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The Caune de l'Arago stone industries in their stratigraphical context

Les industries lithiques de la Caune de l'Arago dans leur contexte stratigraphique

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ABSTRACT

The Middle Stratigraphical Complex of the Caune de l'Arago cave site (Eastern Pyrenées, France) is dated to between 690,000 and 400,000 years old. The site contains successive, spatially distinct archaeological levels. At the base of the sequence, Unit I (OIS 14), where the P levels are among the earliest Mode 2 assemblages presently known in western Europe, contains finely shaped handaxes and a cleaver. Situated above this ensemble, Unit II (OIS 13) has revealed a series of artefact levels lacking handaxes and cleavers. Coiffing the sequence, Unit III (OIS12) has provided numerically rich faunal and lithic assemblages in association with *Homo heidelbergensis* remains. This paper analyses the stone industries from each artefact level taking into account raw material variability and highlights subtle technological and typological differences. This intrasite study uses a multidisciplinary approach to examine common elements and differences between levels, taking into consideration how external impact factors might have influenced global assemblage features. The Caune de l'Arago's long stratigraphical sequence provides an exceptional opportunity to observe both change and stability in Mode 2 stone-tool manufacture over a period spanning nearly 300,000 years, within the context of contrasting paleoenvironmental conditions.

RÉSUMÉ

Le complexe stratigraphique médian du site de la grotte de la Caune de l'Arago (Pyrénées orientales, France) date d'environ 690 000 à 400 000 ans. Le site comporte des niveaux archéologiques successifs, spatialement distincts. À la base de la séquence, l'unité I (OIS 14), où les niveaux P sont parmi les plus précoces parmi les assemblages de mode 2 actuellement connus en Europe occidentale, contient des bifaces finement façonnés et un hachereau. Au-dessus de cet ensemble, l'unité II (OS 13) révèle une série de niveaux à artefacts ne comportant ni biface, ni hachereau. Coiffant la séquence, l'unité III (OS 12) a fourni, en nombre, des assemblages lithiques et fauniques associés à des restes d'*Homo heidelbergensis*. L'article analyse les industries lithiques de chaque niveau d'artefacts, en prenant en compte la variabilité du matériau brut, et met en évidence des différences typologiques et technologiques subtiles. L'étude intrasite utilise une approche multidisciplinaire pour examiner les éléments communs et les différences entre niveaux, en considérant comment

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les facteurs d'impact externes pourraient avoir influencé les caractéristiques globales des assemblages. La longue séquence stratigraphique de la Caune de l'Arago offre une opportunité exceptionnelle d'observer à la fois le changement et la stabilité dans la fabrication d'outils lithiques de mode 2 sur une période couvrant environ 300 000 ans, dans un contexte de conditions paléoenvironnementales contrastées.

1. Introduction

The Caune de l'Arago cave is carved into a limestone cliff overlooking the Gouleyrous Gorges (Tautavel, eastern Pyrenees, southern France). Over millennia, the Verdouble River that sculpted the Gorges provided hominins with fresh water and raw materials for the manufacture of their stone-tools (Fig. 1). Explored by core drilling in the 1980s (de Lumley et al., 1984), the cave's 15 m thick infill is divided into three major sedimentary complexes known to contain numerous distinct artefact levels. The bulk of the infill is attributed to the *Middle Stratigraphical Complex*, deposited between 690,000–400,000 years ago (Table 1). Many of the archaeological levels have been explored during more than 40 years of excavations, revealing intermittent hominin occupations of varying intensity. While some levels have yielded fossils belonging to a wide variety of large mammals, others translate species-specific hunting practices. Combined biostratigraphical and sedimentological analysis have contributed to reconstructing climatic change throughout the cave's occupation during most of the Middle-Middle Pleistocene. This paper examines the main features of the industries from each of the different levels taking into account multidisciplinary studies in order to interpret subtle changes observed in the lithics over time (Barsky, 2001; Barsky and Grégoire, 2001; Barsky and de Lumley, 2004, 2005, 2010; Byrne, 2004; Filoux, 2007; Grégoire et al., 2006, 2008; de Lumley, 1976a, 1976b; de Lumley and Barsky, 2004; de Lumley et al., 2004; Moigne et al., 2005, 2006; Pois, 1999; Quilès et al., 2004; Rivals et al., 2006, 2009; Wilson, 1988).

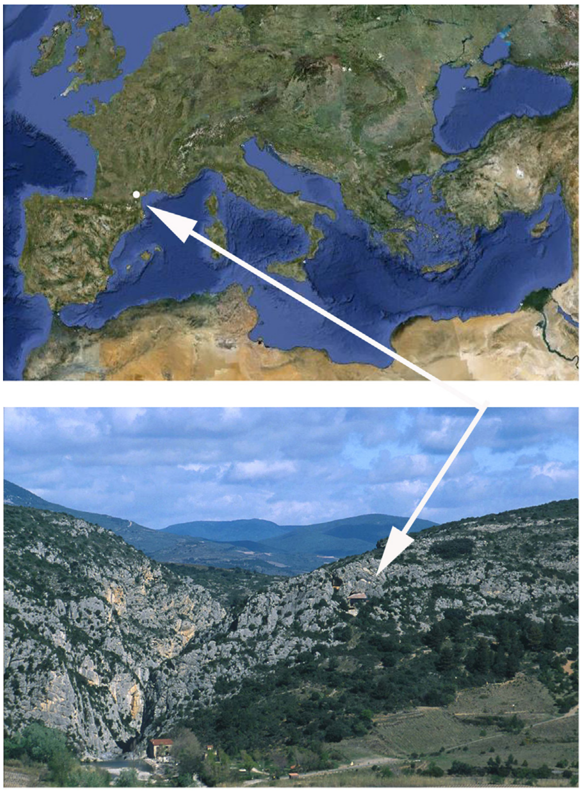

Fig. 1. Top: geographical situation of the Caune de l'Arago cave site in southern France (Tautavel, Pyrénées-Orientales). Bottom: view of the Caune de l'Arago at the mouth of the Gouleyrous Gorges.

Fig. 1. En haut : situation géographique du site de la grotte de la Caune de l'Arago dans le Sud de la France (Tautavel, Pyrénées-Orientales). En bas : vue de la Caune de l'Arago à l'embouchure des gorges de Gouleyrous.

Photo: Denis Dainat, EPCC–CERPT.

The Caune de l'Arago stone assemblages constitute a significant contribution to knowledge about the arrival and subsequent development of Mode 2 (Clark, 1977) in southern Europe. The cave's long stratigraphical sequence provides an exceptional opportunity to study hominin evolution in this region during this little known period of human Prehistory. The rich archaeological heritage contained within its imposing deposits offers a rare occasion to define technical diversity within a precise chronological, climatic and behavioural framework. The different archaeological levels have yielded thousands of pieces of stone waste and shaped tools knapped from an exceptionally wide variety of rock types. Although some authors (Byrne, 2004) have proposed raw material determinism as a stabilizing factor explaining the relative homogeneity of Caune de l'Arago industries over time (dominance of vein quartz), this paper highlights the more subtle typological and technological differences in the industries from each occupation level.

The hominin occupation levels discovered within stratigraphical **Unit I** were buried in layered, sandy deposits during a cold, dry climatic phase (OIS 14). While levels M, N and O have yielded few artefacts, a series of levels known as "P" are attributed to short-term hominin stays (Barsky and de Lumley, 2005, 2010). Higher up within the Unit, artefact levels K and level L indicate short stays of hominins practicing species-selective hunting targeting reindeer (de Lumley et al., 2004; Moigne et al., 2006). In the P levels, on the other hand, the faunal assemblage is dominated by horse, reindeer and bear (Moigne et al., 2006; Filoux, 2007). There, bear remains are generally found near the cave walls and in anatomical connection. They are mostly attributed to elderly individuals and it is likely that they died naturally during hibernation. In contrast to the horse, reindeer, bison and red deer fossils, carnivore bones don't show traces of human intervention. The small bovid fossil accumulation (argali, thar) is attributed to carnivore predation (Rivals

Table 1
Synthetic log showing radiometric dates, stratigraphic units, sedimentology, climate, dominant species hunted and assessed habitat type, in the Caune de l'Arago cave deposits.
Tableau 1
Log synthétique montrant les âges radiométriques, les unités stratigraphiques, la sédimentologie, le climat, les principales espèces chassées, et le type d'habitat répertorié dans les dépôts de la grotte de la Caune de l'Arago.

Radiometric dating	Stratigraphical units	Levels	Sedimentology	Climate	Dominant species	Assessed habitat type
OIS 5	Unit V	A & B	Stalagmitic floors separating archaeological levels	Alternating temperate/humid and cooler phases	Horse, red deer, argali	Bivouacs
104–151 ka 215–229 ka 273 → 350 ka Stalagmitic floor: ESR U/Th > 350 Ka	Unit IV	C	Stalagmitic floors separating archaeological levels	Alternating temperate/humid with cool, dry phases	Horse, red deer, argali	Bivouacs
Quartz dated by ESR 430 ± 85 Ka	Unit III	D	Coarse, layered sands	Cold and dry	Cervids dominant, argali, horse, fallow deer	Seasonal stays; species-specific hunting
		E	Coarse, layered sands	Cold and dry	Argali dominant, horse, red deer, thar, bison, musk-ox	Seasonal stays; species-specific hunting
		F	Coarse, layered sands	Very cold and dry with strong winds	Argali dominant, thar, red deer, horse, reindeer, chamois	Seasonal stays; species-specific hunting
		FG	Coarse, layered sands	Cold and dry	Musk-ox, argali, horse	Bivouacs; species-specific hunting
ARAGO XXI hominin skull dated by spectrometry gamma 455 + ∞–210 Ka		G	Gravel with silty-sand matrix	Fresh to cold and dry	Horse, bison, rhinoceros, reindeer, red deer, argali, thar, musk-ox	Long-term stays; non-specific hunting
> 350 ka < 690 ka	Unit II	H1, 2,3 I1, 2 J	Clayey silty-sands	Temperate and humid	Red deer, fallow deer Fallow deer, red deer Red deer, fallow deer, argali	Seasonal stays Seasonal stays Seasonal stays
	Unit I	K	Layered sands	Cold and dry with strong winds	Reindeer	Selective hunting halt
		L				Selective hunting halt
		M, N O			Horse, reindeer, bison,	Few lithics
		P			Horse, reindeer, bison, argali, bear, panther	Bivouacs
			Lower Stratigraphic Complex (not yet excavated) ↓ Stalagmitic floor dated by ESR to 690 Ka			

After: Barsky and de Lumley (2010); Barsky et al. (2005); Falguères et al. (2004); Fei (2007); Grégoire et al. (2008); de Lumley et al. (1984, 2000, 2004); Moigne et al. (2005, 2006); Pois (1999); Yokoyama and Nguyen (1981); Yokoyama et al. (1985).

et al., 2006). During the P levels' accumulation, the cave may have served alternately as a bear den or carnivore lair and as a temporary living space for hominins (Quilès et al., 2004).

