

# Special Issue: The Apidima Legacy Collections: New Analyses and Interpretations

## Early Upper Paleolithic Technical Behavior at Apidima (Peloponnese, Greece): Technological Analysis of the Lithic Assemblage From the Cave C Legacy Collection

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## ABSTRACT

The Apidima cave complex, located in the Peloponnese, Greece, stands as one of the most significant Paleolithic sites in southeastern Europe. The site is well-known due to the discovery of two fossilized crania, a *Homo sapiens* and a Neanderthal, respectively, found in Cave A during investigations by T. Pitsios in the late 1970s and 1980s. A presumed Early Upper Paleolithic human burial was also uncovered in Cave C, along with isolated human remains, pierced shells, faunal remains, and a lithic assemblage. Despite the significance of these findings, only a limited sample of this lithic assemblage has undergone preliminary study. Given the scarcity of data on the Upper Paleolithic in Greece, a detailed analysis of the Apidima lithic industry holds great potential for deepening our understanding of population dynamics in the southern Balkans during this period. Here, we provide the first comprehensive technological analysis of the lithic finds uncovered in Cave C. The assemblage predominantly consists of local flint (pebbles and blocks) used to mainly produce elongated blanks. The two main concepts of debitage identified at the site are, firstly, an integrated concept with volumetric cores exploited by direct percussion and, secondarily, an additive concept with the use of the bipolar-on-anvil percussion technique. Bladelets were the main target of production, frequently modified along the edges using direct marginal retouch, occasionally inverse or alternate. Several refits were also identified, enabling the reconstruction of the reduction sequences, at times obliterated by the dominant presence of bipolar percussion, particularly employed during the residual phase of blank exploitation. The analysis of the reduction sequences, combined with typological analysis, allows us to frame the Apidima Cave C lithic assemblage within the early phases of the Upper Paleolithic, aligned with Protoaurignacian variability. This study significantly enhances our understanding of Aurignacian technological behavior in Greece and contributes to broader discussions of human occupation and migration in southeastern Europe during this critical period.

## INTRODUCTION

The Apidima cave complex, located in the southern Peloponnese (Greece), is one of the most important Paleolithic sites in southeastern Europe. Excavations conducted in the late 1970s and 1980s by a team from the Museum of Anthropology, University of Athens School of Medicine, made a series of important discoveries. The most famous of these are two Middle Pleistocene fossil human crania from Cave A (Pitsios 1995, 1999; Harvati et al. 2009; 2011; 2019). Subsequently, however, significant discoveries were also made in Cave C by the same team (Harvati and Delson 1999; Mompherratou and Pitsios 1995), including faunal and lithic assemblages from several of the caves (Pitsios 1995).

Despite their importance, until now, these assemblages have only been partially studied, with a small subsample of the lithics from Cave C (Chiotis 2007; Darlas 1995; Kourtesis-Philippakis 2007) preliminarily analyzed and tentatively attributed to the Aurignacian (Darlas 1995) and a comprehensive analysis of this legacy lithic assemblage still lacking. Evidence for the Aurignacian in Greece remains sparse, although well-documented at Franchthi (Douka et al. 2011) and Klissoura, where three phases (Early, Middle and Upper Aurignacian) have been identified (Kaczanowska et al. 2010). Additionally, in closer proximity to Apidima (<5km), an assemblage from Kolominitsa Cave is attributed to the Early Aurignacian (Darlas and Psathi 2016) or possibly to the Protoaurignacian (Litsios 2019). The recently published assemblage from Pounias, on the island of Lemnos, may also be assigned to the Early or Middle Aurignacian (Biagi et al. 2025). In this limited setting, a detailed study of the lithic industry from Apidima Cave C holds great potential

for enriching our understanding of the Early Upper Paleolithic from this region of Southeastern Europe.

Here we provide the first comprehensive technological analysis of the entire Apidima C lithic assemblage from the legacy collections of the Museum of Anthropology. We aim to identify the methods and objectives of lithic production employed by the groups that occupied the site. Furthermore, by contextualizing the results within the regional Paleolithic record, our analysis seeks to refine our understanding of the technological strategies, subsistence practices, and cultural variability of the groups that exploited Apidima Cave C, contributing to a broader understanding of cultural dynamics in the Southern Balkans during the Early Upper Paleolithic.

## THE SITE

The Mani peninsula, southern Peloponnese, is among the richest areas in Paleolithic and fossil human finds in Greece. It is home to multiple cave sites preserving Middle and Upper Paleolithic assemblages and, in several instances, fossil human remains (e.g., Harvati et al. 2003; 2011; 2013; 2019; Panagopoulou et al. 2004; Tourloukis et al. 2016). The Apidima cave complex is located on the western side of the Mani. It consists of five caves, A–E, formed in Middle Triassic–Upper Eocene limestone (Figure 1), and is situated on a steep coastal cliff near the current sea level. Excavations at the caves were conducted from 1978 to 1986 by a team from the Museum of Anthropology, at the Medical School of the National and Kapodistrian University of Athens, led by Prof. T. Pitsios.

At Cave C (about 19 meters above current sea level) (see Figure 1b), several important discoveries were made

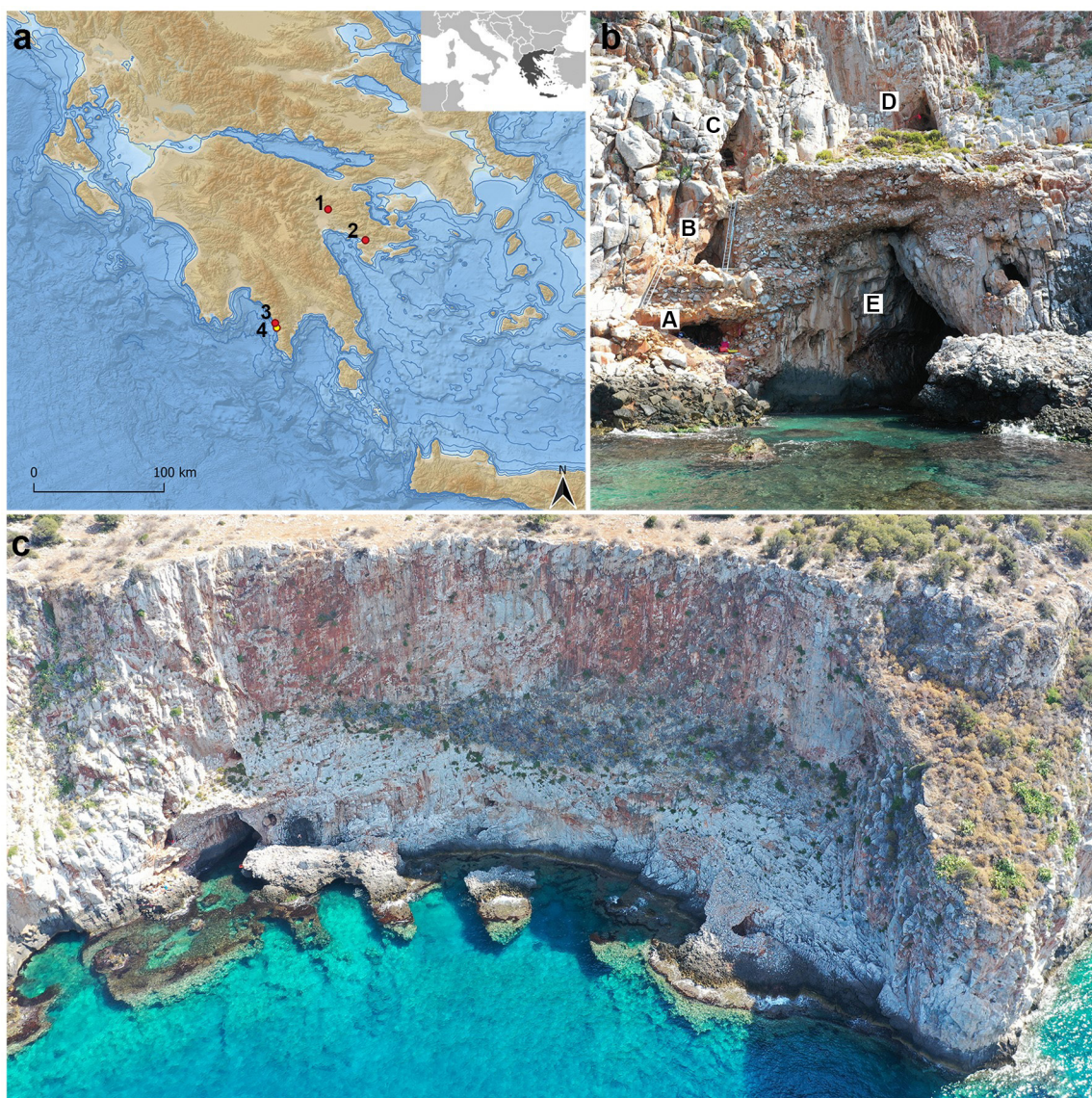


Figure 1. a) Geographic location of Apidima Cave and some of the Aurignacian sites mentioned in the text. Reported sites: (1) Klissoura Cave 1, (2) Franchthi Cave, (3) Kolominitsa Cave, (4) Apidima Cave. The map shows the paleo-geographic reconstruction of Greece, considering the mean sea level  $-62\pm 13\text{m}$  below the current sea level, circa 40,000 BP. The map was generated using QGIS 3.36.3 (<https://www.qgis.org/>). Source of the Digital elevation model and Bathymetry: EMODNET (<https://emodnet.ec.europa.eu/geoviewer/>). b) The Apidima Cave Complex with the position of caves A to E. c) General view of the coastal cliff face. (b, c photo credits: A. Beer).

by the Pitsios team, including a partial human skeleton, termed Apidima 3, interpreted as an Upper Paleolithic human burial, as well as additional isolated human remains (Ligoni and Papagrigrakis 1995; Mompherrattou and Pitsios 1995; Naumann et al. [this issue]). More than 40 pierced *Nassa neritrea* shells were recovered near the upper part of the skeleton, interpreted as personal ornaments associated with the burial (Karali 1995; Roditi et al., in prep). Additionally, an “unusual stone knife” and a “natural piece of rock crystal” are clearly reported as having been found together with the human remains and interpreted as potential offerings (Mompherrattou and Pitsios, 1995).

The preliminary lithic study mentions 62 lithic pieces, preliminarily analyzed and tentatively attributed to the Aurignacian, although with some reservations (Darlas 1995). A large faunal assemblage, comprising several thousand specimens, was also excavated (Lax 1995; Tsoukala 1999).

Preliminary studies on raw material availability and utilization were conducted by S. Chiotis (2007) and G. Kourtessi-Philippakis (2007). This research identified potential outcrops of raw materials within the region of western Mani. Lenses of black flint were documented in the ‘Pantokrator limestones,’ from the Ionian Plattenkalk Zone (IGME 1980), which, according to Chiotis (2007), are

significantly affected by metamorphism and tectonic activity. In general, flint can be found along most of the Mani Peninsula's western coast, extending as far north as Verga, approximately 60km from Apidima (Chiotis 2007), in the Viros Gorge near Kardamyli (Garefalakis et al. 2018; Tourloukis et al. 2016) and in the Trachila area further south (Karkazi et al. 2024).

It is important to stress that only limited contextual information is available for the legacy collection from Apidima. In his report, the excavator briefly describes three stratigraphic layers in Cave C: C-I, C-II, and C-III (Pitsios, 1985). Information on the spatial distribution of the finds is restricted to a general distribution map, which suggests the presence of a distinct lithic-rich horizon at the base of the area occupied by the main accumulation of the human remains (Figure 2d). Additional, albeit limited, information was obtained from the archives and exhibits of the Museum of Anthropology of the National and Kapodistrian University of Athens, including a section drawing (reproduced in Figure 2b) and an excavation photograph (Figure 2c), as well as from labels and catalogue numbers associated with the finds. The lack of contextual data is also reflected in the preliminary publication of part of the Cave C lithic assemblage (Daras 1995), which reports an association with the human skeleton but makes no references to stratigraphic sequence, spatial distribution, or recovery methods. As a result, although the lithics derive from an excavated context, their stratigraphic and spatial relationships with other finds, such as faunal remains, perforated shells, and the human skeleton, can only be partially inferred.

## MATERIALS AND METHODS

This lithics study focuses on the technological analysis of the legacy collection uncovered at Apidima Cave C during the excavation carried out between 1983 and 1986. The finds are stored at the Museum of Anthropology, School of Medicine, National and Kapodistrian University of Athens. Because spatial and stratigraphic data from the excavation are unavailable, the materials were studied as one complete coherent assemblage. Indeed, even though we cannot exclude (due to lack of excavation documentation) the possibility of syn- or post-depositional mixing of artifacts from different periods, the assemblage is, as shown below, internally consistent and allows us to conduct this analysis as a single industry.

