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RESEARCH

IUP Technological Signatures or Mousterian Variability? The Case of Riparo l'Oscurusciuto (Southern Italy)

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Abstract
In the Italian peninsula, the Late Middle Paleolithic exhibits significant technological diversity, featuring blades, points, and bladelets. Assemblages displaying these distinctive characteristics have, in some cases, been labeled as Musteriano evoluto or Evolved Mousterian, and they are interpreted as contributing to the technological and typological variability within the Middle Paleolithic. In this study, we report the results of a detailed technological analysis of the lithics recovered from the latest layers preserved at Riparo l'Oscurusciuto (SU1 to SU3) in southern Italy. These layers were previously attributed to the Late Mousterian based on their chronological age and a preliminary techno/typological analysis of a small number of artifacts. Our comprehensive analysis of entire assemblages reveals the presence of original technological features, including blades, bladelets, and specific production of micro-points on flake cores. Some of these technological traits are comparable to those recently described at Grotte Mandrin in south-eastern France, which have been attributed to an early phase of the Initial Upper Paleolithic and associated with one modern human tooth. The study confirms the variability of the Late Middle Paleolithic in southern Italy and emphasizes the necessity to reassess it considering recent theories on the earlier arrival of *Homo sapiens* in Europe and their potential interaction with local populations.

Keywords Micro-points · Bladelets · Blades · Late Middle Paleolithic · Evolved Mousterian · Neronian

Introduction

Evidence for behavioral change during the Middle (MP) to Upper Paleolithic (UP) shift in western Europe, including material culture, hunting strategies, and raw material procurement, are concurrent to the incoming *Homo sapiens* and the demise of local Neandertal populations. Over the last few decades, lithic studies have consistently been employed to unravel the techno-cultural and techno-economical aspects of hunter-gatherer groups in Europe approximately 55–40 Kya, demonstrating the existence of different macro-regional techno-complexes: Châtelperronian, Uluzzian, Bohunician, Szeletian, Lincombian-Ranisian-Jerzmanowician (LRJ), and Bachokirian (Flas, 2011; Hublin et al., 2020; Moroni et al., 2013; Pelegrin, 1995; Rossini et al., 2022; Roussel et al., 2016; Škrdla, 2017; Svoboda & Bar-Yosef, 2003; Teyssandier, 2024). Late Middle Paleolithic (LMP) assemblages endure in specific regions, chronologically overlapping with some of these techno-complexes. Whereas in Romania, the Middle Paleolithic is followed by the Upper Paleolithic complex, with no form of transition in between despite the presence of *Homo sapiens* with recent Neandertal introgressions being found in that region (Chu et al., 2024). More to the east, during a similar time frame, the Initial Upper Paleolithic covers a vast geographic area, stretching from the Levant through central and eastern Europe to the Siberian Altai and northwest China (Kuhn & Zwyns, 2014; Li et al., 2020; Zwyns, 2021). Initial Upper Paleolithic assemblages are defined on a strict technological foundation focused on the production of blades from sub-volumetric reduction strategies and with a particular emphasis on convergent blanks resembling Levallois points detached through direct hard percussion (Kuhn, 2019; Škrdla, 2017; Tsanova, 2006, Tsanova et al., 2024). Broadly defined, the IUP exhibits significant variability in terms of blanks,

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formal tools, and reduction strategies (Zwyns et al., 2024). The proportions of flakes, points, and blades may vary across different techno-complexes (Kuhn, 2019; Rybin et al., 2020; Zwyns et al., 2019). Additionally, this toolkit can be combined with diverse bladelet reduction strategies and Upper Paleolithic tools, such as end-scrapers and burins (Demidenko & Škrdla, 2023; Demidenko et al., 2020; Zwyns, 2021; Zwyns et al., 2024). Possible correlations between the IUP and the dispersal of *Homo sapiens* from southwest Asia have been suggested (Boaretto et al., 2021; Hublin et al., 2020). Nevertheless, the authorship of these techno-complexes remains largely unknown. Considering the IUP as a techno-complex sensu stricto remains challenging because of its massive extension and technological diversification. Current data suggest that the IUP is more likely a spread of specific technological features (axial points and volumetric blades primarily) locally integrated into diverse productions. Recently, the discovery of a human tooth at Mandrin Cave (south of France) pushed back to roughly 54,000 years ago the first presence of *Homo sapiens* in western Europe (Slimak et al., 2022). Despite concerns raised on the reliability of the stratigraphic context of the tooth (Teyssandier, 2024), the comparison of the lithic industry and the one found in the Levantine IUP at Ksar Akil suggests that the Neronian in southwest France could correspond to the same *Homo sapiens* population (Slimak, 2023).

Within this scenario, the Italian peninsula does not seem to have been touched by the IUP phenomenon. Between 50 and 40 ky years ago, the Italian peninsula exhibited, in fact, two facets: the persistence of Middle Paleolithic assemblages on the one hand and the emergence of novel techno-complexes, namely the Uluzzian and Protoaurignacian both found in association with *Homo sapiens* skeletal remains. However, while the Uluzzian and the Protoaurignacian can be considered two coherent and well-defined techno-complexes (i.e., Falcucci & Peresani, 2018; Falcucci et al., 2017; Moroni et al., 2013, 2018; Rossini et al., 2022), the Late Middle Paleolithic (LMP) in Italy exhibits significant technological diversity that cannot be encapsulated in a singular package. In several (LMP) assemblages, the classical Mousterian background, primarily characterized by Levallois and discoid flake productions, can also incorporate blades, points, and, in some cases, bladelets (i.e., Arrighi et al., 2009; Arzarello et al., 2004; Carmignani, 2017; Carmignani & Sarti, 2018; Gambassini, 1997; Marciani et al., 2016, 2020a, 2020b; Peretto et al., 2020). In the south of Italy, at Castelcivita, the Uluzzian is preceded by an assemblage with a high proportion of points and a tendency to a laminarization of the Levallois production (Gambassini, 1997). At Grotta del Cavallo the level FIIIe containing Levallois flakes, volumetric blades, and bladelets is separated from the Uluzzian by discoid assemblages (layer FI and FII) (Carmignani & Sarti, 2018; Carmignani et al., 2020). At Grotta della Cala, Grotta la Fabbrica, and Riparo del Broion, the final Mousterian layers, which underlie the Uluzzian layers, exhibit a Levallois production characterized by flake-based production (Caramia, 2008; Dini & Conforti, 2011; Dini & Tozzi, 2012; Peresani et al., 2019). In the north of Italy, at Riparo Mochi and Riparo Brombini, two distinct Mousterian assemblages predate the Protoaurignacian. The late Mousterian at Brombini is characterized by a combination of Levallois and discoid production, while at Riparo Mochi, the lithic assemblages include axial convergent points and blades (Douka et al., 2012; Grimaldi & Santaniello, 2014; Holt et al., 2019; Riel-Salvatore et al., 2013, 2022). The variability in Mousterian technologies found underneath the Uluzzian or Protoaurignacian layers does not exhibit a clear geographic or raw-material-related pattern (Fig. 1).

The limited number and resolution of available radiometric dating, coupled with the lack of analysis of the lithic fine fraction may hinder our understanding. Recent research has demonstrated the importance of analyzing complete lithic assemblages, including the small lithics recovered from screening, in uncovering bladelet production in layers as old as 110,000 years ago in southeast France (Carmignani & Soressi, 2023). In this study, we provide a comprehensive analysis of the lithic assemblages discovered at the end of the sequence at Riparo l'Oscurusciuto in the south of Italy to better understand the variability and composition of the Late Mousterian in the region.

The dating of the total sequence at Oscurusciuto indicates that it accumulated in a relatively short period of time. The excavated portion of the stratigraphy is formed by a 3-m deposit radiometrically dated between 55,000 and 43,000 B.P., offering a rare high resolution for the Late Middle Paleolithic (Boscato et al., 2011; Tomlinson et al., 2014; Wulf et al., 2004; Higham et al., 2024). In this paper, our analysis is focused on the lithic assemblages from the latest layers (from SU3 to SU1), comprising more than 7000 lithic items (> than 15 mm). These layers, as well as older ones in the sequence, are all attributed to the Late Mousterian and showed some original features, including laminar technology and points (Boscato et al., 2004, 2011; Marciani, 2018; Villa et al., 2009). Technological variations cannot be attributed to raw material constraints as there is no significant change in raw material procurement throughout the sequence. The raw material used is strictly local and abundant in the vicinity of the site, consisting of pebbles of various sizes and lithotypes (Marciani et al., 2016, 2020a, 2020b; Spagnolo et al., 2020).

The results of our study highlight an unexpected technological variability that currently lacks a direct counterpart in the Italian Mousterian. We propose that existing labels, such as "Late Mousterian" or "Late Middle Paleolithic," inadequately capture the full spectrum of variability observed at Oscurusciuto. Some technological aspects identified at Oscurusciuto align with characteristics typically associated with the Initial Upper Paleolithic, opening the door to diverse interpretations.

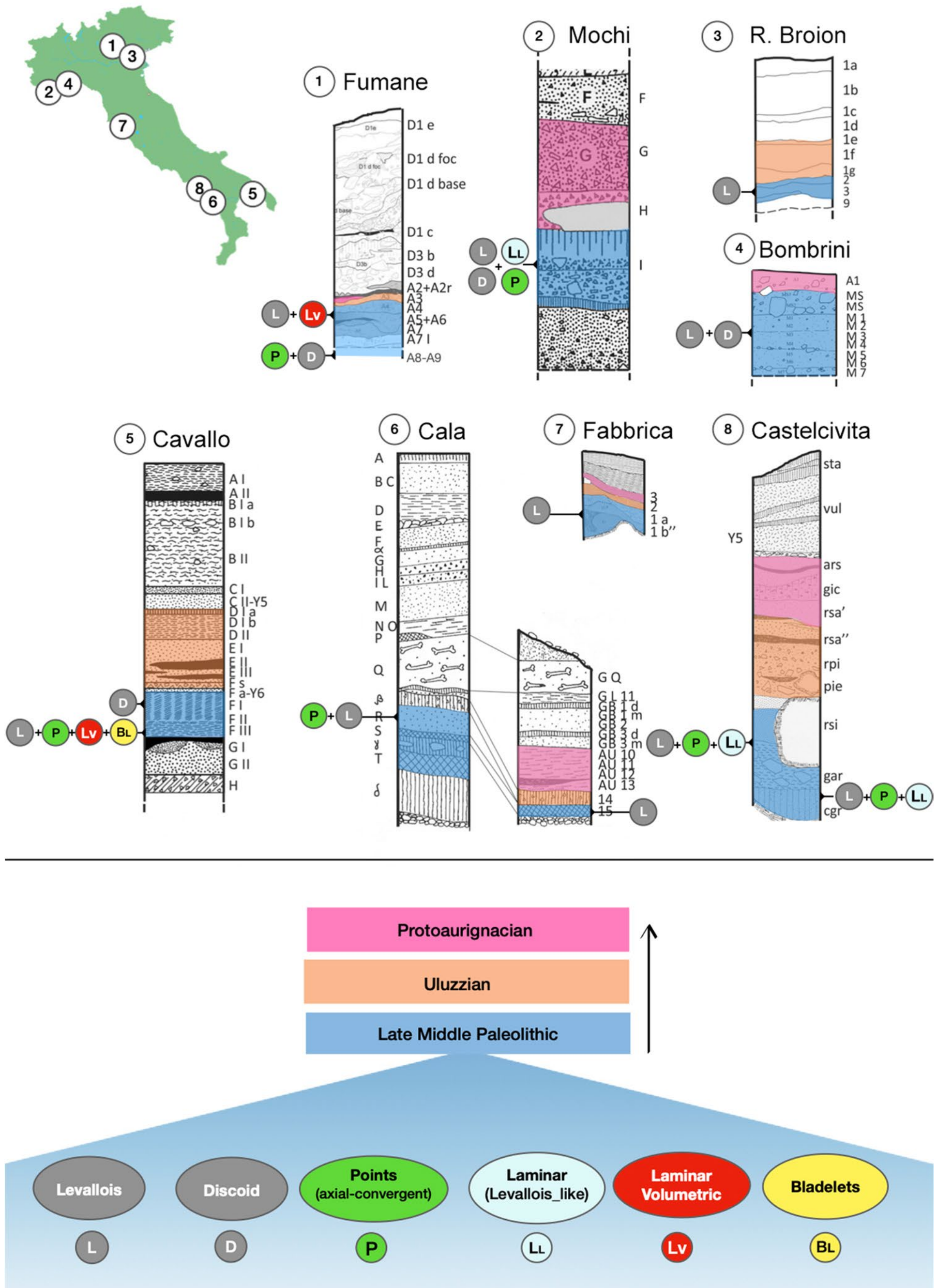

Fig. 1 Stratigraphic sequences with Mousterian, Uluzzian, and Protoaurignacian. **1** Fumane modified from Tagliacozzo et al., 2013. **2** Mochi modified from De Lumley, 1969. **3** R. Broion modified from Peresani et al., 2019. **4** Bombrini modified from Riel-Salvatore and Negrino, 2018. **5** Cavallo modified from Palma di Cesnola, 1964. **6** and **8** La Cala and Castelcivita modified from Gambassini, 1982. **7** La Fabbrica modified from Villa et al., 2018

Material and Methods

Background of Riparo l'Oscurusciuto

The Riparo l'Oscurusciuto is situated in southern Italy at an elevation of 235 m above sea level. Excavations, under the leadership of the University of Siena, began in 1998, and to date, several Middle Paleolithic occupations have been uncovered. The total known deposit is over 6 m deep (Fig. 2). The stratigraphic sequence excavated covers a time span of more than 10,000 years from 55 to 43 Kya. Two dates define the chronological limits: the first is a ^{14}C date, from the bottom of SU1 (Ramsey & Lee, 2013). The second derives from the identification of the tephra layer (SU14) as Mount Epomeo green tuff (Isola di Ischia), dated to about 55 ka BP (Allen et al., 2000; Tomlinson et al., 2014; Wulf et al., 2004). The lithic assemblages analyzed here come from the top six stratigraphic units (SU); from top to bottom, SU1, 2, 29, 30, 31, and SU3 (Fig. 2).

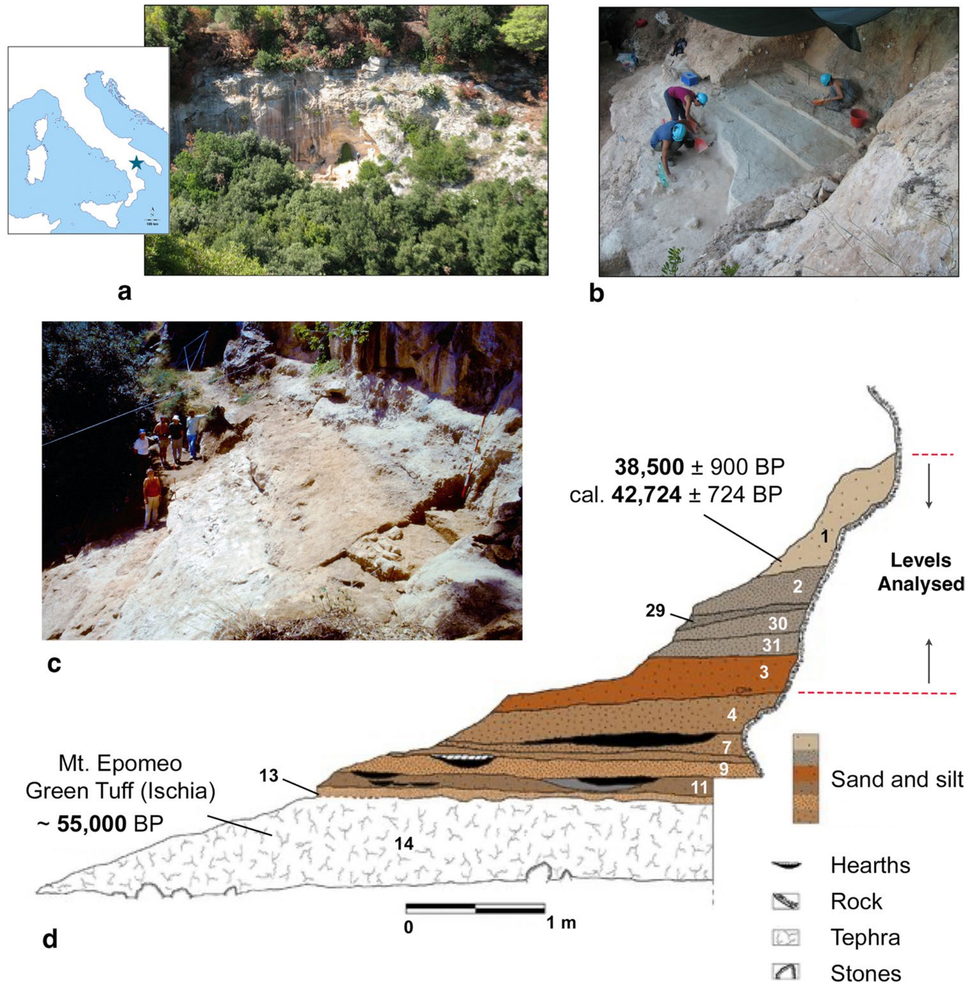

Fig. 2 Oscurusciuto rock-shelter. **a** Location and views of the site. **b** Current excavation area. **c** The rock shelter before excavation at the time of discovery. **d** Stratigraphic section with the details of the levels studied in this paper (Boscato et al., 2011 *modified*)

Starting from the top of the sequence, SU1, 2, 29, 30, and 31 are composed of a breccia of hard limestone with fragments of calcarenite and sandy matrix. Level SU1, which is not covered by any other archeological layer, is the remnant of a thick part of the stratigraphy (70 cm) almost destroyed by erosion. SU1 is grey in color, while SU2 is sandier and dark yellowish-brown. The SU29 is less cemented, darker brownish in color, and has a variable thickness of 1 to 9 cm. The SU30 has a similar color as the previous one, but it is less sandy and with a higher gravel component; it has a maximum thickness of 16 cm. The SU31 is brown in color with similar granulometric features as the previous one, and it reaches a thickness of about 20 cm. Some ash lenses were detected within this stratigraphic unit. Units SU29, S30, SU31 were excavated as a single large palimpsest in the first trench, and the lithic materials were analyzed collectively in this work. The SU3 (33 cm maximum thickness) is a sandy, silty deposit with fragments of calcarenite and represents a clear change in sedimentation, showing an abrupt change toward a more reddish color. It yielded small blocks of calcarenite. Except for SU1 and the top of SU2, where the limited extension prevents us from some stratigraphic considerations, all the stratigraphic units have sub-horizontal layering. Excavations were conducted using stratigraphic criteria. The dry and wet sieving was done with a 1 mm mesh. Despite the limited extension of the deposit, from 2 m^2 for SU1 up to 5 m^2 for SU3, archeological material is abundant.

