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The Lithic Legacy of Loreto: A Technological Perspective on Early Hominin Toolmaking during Lower Palaeolithic

Marco CARPENTIERI[1], Giovanna FIORETTI[2], Antonio PINEDA[1,3], Beniamino MECOZZI[4], Alessio IANNUCCI[5], Giacomo ERAMO[2], Marta ARZARELLO[6], Suzanne SIMONE[7], Marie-Hélène MONCEL[1]

[1] UMR 7194 HNHP (MNHN-CNRS-UPVD), Département Homme et Environnement, Muséum National d'Histoire Naturelle, 1 rue René Panhard, 75013, Paris, France.

[2] Dipartimento Di Scienze Della Terra e Geoambientali, Università Degli Studi Di Bari Aldo Moro, 70125 Bari, Italy.

[3] Institut Català de Paleoecologia Humana i Evolució Social (IPHES-CERCA). Zona educacional 4 - Campus Sescelades URV (Edificio W3), 43007 Tarragona, Spain.

[4] Department of Earth Sciences, PaleoFactory, Sapienza University of Rome. P.le Aldo Moro 5, I-00185, Rome, Italy.

[5] Department of Geosciences, Section of Terrestrial Palaeoclimatology, Eberhard-Karls-University Tübingen. Sigwartstrasse 10, 72076 Tübingen, Germany.

[6] Dipartimento Studi Umanistici, Università Degli Studi Di Ferrara, C.So Ercole I d'Este 32, 44121 Ferrara, Italy.

[7] Museum of Monaco, 31 Bd Rainier III, 98000, Monaco.

Corresponding author:

Marco Carpentieri – marco.carpentieri@mnhn.fr

Abstract

The site of Loreto (Venosa basin, Southern Italy) dates to between MIS 15 and 13, a pivotal phase in the human peopling of Europe. This period marks a moment of change in the Lower Palaeolithic, preceding the glacial break of MIS 12, and the subsequent technological renewal that, from MIS 11 onward, culminated in the transition to the Middle Palaeolithic. Between MIS 15–13, the number of archaeological sites increased, alongside the emergence of bifaces, retouched tools, and more structured land-use strategies. The lithic assemblage from Loreto exemplifies this shift. The technological analysis presented here, focused on layer A, sheds light on hominin behavioural strategies. Core management includes discoid, centripetal, SSDA *(Système par surface de débitage alternée)*, and core-on-flake reduction sequences. Retouched flakes are particularly noteworthy, featuring elaborately worked scrapers and pointed tools with edge rejuvenation, scalariform retouch, and possible soft-hammer use. Beyond its affinities with other coeval sites, the Loreto assemblage may reflect a degree of innovation often linket to biface production, thereby expanding our understanding of Acheulean technical variability. It also contributes to broader discussions on the diversity of lithic strategies adopted by hominins prior to the onset of MIS 11.

Key-words

Lower Palaeolithic – Middle Pleistocene – Venosa basin – Lithic technology

Introduction

The human occupation of Europe during the early Middle Pleistocene (EMP; 774-450 ka; MIS 19–13) coincides with a phase of strong renovation linked with the environmental changes brought by the Middle Pleistocene Revolution (Moncel et al. 2018). An increased number of sites and significant behavioural innovations can be witnessed since MIS 17 over Europe (fig. 1). These include, even if not in all the sites, improved resources' management – better economy of lithic raw materials, systematic primary access to carcasses – better adaptive strategies – human occupation at higher latitudes – and, among lithic assemblages, bifacial and large cutting tools (LCTs) industries, increased production of retouched tools and more complex reduction sequences (Moncel and Ashton 2018; Ashton and Davis 2021).

These changes are commonly associated with the Acheulean techno-complex, although its modalities of arrival over Europe are object of a long-lasting debate (Moncel et al. 2020c). An allochthonous introduction – whether episodical or continuous – of new populations carrying new technical traditions, or a local evolution from previous occupations are, currently, the main supported hypotheses. On top of this, the arrival of a new human species (*Homo heidelbergensis*) from Africa or Asia, and the persistency of non-bifacial industries contributes to portray a multifaceted scenario for the Lower Palaeolithic of Europe (Manzi 2016).

From this perspective, the MIS 15-13 interval stands as a valuable niche to gain a better comprehension of this chronological phase (Hao et al. 2015; Berger et al. 2016; Maiorano et al. 2016; Barth et al. 2018). This interval represents the final phase of the EMP – a moment of climatic turmoil – before the beginning of the late Middle Pleistocene (LMP; 400 – 125 ka; MIS 11–5) which featured more intense climatic oscillations and warmer interglacials, after the severe glacial break of MIS 12 (Lisiecki and Raymo 2005; Hodell et al. 2008).

The EMP – LMP transition coincides with the Mid-Brunhes Event (MBE; Jansen et al. 1986), a climatic turnover globally recorded from MIS 12, characterised by a shift from a low amplitude glacial-interglacial alternation to a large-scale cyclicity, featuring warmer interglacials (Voelker et al. 2010; Blain et al. 2012; Candy et al. 2015; Marino et al. 2018; Barth et al. 2018). To give an idea of the changes, interglacials between MIS 19 and 13 are more similar to interstadials (*i.e.,* warm phases occurring during glacial stages) of the past 450 ka than to interglacials post MIS 12. The implications behind these fluctuations are significant for human's evolution since, starting from MIS 11, a substantial change will occur over Europe gradually leading to the Middle Palaeolithic transition.

The EMP's low amplitude reflects into relatively cool interglacial peaks – like MIS 13 being the coolest interglacial of the past 800 ka together with MIS 17c, and MIS 15 being also cool – but also warmer glacial phases – such as MIS 14, considered a weak glacial and with a considerably lower global ice volume (Hao et al. 2015). As a consequence, MIS 15 and 13 are nowadays better described as "interglacial complexes" (Hodell et al. 2008; Margari et al. 2018) rather than interglacial sensu stricto, including two substages (warm phases; 15c, 15a and 13c, 13a; fig. 1) separated by a cool stage (15b, 13b; fig. 1). The presence of these substages is due to the emergence of millennial-scale climate variability, associated with the upcoming MBE, which featured greater climatic excursions and rapid climate shifts interpreted as short-term climatic oscillations comparable to Heinrich-type events

of the last ice age (Hodell et al. 2008; Voelker et al. 2010; Berger et al. 2016; Maiorano et al. 2016; Barth et al. 2018).

Because of this, the MIS 15-13 interval includes an exceptionally long interglacial-like phase that witnessed the persistence of warm climatic conditions for over 150 ka, even at higher latitudes, encompassing the mild glacial MIS 14 (Hao et al. 2015). This allowed for prolonged hominin occupation and territorial expansion, fostering population growth, increased cultural exchange, and the emergence of more complex technological behaviours (Moncel et al. 2018; Lewis et al. 2019; Oliveira et al. 2020).

The increase in the number of sites during MIS 15-13 is substantial (fig. 1) with several sites recorded across Italy, France, England and Ukraine exhibiting diversified raw materials exploitation, knapping strategies and tools production (Pope et al. 2009; Koulakovska et al. 2010; Barsky 2013; Gallotti and Peretto 2015; Antoine et al. 2015; Aureli et al. 2016; Antoine et al. 2016; Marra et al. 2016; Moncel et al. 2020c; Davis et al. 2021; Key et al. 2022; Rocca et al. 2023; Villa et al. 2024).

The technological and behavioural features documented over time in some of these localities are many, including a higher level of skill in the manufacture of bifacial (bifaces and LCTs) and retouched tools, use of soft hammer for biface shaping and flakes' retouch, discoid reduction sequences, exploitation of exotic raw materials, improved resources' management, not to mention the capability of enduring to freezing temperatures at higher latitudes without the use of controlled fire, seemingly implying a developed intra-group connection and coping mechanisms (Moncel et al. 2018; Rodríguez et al. 2021; Ashton and Davis 2021; Barsky et al. 2021; García-Medrano et al. 2023). Some authors even speculated if the development of traditions/cultures occurred in some regions of Europe (Davis and Ashton 2019; García-Medrano et al. 2023), a topic that will be predominant from MIS 11 onwards with the onset of the Middle Palaeolithic.