We combined attribute analysis (Andrefsky 1998; Odell 2004; Tostevin 2012) with reduction sequence analysis (Boëda et al. 1990; Geneste 1991; Inizan et al. 1995; Shott 2003), thus recording and analyzing a wide range of discrete and metric attributes. Origin from primary or secondary outcrops (pebbles, nodules), type of patina, and presence of combustion traces were recorded. Variety and characteristics of lithotypes were classified macroscopically, using a triplet lens (10x, 16x). The attributes used to construct the raw material subtypes are color, texture, translucency, luster, fractures, and inclusions (Luedtke 1992; Morrow 1994).

All specimens were assigned to technological categories: core; flake (length/breadth ratio ranging from 0 to 2);

blade (length/breadth ratio exceeding 2) (Inizan et al. 1995); bladelet (referring to blades with a width  $\leq 12$ mm) (Tixier 1963); spall (an elongated element detached from a lateral ridge of a flake-core); chunk (a fragmented, altered, or unorientable piece with an area larger than 100mm<sup>2</sup>), chips (flakes and fragments of flakes with an area smaller than 100mm<sup>2</sup>), debris (unorientable pieces with an area smaller than 100mm<sup>2</sup>). The cores were also classified according to the concept of debitage (Boëda 2013), and the general configuration of the striking platform(s) in relation to the flaking surface(s) (Conard et al. 2004; Falcucci and Peresani 2017; Rossini et al. 2022; Sánchez-Martínez et al. 2022).

The technological and morphometrical attributes recorded for the artifacts are detailed in Supplementary Information (SI) 1. For each retouched specimen, the location, mode, and extent of the retouch were recorded (Inizan et al. 1995). To conduct data management, analysis, charting, and basic statistics, we primarily utilized the R environment, specifically leveraging various packages such as "ggplot2," "MASS," "scales," and "Tidyverse" within RStudio Version 1.4.1106 (Lê et al. 2008; Wickham et al. 2019) and IBM SPSS Statistics 29. Given that our sample was not normally distributed according to Shapiro-Wilk and Kolmogorov-Smirnov tests, we performed non-parametric tests (Mann-Whitney and Kruskal-Wallis).

## RESULTS

### RAW MATERIALS

The lithic industry of Apidima Cave C consists of 915 specimens, including one hammerstone (Table 1). The assemblage overall is fresh, patinated pieces are sporadic, including a Levallois point. The latter possibly indicates an earlier occupation of the site or that the blank was collected near the site and later introduced into Cave C. Of the artifacts, 6.3% show traces of combustion (glossy surfaces, the formation of cracks, de-silicified segments, or the presence of potlid fractures).

Overall, we defined six lithotypes: flint, radiolarite, quartz, andesite, limestone, and indeterminate; among these, we distinguished the characteristics of each subtype:

- **Flint:** varieties are matte black, shiny black, grainy black, vitreous white/grey, semi-translucent grey, greyish green, and green. Black and grey flints are both brittle and easy to knap regardless of size, while grey flints are typically more silicious with fewer cleavage plane fractures.
- **Radiolarite:** dusky to weak red to dark reddish brown to brown; green, and yellow varieties are less frequent. From homogeneous with no cleavages to numerous cleavage fractures and veins of various densities, sizes, and colors.
- **Quartz:** milky white and quartz crystal.
- **Andesite (also called *krokeatis*):** opaque green varieties, from fine-grained with phenocrysts to coarse-grained subtypes without phenocrysts.

Less than 15% of the artifacts present natural surfaces, and of these, almost half (6%) preserve a rolled smooth

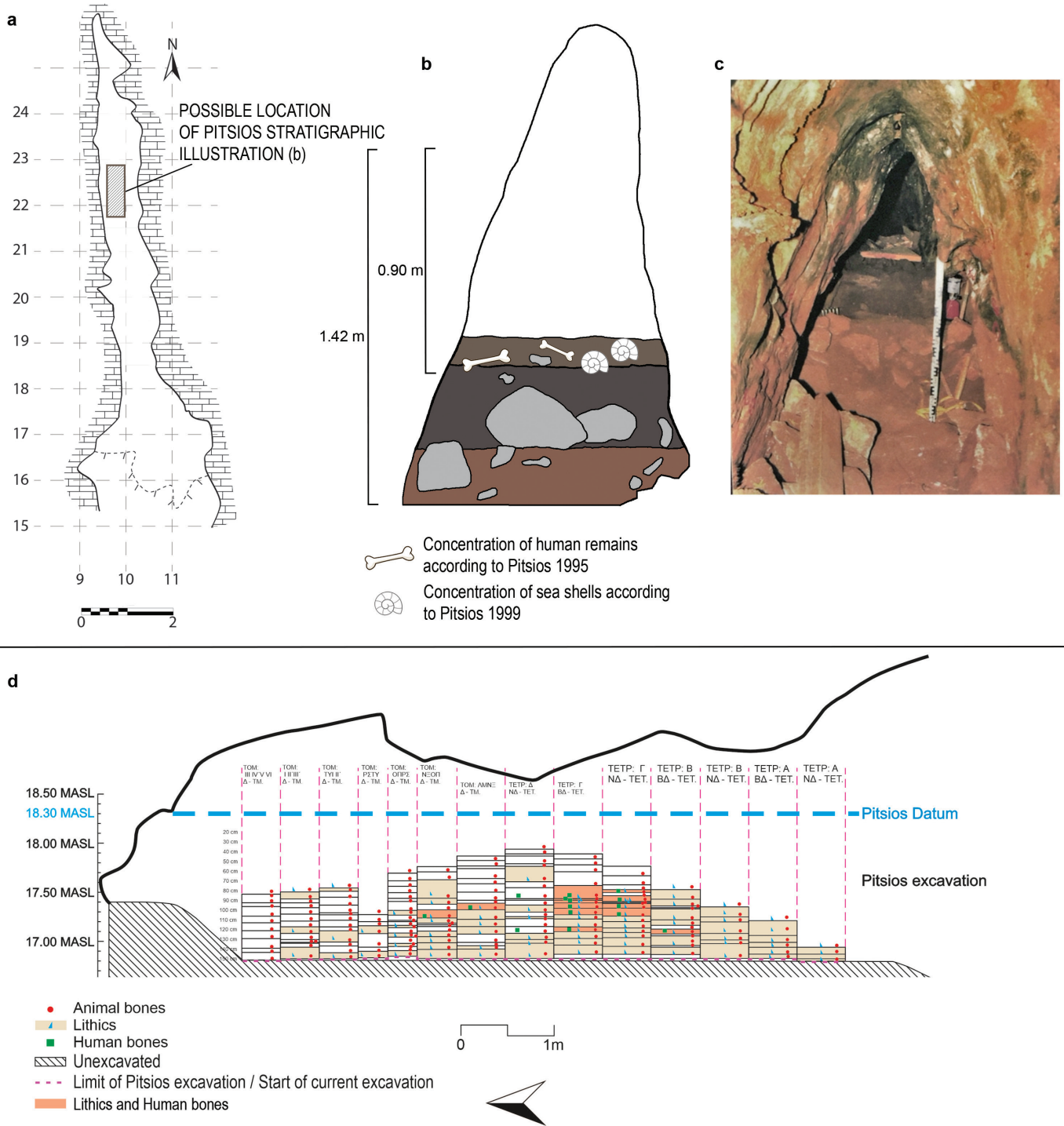


Figure 2. Pitsios' excavation in Cave C. a) Plan view of Cave C with the inferred location of Pitsios' stratigraphic section. b) Legacy stratigraphic profile showing the reported concentrations of human remains, and marine shells. c) Archival photograph from Pitsios' excavation (Museum of Anthropology, National and Kapodistrian University of Athens). d) Distribution of finds, modified after Pitsios (1995).

**TABLE 1. ASSEMBLAGE COMPOSITION.**

Techno category	Direct	Bipolar	Direct - bipolar	Indeterminate	N	%
<b>Blade</b>	<b>10</b>	<b>4</b>		<b>1</b>	<b>15</b>	<b>1.6</b>
Crested blade		1			1	0.1
Naturally backed blade		1			1	0.1
Production	8	2			10	1.1
Technical blade	2			1	3	0.3
<b>Bladelet</b>	<b>88</b>	<b>30</b>		<b>12</b>	<b>130</b>	<b>14.2</b>
Crested bladelet	2	1			3	0.3
Naturally backed bladelet	2	1		2	5	0.5
Production	75	27		9	111	12.1
Semi-crested		1			1	0.1
Sus crête	1				1	0.1
Tablette	1				1	0.1
Technical bladelet	7			1	8	0.9
<b>Flake</b>	<b>147</b>	<b>94</b>		<b>37</b>	<b>278</b>	<b>30.4</b>
First flake	5	3		2	10	1.1
Naturally backed flake	6	3		3	12	1.3
Production	101	71		27	199	21.7
Semi-cortical	2	5		1	8	0.9
Semi-crested	2	1			3	0.3
Tablette	1				1	0.1
Technical flake	30	11		4	45	4.9
<b>Core</b>	<b>22</b>	<b>62</b>	<b>15</b>		<b>99</b>	<b>10.8</b>
<b>Chip</b>	<b>118</b>	<b>29</b>		<b>30</b>	<b>177</b>	<b>19.3</b>
<b>Chunk</b>	<b>16</b>	<b>24</b>		<b>53</b>	<b>93</b>	<b>10.2</b>
<b>Debris</b>	<b>9</b>	<b>1</b>		<b>6</b>	<b>16</b>	<b>1.7</b>
<b>Spall</b>	<b>2</b>	<b>2</b>		<b>1</b>	<b>5</b>	<b>0.5</b>
<b>Tool</b>	<b>58</b>	<b>11</b>		<b>32</b>	<b>101</b>	<b>11.0</b>
<b>Hammerstone</b>					<b>1</b>	<b>0.1</b>
<b>Total</b>	<b>470</b>	<b>257</b>	<b>15</b>	<b>172</b>	<b>915</b>	<b>100.0</b>

pebble cortex, indicating provisioning from marine or continental secondary outcrops. Extremely rare, only two blanks preserve primary cortex residues.

Our analysis confirms the trend observed by Kourtesi-Philippakis (2007), where flint is the most widely used raw material at Apidima Cave C, followed by radiolarite, quartz, and, to a lesser degree, andesite and limestone (Table 2).

The primary use of flint is consistent with all the sites from the western side of the peninsula regardless of the period (Darlas and Psathi 2016; Garefalakis et al. 2018; Karkazi et al. 2024; Tourloukis et al. 2016). The use of radiolarite as the second most preferred material is more common during the Gravettian period (Litsios 2024). At Kolominita, the other Aurignacian site from the region, radiolarite was utilized at only 3%, but at sites with more recent occupations,

**TABLE 2. RAW MATERIALS TYPE FREQUENCIES IN THE KNAPPED ASSEMBLAGE.**

Lithotype	N	%
Flint	503	55.1
Radiolarite	271	29.6
Quartz	92	10.1
Indeterminate	34	3.7
Andesite	10	1.1
Limestone	4	0.4
<b>Total</b>	<b>914</b>	<b>100.0</b>