Lithic Artifact Analysis

We conducted an exhaustive technological analysis of all blanks and cores regardless of the degree of fragmentation and including material from the sieving. No quantitative analysis of the lithic assemblage for these layers has been done previously. Lithic artifacts from each assemblage were divided according to technological types and the stratigraphical sub-units (i.e., spits) of provenience. A preliminary sorting procedure was adopted, dividing the lithics into two broad categories: diagnostic and non-diagnostic items. Diagnostic items consist of all pieces (complete or fragmented) that can be linked to specific reduction strategies (e.g., Levallois, discoid, laminar) or methods (e.g., convergent, centripetal, unidirectional), including also all by-products deemed to have had a significant role in a specific reduction process (e.g., striking platform flakes, crested blades). Complete diagnostic items were counted and analyzed regardless of their size. To have a better approximation of the number of lithic tecno-types through the sequence, the minimal number of flaked products (MNFP) was estimated based on the number of entire pieces and fragmented blanks with preserved butts. For non-diagnostic items (i.e., undetermined fragments and chunks), only pieces > 15 mm were counted and included in the general quantification considering the stratigraphic subdivisions by SU and spits.

Blank fragments (proximal, mesial, and distal) were quantified and displayed in a dedicated table (see SI2). Blanks with residual cortex > 50% were considered only partially diagnostic and treated separately because, in the absence of physical refitting, cortical or half-cortical flakes cannot be truthfully related to specific reduction strategies or methods. The first phases of the decortication of pebbles display similar features regardless of the reduction strategies used in the main production phase. For example, in both convergent and centripetal Levallois methods, the initialization of the core can follow a peripheral configuration of the flaking surface, producing similar cortical by-products.

For both cores and blanks, diacritic schemas were used to reconstruct the knapping sequences, the stages of production, the core configurations, and the concepts used. Methods were defined based on the number, direction, and organization of the scars on the core flaking surface and the dorsal surface of the blanks (Boëda et al., 1990). Identification of volumetric concepts and the distinction between the initialization stage and main production is based on criteria elaborated by Boëda (1990, 1994). The definition and characterization of cores were guided by four technical parameters: (1) the volumetric concept, (2) the type of core configuration, (3) the direction, and (4) the organization of the removals. The manuscript uses the locution "reduction strategy" to refer to the combination of both concepts and the methods used. Blades here are at least twice as long as they are wide. The metric boundary between blades and bladelets was placed at a width of 12 mm. The metric boundary between points and micro-points was placed at 30 mm in length. The length was measured according to the direction of the blow (i.e., technological axis). The identification of axial points is based on strict technological criteria. Only products that meet the following criteria are classified as axial points:

a) The scars on the dorsal surface of points show a predetermined convergent pattern.
b) The tip of the point is located on the distal part of the blank and aligns with the débitage direction.

   Triangular or sub-triangular blanks that lack a predetermined pattern, as well as pseudo-Levallois points that are removed in a chordal direction and have an off-axis tip in relation to the débitage direction, are not classified as points here.
c) The triangular morphology is predetermined during the débitage process. Pieces heavily retouched (i.e., Mousterian points type) are classified as retouched points and not as axial points.

   For the retouched tools, we chose not to employ a traditional typological classification due to the predominant occurrence of retouched artifacts falling into scraper and point categories. Instead, we documented the presence or absence of the retouch on various technological classes of products and by-products.

Results

We analyzed 7231 lithics, including cores, blanks, and debris (> 15 mm). Raw materials include flint, silicified limestone, jasper, quartz, and sandstone and can be easily collected in the marine and fluvial terraces near the site as pebbles of different sizes, from 2–3 to 20–30 cm in diameter (Marciani, 2018; Marciani et al., 2016).

Natural pebbles, entire and fragmented, were found in all the levels studied in different proportions and confirm the introduction of unworked raw material on the site (Table 1). Cortical flakes with more than 50% cortex are present at approximately 10% in all levels (Table 1). The residual cortex on blanks aligns with the local pebble provisioning. The lithic assemblages exhibit a diverse range of blanks, including flakes, points, blades, and bladelets (Table 2). This holds across all studied archeological levels, except for level 3, where flake production predominates, complemented by a numerically smaller proportion of blade or bladelet production systems (Table 2). The cores exhibit the same trend observed for the blanks, highlighting a significant divergence between level 3 and the upper part of the sequence (Table 3).

Flake Production

Flake production is dominant. Flake-cores range from 64.2% in SU29–30-31 to 84.8% in SU3 (see Table 3) and result from different reduction strategies (SI2, Table S1). Considering the angle of exploitation for blank removal, the flake cores can be categorized into two groups: those exploited along parallel planes and those exploited along secant planes. The exploitation along parallel plan is the most common, accounting for up to 72% of the flakes produced, except for the SU1, which only represents 28% (SI2, Table S2). The proportion of Levallois cores is relatively

Table 1 Overview of the lithic débitage

LITHIC ELEMENTS	SU1		SU2		SU29-30–31		SU3	
	Num	%	Num	%	Num	%	Num	%
Cortical flakes (cortex > 50%)	102	*9.4*	159	*9.9*	249	*10.2*	252	*12.1*
Cortical flakes (cortex < 50%)	68	*6.3*	180	*11.2*	235	*9.6*	160	*7.7*
Fragmented cortical blanks	11	*1*	10	*0.6*	17	*0.7*	32	*1.5*
Blanks (flakes, blades, bladelets)	330	*30.4*	655	*40.6*	867	*35.4*	676	*32.4*
Fragmented blanks	155	*14.3*	327	*20.3*	335	*13.7*	221	*10.6*
Cores	58	*5.4*	136	*8.4*	190	*7.8*	46	*2.2*
Core fragments	20	*1.8*	24	*1.5*	22	*0.9*	–	–
Entire Pebbles	–	–	11	*0.7*	26	*1.1*	9	*0.4*
Pebble fragments	9	*0.8*	4	*0.2*	21	*0.9*	11	*0.5*
Debris/chunks > 15 mm	331	*30.5*	106	*6.6*	489	*20.0*	676	*32.4*
Total	**1084**	*100*	**1612**	*100*	**2451**	*100*	**2084**	*100*

Table 2 Minimal number of diagnostic blanks

BLANKS	SU1		SU2		SU29-30–31		SU3	
	Num	%	Num	%	Num	%	Num	%
Blades	52	*12.8*	79	*9.8*	119	*11.8*	24	*3.1*
Bladelets	14	*3.5*	57	*7.1*	83	*8.2*	10	*1.3*
Points	58	*14.3*	160	*19.9*	194	*19.2*	57	*7.4*
Micro-Points (> 20 and < 30 mm)	5	*1.2*	33	*4.1*	27	*2.7*	4	*0.5*
Levallois-type flakes	70	*17.3*	147	*18.3*	207	*20.5*	216	*28.2*
Non-Levallois flakes	206	*50.9*	328	*40.8*	379	*37.6*	455	*59.4*
Total	**405**	*100*	**804**	*100*	**1009**	*100*	**766**	*100*

Table 3 Type of determinable cores (undetermined core fragments are excluded)

CORES	SU1		SU2		SU29-30–31		SU3	
	Num	%	Num	%	Num	%	Num	%
Blade cores	0	*0*	3	*2.2*	7	*3.7*	–	*0*
Bladelet cores	3	*5.2*	4	*2.9*	9	*4.7*	–	*0*
Micropoint cores	4	*6.9*	2	*1.5*	5	*2.6*	1	*2.2*
Point cores	12	*20.7*	29	*21.3*	47	*24.7*	5	*10.9*
Levallois (flakes cores)	7	*12.1*	16	*11.8*	37	*19.5*	19	*41.3*
Flake cores (other systems)	32	*55.2*	82	*60.3*	85	*44.7*	21	*45.7*
Total	**58**	*100*	**136**	*100*	**190**	*100*	**46**	*100*

low in the upper layers, ranging from 17% of the total number of cores in SU1 to 19% in SU29–30-31 (Table 3). The high proportion of Levallois cores found in the SU3 (41% of the total) is one of the traits that differentiate this stratigraphic unit from the rest of the sequence studied. A second group of parallel plan cores, even if they exhibit certain similarities with the definition of Levallois cores proposed by Boëda (1994, 2021), lack some of the specific features that characterize this concept. These cores do not display a clear distinction between the configuration phase and the production phase. More specifically, the flaking surfaces lack preparation of the lateral and distal convexities. After the preparation of the striking platform, exploitation of the flaking surface progresses, taking advantage of the natural shape of the nodule (Fig. 3 n. 5).

The divergence highlighted between Levallois and non-Levallois parallel plan exploitation at Oscurusciuto is technologically consistent but perhaps conceptually artificial. The raw material, locally available and used at the site, consists of pebbles of various sizes and shapes. It is worth noting that certain pebbles may possess the appropriate morphological characteristics to facilitate a Levallois débitage. In this case, the initialization of the cores can rely on selecting an appropriate pebble morphology,

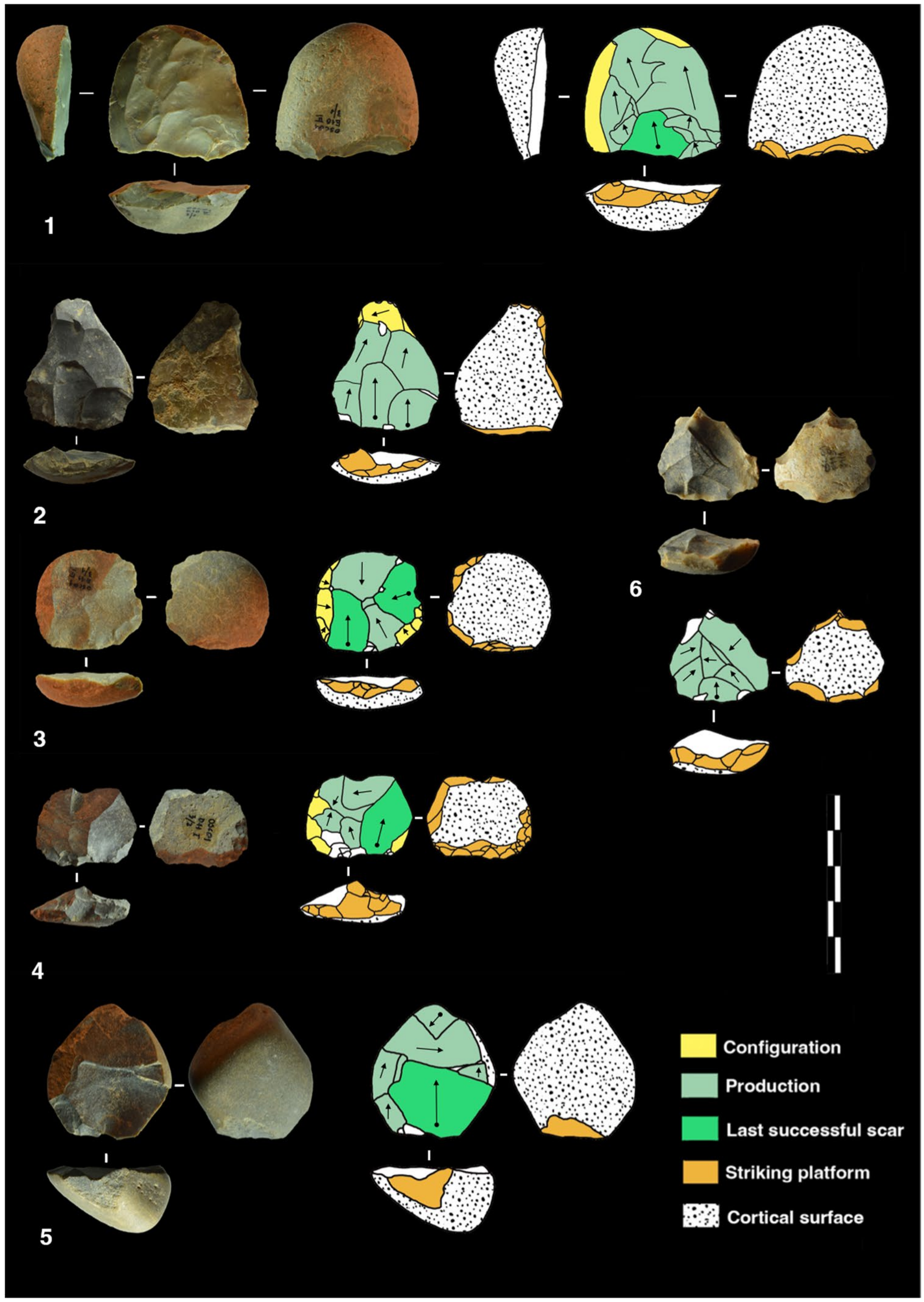

Fig. 3 Parallel plan cores. **1** and **2** Unidirectional Levallois cores from SU3; **3** and **4** Centripetal Levallois cores from SU3. **5** Parallel plan core with simple configuration abandoned in the early stage of production from SU31. **6** Exhausted centripetal parallel plan core from SU29

thus making the preparation of the flaking surface (e.g., the lateral and distal convexities) redundant.

The direction of removals used for the exploitation of the flaking surface are centripetal and unidirectional, more rarely bidirectional. The methods used are similarly represented in both the Levallois and non-Levallois cores, suggesting that there is not a preferential correlation between the type of configuration and the exploitation methods (SI2, Table S3). This aspect reinforces the hypothesis that the two options of configuration are interchangeable and are probably only related to the natural morphology of the pebbles. Only in SU3, the simple configuration seems to be preferentially used for the unidirectional exploitation and the Levallois for the centripetal (SI2, Table S3).

The second macro-group of flake cores follows a secant planes exploitation (Fig. 4). The proportion of those cores ranges from 18% of the total number of core flakes in SU1 to 25% in SU29–30-31 (SI2, Table S2). No configuration of the volume was observed on those cores. The débitage starts directly with a series of secant

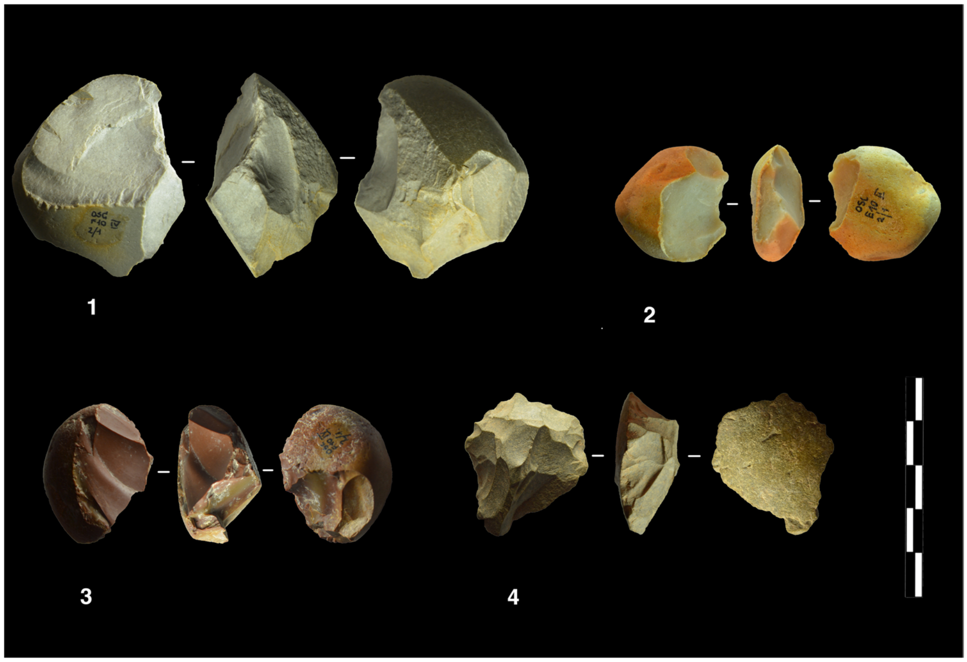

Fig. 4 Secant plan cores. **1–3** Partial peripheral exploitation from SU2. **4** Peripheral unifacial exploitation from SU3

removals on one or two opposite surfaces. Each removal participates in maintaining the convexity and creates a new striking platform for the following removals. The direction of the removal is alternatively centripetal and chordal. The débitage can involve the entire periphery of the core or can be limited to one side, leaving the other part of the volume unexploited. This method shares some features with the Discoid concept (i.e., secant plan exploitation and alternation of two flaking surfaces). However, the organization of the removals does not produce, at least not systematically, the typical products of the discoid concept. Besides 64 cores related to this method, only 16 pseudo-Levallois flakes were found (Table 4). The main goal of the production is focused on the production of short, thick flakes with a peripheral cutting edge (n. 67) and debordant flakes with a natural back opposed to the cutting edge (n. 120).

A third group of cores falls outside the above descriptions. These cores show a very short sequence of removals without any preliminary preparation (Fig. 5). Some can be interpreted

Table 4 Minimal number of flaked blanks per production type

Flake products		SU1		SU2		SU29–30-31		SU3	
		num	%	**num**	%	num	%	num	%
Parallel plan flakes	Levallois type centripetal	35	*12.7*	89	*18.7*	133	*22.7*	172	*25.6*
	Levallois type unidirectional	30	*10.9*	52	*10.9*	69	*11.8*	37	*5.5*
	Levallois type bidirectional	–	*0*	3	*0.6*	5	*0.9*	1	*0.1*
	Levallois type orthogonal	–	*0*	–	*0*	–	*0*	1	*0.1*
	Debordant Levallois type flakes	5	*1.8*	3	*0.6*	–	*0*	5	*0.7*
	Centripetal flakes	46	*16.7*	66	*13.9*	86	*14.7*	205	*30.6*
	Unidirectional flakes	112	*40.6*	201	*42.3*	209	*35.7*	146	*21.8*
	Debordant natural back unidirectional	4	*1.4*	19	*4*	29	*4.9*	15	*2.2*
	Bidirectional flakes	–	*0*	8	*1.7*	10	*1.7*	2	*0.3*
	Orthogonal flakes	–	*0*	–	*0*	–	*0*	3	*0.4*
Secant plan flakes	Secant centripetal flakes	18	*6.5*	8	*1.7*	14	*2.4*	27	*4*
	Pseudo-Levallois flakes	5	*1.8*	1	*0.2*	4	*0.7*	6	*0.9*
	Debordant (natural back)	13	*4.7*	12	*2.5*	15	*2.6*	24	*3.6*
	Debordant (débitage back)	8	*2.9*	13	*2.7*	10	*1.7*	25	*3.7*
	Kombewa flakes	–	*0*	–	*0*	2	*0.3*	2	*0.3*
	Total	**276**	*100*	**475**	*100*	**586**	*100*	**671**	*100*