The levels accumulated within the silty-sandy clays of **Unit II** (OIS 13) have yielded accumulations attributed to seasonal habitats where hominins hunted red and fallow deer in a forested environment (de Lumley et al., 2004; Moigne et al., 2006). Its archaeological levels (J, I, H) are rich in stone industries knapped principally from vein quartz. A small proportion of the lithics were knapped from better quality materials collected some 15 to 30 km away. The artefact levels are separated by archaeologically poor/sterile sediments containing carnivore remains (Pois, 1999).

The occupation levels of **Unit III** were accumulated during a cold, dry phase of OIS 12. These sandy levels have yielded the bulk of the archaeological material; including hominin remains presenting characteristics generally attributed to *Homo heidelbergensis* (de Lumley and de Lumley, 1974; de Lumley, 1976a, 1976b). Situated at the base of this Unit, level G is the richest accumulation in terms of the number of artefacts. The archaeological material is densely accumulated in sparse sands reaching up to 1 m thick. Faunal evidence represents slaughter in all seasons, suggesting year long occupations (Barsky and de Lumley, 2004; de Lumley et al., 2004; Moigne et al., 2006; Rivals et al., 2006, 2009). The degree of palimpsest in the G levels accumulation remains to be determined.

Contrastingly, the level F faunal assemblage indicates a seasonal occupation taking place at the end of spring-beginning of summer (argali, thar, chamois, musk ox, red deer, Mosbach horse, reindeer, Moigne et al., 2006; de Lumley et al., 2004). Level F is less dense in archaeological material than level G but also has a rich faunal and lithic assemblage, including some hominin remains. The intersecting and relatively sterile sedimentary accumulation separating the two major levels, sometimes referred to as "inter-F/G", contains sparse lithics and some carnivore remains.

Continuing upwards towards the top of Unit III, the E levels enclose a series of occupations of lesser density. They contain a lithic assemblage almost entirely knapped from quartz. The fauna, mostly argali, with Mosbach horse and steppe bison, indicates an open landscape and cold climate (Moigne et al., 2006). Coiffing Unit III, the D levels have yielded a lithic assemblage of very small dimensions, mostly knapped from quartz and flint. The fauna suggests a dryer, more temperate climate (cervids, horse, argali; Moigne et al., 2006).

2. Materials and methods

A global profile of each assemblage is provided so that we may more clearly observe morpho-technical variation in the Caune de l'Arago industries, thus contributing to defining the specificity of each occupation. The main criteria discussed include: raw material selection patterns and use, technological features, and typological factors. Some of the archaeostratigraphic levels presenting analogous techno-typological features have been grouped together

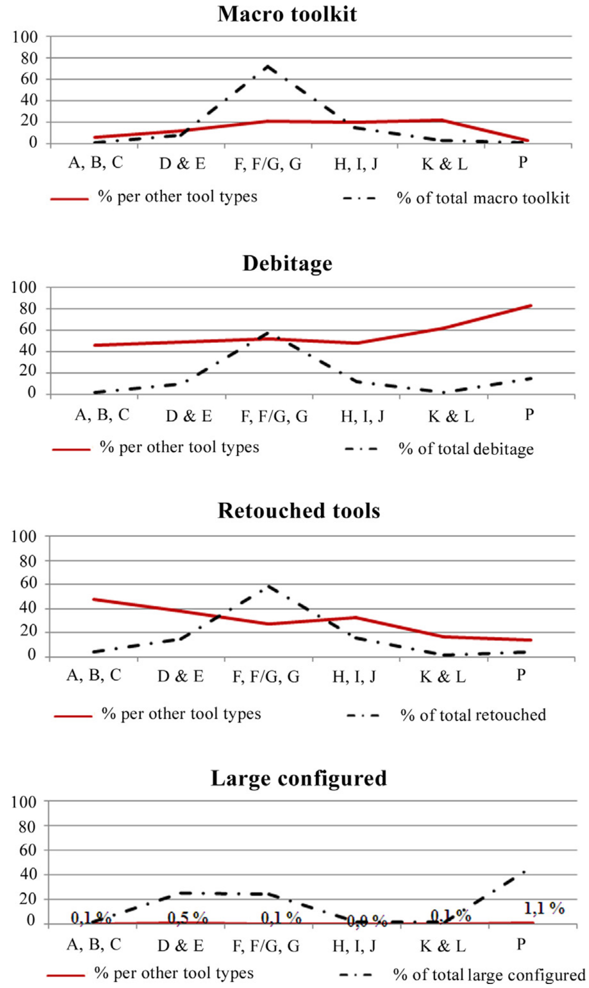

Fig. 2. Tool category frequency within the Caune de l'Arago's stratigraphical sequence: comparative tool category variation and tool category abundance. Fragments are excluded from this graph.

Fig. 2. Fréquence des catégories d'outils dans la séquence stratigraphique de la Caune de l'Arago: variation comparative des catégories d'outils ; abondance des catégories d'outils. Les fragments sont exclus de ce graphique.

After Barsky (2001), de Lumley and Barsky (2004), Barsky and de Lumley (2010).

in order to simplify this comparative study (Table 2). This analysis synthesizes data obtained from nearly 100,000 industries exhumed from 14 stratigraphically distinct occupation levels (Barsky, 2001; Barsky and de Lumley, 2010; de Lumley and Barsky, 2004; Table 2, Fig. 2). Levels were attributed to each stone artefact based on observations recorded in field notes during excavations (Barsky, 2001). Fragments, mostly in quartz, represent more than half of the material considered in this study (> 60,000 pcs) and have yet to be quantified into a global inventory per level. However, they constitute an essential component of the Caune de l'Arago assemblages and their study has largely contributed to our knowledge about core morphology and knapping strategies at this site. Our work on the fragments has also allowed us to monitor the sheer volume of raw materials brought into the cave. For

Table 2
Distribution of different tool categories according to archaeostratigraphical levels. Levels with techno-morphological similarities are grouped together. Fragments are excluded from this table (~60,000 pcs).
Tableau 2
Répartition des différentes catégories d'outils selon les niveaux archéo-stratigraphiques. Les niveaux comportant des similarités techno-morphologiques sont regroupés. Les fragments sont exclus de ce tableau (environ 60 000 pièces).

Tool category	A to C		D & E		F, F/G, G		H, I, J		K & L		P		Total	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Whole and broken pebble	45	4.7	349	7.4	3299	11.6	701	9.1	139	6.8	59	1.1	4592	9.3
Percussor	0	0.0	18	0.4	169	0.6	34	0.4	4	0.2	9	0.2	234	0.5
Pebble-tool	4	0.4	56	1.2	580	2.0	109	1.4	22	1.1	7	0.1	778	1.6
Handaxe (or cleaver)	1	0.1	19	0.4	21	0.1	1	0.0	1	0.0	32	0.6	75	0.2
Core	152	16.0	259	5.5	879	3.1	121	1.6	41	2.0	177	3.3	1629	3.3
Flake	223	23.5	1428	30.2	8884	31.2	1931	24.9	415	20.4	2294	43.3	15,175	30.8
Blade	7	0.7	24	0.5	110	0.4	17	0.2	5	0.2	35	0.7	198	0.4
Small flake	119	12.6	1258	26.6	9392	33.0	3424	44.2	1287	63.2	2260	42.7	17,740	36.1
Retouched tool	397	41.9	1312	27.8	5133	18.0	1402	18.1	122	6.0	420	7.9	8786	17.9
Total	948	100	4723	100	28,467	100	7740	100	2036	100	5293	100	49,207	100

the purpose of this study, each fragment was individually measured and described; recorded features include: raw material, size, corticality and formal morphology. Raw materials were determined for each piece using a referential elaborated during petrographical studies (Grégoire et al., 2006; Wilson, 1988).

Looking beyond the massive quantity of fragments, the overall representation of other types of stone waste (Table 2, Fig. 2) shows that flakes, cores and small retouched tools are well represented in all levels. Most levels contain a macro toolkit with more or less intensively modified/shaped pebbles. All stages of core reduction are represented in each ensemble, attesting to *in situ* knapping, retouched tool shaping and pebble-tool manufacture. Cortical flakes are, however, scarce among all rock types excepting limestone, suggesting that cores were often initiated outside of the cavity while pebble-tools (almost always in limestone) were shaped inside the cave. An increase in core frequency is noted towards the top of the sequence and may be explained by the more extensive use of small sized quartz pebbles in these levels (Table 2). The pebble-tool assemblage is largely dominated by choppers of various morphologies while chopping-tools are very scarce. Retouched tools are most frequent in the upper levels (C, B, A). However, this result may be biased; assemblages from the upper part of the sequence are incomplete because the infill was truncated and eroded after the collapse of the cave's roof (notably levels B and A, de Lumley et al., 1984).

Handaxes (Figs. 3 and 4) and (especially) cleavers are poorly represented overall. They are absent from Unit II (total number of pieces studied from Unit II = 7740, Barsky, 2007), except for a single, poorly standardized piece in hornfel from level J whose morpho-technical characteristics are closer to a core than to an intentionally configured tool (Barsky, 2007). While most of the handaxes were shaped from pebbles, particularly those in hornfel, some of the pieces were configured on flakes (notably in quartzose sandstone). The extensive use of river pebbles may be one explanation for why the production of large flakes intended for the realization of LCT's is not a characteristic of the Caune de l'Arago industries (Sharon, 2009). Some of the handaxes are of very small dimensions. Handaxes show highest frequency in the older, P levels assemblages. Cleavers are extremely rare and poorly standardized throughout the entire sequence (6 pieces: 1 from level P, 3 from level G, 1 from level F and 1 from level E). As in other western European Mode 2 sites of similar chronology (Notarchirico, 0,6 Ma, Italy, Piperno, 1999), handaxes are absent from some levels (Unit II levels and level K in Unit I).

The bulk of our study (Barsky, 2001) focuses on flake morphology, taking into account: extension/localisation of cortical residue on dorsal surfaces, type of striking platform, orientation of removal negatives, average dimensions, and striking angles. Different aspects of the other components of the industry, notably cores and pebble-tools, have been taken into consideration to contextualize our detailed flake analysis. The quantification of the various aspects of the flakes is therefore considered in relation to the rest of the industry and in accordance to the different raw materials used. Archaeometrical comparisons between brute and retouched supports help to define tool support selection criteria. The methodology defined for core classification is outlined below, with special attention given to the technical criteria elaborated during our study.