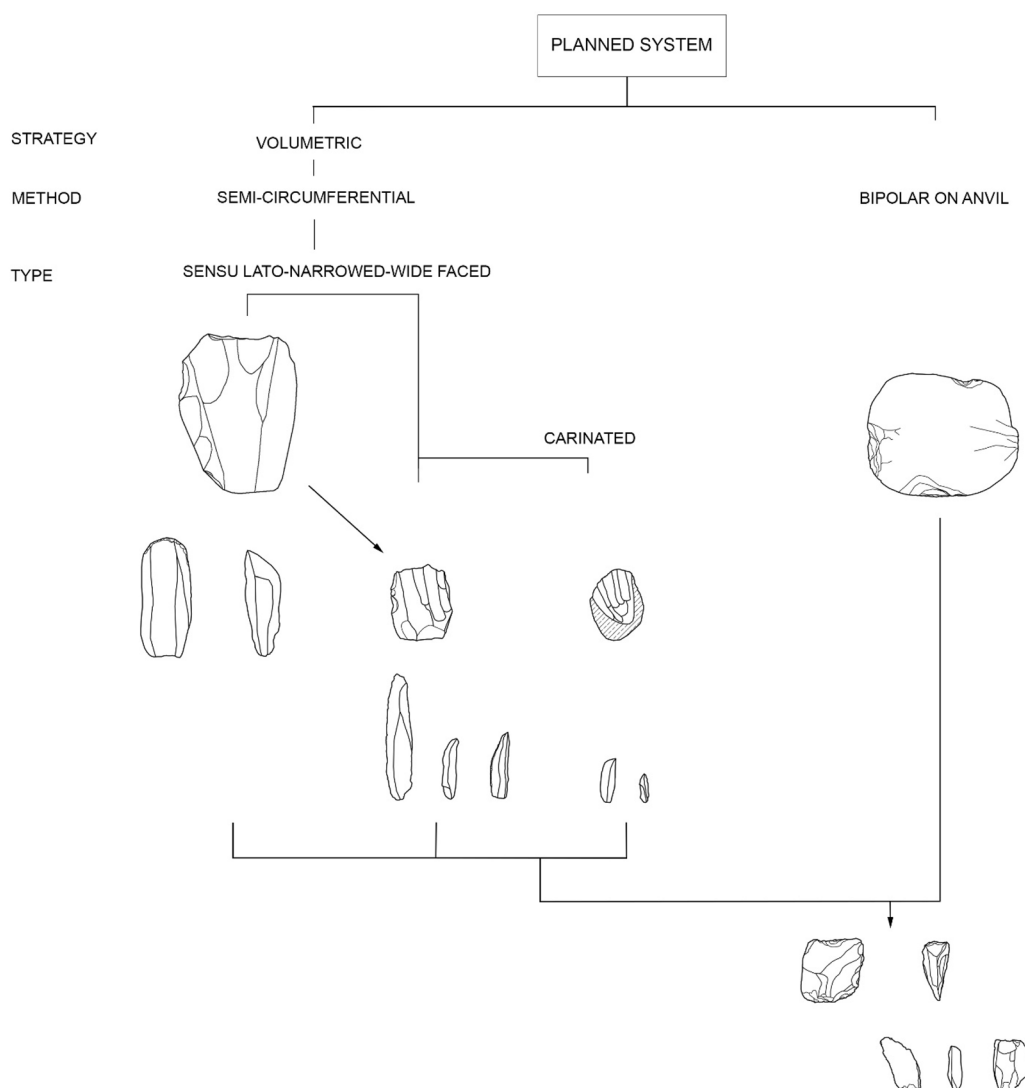


Figure 3. Schematic model representing core reduction systems attested in the Apidima Cave C, organized by strategies, methods and core types. The blanks represented are all archaeological specimens, the drawings are not to scale.

like Melitzia, Skoini, and Tripsana, it ranged from 31% to 45% (at the latter, radiolarite was utilized even more than the local flint, see Litsios 2024). Andesite was generally preferred during the Middle Paleolithic at Lakonis (77%) (Elefanti et al. 2008) and at Kalamakia (22%) (Karkazi 2018), although it continued to be utilized to some extent at all caves in Mani ranging from 1% to 9% (Garefalakis et al. 2018; Litsios 2019; 2024).

The assemblage composition shows that debitage blanks are the most prevalent (flakes 30.4%; blades 1.16%; and bladelets 14.2%), followed by chips (19.3%), tools (11%), cores (10.8%) and, finally, chunks (10.2%) and debris (<2%) (see Table 1). Despite the low frequency of chips, it must be considered that this value may be biased, as it may be a direct result of sampling or excavation methods. Specifically, it remains uncertain whether materials smaller than 1cm were systematically collected or the sediment sieved. In fact, the intense reduction observed on the cores

suggests that the actual number of chips should likely have been much higher than those represented in this legacy assemblage.

A technological analysis was performed on the debitage products and cores to obtain detailed insights into reduction sequences, the management of core reduction, the objectives of debitage, and the flaking techniques. Based on the data collected from the technological and morphometric analyses of the cores (n=99), two main concepts of debitage were identified—integrated volumetric (*sensu* Boëda 2013) and additive bipolar on anvil (Figure 3, Table 3). Volumetric cores (n=17) were used to manufacture mostly elongated products. According to the organization of the last visible scars, exhausted volumetric cores can be classified as blade cores (n=1), bladelet cores (n=9), bladelet and flake cores (n=2), and flake cores (n=2). In total, five cores seem to have been tested and discarded after only a few detachments. Volumetric cores were exploited using several

TABLE 3. CORE TYPE CATEGORIES.

Core category	N	%
Volumetric direct	17	17.2
<i>Semi-circumferential</i>	(7)	(7.1)
<i>Narrow-sided</i>	(6)	(6.1)
<i>Wide-faced</i>	(4)	(4.0)
Bipolar	62	62.6
Direct-bipolar	15	15.2
Tested	5	5.1
<b>Total cores</b>	<b>99</b>	<b>100.0</b>

semi-circumferential methods (see Figure 3). Their main features can be summarized as follows:

1. *Sensu lato* semi-circumferential cores (or platform cores): cores oriented along the longitudinal axis of the raw material blank, characterized by semi-circular delineation of the striking platform (Figure 4: n. 1, 5, 8, 11). Apart from pyramidal and prismatic cores, this type also includes one carinated core (Figure 4: n. 12). These cores produced blades (n=1), bladelets (n=3), and bladelets and flakes (n=3).
2. Narrow-sided cores: cores with a narrow knapping surface (Figure 4: n. 2, 3). They are made on pebbles (3), or blocky pieces (2) selected according to their morphology and used to produce bladelets exclusively.
3. Wide-faced cores: cores with wide knapping surfaces (n=4). The surface is slightly convex, maintained by convergent and curved removals (Figure 4: n. 4, 14). These cores produced bladelets (n=2) and flakes (n=2); sometimes, non-laminar and hinged removals are produced due to the extent of the lateral convexity.

Bipolar cores represent the most abundant category (n=77). This technique was employed at Apidima Cave C with two main objectives:

1. Bipolar technique used in the early stages of debitage for **splitting/opening** of pebbles. This type of use can be recognized only in the case of pebbles that are partially exploited (n=2) (Figure 4: n. 13).
2. Bipolar technique used to further exploit volumes; for instance, **re-use** of volumetric cores exploited by direct percussion (n=15), and bipolar flaking of former tools (n=5) (Figure 4: n. 10) or large blanks that were originally knapped with direct percussion (n=15).

As previously noted, the extensive use of this technique in advanced and residual stages of exploitation often makes it difficult to recognize the original blank. However, the presence of cores initially exploited with direct percussion and subsequently with bipolar percussion suggests that the low frequency of volumetric blade and bladelet cores (compared to bipolar cores) may be partially due to the additional exploitation of these cores/blanks using the

bipolar-on-anvil technique, when freehand percussion was no longer possible (see Figure 3). It is also important to note that larger initial cores often tend to shatter and fragment during bipolar knapping, creating multiple blanks that can serve as new cores (Arrighi et al. 2020; Delpiano et al. 2024; Moroni et al. 2018). This process leads to an overrepresentation of bipolar cores, as the multiplication of residual cores contributes to their higher frequency compared to those produced exclusively by freehand percussion.

Notably, Figure 5 clearly demonstrates how the volumetry of bipolar cores is mainly narrow and elongated, consistently for the production of elongated blanks. Further observations can be made regarding the different exploitation strategies applied to different raw materials (see Figure 5). Radiolarite cores occur only sporadically in the direct percussion group and appear to have been heavily reduced using bipolar percussion, following a pattern similar to that observed for quartz cores. In contrast, flint cores were predominantly reduced by direct percussion, with bipolar reduction being applied as core volume decreased. This preference for bipolar percussion in radiolarite reduction may be linked to the qualitative properties of this raw material, as it is usually dense in natural cleavage planes. Notably, experimental studies have shown that this technique enables better control of force direction, minimizing flaking errors and fractures linked to the characteristics of raw materials (Delpiano et al. 2024; Tallavaara et al. 2010). Due to its flexibility, bipolar percussion is also commonly employed in quartz reduction (e.g., de la Peña 2015; Pargeter and de la Peña 2017; Pargeter and Eren 2017).

#### INITIALIZATION AND MANAGEMENT OF THE REDUCTION SEQUENCES

Completely cortical blades and bladelets are absent from the assemblage, while completely cortical (n=10; 3.6%) and semi-cortical flakes (n=8; 2.9%) are attested, albeit in a low percentage (see Table 1). These blanks provide inferences on the initial phases of the reduction process. However, their low frequency suggests that while some shaping occurred in the cave, the earliest phases of raw material management likely occurred elsewhere.

Naturally backed bladelets (n=5; 4.1%), blades (n=1; 4.5%), and flakes (n=12; 4.3%) demonstrate the use of natural ridges already present in the raw material as guides for initial blank production, without additional preparation. In some cases, however, greater technical investment was required to structure the core volume, leading to partial or total crests (see Table 1).

Maintenance products are common among bladelets and flakes. Their function is the rejuvenation of flaking surfaces or the re-establishment of core convexities, either laterally or from the distal portion. This category includes partial and total core *tablette* (n=2) used to manage the striking platform. Technical blades, bladelets, and flakes generally have asymmetrical cross-sections, and dorsal scar patterns are sub-parallel, perpendicular or parallel, but orthogonal to the debitage axis. In some cases, technical



Figure 4. Cores. *Sensu lato* semi-circumferential cores (n. 1, 5, 8, 11), narrow-faced cores (n. 2, 3), wide-faced cores (n. 4, 14), bipolar cores (n. 6, 7, 9, 13), bipolar core on residual semi-circumferential core (n. 8), bipolar core on end-scraper (n. 10), carinated core with evidence of additional bipolar exploitation (n. 12).

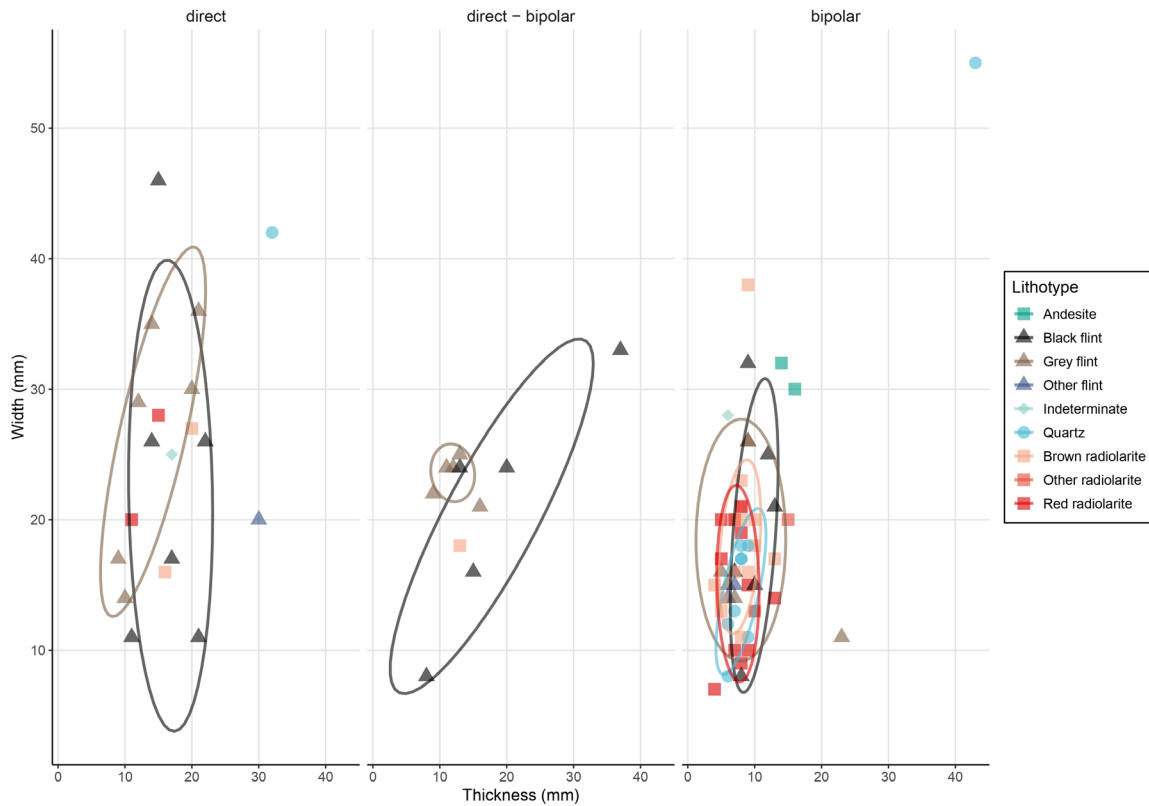


Figure 5. Cores. Scatterplots showing the width and thickness (mm) of complete cores obtained using direct and bipolar percussion, shown by raw material. The central plot displays cores attesting to the switch between the first and second debitage technique. The ellipses represent 68% confidence regions for each raw material group.

blades are used to rejuvenate bladelet cores, as shown in Figure 6, where a blade with bladelet dorsal scars refits onto a semi-circumferential bladelet core.

A flake refitted to a semi-circumferential blade core provides a clear example of how flaking accidents were handled (Figure 7). Following a series of hinged negatives, the flake was detached from a plane opposite the striking platform, to re-establish the core's flaking surface. After the detachment, a new preparation was carried out, followed by a few successful removals.