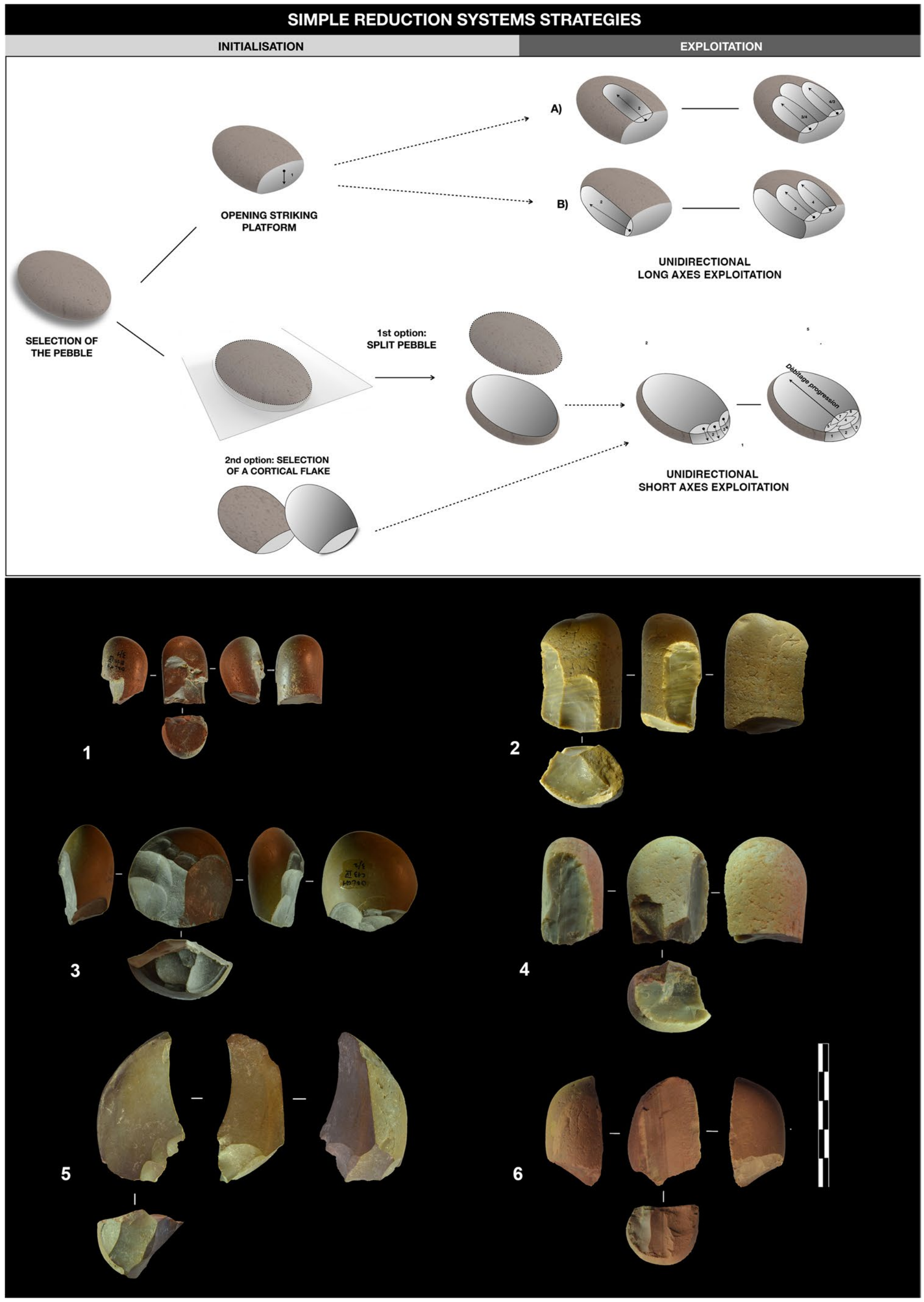

Fig. 5 Simple reduction system cores. **1** to **4** Long axes exploitation from SU3, SU2, and SU29. **5** and **6** Short axes exploitation from SU2 and SU31

as tested blocks. Nevertheless, these cores are numerous throughout the sequence ($n=67$) and represent 23% of the flake cores. The blanks are strucked unidirectionally on the longer axes of the pebble and are quickly abandoned after the production of a small number of cortical flakes.

In only a smaller number of these cores ($n=21$), the unidirectional sequence is repeated on two or more surfaces of the core's volume "Unidirectional multiplatform" (SI2, Table S1). Six cores (4 from SU2 and 2 from SU29-30–31) show a different volume management. In those cores, removals are struck on the narrow surface of thick flakes. The ventral surface of the flake cores is used as a striking platform for a short unidirectional sequence (Fig. 5 n. 5, 6).

Flaking products are coherent with the reduction systems observed on the cores. Products derived from parallel plan exploitation are dominant in the entire sequence

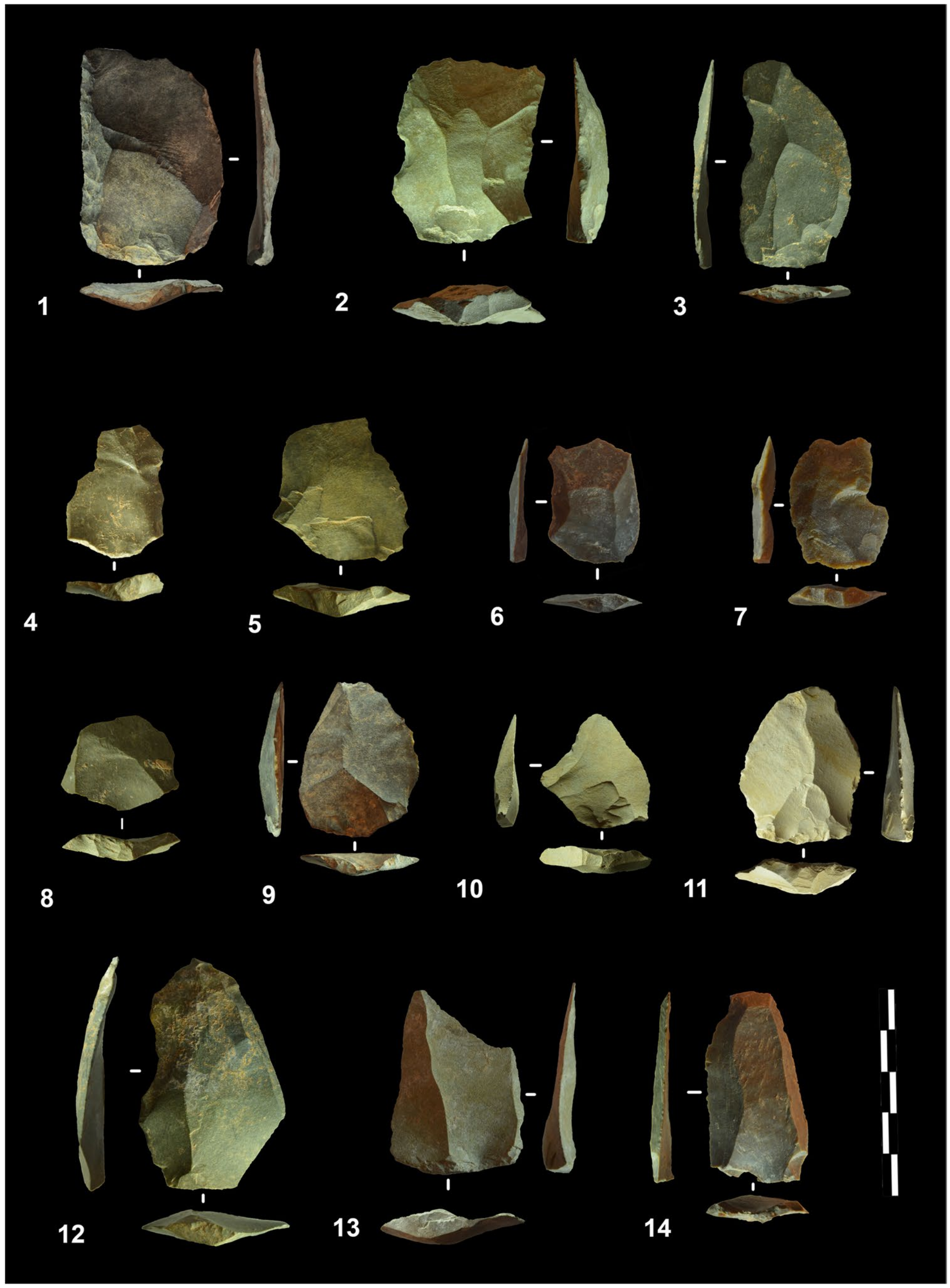

Fig. 6 Flakes products. **1**–**3** Retouched Levallois-type flake "n.1 SU30, n.2 and 3 SU3." **4**–**11** Levallois-type flake "n. 4–8 SU3, n. 9 SU30, n.10 and 11 SU2." **12**, **13** Unidirectional flakes "n. **12** and **13** SU3; n. **14** SU30"

(Table 4). Centripetal and unidirectional flakes constitute the majority in all the levels, reflecting the same trend observed for the cores. Classical Levallois flakes (Fig. 6 n. 1–11) with a finely faceted platform are numerous in all the levels but gradually decrease from SU3 (bottom of the sequence) to SU1 (Table 4).

This trend is partially reversed for flakes with plain platforms. Unidirectional flakes increase from SU3 to SU1 (Fig. 6 n. 12–14). A group of flakes, characterized by an inclined plain platform and secant scars on the dorsal surface, can be related to the secant plan cores. This group of flakes is similarly represented all over the sequence (Table 4).

Points and Micro-Points

Point Production

The production of points is the second most represented reduction strategy after flakes (Tables 2 and 3). Point cores were recovered in SU1, 2, and 29–30-31 in very similar proportions (from 20% in SU to 25% in SU29–30-31) and in smaller quantities in SU3 (5 cores, 11%). Similarly to flake cores, point cores also display varying degrees of predetermination.

Point cores can be ascribed to a Levallois-type due to the predetermined geometry and the separation of the core into two separated volumes: one used to obtain the Levallois blanks "flaking surface" and the other unexploited "reserve surface" (Fig. 7). However, the core initialization deviates from the classic Levallois configuration. There is no evidence of a clearly separated temporal phase between core configuration and exploitation. After the preparation of the striking platform, the flaking surface is initiated by the exploitation of the natural surface of the pebbles by the extraction of lateral removals (Fig. 7). The point is removed at the center of the flaking surface. Cores can produce more than one point per flaking surface (Fig. 7 n. 3, 4). In some cores, the distal convexity of the flaking surface is partially initialized by means of sub-secant transversal or opposite short removals (Fig. 7 n. 1).

A second group of cores shows a simplified exploitation. In those cores, the preparation of the striking platform is followed by a short sequence of removals, playing the double role of establishing the lateral convexity and designing the guideline for the removal of the point (SI1, Fig. S1). This procedure usually obtains only one point for each core. In some cases, the sequence is applied to large flakes. In this case, the ventral surface of the flake core plays the role of a natural pre-configured flaking surface (SI1, Fig. S1 n. 1). Throughout the sequence were found 44 Levallois-type points cores and 50 point cores with simple configurations (SI2 Table S1). The proportion of simple preparation point cores and Levallois-type point cores are similar over the sequence with the only exception of SU3. In this stratigraphic unit, the simplified configuration is predominant.

Axial points are abundant. Throughout the sequence, 469 points were identified (Fig. 8). Points range from 14 to 20% in the top levels (SU1, SU2, SU29-30–31), while at the bottom of the sequence (SU3), the percentage is lower (7.4%), confirming the same trend observed for the cores (Table 3).

Twenty-one points exhibit a tendency towards laminarization (Fig. 8 n. 1, 2). Their technological features closely mirror those of flake points, including a curved profile at the distal end and a faceted platform. These products likely stem from the same reduction process generating the flake points.

The low proportion of those laminar pointed products (4% of whole points) suggests that this combined production of pointed flakes and the laminar points is not systematic. Based on the observation made on the cores, we grouped the points into two categories: Levallois-type points with distal curved profiles and facetted butts and axial non-Levallois points with straight profiles and plain/dihedral butts. The proportion of Levallois-type points and non-Levallois points are similar all over the sequence except for the SU3, where the non-Levallois points are preponderant, representing in this layer 70% of whole points (SI2, Table S4).

Micro-Point Production

The production of convergent blanks also entails a specialized reduction strategy aimed at crafting micro-points with lengths ranging from 20 to 30 mm, measured along their technological axes. Micro points cores ($n = 12$) were found in SU1, SU2, and SU29-30–31. Only one micro-point core was found at the top of SU3 (Table 3). The micro-points are systematically produced from small cortical flakes likely collected, taking advantage of the discard derived from diverse flaking reduction strategies and selected for their suitable size and morphology. However, it is plausible that those cortical flakes were also intentionally produced to serve as cores for micro-points. In this regard, scars visible on some of the cores previously described as "simple débitage" are consistent with the size and morphology of the flake cores used to produce the micro-point (SI1, Fig. S2). Some of them were discarded after a few removals (two or three) on the cortical surface of the pebbles, and no hinged fractures are present that could justify the discard of these cores at this early stage of exploitation. The reduction strategy used to produce the micro-points follows a specific schema (Fig. 9). The initialization starts with careful preparation of the striking platform. The ventral surface of the cortical flakes naturally provides a preconfigured distal and lateral convexity of the flaking surface. A first lateral or central removal provides the ridge that will be used as a "nervure guide" to produce the micro-point (Fig. 9 Schema A).

This schema is applied to short and more elongated cortical flakes, intended to produce, respectively, large-based points and elongated narrow-base points. A second and less common schema involves preparing the flaking surface by striking one first central and two subsequent bilateral removals (Fig. 9 schema B). The ridges created by this initialization form an inverted Epsilon visible on the micro-points' dorsal surface.

Both the schema A and B led to producing one/two micro-points for each core (Figs. 10 and 11). A second generation of micro points can occur, taking advantage of the ridge created by the first production sequence (Fig. 10 n. 4). Only one core from SU2 shows a longer series of removals (Fig. 10 n. 2).

The configuration of the flaking surface is not necessary because the ventral surface of the flake cores provides the essential technical requirement for starting the débitage. However, some cores exhibit traces of minimal corrections of lateral and distal convexities (e.g., Fig. 10 n. 3). As elucidated above, micro-points result from a systematic

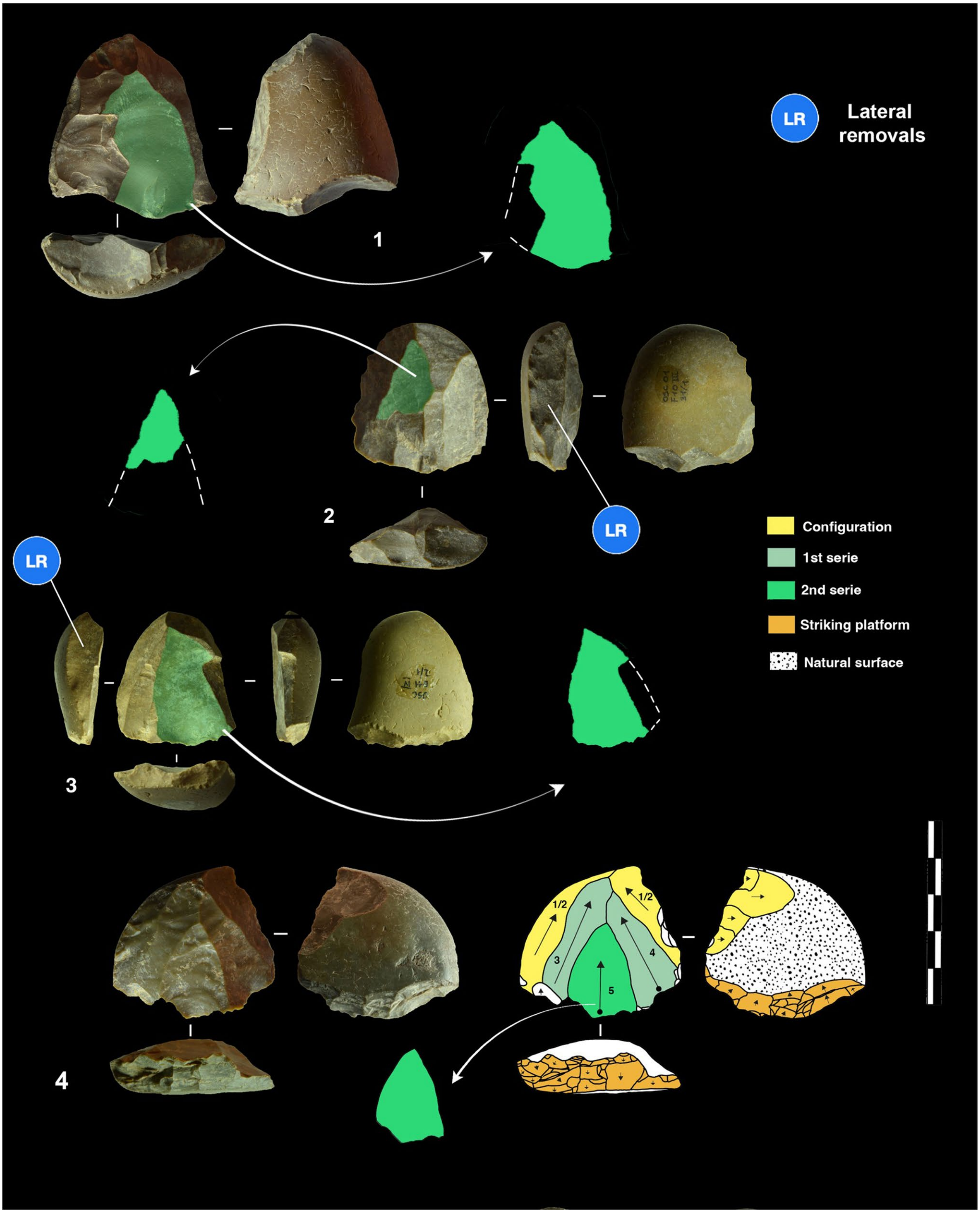

Fig. 7 Point cores. **1** Point-cores from SU2 with transversal distal preparation. **2** Point-core from SU29. **3** Point-core from SU2 with transversal distal preparation. **4** Point core from SU31 with the production of two generations of points visible on the flaking surface

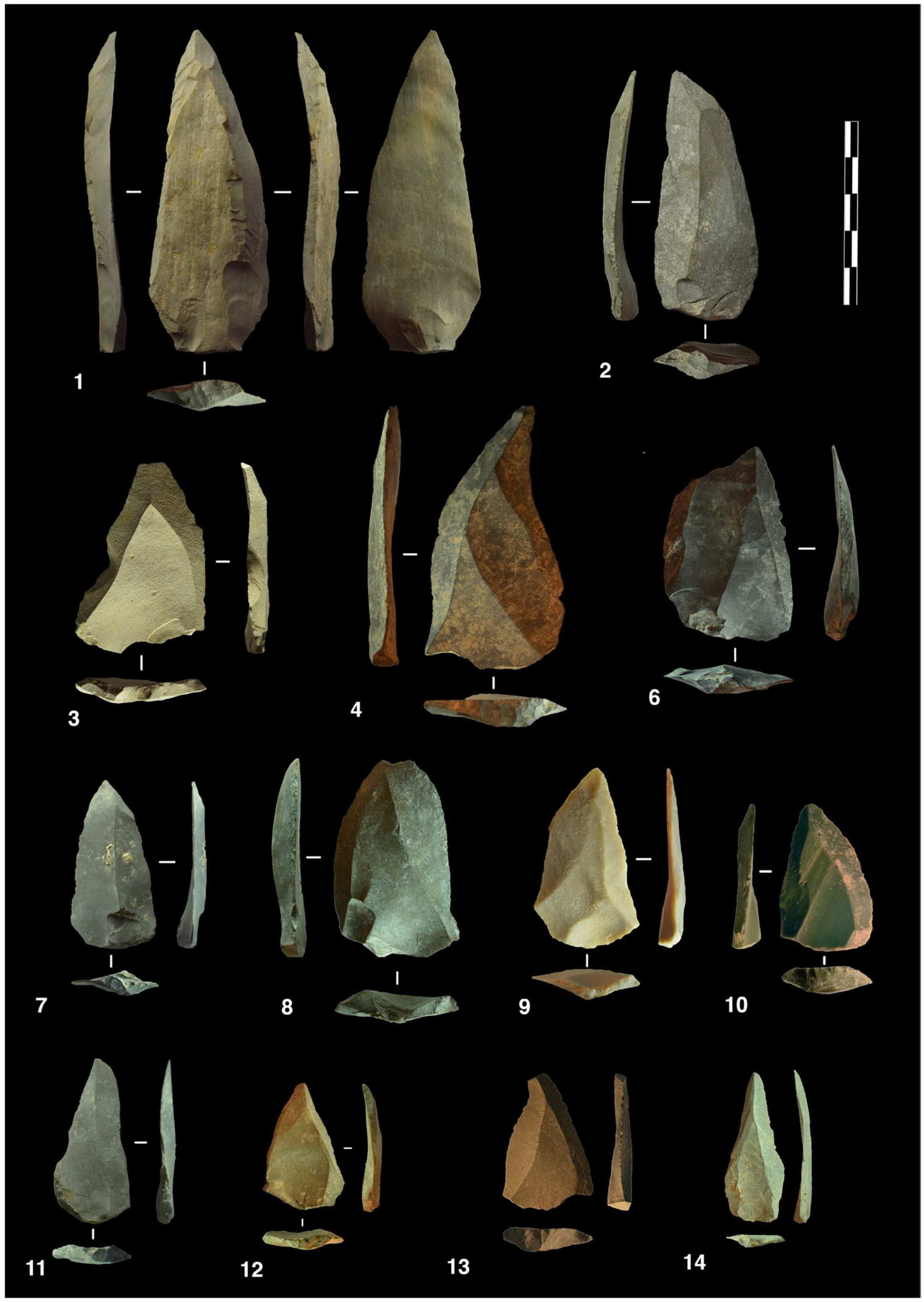

Fig. 8 Convergent axial points. **1** Laminar points from SU30. **2** Retouched laminar point from SU31. **3** to **14** Axial points from SU2 and SU29–30-31

exploitation of cortical flakes. Nevertheless, two cores in sub-layer 31 showcase an intercalated production of points and micro-points, taking advantage of the ridges left by the first production of points (Fig. 12). This secondary production aligns in terms of morphology and dimensions with the negatives visible on the micro-point flake cores. Those cores suggest that micro-points and points production are part of the same technological signature.

