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Lower Palaeolithic Core-Flake Industries in Western Europe: Techno-Functional Study of Layer « L » of Caune de l'Arago Cave (Tautavel, France)

Félicien Capellari¹ · Sophie Grégoire¹ · Henry de Lumley^{2,3}

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Abstract

Technical and socio-economic behaviours of Middle Pleistocene human groups in Western Europe still remain under-studied. In addition to the so-called Acheulean industries that include bifacial tools, other lithic traditions that are focused on flake production are present. This is the case of the 'L' stratigraphic layer of the Caune de l'Arago site in Tautavel, France. Here, we present the results of the techno-economic and techno-morpho-functional study conducted on the lithic industry, which was well-defined and well-preserved in the Caune de l'Arago sequence. Dated to approximately 540 ka and correlated with the end of the MIS 14, it contains 4428 lithic artefacts that are associated with numerous remains of reindeer (*Rangifer tarandus*). This occupation has been culturally attributed to the Acheulean. However, the layer L assemblage does not contain bifacial tools and presents a lithic production *chaîne opératoire* only oriented towards flake production. This study is carried out within a previously refined stratigraphic framework, thereby allowing a relevant return on the lithic material. Despite different raw materials, there are recurrences in the selection of volumes, the production methods, the choice of tool blanks and the desired techno-functional objectives. Additionally, the prehensile components are integrated into the production of tools. Some of the *chaînes opératoires* are fragmented, and we can see techno-economic dynamics with some tool movements more widely across the landscape. These results lead us to question the activities carried out during this occupation and to highlight the diversity of lithic technical expressions during Lower Palaeolithic.

Keywords Middle Pleistocene · Mediterranean area · Caune de l'Arago cave · Techno-functional study · Core-flake industries · Flake-tools

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Introduction

During the first part of the Middle Pleistocene (marine isotopic stage — MIS — 16 to 9, approximately 676–300 kyr), the Lower Palaeolithic culture is recognised in Western Europe. Sites are rare around 800–600 kyr but increase from 500 kyr, coinciding with interglacial periods (Bosinski, 1996; Tuffreau, 2004). At this time, Western Europe was inhabited by an evolved form of *Homo erectus*, called *Homo heidelbergensis* (Bermúdez de Castro et al., 2004a, b; Mounier et al., 2009; Hublin, 2009; Dennell et al. 2011; Stringer, 2012; Manzi, 2016). The arrival of hominins in Western Europe ‘Out of Africa’ is hypothesised along various itineraries, across an overland route through the Middle East or through the Gibraltar and Sicilio-Tunisian straits (Alimen, 1975; Carbonell et al. 1999; Villa, 2001; Rightmire, 2001; Gibert et al. 2003; Kozłowski, 2005; Goren-Inbar & Sharon, 2006; Lycett & Cramon-Taubadel, 2008; Santonja & Perez-Gonzalez, 2010; Kuhn, 2010; Sharon, 2011; Moncel et al., 2020).

The current main pattern envisages two migration waves for the colonisation of Europe. The first, which starts around 1.8 Myr, corresponds to Mode 1 assemblages described as ‘Developped Oldowan’, with only core-and-flake technology with pebble tools (Arzarello & Peretto, 2010; Bar-Yosef & Belfer-Cohen, 2001; Carbonell et al. 2010; Lumley et al., 2009; Mgeladze et al., 2011; Moncel, 2010). The second migration corresponds to Mode 2, or ‘Acheulean’, with which we see the emergence of bifacial tools or other *large cutting tools* (Barsky & Lumley, 2010; Bar-Yosef & Belfer-Cohen, 2001; García-Medrano et al., 2014; Moncel et al., 2015, 2019, 2020; Mosquera et al., 2016; Piperno, 1999). Indeed, these iconic tools first appear in Western Europe around 700 ka, in sites like La Noira in central France (Moncel et al. 2013) and Notarchirico in southern Italy (Moncel et al., 2019, 2020; Piperno, 1999). However, this Mode 1/Mode 2 classification (Clark, 1969) and migration model is frequently challenged (Gallotti, 2016; Rocca, 2016a, b; Aureli et al. 2016). Thus, current research also proposes that bifacial tools were an independent innovation arising out of local technologies among pre-existing European populations (Boëda, 2005; Chevrier, 2012b; Nicoud, 2013a, b, c; Carbonell et al., 2016).

Acheulean techno-complex is historically characterised by the presence of bifacial tools such as handaxes and cleavers (Mortillet, 1872). In actual fact, the so-called Acheulean culture includes a wide diversity of techno-economic behaviours that are not yet well-known. The ‘biface’ from this period has begun to be well-known from a technical and functional point-of-view using various analytical methods (Tuffreau, 1987; Lamotte, 1994; Boëda, 2001; Soriano, 2000; Lhomme & Connet, 2001; Lhomme, 2007; Nicoud, 2013a; Leroyer, 2016; Viallet, 2016; Moncel et al. 2018). However, core-and-flake lithic industries that are less distinctive still remain a topic that is not often addressed (Fluck, 2011; Nicoud, 2013a; Gallotti & Peretto, 2015; Rocca et al. 2016; Aureli et al. 2016). These assemblages existed before the appearance of bifacial tools in Western Europe and continue during this diffusion period, constituting a large part of so-called Acheulean assemblages (Boëda, 2005; Nicoud, 2013a; Santonja & Villa, 2006; Tuffreau et al., 2008). For instance, in Eastern and Central Europe, where bifacial

tools are absent, other technological modalities have been documented, with lithic reduction based on the manufacture of various small tools on natural or knapping blanks (Rocca, 2013, 2016a, b; Rocca et al., 2016).

These lithic reduction sequences focused on flake production appear under both glacial and interglacial conditions and in similar contexts, for example, in the United Kingdom at Clacton-on-Sea (Singer et al., 1973), High Lodge (Ashton et al., 1992), Barnham (Ashton et al. 1994, 2016) and Swanscombe (Conway et al., 1996); in France at Caune de l'Arago cave (de Lumley & Barsky, 2004), Menez-Dregan (Ravon, 2019), Soucy 6 (Lhomme et al., 2003) and La Grande Vallée (Hérisson et al., 2012); in Greece at Marathousa (Panagopoulou et al., 2018; Tourloukis et al., 2018a, b); in Italy at Isernia la Pinetta (Gallotti & Peretto, 2015; Peretto, 1994), Notarchirico (Santagata, 2016), Visogliano (Abbazzi et al., 2000), Ficoncella (Aureli et al. 2016) and Valle Giumentina (Nicoud et al., 2015); in Spain at Aridos (Santonja et al., 1980), Atapuerca (García-Medrano et al., 2014) and Barranc de la Boella (Mosquera et al., 2016); in Germany at Schöningen (Serangeli & Conard, 2015) and in Eastern and Central Europe at Korolevo and Vertesszölös (Rocca et al., 2016). Core-and-flake assemblages do not systematically precede bifacial technology (Villa, 2001), they can be interstratified with bifacial tool levels, as at Notarchirico (Piperno, 1999) or Caune de l'Arago cave (de Lumley & Barsky, 2004). Sometimes, no evidence of bifacial shaping is visible, as in Aridos 2 (Nicoud, 2013a). Most of the time, the two production methods coexist and are complementary.

To explain these associations or dissociations, many propositions have been made: chronological distinction, geographical isolation, different cultural traditions, functional differences, raw material variation, site function, site type or archaeological sample size (Moncel et al., 2015; Piperno, 1999; Santonja & Villa, 2006; Villa, 1991). Outside Europe, the same situation is true in Africa (Delagnes et al., 2006; Sánchez-Yustos et al., 2018), the Middle East (Bar-Yosef and Goren-Inbar, 1993) and Asia (Brumm & Moore, 2012).

However, to identify the full range of technical behaviours, it is essential to understand the respective roles of each tool in the constitution of the tool kit. Thus, beyond the typological divisions that classify industries with and without bifaces, lithic sequences can be studied through a techno-functional analysis (Boëda, 2001, 2013). Our aim in this article is to describe in detail the *chaînes opératoires* and the objectives thereof, in order to obtain a picture of lithic production systems and the toolkit composition for this archaeological level. Since this concerns production, technical and economic aspects, we ask which characteristics we can observe within this lithic assemblage. Which tool blanks were selected for retouch and by which debitage systems were they produced? Are there differences in the debitage methods based on the raw material chosen, which may be of a varied nature? What intentions are perceptible that are related to the construction of flake-tools? Addressing these questions will allow us to describe the technical and socio-economic behaviours of Middle Pleistocene human groups in Western Europe more precisely.

This work was made possible by a previous multidisciplinary study on the stratigraphic sequence of the Caune de l'Arago site (de Lumley et al., 2015), which make it possible to finely delimit the L-unit. This study of lithic material is thus conducted within a well-defined stratigraphic framework that benefits from precisely recorded

spatial distribution of the lithic pieces and is the best condition in which to conduct the techno-economical and techno-functional study of this occupation.