## DEBITAGE PRODUCTS

### Blades and bladelets

Straight profiles predominate in both the blade (61.5%) and bladelet samples (56.3%) (Table 4). Among bladelets, twisted and slightly twisted blanks are also common (18.3% and 8.5%, respectively). Twisted specimens were likely obtained mostly for maintenance operations, from the periphery of the core's flaking surface. Blanks with a wavy profile (8.5% of the total sample) are generally associated with the use of bipolar percussion.

The cross sections are mainly triangular (76.9% blades; 62% bladelets) and less frequently trapezoidal (7.7% blades; 26.8% bladelets). This prevalence of triangular cross-sections suggests that a single central ridge was often used as

a knapping guide, although a natural lateral ridge or cleavage plane was occasionally also used for this purpose.

Unidirectional dorsal scars predominate (69.2% blades; 70.4% bladelets), followed by bidirectional scars (7.7% blades; 16.9% bladelets). Orthogonal and perpendicular removals occur sporadically, but these are mostly related to core management operations, as core rotation would lead to the production of short products. Bidirectional scars generally result from bipolar percussion. However, in a few cases, they indicate the use of opposed platforms to maintain the distal side of the core (e.g., see Figure 6). Distal terminations are generally feathered among bladelets (47.9%), whereas blades exhibit an equal frequency of feathered and plunged distal ends (30.8%). Although overshoot and plunging distal ends are typically the result of striking errors, in some cases they represent intentional management products for maintaining the core morphology.

Butts are predominantly plain for blades (38.5%) and punctiform (35.2%) among bladelets. Plain (28.2%) and linear (23.9%) butts are also frequently observed among bladelets.

The overall morphological and technological analysis of both complete and fragmentary blanks indicates that over 60% of blades (66.7%) and bladelets (67.7%) are produced by direct percussion, while approximately 25% of the elongated blanks were produced by bipolar percussion.

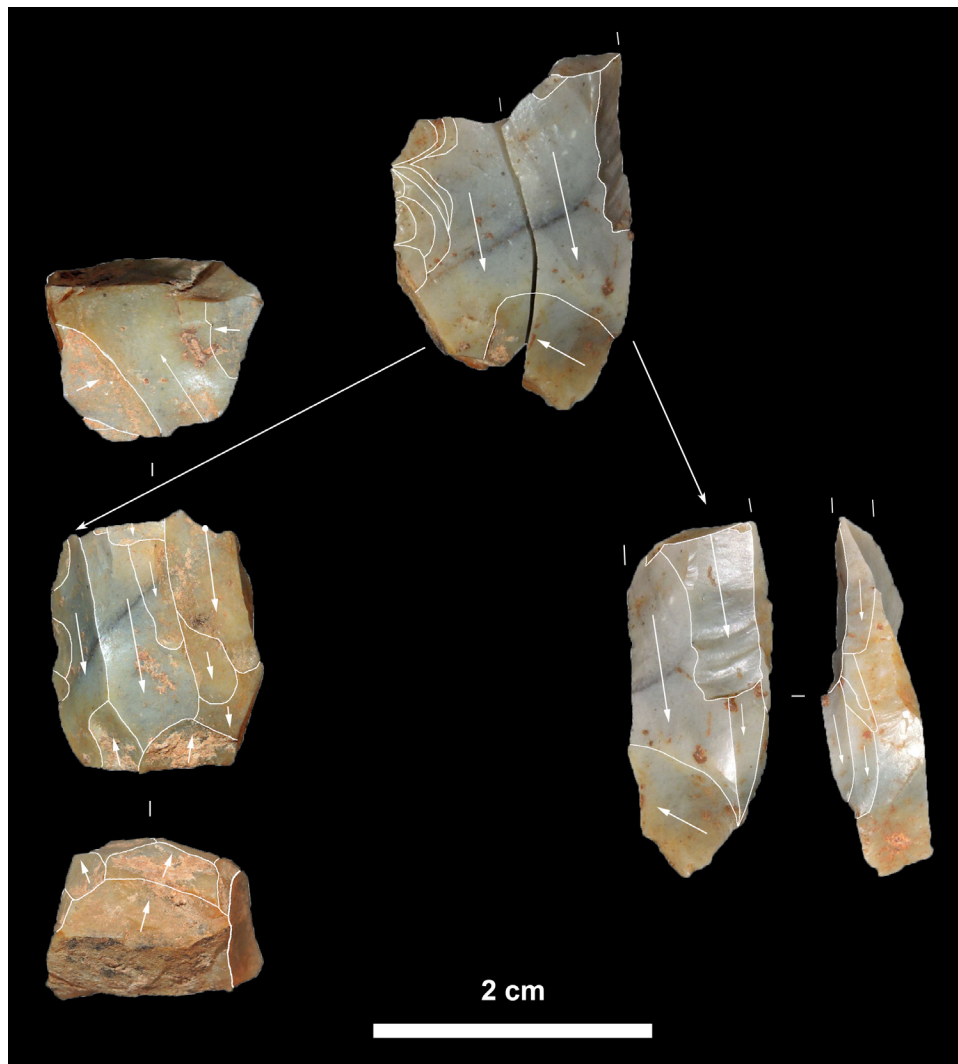


Figure 6. Refit showing a blade with dorsal lamellar negatives, detached to rejuvenate the striking platform surface of a semi-tournant core, following a hinged negative scar. The blade detachment was then followed by further lamellar flaking.

A summary of metric attributes of complete blade and bladelet blanks, categorized by percussion technique, is presented in Table 5. No statistically significant differences are observed in the length, width, or thickness of blades produced by direct and bipolar percussion (length,  $p=0.109$ ; width,  $p=0.054$ ; thickness,  $p=0.839$ ), although it should be noted that the sample size is limited.

Bladelets produced with both techniques are homogeneous in length and width (length,  $p=0.684$ ; width,  $p=0.874$ ), but bladelets produced by bipolar percussion are significantly thicker (thickness,  $p<0.001$ ). This pattern matches well with experimental observations showing that bipolar percussion readily produces blanks with thick edges, which are well-suited for woodworking (Diez-Martín et al. 2011). Although there is no significant difference between the size of bladelets produced by direct and bipolar percussion, it is interesting to note the distribution shown by the scatterplots (Figure 8). Among the bladelets produced by direct percussion, a substantial group measures between 25mm

and 35mm in length, whereas this size category is rare among bladelets produced by bipolar percussion, which tend to cluster around 25mm in length (Figures 9, 10).

These findings support similar observations from other Late Pleistocene sites regarding the cores—bipolar percussion was used as a supplementary technique to direct percussion, enabling the production of elongated and/or thick blanks of the desired size when, for different reasons (e.g., core dimensions, raw material quality) exploitation was not (or no longer) possible with direct percussion (Bietti et al. 2010; D’Angelo and Mussi 2005; Wang et al. 2022).

### Flakes

The morphological and technological attributes of flakes are presented in Table 4. Analysis of the reduction sequences indicates that flakes were not the primary focus of lithic production. Instead, a large portion of the flake assemblage relates to core re-shaping and maintenance. However, flakes with non-diagnostic characteristics cannot



Figure 7. Refit showing a flake detached from a percussion plane opposite the main one after a hinged negative. The detachment of the flake is followed by the preparation of the second platform and the production of some flakes.

be attributed to specific stages within the flaking process. The assemblage is dominated by rectilinear profiles (78%). In cross-section, triangular morphology is the most common (40.2%), followed by flakes with a linear section (25%), a shape rarely observed in bladelets and absent in blades.

The analysis of dorsal removals, consistent with what we observe for bladelets and blades, shows a predominance of unidirectional negatives (51.2%). The increase in bidirectional scars on flakes, when compared to the blade and bladelet blanks, often relates to the use of bipolar percussion and re-preparation for blank production. The larger number of blanks with perpendicular negatives is also worth mentioning.

Distal ends are mostly feathered (49.4%), but plunging and broken ends are also well represented (see Table 5). Plain butts are most common, followed by linear and punctiform, while shattered butts are generally associated with bipolar production. About half of the overall flake assemblage was produced by direct percussion (52.9%), with 33.8% produced by bipolar percussion on anvil. However, it should be considered that the impact of bipolar percussion is always underestimated (Moroni et al. 2019), as some products of this technique can be confused with those produced by direct percussion (e.g., flakes produced by the blowback from the anvil).

Noteworthy are the trends shown by the scatterplot (Figure 11). Direct products are often wide and short (in many instances related to core maintenance operations),

and large ellipses show high variance within the group, especially for the flint subtypes, where ellipses are also wide. Bipolar reduction products, on the other hand, show points closely clustered together, the products of the various raw materials thus show low variance. Also of interest in this group is the positive correlation between length and width, which demonstrates, also among the flakes, the consistent production of elongated products through the use of this technique.

## TOOLS

The classification of tool types reveals significant variability, with retouched bladelets representing the dominant category (>40%) (Table 6, Figure 12). Nearly all retouched bladelets (90.4%) are made on full-production bladelets (products from bladelet reduction strategies), while crested or partially crested bladelets were used less frequently as tool blanks. The most widely used raw material is flint (62.5%), with radiolarite playing a secondary role in the production of blanks for retouching (25%). Overall, the majority of retouched bladelets (73.1%) were produced through direct percussion (Figure 13). Among tools produced on flakes, technical and cortical blanks are more frequent (22.2%). Three tools were made using exhausted bipolar cores as blanks (e.g., Figure 14: n. 5).

Typologically, bladelets with marginal backed retouch are the most common (30.7%), whereas backed bladelets with more invasive retouch are less frequent (8.9%). Mar-

**TABLE 4. MORPHOLOGICAL AND TECHNOLOGICAL ATTRIBUTES OF BLADES, BLADELETS, AND FLAKES.\***

	Blade	%	Bladelet	%	Flake	%
<b>Curvature profile</b>						
concave	1	7.7	6	8.5	10	6.1
convex	1	7.7			3	1.8
rectilinear	8	61.5	40	56.3	128	78.0
slightly twisted			6	8.5	9	5.5
twisted	2	15.4	13	18.3	4	2.4
wavy	1	7.7	6	8.5	10	6.1
<b>Cross section</b>						
half circle					6	3.7
irregular	1	7.7			16	9.8
linear			2	2.8	41	25.0
rectangular trapeze			1	1.4	4	2.4
trapeze	1	7.7	19	26.8	21	12.8
triangular	10	76.9	44	62.0	66	40.2
triangular rectangular	1	7.7	5	7.0	10	6.1
<b>Dorsal removals</b>						
unidirectional	9	69.2	50	70.4	84	51.2
bidirectional	1	7.7	12	16.9	43	26.2
orthogonal	1	7.7	4	5.6	8	4.9
multidirectional					1	0.6
perpendicular	1	7.7	5	7.0	19	11.6
indeterminate	1	7.7			4	2.4
none					5	3.0
<b>Distal end</b>						
broken	2	15.4	8	11.3	25	15.2
feather	4	30.8	34	47.9	81	49.4
hinged	2	15.4	9	12.7	18	11.0
overshoot	1	7.7	4	5.6	4	2.4
plunging	4	30.8	16	22.5	33	20.1
shattered					3	1.8
<b>Butt</b>						
broken			5	7.0	13	7.9
cortical			1	1.4	3	1.8
dihedral					5	3.0
faceted			1	1.4	1	0.6
linear	3	23.1	17	23.9	35	21.3
plain	5	38.5	20	28.2	66	40.2
punctiform	3	23.1	25	35.2	27	16.5
shattered	2	15.4	2	2.8	14	8.5
<b>Total</b>	<b>13</b>	<b>100.0</b>	<b>71</b>	<b>100.0</b>	<b>164</b>	<b>100.0</b>

\*The attributes consider only complete and almost complete specimens.