Fig. 3. Top: D19.DKG2.987. Level G: sandstone-quartzite handaxe with plano-convex profile and reserved cortical base (150 × 74 × 56 cm). Bottom: E15.EGO8B.4659. P levels: finely worked symmetrical quartzite handaxe with edges regularized using soft hammer technique (126 × 74 × 34 cm)

Fig. 3. En haut : D19.DKG2.987. Niveau G : biface de grès quartzique, à profil plan-convexe et à base corticale conservée (150 × 74 × 56 cm). En bas : E15.EGO8B.4659. Niveaux P : biface de quartzite finement travaillé symétriquement, avec des bords régularisés en utilisant la technique du marteau doux (126 × 74 × 34 cm).

Photos: Denis Dainat, EPPC–CERPT Barsky and de Lumley (2010), de Lumley and Barsky (2004).

3. Raw materials

The Caune de l'Arago industries show high petrographical diversity (in order of abundance): vein and translucent

Fig. 4. E16.EHP7.4597. P Levels: quartzite cordiform handaxe with thick base and notched tip (130 × 70 × 45 mm).
Fig. 4. E16. EHP7.4597. Niveaux P : biface de quartzite en forme de cœur, avec une base épaisse et une entaille au sommet (130 × 70 × 45 mm).
Photo: Denis Dainat, EPCC–CERPT Barsky and de Lumley (2010).

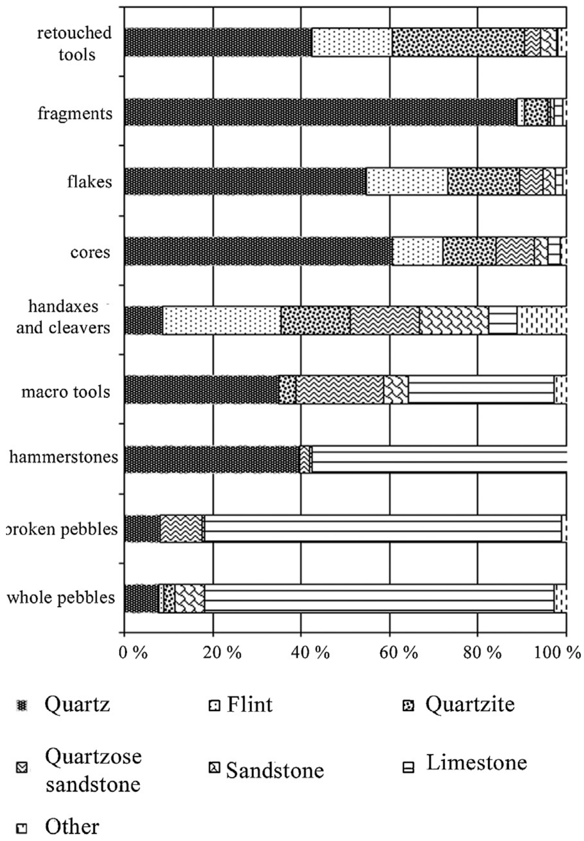

Fig. 5. Global raw material distribution according to tool types at the Caune de l'Arago (after Barsky (2001), Barsky and de Lumley (2010), de Lumley and Barsky (2004)). Note that the when non-modified and retouched flakes and fragments are combined: quartz = 62,1%; flint = 12,6%; quartzite = 17,1%; quartzose sandstone = 3,2%; sandstone = 2,4%; limestone = 1,4%; other = 1,2%.
Fig. 5. Distribution globale des matériaux bruts, selon les types d'outils, à la Caune de l'Arago (selon Barsky, 2001 ; Barsky et de Lumley, 2010 ; de Lumley et Barsky, 2004). À noter que, quand les éclats et fragments sont non modifiés ou retouchés, ils sont combinés : quartz = 62,1 % ; flint = 12,6 % ; quartzite = 17,1 % ; grès quartzeux = 3,2 % ; grès = 2,4 % ; calcaire = 1,4 % ; autre = 1,2 %.
D'après Barsky (2001), Byrne (2004).

quartz, flint (or siliceous sedimentary: including flint, lydian and jasper), quartzite, quartzose sandstone, sandstone, limestone, hornfels, and lava. While most of the rocks were gathered by hominins as river cobbles of various sizes, most siliceous sedimentary rocks (heretofore flint) were collected from outcrops considerable distances away. Poor quality flint was nevertheless accessible from a handful of local or semi-local sources in the form of small pebbles or nodules (Verdouble alluvials and nearby outcrops). Flint more apt for controlled knapping was accessible in the form of large plates or blocks from outcrops at least 30 km away (Grégoire et al., 2006; Wilson, 1988). As a rule, the rocks available close-by were poorly adapted for controlled flake extraction (quartz, sandstone, quartzose sandstone, limestone) while more suitable materials (jasper, flint, quartzite, blue translucent quartz) were accessible further away from the site (15 to 30 km). Although there is little change in the frequency of these different rock types throughout the stratigraphy, detailed analysis of each of the 106 sub-types composing the nine main petrographical groups represented does provide interesting relative frequency results; perhaps reflecting raw material preferences over time (Barsky and Grégoire, 2001). Amongst the local rock types, vein quartz was the preferred raw material in all levels. This may be because it provided more resistant cutting edges compared to other, easily accessible materials (~90% of the level G industry). While in the present day Verdouble river bed vein quartz is relatively scarce, it is found in greater abundance in alluvial terraces believed contemporary to the cave's habitation. Both vein and translucent quartz pebbles were collected in the form of small (fist-sized) to medium sized pebbles (max. L = ~30 cm). Our study shows that each raw material played a specific role in the assemblages (Fig. 5). Interestingly, the raw material/tool type relationship was maintained over time: limestone was invariably preferred for heavy-duty tools and hammerstones, fine-grained siliceous rocks (flint, quartzite) were chosen for more complex and exhaustive knapping sequences (discoid) and for the retouched tools. Handaxes, mostly in hornfel, show the greatest raw material variability.

4. Technology: core and flake type distribution throughout the stratigraphy

Varying raw material quality affected core and flake morphology, dictating technological constraints throughout the different phases of stone reduction. The dominance of vein quartz in particular helps to explain why some

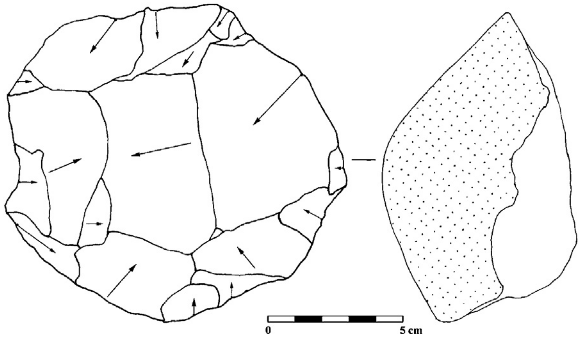

Fig. 6. C16.CHY5.1061. Level G ; unifacial discoidal core in quartzose sandstone with a cortical striking platform, 130 × 118 × 78 mm.
Fig. 6. C16.CHYS.1061. Niveau G ; nucleus discoïdal unifacial avec une plate-forme corticale saillante, 130 × 118 × 78 mm.
After a drawing by J. Krzepkowska, Barsky (2001).

features of the Caune de l'Arago assemblage *appear* unchanged over time. For while it is true that some of the industries' characteristics do remain constant throughout the stratigraphy, there are essential differences that can only be brought to light when each level is considered independently.

The relationship between raw materials and core reduction strategies, for example, always present the following characteristics:

- tested or partially exploited cores tend to be in limestone or sandstone. Scars on these larger sized cores attest to their auxiliary use as percussion tools;
- quartz cores and core fragments (debris) were massively produced by bipolar technique on an anvil, but organized and well-mastered quartz reduction was also achieved by way of direct hammer techniques;
- cores in exotic, fine quality raw materials (notably quartzite and flint) were most intensively knapped. Many are representative of advanced reduction stages (exhausted cores) and display small average dimensions. In some levels (F, G), a few larger flint cores and flakes help to discern operational schemes applied in the initial phases of their exploitation.

4.1. Discoidal and other centripetal recurrent knapping strategies

A wide range of discoidal cores characterize the Caune de l'Arago industries (~20% of all cores, de Lumley and Barsky, 2004). Disk-shaped cores reflect recurrent unifacial (Fig. 6) or bifacial knapping strategies (Fig. 7) but trifacial core management was also commonly used (Fig. 8). Discoidal knapping differs from Levallois core management on volumetric and economic levels (Boëda, 1993, 1994). Although the Caune de l'Arago discoidal cores show a clear evolution towards Levallois-type production with hierarchized surface exploitation appearing as early as the G levels (ca. 450,000 years, Table 1, Fig. 9), no significant evidence for the systematic use of this method has been found in any of the archaeostratigraphical levels – including those situated at the top of the stratigraphy (C, B, A). There is, however, evidence of a more significant Levallois production in the so-called *terres brunes* that coiffe or infiltrate parts of the upper stratigraphical sequence. Brownish red clays post-dating a stalagmitic floor dated to between 120 and 95 Ka also contain some Upper Paleolithic and even Neolithic industries and fauna typical of the beginning of the last glaciation (Moigne et al., 2006).

Flakes from discoidal cores are generally thick and short with ample, inclined butts that may be smooth or facetted, depending on the complexity of discoidal core management. Removal negatives are mostly longitudinal-convergent or centripetal (depending mostly on core size) and *pointes pseudo Levallois* are present in all levels. Similar flake types are documented in Quina-type assemblages and may be produced from a variety of *chaînes opératoires* (Slimak, 1999): Quina (Bourguignon, 1997), Clactonian (Ashton, 1992; Forestier, 1993) or Acheulian (Bordes, 1950). Raw materials chosen for the execution of such recurrent reduction methods vary according to levels, but finer materials were generally preferred. Discoidal cores knapped from fine-grained rocks and from translucent quartz are often small, translating exhaustive knapping episodes. Larger, unifacial discoidal cores were knapped from local materials of relatively poor quality. Rarely, discoidal cores were knapped from large-sized flakes. Towards the top of the sequence (from Unit C) discoidal cores, almost exclusively in quartz, present small average dimensions (all core types = 42,3 mm; Barsky, 2001).

In Unit I, bifacial discoidal cores were knapped using mixed alternate flake extraction and do not have hierarchized surfaces. We situate the technical separation of preparation and extraction surfaces at the base of Unit III (G levels).

Trifacial discoidal knapping (Fig. 8) is ubiquitous throughout the sequence, notably in the P levels. The cores exhibit an equatorial edge interrupted by a perpendicular plane separating the two-secant surfaces. The latter was either conserved from the beginning of knapping sequences (cortical or broken surface), or provoked by an intentional break that occurred at varying stages of the knapping sequence. In both cases the plane surface is situated at about a third of the core's width. Further core reduction was occasionally pursued from this newly created surface by effectuating a series of removals reaching into the core matrix. In this case, knapping was executed using a unidirectional recurrent strategy similar to that described in Quina technology (Bourguignon, 1997). If at this stage a sinuous equatorial edge is not maintained, the discoidal cores may ultimately attain polyhedron morphology (Locht et al., 1995). However, many trifacial cores were simply abandoned following the creation of the perpendicular surface. Some authors suggest that long flakes with a sinuous sagittal crest ("redirecting flakes"; Inizan et al., 1999; McCarthy, 1976) are the result of this kind of "core slicing" or "cross axis truncation" (Crabtree, 1973; Moore and Brumm, 2009) and that such flakes were intentionally produced (Moncel, 1998). But few of the Caune de l'Arago segmented core fragments show any macroscopic use-wear traces that could lend credence to this hypothesis.