Material and Method

The Caune de l'Arago Cave

The Caune de l'Arago cave in Tautavel, France, is a famous archaeological site in the south of France, located 20 km northwest of the city of Perpignan (Fig. 1a), 24 km from the current shore of the Mediterranean Sea and approximately 40 km from the highest altitudes of the Pyrenees Mountains (de Lumley et al., 2014; Perrenoud et al., 2016; Fig. 1a). Caune de l'Arago is a 30-m-long karstic cavity that was formed in an Urgonian Limestone massif on the left bank of the Verdoules River at the outlet of the Gouleyrous gorges at an altitude of 187-m above sea

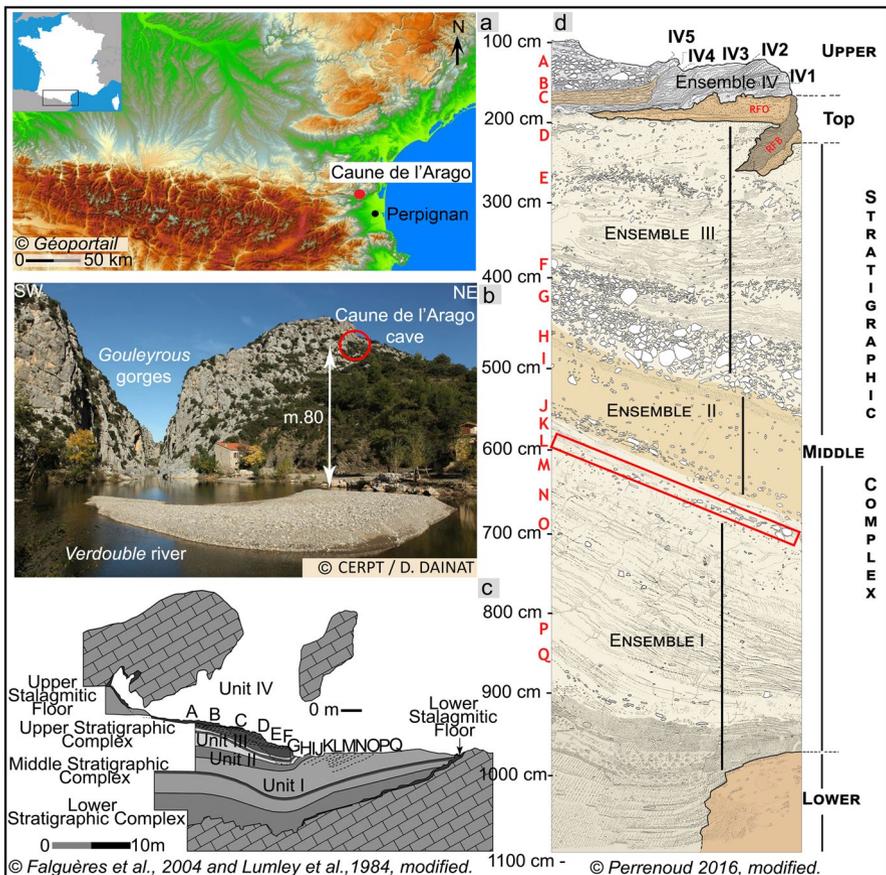


Fig. 1 Geographical (a) and topographical (b) location of La Caune de l'Arago cave; stratigraphy of the filling (c) and position of the archaeological L-layer in the stratigraphic sequence (d) (DAO: F. Capellari)

level. The cave overlooks the Tautavel Valley at an 80-m altitude (de Lumley et al., 2014, Fig. 1b). This world-renowned prehistoric site contains an important Middle Pleistocene deposit that is 17 m high (Perrenoud et al., 2016, Fig. 1d). Radiometric dates indicate that the earliest archaeological levels date to circa 690 ka, and the most-recent layers dates to 95 ka, correlating with MIS 17 to 5 (Falguères et al., 2004, 2015; de Lumley et al., 1984). The stratigraphic sequence is divided into four complexes (de Lumley et al., 2004, 2015, Fig. 1c); the excavated levels are mainly associated with the stratigraphic Middle Complex, which represents the main part of the fill (9 m). This complex is divided into three ensembles (Fig. 1c), which correlate from the bottom to the top with MIS 15 to 12. The lowest stratigraphic Ensemble I (levels Q to K) includes fine sands deposited during a cold, dry period; this correlates with MIS 14. Ensemble II (levels J to H) includes sandy-clay silt that was deposited during a relatively humid and temperate period, which correlates with MIS 13. Finally, Ensemble III (levels G to D) includes fine sands that were accumulated during a cold, dry period, which correlates with MIS 12 (Falguères et al., 2015; de Lumley et al., 2015). According to another recent chronological interpretation based on microvertebrate studies, the Middle Complex could be entirely correlated with MIS 12 and Ensemble II could relate to an interglacial sub-stage within this glacial period (Lebreton, 2018). In total, 55 layers of human occupation that are very rich in archaeological material are present in the excavated area (de Lumley et al., 2015). Caune de l'Arago is one of the few Middle Pleistocene sites in Western Europe to have recorded occupations in a glacial context (Perrenoud et al., 2016), like Valle Giumentina in central Italy (Villa et al. 2016). The site is particularly famous for the many human remains attributed to the species *Homo erectus tautavelensis* (de Lumley, 2015). The lower archaeological layers of stratigraphic Ensemble I (Q and P), which correlate with MIS 14, are among the oldest occurrences of bifacial tool production currently known in Western Europe (Barsky, 2007, 2013; Barsky & de Lumley, 2005, 2010). Furthermore, a diversity of occupation types can be recognised at the site, such as the hunting camp, the seasonal occupation or the long-term camp (Barsky & Lumley, 2004; Barsky et al., 2005; Grégoire et al., 2007; de Lumley et al., 2004). Within these different human occupations, fauna can be varied or sometimes almost exclusive to one type (as *Cervus*, *Dama* or *Rangifer* for instance, Moigne et al., 2006), and the lithic reduction sequences are sometimes only oriented towards flake production and sometimes mixed, which is to say that it is centred on the flaking and shaping production processes at the same time.

The 'L' Stratigraphic Unit

The L stratigraphic unit is located at the top of Ensemble I of the Middle Complex (Fig. 1c and d) and is correlated to the end of MIS 14 and dates to approximately 540 ka (Falguères et al., 2015). The excavated area of this layer was 70 m², preserved within fine and medium sands with a maximum thickness of 30 cm, and it was well-individualised thanks to two levels of sterile sediment that quickly covered it, which permitted optimal conservation of the remains (de Lumley et al., 2015, Fig. 2a). Palaeo-environmental data indicates an open environment with a steppic landscape and

a very cold and dry climate with high winds (Desclaux, 1992; Hanquet, 2011; Hanquet & Desclaux, 2011; Lartigot, 2007; Lebreton, 2018; Montuire & Desclaux, 1997; Paunescu, 2001; Renault-Miskovsky, 1981, 1995). A total of 18,779 archaeological remains were collected. The faunal spectrum is dominated by reindeer (*Rangifer tarandus*) which represents 85% of the faunal remains with a minimum number of

