The Middle and Upper Palaeolithic at La Crouzade cave (Gruissan, Aude, France): New excavations and a chronostratigraphic framework

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Abstract :
This paper presents new archaeological material and first dates on Upper Pleistocene layers at the site of La Crouzade cave (Gruissan, Aude, France). The site was first excavated by T. and P. Héléna at the beginning of the twentieth century, and the excavations were recently completed during three years (2016-2018) of systematic campaigns.
We obtained dates from Middle Palaeolithic layers using two methods: AMS ^{14}C dates were obtained from bone and charcoal, and combined ESR-U series dating was undertaken on horse teeth. Together, these methods allowed us to date this Mousterian sequence to 49776 –44805 cal BP for the deepest level (layer C8) and from 42000 ± 3000 years BP for the top (layer C6).
The Upper Palaeolithic layers are preserved only as patches in the actual excavation area, but a date was obtained from a piece of charcoal collected from a small hearth preserved in the first layer (C5) above Middle Palaeolithic deposits, which indicates an age similar to that of a modern human maxillary previously analysed and re-dated here from 36014–34402 cal BP, confirming its stratigraphic attribution.
The Middle Palaeolithic lithics at the site were first described as para-Charentian cultural facies following typological analyses. The revision of the earlier collection supplemented with the new material, using a technological approach, allow to identify two layers dominated by Levallois production followed by discoid production (Layers C8 and C6) surrounding an original assemblage (layer C7), characterised by a dominant Levallois production completed by three secondary production systems of equal importance, including discoid, SSDA and a Quina-like production. The faunal spectrum predominantly comprises an assemblage of Pleistocene large mammals, and biochronological studies corroborate the dates obtained.

Key words : La Crouzade cave; Middle-Upper Palaeolithic transition; Mousterian; Chronostratigraphy;

1. Introduction

Among the rare Mousterian sites along the west Mediterranean French coast, La Crouzade cave holds particular importance, owing to the richness of the Upper and Middle Palaeolithic materials that have been found there. The history of the site's excavation is long, beginning very soon after its discovery at the end of the nineteenth century (Rousseau, 1874) and continuing during the early twentieth century (Héléna, 1928, 1930) until the last excavation campaign in 1946. Besides these official excavations, and in spite of the site's classification as a historical monument in 1928, the site has suffered from looting, and, sadly, the sequence is now poorly preserved. Those levels that have survived include the deepest levels, which have yielded evidence of Neanderthal occupation.

As part of a larger Mousterian regional research programme (Saos et al., 2016), a pluridisciplinary synthesis of works from the French Mediterranean western coastal area, as well as field investigations, resulted in a new three-year excavation campaign in La Crouzade cave, one of the rare sites allowing the exploration of a Middle Palaeolithic sequence that is still well preserved in a stratigraphical context.

The resumption of the excavation was motivated by three main purposes:

- To assign the old collection from Héléna's excavations to a clear stratigraphic context, allowing their analysis and clear the uncertainties related to a particular layer, the 'Limon Jaune Inférieur' (LJInf = lower yellow silts) excavated by Héléna during the 1926 excavations, which yielded a significant portion of the collection (358 lithics and 550 fauna) and which cannot be clearly situated, having been reported at several levels in the stratigraphy (Héléna, 1928);

- To complete Héléna's collection with new materials, to better document the lithics that are few in number (1071 lithics) in the old collection, with the aim of characterising this Middle Palaeolithic assemblage to assess Neanderthal behaviour and also to complete the faunal elements (1261 in the old collection) to identify palaeoenvironments; and

- To determine the first ages for this sequence, comprising the Upper-Middle Palaeolithic transition, in an area for which very few dates are available.

1.1 Geological setting

La Crouzade cave is situated approximately at 60 m asl in the Mediterranean Cretaceous limestone Massif de la Clape, 3 km from the present coastline, in the municipality of Gruissan in Aude department (Fig. 1).
The La Clape massif is considered to be part of the Corbières formation, overthrusted 40 km towards the north during the formation of the Pyrenées (Lespinasse et al., 1982). Above the Triassic deposits that form the décollement level, an area of 2 km of Jurassic and Cretaceous limestone has been revealed by the deep cores Lezignan 1 and La Clape.
Three facies form the bulk of the outcrops of the Massif de la Clape (Jaffrezo, 1971):
- the 'lower limestones' of the Jurassic and Lower Cretaceous, with a thickness of 700–1000 m, intensely karstified;
- the Gargasian and Bedoulian medium marls, 80 m thick, consisting of glauconitic greyish marls;
- and the 'upper limestones' of the Aptian, 100 m thick, in which the cave is situated.