Whether these MIS 15-13 changes are due to the persistence of the Acheulean, the arrival of *Homo heidelbergensis*, or an autochthonous development – or all these combined – there is a common consensus in assessing that a cognitive shift occurred during this timeframe over Europe (Manzi 2016; Ashton and Davis 2021; Hu et al. 2023). Despite the presence of these innovations is far from being homogeneous, the MIS 15-13 is a bridge-like phase connecting the Lower to the Middle Palaeolithic and being, at the same time, similar and different from both chronologies.

Within this chrono-cultural frame the Italian peninsula is a valuable area to investigate the evolution of human's technical behaviours. Its favourable climatic and environmental conditions and the presence of numerous intermountain basins made it a refugial area for hominins, enhancing prolonged and stable periods of occupations (Orain et al. 2013; Combourieu-Nebout et al. 2015). The presence of sites such as Notarchirico, Isernia La Pineta, Atella, Ficoncella, Valle Giumentina, Cretone, and Loreto is a proof of this.

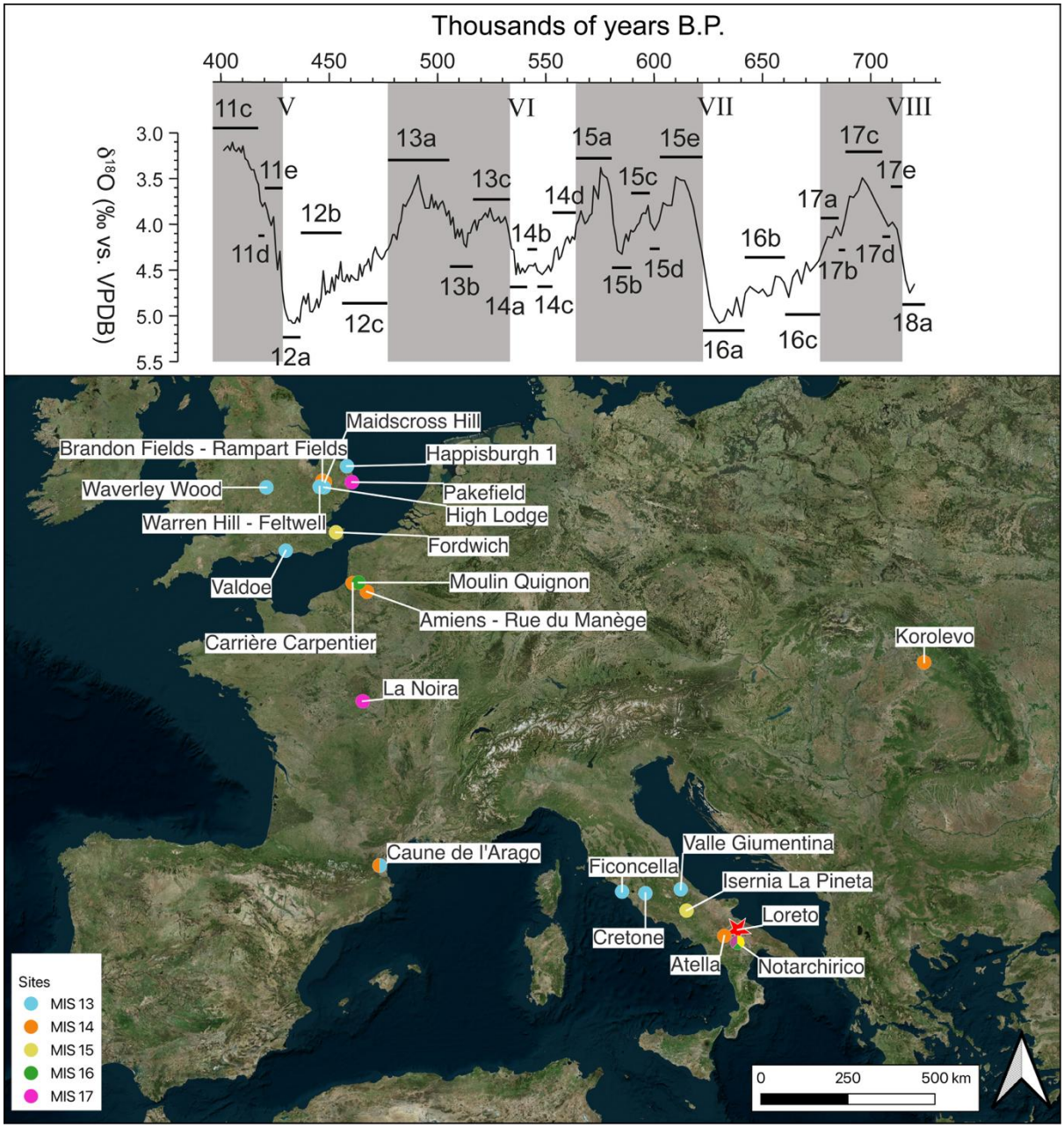


Figure 1 - Location of Lower Palaeolithic sites in Western Europe between MIS 17 and MIS 13.

The site of Loreto

The site of Loreto is located within the Venosa basin (Basilicata, Italy), on top of a hill a few hundreds of meters from the site of Notarchirico, and it is part of the Mount Vulture volcanic complex (fig. 2). The site belongs to a series of artificial caves named caves of Loreto (or Loretello).

Discovered in 1929 by Don Briscese, the first investigations were conducted during 1930s by Rellini and d'Erasmo (1932), though systematic excavations were carried out twenty years later, from 1956 to 1961, under the direction of Chiappella of the Istituto Italiano di

Paleontologia Umana (IsIPu Blanc 1953; Chiappella 1964). Further excavations were also carried out between 1974 and 1981, by Barral and Simone of the Musée d'Anthropologie Préhistorique of Monaco (Bonifay 1977; Barral et al. 1978; Barral and Simone 1983).