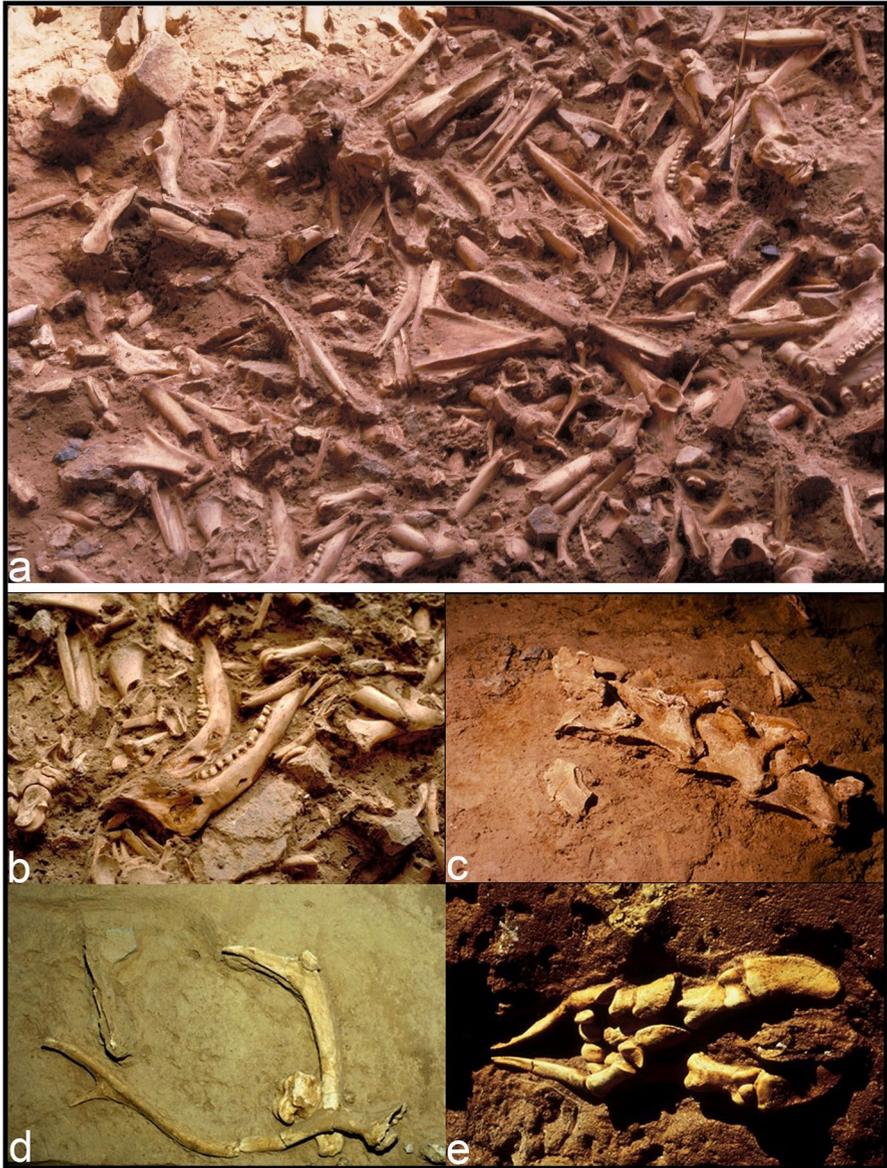


Fig. 2 A general view of the L-layer of La Caune de l'Arago cave during excavation (a) and some faunal remains details: a reindeer mandible (b), vertebrae in anatomical connection (c), reindeer slaughter wood (d) and a reindeer metapod (e) (Photos: CERPT; DAO: F. Capellari)

individuals of 49 (Magniez et al. 2011). Most of the animals hunted are adult females and their juveniles (Pernaud-Orliac, 1990, 1991, 1993, 1992–1995; Moigne & Barsky, 1999; de Lumley et al., 2004; Rivals et al. 2004; Grégoire et al. 2007; Magniez & Moigne, 2011; Magniez et al. 2011, 2013; de Lumley et al., 2015). The remains, which are generally well-preserved (Fig. 2a and b), were secondarily modified by carnivores. This unit, the complete excavation of which was conducted over a large area, displays a very specialised and relatively short occupation episode, which can be interpreted as a ‘hunting camp’ (Grégoire et al., 2007; de Lumley & Barsky, 2004; de Lumley et al., 2004). This kind of brief occupation ‘snapshot’ is very rare for the Lower Palaeolithic. Finally, no human remains were found in this layer.

Thanks to the recently refined stratigraphic context, it is possible to use the L-level assemblages to document techno-economic behaviours and discuss the management of raw materials and lithic production in this specific context. At the same time, we can put the functional interpretation (a ‘specialised hunting camp’) of the L-level to the test. These socio-economic aspects are easier to discuss in this fine type of archaeological unit (Fig. 2), rather than palimpsests constituted by successive occupations. Previous lithic studies of the L-level (Barsky, 2000; Byrne, 2001; de Lumley & Barsky, 2004) can be reassessed within this new framework and augmented by a new approach (see ‘Lithic Refits’). Interpretations of broader behavioural patterns, such as technological choices, knapping methods, active parts on tools, raw material economy and tools and human groups mobility, can then be made.

Raw Material and Lithic Assemblage

There are 5581 lithic artefacts (including non-knapped lithic material) in the assemblage, with 4428 lithic artefacts (the knapped pieces) studied here (Table S1, in supplementary information). As in most of the occupation levels of the Caune de l’Arago cave, multiple raw materials are used (Barsky & Grégoire, 2001; Grégoire, 2000, 2012; Grégoire et al., 2006; Wilson, 1986, 1988). Previous works have defined the raw material source zones related to each petrological facies known throughout the lithic series of the cave. This large stone resource area presents a unique framework within which it is possible to discuss the provenance of raw materials and compare procurement strategies between units (Grégoire, 2012). The supply territory pattern is established according to a division into three zones around the site: the local zone, which extends from 0 to 5 km; the semi-local or intermediate zone, which is from 5 to 20 km, and the distant zone, beyond 20 km. This zoning corresponds to frequent practices in the field of techno-economic studies (Geneste, 1985; Grégoire, 2012), as it allows the comparison of the economic modalities of one site or region to another. Previous studies conducted on two time periods (Grégoire, 2000; Wilson, 1986) offer a new frame-of-reference for the identification of the petrographical types. Indeed, internal and external raw material properties must be known in order to identify the mechanical knapping properties and the form of the initial nodule.

Prior to the technological study, we carried out a systematic updating of raw material determinations in order to reach the finest possible petrographic characterisation. These groups (Table S1, in supplementary information) and subgroups of

raw materials are needed for the techno-economic study. In particular, they facilitate an estimation of the minimum number of blocks exploited for each type of rock, and they are also a prerequisite for lithic refits.

The L-layer lithic industry is mostly produced in local quartz collected in the Verdouble alluviums in the plain of Tautavel, less than 5 km from the cave. Semi-local rocks, such as quartzite and jasper, were also used, derived from the Agly and Têt river alluvial deposits located 15–20 km to the south. Finally, allochthonous flints from the coastal plain were found on the Narbonne-Sigean sedimentary basin, which is located 28–35 km to the northeast of the site (Grégoire et al., 2007; de Lumley & Barsky, 2004; de Lumley et al., 2004, 2015). Here, we present our results by raw material category.

A Technological and Techno-Morpho-Functional Study

First, a traditional technological approach is focused on how blanks were obtained (i.e., the production-oriented approach). It aims to understand the workflow and objectives of the *chaîne opératoire* (Leroi-Gourhan, 1943, 1945; Pelegrin et al., 1988; Boëda et al., 1990; Inizan et al., 1995); for this, each stage of the production is identified, through the lithic pieces that characterise them. The count of artefacts by technological categories (Table 1), and taking into account the rate of cortical flakes, brings about an economic dimension with, for example, the ability to demonstrate an incomplete (partial or truncated) or complete *chaîne opératoire* (Boëda et al., 1990; Geneste, 1985; Perles, 1980). To study the cores, in addition to the description of the debitage method and the flake-scar organisation by means of classical diacritic schemas, we also use a ‘structural analysis’ (Boëda, 2013). This is interested in useful features for debitage (i.e., morphology of natural surfaces on the selected blocks), potential initialisation processes (i.e., setting up of lateral and/or distal convexity), as well as the morpho-technical characteristics of the flakes produced. Morpho-technical characteristics registered on debitage flakes (i.e., dimensions, morphology, butt-type and cortex) are then compared to the characteristics observed on the flake scars of cores. Lastly, to characterise the tool’s retouch stage, we use the term ‘retouch’ when the flake scars only change the blank cutting edge, and the word ‘shaping’ when the flake scars change the volume and the morphology of the tool blank (or a sub-part). When these two distinct stages of blank transformation are mixed, we use the term ‘confection’ (Rocca, 2013).

In the second methodological step, the techno-morpho-functional approach focuses on the blank transformation modalities and on the techno-morphological characteristics added during the retouch stage. Initially theorised by Lepot (1993) and subsequently developed by Boëda (1997, 2001, 2013), this method has been applied in many lithic studies over the past 25 years, including on Lower Palaeolithic lithic industries (Bodin, 2011; Nicoud, 2011; Chevrier, 2012a; Rocca, 2013; De Weyer, 2016; Viallet, 2016). The goal is to determine the techno-functional units (TFUs) present on the tool and to understand their arrangement (Boëda, 1997, 2001, 2013). These TFUs can be transformatives (TFU-T=edges), meaning they were the part of the tool in contact with the material worked; prehensibles (TFU-P), meaning they were the part that was in contact

Table 1 Number of lithic pieces by technological category and by raw material in the Caune de l'Arago L-layer lithic industry

	Milky quartz	Hyaline quartz	Quartzite	Local flint	Allochthonous flint	Radiolarite	Varied rocks	Total
Unmodified blanks	3115	568	98	175	145	113	141	4355
Raw material pebbles		1						1
Pebble fragments	39	2						41
Tested block or core with one removal			1				7	8
Core	18	3	5	1			4	31
Flakes and flake fragments ≥ 20 mm	292	56	17	22	8	10	32	437
Small flakes and fragments < 20 mm	39	42	19	35	14	15	12	176
Retouch flakes	29	99	39	62	84	75		388
Typical shaping flakes			3					3
Undefined fragments ≥ 20 mm	107	10	3	10		6	66	202
Small undefined fragments < 20 mm	2591	355	11	45	39	7	20	3068
Modified blanks	25	7	14	4	6	11	6	73
Flake-tools	25	7	14	3	6	10	6	71
Tools on other blanks (pebble, nodule)				1				1
Core tools						1		1
Total	3140	575	112	179	151	124	147	4428

with the user's hand; or a transmitter/receiver of the energy (i.e., an intermediate part); the latter are often difficult to distinctly isolate on the tool. TFU-T (edges) are characterised by a set of recurrent and coherent technical criteria associated with the blank. Specifically, we distinguish these TFU-T by a precise diacritical analysis of the chronology of the flake scars or the groups of flake scars that participated in the construction of the tool and their technical consequences on the blank (Boëda, 2001). Several criteria are recorded (Fig. S1, in supplementary information): delineation of the cutting edge in the frontal and sagittal view, cutting-edge morphology (i.e., morphology in sections of the surface that create the cutting edge), cutting angles and extension of retouching. These criteria can also be observed on unretouched products. TFU-P are identified by techno-morphological criteria (i.e., bulb, butt, back and cortical area) and by their position regarding the transformative part (i.e., opposed and adjacent). Thus, the observation of the morpho-technical consequences of the gestures made on the blank leads to a perception of the potential 'functional intentions' of the tools.