Throughout the sequence, 69 micro-points were identified. The outline morphology of the micro-points corresponds to the shape of the last successful scars observed on the cores (Fig. 13 A versus B). Micro-points are concentrated in the middle part of the sequence studied, SU2 and SU29–30-31 (Table 2). Only four micro-points were discovered in SU3, all located at the uppermost part of this layer, and five in SU1. The platforms of micro-points exhibit meticulous preparation, confirming what is observed in the corresponding cores. The 80% of the micro-points show a faceted platform (SI2, Table S5).

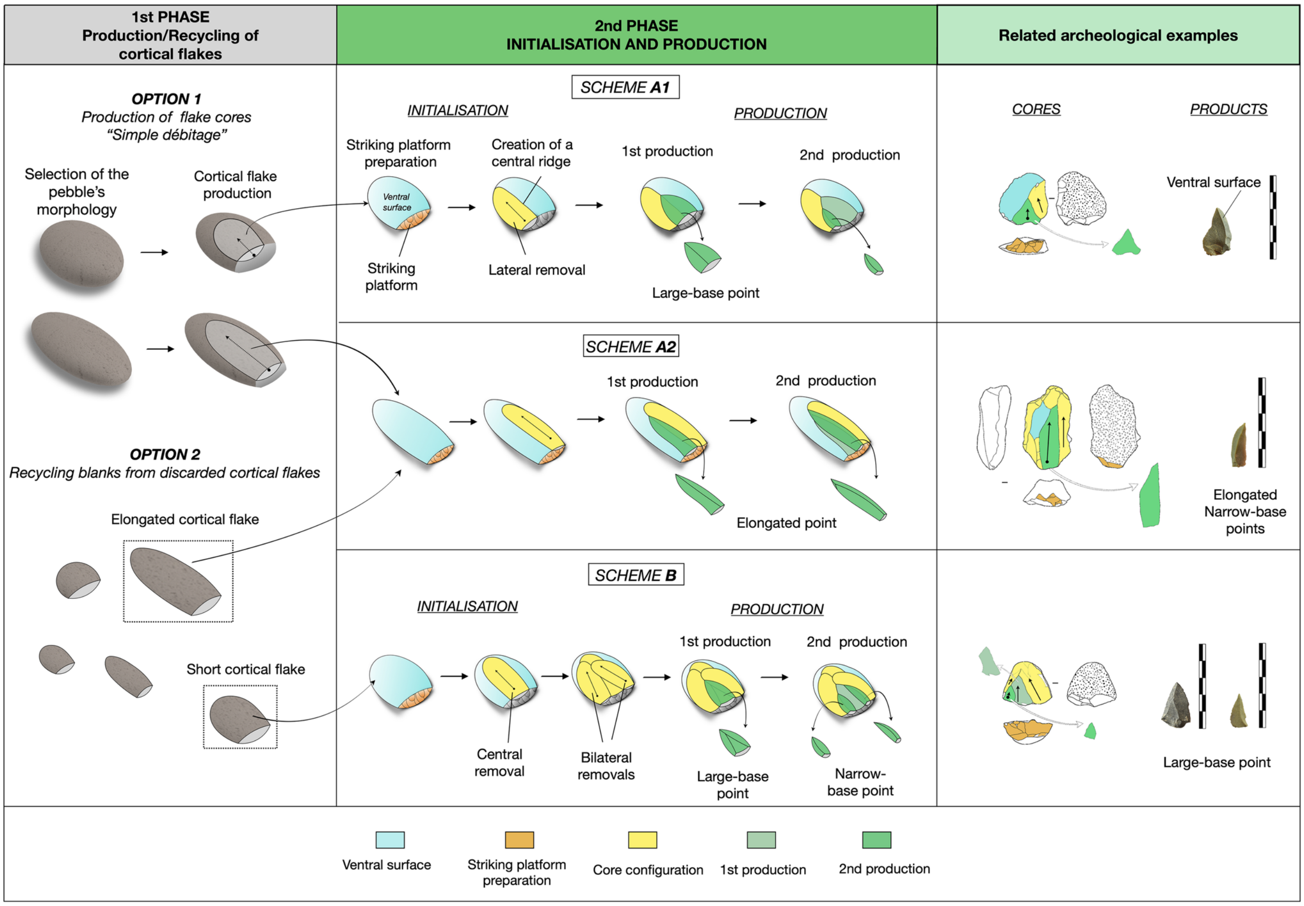

Fig. 9 Micro-points reduction strategies

Blades and Bladelets

Blade Production

Laminar technology was identified in SU1, SU2, and SU29–30-31 in comparable proportions ranging from 12 to 10%. In SU3, blades are notably more sporadic, accounting for only 3% of the blanks. Blade cores were exclusively discovered in SU2 (n. 3) and SU29–30-31 (n. 7) (refer to Table 3). All blade cores show parallel unidirectional exploitation patterns (Fig. 14). The configuration of the blade cores is minimal and is strictly based on a careful selection of the natural pebble's morphology. Crested blades are absent. After the selection of the pebble, the initialization of the core only foresees the preparation of the striking platform. The débitage starts directly with the extraction of cortical blades. Elongated cortical blanks are present all throughout the sequence (SI1, Fig. S3; SI2, Table S7). The débitage progression was guaranteed by the extraction of debordant blades contributing to the maintenance of the lateral convexities of the core (see Fig. 14). Blade cores were often discarded due to the presence of hinged fractures (Fig. 14 n. 1, 2, 4). In some cases, hinged fractures have resolved through the extraction of thick plunging blades with the aim of re-establishing the volume for a second series of removals (Fig. 15). Core rejuvenation tablets are absent, which is likely due to the small size and morphology of the available/selected pebbles.

Throughout the sequence, 221 entire blades and 132 fragmented blades were identified (SI2, Table S6). According to the minimal number, the proportion of blades ranged from 12.8% in SU1 to 3.1% in SU3 (see Table 2). The low number of blade products in SU3 reflects the same tendencies observed for the cores.

Blade products include distal convergent blades, parallel edge blades, and debordant blades, preserving a natural lateral back (Fig. 16). The large majority of full débitage blades present parallel edge and unidirectional parallel scars confirming what is observed on the blade cores (SI2, Table S7). Distal convergent blades are present in a small proportion (from 8% in SU29–30-31 to 14% in SU1).

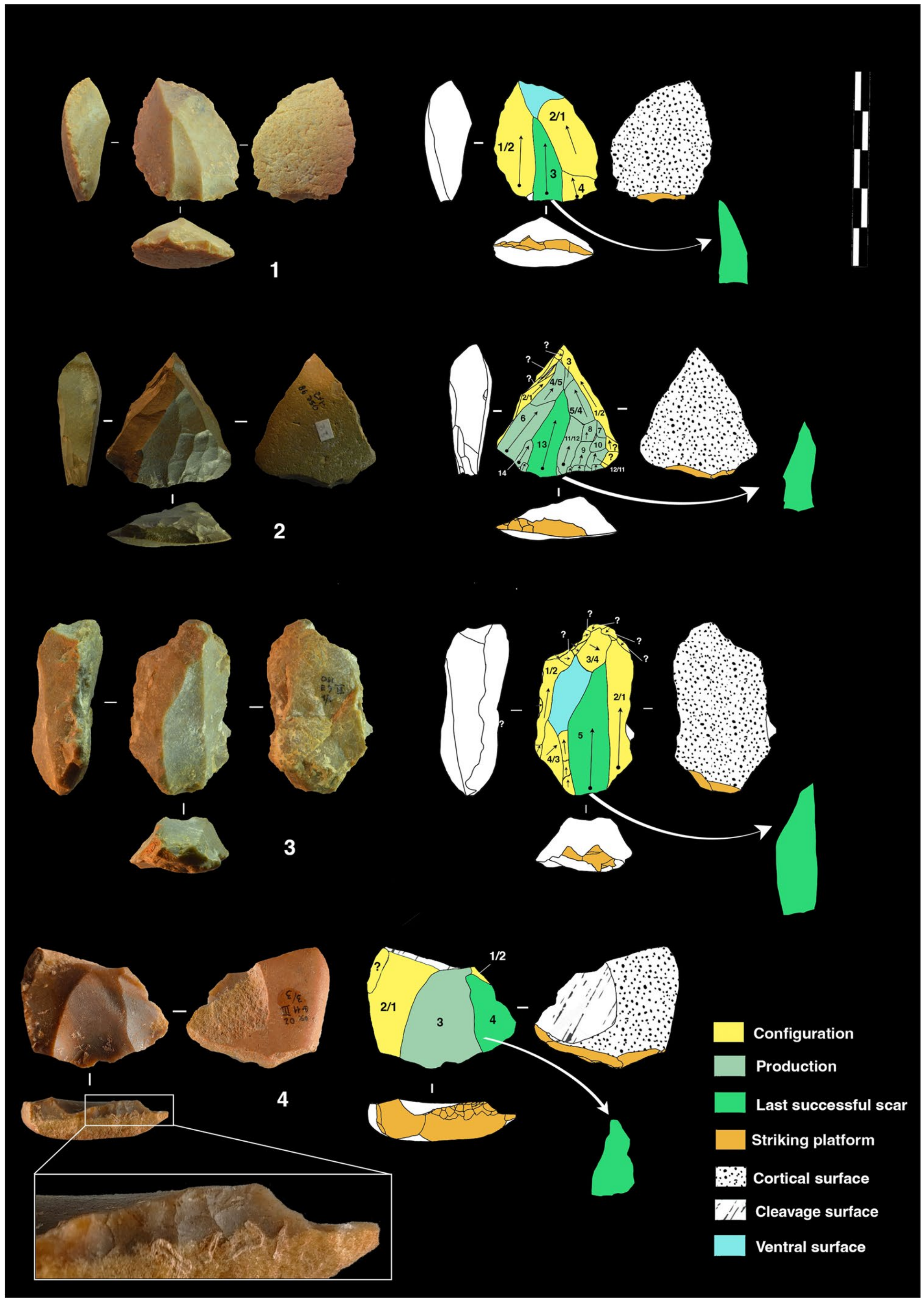

Fig. 10 Micro-point cores from SU1, SU2, SU29–30-31, and SU3

Bladelet Production

Bladelet cores ($n=16$) were found in SU1, 2, and 29–30-31 (Table 3). A total of 99 complete bladelets and 188 fragments were recovered (SI2, Table S8). Bladelets were found in all the layers studied in similar proportion except the SU3, where only three complete bladelets and fourteen fragments were found, all recovered at the top of this layer (SI2, Table S8).

In contrast with what was observed for the micro-point production, we do not notice for bladelets the same univocal choice of cortical flakes. Flakes, chunks, and small elongated pebbles were selected to produce bladelets (Fig. 17). Bladelet cores are exploited by parallel unidirectional removals. Core configuration mainly foresees the preparation of the striking platform and the direct extraction of the first removals on the natural edges of the volume selected. The sporadic preparation of the flaking surface is, however, attested by the

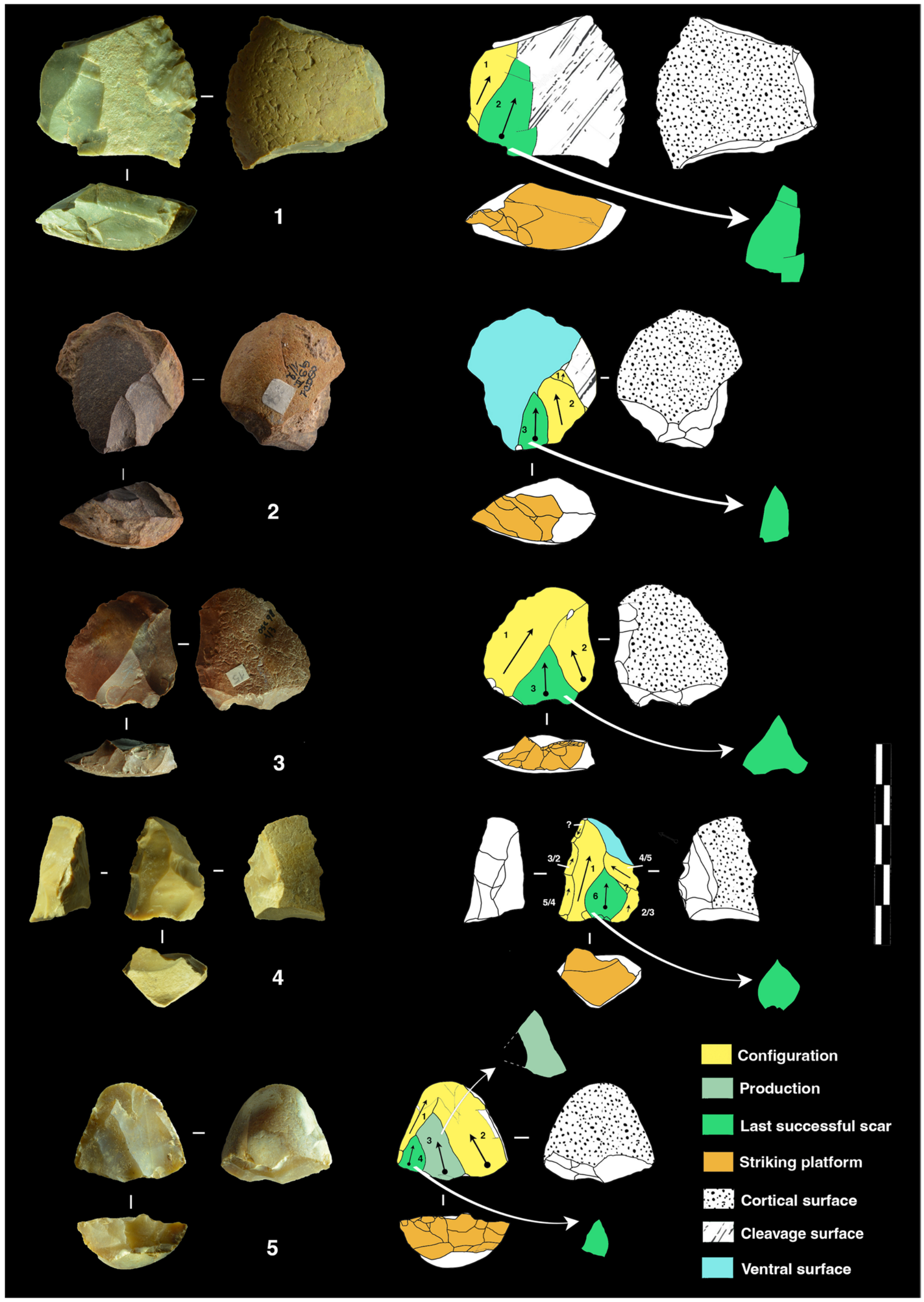

Fig. 11 Micro-point cores from SU1 and SU2 and SU SU29–30-31

presence of six crested bladelets found in SU1, SU2, and SU29–30-31 (Fig. 18 n. 8, 9; SI2, Table S9).

There is no indication of systematic maintenance of the cores. Core rejuvenation tablets are absent.

The lack of preparation and maintenance of distal convexities on the flaking surface is the cause of frequent hinged fractures and the subsequent abandonment of the core after a short series of removals. Cores generally show one to three successful scars on the flaking surface. The use of a short sequence of removals is confirmed also on the product. For the large majority, bladelets show one or two scars on the dorsal surface. Proportions of bladelets with three dorsal scars range only from 33% in SU1 to 17% in SU3 (SI2, Table S10). Platform edge abrasion and trimming are occasionally present and can be associated with the sporadic use of marginal percussion. However, all the features indicate the use of hammer-stone by internal percussion: straight profile, prominent bulb, and visible fracture initiation point (SI2, Table S11, S12). Unidirectional parallel exploitation is aimed at obtaining bladelets

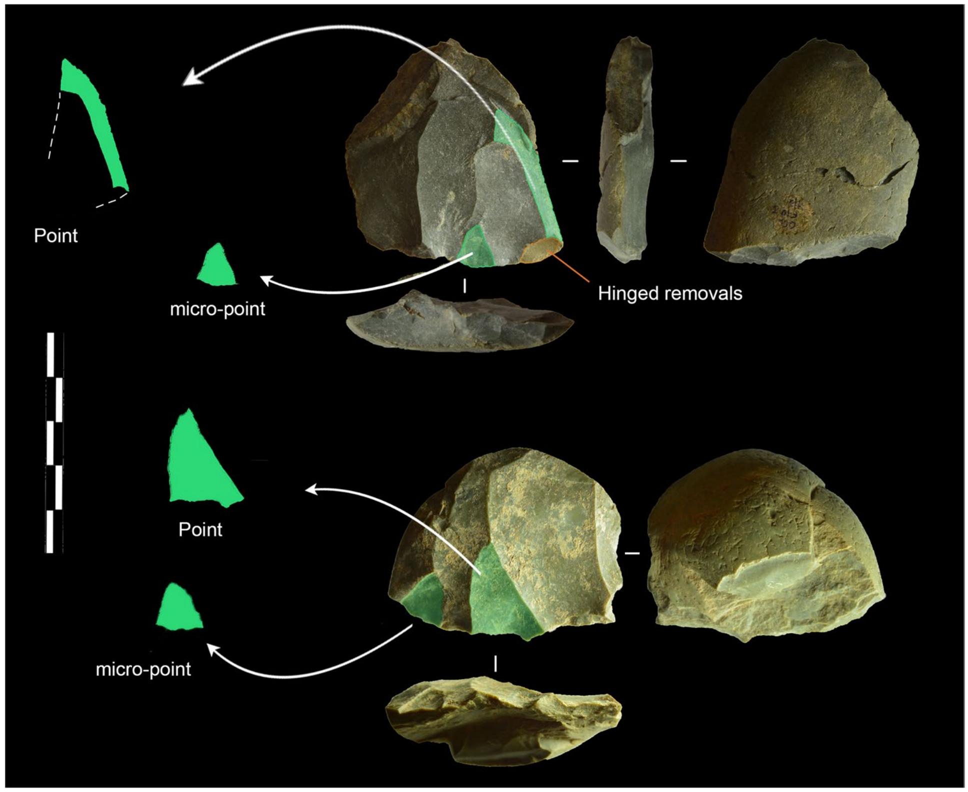

Fig. 12 Point cores found in SU31 showcasing the combined production of points and micro-points

with parallel edges. Only four convergent bladelets were found (SI2, Table S9).