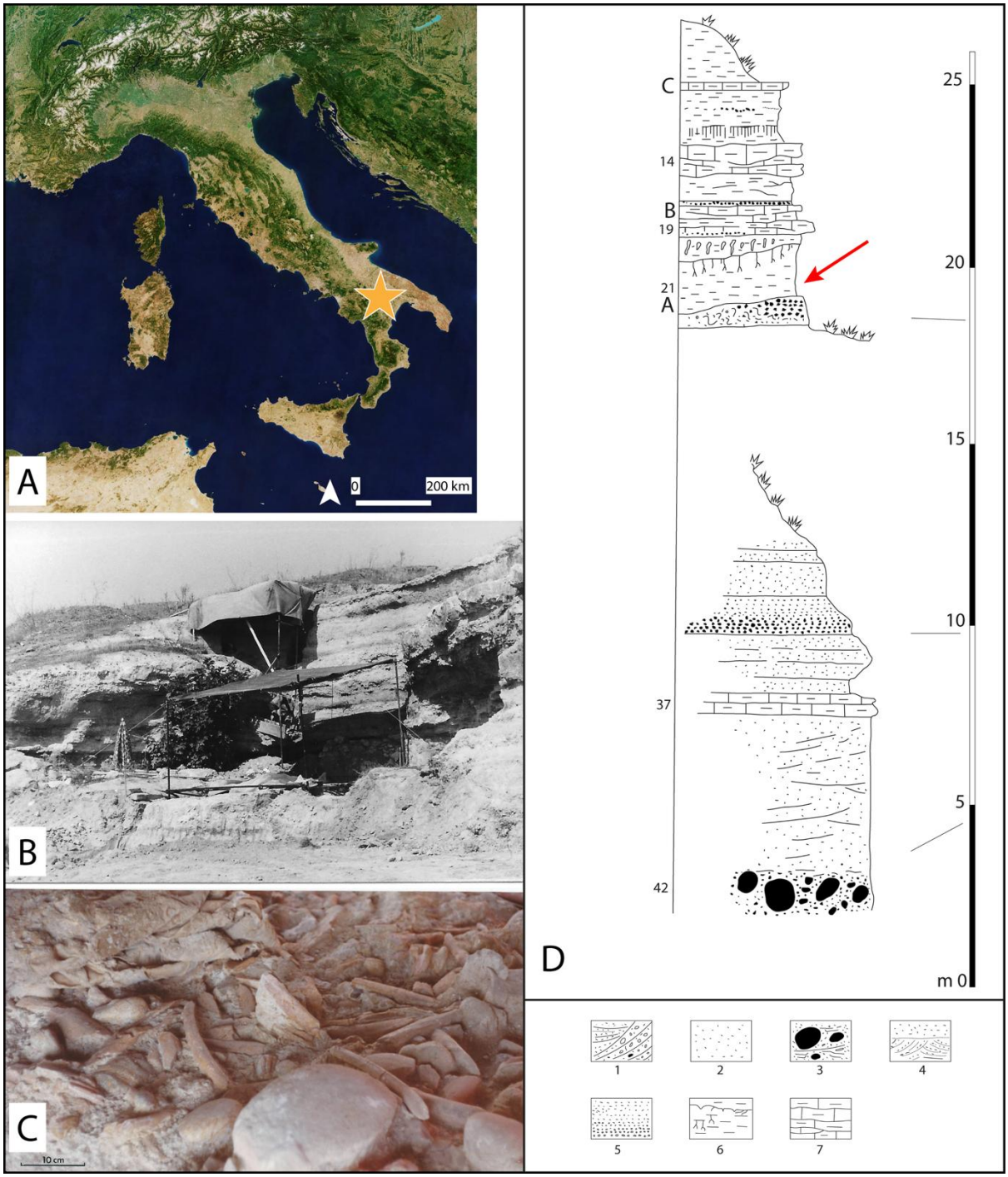


Figure 2 – A) Geographic location of Loreto. B) Excavations during the 1970s. C) Detailled picture of Layer A. D) Stratigraphic section of Loreto: 1 Fluvial deposits; 2: Pumice; 3: Lahar and epilahar; 4: Tephra and epiclastites; 5: Direct ash fall; 6: Silt and carbonate beds; 7: Limestones (modified from Lefèvre et al., 2010). Photos B and C were kindly provided by S. Simone.

The stratigraphic sequence (fig. 2), belonging to the Tufarelle Formation, is 30-m-thick and includes 42 sedimentary levels (Lefèvre et al. 2010). Over the years, three main archaeological levels bearing evidence of human occupation (lithic tools) associated with faunal remains have been identified (Chiappella 1964; Barral and Simone 1983; Pereira et al. 2024). From the top to the bottom of the sequence they consist of:

- Layer C (formerly named "a chopper" in Chiappella (1964): 3m thick of sandy silt with pebbles;
- Layer B: 25 cm thick of green cemented sand with volcanic material;
- Layer A: 40-60 cm thick of sandy silt cemented level (on which both fieldworks of Chiappella and Barral and Simone focused opening a surface of 20 m^2).

These layers are intercalated by sterile levels of fluvio-lacustrine origin rich in sand, silt, clay and travertine. The chronostratigraphic framework of the site, currently under revision, has been attributed to the early Middle Pleistocene (Bonifay 1977; Lefèvre et al. 2010). The last radiometric analyses performed on layers A, B and C ($^{40}Ar/^{39}Ar$, ESR, ESR/U-series; Pereira et al. 2024)) did not yield conclusive results though a chronological frame between MIS 15 and MIS 13 for the lowermost portion of the sequence was identified and is in accordance with previous works (Lefèvre et al. 2010).

The presence of lithic artefacts was documented in all archaeological layers identified, though only the industry from layer A (the richest and best-preserved level) was properly investigated over the years (Barral and Simone 1983; Crovetto 1993). The lithic industry from layer A consists of flakes, retouched flakes, cores, and pebble tools on chert, limestone and other volcanic rocks. One "proto-biface" made on a chert pebble flake was also found during the Barral & Simone excavations.

The previous technological analyses ascribed the lithic artefacts from layer A to the "Tayacian culture" of the Lower Palaeolithic, characterised by large-sized flakes, open debitage angles and scalariform retouches to produce scrapers and pointed tools (Chiappella 1964; Barral and Simone 1983; Crovetto 1993; Pereira et al. 2024). The number of lithic artefacts recovered during the 1974-1981 fieldwork is 528 while the number of pieces found during 1956-1961 campaigns – including the excavation of layers B and C – is unavailable. The industry from level B was described as technologically similar to layer A, though quantitatively inferior, while the artefacts from level C includes Mousterian-type tools and might be associated to the Middle Palaeolithic (Chiappella 1964).

The mammal assemblage includes rhinoceroses, equids, bovids, cervids, hippopotamus, canids, hyaenids, felids and bear from layer A, elephants, equids and bovids from layers B and C (Chiappella 1964; Bonifay 1977; Barral and Simone 1983). This record has been attributed to the early Middle Pleistocene (Bonifay 1977; Angelelli et al. 1978; Alberdi et al. 1988).

The faunal assemblage from Level A has undergone a recent taphonomic and taxonomic review (Pineda et al., submitted). The assemblage is biased, likely due to mid-20th-century excavation methods, with a predominance of larger, anatomically and taxonomically identifiable, remains while smaller remains are absent, limiting taphonomic inferences. Preliminary data indicate a dominance of medium-sized (cervids) and large-sized ungulates (equids and bovids). Evidence of anthropic activity, though

scarce, includes cut marks and breakage, suggesting primary access to carcasses by human groups. Carnivore activity is also documented, albeit less frequently. Probably both agents acted independently, with partial access to carcasses deposited during the assemblage's formation.

The environmental data indicate an open environment ecosystem featuring the presence of a lake surrounded by mixed vegetations, similar to Notarchirico. Durante and Settepassi (1978) analysed the terrestrial gastropods recovered from Loreto to provide a paleoenvironmental reconstruction. In their work, layer A is associated to wet and forested conditions while layers B and C witnessed a drier and warmer environment.

Materials and Methods

This work features a complete revision of the available lithic assemblage from the layer A of Loreto collected during the 1974-1981 fieldwork, and stored at the Archaeological Museum of Venosa "M. Torelli" (Basilicata, Italy). The layer A was selected as it is the richest and best-preserved layer of the sequence of Loreto. To analyse lithic artefacts the techno-economic approach and the concept of *chaîne opératoire* have been employed, being the most efficient tools to address the behavioural evolution of human groups' material culture during the Lower Palaeolithic (Leroi-Gourhan 1965; Tixier and Inizan 1983; Goodale and Andrefsky 2015).

The identified technological categories include cores, flakes, retouched flakes, retouched tools (when the retouched support is not a flake), debris (indetermined fragments bearing knapping marks), heavy-duty tools (tools made on pebbles or large flakes), and hammers. The hierarchy of flaking surfaces, removal organisation, type of striking platform, debitage angle, and stage of abandonment were considered on cores to evaluate the knapping strategies and techniques employed by the hominins. Similar characteristics were also applied for flakes description, including, when present, the location, extension and angle of retouch. Furthermore, we applied a standard typological classification modified from Bordes (1961), to facilitate the comparison with other lithic assemblages. For the heavy-duty component, the classification was made according to the organisation of the removals and volume management similar to other works (Moncel et al. 2021).

The raw material identification was made through a macroscopic approach and features the presence of chert, limestone and sandstone (tab. 1). The photographic collection was performed in a lightbox equipped by a support using a Canon EOS R100 camera with Canon lens (RF-S 18-45mm F4.5). After, the microscopic observation was carried out by a Leica EZ4 W stereoscope, putting samples in water to enhance the visualization of petrographic features. Analytical details about the petrographical analysis are provided in a dedicated paper (Eramo et al. 2025).