The final objective of this method is to determine groups of tools ('techno-types') based on the association of one or more TFU-T with a TFU-P and then to quantify them. In this regard, it is important to point out that the number of artefacts studied with the techno-functional analysis (see Tables S2 and S3, in supplementary information) is often lower than in the general-count table (Table 1), because only artefacts that are able to offer probative information are taken into account (i.e., whole pieces), and the others (e.g., proximal/distal parts and altered pieces) are discarded from the analysed sample.

Overall, this methodology provides information on the creation of these tools, from the selection of raw material blocks to the setting up of the active parts, and furthermore enables us to establish the relationships between the characteristics of the blanks (morphology, volume), their transformation modalities and the cutting edges that were created. This method is therefore appropriate for characterising the often poorly standardised industries of the Lower Palaeolithic period. This approach makes it possible to address the territory exploited for raw materials and the range of tools created and, thus, to take another step towards the cultural characterisation of human groups, understanding their cognitive abilities and their social organisation.

Results

Raw Materials and Technological Classification of the L-Lithic Assemblage

The revision of the whole assemblage allowed us to update the petrographic attributions following the reclassification of raw materials (Table S1, in supplementary information). Within these groups, subgroups have been identified, taking into account not only the nomenclature established in the previous works but also through a process of comparing material piece-by-piece to try to find elements that are part of the same block. During this analysis, the technological category of each lithic element was defined and is presented here (Table 1). At this step, the distinction of local and allochthonous flint was done as a first division by provenance, and

then a geological subdivision was applied to better understand the material's physical constraints.

The Milky Quartz Corpus ($n = 3140$)

Milky quartz is the most abundant local raw material. A large number of small fragments are present (Table 1) because of the poor quality of this rock (tendence to shatter); these micro-fragments were retrieved by sieving. Although they constitute a large part of the quartz corpus, they are unfortunately unusable for the technological study. The selected volumes are pebbles of cubic morphology (Fig. 3a) with average dimensions of approximately $150 \times 100 \times 50$ mm and have plane cortical surfaces that serve as striking platforms. Here, the selection stage plays a very important role, because the blocks and the striking platforms are not prepared before knapping. The unmodified features of the block, such as natural convexities, are sufficient for the debitage. Bipolar percussion on an anvil is the most frequently used technique. More rarely, direct percussion with a hard hammer is used for the most homogeneous blocks (Fig. S2, in supplementary information). Flake-scar sequences are mainly unipolar. The blocks can be reduced in their length (longitudinal axis, Fig. 3a) or in a peripheral way, which then implies two kinds of cores. The debitage stops when the volumes become too small or too damaged to be exploited, when the flakes are hinged or when the volume is no longer sufficient to fulfil the techno-morpho-functional criteria desired on the debitage products. Several flake techno-types are found on the same core (Fig. S2, in supplementary information and Fig. 3a) with various techno-functional potentials at each step of the debitage sequence. Two tool groups ('techno-types') are observed among the unretouched flakes (Table S2, in supplementary information).

The transformed blanks mainly come from the beginning of the *chaîne opératoire*. These are cortical flakes, flakes with cortical backs or thick fragments; they are among the widest and thickest products. The prehensile areas are varied: cortical areas (i.e., flat or convex), cortical or naturally backed, natural fracture area, sirt break or the proximal part of a flake (i.e., butt or bulb). Blanks are transformed by a short retouch phase. The edges created (i.e., TFU-T) are straight, curved, denticulate and punctiform, so four tool groups are present (Table S3, in supplementary information). Overall, the *chaîne opératoire* is complete with all stages are represented.

The Hyaline Quartz Corpus ($n = 575$)

Hyaline quartz is a local and semi-local raw material, the selected volumes of which are small pebbles of cubic or spheroid morphologies (Fig. 3b and e). This kind of quartz is more homogeneous than the previous type. The volumes have one or more plane cortical surfaces that serve as striking platforms which are not prepared (Fig. 3b). Bipolar percussion on anvil technique and direct percussion with hard hammer are used (Fig. 3b and e), and blanks are obtained by a short or long sequence of unipolar recurrent removals (Fig. 3b and e). There are multiple objectives of production: varied thick cortical flakes with outlying edge, flakes

Fig. 3 Photos, drawings and diacritical schema of various cores from Caune de l'Arago L-layer lithic industry: **a** core in milky quartz exploited by freehand percussion technique and a frontal method with refit of five flakes; **b** core in hyaline quartz exploited by freehand percussion technique and a peripheral method; **c** core in quartzite exploited by freehand percussion technique and a peripheral method; **d** core in quartzite exploited by freehand percussion technique and a centripetal method; **e** core in hyaline quartz exploited by bipolar on anvil technique and an alternating method; **f** core in local flint exploited by freehand percussion technique and a centripetal method with refit of one flake; **g** core in quartzite exploited by freehand percussion technique and a centripetal method (percussion stigmata can be seen at the bottom) (Photos: D. Dainat; Drawings: C. Milizia; DAO: F. Capellari)

with a back (cortical or non-cortical), non-cortical triangular flakes with transversal edges and small quadrangular non-cortical flakes with lateral edges. Three groups are identified among the unretouched flakes (Table S2, in supplementary information).

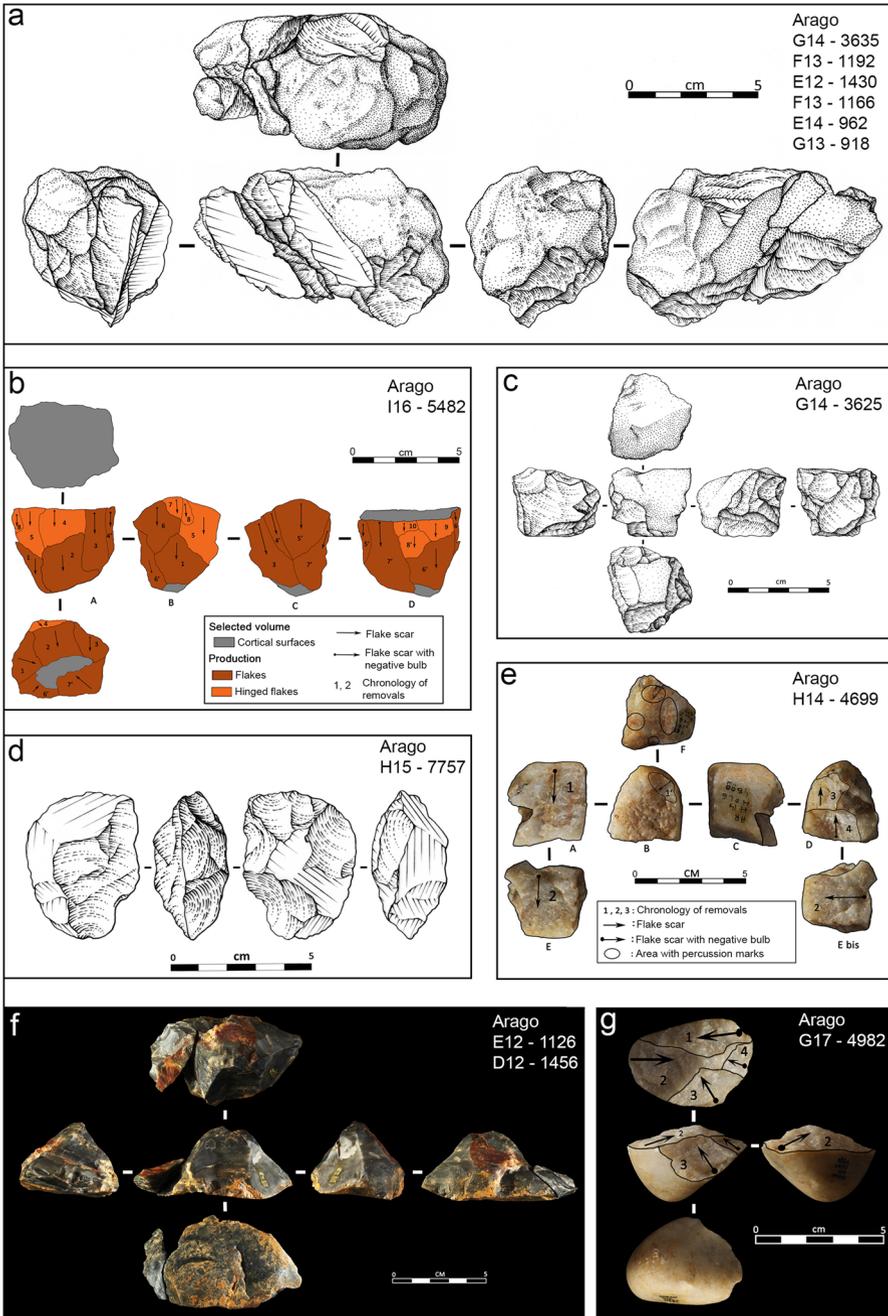
The retouch stage is represented by seven transformed blanks and 99 small retouch flakes, 80% of which are in local hyaline quartz. The selected tool blanks are among the widest and thickest flakes, mainly coming from the first stages of the debitage (i.e., cortical flakes with a back and/or cortical butts). The retouch stage is short, as it modifies the blank by a single sequence of retouch removals. The TFU-P are cortical back, cortical butt, silet break or thick cortical areas. Two groups of tools are identified among the transformed blanks (Table S3, in supplementary information). From an economic perspective, the *chaîne opératoire* is complete.