Two truncated faceted cores show a careful preparation of the striking platform and the exploitation pursuit on the dorsal surface of the flakes "Kostienky type." One of those cores exhibits an intercalated production of micro flakes—extracted on the center of the flaking surface—and bladelets laterally removed on both sides of the core (Fig. 17 n. 6). The second core is quickly abandoned due to the presence of a hinged fracture (Fig. 17 n. 5).

Retouched Tools

Throughout the sequence studied, 443 retouched pieces were identified (Table 5). In SU1, SU2, and SU29-30–31, the proportion of retouched pieces is similar and ranges from 13.8% in SU1 and 9.6% in SU29–30-31. In SU3 the proportion is lower (5.5%). Points are the most frequently retouched (from 31% in SU1 to 17.4% in SU3). Two points show a marginal inverse lateral retouch. At the state of the research is not possible to clearly establish the nature of this marginal modification. Intentional retouching, use traces, or taphonomic origin need to be confirmed (Fig. 19 n. 7, 8). A high proportion of retouched pieces is also present for blades in SU1 (24.6) and SU3 (25%). Cortical flakes are rarely retouched (Table 6). Retouch rarely modifies the shape of the blanks and usually only regularizes the cutting edge without changing the original morphology. Typologically, flakes and blades fall into the scrapers category. The retouching of points is, in rare cases, more invasive and modifies both the edges and the tip of the point (Fig. 19 n. 2–6). Only two micro-points are marginally retouched (Fig. 13 n. 16, 24).

Summary

The lithics studied from the top of the Oscurusciuto sequence (SU1, 2, 29–30-31) are composed of a wide variability of products (Fig. 20). Flakes, blades, bladelets, points, and micro-points are the result of independent reduction strategies. Laminar production is confirmed by the presence of several clear technological elements (cortical blades, products, cores), including intermediate stages of blade production represented by rejuvenation blanks (see Fig. 15). The absence of blade cores in SU1 can be attributed to its very limited extension. However, this layer shows the same evidence of blades, bladelets, points, and micro-points (both cores and products). The technological pattern is then identical to SU2 and SU29-30–31. Bladelets cannot be interpreted as an "accidental" feature. Bladelet production includes cores, products, and by-products such as semi-cortical and cortical bladelets and occasionally crested bladelets (see Fig. 18). Micro-points do not result from the Levallois concept, setting them apart from conventional Middle Paleolithic production.

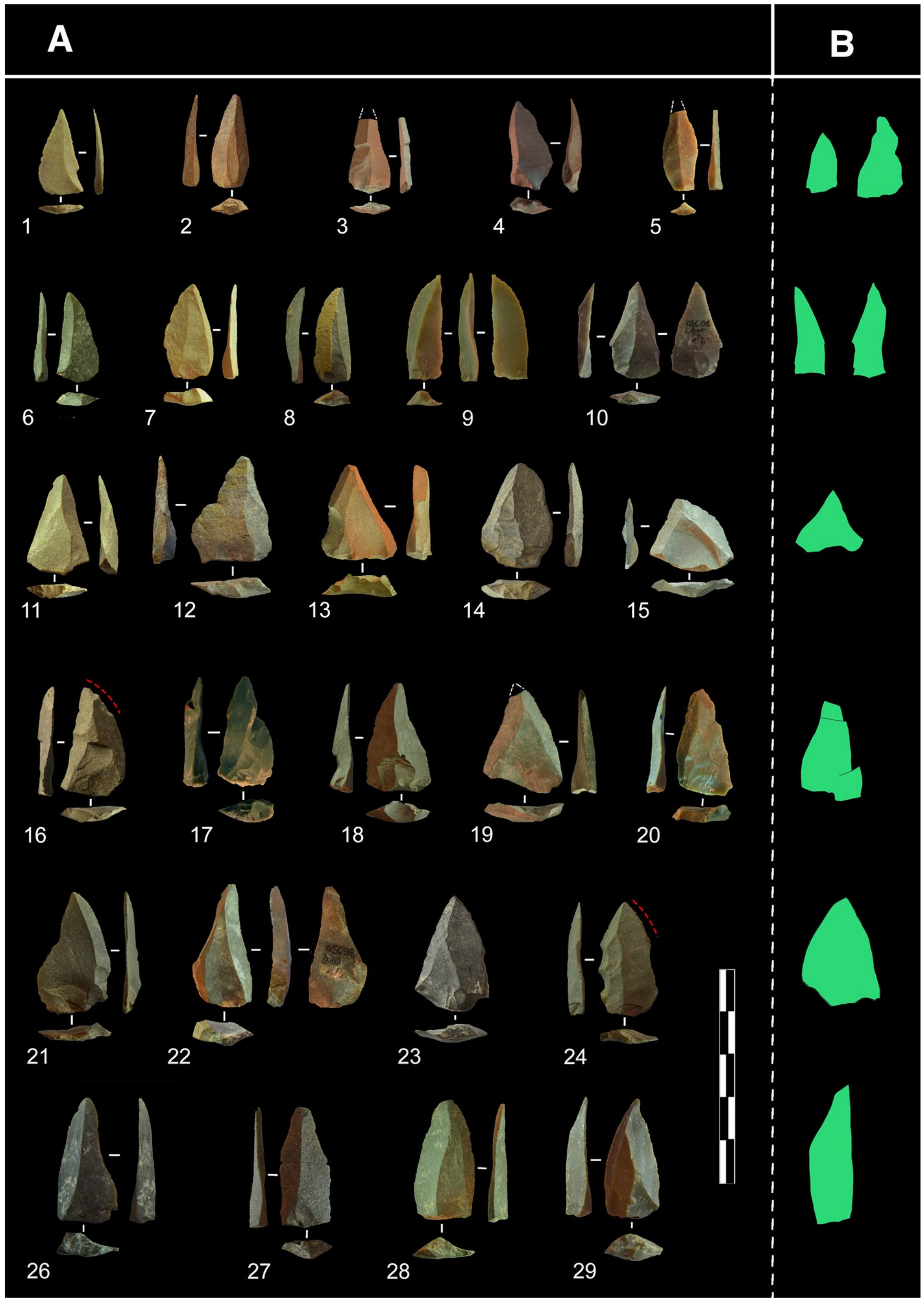

Fig. 13 Micro-points from SU1, SU2, and SU29–30-31. **A** Archeological artifact. **B** Outline morphology corresponding to the shape of the last successful scars observed on the micro-point cores. **16** and **24** Retouched micro-points

The SU3 displays several divergences with no relation to the other layers. In this layer, the toolkit is dominated by Levallois production. Levallois cores in this layer represent 41% of all the flake cores, while the upper layers Levallois cores only range from 11% in SU2 and 19% in SU29–30-31. Only a few bladelets (10 out of 164) and micro-points (4 out of 65) were recovered, uniquely at the top of this layer. Considering also that SU3 is the largest excavated area (5 m), those small lithic elements are likely infiltrated from the upper layers. Yet, the lack of bladelet cores and the presence of only one micro-point core, which is also found at the top of this layer, reinforce this hypothesis. Blades and axial points are present in all the layers studied, but again, SU3 stands out for a significantly smaller percentage of both of those techno-types. Axial points account for 3% in SU3, unlike the 10–13% found in other levels. Blades constitute 7% in SU3, contrasting with the 14–20% observed in the other levels.

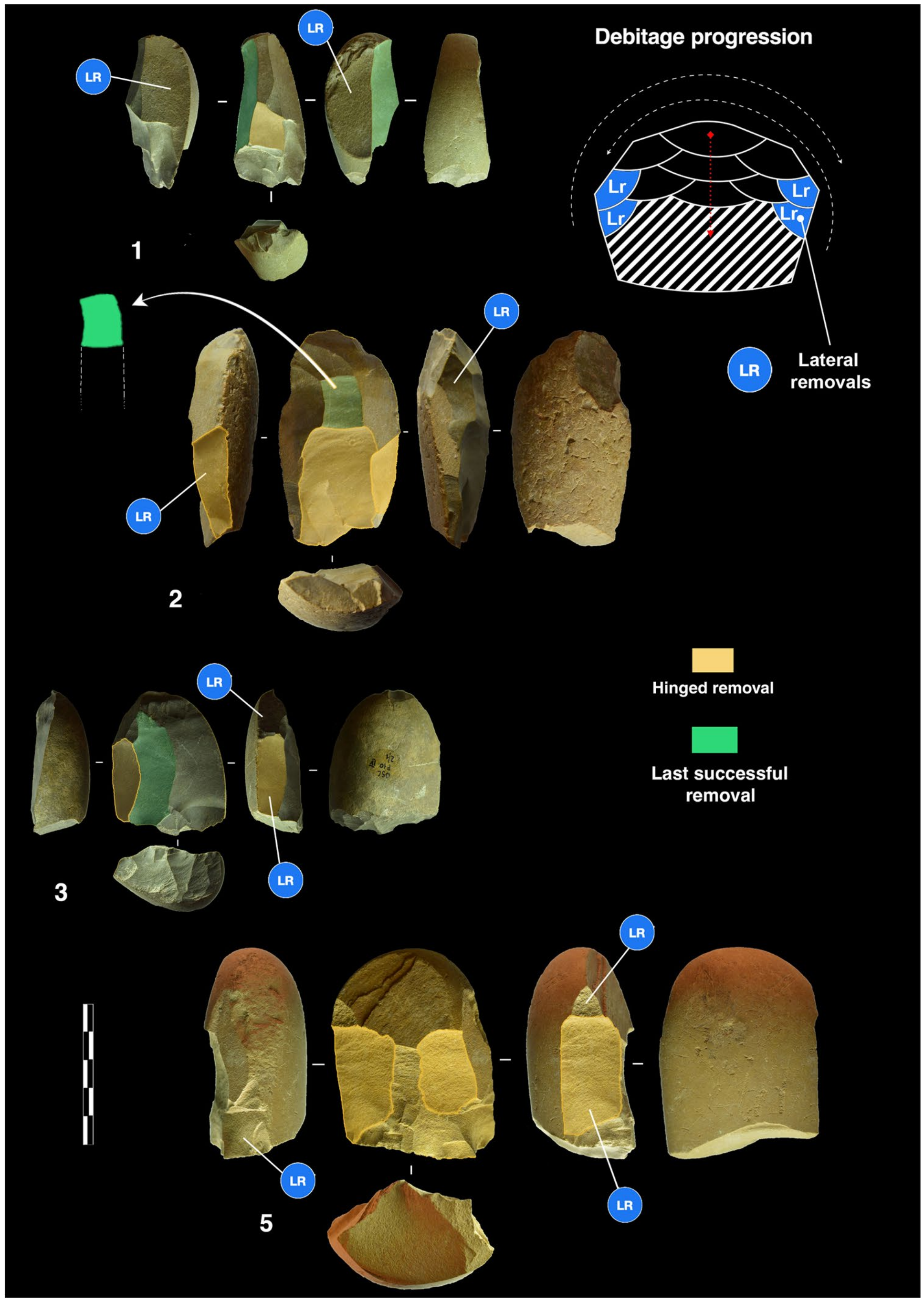

Fig. 14 Blade cores. **1** and **3** Blade core from SU2. **2** Blade core with preparation of distal convexities from SU31. **4** Blade cores from SU31

Raw materials used are strictly local, including different lithotypes (flint, radiolarite, quartzite, silicified limestone), and were collected in the form of pebbles of different morphology and size. The adaptation to pebble morphology is visible in both flake and blade production. The selection of technical criteria that are naturally present in the initial block was used, in certain cases, to "simplify" the Levallois core configuration. This simplified procedure is also visible for blade production, where the initialization is mainly based on the selection of technological criteria already present in the material: selection of elongated pebbles and first exploitation through the extraction of a cortical elongated blade. This choice of pebbles, depending on the production, was also observed in the deeper layers of Oscurusciuto (Spagnolo et al., 2020).

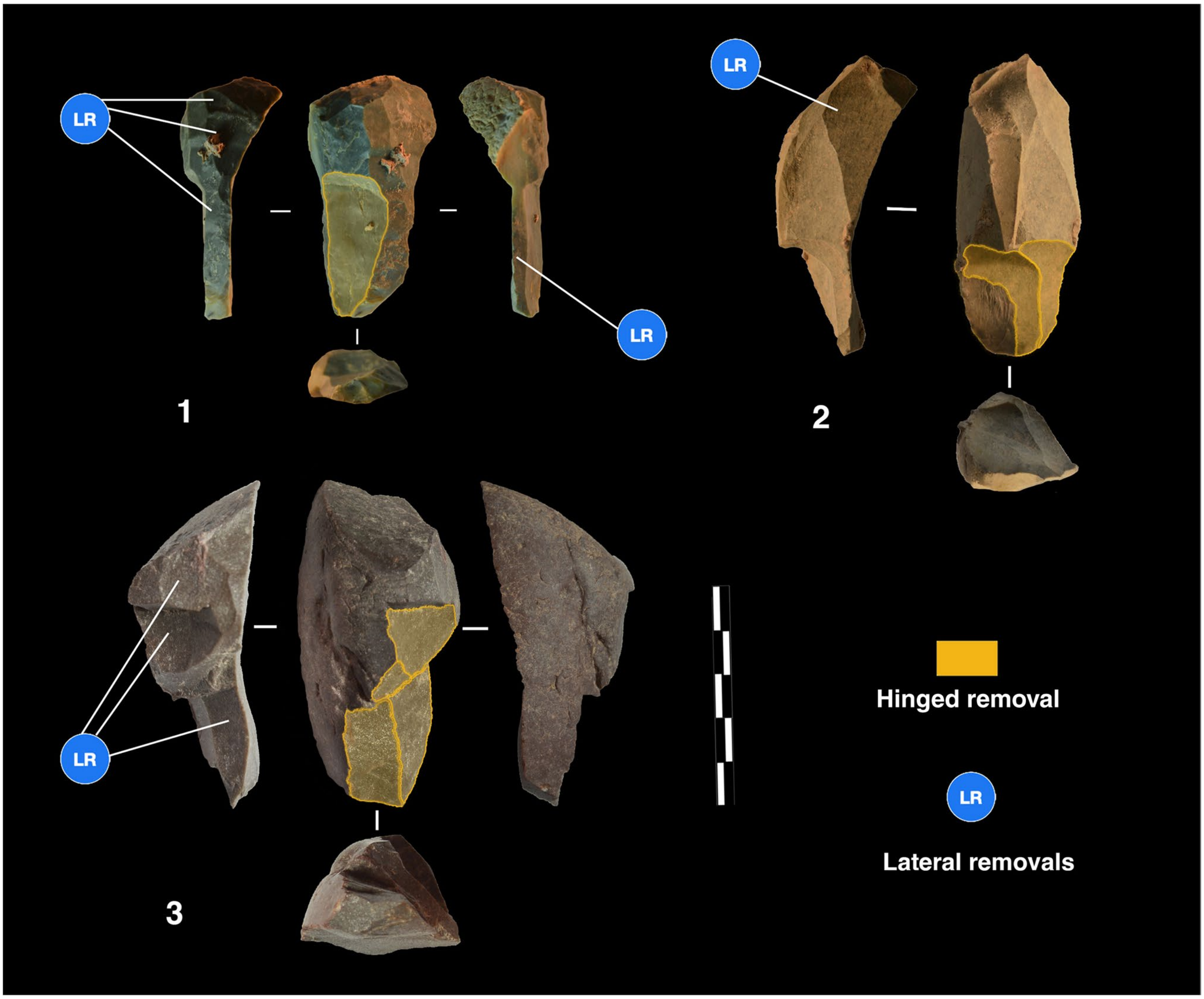

Fig. 15 Plunging blades from SU2 and SU29–30-31. **1** and **2** Plunging blades removed in an advanced stage of production from SU30 and SU31. **3** Plunging blade removed at the initial stage of the core reduction from SU29

Discussion

Oscurusciuto in the Italian Late Mousterian Context

The uppermost layers of Riparo l'Oscurusciuto (SU1, SU2, SU29-31) showcase a varied composition that includes points, micro-points, blades, and bladelets alongside a more conventional Middle Paleolithic background. At present, the conformation of this assemblage represents a distinct occurrence for the Italian peninsula. Certain techno-typological aspects identified at Oscurusciuto are not entirely absent in the Late Middle Paleolithic of Italy. Blade production has been documented in several Mousterian sites across Italy. In northern Italy, notable examples include Grotta di Fumane, Riparo Tagliente, and Riparo Mochi (Carmignani, 2017; Frouin et al., 2022; Grimaldi & Santaniello, 2014; Peresani, 2012; Peresani & Centi Di Taranto, 2013). In central Italy, Grotta Reali exhibits a Middle Paleolithic background characterized by Levallois and discoid methods, along with laminar production incorporating bladelets produced within a continuous volumetric blade reduction system (Peretto et al., 2020). Riparo del Poggio, on the other hand, is notable for its laminar technology alongside Levallois production (Boscato et al., 2009; Caramia, 2008; Caramia & Gambassini, 2006). Conversely, Grotta del Cavallo exhibits the coexistence of volumetric laminar technology associated with Levallois and an independent bladelet reduction strategy (Carmignani & Sarti, 2018; Carmignani et al., 2020).