A total of 415 lithic artefacts from layer A has been analysed and studied (tab. 1). Flakes predominates, followed by retouched flakes, while cores, heavy-duty tools and debris are rarer. Only one, probable, fragmented hammer has been found. In the previous work of Crovetto (1993), the original number of pebble-tools was 145, indicating that a large part of these artefacts was not found, preventing us from providing a comprehensive description.

To evaluate potential dimensional differences between artefact categories, we performed Chi-square tests and Kruskal–Wallis tests on the variables *Length*, *Width*, and *Thickness*. The analyses were restricted to complete artefacts, and only categories with sufficient sample size to ensure statistical relevance were included in the comparisons. Chi-square tests were conducted on binned data, obtained by dividing each dimensional variable into four equal-width intervals. To address possible violations of assumptions related to low expected frequencies, p-values were estimated via Monte Carlo simulation with 10,000 replicates. Kruskal–Wallis tests were applied to the original continuous measurements to compare distributions across artefact types. All statistical analyses were performed in R (version 2025.05.0+496), using base functions from the stats package and dplyr for data processing.

Detailed descriptive statistics and the full results of the dimensional analyses by lithotype and technological categories are available in the Supplementary Material (Table S1, S2).

Table 1 Distribution of lithic artefacts and raw materials from Loreto

Raw Materials/ Lithic	Chert		Limestone		Sandstone		Indet.		**Total**	
	n	%	n	%	n	%	n	%	**n**	**%**
Debris	8	2.4	2	2.8	-	-	-	-	**10**	**2.4**
Flakes	245	72.7	62	86.1	-	-	5	100	**312**	**75.3**
Retouched Flakes	74	22	2	2.8	-	-	-	-	**76**	**18.3**
Retouched Tools	1	0.3	-	-	-	-	-	-	**1**	**0.2**
Hammers	1	0.3	-	-	-	-	-	-	**1**	**0.2**
Pebble Tools	1	0.3	4	5.5	1	100	-	-	**6**	**1.4**
Cores	7	2	2	2.8	-	-	-	-	**9**	**2.2**
Total	**337**	**81.2**	**72**	**17.3**	**1**	**0.2**	**5**	**1.2**	**415**	**100**

Results

Raw materials

Lithic artefacts are made on chert, limestone and sandstone available in different supports (nodules, pebbles and slabs). Chert is vastly predominant (81%), followed by limestone (17%), and only one artefact on sandstone (tab. 1). The privileged supports of chert artefacts are nodules, then pebbles, flakes, and slabs. For limestone and sandstone, pebbles are the most exploited support with a small percentage of nodules.

Macroscopically, chert is characterised by a global high quality, ranging from lithotypes with extremely fine textures to others with coarser inclusions. The presence of visible fractures is rather low, documented on 14% of the artefacts. The quality of limestone is good featuring different degrees of fine and medium textures. The state of preservation of the artefacts is good, with fresh margins and the absence of strong taphonomical or mechanical alterations.

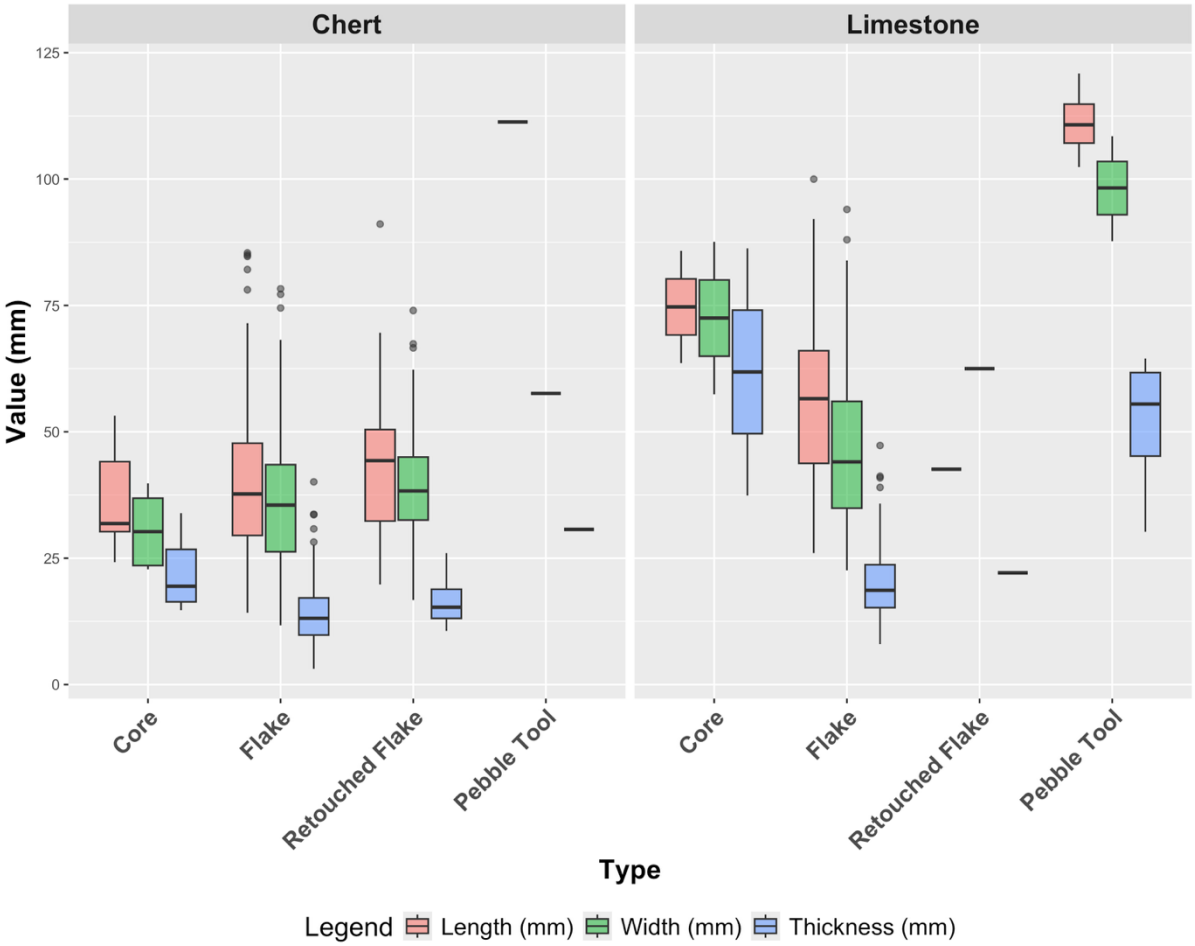


Figure 3 – Dimensional values of technological categories

Cores

Direct percussion with the hard hammer is the most employed technique for debitage production even though evidence in the use of the bipolar on anvil has been detected on seven flakes and, possibly, two cores (fig. 4, nº 5).

Chert cores are small-sized and obtained from five nodules and one pebble (tab. 1; fig. 3, fig. 4). Though cores on flakes are absent, the Kombewa method is documented on 6% of the flakes. Cortex is attested on two cores, located on one face. The reduction sequences feature the exploitation of one, two or more knapping surfaces through a mixture of unipolar, orthogonal, centripetal and bipolar removals. The striking platforms are predominantly natural, with no evidence of platform preparation.

One core shows a S.S.D.A. (*Système par surface alterne de débitage*) conception (fig. 4, nº 1) while two others show similarities with the discoid method (fig. 4, nº 3, 4). The remaining two show a centripetal exploitation in one case, while the other could have been knapped with the bipolar on anvil technique and is associated with bipolar removals and crushed platforms. One of the discoid cores is pyramidal-shaped and exploited through centripetal removals. The support is a chert pebble, seemingly opened by split fracture given the presence of Hertzian cones on its surface (fig. 4, nº 4).