The Quartzite Corpus ($n = 112$)

Local or semi-local quartzite is collected in the form of small alluvial pebbles (Fig. 3g). The striking platforms are planes and natural surfaces and are unprepared (Fig. 3c and d). Only a direct freehand percussion technique seems to be used. The debitage is recurrent; flaking sequences are a little longer than for quartz and of centripetal or peripheral modality (Fig. 3c, d and g). The desired products at the beginning of the debitage are large and thick flakes, then flakes that are shaped like 'orange wedges' are present (flakes with cortical backs, Fig. 4c) and finally, there are small, varied, non-cortical flakes. These three different products have various techno-functional characteristics (Table S2, in supplementary information).

The selected tool blanks are among the widest and thickest products (flakes with cortical back, big fragments or cortical flakes, Fig. 4h). The retouch stage is poorly developed and it only modifies the edge of the blank through a short retouch sequence. The techno-morpho-functional analysis highlights four groups of tools (Table S3, in supplementary information). The TFU-P are cortical backs, butts, butt-back or silet break.

Three typical shaping flakes and one bifacial tool fragment (probably a broken apex portion of the biface) are present. They testify to a quartzite bifacial shaping stage and perhaps bifaces initially used in the cave but then transported elsewhere. From an economic point-of-view, the *chaîne opératoire* appears to be complete.



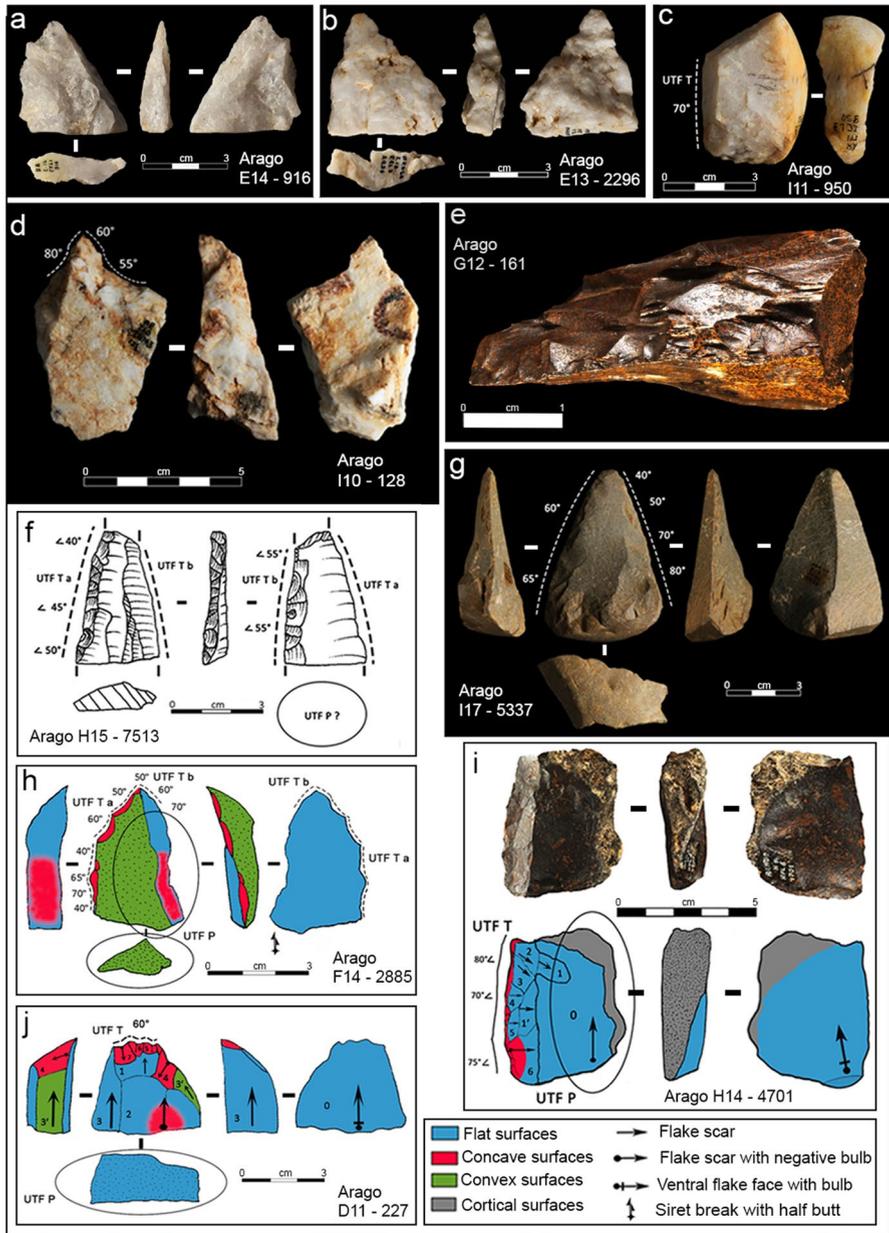


Fig. 4 Photos, drawings and techno-morpho-functional analysis of transformed and unmodified blanks from Caune de l'Arago L-layer: **a** triangular flake in hyaline quartz; **b** triangular flake in milky quartz; **c** flake-tool in quartzite with cortical back; **d** point on fragment in milky quartz; **e** flake-tool in jasper with scaled retouch; **f** flake-tool fragment in flint with straight convergent edges; **g** tool in quartzite-sandstone with linear convergent edges on a large flake with a thick butt; **h** edge-point tool on a flake in quartzite; **i** jasper tool on a thick flake with cortical back, modified by two stages of retouch (a first 'shaping' and subsequent fine-retouch); **j** denticulate tool on small, thick flake in quartzite-sandstone (Photos: D. Dainat; Drawings and DAO: F. Capellari)

The Radiolarite Corpus: Jasper and Lidite ($n = 124$)

Jasper is available in the form of small alluvial pebbles and large blocks. Lithic artefacts are brought to the site in the form of finished or semi-finished products. Cortical flakes, cores and whole blocks are absent. Unmodified flakes are varied: wide and thick, small or elongated (Table S2, in supplementary information).

The selected blanks for tools are among the widest and thickest products and flakes with cortical backs (Fig. 4i). The retouch stage modifies the blanks by several successive sequences of direct and invasive retouch (i.e., intercalated scaled removals), which can sometimes be concave and abrupt, as a scaled retouch type (Fig. 4e). The modality of the tool retouch can be a single retouch phase or shaping followed by micro-retouch. TFU-P are natural or cortical backs, a thick bulb with a wide butt and a thick natural and convex surface. TFU-T have linear and convergent cutting edges. Three groups of tools are present (Table S3, in supplementary information). We note that 75% of the elements of this series belong to the transformation stage of the blanks (i.e., small retouch flakes or re-sharpening flakes), so we can say that economically, the *chaîne opératoire* is partial.

Another local rock, lidite, is also present in a small quantity ($N=4$). This rock is available in the Verdoube alluviums in the form of small pebbles. It is only represented by one non-cortical flake and three fragments, limiting further discussion of this raw material.

The Flint Corpus ($n = 334$)

The flint series consists of allochthonous and local flint (Table 1). Local flint is rare, and it occurs very intermittently in the form of black alluvial pebbles (SCH8-type, $N=178$) and was collected in the Verdoube alluvium (Grégoire, 2000, Fig. 3f). Here, it constitutes 53% of the flint assemblage and 4% of the whole lithic assemblage (Table 1). Only one core is present (Fig. 3f), consisting of a volume with a very flat cortical unprepared surface that serves as a striking platform. The debitage is recurrent with a centripetal method. The knapping objectives are flakes with backs or cortical butts and backs. However, we did not find these products in the assemblage so must ask whether they were exported from the site. Unmodified flakes do not have obvious techno-functional criteria; TFU-P are hard to discern and no TFU-T is specific. Also, no product is recurrent. A large number of fragments is present and only one tool group can be identified (Table S2, in supplementary information).

The retouch stage is represented by a corpus of very small flakes (Fig. S3, in supplementary information), but there are few transformed blanks (Table 1). From an economic point-of-view, the *chaîne opératoire* is incomplete, lacking the initial cortical flakes and some products from the final stage of debitage (visible technical objectives on the core, see above). This particular flint has very distinctive macroscopic characteristics, and it seems clear that all the pieces of this corpus are related to the exploitation of a single pebble (Fig. 3f). In squares H9 and E-F11, small concentrations of artefacts are noticeable (Fig. S4, in supplementary information).