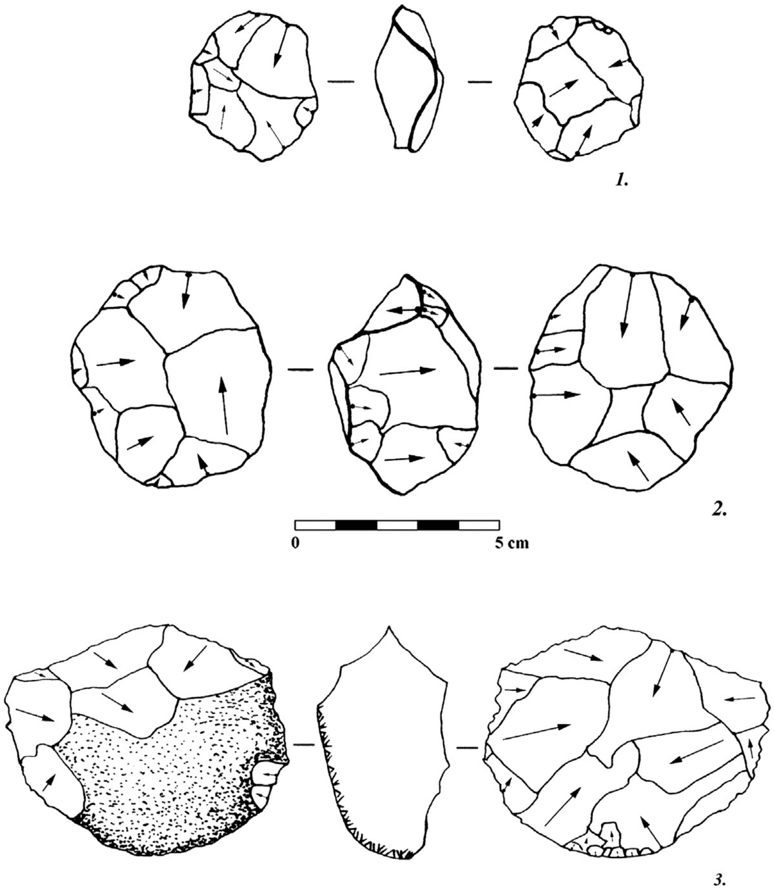

Fig. 7. G24.GPC1.234. Level C: 1: Bifacial discoidal core in quartzite with mixed removals 30 × 28 × 13 mm; 2: E17.EKY6.3101. Level G: Bifacial discoidal core in quartzite with mixed removals and pyramidal base 50 × 35 × 25 mm; 3: C14.CFP1.3415. P levels: Unifacial discoidal core in quartzose sandstone with partially prepared striking platform 70 × 55 × 30 mm.
Fig. 7. G24. GPC1.234. Niveau C : 1 : Nucleus discoïdal bifacial en grès quartzeux, avec des enlèvements mixtes, 30 × 28 × 13 mm ; 2 : E17.EKY6.3101. Niveau G : Nucleus discoïdal bifacial en quartzite, avec enlèvements mixtes et base pyramidale 50 × 35 × 25 mm ; 3 : C14.CFPI.3415. Niveaux P : Nucleus discoïdal unifacial en grès quartzeux, avec une plate-forme saillante partiellement préparée (70 × 55 × 30 mm).
From drawing by J. Krzepkowska, Barsky (2001).

4.2. Pyramidal or cone shaped knapping strategies

Conical cores were knapped using recurrent peripheral technology by removals converging towards a more or less central summital point (Fig. 10). Striking platforms were not generally prepared by removals and a fracture plane or flat cortical surface was preferred. Once the peripheral knapping sequence was completed, a new set of removals was sometimes effectuated in an opposite direction from the dihedral situated at the summital point. Throughout the stratigraphy, pyramidal cores show small average dimensions. This method could reflect an ultimate technical approach aiming at complete raw material depletion. Flakes were small, with unidirectional-convergent or orthogonally oriented removal negatives on their dorsal surfaces. When used to reduce crystalline rocks, this knapping strategy was sometimes performed on an anvil applying a precise, sequential gesture. This method probably caused frequent core breakage, perhaps accounting in part for their overall scarcity (3,8% of the cores), especially in levels H, I and K (~1%) (Barsky, 2001).

4.3. Prismatic knapping strategies

More or less cube-shaped or prismatic cores were commonly knapped from crystalline rocks. Their frequency, although biased by breakage, remains constant throughout the stratigraphy. Most often, cube-shaped pebbles were selected for controlled, peripheral extractions using the bipolar on an anvil technique (core slicing). This method is very effective for quartz reduction and, while the flakes do not necessarily provide evidence for the use of bipolar percussion, the cores do clearly display opposite percussion marks and parallel removal negatives (Barsky and de Lumley, 2010, Fig. 11). Resulting flakes are generally small and often show transversal breakage or Siret type accidents. Their dorsal surfaces have unidirectional, parallel removal negatives and striking angles close to 90°C. Such prismatic cores are referred to as *longitudinal polarized* in

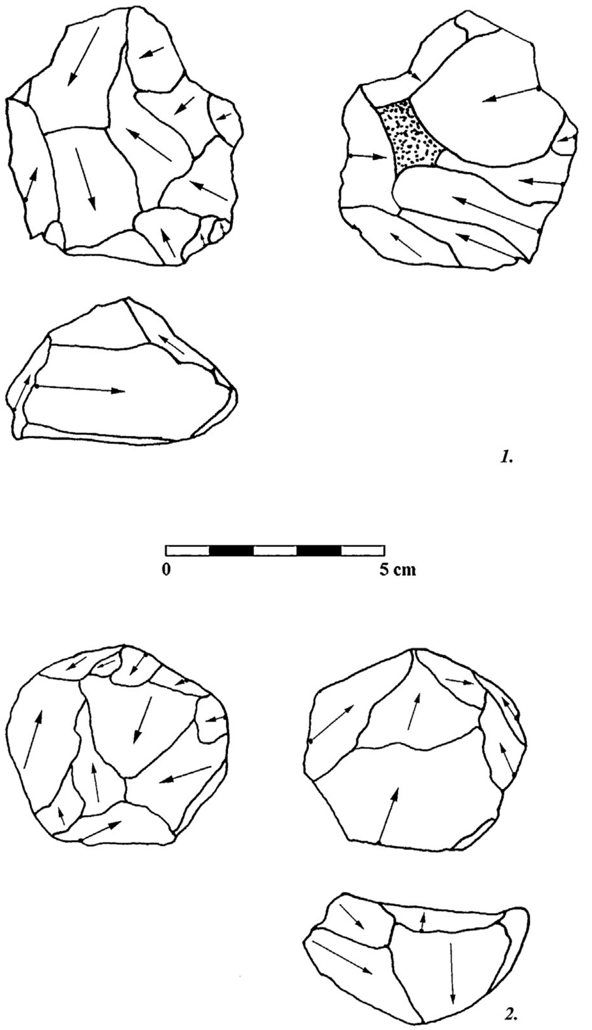

Fig. 8. 1 : H15.HAT6.2284. Level FG; discoidal quartzose sandstone core. Knapping was bifacial alternate, with an intermediary platform on the profile (trifacial knapping). The latter platform served to initiate knapping on the lower face 58 × 48 × 40 mm; 2: F16.FKY5.2999. Level G: discoidal translucent quartz core showing trifacial knapping strategy and a preferential flake negative, 50 × 45 × 25 mm

Fig. 8. 1 : H15.HAT6.2284. Niveau FG; nucleus de grès quartzeux discoïdal. Le façonnement a été bifacial alterné, avec plate-forme intermédiaire sur le profil (façonnement trifacial). Cette plate-forme sert au point de départ du façonnement sur la face inférieure, 58 × 48 × 40 mm ; 2 : F16.FKY5.2999. Niveau G : nucleus de quartz translucide discoïdal montrant une stratégie de façonnement trifacial et un éclat préférentiel négatif, 50 × 45 × 25 mm.

From drawing by J. Krzepkowska, Barsky (2001).

Atapuerca's Galeria assemblage (Carbonell et al., 1995a, 1995b; Ollé et al., 2013). Small prismatic cores are very common in the P levels and also towards the top of Unit III. There are larger specimens in the G levels that were produced by direct hammer method with a recurrent gesture. On these cores, flakes were extracted from striking platforms situated on opposing ends of cube-shaped matrices. Although striking platforms are not facetted, rounded pebbles were occasionally initiated by breakage or by invasive removals, lending them a cube shape.

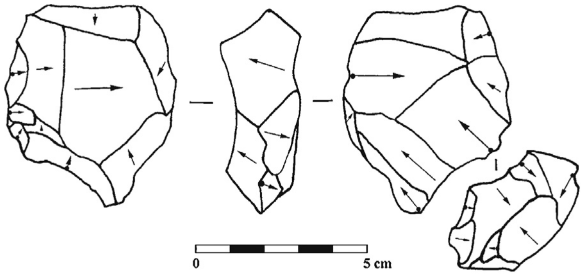

Fig. 9. F15.FG1.469. Level F; discoidal core in quartzose sandstone with two prepared striking platforms comparable to recurrent Levallois conception, 49 × 43 × 21 mm.

Fig. 9. F15.FG1.469. Niveau F : nucleus discoïdal en grès quartzeux, avec deux plates-formes saillantes comparables à la conception Levallois récurrente, 49 × 43 × 21 mm.

From drawing by J. Krzepkowska, Barsky (2001).

4.4. Globular and multiplatform knapping strategies

Spherical or semi-spherical cores are mostly in quartz. They are most common in the upper sector of Unit III; from level F onwards (Fig. 12). Although this core "type" refers to a specific morphology (globular or spherical) it was produced by a variety of technological schemes and morphologies vary from one level to the next. Removal negatives served successively as platforms and cores were regularly rotated, producing polyhedron shaped matrices. The cores were either abandoned when no suitable extraction surfaces remained, or broken on an anvil to produce sharp-edged fragments.