Cores show a mean of four scars with the last removals showing 10-20 mm in length and width. The associated debitage angles are of 84° on the SSDA core, 80° on the bipolar one, and 70° for the cores of discoid and centripetal conception. Regarding the stage of abandonment: in two cases the surfaces appear exhausted, the SSDA one still shows exploitable angles and volumes, while the remaining three exhibit traces of retouch (fig. 4, nº 3, 6). In two cores the final phase of retouch is clear, covering previous removals, and producing functional edges, while in the third case there is a single removal creating a notch but it is unclear whether the aim was the production of a notch or the flake itself, or both.

The two limestone cores show higher dimensions (fig. 3) and are made on pebbles (fig. 4, nº 2, 5). They exhibit bipolar and centripetal scars associated with natural and flat striking platforms and are knapped on one and two knapping surfaces. The bifacial core shows the presence of a semi-peripherical striking platform, seven scars and a mean debitage angle of 82°. The unifacial core has nine removals and wide debitage angles with a mean of 97° and could have been knapped by bipolar on anvil. Both cores seem abandoned due to a lack of suitable debitage angles.

Flakes

According to the different lithotypes flakes exhibit a rectangular shape and are medium/large-sized. Flakes produced on chert are smaller than the ones obtained on other raw materials (fig. 3, 5; tab. S1).

The presence of cortex is documented on 41% of chert flakes, often being rare or covering less than 50% of the dorsal face. The removals organisation shows a predominance of unipolar scars (45%) followed by orthogonal (16%), and bipolar (11%) ones. Flakes without removals represent 18% of the production. The mean number of removals per flake is 1,8. Platforms are natural (35%), flat (29%), and cortical (20%) with a small occurrence (<5%) of linear, punctiform, dihedral and crushed butts. The mean debitage angle is 76°, ranging between 72° (flat platforms) and 78° (natural platforms). The presence of a backed margin, often opposed to a cutting margin, is attested on 40% of the flakes recurrently placed on the lateral margin (debordant) and, less frequently, on the distal one (plunging). Backed margins are mostly natural (71%) but highlight the presence of an additional striking platform or knapping surface on 29% of the flakes.

Limestone flakes, mostly obtained from pebbles, are characterised by unipolar (46%) and absent (37%) removals associated with natural (48%), flat (23%), linear (17%) and punctiform (12%) platforms. The mean number of removals per flake is 1,4 with a mean debitage angle of 82°. The presence of a backed margin is attested on 46% of the flakes, often located on the lateral margin, corresponding to natural surfaces.

Retouched flakes

Retouched flakes are made almost exclusively on chert (fig. 6). Their size is slightly bigger than unretouched flakes, though the statistical analyses revealed a global homogeneity except for the thickness (fig. 3; tab. S1, S2). The retouch was applied more often on the dorsal face (75%), then on the ventral face (11%), or on both (14%). Its location is rather diversified, often placed on a margin's portion (30%), affecting the entire lateral (28%) or distal (7%) sides, being convergent (13%), on two parallel margins of the flakes (3%),

and even located on the entire perimeter or semi-perimeter (20%; fig. 5). Regarding the retouch extension, it is primarily marginal (66%), then covering (16%), and abrupt (13%). The associated angles range from 56° (covering) to 72° (abrupt). Typologically, the tools produced consists of scrapers (44%), pointed tools (21%), denticulates (19%), notches (5%), and various composite tools (11%; fig. 6). It is worth noticing that on some tools the retouch is attested by different generation of removals, often being very thin and scalariform which might indicate the use of a soft hammer and a possible rejuvenation of the margins (fig. 6, nº 4, 7, 9, 13).

Pebble-tools

Regarding the heavy-duty tool component, they are four on limestone, one on sandstone and one on chert, obtained from four pebbles, one nodule and one flake (fig. 3, 7). The morphology of the supports is various, including flat, plano-convex and oval shapes. They consist of five unifacial and one bifacial tool with a mean of seven removal per tool. The removals' localisation is either on one margin or semi-peripherical/peripherical with an abrupt or covering extension. The edge delineation includes convex, denticulate and pointed shapes with a mean angle of 73°. The chert tool shows a final phase of retouch and is obtained from a flake (fig. 7, nº 1).

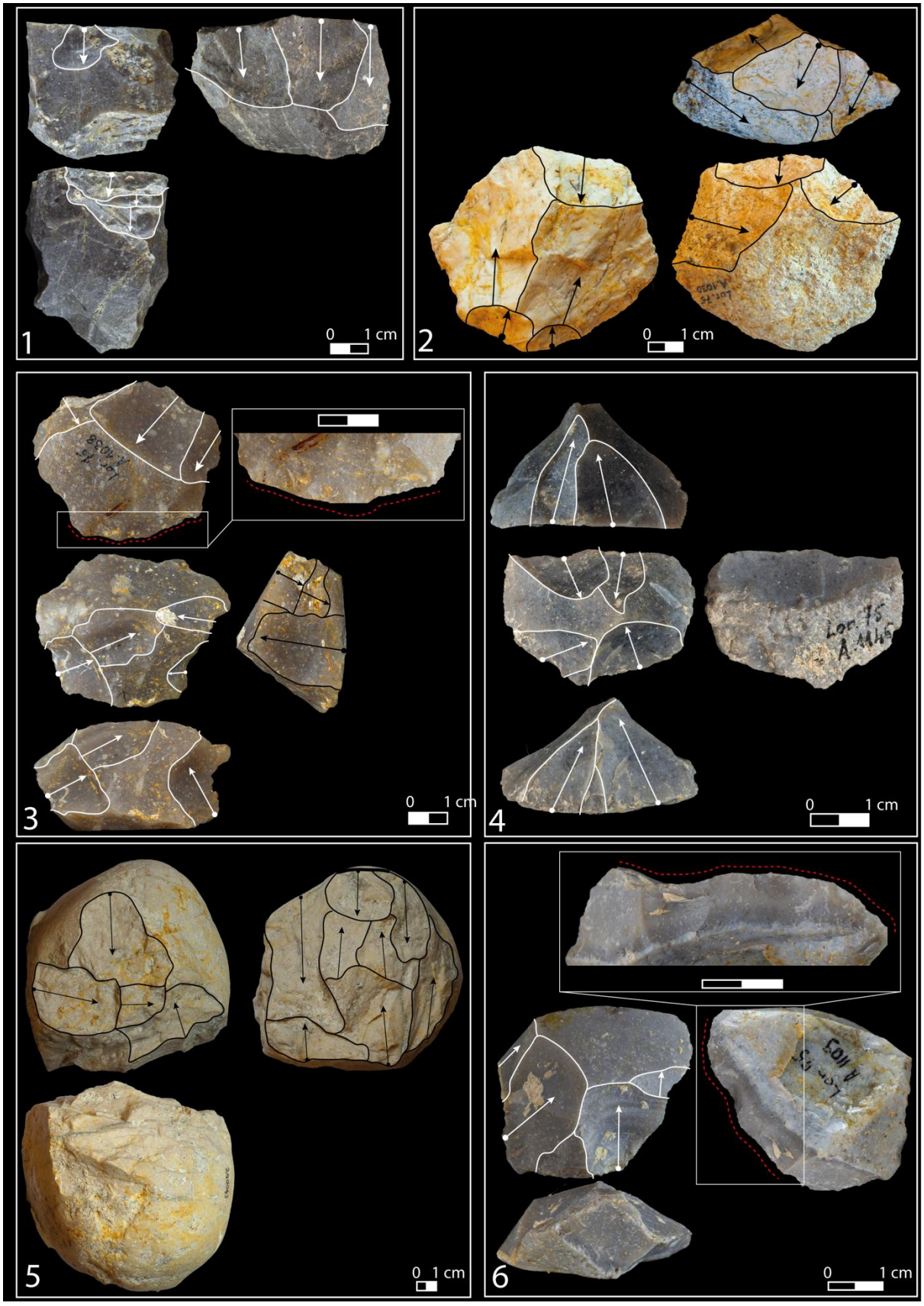


Figure 4 – Cores: 1 Multifacial core on chert; 2 Centripetal core on limestone; 3 Retouched core on chert with discoid conception; 4 Piramydal core; 5 Bifacial core on limestone; 6

Retouched core on chert. Images allowed by the agreement of the Italian Ministry of Culture and the Museo Parco Archeologico Melfi e Venosa.

