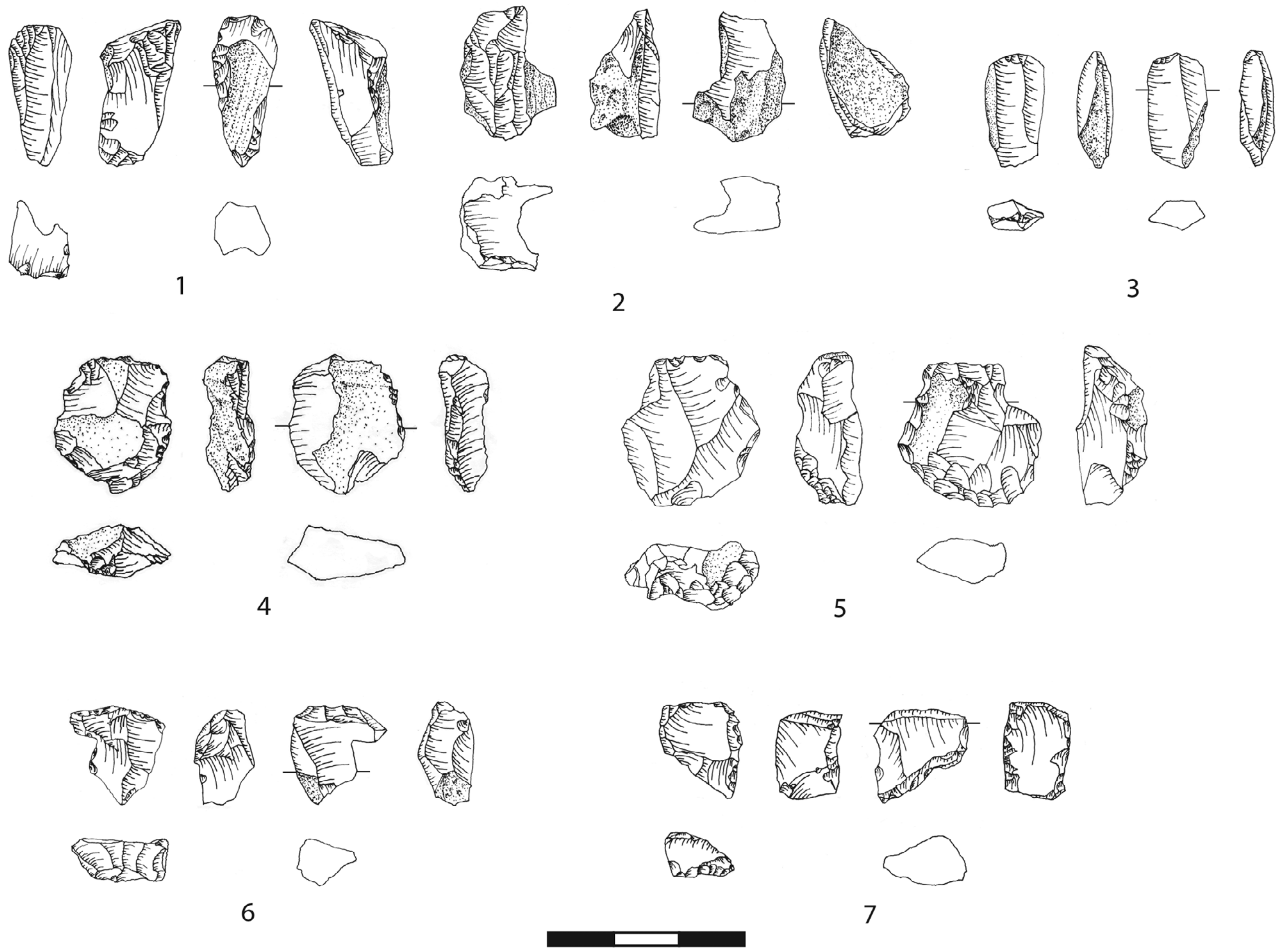

FIGURE 9 S-Group cores: 1–3 blade cores, 4–7 flake cores. Scale in cm
CREDIT: H. ROHRINGER

Palaeolithic traits" of the knapping at Mochena Borago. Twisted cross sections and offset impact points can be observed frequently on core trimming elements, indicating an intentional twisting of the products. Flake scars, some of which can be characterised as *esquiellement du bulbe* (after Pelegrin 2000 and Floss & Weber 2012) indicate the use of a soft stone hammer among other possible hammers made from perishable antler, bone, and/or wood. Furthermore, platform depths and degree of bulb development of the non-cortical blades (Suppl. Table 27) indicate a dynamic difference between direct and tangential percussion with a soft hammerstone (Pelegrin 2000; Soriano et al. 2007; Floss & Weber 2012). Core impact angles of the core trimming elements and cortical blades show a wider range (85–105 °) than non-cortical blades (80–90 °), thus attesting to targeted efforts to achieve favorable impact angles (Fig. 11). However, evidence of pressure flaking is lacking, as the knapping angles are not strictly 90 ° and the longitudinal sections are more curved and twisted than straight.

TABLE 5 Preparation and maintenance products

	R-Group		S-Group	
	n	%	n	%
Unilateral primary	23	69.7	12	75
Unilateral secondary	3	9.1	1	6.3
Bilateral 1× primary 1× secondary	3	9.1	0	0
Bilateral primary	1	3	0	0
Unilateral primary and secondary	3	9.1	1	6.3
Bilateral primary and secondary			2	12.5
Total	33	100	16	100

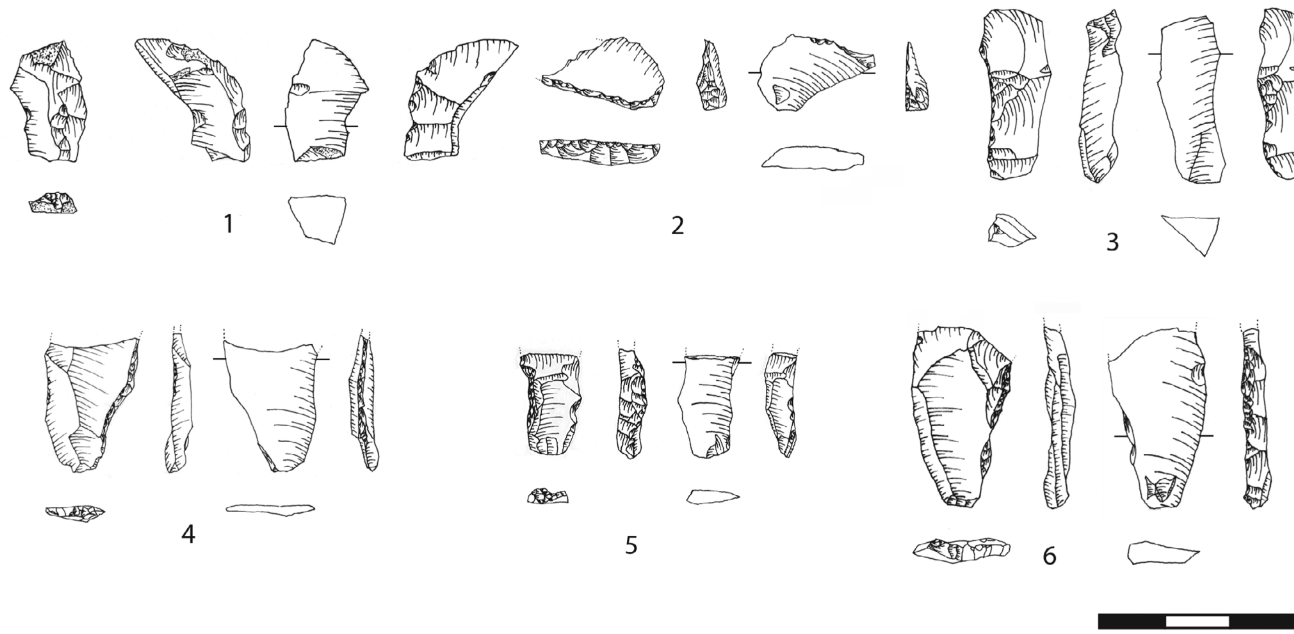

FIGURE 10 S-Group preparation/maintenance: 1 initial crested blade, 2 core tablet, 3–6 neocresting blades. Scale in cm
CREDIT: H. ROHRINGER