**TABLE 5. SUMMARY OF METRIC ATTRIBUTES OF ELONGATED BLANKS (mm).\***

Techno Category			L	W	T
bipolar	N		<b>4</b>	<b>4</b>	<b>4</b>
	Std. Error of Mean		1.826	0.707	2.056
	Std. Deviation		3.651	1.414	4.113
	Percentiles	25	26.50	13.00	3.00
		50	30.00	13.50	8.00
		75	33.50	15.50	10.75
blade	direct	N	<b>8</b>	<b>10</b>	<b>10</b>
		Std. Error of Mean	1.652	0.884	0.712
		Std. Deviation	4.673	2.797	2.251
		Percentiles	25	30.50	14.00
		50	36.00	16.00	6.50
		75	39.75	18.00	8.00
bipolar	N		<b>25</b>	<b>30</b>	<b>30</b>
	Std. Error of Mean		0.864	0.364	0.243
	Std. Deviation		4.319	1.995	1.333
	Percentiles	25	16.50	6.00	4.00
		50	19.00	7.50	4.00
		75	23.00	9.00	5.00
bladelet	direct	N	<b>44</b>	<b>88</b>	<b>88</b>
		Std. Error of Mean	1.002	0.245	0.163
		Std. Deviation	6.644	2.294	1.525
		Percentiles	25	16.25	6.00
		50	19.50	7.50	2.00
		75	24.75	10.00	4.00

\*Only complete and almost complete blanks were included for length, while the fragmented specimens were included only for width and thickness.

ginal retouching often involves the entire lateral edge of the blank but is sometimes used only to regularize parts of the tool, which is also the case with some marginally retouched flakes. The retouch is predominantly direct, three specimens display inverse retouch, and one specimen has alternate retouch (see Figure 12: n. 5). Four specimens with direct retouch also display a complementary inverse marginal retouch. Of note is that more than half of the retouched bladelets (63.2%) are fragmented, making it sometimes difficult to define with certainty whether the retouch defined a convergent pointed morphology or not.

The category of side scrapers is varied and predominantly produced on flakes (52.7%), often with partial or discontinuous retouch. Two transverse scrapers were made

on management blanks. End-scrapers are generally made on flakes, with only two examples produced on blades (Figure 14: n. 1, 2), one of which is a technical blade. Only one end-scraper was made on a bladelet, which features a lateral, total alternate abrupt retouch. One bladelet (found broken in two pieces and re-fitted) stands out for its distinct characteristics. The right margin is entirely retouched with a particularly steep, abrupt retouch, and an irregular, almost denticulated abrupt retouch is present on the left margin. This tool was likely recovered from a more recent stratigraphic horizon, such as the surface layer (it is worth noting that the distal fragment of this bladelet is reported among the 62 finds analyzed by Darlas 1995 and reported as possibly in association with the skeleton Apidima 3).

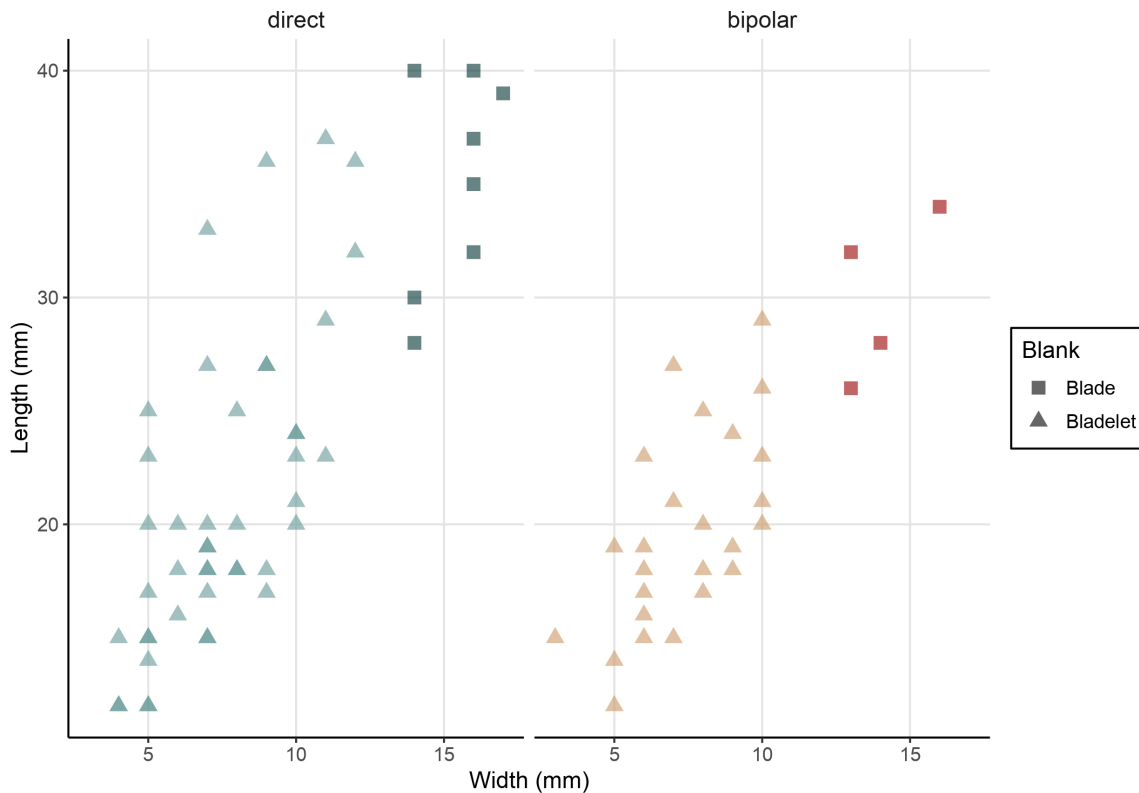


Figure 8. Scatterplot showing the length and width (mm) of blades and bladelets obtained from bipolar and direct percussion.

## DISCUSSION

### TECHNOLOGICAL BEHAVIOR AT APIDIMA CAVE C

Given the scarcity of contextual information regarding the recovery of the artifacts from Apidima Cave C, a cautious approach is required. In Pitsios (1995), a schematic profile showing lithic distribution suggests the presence of a horizon rich in cultural material (see Figure 2d). However, this interpretation cannot be accepted uncritically, as the original literature contains ambiguous and sometimes contradictory information concerning the possible relationship between lithic artifacts, shell ornaments, and human skeletal remains. Although the human remains have been directly dated to the Terminal Pleistocene through U-series dating (Harvati et al. 2021), this result represents only a minimum age. Moreover, the absence of a secure contextual link between the skeletal material and the associated artifacts limits the relevance of this date for assessing the chronology of the assemblage. Radiocarbon dates obtained from shells recovered during Pitsios' excavations indicate an age range of approximately 24–32 ka cal BP (Harvati et al. 2026 [this issue]), providing a more constrained minimum age for the cultural material. Absolute dates of materials from the new, ongoing excavation of the site will help clarify these chronological relationships. Despite these limitations, the present analysis demonstrates that a coherent

technological pattern can be identified within the assemblage, allowing a proposal of a chrono-cultural attribution.

Flint and quartz are the most locally available raw materials in the region and were most likely collected at short distances from the site, as reported also for neighboring sites with Upper Paleolithic material (Darlas and Psathi 2008; Karkazi et al. 2024), while radiolarite and andesite were probably procured at greater distances (>20km from the site) (Karkazi et al. 2024). The low rate of cortex suggests that the initial stages of testing and shaping occurred prior to the raw materials being transferred to the cave.

The lithic industry of Apidima Cave C is clearly oriented towards the production of bladelets. The integrated volumetric cores are generally poorly prepared, with platforms opened by a single or a few detachments. Natural ridges are utilized to initiate the blade and bladelet production, and where these are absent, lateral crests, either total or partial, are made. Core maintenance is performed through rejuvenation of the lateral flanks, with occasional opposing removals to maintain the core distal convexity. While cores for blades are few in number, their presence is nonetheless evident. Noteworthy is the presence of some blades (e.g., see Figure 14: n. 1) probably introduced to the site as finished blanks, made of possibly exogenous raw materials. It cannot be excluded that some bladelet cores may initially have been used for blade production; however, given the small size of the initial core volumes, when

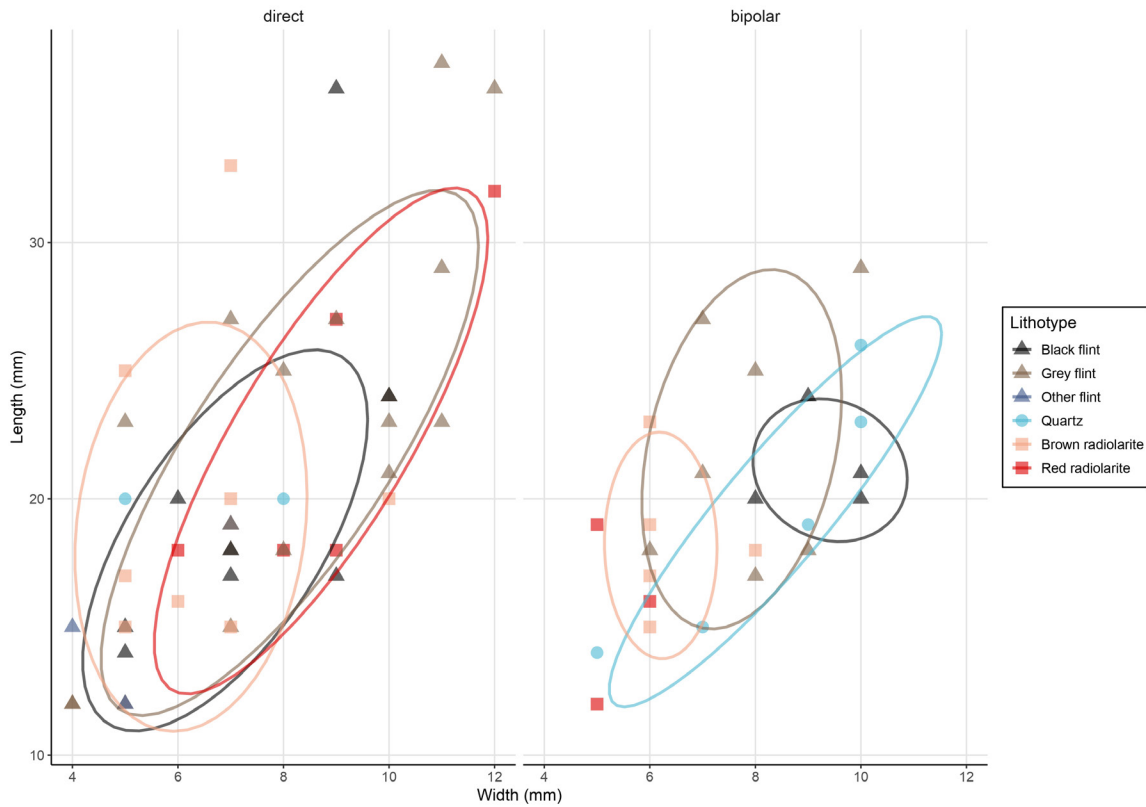


Figure 9. Scatterplot showing the length and width (in mm) of bladelets obtained from direct and bipolar percussion, shown by raw material. The ellipses represent 68% confidence regions for each raw material group.

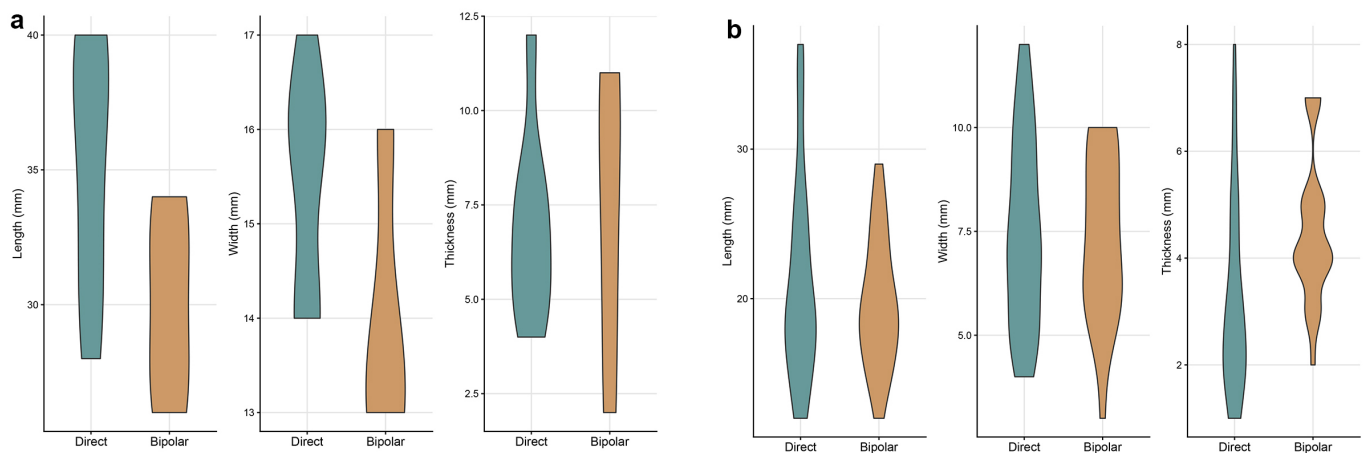


Figure 10. Violin plots showing the distribution of length, width, and thickness (in mm) across elongated blanks produced by direct and bipolar percussion. a) Blades. b) Bladelets.