The facies of the lower and upper limestone units appear under the classical bioclastic facies with rudists, polyparites, orbitolines, etc.

Karstification was well developed through the end of the lower Cretaceous, as demonstrated by karstic holes, such as *gouffre de l'œil doux*, springs (La Goutine) and geological cores (Clape 1).

The hydrological context was investigated to determine the origin of saltwater found in the lower karstic unit, which shows contamination from old saltwater, possibly resulting from the Flandrian transgression (Khaska et al., 2013).

Miocene marine deposits (pebbles, beachrocks, corroded marine cliffs) are primarily found along the south rift of the La Clape massif at around 20 m asl.
Indicators of Thyrrenian transgression were also found along the south rift of the La Clape Massif, (Ambert, 1999) reaching 7-8 m asl.
The massif is actually surrounded by the Aude river deposits, which moved from the western part to the north-eastern part. The Flandrian transgression turned the La Clape massif into an island, and it remained so until the Roman period.

1-2. Historical context

Soon after the cave's discovery, T. Rousseau undertook the first excavations at the entrance and reported a Magdalenian occupation (Rousseau 1874). Following this, the Héléna family—father Théophile and son Philippe—occasionally supported by the Institut de Paleontologie Humaine, excavated over several years (1906, 1912, 1914, 1918, 1921, 1928, 1930, 1946), and found remains from the Upper and Middle Palaeolithic (Fig. 2).
P. Héléna produced the first stratigraphic description of the site (Héléna, 1928), which is a synthetic view of the infilling from two parts of the excavation, in which he distinguished a rich Upper Palaeolithic succession (Aurignacian, Gravettian, Magdalenian, Azilian) and Mousterian layers at the base.
Lithic and faunal materials from these excavations are housed in museums at Narbonne, Carcassonne and Tautavel.

The Upper Palaeolithic lithic material was studied as part of a regional synthesis (Sacchi, 1986), and the Middle Palaeolithic lithic material was studied by de Lumley (1971). More recently, F. Lebègue (2012) revisited the Mousterian collection and confirmed the « paracharentien » Mousterian type previously defined by de Lumley. The raw material, mostly comprising flint, revealed that most lithic material was procured locally, with the exception of a few pieces that came from a more distant location (Grégoire, 2000).
Faunal assemblages from Héléna's collection were first studied by Gerber (1973), and subsequently portions of them were studied by Banes (1996). These scholars identified the classical mammal assemblage attributed to the Würm II (MOIS 3). More recently, the artiodactyls from both old and new collections were compared (Bachellerie, 2016, 2017).
Neanderthal human remains were studied by de Lumley (1973) and by Bertrand (1999). Henry-Gambier and Sacchi (2008) described an incomplete skull from a modern human and obtained dates from a maxillary bone coming from the same layer (Layer C5), revealing the oldest modern human remains from a French context.

2- Methods

Excavation
The excavation was undertaken 60 m from the entrance (Fig. 2), in front of Héléna's excavation site, and comprised a 2.5 m indurated wall and a 3 m deep trench, which had been refilled.
The Mousterian layers described by Héléna in their last excavation were relocated in a pit in the main cross section (Perrenoud, 1995) and below the debris talus. Since we also recognised the three main layers described by Héléna (1930), we have retained their nomenclature for those layers to facilitate ease of comparison against the old collection.
The LJInf (lower yellow silts) level reported by Héléna during the first excavation is not clearly situated or is found at several stratigraphic levels (Héléna, 1928). To situate this layer in the stratigraphy and relate it to the Mousterian layers (C6, C7, C8) that were identified during the 1946 excavations, we accelerator mass spectrometer (AMS) dated *Equus* bones from the sequence as a point of comparison.

The site was excavated in contiguous squared zones of 1 m, totalling 12 m^2 (Fig. 2). The remains are recorded in terms of their spatial positions in three-dimensional coordinates, including slope and orientation, following the convention whereby north corresponds to the

back of the cavity, and using a grid and an altitude reference established in 1995 fieldwork. Cross sections were drawn at a 1/10 scale, with plans of the finds in each square.
The sediments were then washed in sieves of 2 mm in diameter for the purpose of recovering small lithic, faunic, microfaunic or malacological remains.

For the oldest collection, which came from Héléna's excavations, we have only the layers noted on the materials—C6, C7, C8 or LJInf—and the year of excavation (1926, 1930 or 1946).