Another local flint (SCH14-type, $N=1$) that came from the Aptian limestones at a distance of 500 m from the cave (Grégoire, 2000) is represented by a single tool made on a small nodule of this grey-purple flint.

Allochthonous flint is composed of several facies ($N=6$), which are distinguished by their texture, colour, translucency and patina. Their source is the Oligo-Miocene limestones of the Narbonne-Sigean tertiary basin, which is located northeast of Caune de l'Arago at a distance of approximately 35 km. These materials can be identified by the micro-fossils of ostracods and charophytes they contain (Grégoire, 2000). Depending on the deposits from which they are derived, they are available in various morphologies, with slabs, blocks or nodules of different sizes collected by the Caune de l'Arago hominins. The assemblage is made up of imported, finished tools (Fig. 4f) and retouched flakes, which alone represent 44% of the flint artefacts (Fig. S3, in supplementary information).

When all flint is combined, the techno-functional analysis indicates a selection of varied tool blanks: Kombewa flakes, ordinary flakes, flake fragments, small nodules, elongated flakes, cortical or non-cortical flakes, etc. The modality of transformation is a retouch stage which generally has a low impact on the blank. Three groups of tools are identified (Table S3, in supplementary information). The TFU-P are similar and are always a technical part of the blank (i.e., butt, bulb and back), and it is more difficult to identify them on these flint tools than on other raw materials. There are also fragmented tools (Fig. 4f). On an economic level, we observe that each kind of allochthonous flint was not temporally and spatially treated in the same way. For example, some SCHAT 5 flint-type tools are introduced as finished tools and are not transformed on the site, whereas SCHAT 1 flint-type tools were introduced as unmodified blanks and then transformed on the site, and for SCHAT 4 and 9 flint-types, the finished tools are absent from the site while manufacturing waste is present. We can therefore say that flint tools are very mobile elements and the allochthonous flint *chaîne opératoire* is partial.

The Varied Rocks Corpus ($n=146$)

Several local rocks are also present (Table S1, in supplementary information), each in only a small quantity (e.g., sandstone, quartzite-sandstone, limestone, hornfels, schist and mica-schist). These rocks are varied from a petrographic point-of-view, but for convenience, these are considered as a single group since they each have low frequencies (Table 1). Hornfels is very poorly preserved in sediments and therefore reading the lithic artefact is often very difficult, if not impossible. In our sample, these artefacts are in the form of powdery fragments, which disintegrate when we touch them. Thus, we counted artefacts without being able to conduct detailed technological analysis. To avoid bias, the rare, reliable data obtained from these objects have not been included in the industry summary.

On the other rock types, we observe a selection of alluvial pebbles of parallel-sided or ovoid morphologies, which present plane and convex cortical surfaces. There are three cores with a single removal on a sub-volume of the block; these objects can also be interpreted as tested blocks. One core presents a multi-directional removal sequence on multiple peripheral sub-volumes of the pebble. We observe

production of cortical flakes with cortical butts of various sizes and morphologies. Only one group of tools can be identified (Table S2, in supplementary information).

Most of the transformed blanks arrive on the site as finished tools. Tool blanks are non-cortical debitage flakes that are wide and thick, and sometimes have large and thick cortical butts (Fig. 4g and j). The prehensile areas are cortical butts or thick and convex proximal portions (Fig. 4g and j). The modality of tool retouch is a single retouch phase or initial shaping followed by retouch. Three groups of tools are identified (Table S3, in supplementary information). It is in this corpus that we find the longest cutting edge, 100 mm in length (Fig. 4g). From an economic point-of-view, the *chaîne opératoire* appears to be incomplete.

Lithic Refits

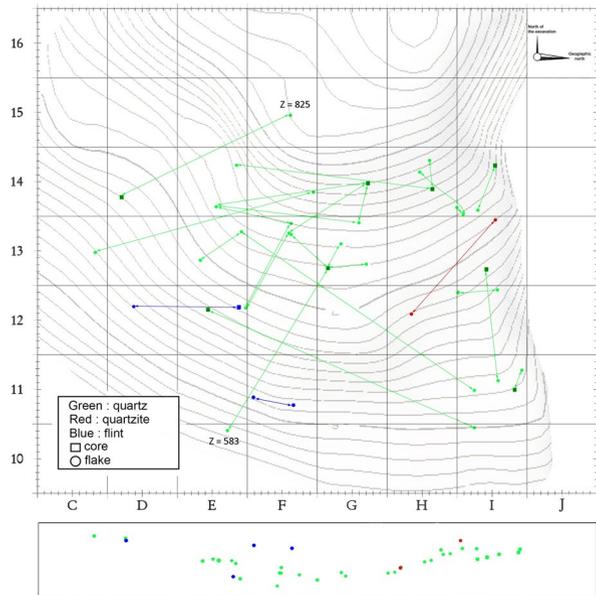
Lithic refits provide information on the techno-economic aspects and intra-site spatial dynamics (Lamotte, 1999; Lhomme et al., 2004) and can also indicate taphonomic processes (López-Ortega et al., 2019). The previous work of individualisation of the stratigraphic units (de Lumley et al., 2015) makes it possible to assign levels as reliably as possible both in the stratigraphy and in plan form. The lithic assemblage therefore appears to be more coherent, and the analysis is more congruent. Under these conditions, we were able to study all of the artefacts and carry out numerous refits (Fig. 5), which confirms, in terms of taphonomy, the good preservation of this layer. At least 26 refit units (i.e., combinations of two artefacts) were produced, mainly on the milky-quartz artefacts. Indeed, this local and abundant material is the most-represented in the lithic industry, and it is on this raw material that the *chaîne opératoire* is most complete (Fig. 5).

Regarding the spatial distribution, we note that the cores are more concentrated in the centre of the excavated area, and the debitage products are more common in the periphery (Fig. 5). This may indicate anthropogenic movement, but the tilt of the archaeological level from the sedimentary bending of the layers may have also caused these spaces between objects. For instance, we observe on the plan (Fig. 5) a drop in altitude of 2.42 m between the uppermost and the lowest object at a horizontal distance of 4.55 m, which is a 53% slope. The vertical projection of the refits (Fig. 5) shows that the connected artefacts can be at the top, in the middle or even at the bottom of the layer. Some are connected between the bottom and the top. Thus, the refit work does not allow for a more precise subdivision of this archaeological level. On the contrary, these associations instead attest to a singular archaeological level, with multiple occupations not discernible within this stratigraphic unit. These considerations argue in favour of the assumption of a single phase of human occupation, as has already been proposed for this layer (de Lumley et al., 2015).

Non-knapped Lithic Material

Unmodified lithic material resulting from anthropogenic input is also present (Table S4, in supplementary information). These include calcareous stones (Fig. 6a

Fig. 5 Planimetric view and altitudinal projection (view in perspective) of lithic refits carried out during the study of the Caune de l'Arago L-layer lithic industry (DAO: C. Fontaneil and F. Capellari)



and b) and limestone or sandstone pebbles. The dimensions and morphologies vary. Some are massive ($N=6$), measuring 20 cm and weighing up to 3 kg (Fig. 6c). These materials are local; the stones come from the scree of the slope below the cave, and the pebbles come from the alluvial deposits in the valley. The function of these natural objects is difficult to define, because they do not present particular modification features (e.g., heating), but their useful role is probably not negligible in view of their quantity. Among the most massive stones, there is a recurring cubic morphology (Fig. 6a and b), which could be a selection criterion. Various use hypotheses can be envisaged: anvils for debitage, passive hammer, wedging or ballast elements, percussion tool, paving, structural elements, supports for various activities, a reserve of raw material, etc. Some stones have natural bevels, so they could have been used, for example, as blunt tools. No particular spatial distribution is perceptible.