Globular or polyehedron-shaped cores were occasionally knapped from better quality materials such as flint or quartzite (Fig. 12, no. 1). These cores are very small and they reflect the ultimate reduction stage for these rock types that were previously reduced by other strategies. The presence of some large-sized flint flakes reveals that bifacial discoidal knapping was the preferred technology in the initial stages of reduction for this rock type. In levels G and F, fist-sized quartz globular cores were knapped by peripheral removals from flat, cortical platforms. Once exhausted, the cortical platform was abandoned and a final series of flakes was extracted from removal negative platforms oriented perpendicularly to the latter. This volumetric reduction lends an imperfect spherical form to these cores that conserve their flat, cortical base. Along with the discoidal cores, globular cores are tiny towards the top of the sequence (average length of globular cores in levels A, B, C = 35.2 mm).

Globular cores are akin to multiplatform cores in both knapping strategy (use of previous platforms and frequent core rotations) and final morphology (polyhedron shape). In both cases knappers constantly adapted their technique to advantages offered by each new removal negative, appropriate angles and progressively changing bloc morphology. Striking platforms were sometimes facetted to facilitate flaking. Since each removal determines the next, there is no formal shaping. Resulting flakes would therefore present a range of shapes and sizes.

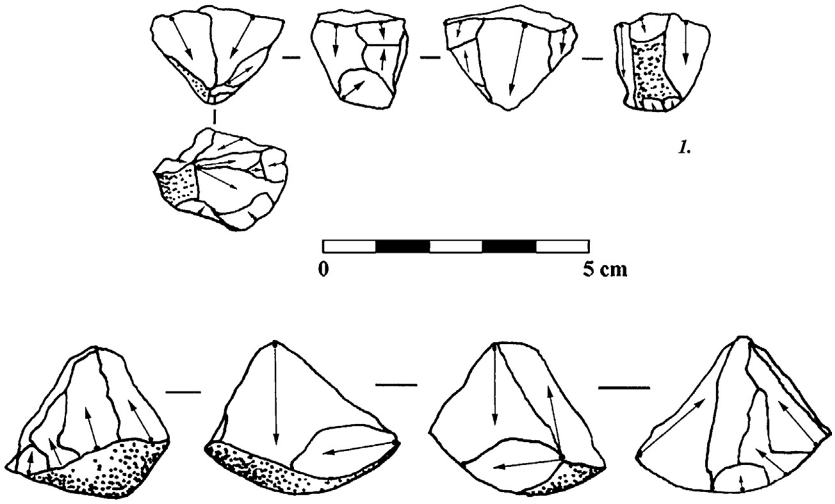

Fig. 10. 1: H15.HAT8.2707. Level inter F/G; pyramidal core in quartzite knapped using bipolar technique on an anvil 25 × 21 × 21 mm; 2: F15.FKY10.3676. Level G; pyramidal core in quartzite with a cortical striking platform, knapped using bipolar technique on an anvil, 35 × 27 × 24 mm
Fig. 10. 1 : H15.HAT8.2707. Niveau inter F/G : nucleus pyramidal en quartzite, façonné en utilisant la technique bipolaire sur une enclume, 25 × 21 × 21 mm ; 2 : F15.FKY10.3676. Niveau G : nucleus pyramidal en quartzite, avec une plate-forme corticale saillante façonnée en utilisant une technique bipolaire sur une enclume, 35 × 27 × 24 mm.
After drawings by J. Krzepkowska, Barsky (2001).

4.5. Orthogonal knapping strategies

Orthogonally knapped cores (Fig. 13) are common in levels with large-sized knapped products (J, H, G). They are defined by an initializing phase of surface preparation (generally an invasive removal negative) for a perpendicular series of flakes extracted from core profiles. Throughout the stratigraphy, the orthogonal knapping strategy was preferred for reducing large, cubic or rectangular pebbles in local raw materials (notably quartzose sandstone). Orthogonally knapped cores are amongst the largest since they were most often abandoned before raw material depletion. Resulting flakes are short with generous, open-angled, non-facetted platforms.

4.6. Uni- and bidirectional knapping strategies

Like orthogonal cores, these summarily knapped pebbles with uni- or bidirectional removals on one or more surfaces are frequent in levels with large-sized industries and where the use of poor quality materials from local sources was widespread (J, H, G). In some cases, pebbles were fractured in order to expose fracture planes to use as platforms. Short series of flakes were extracted by way of a recurrent gesture (*longitudinal unipolar massive recurrent*, Carbonell et al., 1995a, b). Core negatives translate short flakes with generous platforms and unidirectional negatives on dorsal surfaces. Some flakes have cortical distal planes. Formal technical variability occurred when knapping strategies

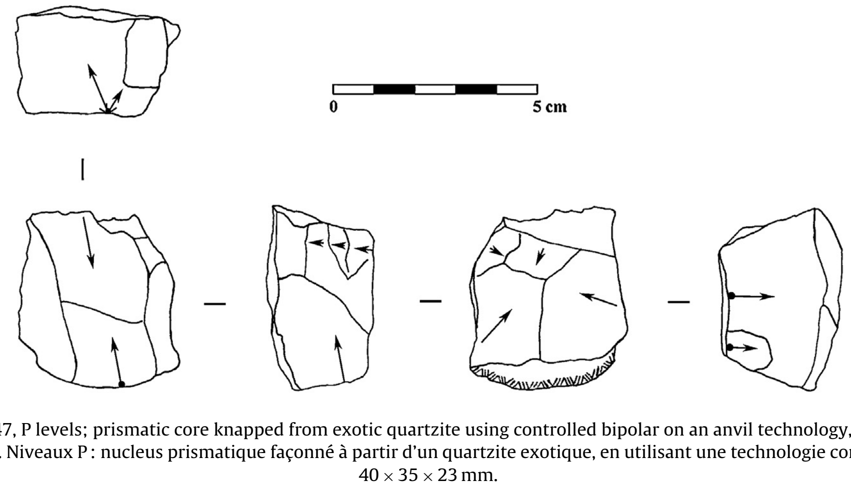

Fig. 11. I10.IBP8. No. 447, P levels; prismatic core knapped from exotic quartzite using controlled bipolar on an anvil technology, 40 × 35 × 23 mm.
Fig. 11. 110.IBP, n° 447. Niveaux P : nucleus prismatique façonné à partir d'un quartzite exotique, en utilisant une technologie contrôlée sur une enclume, 40 × 35 × 23 mm.
After drawings by Daniel Perez, Barsky and de Lumley (2010).

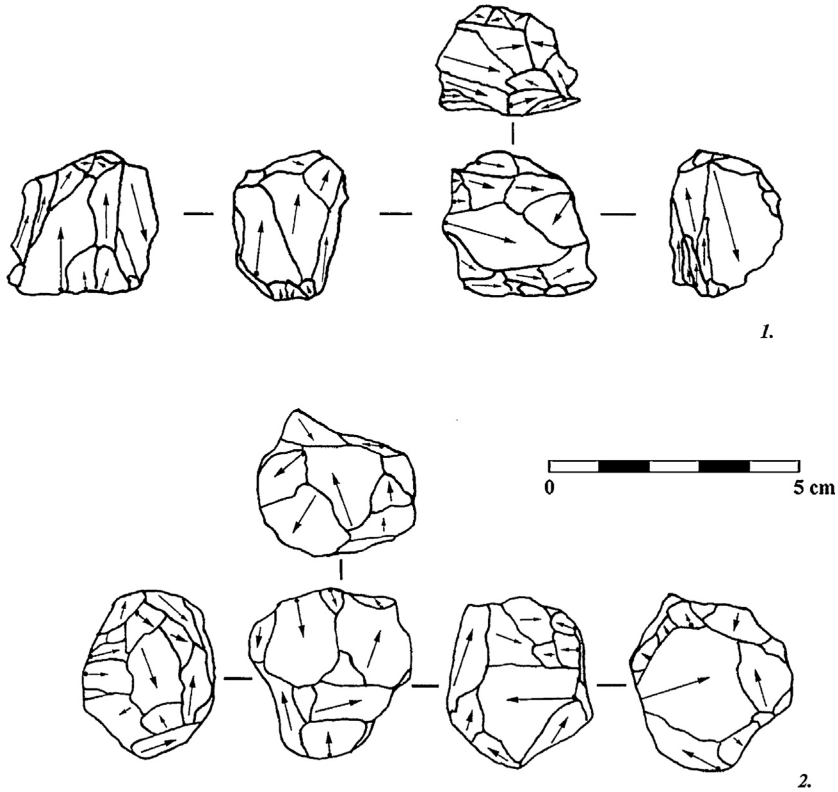

Fig. 12. 1: H15.HAY14.6862. Level G; multiplatform flint core 27 × 27 × 26 mm ; 2: K20.KLC3.1242. Level C; globular core in translucent quartz 35 × 30 × 25 mm.

Fig. 12. 1 : H15.HAY14.6862. Niveau G : nucleus de flint multi plate-forme 27 × 27 × 26 mm ; 2 : K20.KLC3.1242. Niveau C : nucleus globulaire en quartz translucide 35 × 30 × 25 mm.

After a drawing by J. Krzepkowska, Barsky (2001).

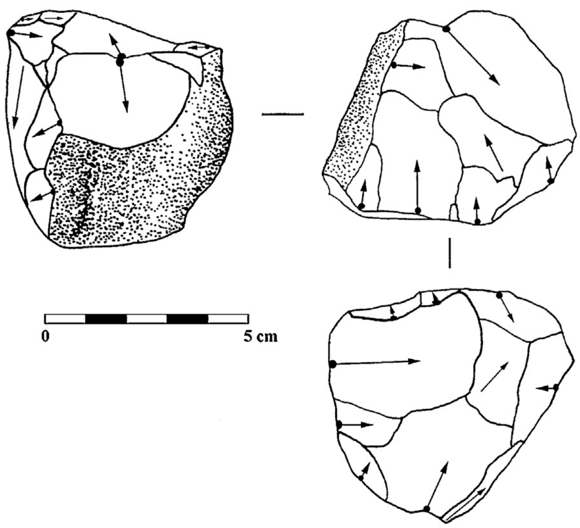

Fig. 13. I18.IST6.2063. Level FG; vein quartz core showing orthogonal removals from cortical and prepared striking platforms 63 × 58 × 58 mm.

Fig. 13. I18.IST6.2063. Niveau FG : nucleus dans une veine de quartz montrant des enlèvements orthogonaux à partir de plates-formes corticales saillantes préparées 63 × 58 × 58 mm.

After a drawing by J. Krzepkowska, Barsky (2001).

were prolonged, leading to the production of various core types (unifacial discoidal, prismatic). Some pebbles in materials poorly suited for controlled knapping (quartz) show bidirectional removals (on a single core surface) with two, independent extraction platforms and a few, parallel removals. These cores are most common in level L but their frequency varies little throughout the stratigraphy. Flakes from bidirectional cores have plain or cortical butts and unidirectional or orthogonally oriented removal negatives.