TABLE 6 Tools

	R-Group		S-Group	
Total assemblage	**1369**		**979**	
	n	**%**	**n**	**%**
Non-geometric backed pieces	4	5.3	4	7
Points	9	11.8	4	7
End-scrapers	10	13.2	5	8.8
Side-scrapers			1	1.8
Burins	5	6.6		
Drills	1	1.3		
Notched pieces	2	2.6	2	3.5
Denticulates	1	1.3		
Shaped tools	32	42.1	16	28.1
Use wear	25	32.9	18	31.6
Unshaped tools	19	25	23	40.4
Total tools	76	5.6	57	5.8

The S-Group tool inventory (Fig. 12, Table 6) contains 57 tools (5.8%) which can be separated into 16 formal or shaped tools (28.1%), and 41 informal or unshaped tools (72%), the latter including 18 lithics with macroscopically visible use wear (31.6%). Five end-scrapers form the dominant formal tool class and are made on flakes (n = 3) and blade fragments (n = 2). Four backed pieces are made on blade fragments, with two showing use wear. The four unifacial and bifacial points are all fashioned on flakes. The sole side-scraper is made from a burin spall fragment, but there are no burins in spite of six burin spalls that attest to the production of this tool class. Two notched pieces complete the formal tool inventory. Twelve lithics hint at lateral and/or distal retouch, but their retouch is too informal and non-invasive to term them truncations.

Overall, three complete blades and 20 blade fragments have been fashioned into tools, which represent 40.4% of all tools. In comparison with the percentage of blades in the complete analyzed sample (16.7%) and the percentage of blades in the unretouched blank inventory (28.4%), the share of blades in the tool inventory is higher, although this distinction just misses statistical significance (Table 7) and can therefore only be interpreted as a trend.

4.3 *R-Group*

The R-Group assemblages constitute 2,544 lithics of which 1,369 (53.8%) attests to a primary depositional context (Table 2). Again, the R-Group assemblages are dominated by flake debitage (Table 1), although here blade cores are more frequently present than flake cores (Table 4). Chips form the highest frequency of debitage, suggesting no significant loss of fine-grained material to post-depositional processes.

The 50 cores (Fig. 13) are on average very small (Table 4, Suppl. Tables 2–8), with few outliers. Cortex coverage is minimal (Table 4) and mostly preserved on core backs (Fig. 13.6–7; Suppl. Plates I.1; II.3; III.1,3,5), indicating intensive

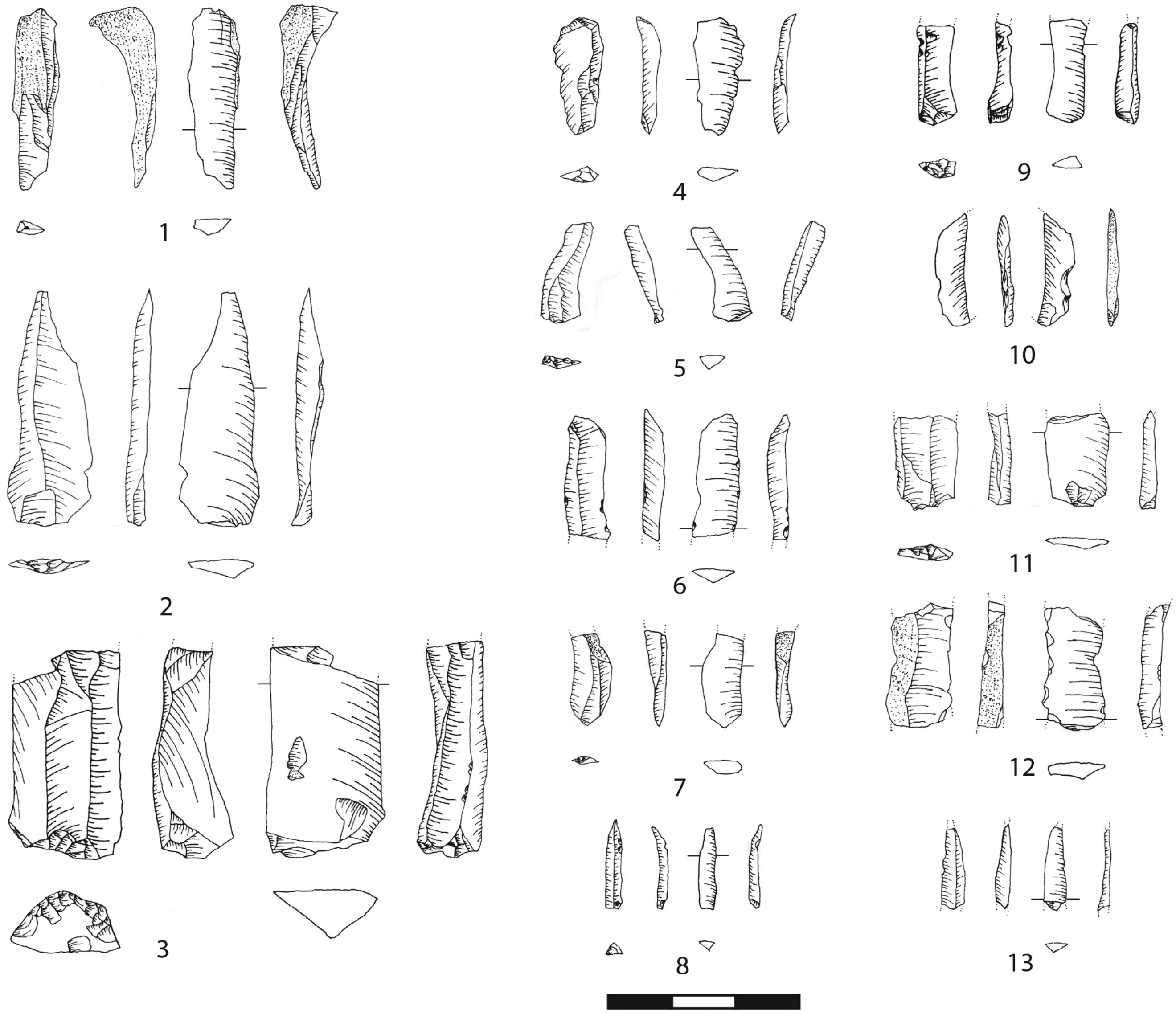

FIGURE 11 S-Group blades and blade fragments. Scale in cm
CREDIT: H. ROHRINGER

reduction. The larger core sample (n = 50) in the R-Group includes five different core types and is dominated by unidirectional or bidirectional blade cores (Fig. 13.1–5) with facetted or plain platforms (Suppl. Table 9). Flake cores (Fig. 13.6–7, Suppl. Table 4) predominantly show plain platforms but are less formalised in their directionality of reduction (Suppl. Table 9). Two additional cores on flakes (Suppl. Table 7) show the same conceptual characteristics as the flake cores. The Levallois-concept (Suppl. Table 5) plays a very minor part and is represented by only three cores, one of which bears a faint resemblance to the Nubian concept (Fig. 13.9). These are larger than the blade or flake cores and roughly follow a unidirectional-recurrent reduction scheme.