Technological and Techno-Functional Summary

In terms of the production aspects, the selection stage is fundamental because there is no core preparation. The lateral and distal natural convexities of the block or pebble are exploited without prior preparation of the striking platforms and the knapping surfaces. The criteria for selecting volumes are consistent. Their management is also sometimes similar (Fig. S5a, in supplementary information). The cores essentially correspond to ‘additional volumetric structures of Type-C’ (Boëda, 2013), in which one or more useful sub-volumes of the blocks are exploited (Fig. S5a, in supplementary information). This exploitation stops at the exhaustion of natural

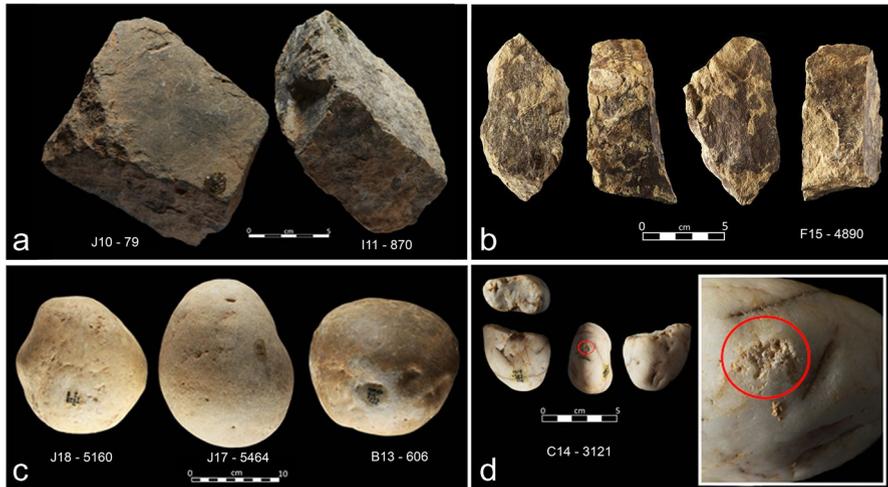


Fig. 6 Non-knapped lithic material from the Caune de l'Arago L-layer: **a** and **b** large quadrangular stones; **c** spherical massive pebbles weighing several kilograms; **d** small pebble with percussion traces (Photos: D. Dainat DAO; F. Capellari)

convexities, with the first reflected flakes or when the volumes no longer provide the desired objectives. Debitage is almost always recurrent with a short removal sequence. It is invariably led by hard-hammer percussion with a bipolar percussion technique on an anvil (when convexities are missing or when cores are too small), and also with direct percussion. The series of removals are mainly unidirectional and more rarely, centripetal and orthogonal (Fig. S5a, in supplementary information). The volumes are exploited in a frontal or peripheral modality. Products with different morpho-functional features are obtained on the same volume all along the production (Fig. S5a, in supplementary information).

For each rock type, multiple techno-functional groups can be discerned, both for retouched and unmodified blanks (Fig. S5a, in supplementary information; Tables S2 and S3, in supplementary information). However, when all raw materials are combined, many groups can be combined according to their techno-morpho-functional characteristics (Tables S5 and S6, in supplementary information). We can observe common characteristics regarding tool blanks, cutting edges or prehensile parts.

Thus, we obtain three main groups of tools for unmodified blanks (Table S5, in supplementary information, groups 1–3). We note that unretouched products are varied but often occur across the different raw material types (Table S5, in supplementary information). Likewise, for some rocks, there are several groups of tools recognised, whereas others have only one tool (i.e., radiolarite). The prehensile areas are varied and some are recurrent for all raw materials. Sometimes, this can be linked to a cutting edge (i.e., the cortical backs are always opposed to rectilinear cutting edges with cutting angles around 60–70°, or small butts that are adjacent to short cutting edges with cutting angles from 30° to 50°). Similarly, a link between cutting edge and tool blank is sometimes apparent. This is the case with group 1, for instance,

wherein TFU-T only appears on small non-cortical flakes of various morphologies. However, the same cutting edge can sometimes appear on other tool blanks with different TFU-P. Therefore, the relationship between a tool blank, a prehensile area and a cutting edge is not systematic. The morphological characteristics of the cutting-edge surfaces are quite similar for the different groups of tools (Table S5, in supplementary information), with differences more apparent in the cutting angles and in the length (e.g., between milky quartz and quartzite). The longest cutting edges are found on sandstone and quartzite-sandstone artefacts. There are three types of TFU-P and TFU-T combinations.

Regarding the transformed blanks (Table S6, in supplementary information), when all raw materials are combined, the different groups identified in each corpus can finally be grouped into five categories (Table S6, in supplementary information, groups 1–5). The most important group, quantitatively speaking, is group 5, which forms a heterogeneous category. Products share common techno-morphological characteristics, but they can be differentiated by raw materials, the cutting angles or the length of the cutting edge (i.e., the cutting edges for milky quartz are longer than for hyaline quartz and quartzite). On the one hand, the same TFU-T can appear on different blanks with different positions of the prehensile part (i.e., opposed or adjacent) on different or the same raw materials and with a different cutting-edge length. On the other hand, the prehensile areas can be similar. The longest cutting edges are found on large flakes of milky quartz and in the corpus of various other rocks. We note that the cutting angles are very rarely less than 50° or located between 40° and 60° , and they are absent below 40° (Table S6, in supplementary information). There are three types of TFU-P and TFU-T combinations (Table S6, in supplementary information).

Discussion

Although the TFU-T are varied, the selected tool blanks are similar in their morpho-technical configuration; cortical flakes, with cortical or natural backs or large and thick products. The prehensile areas are natural and varied and are never created by a retouch stage. Sometimes this can be a sirt fracture, which is a common knapping accident on quartz, or a natural flat area. Among the tool corpus, one specific techno-type often appears on raw or transformed blanks. The latter has a straight, linear cutting edge, a bi-planar or plano-convex cutting-edge morphology, a cutting angle of approximately 70° , opposed to a prehensile part or more rarely, adjacent. If other edges are present on a tool (i.e., denticulate edge, curve or point-edge), there are more cutting edges of this straight-edge type with high cutting angles (between 65° and 85°). The transformation stage of the blanks makes it possible to create edges that cannot be directly obtained through debitage, as well as more obtuse cutting angles, or even regulated rough edges. Although the raw materials are different, the edges and the morphometric characteristics of the tools can be similar, which leads us to think that there is not always determinism of the raw material here. However, for the same type of cutting edge, differences in efficiency and resistance on the materials worked can exist between the various raw materials. Here, the question

of raw material choice arises: with an identical edge, does the difference in the rock that is used imply a separate functional efficiency (Beyries, 1988; Clemente & Terradas, 1993; Ollé, 2003; Claud 2008; Astruc, 2012; Lemorini et al., 2014, 2019; Claud in Thiébaud et al., 2019 p.442)?

Different modalities of grip are present on modified or unmodified products (Tables S5 and S6, in supplementary information), which may have an implication on the handling of the tool and the transmission of energy (Boëda, 2013; Lepot, 1993). There are several groups of tools for each corpus of rocks. Some edges are only present on one rock type, while others are found on multiple raw materials. In addition, some similar TFU-T are found on different blanks, both in terms of morpho-technical characteristics and relating to its position in the *chaîne opératoire*. The relationship between a blank and its edges can sometimes be seen, but it is not systematically present. Also, the same edge shape can be obtained from different retouch methods. Finally, for each rock type, there is a group of tools with large cutting angles (60–80°).

Even if the assemblage is only centred on flake production and does not include any bifacial tools, we note that rare examples of shaping are present (e.g., two shaping flakes and one fragment of a bifacial tool in quartzite). Thus, it is possible to imagine that some bifacial tools have passed through the site. But here, it is clear that its importance in the structure of the assemblage is extremely low. Instead, debitage provided all the tools and tool blanks (Fig. S5a, in supplementary information) and, moreover, we see that a lithic industry structured on flake production can produce transformative parts like tips or edge-tip types (Fig. S5a, in supplementary information). It is therefore necessary to ask whether these are complementary or reflect a techno-functional overlap with the tools produced on a bifacial blank (Capellari et al., 2018; Guibert-Cardin et al., 2021).

At the economic level, we observe a differential presence of the quantity of technological products for each stage of the *chaîne opératoire*, depending on the raw material type (Fig. S5b, in supplementary information). The *chaînes opératoires* for certain raw materials appear incomplete, such as allochthonous flint and jasper (Fig. S5b, in supplementary information); thus, we perceive distinct techno-economic dynamics (Fig. S5b, in supplementary information). Some tools (mostly made in allochthonous rocks, but not exclusively) are imported finished/semi-finished, used and then abandoned, while others, made in local rocks, are produced, used and then discarded at the site. Conversely, it is possible to suppose the export of tools in local rocks (such as lidite, local flint or even quartz), but it is unfortunately more difficult for us to perceive it. In many other layers, the flint artefacts imported to the site includes bifacial tools in particular (de Lumley & Barsky, 2004), whereas in layer L, this contribution comprises only flake-tools. These indicators of the segmentation of the *chaîne opératoire* and transport of tools across the landscape bring us to consider the movements of individuals and the territory traversed by Middle Pleistocene hominin groups.

In the studied assemblage, we can observe great mobility through some flake-tools, as in many other layers of the Caune de l'Arago (de Lumley & Barsky, 2004). It is unusual to note this flake-tool mobility behaviour, which is rarely visible in other contemporaneous Lower Palaeolithic sites notably due to the frequent use of

a single local raw material on most sites (flint generally). For instance, within one layer of the Boxgrove site (UK), a large flint flake seems to have been transported away from the site (the only flake missing in the refit), as well as the bifacial tools which were shaped on site (Roberts & Parfitt, 1999), but this is a rare exception. At the Caune de l'Arago, it is observable due to the exploitation of different raw materials present in the environment. Thus, the transport of tools, often attested in the literature for bifacial tools whose mobility is better known because it is more easily demonstrable (shaping flakes, broken points) (Lhomme, 2007), also apparently exists for other tools/blanks as shown by this layer.