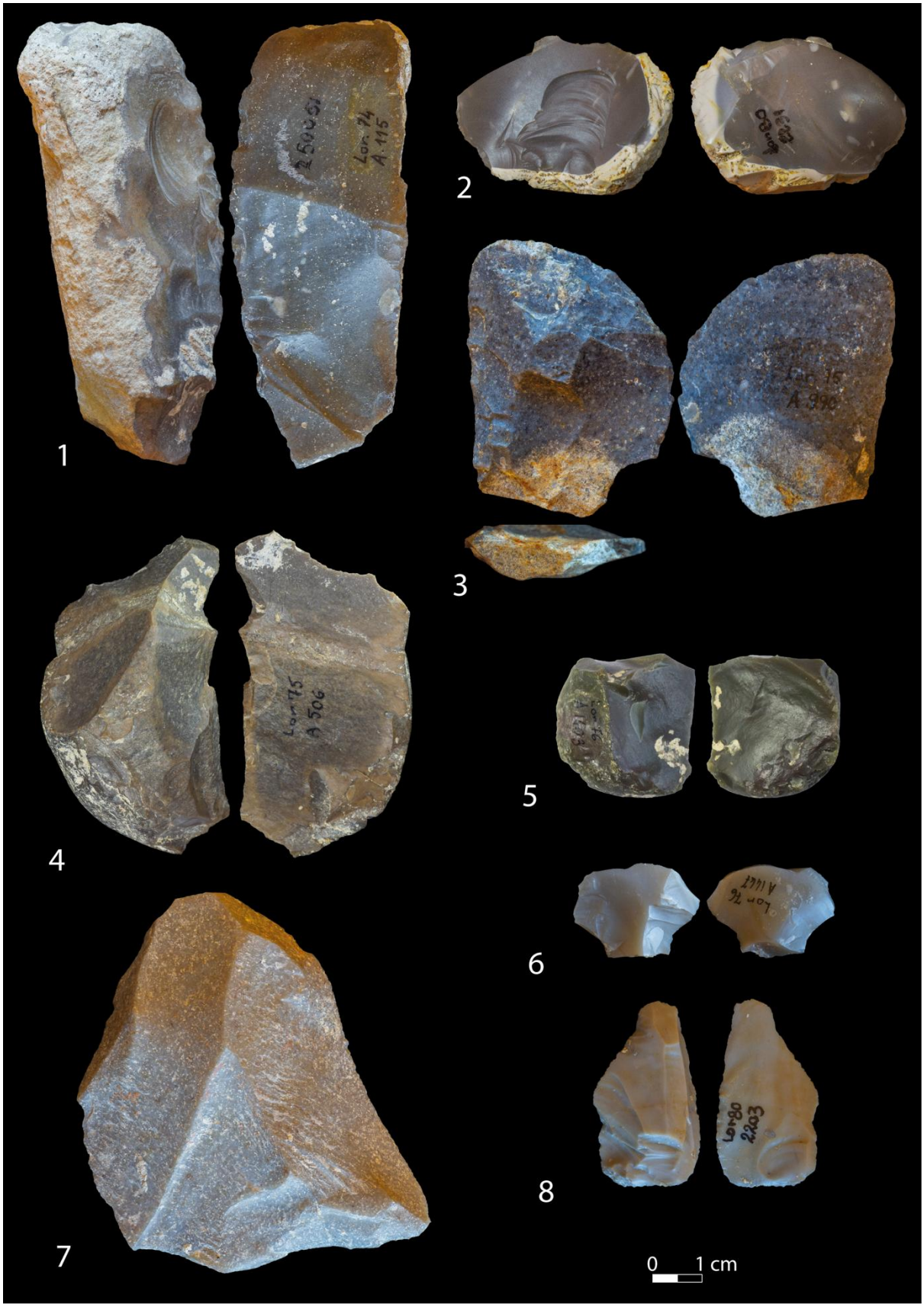


Figure 5 – Chert flakes: 1 Laminar flake; 2 Kombewa flake; 3, 6 8 Flakes with unipolar removals; 4-5 Flakes obtained from pebbles; 7 Flake with orthogonal removals. Images

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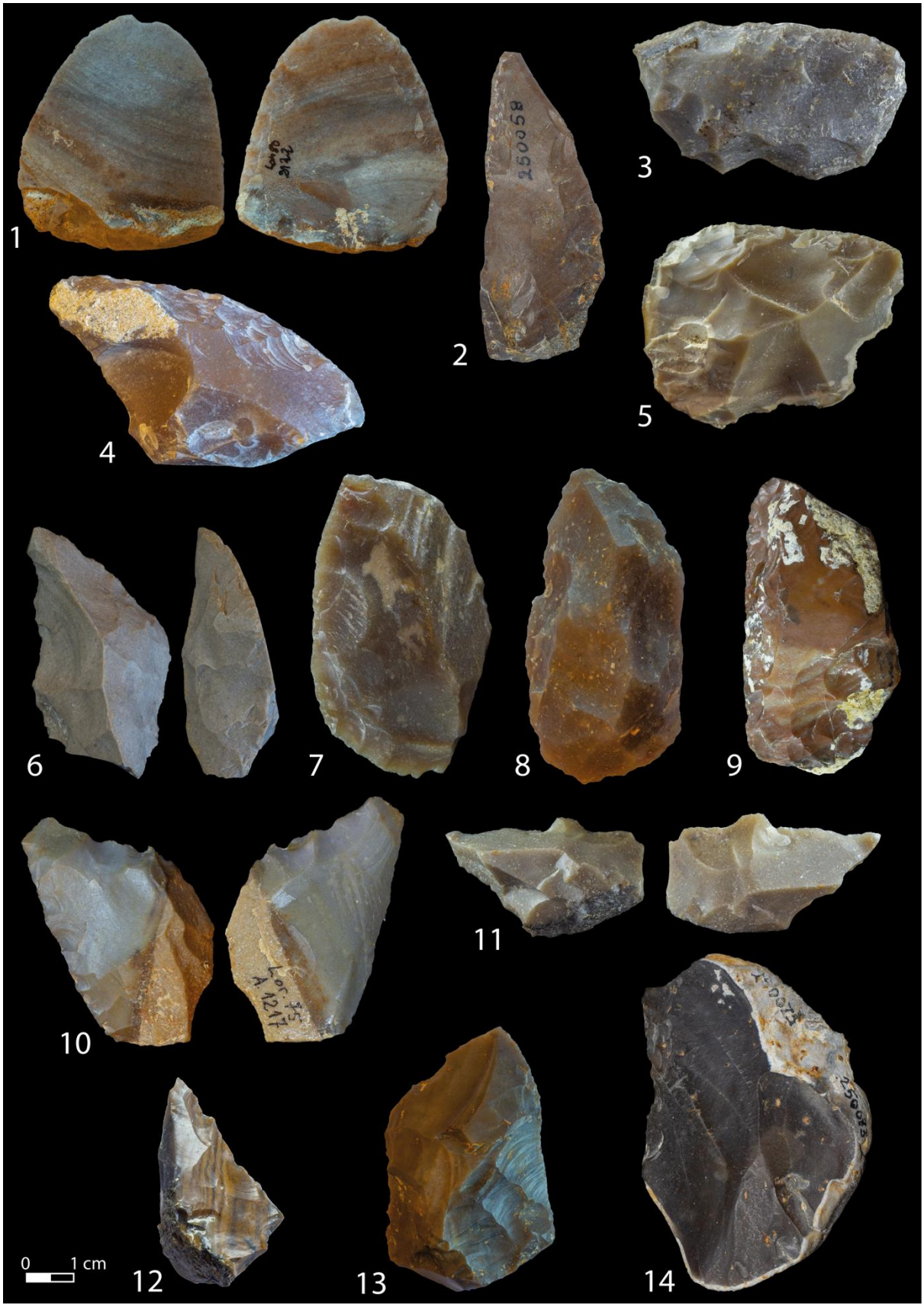


Figure 6 – Retouched flakes on chert: 1 Scraper on Kombewa flake; 2, 3 Composite tools; 4, 5, 7, 9, 10, 13, 14 Scrapers; 6, 8, 12 Pointed tools; 11 Denticulate. Images allowed by the agreement of the Italian Ministry of Culture and the Museo Parco Archeologico Melfi e Venosa.