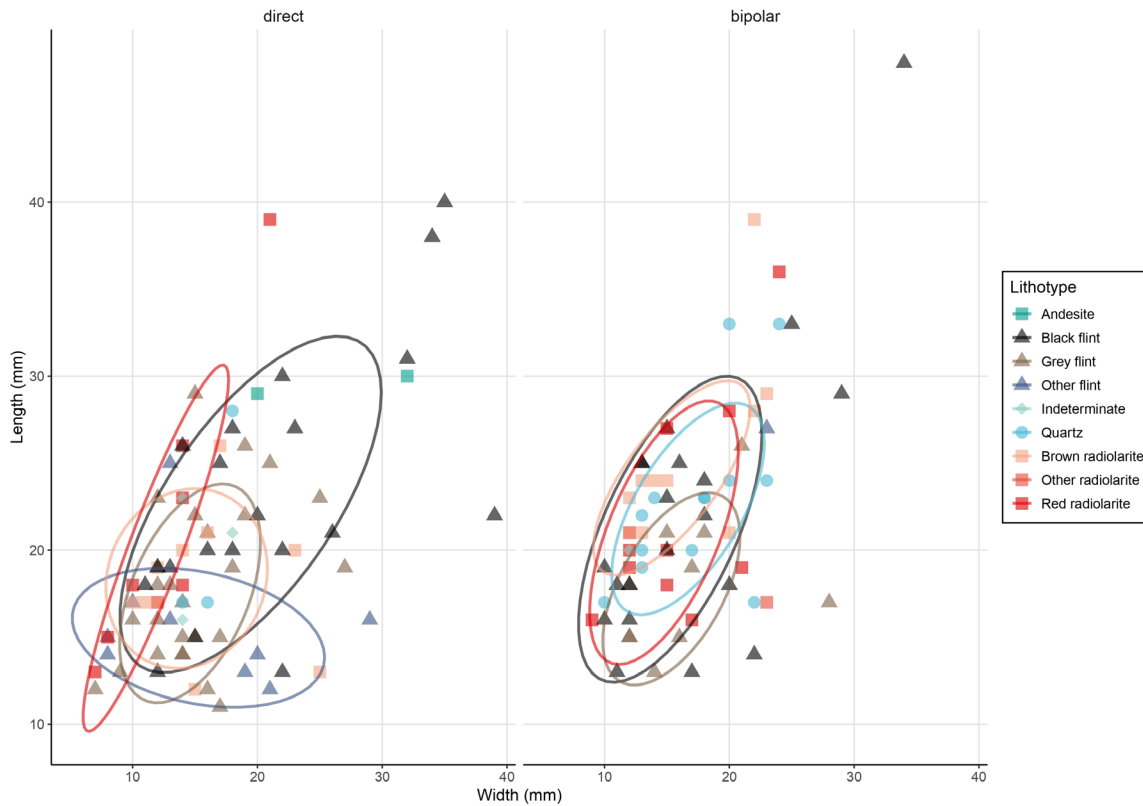


Figure 11. Scatterplot showing the length and width (in mm) of flakes obtained from direct and bipolar percussion, shown by raw material. The ellipses represent 68% confidence regions for each raw material group.

TABLE 6. GENERAL OVERVIEW OF THE TOOL TYPE CATEGORIES.

	N	%
marginal backed bladelet	31	30.7
marginal backed piece	2	2.0
backed bladelet	9	8.9
backed piece	1	1.0
shouldered bladelet	1	1.0
side scraper	13	12.9
elongated side scraper	6	5.9
denticulated side scraper	4	4.0
<b>Tool</b> transversal scraper	2	2.0
<b>categories</b> end-scraper	10	9.9
long end-scraper	2	2.0
long end-scraper on a backed bladelet	1	1.0
point	2	2.0
retouched bladelet	4	4.0
retouched fragment	9	8.9
truncation	2	2.0
marginal truncation	2	2.0
<b>Total</b>	<b>101</b>	<b>100.0</b>



Figure 12. Bladelets with backing retouch. Backed bladelet with convergent bilateral retouch (n. 1), marginal backed bladelet with proximal complementary retouch (n. 2), backed bladelet (n. 3), marginal backed bladelets (n. 4, 6, 7, 9-16) marginal backed bladelet with alternate retouch (n. 5), marginal backed bladelet with convergent bilateral retouch (n. 8). In dorsal view, the solid lines indicate the localization of direct retouch, while dashed lines indicate the localization of inverse retouch.

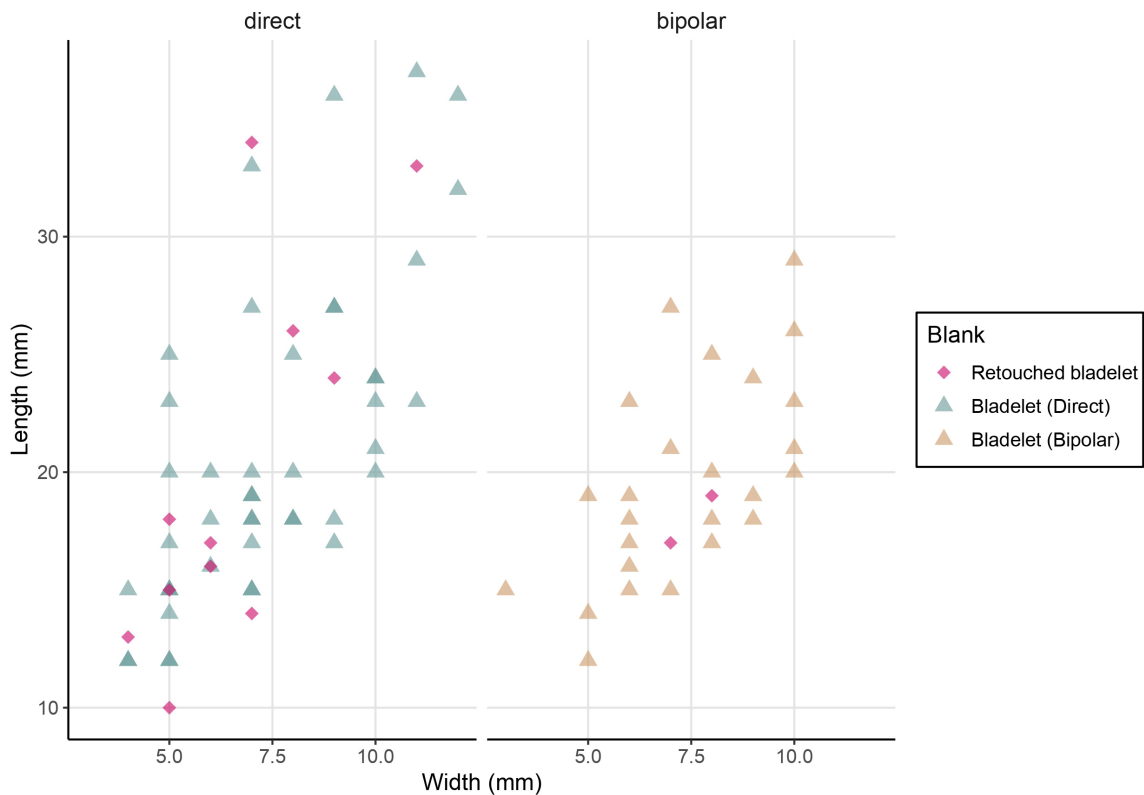


Figure 13. Scatterplot showing the length and width (in mm) of bladelets and backed tools on bladelets obtained with bipolar and direct percussion.

this can be identified, it is likely that several blanks were selected specifically for bladelet production from the outset.

Clarifying the nature of the initial blanks and core volumes is difficult because of the extensive use of the bipolar method. In fact, numerous cores previously exploited by direct percussion ( $n=15$ ) have been clearly reworked via bipolar percussion on anvil. This method likely explains the underrepresentation of volumetric blade and bladelet cores, as bipolar percussion must have largely obliterated their initial form.

The analysis of the debitage products indicates that both percussion techniques targeted similar blanks—the bladelets produced through bipolar percussion align with the dimensions of those produced by direct percussion, although the former are notably thicker. Elongated blanks are also consistently present within the group of flakes produced by bipolar percussion. This evidence suggests that bipolar percussion served as a supplementary method, supporting the primary production with direct percussion technique.

The retouched tools are dominated by flint bladelets, produced mainly by direct percussion, and modified with lateral abrupt or semi-abrupt retouch. The specific function of this tool type requires further assessment; while they are commonly associated with projectile use (Broglia et al. 1998), functional studies have also documented traces of cutting (Broglia et al. 2005; Grimaldi et al. 2014); hence, ap-

parently, their use in domestic and hunting tasks was not mutually exclusive. Future use-wear analysis will be essential to clarify the role of Apidima Cave C backed bladelets, especially regarding the high percentage of broken specimens and breakage patterns possibly related to use and then discard at the cave.

The abundance of cores and their extreme level of exploitation, along with the large number of management products, indicate that at least part of the flaking process occurred on-site. The study of faunal remains, ornaments, bone tools, and hematite blanks from the Apidima legacy collection is currently ongoing (for a preliminary analysis, see Pitsios 1995). By combining the forthcoming results with data from the present study and new excavation campaigns, it will be possible to reconstruct a more complete picture of the site.

#### EXCLUDING POSSIBLE SCENARIOS

In order to propose a chrono-cultural attribution, it is necessary to exclude, if possible, alternative scenarios. When looking at the core reduction, a large number of bipolar cores are present in the assemblage of Apidima Cave C. Bipolar technology on anvil has been, for a long time, and with various interpretations, linked with the Uluzzian technocomplex (Delpiano et al. 2024 and references therein). Is this element enough to interpret the Cave C lithic industry as Uluzzian?

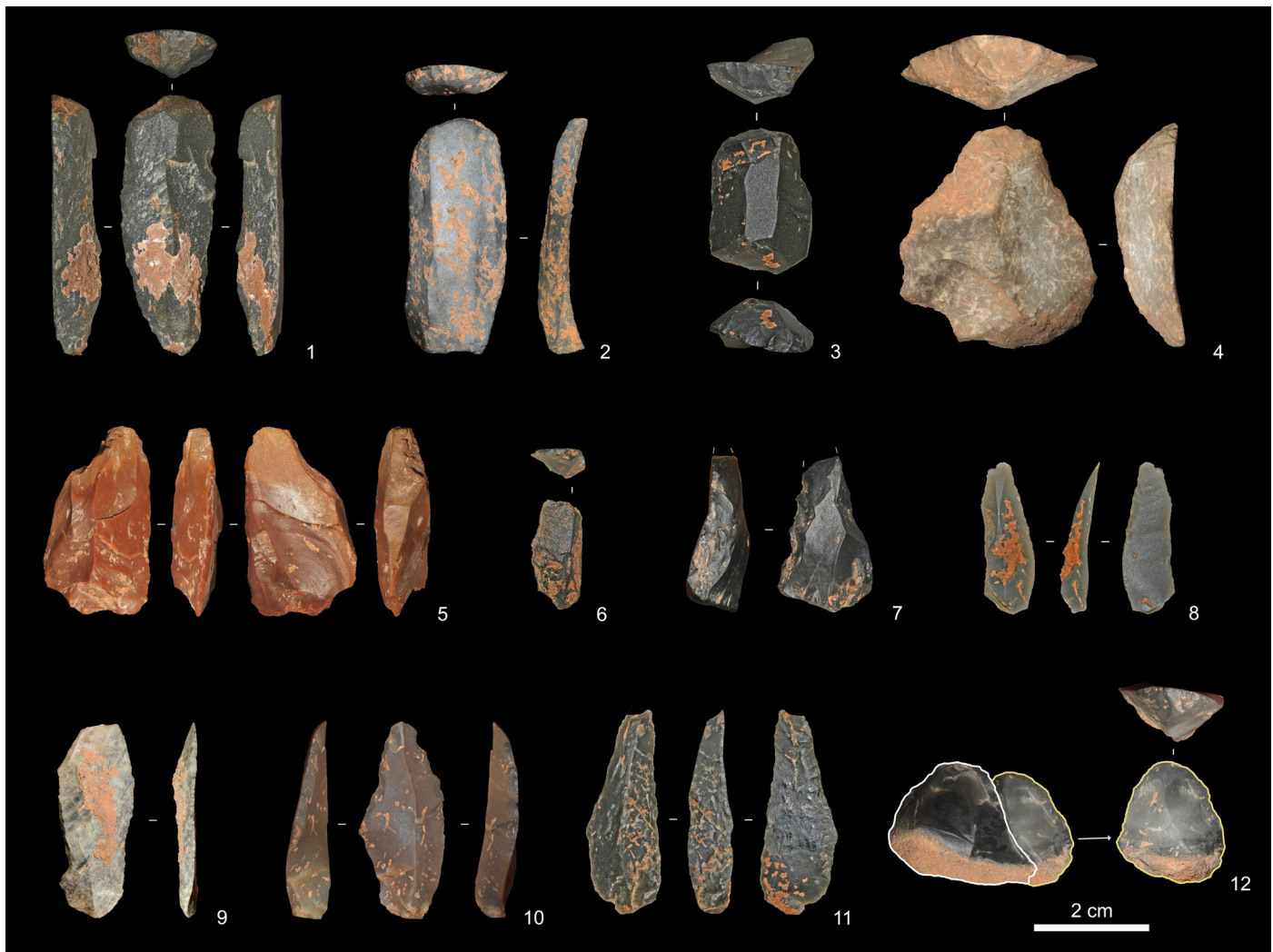


Figure 14. Tools. End-scrapers (n. 1-4), marginal backed retouch on bipolar core (n. 5), truncation (n. 6), side-scrapers (n. 7-11), refit showing an end-scrapers on flake obtained by bipolar percussion on a semi-cortical flake (n. 12).