4.7. Comments on the reduction sequences

We have seen that, with the exception of the limestone, lithic reduction sequences appear quasi-complete with the only low representation category being the cortical flakes (Barsky, 2001). This suggests that most cores were pre-formed outside of the cave while pebble-tools were shaped on-site. Flakes belonging to different size categories translate flaking intensity but they also reveal the occurrence of all stages of reduction in the industry. We underline that the presence and morphology of the thousands of fragments (mostly quartz) found in the different archaeostratigraphical levels are other important features essential to gain full understanding the Caune de l'Arago reduction sequences. The small initial pebble size for both translucent and vein quartz types – usually not bigger than fist-size, is translated by these fragments, which often conserve large areas of residual cortex. The morpho-metrical features of these convex cortical zones are revelatory both of the initial pebble size and its shape. Many fragments bear traces of percussion – often bipolar on an anvil – an appropriate method for reducing small quartz pebbles. Other quartz fragments include: split pebbles and *quartier d'orange*. Also, a high fracture index among quartz cores – and flakes in general (nearly a third of the flakes are broken, Barsky, 2001) – translates the overall poor quality of the raw materials knapped in the cave.

In the case of the flint, the full chain of reduction sequences is more difficult to assess since this rock type was generally very intensively reduced. We have seen that large blocks of quality flint were available at sources located some 30 km away, but we actually know relatively little about the ways that it might have been transported and introduced into the cave. In fact, there are only a few large flakes and, as we have mentioned, their morphology suggests preferential use of centripetal reduction for initiating knapping phases. In all levels, as reduction advanced, the smaller size of the matrixes required more numerous platform changes and small cores with polyhedral or globular shapes resulted. It is presently unclear what the tiny flakes that were produced from these cores could have been used for.

In fact, there are a large number of small flakes in different raw materials (< 2 cm) in all of the archaeostratigraphical units. While some were certainly intentionally produced, others could result from small tool manufacture, final stages of handaxe shaping or even core angle adjustment during the different reduction schemes outlined above. Raw material proportions generally reflect retouched tool frequency and thus represent a final stage of reduction. In any case, all of the tool manufacture activities mentioned above apparently took place inside the cave.

Limestone and sandstone flakes, cores and macro tools reflect a preference for unidirectional sequences and high proportions of cortical flakes in this rock type confirm low intensity knapping and shaping taking place inside the cavity (except P levels); especially in level G. Flakes and their matrixes are even sometimes found in the same square metre (level G).

In the P levels assemblages, a few flakes present morphologies typical of handaxe fabrication (flint, quartzose sandstone). The presence of a large number of broken handaxe tips in these same levels suggests that these tools were both made and used in the cave (Barsky and de Lumley, 2010).

5. Artefact level descriptions

The wide technological diversity and long stratigraphical sequence at the Caune de l'Arago presents the opportunity to effectuate significant intrasite comparisons. We examine subtle variations in raw materials, technology and typology from one level to the next in order to appreciate each ensemble within the larger framework of Mode 2 in southern Europe.

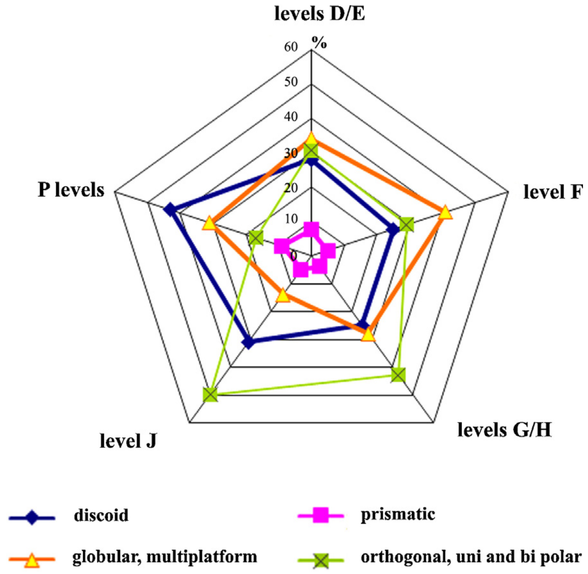

Fig. 14. Caune de l'Arago core type distribution grouping artefact levels with technological affinities.

Fig. 14. Distribution des types de nucleus de la Caune de l'Arago, regroupant les niveaux d'artefacts à affinités technologiques.

Modified after de Lumley and Barsky (2004).

5.1. Stratigraphical Unit I (levels P to K)

The lithic assemblages from Unit I show highly structured manufacture (Barsky, 2001; Barsky and de Lumley, 2005, 2010; de Lumley and Barsky, 2004). This is especially true of the P levels industries whose knapping episodes were long and elaborate. Furthermore, in P levels some of the handaxes and small retouched tools were shaped using a soft percussion instrument. Throughout the Unit local raw materials dominate, but the presence of finer quality, exotic raw materials from distant sources underlines group mobility. Handaxes and finely retouched pointed tools (including *pièces bifaciales*) show a high level of standardization (repeated morpho-types) and well-mastered production techniques (mainly bifacial discoidal, Fig. 14). It is interesting to note that handaxes are relatively numerous and finely manufactured in the lower (P) levels, with entirely peripheral cutting edges and a developed symmetry, compared to those found further up in the stratigraphy (Unit III) that are partially worked with poorly developed bi-lateral and bifacial symmetry.

The P levels' retouched toolkit includes numerous notched tools and points (Bill Hook tools; Tayac and Quinson points, Barsky and de Lumley, 2010). Some of the tools display tiny, intentionally shaped points, such as borers and awls. The P level industries are also characterized by pointed flakes, intentionally produced from discoidal cores (Fig. 14). The abundance of large and small pointed tools and flakes may point towards task-specific activities that could, in future, be better understood through a detailed traceological study. The specificity of the P levels' retouched toolkit is further underlined when it is compared to other Unit I levels (L and K) and elsewhere in the stratigraphy, where side scrapers are invariably most representative (Byrne, 2004) and flakes are mostly short and trapezoidal (Barsky, 2001).

Another significant trait of the P level industries is the paucity of whole, broken or worked limestone pebbles-significant elements in all the other occupation levels of the Caune de l'Arago. Such a paucity in the heavy-duty toolkit that so typifies the rest of the Caune de l'Arago industries may underline a significant behavioural feature underlining the uniqueness of the P level stone-tool assemblages.

Looking at stone knapping strategies in the P levels, alternate surface bifacial discoidal knapping is dominant. Cores are small, resulting from simple, but exhaustive core reduction. Controlled use of the bipolar knapping method on an anvil is characteristic of the P levels, whereas quartz "crushing" is more common in levels L and K. Also, the finer quality translucent quartz is more frequently used for flake production in the P levels, while vein quartz dominates more clearly in all other levels. On the whole, the L and K assemblages differ from the P levels in that they: contain fewer retouched tools, no (or few – there is one in level L) handaxes, relatively frequent whole and worked pebbles and cores with non-exhaustive knapping sequences. Also, the blade index is nil and flakes do not show dihedral or facetted platforms. Similarities observed between the L and K assemblages go beyond the lithic assemblages since hunting practices and climatic conditions also appear to be analogous (Table 1).

The industries from Unit I are a model for defining some characteristics which were to develop just after the appearance of Mode 2 in western Europe (~0,7–0,6 Ma, Barsky and de Lumley, 2010; Despriée et al., 2009, 2010) such as: an enlarged raw material collection area, symmetrical, finely worked handaxes, scarcity of worked pebbles in relation to flake industries, scrapers show higher proportions than notched tools, a high incidence of notched and pointed tools fashioned by different kinds of retouch, few multiple tools, dominant alternate surface bifacial discoidal knapping accompanied by Clactonian-type technology (production of large, short flakes with ample, inclined platforms) and few cores with prepared platforms.

5.2. Stratigraphical Unit II (levels J to H)

The Unit II assemblages are characterized by selective use of quality materials, no handaxes (possible exception of one, irregular core-like piece in hornfel from level J, Barsky, 2007), numerous retouched tools, stones, whole pebbles, broken pebbles, pebble-tools and relatively few cores. As observed elsewhere in the stratigraphy, the largest flaked products were reserved for retouched tools, comprising mostly single lateral, double or converging-edge scrapers (Barsky, 2001; Byrne, 2004, Fig. 15). Cores, mostly in quartz, are scarce relative to flakes. Bifacial discoid cores show alternate surface strategy. Knappers preferentially used cortical platforms, especially when reducing crystalline rocks such as quartzite. Centripetal flaking methods were preferred for knapping finer quality raw materials. Small vein quartz pebbles were crushed on an anvil to produce fragments. Larger flakes were produced in other materials (sandstone) from ample, cortical or non-prepared platforms using recurrent, parallel removals. Overall, flakes are

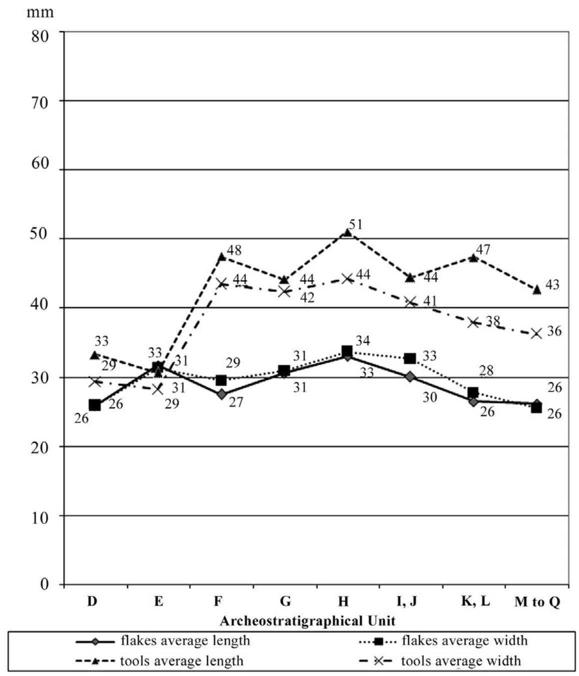

Fig. 15. Average length and width (in mm) of flakes and tools according to the different archaeostratigraphical levels of the Caune de l'Arago (Barsky, 2001; Byrne, 2004).

Fig. 15. Longueur et largeur moyennes (en mm) d'éclats et d'outils selon les différents niveaux archéo-stratigraphiques de la Caune de l'Arago (Barsky, 2001 ; Byrne, 2004).

short with cortical or smooth butts, and, reflecting recurrent knapping methods, most often display unidirectional removal negatives.

The level H industries are amongst the largest of the ensemble (all levels), with many macro tools: whole and broken pebbles with traces of percussion and pebble-tools (choppers of varying morphology). They contain few retouched tools. Quartz crushing on an anvil was massive compared to Unit I and the base of Unit II. Clactonian-type unidirectional recurrent knapping technology was more commonly used than discoidal. Flake dorsal surfaces most often display unidirectional negatives and have wide, smooth or cortical striking platforms. The fact that simple technologies were used for flake extraction is underlined by the low *facettage* index. Cortical flakes are scarce (except limestone), suggesting that the initial stages of reduction were carried out away from the cave, while pebble-tools were shaped inside the cave.