Figure 7 – Pebble tools: 1 Unifacial tool on chert flake; 2 Unifacial tool on chert; 3 Unifacial tool on limestone. Images allowed by the agreement of the Italian Ministry of Culture and the Museo Parco Archeologico Melfi e Venosa.

Discussion

The human occupation of Layer A – Technological strategies

The cornerstone of the lithic production from layer A of Loreto is flakes manufacture and retouched flakes confection. Hominins exploited chert, limestone and sandstone, vastly preferring chert. These raw materials were collected locally in a secondary position compatible with a lacustrine environment. Direct percussion is predominant across all raw materials, though the use of the bipolar on anvil seems to be attested on a small percentage of the assemblage, either to knap or open large limestone blocks, optimise the volume of small-sized chert cores, and exploit rounded or oval pebbles.

The low number of chert cores – small-sized or retouched when present – cast doubts whether the hominins knapped somewhere else and then transported *in situ* the end-products. From this perspective the high ratio of flake-tools might indicate a scenario where the processing of materials/specific activities was favoured over knapping. On the other hand, limestone artefacts seem to be knapped *in situ*, given cores' size and stage of abandonment, and the presence of several opening flakes. However, as pointed out in the review of the faunal remains (Pineda et al., in press), there is a concrete possibility that the assemblage is biased, due to excavation methods, hence representing only a part of the real lithic assemblage. Additionally, the assemblage does not show traces of transport or selection due to secondary agents. The almost absence of <20 mm flakes, high frequency of complete pieces and large-sized flakes might confirm this hypothesis preventing us from inferring over the actual reconstruction of the *chaîne operatoire*, and the type of occupation of Loreto.

Since Loreto belongs to the Venosa basin, where also the site of Notarchirico is located (fig. 1), the layer B of Notarchirico was taken as a reference for the geological variability, being perfectly preserved and bearing traces of anthropisation (lithic artefacts). The median length of the chert artifacts from Loreto is smaller than limestone ones, probably because they mirror the grain size of clasts in the gravel, as observed in the level B of Notarchirico (Fioretti et al., submitted). The pebble tools show the largest grain size independently of lithology and point to deliberate selection according to size (Fig. 3). Although the limestone cobbles are relatively more frequent, it cannot be assumed as preferred lithology because of the small number of samples and of the probable diffused presence of limestone clasts in the gravels of the Venosa Basin. A comparison between size and lithology for the other technological categories shows that no correlation exists between the length and the texture of the lithotypes and that the relative abundance of the different lithotypes probably expresses the natural lithological variability of the gravels available in the area (see Eramo et al. 2025 for details).

Chert flakes production was achieved without the selection of a privileged support, and through several knapping strategies mostly characterised by a SSDA conception featuring the exploitation of one or two knapping surfaces through unipolar removals starting from natural or cortical platforms, and taking advantage of the natural morphologies of the blocks. Flakes are medium and large-sized, exhibiting a regular profile and thickness, showing the ability of the hominins to obtain regular products from larger blocks. No clear discoid flakes were documented, though a few discoid cores, or recalling a discoid

conception, are present together with two centripetal ones. They exhibit a good management of convexities and volumes through natural peripherical striking platforms and debitage angles of ~70°. The exploitation of flakes as cores is also attested, being an efficient and skilful strategy employed by the hominins and one of the innovative traits of the early Middle Pleistocene.

Another interesting aspect is the presence of retouched cores, stressing the importance for tools' confection at Loreto and, perhaps, enhancing the possibility that the hominins activities were more oriented to functional actions (*e.g.* cutting, scraping, drilling, etc.) connected to processing different materials rather than focused on flakes production. The retouch of cores also shows the extreme flexibility of the operative schemes, giving to the site an element of "expediency" where the need for using flakes or retouched tools was, possibly, primary over the rest. This might also hint to a specific management of chert, which could have been collected far from the site and, consequently, majorly exploited to maximise its availability.

The production of large-sized flakes and pebble tools was prominently related to limestone and sandstone. The flakes' obtainment was accomplished through unipolar removals and short reduction sequences on one or two knapping surfaces. Since the privileged supports were pebbles, the opening of a striking platform – through the split fracture technique or a simple removal – was often required to initiate the production. It is possible that some of the limestone flakes were *façonnage* flakes, connected to pebble tools' confection. This would indicate that, differently from chert, limestone was knapped *in situ*, portraying a possible distinct economy of the raw materials.

Pebble-tools production represents a marginal part of the assemblage with only six pieces documented in our study. The data indicates the production of unifacial or bifacial tools without a standardisation in the removals' localisation and edges shape. No bifaces were found, and concerning the "proto-biface" found by Barral and Simone (fig. 7, nº 1), it is a unifacial tool with convergent edges obtained from a chert flake exhibiting a final phase of retouch that does not share similarities with any biface.

On the other hand, retouched flakes are a significant component of the Loreto production. Hominins selected bigger flakes for edge modification. No specific association was found between the retouch and flakes' characteristics indicating that except for size and raw material (chert), all flakes were suitable for retouch. Though the mean dimensional values and the statistical analyses performed do not show great discrepancies between unretouched and retouched flakes, we have to consider that given the intensity of retouch on several tools, these could have witnessed a prolonged use or "life", originally being even larger. This might shed light on the hominins' strategies as intense tools' reduction is usually correlated to a high-mobility over the territory and specific raw material's economy.

Additionally, the presence of several tools witnessing a scalariform and thin retouch could indicate the use of a soft hammer, representing a unicum in the Italian peninsula for the early Middle Pleistocene. Despite further investigations are needed to fully validate this hypothesis, it is among one of the most interesting traits of Loreto's industry.

Loreto in the European framework of the early Middle Pleistocene

The lithic corpus of Loreto shares several similarities and discrepancies with other roughly coeval sites from Western Europe. For instance, pebble tools are more frequently attested in Italy (Notarchirico, Isernia, and Atella; Rufo et al. 2009; Moncel et al. 2020c; Rocca et al. 2023) than in the rest of Europe (Arago; Barsky 2013). This might be related to bifaces production which, on the contrary, is much more frequent in France and England (Fordwich, Caune de l'Arago, Brandon Fields, Rampart Field, Carrière Carpentier, Maidscross Hill, High Lodge, Happisburgh 1, Warren Hill, Waverley Wood and Feltwell; García-Medrano et al. 2023) than Italy (Notarchirico, and Cretone basin; Ceruleo et al. 2015; Moncel et al. 2020c). It might also be a matter of raw materials' availability since Central and Northern Europe almost feature a complete absence of pebbles which, on the other hand, are much more frequent in the Mediterranean basin.

Commonly, pebble tools do not represent an element of innovation, being a more or less recurrent aspect of Lower Palaeolithic productions since the Early Pleistocene (Barsky et al. 2018), though a gradual increase in their manufacture-skill can be witnessed over time, concurrently with the diffusion of the Acheulean and the Lower Palaeolithic's development (Mosquera et al. 2018; Moncel et al. 2020b).