The Uluzzian (dated approximately 43 to 39 ka BP) represents one of the earliest *Homo sapiens* dispersals into Europe, with sites in Italy and Greece. This technocomplex is characterized by cohesive features, including the production of distinctive ornaments and bone tools (Arrighi et al. 2020a) and the systematic use of bipolar technology (Arrighi et al. 2020b; Collina et al. 2020; Kaczanowska et al. 2010; Marciani et al. 2020; Moroni et al. 2018; Peresani et al. 2019; Rossini et al. 2022; Silvestrini et al. 2022). The latter consistently applies regardless of variations in blank size, quality of raw materials and site-specific peculiarities (Delpiano et al. 2024). The technique was used with the aim of optimizing time and energy and maximizing efficiency in production (Delpiano et al. 2024; Rossini et al. 2022). The produced blanks usually exhibit very high morphological variability, although the use of the bipolar technique allows the production of blanks with recurrent characteristics (e.g., straight profiles, thin cutting edges). The Uluzzian can be defined as a flake-based industry even though the

production of bladelets is always evidenced and increases over time, as in the evolved-final Uluzzian of Grotta del Cavallo and Klissoura Cave (Marciani et al. 2024; 2025). Considering the retouched tools, the Uluzzian is characterized by the systematic production of end-scrapers and the presence of lunates, elongated blanks (mostly bladelets) carefully retouched with backed retouch. The lunates are usually very few in number, with notable exceptions, such as Grotta del Cavallo (especially in the evolved/final phase) and Klissoura. It is interesting to note that, in cases where the lunates on bladelets are very common, an increase in the management of volumetric debitage is also observed (Marciani et al. 2024; Moroni et al. 2018).

At Apidima Cave C, the bipolar technique was mainly employed to split open pebbles, to prolong the use-life of raw materials initially exploited by direct percussion, as well as to strategically optimize the exploitation of blocks that are affected by cleavage plane fractures, as is the case with radiolarite and quartz. Therefore, it appears that the

use of the bipolar technique relates to specific technological decisions and economic approaches to lithic production, which are conditioned primarily by the size, morphology, and mechanical behavior of the raw materials and possibly also by supply strategies and substance activities. The volumetric core management and tool types suggest that, regardless of the extensive use of bipolar percussion, the Cave C industry cannot be ascribed to the Uluzzian technocomplex. Also, even in the evolved/final phase of the Uluzzian, when core management starts to be present, the number of lunates increases significantly, while marginal retouched bladelets are very sporadic (Marciani et al. 2024; Moroni et al. 2018). In contrast, at Apidima Cave C, lunates are absent and marginally backed bladelets are the predominant tool type.

In order to highlight possible differences in the retouched tools assemblage that might lead to multiple interpretations, we decided to separate bladelets that display marginal retouch from the bladelets that display a slightly more invasive, abrupt retouch (see Table 6). Does the presence of backed bladelets reflect the existence of a Gravettian use of the cave? Do we have other elements to support or exclude a Gravettian (or even younger) component?

Treating the Gravettian as a cohesive cultural unit is increasingly being questioned. As Reynolds (2021) has pointed out, “Any conceptualisation of ‘the Gravettian’ as representing a discrete culture, or population, or even technocomplex, is more epistemologically dubious than is often assumed.” We can generally define “Gravettian” archaeological assemblages found in Europe, dating to 30–22 ka BP, as characterized by the systematic production of backed lithic artifacts (including Gravette points, various backed bladelets and shouldered points) (Reynolds 2021). However, there is no single “Gravettian technocomplex” or a unique Gravettian technical system, as an extremely wide range of technical solutions is used in lithic production (Pesesse 2017).

“Gravettian points” are often present, alongside truncated and bi-truncated bladelets, points with truncated base, and angular backed points (Pesesse 2017), while shouldered points are rare and see an increase in the Epigravettian (Kozłowski 1999). The shared trait of these tools is the generally invasive, abrupt backing retouch, with occasional complementary retouch on one or both ends also present. The cores, generally infrequent, can be unidirectional unipolar, bidirectional (alternating two opposing equivalent striking platforms), or additive with multiple unipolar exploitations (Kozłowski 2015; Pesesse 2017).

Even though numerous attempts at constructing a synthesis have been made (Adam 1989, 2007; Kozłowski 1999; Litsios 2024; Tourloukis and Harvati 2018), defining trends in the “Gravettoid” or “Mediterranean Gravettian” in the Balkans and Mediterranean region is not straightforward (Kozłowski 2015). Sites are often sporadic and often have low-density lithic assemblages, sometimes lacking diagnostic elements (Plavšić and Popović, 2019; Stiner et al. 2022) and, therefore, in the lack of absolute dating, the boundary between Gravettian and Epigravettian is challenging to assess (Alex et al. 2019; Anghelinu et al. 2012; Litsios 2024;

Mihailovic and Mihailovic 2007). In the Oitylo Bay, the Gravettian sites are characterized by the preference for small tools such as backed bladelets, backed points, and micro-gravettes, while the typical Gravettian points, present in the other Balkan and Italian sites, are rare (see Litsios 2024; Tripsana and Skoini IV). Burin-cores for the production of bladelets and micro-bladelets are attested (Litsios 2024). But even taking into account the great variability hidden under the label of “Gravettian,” it seems clear that the Apidima Cave C industry diverges in its general characteristics from what has been described above. Burins, burin cores, and double platform bidirectional cores are absent, and the assemblage lacks Gravettian points, microgravette points, or backed bladelets with angular back (in contrast, bladelets of this type are attested in the Cave D assemblage, see Lombardo et al. 2026 [this issue]). The retouched bladelets generally display marginal retouch (30.7%) while more invasive retouch is seen only sporadically (8.9%). Due to the lack of stratigraphical information, we cannot rule out that some of these bladelets may represent an ephemeral Gravettian presence, even though the elements supporting this kind of occupation in Cave C are very limited.

#### APIDIMA CAVE C WITHIN THE AURIGNACIAN TECHNICAL VARIABILITY

At Apidima Cave C, both direct and bipolar percussion were effectively employed primarily to produce elongated blanks. One carinated core is present, and marginally retouched bladelets dominate the tool type assemblage. The reduction sequences directed toward the production of bladelets through varied methods, along with the typological composition of the retouched assemblage, suggest that we can validate what was hypothesized in the preliminary analysis of the industry (Darlas 1995) and that the lithic assemblage falls within the typo-technological variability of the earliest Aurignacian.

The Aurignacian is an Upper Paleolithic technocomplex attributed to *Homo sapiens* (Benazzi et al. 2015; Mellars 2004) and is commonly associated with the modern human expansion through the Levantine corridor towards Atlantic and continental Europe (Hublin 2015; Mellars 2006). It was initially defined based on the association of lithics and bone tools at the type-site of Aurignac, in the Lower Pyrenees (Lartet 1860). Since then, it has been further divided into chrono-cultural phases based on technological features (Bordes 2006; Dinnis et al. 2019; Teyssandier and Zilhão 2018). The earliest phases are known as Protoaurignacian (hereafter PA) and Early Aurignacian (hereafter EA). Where both cultural variants are present, PA consistently underlies EA in stratigraphic sequences (Falcucci et al. 2024; Wood et al. 2014).

First defined by Laplace (1966), on a technological basis, the PA is characterized by the production of slender and straight bladelets from volumetric cores through direct, marginal percussion (Falcucci et al. 2017). This core reduction scheme subsequently results in the production of management blades that are detached for shaping and maintaining the core flanks and lateral convexities. Blade-

**TABLE 7. MAIN CHARACTERISTICS FOR THE IDENTIFICATION OF PROTOAURIGNACIAN AND EARLY AURIGNACIAN FACIES facies (following Falcucci et al. 2024).\***

		Apidima C	Klissoura	Franchthi	Kolominitsa
<b>Protoaurignacian</b>	Predominant use of volumetric cores for the production of slender and straight bladelets	Yes	No	No	-
	Blades obtained in the bladelets reduction sequences as result of management operations as well as part of the production	Yes	No	No	Yes
	Sporadic presence of carinated cores and end-scrapers	Yes	No	No	No
	Marginally retouched backed points and bladelets	Yes	No	No	No
	Occasional presence of antler points with lack of basal modification	No	No	No	No
	<b>Early Aurignacian</b>	Predominant use of carinated cores	No	Yes	Yes
Low frequency of volumetric platform cores		No	Yes	Yes	-
Independent production of blades from volumetric cores		No	Yes	No	No
Bladelets rarely retouched		No	Yes	Yes	Yes
End-scrapers (especially carinated) as dominant tool type		No	Yes	Yes	Yes
Antler points, when present, often with split basal end		No	No	No	Yes

\*Apidima (this study) is juxtaposed to Klissoura (Kaczanowska et al. 2010), Franchthi (Douka et al. 2011; Perlès 1987) and Kolominitsa (Darlas and Psathi 2008; Litsios 2019).

lets are frequently marginally retouched on one or both edges, with profiles, retouch types (inverse/direct, bilateral/alternate or not), and frequencies that vary across different sites (Falcucci et al. 2018); antler points are rarely found and, when present, lack basal modifications (Tejero and Grimaldi 2015).

The EA is characterized by the production of short bladelets using carinated cores, while blades are produced from unidirectional volumetric cores. The bladelets are frequently unretouched, and antler points, when present, often feature a split base (Dinnis et al. 2019; Kitagawa and Conard 2020). It is essential to mention that these differences between the PA and the EA should be seen as tendencies rather than sharp divisions; in that sense, the PA and EA can be considered as different adaptive manifestations of a broadly uniform technological system (Bataille et al. 2018; Falcucci et al. 2017; Tafelmayer 2017). Nevertheless, it remains unclear whether there is any cultural or biogeographic patterning reflected in the distribution of the PA in the Mediterranean and adjacent areas (e.g., Italy, France, Catalonia, Cantabria), as well as parts of the Balkans (Ro-

mania, Bulgaria) (Falcucci et al. 2018 and references therein).

In Greece, the earliest dated Aurignacian from stratified contexts is well-represented only at two sites—Klissoura Cave 1 and Franchthi Cave, in the Argolid (Peloponnese) (see Tourloukis and Harvati 2018). The lithic industry of layer IV at Klissoura (32,400±600 and 33,150±120 <sup>14</sup>C yrs BP, Kuhn et al. 2010) is characterized by the predominant use of carinated technology, accounting for more than 35% of the total cores, with bipolar percussion also playing a significant role in blank production (Kaczanowska et al. 2010). Similarly, Franchthi Cave's Stratum Q (34,980±220, 30,580±160, and 29,780±160 <sup>14</sup>C yrs BP) exhibits an industry dominated by carinated pieces, attested by the presence of small, straight, and curved bladelets and rejuvenation flakes, with very few retouched bladelets (Douka et al. 2011; Perlès 1987). Based on these elements, the two industries have been defined as Early Aurignacian (Douka et al. 2011; Kaczanowska et al. 2010; Perlès 1987) (Table 7).

There seem to be clear differences between the industries of the Argolid sites and the industry of Apidima Cave

C, where the production of elongated bladelets through volumetric platform cores and marginal abrupt retouching are predominant. In addition to the evidence from the Argolid, the assemblage from Kolominitsa Cave is closer to Apidima (circa 5km to the north). Although limited information is available on the reduction sequences at the site (Darlas and Psathi 2016; Litsios 2019), the Kolominitsa Aurignacian assemblage (spits 3–8) contrasts with that from Apidima because it is characterized by the presence of carinated end-scrapers and unretouched bladelets (Darlas and Psathi 2008); Additionally, one antler point with a split base was found in spit 6, which has been directly dated at  $33,870 \pm 550$   $^{14}\text{C}$  yrs BP (Darlas and Psathi 2016). Notably, and similarly to Apidima and other sites in the Oitylo Bay, several hematite fragments have been recovered at both Kolominitsa and Klissoura (Darlas and Psathi 2008; Kaczanowska et al. 2010). Whether the regional differentiations were driven by constraints due to the raw materials, by a different technological choice, or by chronological differences, this subject still needs to be investigated further.