Notable changes from Unit I include: absence of handaxes, more retouched tools, high scraper versus notched tool index and retouched tool-type diversification.

5.3. Stratigraphical Unit III (levels G to D)

Throughout Unit III, the bulk of the stone industry was knapped from poor quality, local raw materials, especially vein quartz (the frequency of vein quartz increases from the base to the top of this Unit). Flint also increases progressively in the stratigraphy, to the detriment of other rock types. Although it is difficult to ascertain changes in raw material procurement and use patterns between levels, we have noted that jasper is a characteristic feature in level F and that this rock type is very scarce in the G levels (Grégoire et al., 2006). Jasper pebbles were accessible in river alluvials situated at least 15 km to the southwest of the site. Their absence in the G levels may indicate that hominins were unaware of these alluvials at different periods or that they did not cross through this zone before coming to the cave. Other, relatively poor quality siliceous sedimentary rocks are quite common in level F (lydian, local flint types).

An overwhelming abundance of quartz fragments distinguishes the Unit III lithic assemblages. They were intensively produced from small quartz pebbles by bipolar flaking on an anvil. Cores knapped by direct hammer technique show a significant increase in globular types from level F. Discoidal cores are asymmetrical and display hierarchical removals from the base of the Unit: extraction surfaces are slightly convex, allowing for the production of thin flakes, while preparation surfaces are ample and cone or cube-shaped. This technology shows affinities to Levallois predetermination (especially from level F) however, these cores remain discoidal in their conception and, lacking standardization, do not fulfil Levallois criteria outlined by (Boëda, 1993, 1994). More specifically, they lack systematics in their volumetric conception and are poorly analogous in their platform preparation to fully achieved Levallois-type cores. Especially, predeterminate flakes are extracted using a secant, rather than a parallel angle to the intersecting plane of the cores.

Finally, Unit III is characterized by its large-sized, Clactonian-type cores, displaying uni-, bidirectional or orthogonal removals. Such cores are especially typical of the level G assemblage but tend to grow scarce towards the top of the stratigraphy, where the average flake size is also reduced (Figs. 1 and 16).

The level G industries show the largest average dimensions and there is a general tendency towards size reduction further up in Unit III. There also tends to be a decrease in the frequency of whole and broken pebbles, hammerstones and pebble-tools from level G upwards into level D (de Lumley and Barsky, 2004). The retouched toolkit maintains typological continuity throughout Unit III, with a high retouch index amongst flint and quartzite supports. Although side scrapers dominate, notched tools, end-scrapers and multiple tools are more numerous in Unit III than in Units I and II (Byrne, 2004). We conclude that typological diversity is expressed at the base of Unit III not through the invention of new tool types, but rather by experimenting with new tool combinations on a single support. There are a few cleavers present in some levels (one in each of levels E & F and 3 in level G) but they are poorly standardized and do not constitute a significant element of the industries. Handaxes show a high petrographical diversity but are most often in hornfel. Unit III handaxes are irregular, partial and asymmetrical. Generally on pebbles, they were worked using hard hammer technique only.

Flakes are almost always short but, although the blade index is very low, it does show a minor increase towards the top of the Unit. The flake-core index is also low, especially for quartzose sandstone and limestone, reflecting the

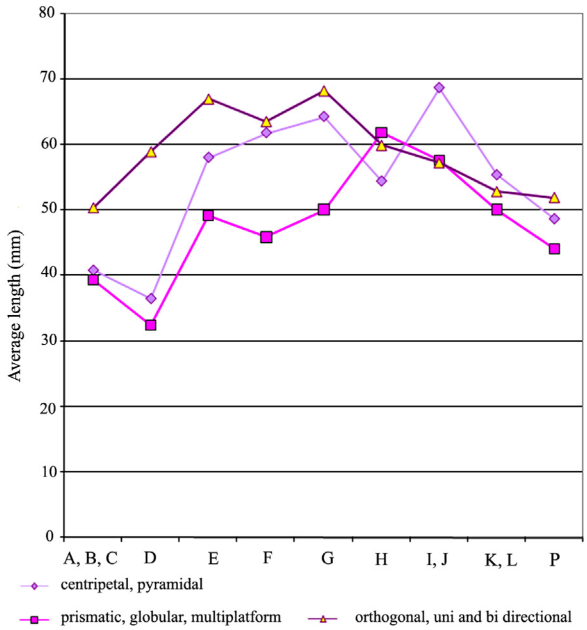

Fig. 16. Average length (in mm) of cores according to reduction strategies and archaeostratigraphical levels of the Caune de l'Arago.

Fig. 16. Longueur moyenne (en mm) des nucléi selon les stratégies de réduction et les niveaux archéo-stratigraphiques de la Caune de l'Arago.

non-exhaustive knapping sequences applied to these rocks. From level F onwards, technical execution and tool manufacture tend to be more complex (more platform preparation, longer operational schemes). The level E assemblages strongly resemble industries from levels G and F with, however, a marked increase in the tendencies observed throughout Unit III, such as: a decrease in the frequency of whole, broken and worked pebbles; smaller dimensions; more non-cortical flakes with an increased (but still low) *facettage* ratio; more removal negatives and knapping directions. In level D, these characteristics are followed through and become even more clearly marked. With the exception of a few pieces, there is only sparse evidence of the use of Levallois knapping methods. Finally, level D appears to represent a breach with the technological traditions practised throughout Unit III because of the reduced size of the industries (Figs. 15 and 16) and the abundance of tiny, globular and multiplatform cores (quartz, quartzite).

6. Discussion

While some factors remain unchanged throughout the Caune de l'Arago's thick stratigraphical sequence, others do change according to the different occupation levels. We do not advocate the idea of a progressive evolution in the stratigraphy, since this hypothesis must be tempered by considerations regarding external impact factors such as climate change, hunting practices and raw material preferences. Characteristics that remain unchanged throughout the stratigraphy include the following ones:

- raw material sources and the relationship between rock and tool types;

- the largest supports were systematically chosen for the shaping of retouched tools. This may be explained by the overall scraper dominance in the toolkits and by a preference for long retouched cutting edges;
- the initial knapping stages for most rock types occurred outside of the cave, regardless of the distance from which the raw material was collected. Exception is made for limestone, a material reserved for pebble-tool manufacture which does appear to have taken place inside the cave;
- vein quartz was the preferred raw material among all technological and typological groups, in spite of the availability of other kinds of rocks nearby. The only exceptions are pebble-tools, made mostly from limestone, and handaxes, made mostly from hornfel;
- more complex and longer knapping sequences (globular, multiplatform or discoidal core types) were executed on best quality raw materials (flint, quartzite, translucent quartz).

Amongst the factors that do show some variation within the sequence, we note the following ones:

- an overall decrease in product size throughout Unit III with an almost microlithic industry in levels D through A. Assemblages at the base of the sequence (P levels) also show small average dimensions;
- excepting P levels, removal negatives on flake dorsal surfaces are more numerous as we approach the top of Unit III and they tend show multiple orientations (crossed, centripetal);
- platform preparation as reflected by dihedral or facetted butts is more frequent towards the top of Unit III (and in P levels);
- non-cortical flakes translating more intensive knapping sequences are more frequent towards the top of the stratigraphy (and in P levels);
- there is a decrease in the frequency of whole and broken pebbles and pebble-tools over time (except P levels);
- there is a progressive increase in the blade index over time;
- handaxes show finer craftsmanship in the lower (P) levels than higher up in the stratigraphy.

Handaxes are symmetrical and finely worked in the P levels, they are absent from Unit II and then become an irregular occurrence in the rest of the sequence. Pointed and converging-edge choppers appear at the base of Unit III. While retouched tools show little variability (Byrne, 2004), the *associations* between different tool types and overall tool morphology, rather than the tool types themselves, may help to distinguish transformative characteristics: scraper versus notched tool proportions, frequency of multiple tools or converging-edge shaped tools, presence and morphology of handaxes, toolkit diversity, tool standardization and quality of retouch, are all characteristics which show diachronic developments over time. Concerning flake production, discoidal flaking was performed using alternate surface technology in Unit I while discoidal core surfaces become asymmetrical from Unit III onwards with separate preparation (cone shaped) and extraction (slightly convex) surfaces. From level G, quartz shattering (versus controlled bipolar on an anvil in P levels) is the most common knapping method used and voluntary, massive production of fragments is manifest. Clactonian-type knapping methods, rare in P levels, dominate in level G, and are less common towards the top of Unit III. Globular cores, rare in Units I and II, are typical in level F and progressively more common towards the top of the sequence.

Levels defined as **short-term stays** (Table 1) have sparse accumulations of lithics, species-specific hunting and a relative frequency of carnivore remains. The industries share the following characteristics: initial stone reduction stages were executed off-site while products were finished inside the cave. Fine quality rocks are more common, even if they originate from sources further away from the cave. Knapping strategies are complex (multiplatform or discoidal), probably aimed at obtaining maximal exploitation.

In levels interpreted as **seasonal stays** (Table 1) where a single species was preferentially hunted, rocks were mostly collected from the immediate vicinity of the cave, although there are some imports from far away sources. There are numerous retouched tools, often shaped from fine quality rocks. The industries include heavy-duty tools, with whole and broken pebbles used as hammerstones. In spite of scraper dominance, retouched tools show fine workmanship and diversity. Knapping was carried out by multidirectional (exhaustive) methods, mainly discoidal, most often applied to finer rocks and Clactonian methods for knapping rocks poorly adapted for controlled flake extraction. Quartz was largely exploited by the bipolar on an anvil technique, but was also used for other, direct hammer core reduction methods.

In the G level, the faunal assemblage seems to translate **longer-term stays** since faunal remains cover different seasons of the year. Many different kinds of animals were hunted and the artefact accumulation is very dense (Barsky et al., 2005; Grégoire et al., 2008; de Lumley et al., 2004; de Lumley and Barsky, 2004). Looking at the industries, raw materials are mostly local but some rocks were brought from distant sources. These, finer quality rocks were economically used (exhaustive knapping) and even small flint nodules and quartzite fragments were crushed on anvils to maximize their reduction. The industries comprise numerous non-modified elements such as: stones, anvils, whole and broken pebbles and numerous pebble-tools. Retouched tools are abundant and highly diversified, often with several tools on a single support (multiple tools). The overall aspect of the toolkit shows high diversity; there are finely worked tools as well as expedient or poorly finished ones. Knapping techniques were also very diverse, in spite of prolific quartz crushing. Poor quality materials were reduced by Clactonian rather than multiplatform methods and sequences were non-exhaustive. This partially explains the large average size index for these industries. The lithic assemblages seem to reflect that a larger array of activities was performed at the site. This hypothesis has recently been further supported by a study showing variable dental wear patterns on game animal teeth (Rivals et al., 2009).