Regarding the lower acceptable length of debitage, a clear pattern emerges in the R-Group: Blade cores are abandoned when no blanks larger than 1.7–2.5 cm could be obtained. Flake cores are abandoned at a later stage than the blade cores (10–15 mm). The very small multidirectional residual cores (Fig. 13.10) were discarded around 8–13 mm remaining blank length. Some of the flake cores bear resemblance to the Levallois concept (e.g. Fig. 13.6) but are missing much of the characteristic centripetal preparation (Boëda 1995). Possibly, the blade and Levallois cores represent the first stage of determined production. The size and morphology of the flake cores suggest a transformation from blade and Levallois core types into flake cores to use up the remaining raw material volume. Assuming no knapping accident caused a core's premature demise, flake production could continue until the discard of the very small residual cores. Similar to S-Group, R-Group core preparation and maintenance (Fig. 14; Table

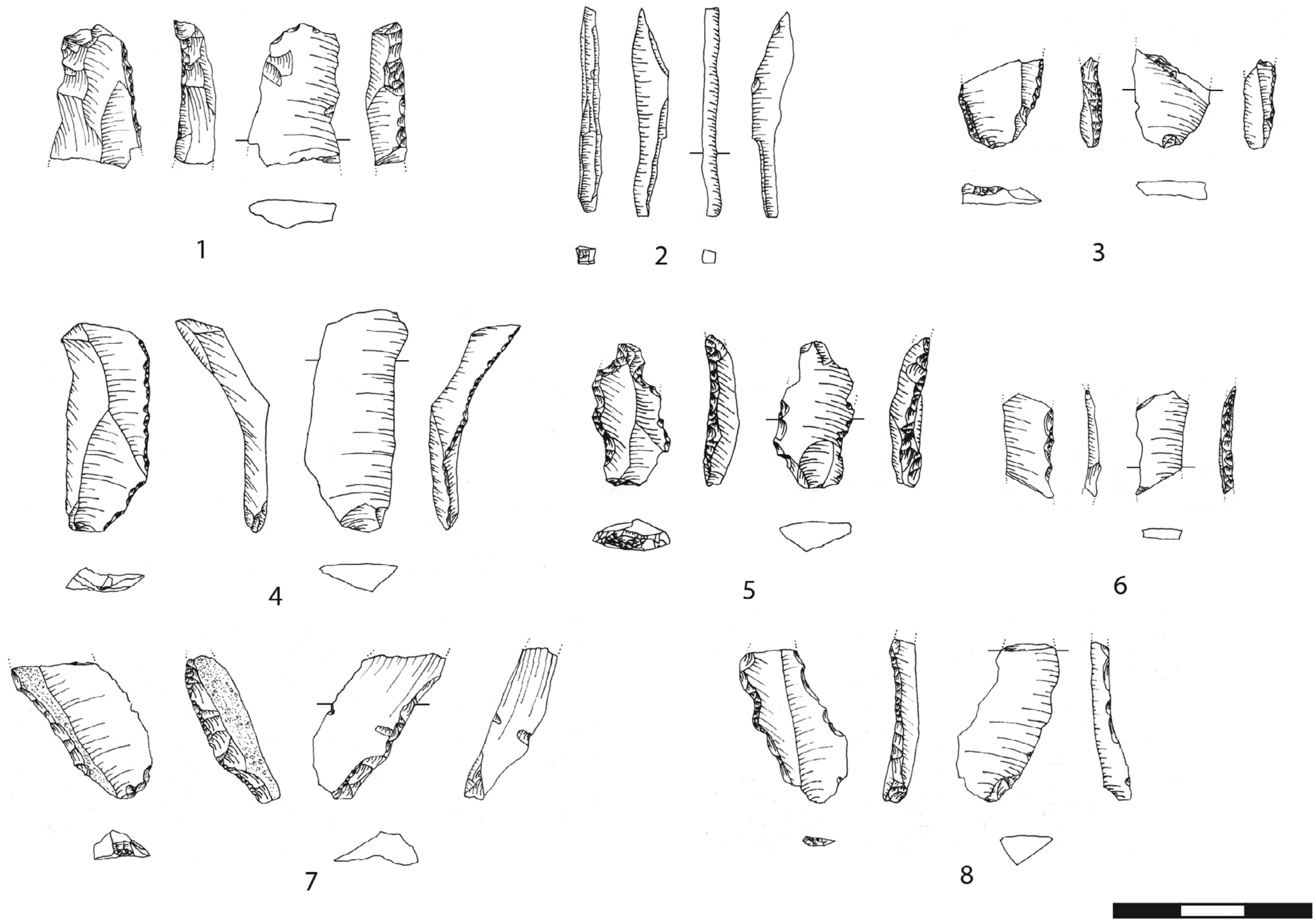

FIGURE 12 S-Group tools and tool resharpening waste: 1 endscraper, 2 burin spall, 3, 6 backed pieces, 4, 7, 8 use wear, 5 notched piece. Scale in cm
CREDIT: H. ROHRINGER

TABLE 7 Mann Whitney tests between blank and tool assemblages

R-Group	Blanks	All tools	Use wear	Informal tools
Blades	73	8	4	5
Blade fragments	141	28	15	7
Flakes and flake fragments	582	40	6	7
Mann Whitney test against blanks p =		0.08	0.08	0.07
S-Group	**Blanks**	**All tools**	**Use wear**	**Informal tools**
Blades	41	3	1	1
Blade fragments	122	20	7	6
Flakes and flake fragments	408	34	7	25
Mann Whitney test against blanks p =		0.08	0.08	0.07

5) again focuses on the platform and distal convexities. Core tablets (Fig. 14.1; Suppl. Plate VI.1,3) and neocresting blades (Fig. 14.2–6, Suppl. Plates VI.4–9; VII.1–8) were used to shape and maintain the cores' desired characteristics. The presence of neocresting blades with length dimensions ranging from 12 to 56 mm demonstrates the use of this core preparation technique throughout the reduction process and attests to the presence of formerly larger cores. Secondary flaking characteristics (Suppl. Table 17) also indicate the use of a soft stone hammer.

Blade debitage (Fig. 15, Suppl. Tables 10–14, 21,25, 29, 31–32) shows a size separation between the cortical and non-cortical blades, the latter of which are on average 7 mm shorter (Table 8). Secondary flaking characteristics (Suppl. Table 25) again indicate the absence of hard hammer percussion and indicate the use of a soft stone hammer in tangential application during the reduction process. Knapping accidents, resulting in hinged or overshot blades, are rare and if present only appear among cortical blades.