The production of axial points is known in the Late Middle Paleolithic of the Italian peninsula. However, based on the available data, the proportion of points is typically very low and usually less than 5% (SI2, Table S13). In contrast, at

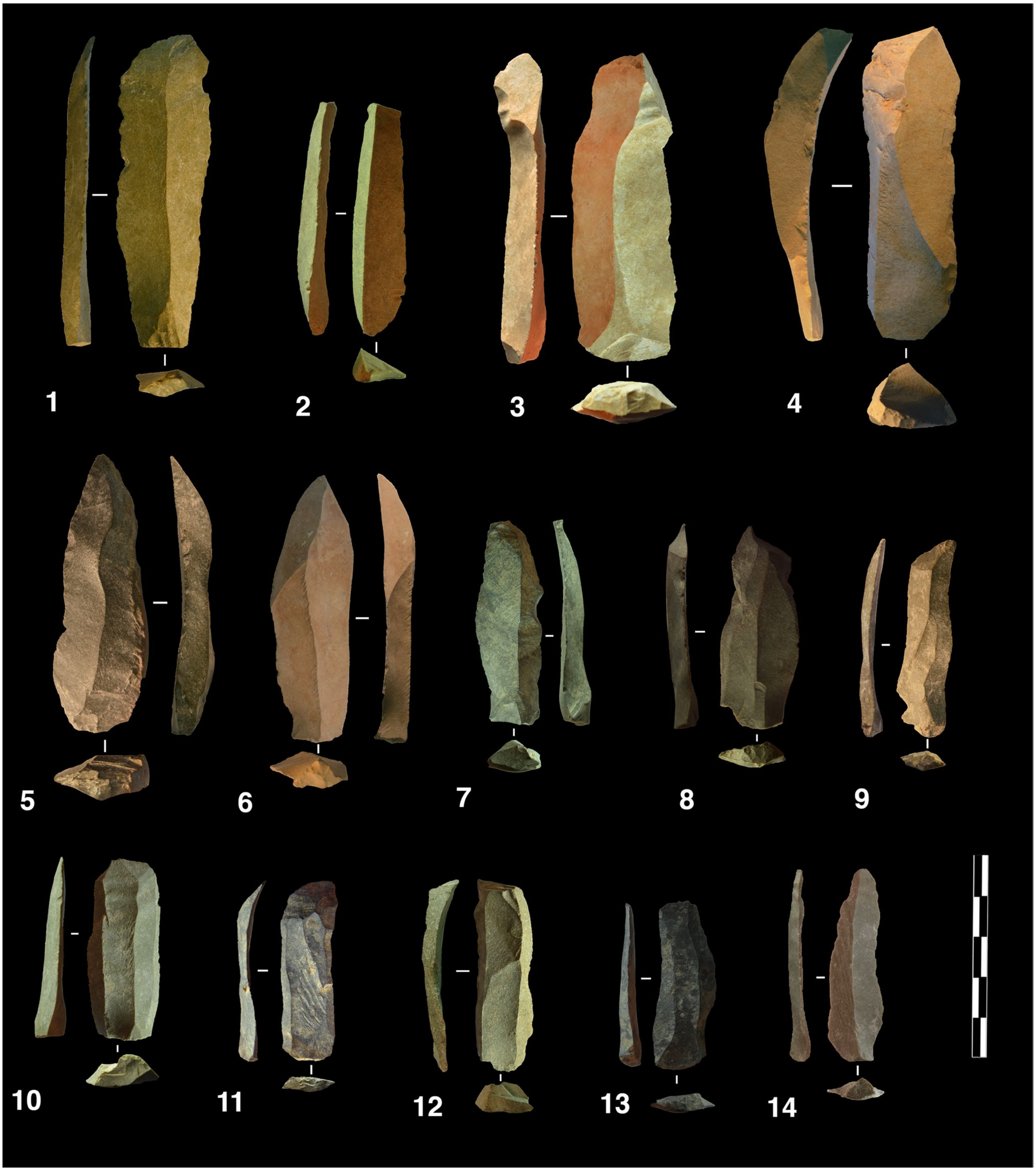

Fig. 16 Blades from SU2 and SU29–30-31. **1** Distal cortical blades. **2**, **4** Debordant blades. **5**, **6** Distal convergent blades. **7–14** Parallel edge blades

Oscurusciuto (SU1 to 31), points account for 14 to 20% of the blanks, making them the second most common production target after flakes. This percentage is notably unusual in the context of Italian Middle Paleolithic sites. The only site exhibiting a similar percentage of points (19%) is Grotta di Castelcivita (Gambassini, 1997). Interestingly, this site also yielded a relatively high proportion of laminar products (12%) and possibly bladelet production if we speculate that the burin

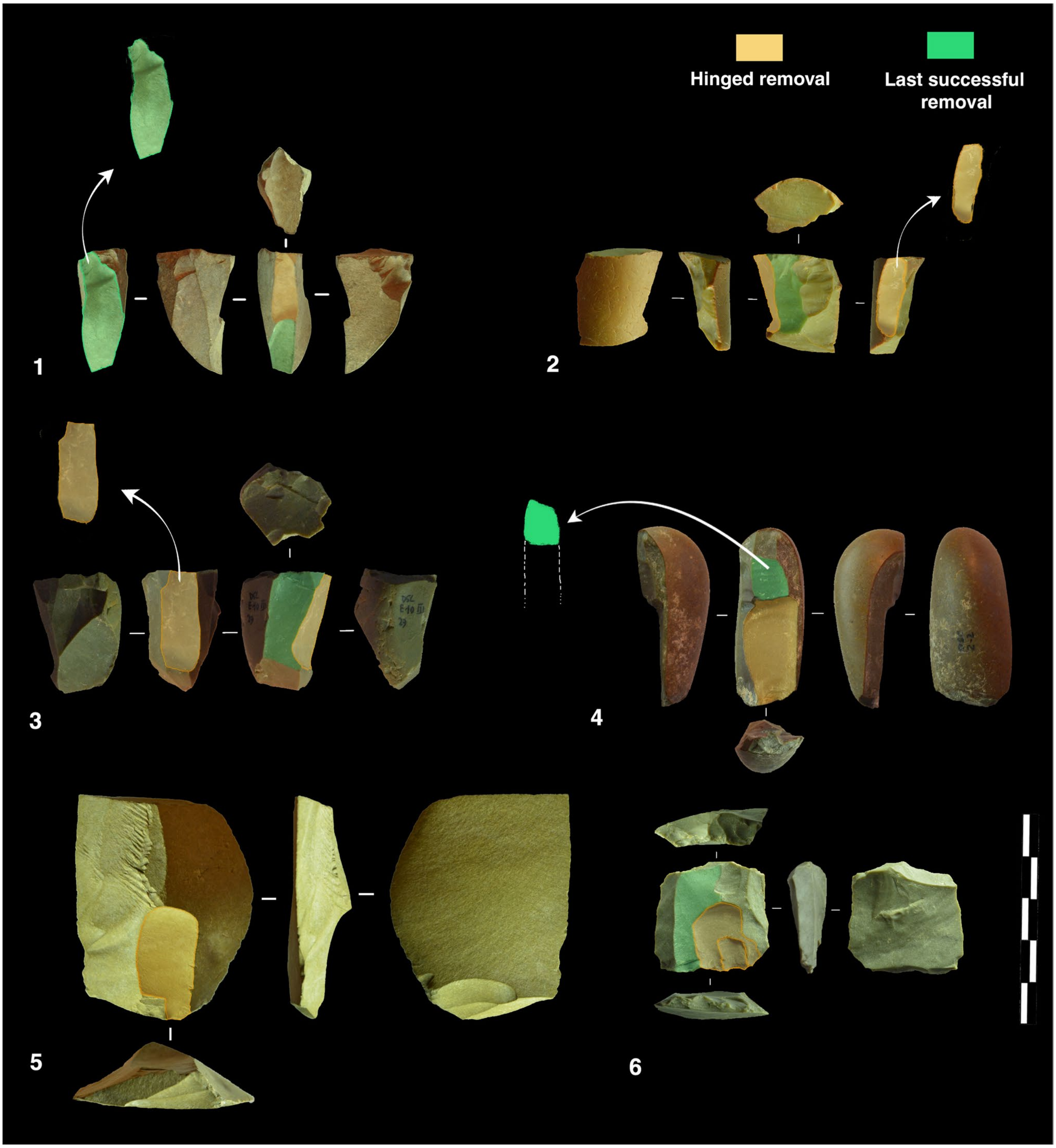

Fig. 17 Bladelets cores. **1**, **2** Bladelet core on flakes from SU2. **3** Bladelet core on a chunk from SU29. **4** Bladelet cores on a small pebble from SU2. (**5** and **6**) Truncated faceted cores "Kostienky types" from SU2 and SU30. Number 5 is abandoned after hinged step removals. The faceted truncation is visible on the proximal part of the piece and extends onto the ventral surface

cores illustrated were used as bladelet cores. In the description, Gambassini refers to this assemblage as the "Musteriano evoluto" (evolved Mousterian) and establishes a connection with Level FIIIe of Grotta del Cavallo (see Fig. 21). It is important to notice that these two sites are not far from Oscurusciuto: Grotta del Cavallo is located 120 km southeast, while Grotta di Castelcivita is 130 km to the west. Concerning Level FIIIe of Grotta del Cavallo, the resemblance to Oscurusciuto is even more pronounced, suggesting a similar association of Levallois with independent blade and bladelet

Table 5 Minimal number of retouched pieces throughout the sequence

Levels	Count	Retouched N	Retouched %
SU1	575	92	*13.8*
SU2	1143	123	*9.7*
SU 29–30-31	1493	159	*9.6*
SU3	1178	69	*5.5*
Total	4389	443	*9.2*

reduction strategies (Fig. 21). However, at Grotta del Cavallo, the percentage of points is significantly lower, and there is no evidence of micro-points (SI2, Table S13). The identification of micro-points at Oscurusciuto would, therefore, be a distinctive feature. However, it is important to account for two factors that could potentially influence this apparent uniqueness at Oscurusciuto: the excavation methodology and the level of detail in the analysis of lithic assemblages. At Oscurusciuto, dry and wet sieving with a 1 mm diameter mesh was performed, and whole assemblages, including micro-debris, were thoroughly studied. Consequently, it is worth exploring whether the perceived absence of micro-points in other LMP assemblages might be influenced by research biases.

Furthermore, it is necessary to note that micro-points, unlike Levallois flakes, blades, or large points, have only recently gained attention from researchers thanks to a recent discovery at Grotte Mandrin (Metz et al., 2023; Slimak et al., 2022). For instance, the assemblage of the level FIIIe at Grotta del Cavallo was studied more than 10 years ago by one of us (Carmignani, 2010), and at that time, this specific micro-lithic production may have gone unnoticed. In this respect, small convergent flakes were also noticed at Oscurusciuto in SU11 (Marciani, 2018). However, at this stage of research, it is not possible to state if these small tools found in the lower levels are comparable with the micro-points described in this paper.

Taking a more extended view of the Italian Middle Paleolithic, the contrast between the late Mousterian and older assemblages is evident. During MIS 4 and MIS 5, Mousterian assemblages exhibit a dominant flake-based production. The emergence of more "complex" associations, including blades, bladelets, and points, becomes evident only during MIS 3 (Fig. 22). The phenomenon of "laminarization", for instance, appears to occur relatively late, between 60,000 and 40,000 years ago. Prior to MIS 3, the only site exhibiting blade volumetric production is Santa Croce, dated to the end of MIS 4 (Arrighi et al., 2009; Boschin et al., 2022). Intentional production of bladelet is attested only in MIS 3, with the exception of Riparo del Molare, where an ephemeral bladelet reduction sequence is represented by some isolated burin cores found in levels dated to MIS 5 (Aureli & Ronchitelli, 2018; Ronchitelli et al., 2010).

The second prominent difference between MIS 3 and MIS 5–4 pertains to the production of predetermined axial-convergent points, which appear to be lacking during MIS 5–4, whereas they are quite common in the late Mousterian (SI2, Table S13). In some cases, such as Grotta di Castelcivita, axial points are present in relatively high proportions, reaching 19.4% (Gambassini, 1997).

Moreover, specific associations in the same assemblages, such as flakes-points-blade-bladelets and flakes-blade-point, were unknown prior to MIS 3 (Fig. 22). In general, what emerges is an increase in technological variability during MIS 3, both quantitatively and qualitatively. Our analysis at Oscurusciuto reinforces this pattern and suggests the presence of a larger variability that went unnoticed until now. It is also noteworthy that this apparent turnover in technology coincides with the emergence of IUP in Europe.

Out-of-Italy Comparisons

The variability found at Oscurusciuto does not find any precise correlation in the Italian peninsula. The manufacturers of bladelets, axial points, and laminar blanks, associated or not with Levallois-like technology, characterize instead the IUP techno-complexes that emerged in Europe between 55 and 40 thousand years ago and that chronologically corresponds with the latest layer of Oscurusciuto.

Recently, the Neronian has been in the spotlight thanks to the discovery at Grotte Mandrin (France) of a deciduous tooth assigned to modern humans and found in association with a specific assemblage (Slimak et al., 2022). The Neronian industry is focused on the production of blades and bladelets with a very high proportion of points. A specific flaking reduction strategy described as "schéma croisé" was employed to create small points ranging from 10 to 30 mm (Slimak et al., 2022). This reduction strategy was observed to be similar to the one utilized in the IUP levels of Ksar Akil and is described as follows: "*The left part of the core is a ventral surface. The extraction of the micropoint is precisely located in between the flaking surface of the right and the ventral surface of the left of the core. This "schéma croisé" allows the obtention of a (micro)point showing perfect axial and transversal symmetry and having one of its flanks composed of a positive surface"* (Slimak et al., 2022 p. 57, suppl. materials). This procedure is similar to the schema A1 at Oscurusciuto (see Figs. 9 and 23). The micro-point discovered at Oscurusciuto shares several similarities with this description:

- The micro-points are obtained from a distinct reduction strategy.
- The ventral surface of blanks is used as a flaking surface for the production of micro-points (see Fig. 23).
- Micro-points are left unretouched.

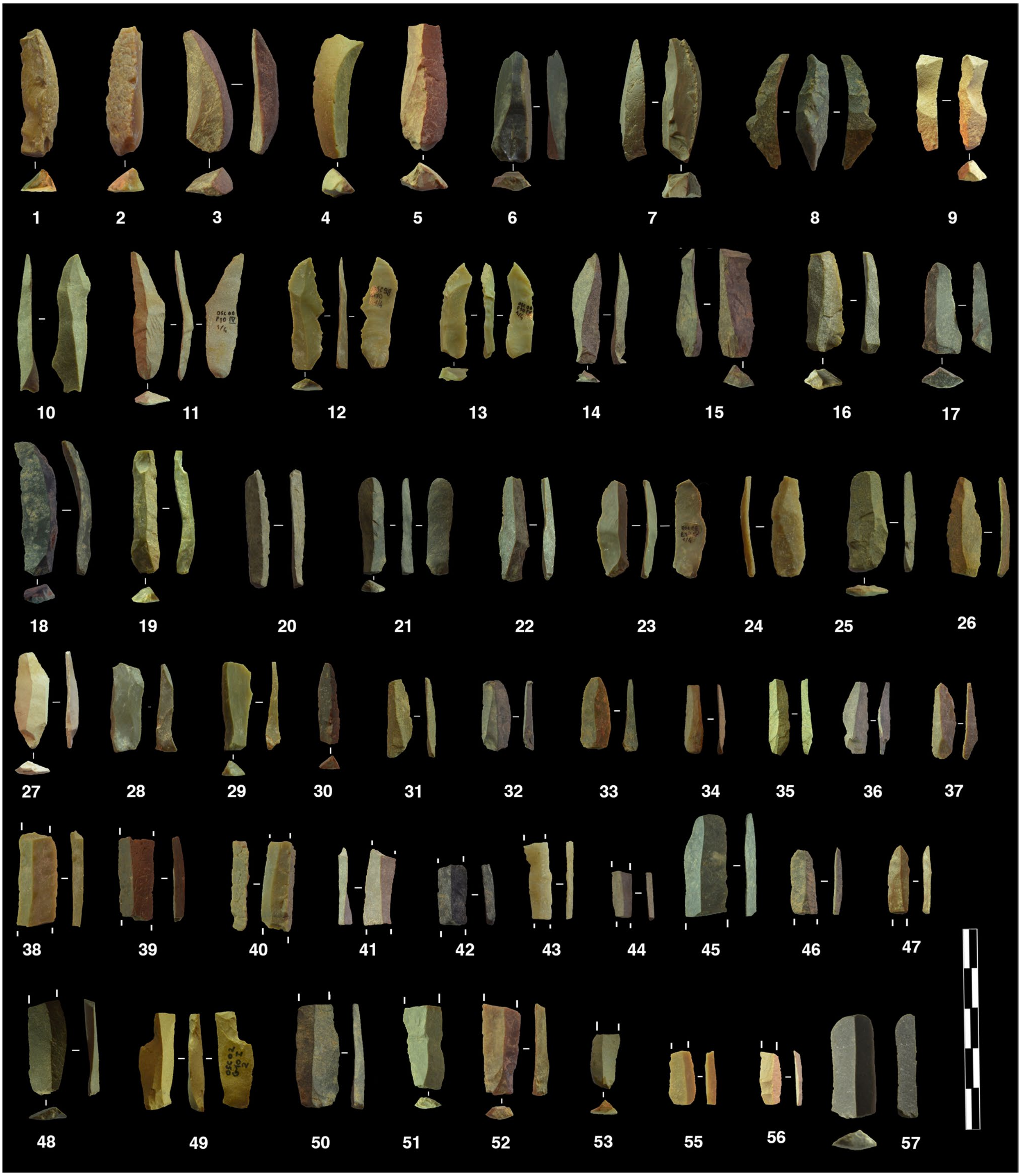

Fig. 18 Bladelets from SU1, SU2, and SU 29–30-31. **1–7** bladelets with residual cortex. **8**, **9** Crested bladelets. **10–37** Complete bladelets. **38–57** Fragmented bladelets. **49** Proximal fragments with lateral distal inverse retouch

Similarities between Oscurusciuto and Mandrin encompass the tool-kit composition and the reduction systems used (Fig. 24). Upon closer examination, certain production procedures and the selection of blank cores partially distinguish the two sites. At Mandrin, various types of blanks, such as cortical flakes, blades, and points, were used in the production of micro-points (Metz et al., 2023; Slimak et al., 2022). In contrast, at Oscurusciuto, micro-points were

Table 6 Minimal number of retouched pieces for each of the main categories of blanks in the assemblages

Blanks	SU1			SU2			SU29-30–31			SU3		
	N	*Ret. N*	*Ret%*	N	Ret. N	*Ret%*	N	Ret. N	*Ret%*	N	Ret. N	*Ret%*
Blades	52	*17*	*24.6*	79	8	*9.2*	119	20	*14.4*	24	8	*25*
Bladelets	14	–	*0*	57	1	*1.7*	83	–	*0*	10	–	*0*
Points (> 30 mm)	58	*26*	*31*	160	58	*26.6*	194	52	*21.1*	57	12	*17.4*
Micro-point (< 30 mm)	5	*1*	*16.7*	33	–	*0*	27	1	*3.6*	4	–	*0*
Levallois flakes	70	*12*	*14.6*	147	14	*8.7*	207	29	*12.3*	216	10	*4.4*
Non-Levallois flakes	206	*26*	*11.2*	328	24	*6.8*	379	32	*7.8*	455	27	*5.6*
Cortical flakes (cortex > 50%)	102	*8*	*7.3*	159	5	*3.0*	249	15	*5.7*	252	8	*3.1*
Cortical flakes (cortex > 50%)	68	*2*	*2.9*	180	13	*6.7*	235	10	*4.1*	160	4	*2.4*

systematically produced on cortical flakes. In this regard it is significant to underline that the above-mentioned "simple cores" at Oscurusciuto show a short series of removals (one to three) after their discard. The dimension and shape of the outline of those scars are very similar to the shape and dimension of the micro-point core, suggesting a predetermined production of those cortical blanks (SI1, Fig. S2). Another difference in the microlithic production between Oscurusciuto and Mandrin lies in the fact that at Mandrin, micro-points and bladelets are the results of different stages in the same reduction process. However, Metz specifies also that: "*Some bladelets may also have been obtained independently of the BM concept, as shown by cores involved exclusively in obtaining bladelets"* (Metz et al., 2023 p. 4, suppl. materials). This dichotomy of production (micro-points/bladelets) is repeated in a sort of macro-lithic transposition also for the production of blades and points obtained from the same cores (Slimak et al., 2022). The extraction of crested blades/bladelets initiates both blade-point cores and micro-point bladelet cores. At Oscurusciuto, micro-points, points, bladelets, and blades come from distinct reduction strategies. Blade and bladelet core initialization are based on a selection of an appropriate volume: pebbles for blades and diversified blanks or small pebbles for bladelets. The débitage starts without preparation of the flaking surface. The preparation of crested bladelets for the initialization of burin cores is not completely absent but cannot be considered a process systematically integrated into the configuration of the volume. The direction of removals is unidirectional, producing bladelets with parallel edges. At Mandrin, bladelets show a general triangular morphology resulting from the unipolar-convergent procedure. At Oscurusciuto, pointed bladelets are rare and result from the micro-point process. Micro-production at Mandrin also includes numerous cores (~ 1/3 of the microlithic cores) exploited on the dorsal face of blanks (flakes/blades fragments) after a proximal or distal truncation "Kostienky type" (Metz et al., 2023). At Oscurusciuto, two cores found in SU2 attest to this practice (Fig. 17 n. 5, 6).