We conclude that, at the Caune de l'Arago, a more "specialized" lithic assemblage is characteristic of shorter-term stays with species-specific hunting and that, inversely, a more diversified toolkit corresponds to longer-term stays with a wider array of hunting practices.

7. Conclusions

In spite of the importance attributed to the appearance of handaxes and cleavers, these tools cannot constitute the sole indicators of a single cultural complex. Although they are emblematic of Mode 2, handaxes and cleavers exist in stone-tool assemblages in different regions of the world from about 1.7 to 1.5 my (Africa, India) up to the end of the Middle Palaeolithic, and cannot therefore serve as viable chrono-cultural markers. Outside Africa, the lower chronological limit for the appearance of Mode 2 varies from 1.6–1.4 my in the Near East (Ubeidiya, Bar-Yosef and Goren-Inbar, 1993; Bar-Yosef and Belmaker, 2011; Martínez-Navarro et al., 2012; Tchernov, 1992) to around 900,000 years in China (Lanxian, in Shaanxi Province and Yunxian, in Hubei Province; de Lumley and Tianyuan, 2008) and in South China's Bose Basin (Yamei et al., 2000). At the Caune de l'Arago, the P levels are a rare example of how innovative Mode 2 techno-typological features and associated behaviours took root in western Europe around 0,7–0.6 my (P levels of the Caune de l'Arago, Barsky and de Lumley, 2005, 2010; Middle Loire River Basin, Despriée et al., 2009; Notarchirico, Venosa; Piperno, 1999). Globally, the production of Mode 2 industries marks a new phase in human development and signals the appearance of a greater abundance of sites (after ~500,000 years, Dennell, 2003). Work is still needed to understand whether the appearance of Mode 2 assemblages in different parts of the globe reflects a learned or imported phenomenon (Sharon, 2009).

Presently, archaeological evidence in western Europe dating to between 0.7 and 0.5 my is scarce and indicates that the appearance of Mode 2 technology occurred there around this time (Barsky and de Lumley, 2010; Despriée et al., 2009, 2010; Piperno, 1999). Some sites dating to within this timeframe lack handaxes and cleavers or show only alternate presence of these tool types: Isernia La Pineta, Caune de l'Arago, Vértesszölös, Bilzingsleben (Barsky and de Lumley, 2005, 2010; Coltorti et al., 2005; Mania, 1990; Peretto, 1994; Svoboda, 1987). At the same time, these sites present a range of other characteristics linking them to Mode 2, such as: enlarged raw material diversity and greater acquisition territory, diversification and standardisation of small and large retouched toolkits, use of discoidal and/or hierarchical flaking technology. In spite of the chronological and geographical gap separating Western Europe from the oldest Mode 2 in other areas of the globe: *ca*. 1.7 my in Africa, *ca*. 1.5 my in India, *ca*. 1.6 my in the Levant and *ca*. 1 my in North Africa (Bar-Yosef and Goren-Inbar, 1993; Beyene et al., 2013; Lepre et al., 2011; Pappu et al., 2011; Raynal et al., 2001), some or all of the techno-typological changes defining this techno-complex could have occurred in Western Europe within the context of demographical continuity, since the presence of hominins from at least 1.4–0.8 My is now well attested at a growing number of sites – in Spain (Orce, Atapuerca, Vallparadís), France (Le Vallonnet, Pont-de-Lavaud) and Italy (Pirro Nord, Ca' Belvedere di Montepoggiolo) and others (Berger et al., 2008; Bermúdez de Castro et al., 2010, 2011; Carbonell et al., 1995a, b, 2001, 2005, 2008; de Lumley et al., 1988; Despriée et al., 2006; Duval et al., 2011a, b, 2012; Falguères et al., 1999, 2001; Garcia et al., 2011, 2012; Ollé et al., 2013; Parés et al., 2006; Rodríguez et al., 2011; Rosas et al., 2001; Toro-Moyano et al., 2013).

A important feature shared by a number of early Mode 2 African and South Asian sites is the practice of large flake production for LCT's (Leakey, 1971; Pappu et al., 2011; Raynal et al., 2001). LCT's are also documented at some sites in the Levant, with chronologies varying between 1.6–1.4 and 0.78 my (Bar-Yosef and Goren-Inbar, 1993; Goren-Inbar, 1998; Goren-Inbar et al., 2000; Martínez-Navarro et al., 2012; Verosub et al., 1998), while others represent quite different knapping technologies (Bizat Ruhama, 1.2 Ma, Levant, Ronen et al., 1998; Zaidner et al., 2010). Yet this feature is not shared by most western European Mode 2 sites; except in the Iberian Peninsula where it appears relatively late and where some knapping methods and morpho-types resemble those from some older North African sites (OIS 9, Sharon, 2011). This might point towards cultural transmission or replacement by North African populations moving into western Europe; perhaps via the Straits of Gibraltar. Although the origins for western European Mode 2 remain uncertain (local or regional evolution, cultural transmission or renewed colonization), demographic growth is clearly perceptible in the archaeological record after around 0.5 my, underlining the adaptive advantages of new techno-functional behaviours and justifying their widespread implementation. Presently, the debate about whether convergence or cultural diffusion (or both) were agents for technical transmission remains open.

Several Middle Pleistocene assemblages in Italy appear analogous to the Caune de l'Arago Unit II industries, such as those from Monte Conerno, Layer L (Bartolomei et al., 1966; Peretto and Scarpanti, 1984), whose typological composition is similar: Levallois is absent and most cores are discoidal or polyhedral (Palma Di Cesnola, 1996). At Castro de' Volsci (Biddittu, 1974, 1984; Segre et al., 1984), industries present similar characteristics but also include symmetrical handaxes. The Isernia la Pineta assemblage (Crovetto et al., 1994; Peretto, 1994; Rufo et al., 2009) contributes to defining Mode 2 diversity since it is devoid of handaxes: its unique morphology is partially attributed to petrographical features (tabular flint and limestone).

In France, the industries from the Middle Loire Basin (Despriée et al., 2006, 2009), the lower levels (H, I and K) of Aldène Cave (Cesseras, Hérault; Barral and Simone, 1976), la Baume Bonne (Quinson, de Lumley, 1969, 1976a, 1976b) and Orgnac 3 (Combier, 1967; Moncel, 1999) show similarities in their structural development to the Caune de l'Arago Unit III assemblages, with some elements showing a progression towards Mode 3 alongside the presence of residual types (handaxes, choppers, Tayac and Quinson points).

In Spain, The Atapuerca Middle Pleistocene sites of Galería and Gran Dolina show a similar evolutionary trend in sites ranging from around 500,000–300,000 years old, while technology reflects occupational features (Ollé et al., 2013). At Dolina's TD10.2 where hunting strategies were focused on bovids, the lithic assemblage displays more specialized features (intensified use of chert). In the artefact-dense TD10.1 level, where activities appear more diversified and complex, raw materials are also more varied (Ollé et al., 2013). This accumulation has been interpreted to result from *high intensity occupations* (probably base camps) reflecting a wide diversity of on-site tasks (Carbonell et al., 2001; Márquez et al., 2001; Rodríguez, 2004; Rosell et al., 2011; Terradillos, 2010). As with the Caune de l'Arago G levels, the TD10-1 accumulation seems to correspond to cyclical occupations with a somewhat palimpsest structure, where more divers toolkits reflect a wider range of on-site activities. The inverse trend of more finely worked handaxes in older levels and more crudely worked pieces in more recent levels is likewise observed at Dolina (Ollé et al., 2013).

The relative abundance of cleavers at Spanish sites such as Galería constitutes a significant difference not only with the Mode 2 assemblages of the Caune de l'Arago, but also with western Europe in general. Some authors have suggested a technological relationship and, by extension, probable migrations over the Gibraltar Straits at different times during the Pleistocene (Sharon, 2011). At Galería as at the Caune de l'Arago, small retouched tools are well developed although at the latter site their production occurred off-site. Differences in the technological choices (dominant centripetal at Dolina and Galería) may be attributed – at least in part – to the overall dominance of quartz at the Caune de l'Arago. Also, a regional-specific cultural shift from Mode 2 to Mode 3 is perceived in both the Dolina and the Caune de l'Arago major stratigraphical sequences. Finally, we note that there are strong techno-morphological similarities between the single quartzite handaxe from la Sima de los Huesos (Carbonell and Mosquera, 2006) and two quartzite handaxes from the Caune de l'Arago P levels (Figs. 3 and 4).

At the chronologically and geographically related sites of Cau del Duc and La Selva (Catalunya), differences in the industries are also attributed to site function variability (Carbonell, 1985). Elsewhere in Spain, in open-air sites near Madrid and in the Duero, Tage and Guadiana river basins, assemblages are dominated by flakes and include pebble-tools and handaxes shaped by direct hammer technology. Once again, unlike in France and Italy, these Spanish sites generally include more cleavers. The assemblage from Pinedo (Toledo) has been interpreted as representative of an archaic phase of the Acheulian (Santonja and Perez-Gonzáles, 1996), with pebble-tools, trihedrals and handaxes showing a low degree of symmetry. Discoidal flaking is prominent. Retouched tools are mostly scrapers with denticulates. Torralba and Ambrona (central Meseta; Gonzàles-Echegaray and Freeman, 1998; Howell, 1962, 1965; Santonja and Villa, 2006), correlated to OIS 12 have also yielded Middle Pleistocene faunal and stone assemblages. At Torralba tools were made on pebbles from distant sources. Retouched tools from these sites and from the nearby Aridos I and II sites include numerous scrapers, as well as notches, denticulates and some points. Handaxes and cleavers are present and knapping is mainly discoidal. All three sites evolve towards a more standardized toolkit and Levallois technology towards the top of their sequences (Freeman, 1991; Gonzàles-Echegaray and Freeman, 1998; Santonja and Villa, 2006).

During the Middle Pleistocene the typology and technology of stone industries develops and diversifies. Although this diversity certainly results from multiple factors, the transition from Mode 2 to Mode 3 industries in the Mediterranean basin does seem to follow some specific typo-technological stages, indicating a more or less coherent chrono-cultural context. The Caune de l'Arago industries may be placed within this complex and non-linear framework. Their richness and the extensive chronological period they cover make them a reference for several developmental stages of the Mediterranean Mode 2, while they express the typo-technological diversity of Lower Palaeolithic industries within a variety of paleoenvironmental conditions. The industries from the base of Unit I are amongst the earliest western European handaxe assemblages; the Unit II industries demonstrate that Mode 2 assemblages may not include handaxes and the Unit III assemblages show a regional progression towards a more standardized, Mode 3 type ensemble while conserving remnant Mode 2 features.

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