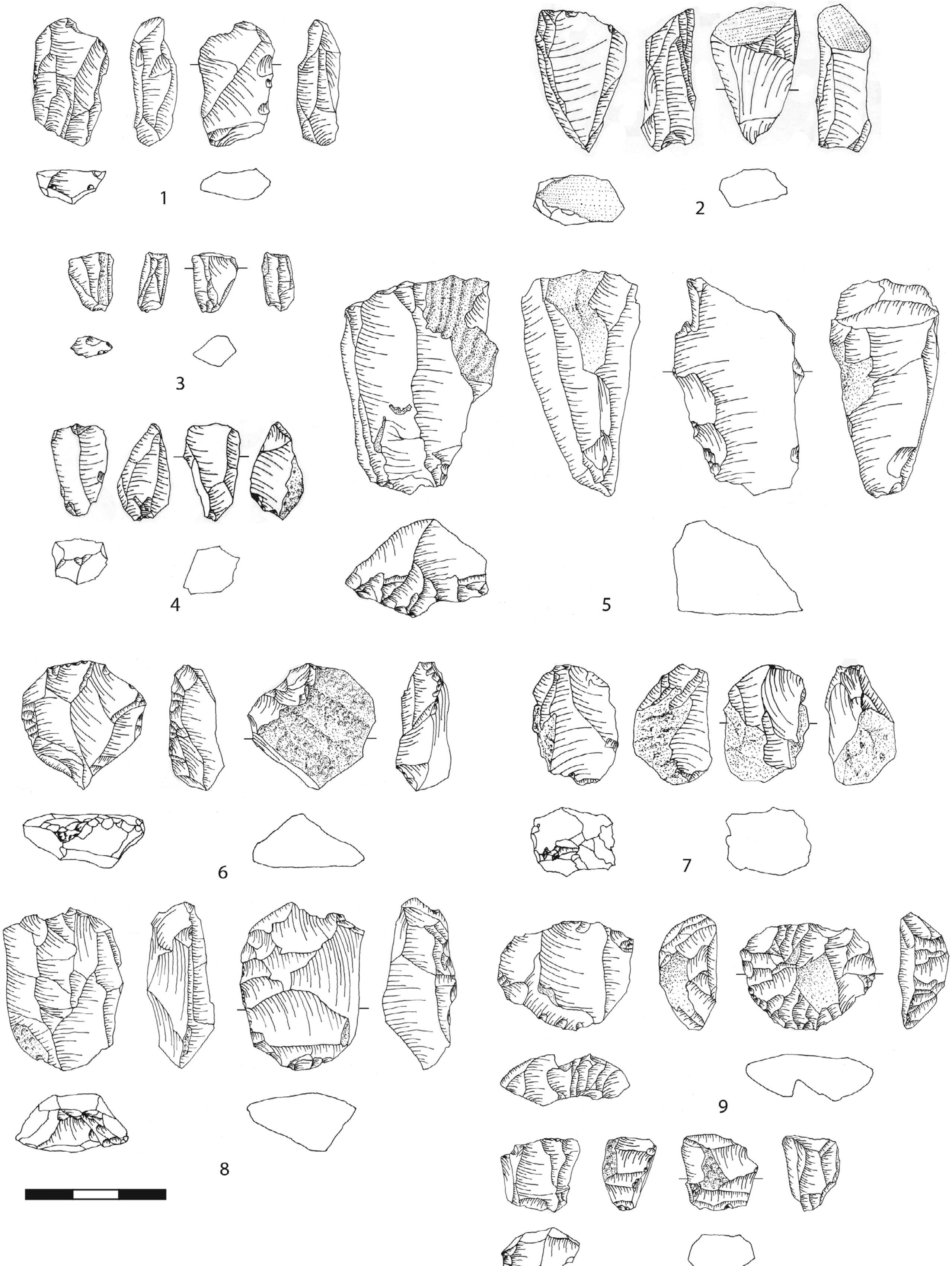

FIGURE 13 R-Group cores: 1–5 blade core, 6–7 flake core, 8–9 Levallois cores, 10 residual core. Scale in cm
CREDIT: H. ROHRINGER

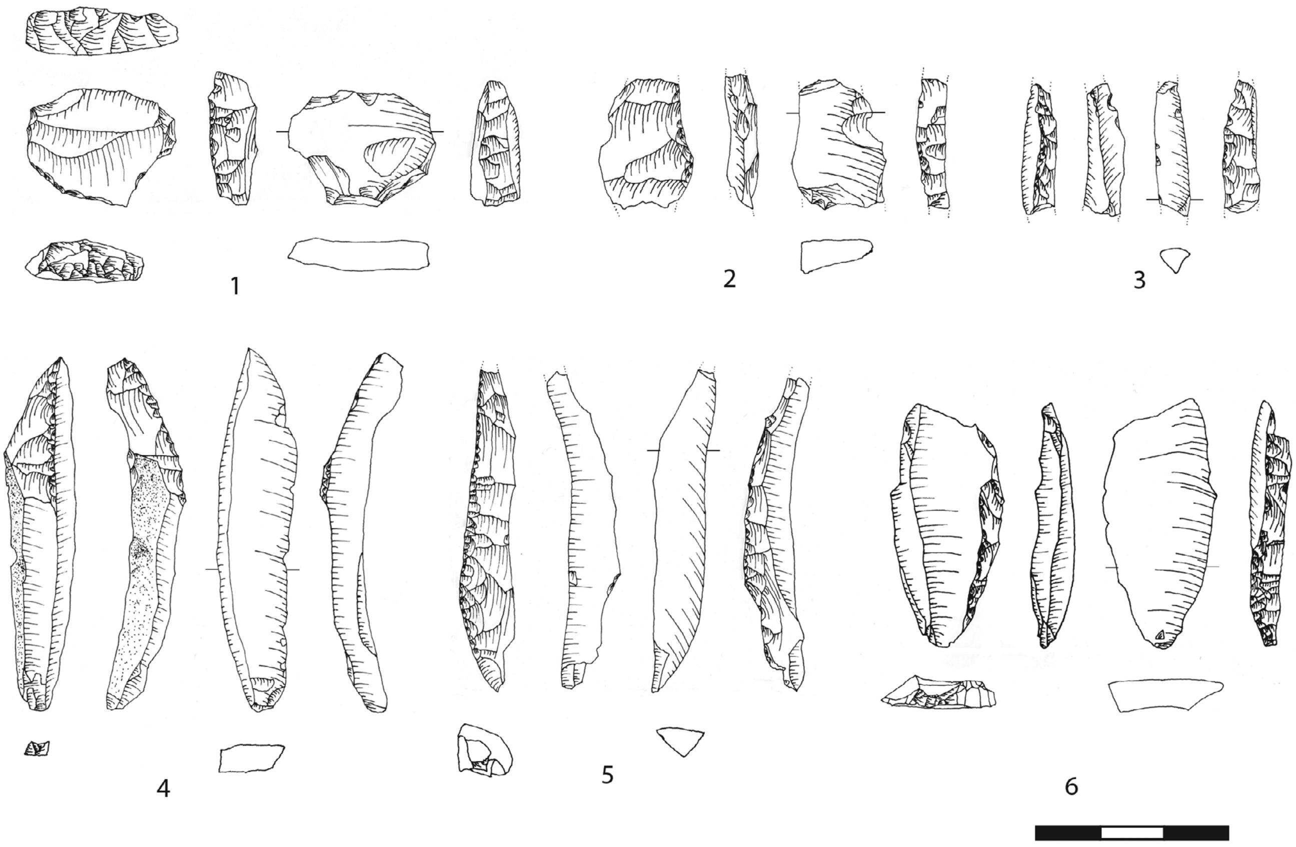

FIGURE 14 R-Group core preparation/maintenance: 1 core tablet, 2–6 neocresting blades. Scale in cm
CREDIT: H. ROHRINGER