Despite the marked regional variability of the Protoaurignacian, the lithic assemblage at Apidima Cave C largely aligns with PA assemblages across Europe (Bataille et al. 2018; Falcucci and Peresani 2018; Falcucci et al. 2018; 2024; Tafelmaier 2017). Technological similarities are evident in production methods aimed at the manufacture of bladelets with sub-parallel edges from volumetric cores and the large presence of bladelets with marginal retouch (see Table 7).

A closer comparison can be drawn to sites along Italy's Tyrrhenian coast, including Riparo Bombrini (Falcucci et al. 2025; Riel-Salvatore and Negrino 2018), Riparo Mochi (Kuhn and Stiner 1998), Grotta La Fabbrica (Lombardo 2016; Villa et al. 2018), and Grotta Castelcivita (Falcucci et al. 2024; Gambassini 1997), as well as sites in Eastern Europe and the Balkans, such as Românești-Dumbrăvița (Chu et al. 2022) and Tincova (Sitlivy et al. 2014) in Romania, and Kozarnika in Bulgaria (Tsanova et al. 2012). In particular, Apidima C shares with Kozarnika layer VII (Tsanova 2023; Tsanova et al. 2012) a preference for direct retouch, although bladelets characterized by abrupt marginal inverse or alternate retouch are present at both sites. It should be noted that (Proto-)Aurignacian sites are quite rare in Eastern Europe, sometimes representing possibly only ephemeral occupations, as observed at Tabula Traiana in Serbia (Borić et al. 2012; 2022). Bone tools and/or ornaments are also common among the PA sites (Arrighi et al. 2020); the analysis of such artifacts from Cave C is currently underway (for preliminary analysis, see Pitsios 1995).

Absolute chronological evidence for Apidima Cave C remains limited. Direct uranium-series dating of the human remains indicates a minimum age within the Terminal Pleistocene (Harvati et al. 2021), but the date's relevance for the lithic assemblage is uncertain given the lack of a secure contextual link. Recent U-series analyses on section profiles, together with radiocarbon determinations on shell ornaments from the legacy collection, suggest an age range of approximately 24–32 ka cal BP (Harvati et al. 2026 [this issue]), providing a more consistent chronological frame-

work. Nevertheless, in the absence of detailed stratigraphic documentation from the original excavations and further direct dating, the internal chronostratigraphic relationships among the different components of the assemblage remain unresolved (see Harvati et al. 2026 [this issue] for a discussion). Within these constraints, the attribution of the Apidima lithic industry to the Protoaurignacian represents a significant step toward refining the interpretation of the site and situating it within the broader archaeological record of Greece and south-eastern Europe.

## CONCLUSIONS

For the first time, our research presents a comprehensive analysis of the lithic assemblage uncovered during the first excavation at Apidima Cave C. Given the scarcity of Aurignacian sites in the region and the significance of this technocomplex for understanding the arrival and dispersal dynamics of *Homo sapiens* in Europe, the identification of a Protoaurignacian assemblage at Apidima holds critical importance, despite the lack of secure context and chronology. The technical features highlighted in the lithic industry of Apidima Cave C indicate that this is the first assemblage in Greece that can be ascribed with confidence to the Protoaurignacian.

The main typo-technological characteristics of the assemblage include: 1) the use of local flint and, to a lesser extent, radiolarite and quartz, collected from areas near the site; 2) reduction sequences focused on producing elongated blanks, predominantly bladelets; 3) the use of direct and bipolar percussion both in distinct and in the same reduction schemas; and, 4) the dominance, among the tools, of bladelets modified by direct marginal retouch.

Furthermore, our study emphasizes the necessity for interdisciplinary research to further investigate the processes underlying the distinct regional adaptations within the Aurignacian of Greece and beyond. Future research in this direction will contribute to a more comprehensive and nuanced understanding of the behavioral adaptations and social organization of human groups at the beginning of the Upper Paleolithic in this region of southeastern Europe.

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## DATA AVAILABILITY STATEMENT

The datasets generated and analyzed in the current study are available at <https://doi.org/10.5281/zenodo.20325568>.

The complete R code, detailing each step of the data analysis process, is also available at <https://doi.org/10.5281/zenodo.20325568>. All raw data are therefore shared as a free compendium to enhance transparency and reproducibility.

### AUTHORS CONTRIBUTION

**SL:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing; **NCT:** Investigation, Methodology, Writing – review & editing; **VGG:** Resources, Writing – review & editing; **KE:** Resources, Writing – review & editing; **KH:** Funding acquisition, Project administration, Resources, Supervision, Validation, Writing – review & editing; **VT:** Project administration, Supervision, Validation, Writing – review & editing.



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# Special Issue: The Apidima Legacy Collections: New Analyses and Interpretations

## Supplement 1 to Early Upper Paleolithic Technical Behavior at Apidima (Peloponnese, Greece): Technological Analysis of the Lithic Assemblage From the Cave C Legacy Collection

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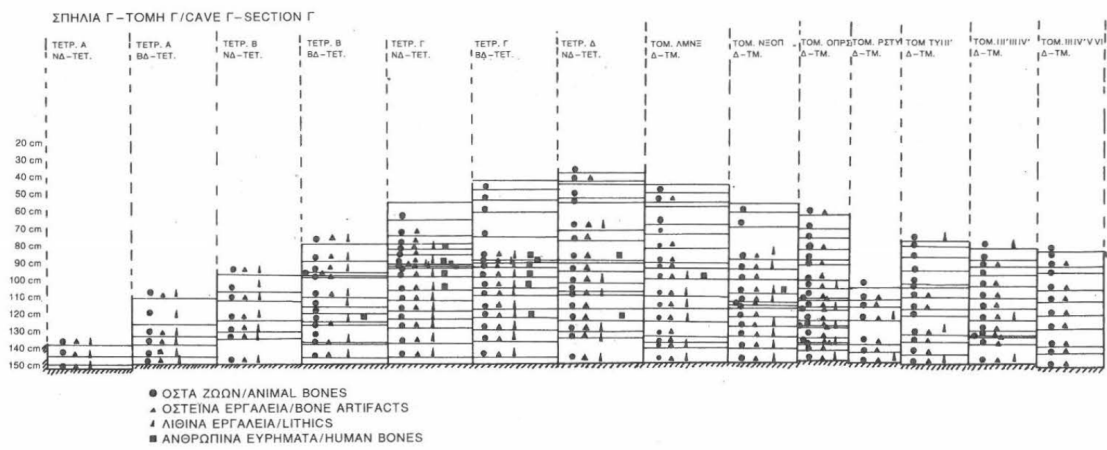
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### SUPPLEMENT 1

This supplement contains: Figures 1–2, Table 1, and References.



Σχεδ. 3 / Fig. 3

Figure 1. Cave C distribution of finds (Pitsios and Liebhaber, 1995).

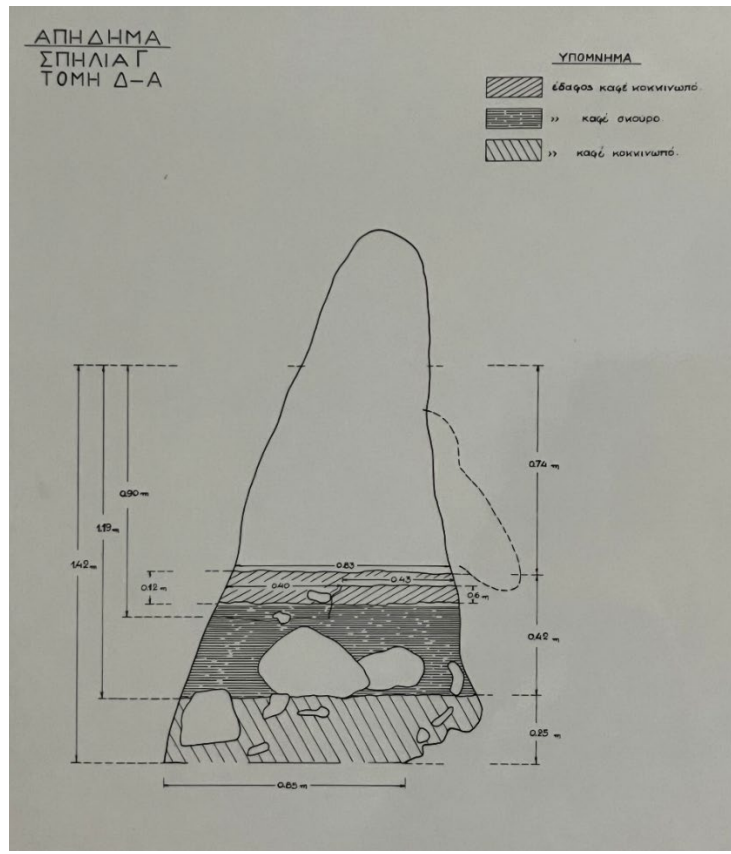


Figure 2. Cave C stratigraphic profile (museum exhibit, Museum of Anthropology, National and Kapodistrian University of Athens).

## Technological analysis

Identification number	Running ID
Excavation details	Date, box number, old ID (if present)
Raw material	Andesite, flint, hematite, indeterminate, quartz, limestone, radiolarite
Raw material subtype	Black, brown, green, grainy black, grey, red
Alteration	Fire, patina, indet, no
Degree of integrity	Integer, distal, lateral, mesial, mesio-distal, proximal, proximal-mesial, composite fragment
Metrical attributes	for each debitage blank >100mm <sup>2</sup> : Length, width, thickness (along the technological axis or considering the longest dimension as length)
Technological categories	Core, flake (length/width ratio ranging from 0 to 1.9), blade (length/width ratio exceeding 2) bladelet (referring to blades with a width ≤ 12 mm) (Inizan et al., 1992), backed flake, spall (an elongated element detached from a lateral ridge of a flake-core), chunk (a fragmented, altered or unorientable piece), chips (flakes and fragments of flakes with an area smaller than 100 mm <sup>2</sup> ), debris (unorientable pieces with an area smaller than 100mm <sup>2</sup> )
Production technique	Direct, bipolar, indeterminate, direct-bipolar (for blanks detached by bipolar percussion that display dorsal direct percussion characteristics), bipolar-direct (for blanks detached by direct percussion that display dorsal bipolar percussion characteristics)

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### For each debitage blank >100mm<sup>2</sup>

Cortex coverage	In percentage
Cortex position	Proximal, lateral, lateral back, mesial, distal, transversal, semi-total, total
Cross-section shape	Trapezoidal, rectangular, triangular, semi-circular, linear, irregular
Longitudinal profile of the ventral face	Straight, concave, convex, twisted, wavy
Orientation of dorsal scars (including the detached piece)	Unidirectional, bidirectional, perpendicular (for removals on the same debitage surface), orthogonal (for removals on different and orthogonal debitage surfaces), convergent, centripetal
Butt characteristics	Linear, punctiform, plain, broken, cortical, dihedral, faceted, shattered, retouched
Bulb characteristics	Diffuse, pronounced, negative, retouched, absent
Distal end	Feathered, hinged, broken, plunging, overshoot, shattered, retouched
Management blank type	(Full)production, Completely cortical flake, Semi-cortical flake, Naturally backed blade, Naturally backed flake, Technical blade, Technical bladelet, Technical flake, Crested blade, Crested bladelet, Crest bilateral, Semi-crested, Sus crete, Tablette
Erailure scar	Yes, no, esquillament

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### For each core

Metrical attributes	Length, width, thickness. Cores are technologically oriented, with the distal end serving as the primary striking platform and the most utilised face, typically exhibiting the latest removals and being designated as the main core face. Measurements were taken in accordance with this orientation whenever feasible; otherwise, the longest dimension was conventionally considered as the length.
Volumetry of the block	Flat parallelepiped, polygonal, triangular prism, trapeze prism, pyramidal, prismatic, irregular
Core blank	Blade, core, flake, fragment, indeterminate, pebble, plaquette, tool
Number of exploited faces	Numerical
Axis	Numerical
Axis type	Long, short, equivalent
Hierarchy of surfaces	Yes, no
Platform preparation	One removal, several removals, no preparation
Direction of the scars	Unidirectional, bidirectional, perpendicular, convergent, centripetal
Target of debitage	Flakes, blades, bladelets, blade-bladelets, flakes-bladelets
Core management	Lateral, distal, no
Exploitation state	Tested, initial, medium, exhausted
Volumetric concept	According to Rossini et al. 2022
General configuration	Semitourning, narrow, wide, tranche

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### For each retouched specimen

Position, extent and description                      Mode (Simple, abrupt, flat, superelevated); extent (Marginal, deep); delineation (Rectilinear, convex, concave, denticulate); direction (Direct, inverse, alternate, bipolar)

Table 1. Description of variables recorded during the technological analysis.

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