The microlithic production, comprising bladelets and micro-points, accounts for 25.2% of all blanks at Mandrin. This proportion is lower at Oscurusciuto, ranging between 4.6% in SU1 and 11.2% in SU2 (Table 7). Nano-points (measuring 10 to 20 mm, 1.6% in Mandrin E) are completely absent at Oscurusciuto, and any excavation biases can be ruled out. However, three micro-point cores show nano-point scars that indirectly attested to the presence of this production also at Oscurusciuto (Fig. 11 n. 2, 4, 5).

The top layers of Oscurusciuto (SU1 to SU29–30-31) have a similar proportion of blades compared to Mandrin, while bladelets are significantly less represented (Table 7). The absence of crested blades at Oscurusciuto can be explained by an adaptation to the local raw material. The exploitation of pebbles, compared to a nodular morphology, does not necessarily require a pre-configuration of the flaking surface. The configuration of blade and point cores is replaced by the selection of the appropriate pebble's morphology "concept of affordance" (Boëda, 2021; Pérez-Balarezo & González-Varas, 2023).

Regarding the retouched pieces, both Mandrin and Oscurusciuto have a relatively low proportion. At Mandrin, slightly over 7% of all blanks are retouched, while at Oscurusciuto, the proportion ranges from 5% in SU3 to 13% in SU1 (see Table 6). It is worth mentioning that at Oscurusciuto, the proportion of retouched points is relatively high. In SU1, 31% of the points exhibit secondary modifications (Table 6).

The most iconic Neronian retouched points are the so-called Soyon points, characterized by an inverse retouch. At Mandrin layer E, out of 56 retouched points, 13 are "Soyons points." At Oscurusciuto, only two points show a marginal inverse retouch, but confirmation of the intentional modification of those objects needs further analysis (Fig. 19).

In the IUP, the retouched toolkit may also comprise Upper Paleolithic forms such as burins and end-scrapers made on blades or blade fragments. The presence of such tools is attested at Mandrin and is absent at Oscurusciuto.

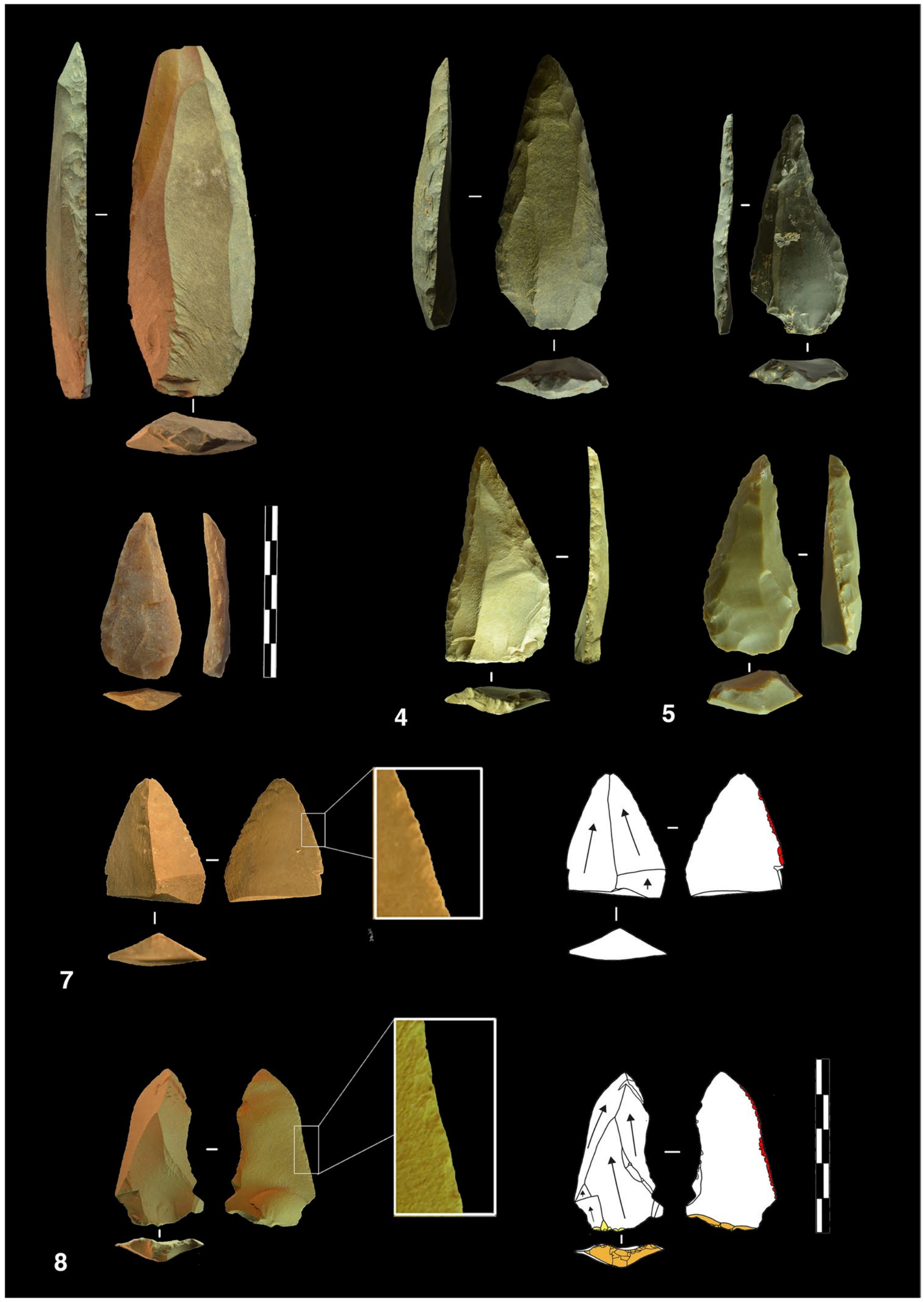

Fig. 19 Retouched pieces. **1** Blade from SU1. **2**, **3** Point from SU3. **4**, **5** Points from SU31. **6** Point from SU2. **7** Distal fragment of point with inverse marginal modification from SU29. **8** Point with possible inverse marginal modification from SU2

However, in the IUP, with few exceptions, the proportion of burins and end-scrapers, when present, constitutes a very small portion of the retouched pieces. The absence or presence of these tools may be biased, as in the case of Oscurusciuto, by the extent of the excavated area.

The micro-points at Mandrin have been confirmed to have been used as projectile points (Metz et al., 2023). Preliminary studies conducted at Oscurusciuto on a sampled number of macro points highlight the presence of impact scars, suggesting their use as tip spears (Villa et al., 2009). Concerning the micro-point, the lack of functional analysis does not allow us to make precise hypotheses about the functions of this micro-production.

Flake production at Oscurusciuto represents more than half of the production in SU1, SU2, and SU29–31. In SU3, the proportion of flakes reaches 88% of the blanks, marking another divergence between this stratigraphic unit and the rest of the sequence studied. In Level N of Mandrin, blanks other than blades, bladelets, and all sorts of points represent 34% of the assemblages (Metz et al., 2023; Slimak, 2023).

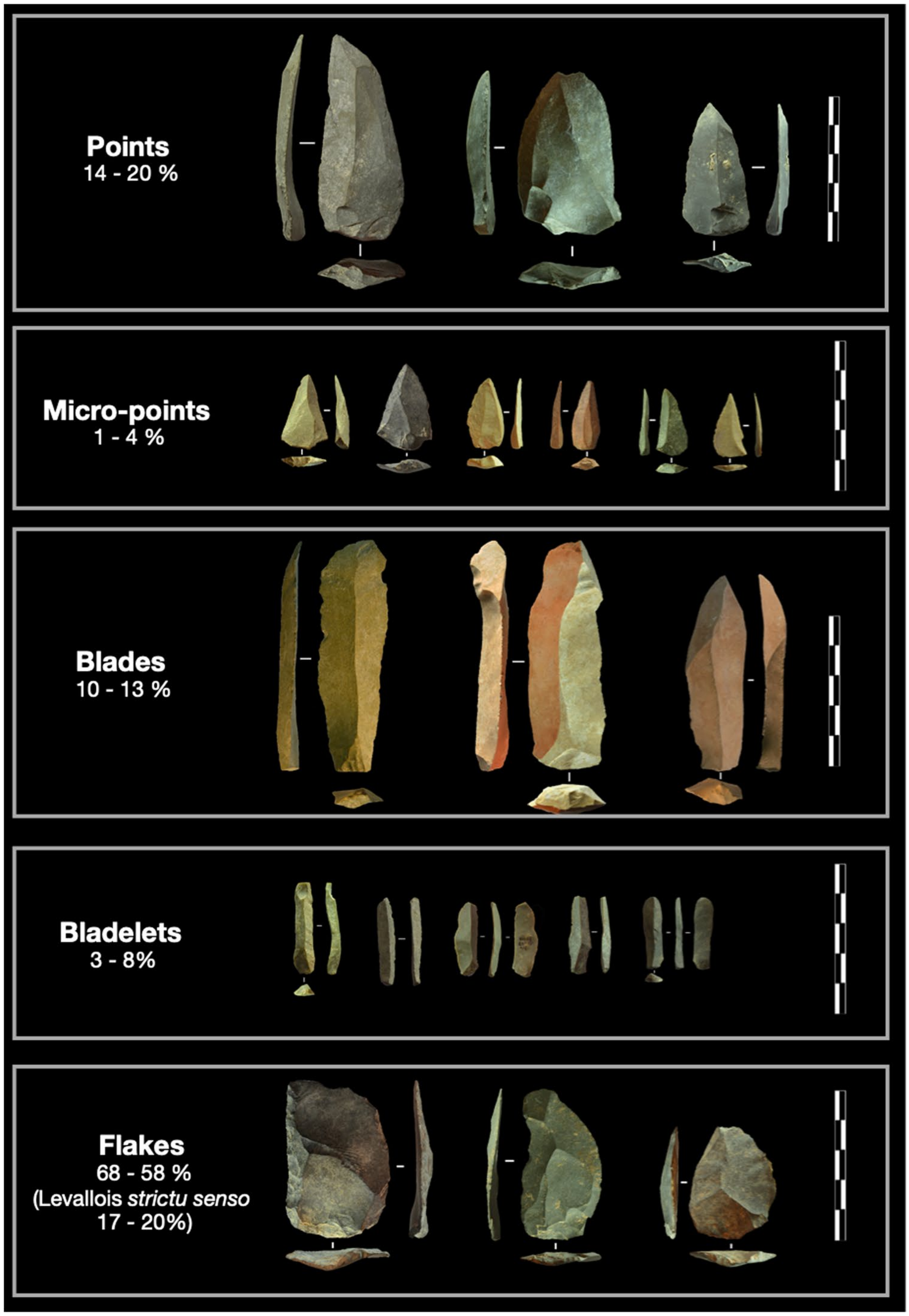

Fig. 20 Overview of the tool-kit composition at Riparo l'Oscurusciuto (SU1, SU2, SU29-30–31)

At Oscurusciuto, Levallois cores in SU1, SU2, and SU29–30-31 range between 12 and 18% of all cores, and Levallois-type flakes represent between 17 and 20% of all the flakes (see Tables 2 and 3). In contrast, the high proportion of Levallois cores found in SU3 (41% of all cores) represents a remarkable difference. This difference is even more accentuated when comparing it with the lower level of Oscurusciuto (SU11 and SU13), where Levallois cores and blanks represent more than 90% of the entire production (Spagnolo et al., 2020). Most flakes in the levels studied in this paper derive instead from short sequences of unidirectional removals, "simple débitage" (Fig. 5). This reduction strategy is not diagnostic for any chronological or tecno-cultural attribution. Flakes produced with direct freehand percussion through a short sequence of removals are also attested, for example, in the Uluzzian (Rossini et al., 2022).

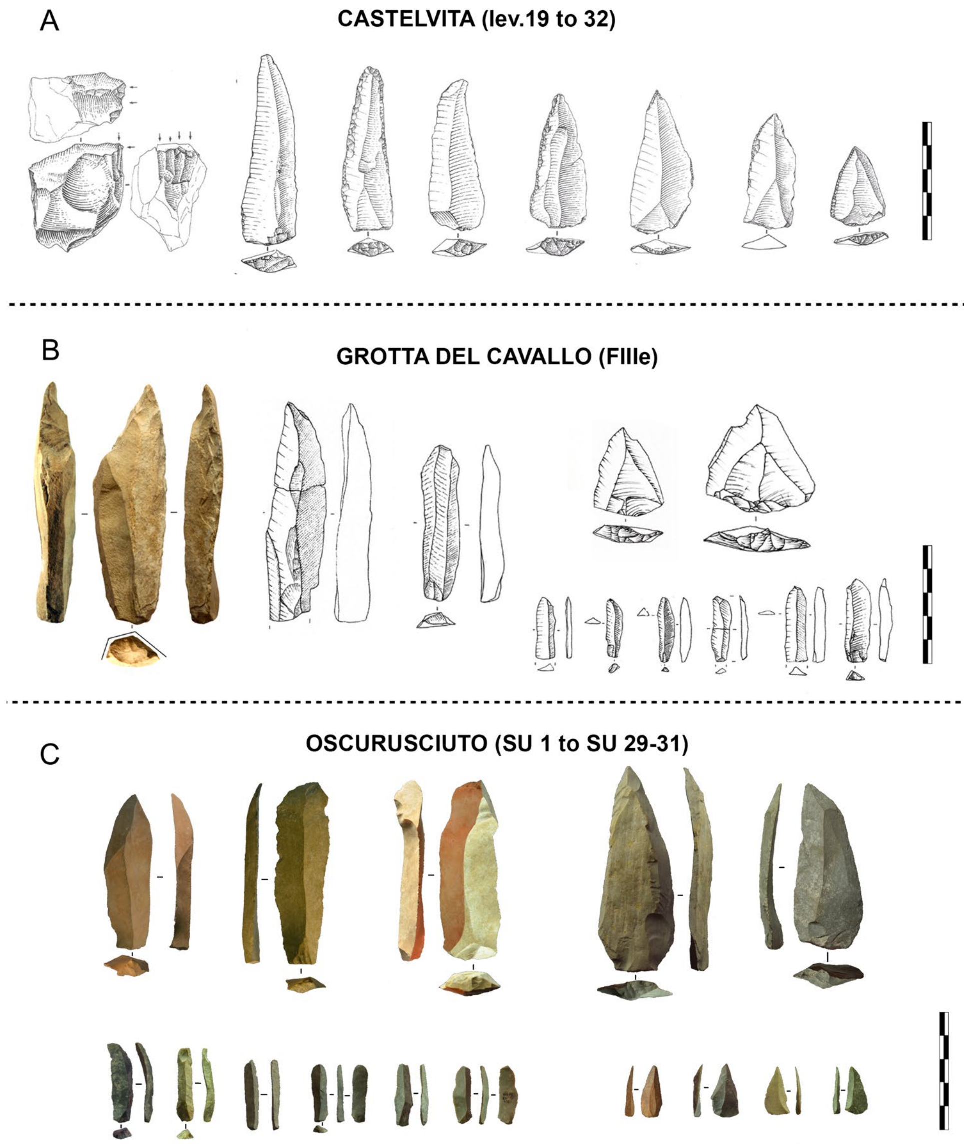

Fig. 21 Visual comparison of a selection of end-products from Oscurusciuto and two Late Middle Paleolithic sites attributed to the "Evolved Mousterian." **A** Grotta di Castelcivita (Drawings by G. Fabbri, University of Siena.) **B** Grotta del Cavallo after modified after Carmignani & Sarti 2018. **C** Oscurusciuto

Mousterian Tradition or IUP Interstratification?

Oscurusciuto's latest assemblages undoubtedly show a "hybrid" technology with a mixture of IUP signatures (bladelets, blades, axial points, micro-points) associated with a minor proportion of Levallois technology. This naturally raises the question: how can we interpret this combination of IUP – MP features at Oscurusciuto? To provide some context regarding the origins of these blended features, two potential scenarios can be put forth: the first scenario suggests that these innovations may have simply arisen from the existing techno-cultural background of local groups in the form of local innovations. The second scenario proposes that these innovations could be the result of external influences, such as the introduction of novel populations or direct/indirect contact with nearby groups, which facilitated the transfer of technological knowledge within a relatively short timeframe.