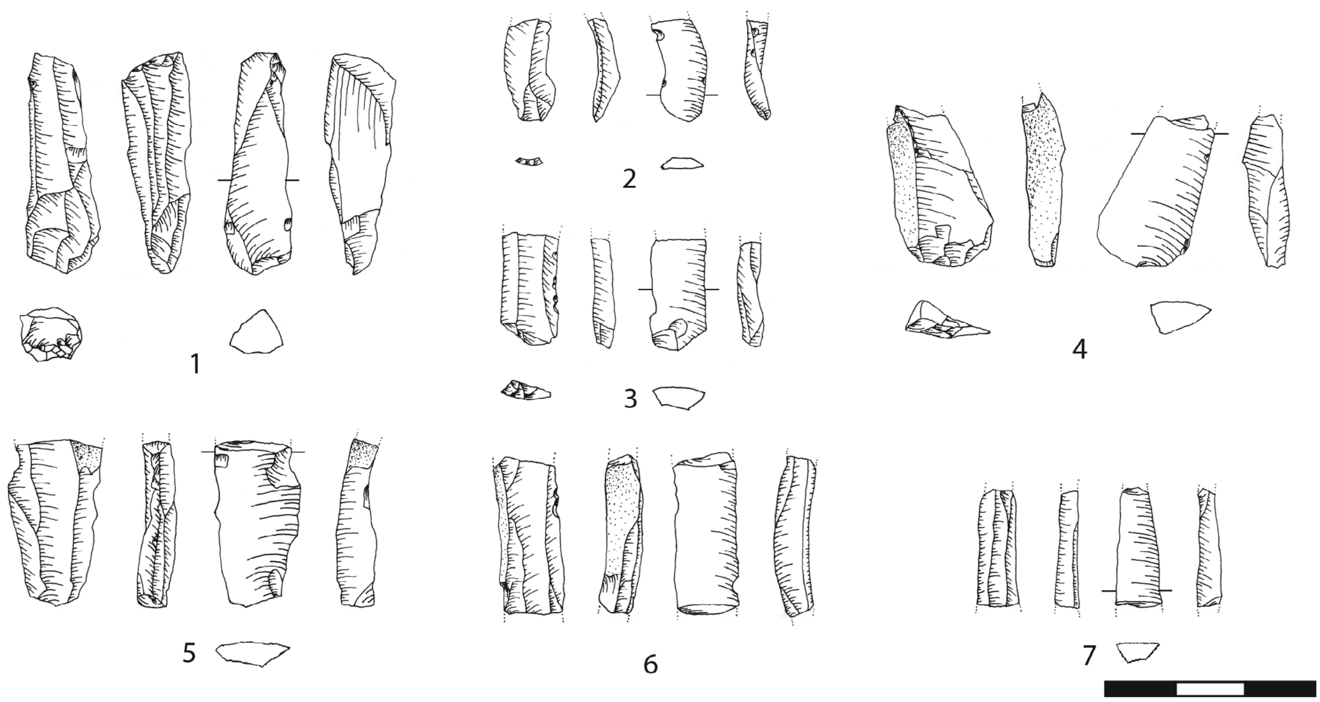

FIGURE 15 R-Group blades and blade fragments. Scale in cm
CREDIT: H. ROHRINGER

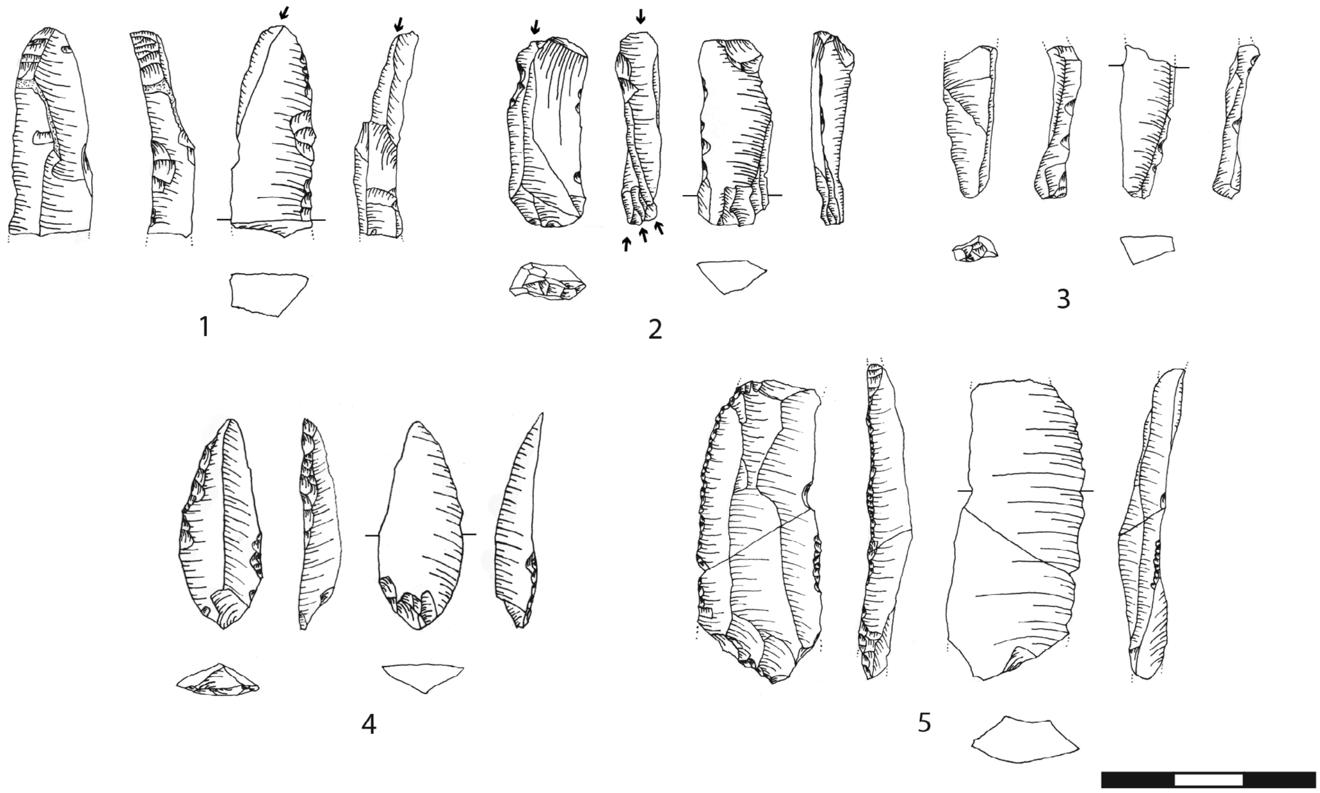

FIGURE 16 R-Group tools: 1–2 burin, 3 burin spall, 4–5 unshaped blades with marginal retouch. Scale in cm
CREDIT: H. ROHRINGER

TABLE 8 Size distribution of cortical and non-cortical blades

	R-Group		S-Group	
	Cortical	Non-cortical	Cortical	Non-cortical
Min	14	11	8	9
Max	52	59	38	36
Mean	29.4	22	22.3	20.8
Standard deviation	11.5	9.4	9.3	7.3
Median	26.5	20	21	20

R-Group blades show several requirements for a specific blade production, including: 1) bending fracture technique with a soft percussor in tangential use; 2) guiding ridges and 3) carefully prepared platforms to get the desired knapping angle, sometimes resulting in nearly pyramidal cores. In contrast to this, the products often do not reveal parallel edges or parallel ridges and a frequent core – and especially platform correction was necessary to maintain the reduction process. The basics of blade technology seem to have been known, but they were not used in such a regular and formalized way as can be observed in other specialised blade inventories (cf. Monigal 2003; Goring-Morris & Davidzon 2006; Soriano et al. 2007; Sari 2014). The proportion of blades is low in comparison to blade cores, potentially indicating an export of blades from the site.

The 76 tools (Fig. 16) are composed of 32 shaped tools (42%) and 44 unshaped tools, the latter of which includes 19 modified pieces (25%) and 25 lithics with macroscopic evidence of marginal retouch/damage along one or more lateral edges (32.9%, Table 6). More than half of the shaped tools are made on blades (n = 4) or blade fragments (n = 15). However, the ten endscrapers which represent the highest percentage of shaped tools (13%) are all made on flakes or flake fragments, with the exception of one made on a blade fragment. Unifacial/bifacial points are second in frequency (12%) and are also only manufactured from flakes. Non-geometric backed pieces are rare with only three made on blade fragments and one made on a flake fragment. Other shaped tools include single and multiple burins (n = 5), a borer (n = 1), notches (n = 2) and a denticulate (n = 1), all of which are on flakes or flake fragments. Only 23% of the unshaped tool blanks are on blades (n = 5) or blade fragments (n = 5).

Among the blanks with macroscopic use-wear, blades (n = 4) and blade fragments (n = 15) dominate. Among the informal tools, five blades and five blade fragments have been used. They are mainly laterally retouched, and all of the blade fragments and one blade show use wear opposite the lateral retouch. Although in direct comparison, flake and blade tool shares seem comparable, if set into relation to their distribution in the unretouched assemblage, blades are present in higher numbers among the tools than they should be. Blades are therefore much more frequent among the tools than among the complete inventory (15.6%), and also among the sample of all unretouched blanks without chips, cores, and angular waste (26.9%). This difference just misses the significance threshold as a Mann Whitney test only results in a p-value of 0.8 (Table 8). Most likely the overall small sample size of the tools is responsible for this lack of statistical significance Although one cannot speak of a clear positive selection of blades for tool production, a trend in this direction is certainly visible.

4.4 *Damaged Material*

As previously mentioned, almost half of the lithics from both S (40%) and R-Group (45%) show evidence of "damage," characterized by rolled or chipped edges and strongly weathered surfaces.

Technologically the damaged assemblages are not very different from the fresh ones (see all Supplementary Tables). In general, core types, reduction concepts, and technological solutions are the same. The damaged lithics in both S-Group and R-Group are predominantly flake-based but also contain small frequencies of blade cores. However, the focus on blade technology found in the fresh R-Group assemblage is missing. In the S-Group both damaged and fresh blade cores lack bidirectional reduction, while in the R-Group, the damaged blade cores mirror the fresh ones in having equal percentages of unidirectional and bidirectionally reduced cores. The damaged R-Group assemblage lacks the Levallois element present in the other three inventories, where it seems to represent a distinctly separated reduction concept from the flake/blade core reduction. The blade production of the damaged inventories features a change in knapping instrument between preparation and reduction, a feature that was not observed in either fresh inventory. In terms of metrical analysis, both damaged assemblages fail to yield statistically significant differences between the two.