On the other hand, retouched flakes' manufacture at Loreto raises several questions. The use of soft hammer has been recognised in the sites of Boxgrove and High Lodge (MIS 13) associated with a production of refined scrapers (Stileman et al. 2024). Such tools occur also in other British sites such as Waverley Wood, Warren Hill and Happisburgh 1 (Davis et al. 2021). Evidence of the soft hammer's use has also been found in the sites of la Noira (MIS 17), Brandon Fields (MIS 15), Caune de l'Arago (MIS 14), Happisburgh 1, Warren Hill, High Lodge and Boxgrove (all MIS 13) connected to biface shaping (García-Medrano et al. 2023).

For the British sites, the development of a regional network has been proposed to explain the diffusion of these scrapers – and connected with the Acheulean (Ashton and Davis 2021; García-Medrano et al. 2023). Several resemblances were detected between the British refined scrapers and the Middle Palaeolithic flake-tool strategies (Stileman et al. 2024). For instance, the work of Brumm and McLaren (2011) revealed the prolonged use and multiple lives that the High Lodge scrapers underwent through various phases of retouch aimed at rejuvenating the margins, recycling old tools, changing their function/use, etc. These traits, besides being innovative, are powerful indicators of hominins' land-use and resource management, and among the fossil markers of the Middle Palaeolithic (Hiscock and Attenbrow 2005).

Intense tools' reduction can be correlated to a high-mobility over the territory – whether due to seasonality or hunting purposes – optimisation of the available raw materials – whether the collection source is far, their availability is low – the need to systematically perform specific tasks leading to the introduction of the tool-kit's concept and, more in general, to a progressively greater importance held by retouched tools. Such aspects, while being absent from Lower Palaeolithic chronologies, started to emerge at Caune de l'Arago – where the transport of exotic raw materials associated to specific tools production and reduction sequences was documented (Barsky 2013) – or in the MIS 15-13 British contexts. The presence of scalariform and Quina-like retouches was also found in the lithic assemblage of Korolevo (MIS 14; Koulakovska et al. 2010).

Though all the discussed traits might not be fully present at Loreto, there are several similarities that enhance its relevance, especially when compared with other coeval Italian sites (Notarchirico, Isernia La Pineta, Ficoncella, Atella, Valle Giumentina and the Cretone basin sites-complex) where similar tools and behaviours have not been documented yet. Moreover, while the British scrapers and the soft hammer retouch are associated with bifacial tools, in Loreto and Korolevo's cases this link is absent.

About this, in the work of Medrano (2023), an incremental pattern in bifacial shaping from French and British sites from MIS 15 to 11 has been noted, with a tendency towards the production of thinner tools (so-called ovate bifaces), soft hammer's use and more invasive removals, and linked to the development of a sort of cultural foundation. Interestingly, a similar process is documented on the retouched flakes from the same sites and, perhaps, the same process occurred on Loreto's retouched tools, having the same innovative potential despite the absence of bifaces from the site. For instance, in the work of Stileman et al. (2024), the High Lodge scrapers were considered the equivalent of LCTs from a functional and mental template perspective. The authors used this argument to strengthen the view of the Acheulean as a cohesive cultural complex featuring diversified technological strategies.

In this regard, non-handaxes industries from Europe characterised by wide flake and flake-tools production were associated to the Clactonian or, for more recent contexts, to the Tayacian cultures – as in the case of Loreto. Nowadays the use of such terms has decayed since the presence/absence of bifaces is not considered anymore a discriminating aspect in terms of culture and complexity for Lower Palaeolithic industries (Dibble et al. 2006). The term Acheulean itself, often opposed to Clactonian and Tayacian, is being questioned since it became a term for describing the puzzle of assemblages and strategies recorded in western Europe, rather than a well-defined cultural facies (Moncel and Ashton 2018).

The presence of discoid cores at Loreto is also among the site's outstanding traits. They are found at Isernia La Pineta (Gallotti and Peretto 2015), Rue du Manège (Antoine et al. 2015) and Caune de l'Arago (Barsky 2013), being part of the increased complexity process witnessed among centripetal reduction strategies during the Middle Pleistocene. Indeed, similar traits were already documented on cores from La Noira (Moncel et al. 2020b), Moulin Quignon (Moncel et al. 2022) and Atapuerca-TD6 (Lombao et al. 2023) and there is a general consensus in linking the bifacial concept with centripetal debitage from a methodological and behavioural perspective. The progressive diffusion of discoid and centripetal strategies culminated with the spreading of the Levallois method from the beginning of MIS 12 (Cagny-La Garenne), during MIS 11 and through MIS 10 and 9 (Moncel et al. 2020a).

At the same time, the persistency of Early Pleistocene core strategies (SSDA-like) is documented in many Middle Pleistocene sites, including Loreto, confirming their efficiency and productivity through different chronologies and geographical areas. For instance, in the cluster of British sites the refined scrapers were all obtained from SSDA cores (Davis et al. 2021).

A last worth-addressing topic regards the absence of bifaces from Loreto and its proximity (geographical and chronological) with Notarchirico (695 – 615 ka, MIS 17 – 15; fig. 1) – where bifaces are attested. Several aspects need to be considered:

- Both sites share analogous environmental conditions (lacustrine environment, vegetation cover in the surroundings, raw material availability and animal presence) and were, seemingly, passage areas for hominins (Moncel et al. 2023).
- Bifaces are rare objects among lithic assemblages, and, presumably, were valuable tools for hominins, being moved over large areas for different tasks. For instance, at Notarchirico, few bifaces were recovered from more than 100 m^2, while Loreto has been excavated only on a surface of 20 m^2.
- The quality and volume of the available raw material might not be an issue. The lithotypes from Loreto and Notarchirico belongs to the same gravel deposits associated to the Venosa basin (Eramo et al. 2025).
- Additionally, hominins from Loreto were able to obtain and shape large-sized flakes and tools, therefore excluding a lack of knapping skills.
- The presence of different techno-cultural behaviours or human groups over the territory could be a possible explanation for the presence – or absence – of bifaces, though it is a challenging, if not impossible, aspect to verify.
- The type of activities performed could be a valuable indicator: the data from Notarchirico highlights several activities, from carcass processing to the exploitation of plants and wooden materials. This might explain the need for various tools production, including bifaces' confection, which are often multipurpose objects (Hardy et al. 2018; Zupancich et al. 2021; Stileman et al. 2024). On the other hand, the data from Loreto are scarce, with cut-marks on the herbivores remains, and no available use-wear analyses. The presence of numerous retouched tools likely indicates a range of activities beyond carcass processing and may even suggest prolonged occupation or specific raw material management. However, it does not allow us to determine whether the hominins at Loreto actually produced bifaces.

Ultimately, the recent history of research suggest that the presence or absence of bifaces is not necessarily attributable to a single quantifiable factor. Rather, it reflects our interpretative framework when approaching lithic assemblages and reconstructing the evolution of human behaviour during Lower Palaeolithic. The production of bifaces appears to result from – and be influenced by – multiple factors, including environmental adaptations, technical behaviours, and both intra- and extra-site spatial organisation. Nevertheless, bifaces represent just one of the many proxies available for documenting and investigating prehistoric archaeology.

Conclusions

The site of Loreto plays a critical role in our understanding of evolution of human behaviour during the Lower Palaeolithic, specifically between MIS 15 and 13.

During this period, hominins took advantage of the favourable climatic conditions that persisted across Europe – preceding the MBE and the glacial interruption of MIS 12 – which allowed for prolonged occupation, encouraged local adaptations, facilitated the exchange of ideas, and the development of social and technological networks. The lithic assemblage of Loreto reflects the hight degree of variability observed in other coeval Italian and European sites, presenting a mosaic of both archaic and innovative features in

core reduction strategies, flake production methods, tool manufacture and pebble tool shaping.

In particular, the retouched flakes production is arguably the most distinctive aspect of the site, including tools with scalariform retouch, margin rejuvenation, and, possibly the use of soft hammer. These instruments may carry the same innovative significance as bifaces in other contexts, offering thought-provoking comparisons with British sites and, more broadly, with the Middle Palaeolithic Transition.

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The authors report there are no competing interests to declare.

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