A key question is how to interpret these techno-functional objectives in this precise context, particularly with regard to the activities at and the function of the site during this occupation period? An initial technical observation can be drawn: in view of the large number of unretouched flakes and the low rate of transformed blanks, it seems that unmodified products played an important role in the industry and therefore in the activities that were carried out. The recurrent presence of edges with high cutting angles that were often greater than 60° is also interesting, prompting us to ask what kind of tool it was, with which cutting movement was it used, for which activity and which material worked? For example, what was the functional use of tools where the cutting movement can be qualified as 'transverse cutting' (Abril et al., 1981; Lepot, 1993; Siegel, 1985; Soressi, 2002; Soriano, 2000; Wilmsem, 1968)? Further functional analysis is necessary for more detailed insights.

Alternatively, we can consider whether scraping and tanning activities are relevant, such as working skins. Overall, the absence of elongated products and macro-tools (e.g., pebble tools), the scarcity of transformative parts like punctiform type (tip, edge-tip, edge-tip-edge) and the lack of products with converging edges among the flakes, when combined with the low percentage of fractured bones and signs of butchery and cutting up (cutmarks on the metapodials of reindeer), allow us to at least consider activities centred on the work of meaty materials and, perhaps also, on the skins of reindeer. The faunal spectrum, dominated by numerous reindeer (at least 49 individuals, representing tons of meat) comprising adult females and juveniles, reinforces the hypothesis of a particular, perhaps, recurrent activity, which could explain some of the recurrences observed in the toolkit on different raw materials that arrive at the site from various distances. All of this implies hominin behaviours that are far from opportunistic.

The Caune de l'Arago Layer L in a Broader Mediterranean Context

Remarks About Comparisons Work

Meaningful comparisons are not easy to make because there are few assemblages that date to this period (MIS 14 in particular). Moreover, the sites, which are generally younger, often appear in interglacial periods (MIS 15–13–11–9). Sites also vary across other factors: they can be found in karstic or open-air contexts, may contain different or unique raw materials, record few artefacts which may or may not include bifacial tools, show variable faunal preservation, represent more or less

varied taphonomic processes or have been excavated over a small area. Additionally, problems related to chronological attribution are frequent; the sometimes very large intervals of uncertainty in the dates of certain sites (± 90 kyr!) make it difficult to include them for precise comparisons. Depending on the site, data concerning the lithic industries are quantitatively uneven and methodologically heterogeneous. Finally, very few assemblages have been the subject of a techno-functional approach as we have developed here but, whenever possible, we selected assemblages studied with this method. Thus, because of these archaeological and methodological differences, comparisons are sometimes difficult to draw and then to interpret. It is therefore necessary to do precise and targeted comparisons. The simplest and most consistent comparisons here are those made with other levels of the Caune de l'Arago.

Considerations After the Comparisons

We made comparisons with archaeological layers of Arago cave and other Lower Palaeolithic sites of Mediterranean basin from MIS 16 to 12 (see supplementary information). Concerning the Arago layers, both shaping and debitage *chaîne opératoire* can be interlinked, as we can see it in the underlying P-layers at the site (Barsky & de Lumley, 2010). In these latter layers, one *chaîne opératoire* can be partly dependent on the other (need to obtain a large flake for the shaping of the biface). They are therefore in interaction on production, economic (same raw material sought) and perhaps also functional level? (Capellari, since 2017). In both cases, (L- and P-layers) some flake-tools are imported and some are probably exported. However, in P-layers, bifacial tools are produced, used and then abandoned on site. In the L-layer, bifacial tools may have passed through the site but during this occupation period, the production of tools like this was clearly not the objective. The absence of bifacial tools in layer L cannot be explained by the constraints of raw materials, which are the same available as for the other layers, especially when these are already not an obstacle to achieving similar technical objectives through flake-tools. A cultural dimension could be considered, but some very rare evidence of shaping is present and the occurrence of bifacial tools in the underlying level P, close in temporal terms in MIS 14, argues against this explanation. Thus, despite the possibility of making bifacial tools, these are absent. Here, the functional hypothesis seems to take precedence. The function of the site during this occupation period and the activities carried out there did not require the production and use of bifacial tools, at least not in a way that structured the lithic assemblage.

There are more technical similarities than differences between L and K, which are layers without bifacial tools. It is interesting to note that they present the same archaeological context (fauna, duration and kind of occupation, similar palaeo-climatic and palaeo-environmental conditions) and, importantly, a lithic assemblage with very similar technical characteristics. This leads us to the same functional interpretation of one or more similar specific activities that generated specific tools. This correlation between the L and K layers has been mentioned in previous research: '*Similarities observed between the L and K assemblages go beyond the lithic assemblages since hunting practices and climatic conditions*

also appear to be analogous' (Barsky, 2013). However, concerning flake-tools, there are more differences with the P-layers, but these are not solely due to the presence of bifacial tools in the latter. In fact, if we remove bifacial tools from our consideration of the P-layers; we can already see production, functional and economic differences in overall reduction patterns. Thus, the debate lies more in the variability of core-and-flake reduction sequences (as it exists already for bifacial tool sequences) and not only in the bifacial or not-bifacial debate. Here, we see that considerable intra-layer variability already exists, as well as inter-layer variability, and so inter-site variability is highly predictable.

Precisely, at a European level, each assemblage appears to be unique. A wide range of petrographic, technical, technological, economical, and techno-functional variability is noticeable. This technical heterogeneity appears to be both synchronic and diachronic. Thus, how are we to meaningfully compare them? It is difficult to perceive a 'global technical pattern' in hominin behaviour which could encompass all of these assemblages. At the same time, all assemblages are similar in some ways, sharing some technical or economic features. Technical criteria used for flaking are rarely opportunistic and most of the time they seem to be highly structured. There are one (or more) technical and behavioural recurrences that connect these assemblages. Some invariable parameters, linked to universal imperatives, such as the prehensile parts included in the production (the presence of backs), can be found from one assemblage to another. In fact, in the current state of our knowledge, these tools have to be adapted to the hands in order to be suitable for use (which is fundamental for the transmission of energy and the holding of the tool) and not attached to a handle as we see later in the Middle Palaeolithic. In some cases, there are more commonalities than differences. For example, the differences seem to be more pronounced between the L- and P-layers of the Caune de l'Arago than between the L-layer and Marathousa (Greece). We see recurrences both in the general aspects that structure the industry and in the small particularities.

Thus, there seem to be some technical constants and more punctual adaptations to the context. In our opinion, it is more a factor of site function and the activities carried out, than of raw materials, chronology or cultural differences. These industries appear at first sight simple, flexible, varied or even 'nebulous' (Nicoud, 2013a), but this is an external impression. From the inside, they hide a large quantity of technical facts and only in the details can we really recognise the complexity of these assemblages. It is therefore essential to question this variability and the value that these similarities and differences take on within this set of lithic industries. For this, it is necessary to adapt our methodological means and to rethink our ways of approaching these assemblages.

Conclusion and Work Prospects

This study brings new data and enriches our understanding of the occupation of this major Middle Pleistocene site in the Mediterranean Basin. Examples of this precise type of brief occupation, also called a 'snapshot', are still rare and few documented for the Lower Palaeolithic. In some respects, they can be compared with single

carcass processing sites. In this specific context, the techno-economic and techno-morpho-functional study presented here highlights recurrences in technological choices and variability in the economic management of the different rocks exploited. Where the production methods vary depending on the raw materials, the techno-functional objectives are often similar. The search for tool blanks with specific morpho-technical criteria (cortical surfaces, large and thick flakes, butts and cortical back) and the predominance of some techno-types (variability of straight cutting edge with high cutting angles) seem to be linked to one or more specific activities (reindeer processing) being carried out within this occupation level. The influence of the raw material therefore must be put into perspective: it can cause differences in production, but not necessarily at the techno-functional level. Knappers are flexible in adapting their knapping methods to suit the constraints of particular raw material types, to make the tools they need and which correspond to one or more specific activities in a certain cultural, palaeo-climatic and palaeo-environmental context.

As emphasised in the 'Introduction', this kind of precise study is only possible thanks to a well-defined archaeological context upstream (fine stratigraphic resolution, good integrity and homogeneity of the archaeological layer, excavation over a representative area, presence of fauna, good preservation of the remains, large sample size, etc.). This is a necessary condition for carrying out the techno-economic and techno-functional study at this scale, as well as for making substantial comparisons after.

These first results have further potential for diachronous comparison with other lithic sequences at the site, dating from MIS 14 to 12. Additionally, it would be interesting to couple these technological data with a functional approach on macro-traces (Viallet, 2016) and micro-traces (Claud 2008; Bonilauri, 2010) in order to carry out combined studies, which are still underdeveloped for the Lower Palaeolithic though widely applied in later periods (Guibert-Cardin et al., 2021). The techno-functional variability of the tools is important and is much greater than what the typology — still often used as the basis of Lower Palaeolithic lithic studies — suggests. It is this variability that needs to be explored (Nicoud, 2013a). To better understand the techno-complexes of the lower European Palaeolithic, all tools must be considered equally and not just bifacial tools which have previously generated the most interest. Core-and-flake assemblages are therefore crucial to future research into the great diversity of what is called 'Acheulean', with studies necessary across Western Europe. Once compared and synthesised, these new data will then make it possible to describe the technical and socio-economic behaviours of hominin groups from the Middle Pleistocene in Western Europe more precisely.

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Declarations

Conflict of Interest The authors declare no competing interests.

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