Overall, the damaged lithics are generally similar to the fresh material. Therefore, questions about the ages or origins of the damaged assemblages are currently difficult to answer. Recently renewed geomorphological studies at MB may contribute to the decipherment of this issue (C. Mologni pers. comm.), but in any case, the answers to these questions need to be better understood before more detailed analyses of the damaged lithics can be undertaken. Because of all these uncertainties, the damaged lithics were not included in the technological/typological analyses just presented.

5 Discussion

5.1 *Intra-site and Inter-site Comparisons*

Some basic conclusions can be drawn from intra-site comparisons of the S and R-Group assemblages as well as inter-site regional comparisons with other Late Pleistocene sites in the Horn of Africa.

5.1.1 Intra-site Variability

The S and R-Group lithics from Mochena Borago reveal many technological similarities but also an internal development towards a conscious blade production. Neither are "typical" Levallois-based industries characterized by a dominance of the Levallois concept in cores and tools. Both groups focus on non-Levallois methods of flake production. Both reveal a broadening of their technological repertoire and a greater reliance on true blade production over time.

Similarities are especially obvious in technological solutions: the parallel use of platform faceting and core tablets shows an extension of the "toolkit" for technological problem-solving. This concept is well-developed, as the ideal knapping angles for the chosen soft stone hammers are met and re-established in the preparation and maintenance process. Those knapping devices are used in direct and tangential percussion employing bending fracture techniques to strike off blanks along guiding ridges. The use of soft stone hammers might be explained by the high sensitivity of the raw material. The brittle percussion characteristics of obsidian allow excellent control of the fracture mechanics, but the small size of the core nodules might have required the use of softer percussors to achieve full use of the available core volume. The few hammerstones found in Mochena Borago have not yet been petrographically analyzed.

The appearance of the neocresting blade, a distinctly non-Levallois maintenance product, introduces deliberate twisting of blanks and clears the way for a fully volumetric reduction. Their presence is characteristic of specialized blade production seen, for example, in the early European Upper Palaeolithic (e.g. Uthmeier 2012) and the Levantine Ahmarian (e.g. Monigal 2003; Goring-Morris & Davidzon 2006). They are also already known from the Howiesons Poort layers in Rose Cottage Cave (Soriano et al. 2007: 688) and the Iberomaurusian industry of Algeria (Sari 2014). While these technological solutions are present in both stratigraphic units at Mochena Borago, they improve in execution and increase in importance in the R-Group. Here a diachronic development is manifested that can also be seen in the composition of the total assemblages. An increase in the frequency of blade cores and a higher blade ratio for tools is noticeable in the R-Group, while at the same time the share of blade blanks is decreasing. Overall, there is an internal continuity in the technological repertoire as well as a diachronic development from a non-Levallois flake production towards a non-Levallois blade industry.

The artifacts from both strata are very small in size. No artifact exceeds 6 cm in length, and the majority range from 2–3.5 cm in length. The cores are heavily reduced and are at odds with the proximity of an extensive obsidian source(s) just 25 km away. The excessive exploitation of available raw material volume may reflect difficulties in the obtainment of obsidian and the general realization of the economic effectiveness of blade production, leading to increases in blade numbers in the R-Group. Some of the cores from R-Group also reveal a transformation from blade or Levallois cores to flake cores to residual cores, indicative of strategies to maximize raw material. Finally, the overall proportion of blades is low compared to the frequency of blades in the production of shaped and unshaped tools, suggesting purposeful selection of blades for tools. Apparently, the S-Group strategy of dealing with raw material stress focused on the extensive reduction of flake cores into small, nearly unmanageable blanks, while the R-Group focus was towards blade production.

5.1.2 Regional Comparisons

Any attempt to interpret the development towards a more conscious blade production at Mochena Borago is complicated by the paucity of comparable studies of material from other sites in the direct vicinity as well as from sites in the wider regional context. Available is the local assemblage from Porc Epic (Pleurdeau 2005) as well as the non-local assemblage from the Howiesons Poort layers of Rose Cottage Cave (Soriano et al. 2007). While Rose Cottage Cave is neither chronologically nor regionally relevant as a comparison, its technological analysis was used as a reference for this study and is therefore directly comparable. The relative importance of blade technology at both sites can be compared in order to put a perspective upon the importance of blade technology. Such a comparison relativizes the importance of the blade component at Mochena Borago, where a much reduced blade production volume is noticeable. Similar technological approaches can also be found at Porc Epic and Rose Cottage Cave, but the standardization and the number of blades is much less distinctive at Mochena Borago than at either of those sites. The clear correlation of raw material scarcity, size reduction of artifacts and an increase in blade production at Aduma (Yellen et al. 2005) might also be present at Mochena Borago. A comparison to the nearby sites of Fincha Habera will be a task for the future, once an analysis of both inventories is completed. Gorgora Rockshelter (Sahle et al. 2024) preserves assemblages of a comparable age to Mochena Borago, yet the industry is a flint industry and not, as at Mochena Borago, an obsidian industry. The published material from Gorgora Rockshelter gives extensive information about the site's retouched points, and the presence of backed items is also noted.

5.2 *Conclusions: Late Pleistocene Lithic Variability at Mochena Borago and the Horn of Africa*

The basic question raised at the beginning of this essay regarding whether or not the flintknappers responsible for lithic production at Mochena Borago between ~45–35 ka made a conscious effort to establish true laminar blade production can be answered in the affirmative. The lithic assemblages encompassed within the S- and R-Group lithostratigraphic units clearly reveal temporal changes in attributes indicative of purposeful non-Levallois blade production. But why this sudden shift towards a laminar blank production? One hypothesis is that blade technology is connected to an increased use of backed tools that replaced points as projectile armaments or that were used as hafted knives. This shift towards laminar blank production might also imply a change in hafting strategies and/or new weaponry, away from proximal hafting towards lateral hafting (Tryon & Faith 2013). It could also reflect changing foraging strategies resulting from shifts in the availability of faunal and floral resources due to major environmental fluctuations characteristic of MIS 3 in eastern Africa. Increases in blade production and an associated reduction in lithic size may reflect changing climatic conditions that reduced the accessibility and visibility of raw material sources (Hensel et al. 2019: 210), thereby putting pressure upon flintknappers to figure out ways of maximizing the number of produced blanks with more cutting edge during times of obsidian paucity (Yellen et al. 2005). In any case, the overall low percentage of blades in the S and R-Group assemblages at Mochena Borago in comparison with flakes, as well as in terms of the scarcity of backed tools, would not seem to lend much support to these hypotheses.

Another important question was whether the S- and R-Group lithic assemblages are distinct enough to be placed within a specific cultural-historic stage such as the MSA or LSA, as researchers are so tempted to do. A common definition of the MSA is the reliance upon Levallois technologies and unifacially/bifacially retouched points as the dominant tool type. (Phillipson 1990: 58; Yellen et al. 2005: 43; Willoughby 2007: 244). In this sense, S and R-Group assemblages could be classified as "MSA" or "Late MSA" (Tryon & Faith 2013; Pleurdeau et al. 2014; Leplongeon et al. 2017). However, the very low frequency of Levallois-based artifacts, the presence of non-geometric backed tools, and increases in blade production could just as easily argue for a "LSA" designation (Phillipson 1990: 58; Ménard et al. 2014).

Although the number of sites comparable to Mochena Borago is limited, it is our opinion that Late Pleistocene technological strategies in the Horn of Africa, for whatever reason(s), appear to reflect distinctive behavioral trajectories over time and space that in some cases are more prolonged and/or less specifically defined than in neighboring regions of Late Pleistocene Africa (Brandt et al. 2012; Tryon & Faith 2013). The reasons for this are still poorly understood, as significantly more research is needed at local and regional scales. We would thus prefer not to place Late Pleistocene assemblages from Mochena Borago and other sites in the Horn of Africa into specific culture-historic divisions such as the "Late MSA" or "Early LSA", as doing so only masks our currently poor understanding of Late Pleistocene technological variability.