When considering the first scenario (local innovations), several factors lead us to believe that it is unlikely. First and foremost, as we saw before, during the MIS 5 and MIS 4 there is a lack of clear technological antecedents that would suggest a local or sub-local origin for these multiple innovations. Strong evidence of intentional bladelet reduction strategies is absent prior to the MIS 3. In MIS 5 and MIS 4, only one bladelet occurrence came from Riparo del Molare (Aureli & Ronchitelli, 2018; Ronchitelli et al., 2010). Volumetric blade production is absent in MIS 5, and only one occurrence is present at the site of Santa Croce (Arrighi et al., 2009), dated at the end of MIS 4. Axial points predetermined during the débitage are relatively common during MIS 3 but absent during MIS 4 and 5. Furthermore, at the state of the research, the association of axial-points/blades/bladelets, or axial-point/blades, is completely absent prior to MIS 3. This scenario makes it challenging to explain

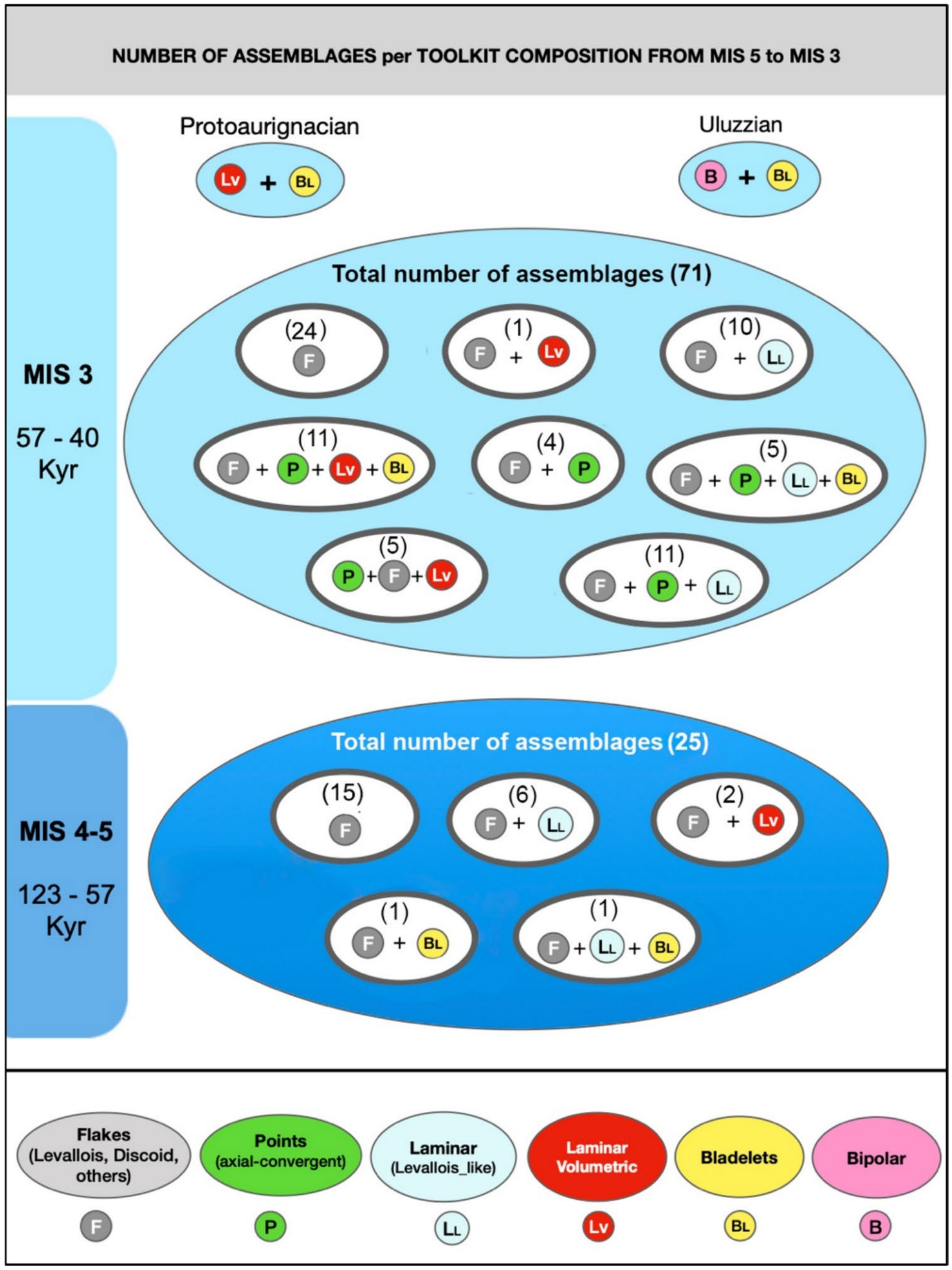

Fig. 22 Middle Paleolithic toolkit composition in the Italian peninsula between MIS 5 and MIS 3. Numbers in () are the number of lithic assemblages. Assemblages with less than 50 pieces and assemblages with no clear chronostratigraphic position were excluded (For more details, see also Table S13)

the occurrence of those multiple innovations within MIS 3 evolving from the MIS 4 and MIS 5 local technological background.

The second scenario—the arrival of novel populations and/or external influences provides another explanation for this technological shift, but it does not help to elucidate the presence of the typical Middle Paleolithic (MP) flake components that constitute the majority of the LMP assemblages, including Oscurusciuto. A potential solution to this puzzle may lie in the variability within Oscurusciuto's assemblages. The reduction strategies employed at Oscurusciuto resulted in a diverse array of end-products, including points, micro-points, blades, bladelets, and Levallois flakes. Additionally, flakes are obtained from methods other than Levallois, mainly from simple flaking strategies. This large variability, encompassing both products and reduction strategies, raises questions about whether this diversity characterizes the toolkit or reflects the presence of different groups inhabiting the rock shelter, each with distinct technological traditions.

In considering a third scenario where multiple groups occupy the site within a relatively short timeframe, we encounter a complex situation involving archeologically invisible interstratifications that are not visually

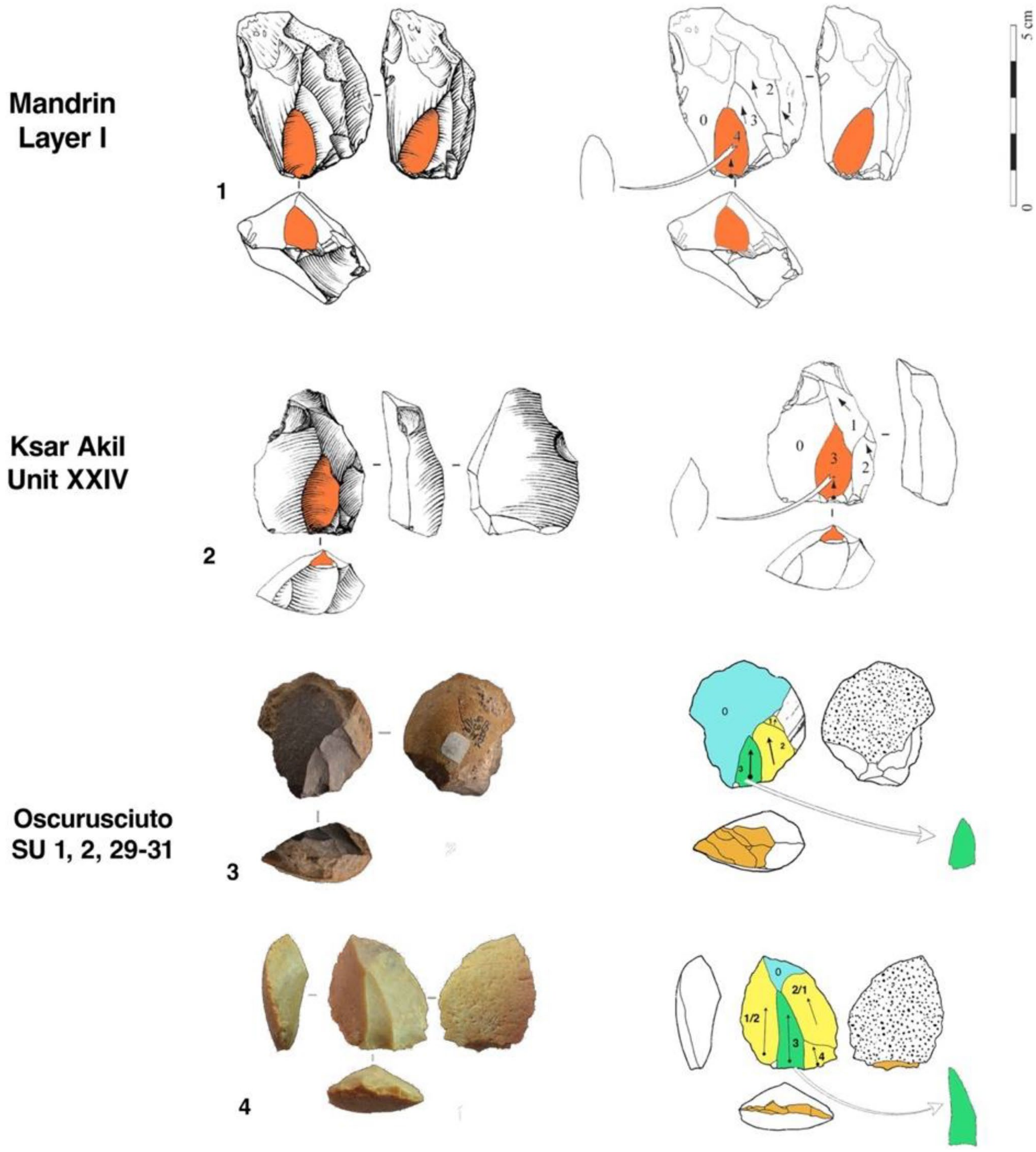

Fig. 23 Visual comparison of a selection of representative point cores from Oscurusciuto, Mandrin, and Ksar Akil. The reduction scheme applied on the ventral surface of blanks at Oscurusciuto (n. **3** and **4**) strictly mirrors the procedure described at Mandrin (n. **1**). Numbers **1** and **2** adapted from Slimak et al., 2022

distinguishable during excavation. In locations with ample local raw materials like Oscurusciuto, it is likely that multiple groups at the site exploited the same resources. While refitting may aid in distinguishing assemblages, its effectiveness may be limited without extensive excavations, which are uncommon for most Middle Paleolithic (MP) sites in Italy, including the case of the upper deposit of Oscurusciuto. Improving stratigraphic resolution during

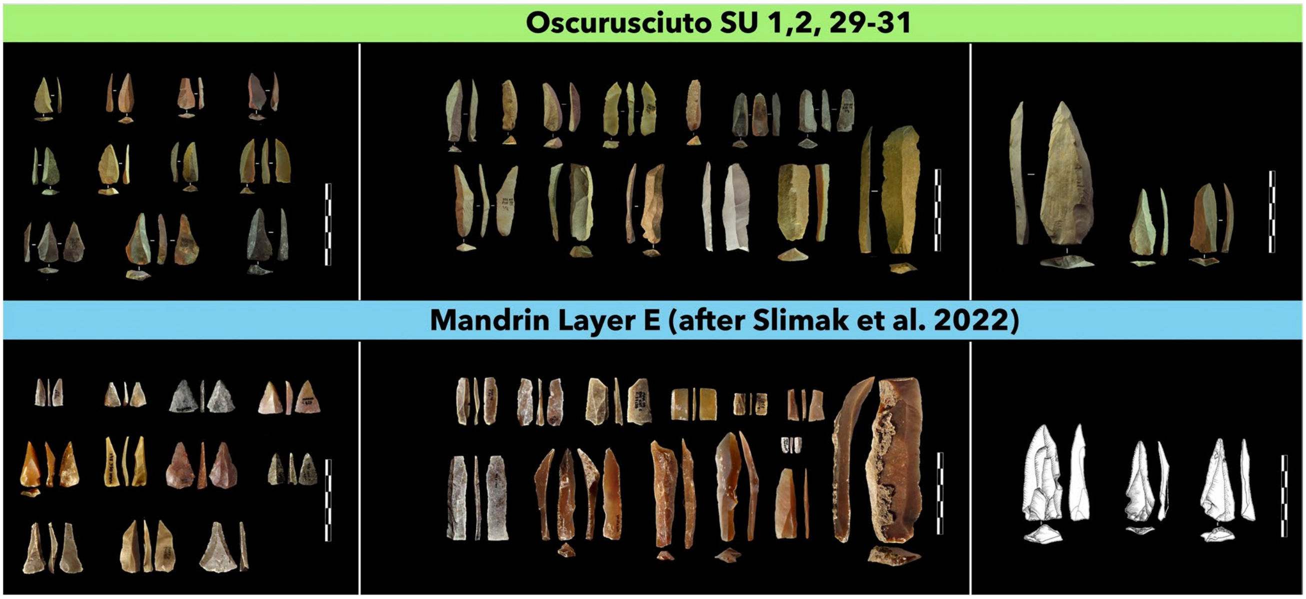

Fig. 24 Comparison between Oscurusciuto (SU1 to SU29–31) and Mandrin. Adapted from Slimak et al., 2022

Table 7 Proportions of techno-types at Oscurusciuto and Mandrin. The percentage of flakes for Mandrin is calculated by extrapolation from the total number of pieces > 20 mm. In bracket () the proportion of Levallois-type flakes identified at Oscurusciuto

Techno types	Mandrin level E (%) (*After* Slimak, 2023*;* Metz et al., 2023)	Osc 1 (%)	Osc 2 (%)	Osc 29–30-31 (%)	Osc 3 (%)
Blades	14	*12.8*	*9.8*	*11.8*	*3.1*
Bladelets	16.8	*3.5*	*7.1*	*8.2*	*1.3*
Points	27.2	*14.3*	*19.9*	*19.2*	*7.4*
Micro-points (< 30 mm)	8.4	*1.2*	*4.1*	*2.7*	*0.5*
Flakes	33.7	*68.2 (17.3)*	*59.1(18.3)*	*(58.8)20.5*	*(87.7)28.2*
Number of pieces	**2477**	**405**	**804**	**1009**	**766**

or after the excavation poses challenges that affect our data interpretation (Discamps et al., 2019, 2023). If we consider Oscurusciuto's formation as a series of short occupations within a brief timeframe resulting in a complex palimpsest, it is very likely that alternations of occupations by different groups occurred repeatedly over a relatively long time span. Identical technological features are present in SU1, SU2, and SU29–30-31, spanning almost 2 m of stratigraphy. An alternative plausible scenario involves the local population integrating IUP technology without necessarily abandoning the previous technological background. This integration might have occurred gradually or relatively fast through direct or indirect contact.

In this regard, although a comprehensive technological comparison between the uppermost and deeper layers of Oscurusciuto is still lacking, SU11 and SU13 sporadically contain blades, bladelets, and points—as well as "convergent flakes" smaller than 3 cm, following Marciani's (2018) definition. Notably, SU11 has been studied with the aim of untangling the palimpsest, and in this case, potential interstratifications are unlikely (Spagnolo et al., 2020). Future investigation will help to clarify the presence of eventual anticipation of IUP elements in the deepest layer at Oscurusciuto.

At this stage of the research, explaining the variability of Oscurusciuto assemblages is challenging and premature. However, we think that the current labels, such as "late Mousterian" or "evolved Mousterian," do not adequately highlight the specific technological characteristics elucidated in this paper.

Artefacts and Hominins

The implications of the unique technological aspects identified at Oscurusciuto remain to be clarified, and the genetic identity of the makers of these assemblages is currently unknown. The correlation between material culture and the genetic identity of its creator is a vast subject that we do not aim to address in this paper. Nonetheless, we want to make some general observations we consider helpful to speculate on the specific case of Oscurusciuto.

In Europe, prior to the full Upper Paleolithic industries (i.e., Protoaurignacian), modern humans are found in association with very diverse technologies. This included the production of blades, bladelets, and points, as in the case of the Neronian, but also the use of bipolar technique and freehand flake production in the Uluzzian culture or a combination of features, as seen in the case of the Bachokirian (Hublin et al., 2020; Rossini et al., 2022). In the Italian peninsula, Late Middle Paleolithic assemblages found in association with human fossils in a securely stratified and well-dated context are rare. However, until now, Neanderthal remains have been found only associated with a flake-based technology (Levallois, discoid, Quina) and, in a few cases, with laminar Levallois technology (see SI2, Table S14). Assemblages exhibiting similar characteristics to Oscurusciuto, such as "points-blades-bladelets," as seen in sites like Grotta di Castelcivita, Grotta del Cavallo layer FIIIe, and Grotta Reali, did not yield human fossils associated with lithics (Carmignani & Sarti, 2018; Gambassini, 1997; Peretto et al., 2020). Conversely, the few human remains found in association with the IUP technology in Europe are all attributed to anatomically modern humans (see SI2, Table S15).

Techno-typological traits found at Oscurusciuto exhibit similarities with the IUP variability, and they are chronologically sub-contemporaneous. The earliest presence of modern humans in western Europe dates back approximately 54,000 years (Slimak et al., 2022), preceding sites like Oscurusciuto and other Late Mousterian assemblages in Italy. This suggests the need for caution in automatically attributing the entire late Italian Mousterian to Neandertals. Acquiring more data on the biological identity of the individuals responsible for producing these late Mousterian assemblages, particularly at sites such as Oscurusciuto, will be essential to address this gap.

With the data at our disposal, the IUP appears as a broad technological turnover branching into diverse techno-complexes but sharing some common techno-cultural features. In this perspective, it is plausible that the transmission of those shared features that occurred through social contact and interaction between different groups of populations, for which the genetic identity is only partially known, is at the origin of the observed innovation (Greenbaum et al., 2019). Recent studies suggest that a higher rate of innovation occurs when social groups interact on an intermediate level. Homogenization is expected with a high level of interaction, while cultural loss is associated with a low level of interaction. This concept may explain the cultural diversity and technological variability during the MP-UP transition (Derex & Boyd, 2016; Derex et al., 2018).

Conclusion

The uppermost layers of Oscurusciuto, except for SU3, feature volumetric blades, bladelets, axial points, and micro points alongside a minor Levallois component. Similar patterns are observed in the Neronian of south-eastern France. The current use of the label late Mousterian for Oscurusciuto fails to emphasize the specific technological characteristics exposed in this study. The origin of these new technological aspects and their creators remain unknown.

In the past decades, discussions about the Middle to Upper Paleolithic transition in the Italian peninsula have largely focused on Uluzzian industries, potentially overshadowing the technological diversity of the Late Middle Paleolithic. Our extensive in-depth analysis of complete assemblages, including material from the sieve, reveals that lithic assemblages previously classified as Late Middle Paleolithic at Oscurusciuto exhibit distinct features not consistent with conventional definition of the Middle Paleolithic or Mousterian. We believe the main issue lies in the common practice of employing a strict binary classification (MP or IUP). Specific technological features define the IUP but also encompass significant variations that are crucial if we want to clarify the intrinsic value of these technological variabilities. Furthermore, Oscurusciuto may not be an isolated case within the Late Middle Paleolithic context in southern Italy and reassessment of complete LMP assemblages is necessary.

The technological changes observed in the upper layers of Oscurusciuto are sub-contemporaneous with the emergence of the IUP phenomenon in Europe. This parallel technological turnover raises the unresolved question of their possible interdependence. Our results suggest that certain assemblages, often the ones categorized as evolved Mousterian, warrant thorough re-evaluation, considering the entire assemblages, including the fine fraction coming from the sieve when available. Attention should be directed toward discrete and ephemeral productions which, beyond their statistical significance, may contain relevant information. Labels such as IUP (Initial Upper Paleolithic), LM (Late Mousterian), and EM (Evolved Mousterian) can be used more effectively only after thorough technological re-evaluations.

Further research and analysis of archeological sites, artifacts, and biological data will provide a deeper understanding of the nature and extent of interactions between modern humans and Neanderthals, as well as their latest technological productions. This ongoing investigation promises to illuminate the complex dynamics of cultural transmission and technological development during this fascinating period of human history.

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Author Contribution L.C. Conceptualization, data curation, formal analysis, investigation, methodology, writing the original draft; M.S. conceptualization, resources, funding acquisition, project administration, draft review, and editing; A.R. and F.B. validation, draft review, and editing.

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Data Availability The author confirms that all data generated or analyzed during this study are included in this published article.

Declarations

Ethical Approval Not applicable.

Competing Interests The authors declare no competing interests.

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