Acknowledgments

Special thanks go to the people of Wolaita for their committed help in all aspects of field work and the Ethiopian Authority for Research and Conservation of Cultural Heritage for their gracious help and support. We are very grateful to Jürgen Richter, Oliver Bödeker, Ingrid Koch, Andreea Darida, Daniel Schyle and Kylie DeGersigny. This research was funded by the German Research foundation (CRC 806 – "Our Way to Europe" DFG, German Research Foundation; No. 57444011 – SFB 806; research group A1).

References

Bermensolo, K. 2013. Flaked Stone Artifacts from the R-Group at the Mochena Borago Rockshelter, Ethiopia, and their Implications. Unpublished M.A. Thesis, University of Florida.

Boëda, E. 1995. Levallois: A Volumetric Construction, Methods, A Technique. In: Dibble, H.L., & Bar-Yosef, O. (eds.), *Definition and Interpretation of Levallois Technology. Monographs in World Archaeology No 23*. Prehistory Press, Madison, Wisconsin pp. 41–68.

Brandt, S., Hildebrand, E., Vogelsang, R., Wolfhagen, J., & Wang, H. 2017. A new MIS 3 radiocarbon chronology for Mochena Borago Rockshelter, SW Ethiopia: Implications for the interpretation of Late Pleistocene chronostratigraphy and human behavior. *Journal of Archaeological Science: Reports* 11, 352–369. https://doi.org/10.1016/j.jasrep.2016.09.013.

Brandt, S.A., Fisher, E.C., Hildebrand, E.A., Vogelsang, R., Ambrose, S.H., Lesur, J., Wang, H. 2012. Early MIS 3 occupation of Mochena Borago Rockshelter, Southwest Ethiopian Highlands: Implications for Late Pleistocene archaeology, paleoenvironments and modern human dispersals. *Quaternary International* 274, 38–54. https://doi.org/10.1016/j.quaint.2012.03.047.

Brandt, S.A., Hildebrand, E.A., Vogelsang, R., Fisher, E.C., Kelsy, B., Lanzarone, P., Parow-Souchon, H., Smith, B.D., Mengistu Taffere, A., Lesur, J., Bermensolo, K. 2023. Mochena Borago Rockshelter, Ethiopia. In: Beyin, A., Wright, D.K., Wilkins, J., Olszewski, D.I. (eds.), *Handbook of Pleistocene Archaeology of Africa*. Springer Nature, Cham, pp. 461–482.

de la Torre, I., Benito-Calvo, A., Mora, R., Martínez-Moreno, J., Morán, N., & Tibebu, D. 2007. Stone Age occurrences in the western bank of the Bilate River (Southern Ethiopia) – Some preliminary results. *Nyame Akuma* 67, 14–25.

Fisher, E.C. 2010. Late Pleistocene Technological Change and Hunter-Gatherer Behavior at Moche Borago Rockshelter, Sodo-Wolayta, Ethiopia: Flaked Stone Artifacts from the Early OIS 3 (60–43ka) Deposits. Unpublished PhD. Thesis, University of Florida.

Floss, H., & Weber, M.-J. 2012. Schlagtechniken. In: Floss, H. (ed.), *Steinartefakte vom Altpaläolithikum bis in die Neuzeit*. Tübingen Publications in Prehistory. Kerns, Tübingen, pp. 133–136.

Friis, I., Demissew, S., & van Breugel, P. 2011. *Atlas of the Potential Vegetation of Ethiopia*. Ababa University Press & Shama Books, Addis Ababa.

Fusco, M., Asrat, S., Aureli, C., Bucci Casari, F., Talamo, S., Urban, P., Meyer, M., Gallinaro, M., Zerboni, A., & Spinapolice, E.E. 2022. The Middle Stone Age site of GOT10, Gotera, southern Ethiopia, in its cultural, chronological, and environmental contexts. Presentation at the Eastern African Association of Paleoanthropologists and Paleontologists (EAAPP) Conference, 31st July–2nd August 2022, Arusha.

Fusco, M., Carletti, E., Zerboni, A., Gallinaro, M., & Spinapolice, E.E. 2021. Lithic variability and raw material exploitation at the Middle Stone Age (MSA) site of Gotera, southern Ethiopia: a combined technological and quantitative approach. *Journal of Lithic Studies* 8 (1), 1–29. https://doi.org/10.2218/jls.6530.

Goring-Morris, A.N., & Davidzon, A. 2006. Straight to the point: Upper Paleolithic Ahmarian lithic technology in the Levant. *Anthropologie* 44 (1), 93–111.

Gutherz, X. 2000. Sondages dans l'abri sous-roche de Moche Borago Gongolo dans le Wolayta (Éthiopie). *Annales d'Ethiopie* 16, 35–38. https://doi.org/10.3406/ethio.2000.959.

Gutherz, X., Jallot, L., Lesur, J., Pouzolles, G., & Sordoillet, D. 2002. Les fouilles de l'abri sous-roche de Moche Borago (Soddo-Wolayta). Premier bilan. *Annales d'Éthiopie* 18, 181–190. https://doi.org/10.3406/ethio.2002.1019.

Hensel, E.A., Bödeker, O., Bubenzer, O., & Vogelsang, R. 2019. Combining geomorphological hydrological analyses and the location of settlement and raw material sites – a case study on understanding prehistoric human settlement activity in the southwestern Ethiopian Highlands. *E&G Quaternary Science Journal* 68 (2), 201–213. https://doi.org/10.5194/egqsj-68-201-2019.

Kappelman, J., Todd, L.C., Davis, C.A., Thure E. Cerling, T.E., Feseha, M., Getahun, A., Johnsen, R., Kay, M., Kocurek, G.A., Nachman, B.A., Negash, A., Negash, T., O'Brien, K., Pante, M., Ren, M., Smith, E.I., Tabor, N.J., Tewabe, D., Wang, H., Yang, D., Yirga, S., Crowell, J.W., Fanuka, M.F., Habtie, T., Hirniak, J.N., Klehm, C., Loewen, N.D., Melaku, S., Melton, S.M., Myers, T.S., Millonig, S., Plummer, M.C., Riordan, K.J., Rosenau, N.A., Skinner, A., Thompson, A.K., Trombeta, L.M., Witzel, A., Assefa, E., Bodansky, M., Desta, A.A., Campisano, C.J., Dalmas, D., Elliott, C., Endalamaw, M., Ford, N.J., Foster, F., Getachew, T., Haney, Y.L., Ingram, B.H., Jackson, J., Marean, C.W., Mattox, S., de la Cruz Medina, K., Mulubrhan, G., Porter, K., Roberts, A., Santillan, P., Sollenberger, A., Sponholtz, J., Valdes, J., Wyman, L., Madeta, M., & Yanny, S. 2024. Adaptive foraging behaviours in the Horn of Africa during Toba supereruption. *Nature* 628, 365–372. https://doi.org/10.1038/s41586-024-07208-3.

Leplongeon, A. 2014. Microliths in the Middle and Later Stone Age of eastern Africa: New data from Porc-Epic and Goda Buticha cave sites, Ethiopia. *Quaternary International* 343, 100–116.

Leplongeon, A. 2017. Technological variability in the Late Palaeolithic lithic industries of the Egyptian Nile Valley: The case of the Silsilian and Afian industries. *PLoS ONE* 12 (12), e0188824. https://doi.org/10.1371/journal.pone.0188824.

Leplongeon, A., Douze, K., Habte, B., Khalidi, L., Ménard, C., Pleurdeau, D., & Bon, F. 2023. A comparative look at technical traditions in the Horn of Africa and the Nile Valley at the end of the Pleistocene. In: Lesur, J., Cauliez, J., Khalidi, L., Bruxelles, L., Crevecoeur, I., Pleurdeau, D., Tribolo, C., Bon, F. (eds.), *From the Big Dry to the Holocene in the Eastern Africa and Beyond. Actes de la séance de la Société's préhistories française de Toulouse* (*septembre 2019*). Société préhistorique française, Paris, pp. 39–74.

Leplongeon, A., Pleurdeau, D., & Hovers, E. 2017. Late Pleistocene and Holocene lithic variability at Goda Buticha (southeastern Ethiopia): Implications for the understanding of the Middle and Late Stone Age of the Horn of Africa. *Journal of African Archaeology* 15, 202–233. https://doi.org/10.1163/21915784-12340010.

Leplongeon, A., Pleurdeau, D., Ménard, C., Douze, K., & Habte, B. 2020. The Horn of Africa at the end of the Pleistocene (75–12ka) in its macroregional context. In: Leplongeon, A., Goder-Goldberger, M. & Pleurdeau, D. (eds.) *Not Just a Corridor. Human Occupation of the Nile Valley and Neighbouring Regions between 75,000 and 15,000 Years Ago.* Natures en Sociétés, 3, Muséum national d'Histoire naturelle, Paris, pp. 269–283.

Loewy, S.L., Valdes, J., Wang, H., Ingram, W., Miller, N.R., de la Cruz Medina, K., Roberts, A., Yanny, S., Banner, J., Feseha, M., Todd, L., & Kappelman, J. 2020. Improved accuracy of U-series and radiocarbon dating of ostrich eggshell using a sample preparation method based in microstructure and geochemistry: A study from the Middle Stone Age of Northwestern Ethiopia. *Quaternary Science Reviews* 247, 106525. https://doi.org/10.1016/j.quascirev.2020.106525.

Ménard, C., & Bon, F. 2023. The Bulbula River sites, Ethiopia. In: Beyin, A., Wright, D.K., Wilkins, J., Olszewski, D.I. (eds.), *Handbook of Pleistocene Archaeology of Africa*. Springer Nature, Cham, pp. 275–283.

Ménard, C., Bon, F., Dessie, A., Bruxelles, L., Douze, K., Fauvelle, F.-X., Khalidi, L., Lesur, J., Mensan, R. 2014. Late Stone Age variability in the Main Ethiopian Rift: New data from the Bulbula River, Ziway–Shala basin. *Quaternary International* 343, 53–68. https://doi.org/10.1016/j.quaint.2014.07.019.

Monigal, K. 2003. Technology, economy, and mobility at the beginning of the Levantine Upper Palaeolithic. In: Goring-Morris, A.N. & Belfer-Cohen, A. (eds.), *More than Meets the Eye*: *Studies on Upper Palaeolithic Diversity in the Near East*. Oxbow Books, Oxford & Oakville, pp. 118–133.

Ossendorf, G., Groos, A.R., Bromm, T., Tekelemariam, M.G., Glaser, B., Lesur, J., Schmidt, J., Akçar, N., Bekele, T., Beldados, A., Demissew, S., Kahsay, T.H., Nash, B.P., Nauss, Th., Negash, A., Nemomissa, S., Veit, H., Vogelsang, R., Woldu, Z., Zech, W., Opgenoorth, L., & Miehe, G. 2019. Middle Stone Age foragers resided in high elevations of the glaciated Bale Mountains, Ethiopia. *Science* 365, 583–587. https://doi.org/10.1126/science.aaw8942.

Parow-Souchon, H. 2013. Die Klingentechnologie von Mochena Borago / Äthiopien. Innovation vor 40.000 Jahren. Unpublished MA thesis, University of Cologne.

Pelegrin, J. 2000. Les techniques de débitage laminaire au Tardiglaciaire: critères de diagnose et quelques réflexions. In: Valentin, B., Bodu, P., & Christensen, M. (eds.), *L'Europe centrale et septentrionale au tardiglaciaire*: *Confrontation des modèles régionaux de peuplement*. Mémoires du Mesée de Préhistoire d'Ile de France, Vol. 7. Nemours: A.P.R.A.I.F., pp. 73–86.

Phillipson, D.W. 1990. *African Archaeology*. Cambridge University Press, Cambridge.

Pleurdeau, D. 2005. Human technical behavior in the African Middle Stone Age: The lithic assemblage of Porc Epic Cave (Dire Dawa, Ethiopia). *African Archaeological Review* 22, 177–197.

Pleurdeau, D., Hovers, E., Assefa, Z., Asrat, A., Pearson, O., Bahain, J.-J., Lam, Y.M. 2014. Cultural change or continuity in the late MSA/Early LSA of southeastern Ethiopia? The site of Goda Buticha, Dire Dawa area. *Quaternary International* 343, 117–135. https://doi.org/10.1016/j.quaint.2014.02.001.

Richter, J., Kindermann, K., Vogelsang, R., & Henselowsky, F. 2024. Cultural rhythms and pulses on MIS 5–3 migration episodes of *Homo sapiens* dispersal in Northeast Africa. *Quaternary Science Advances* 16: 100248.

Richter, J., Melles, M., & Schäbitz, F. 2012. Temporal and spatial corridors of *Homo sapiens sapiens* population dynamics during the Late Pleistocene and early Holocene. *Quaternary International* 274, 1–4. https://doi.org/10.1016/j.quaint.2012.06.009.

Sahle, Y, Firew, G.A., Pearson, O.M., Stynder, D.D., & Beyin, A. 2024. **MIS** 3 innovative behavior and highland occupation during a stable wet episode in the Lake Tana paleoclimate record, Ethiopia. *Nature Scientific Reports* 14: 17038.

Sari, L. 2014. Technological change in Iberomaurusian culture: The case of Tamar Hat, Rassel and Columnata lithic assemblages (Algeria). *Quaternary International* 320, 131–142.

Smith, B.D., Johnson, L.R.M., & Brandt, S.A. 2024. Imports and outcrops: Characterizing the Baantu obsidian source and artifacts from Mochena Borago Rockshelter, Wolaita, Ethiopia, using portable x-ray fluorescence. In: Johnson, L.R.M., Freund, K.P., & Tripcevich, N. (eds.), *Reflections on Volcanic Glass*. Proceedings of the 2021 International Obsidian Conference. University of California, Berkeley, pp. 91–122.

Soriano, S., Villa, P., & Wadley, L. 2007. Blade technology and tool forms in the Middle Stone Age of South Africa: the Howiesons Poort and post-Howiesons Poort at Rose Cottage Cave. *Journal of Archaeological Science* 34, 681–703. https://doi.org/:10.1016/j.jas.2006.06.017.

Spinapolice, E.E., Gallinaro, M., & Zerboni, A. 2017. New investigations in southern Ethiopia (Yabelo and Gotera): Pleistocene and Holocene archaeological evidence. *Scienze dell'Antichit`a* 23 (1), 37–47.

Tryon, C.A., & Faith, J.T. 2013. Variability in the Middle Stone Age of eastern Africa. *Current Anthropology* 54, S234–S254. https://doi.org/10.1086/673752.

Uthmeier, T. 2012. Frühjungpaläolithische Grundformenerzeugung in Europa. In: H. Floss (ed.), *Steinartefakte vom Altpaläolithikum bis in die Neuzeit*. Kerns, Tübingen, pp. 327–340.

Vogelsang, R. 2023. Living the high life? Prehistoric occupation of high-altitude environments in Ethiopia. In: Lesur, J., Cauliez, J., Khalidi, L., Bruxelles, L., Crevecoeur, I., Pleurdeau, D., Tribolo, C., & Bon, F. (eds.), *From the Big Dry to the Holocene in the Eastern Africa and Beyond. Actes de la séance de la Société's préhistories française de Toulouse* (*septembre 2019*). Société préhistorique française, Paris, pp. 75–94.

Warren, A.M. 2010. Preliminary Characterization and Provenance of Obsidian Artifacts from Ethiopian Archaeological Sites using Portable X-Ray Fluorescence. Unpublished B.A. Thesis, University of Florida.

Willoughby, P.R. 2007. *The Evolution of Modern Humans in Africa: A Comprehensive Guide*. AltaMira Press, Lanham.

Yellen, J.E., Brooks, A.S., Helgren, D., Trappen, M., Ambrose, S.H., Bonnefille, R. de, Feathers, J., Goodfriend, G.A., Ludwig, K., Renne, P., & Stewart, K.M. 2005. The archaeology of Aduma Middle Stone Age sites in the Awash Valley, Ethiopia. *PaleoAnthropology* 10, 25–100.