ESR-U series method

Teeth were prepared and analysed according to the experimental protocol described in Bahain et al. (2002). In the laboratory, the external enamel layers were extracted from the teeth, and cleaned using a dentist's drill. The enamel sample was then crushed mechanically and sieved. The 100-200 µm fraction was selected and separated in ten aliquots. Nine were irradiated with a ^{60}Co gamma source (CENIEH, Burgos, Spain) at the following doses : 32, 50, 80, 125, 200, 320, 500, 800, 1250 and 2000 Gy.
The ESR intensities of the ten aliquots were then measured with a Bruker EMX spectrometer. The growth curve intensities *vs* doses were plotted. Palaeodoses were fitted with an exponential extrapolation and linear function using Origin software.

The activities of the various radionuclides present in dental tissues (essentially 238U, 226Ra and 222Rn) were measured by gamma spectrometry and were also analysed by MC-ICP-MS at Nanjing Normal University, China. This enabled us to obtain isotopic ^{234}U / ^{238}U, ^{230}Th / ^{234}U and ^{222}Rn/^{230}Th ratios, essential to the calculation of the U-uptake parameters for each tissue. The activities of the various radionuclides contained in the sediment surrounding the samples were also measured by gamma spectrometry, for the purpose of evaluating the contribution of the B doses received by the samples. Water content was also measured by drying the samples into an oven at 40°C for a week. The average values of 18 ± 5% and 10 ± 5% were ultimately used.
The ESR/U-series ages, various dose-rate contributions and U-uptake parameters were calculated for each dental tissue. The average radioelements contents of associated sediments and the conversion factor contents-doses of Guérin et al. (2011) were used as well as the in situ gamma doses, taking into account the samples' depths, to estimate the cosmic dose received during their geological history.
In situ gamma dose rates were measured using an Inspector 1000 gamma spectrometer (Canberra) via the threshold approach (Mercier and Falguères 2007). The measured doses (760 ± 38µGy/a for C6 layer and 907 ± 45 µGy/a for C7 layer) were used for the age calculations.

^{14}C AMS method

Radiocarbon dates were obtained from the Poznan laboratory (Lab-code Poz) and the Oxford Radiocarbon Accelerator Unit (ORAU) (Lab-code OxA).
Bone samples were prepared in both laboratories using procedures based on the original method described by Longin (1971). Both laboratories modified the original method. The current procedures for the Poznan and Oxford laboratories are described in detail in Piotrowska and Goslar (2002) and Brock et al. (2010), respectively. These procedures comprise decalcification, base wash, reacidification, gelatinisation and ultrafiltration steps. The extracted collagen samples were then converted to graphite and measured on the AMS available in both radiocarbon facilities. The %C, %N and atomic C/N ratio of the samples were measured using an automated carbon and nitrogen elemental analyser coupled with a continuous-flow isotope-monitoring mass spectrometer.
Charcoal samples were prepared at Poznan laboratory according to the classical AAA (acid-alkali-acid) three-step treatment with solutions of acid and base (Goslar, 2019). At ORAU, charcoals were prepared following the acid-wet oxidation stepped-combustion procedure

(AOx-SC, coded 'YR' at the ORAU) modified from the ABOx-SC, as described in Bird et al (1999), by removing the base wash.
The radiocarbon-calibrated dates were obtained using the OxCal 4.3.2 calibration curve (Bronk Ramsey, 2017), based on the IntCal13 dataset (Reimer et al., 2013).

Archaeozoological methods
Archaeozoological analysis was conducted across the entire sample (i.e., the older collections and those from recent excavations) to determine the mortality and seasonality of occupation of the different layers. We have compiled the tooth eruption and wear stages into three main categories (juvenile, adult and senile), using detailed data from modern populations, particularly reindeer, ibex, deer and horses (e.g. Riglet, 1977; Klein et al. 1981, 1983; Couturier, 1961; Moigne et al. 1998; Valensi and Psathi, 2004). Analysis of bone modifications focused on the state of the bones (i.e., green or dry) (Moigne, 1983), bone breakage patterns, percussion pits, notches and impact flakes (Capaldo and Blumenshine, 1994; Pickering and Egeland, 2006).

Lithic analysis
The lithic material studied consists of the historical Héléna collection, already studied by Lumley and Lebègue (Lumley, 1971, Lebègue, 2004, 2012), in addition to the unpublished artefacts from the most recent excavations (2016-2018).
The general trends in the lithics, in terms of the raw materials, technology and typology, were similar across both collections, allowing us to group them and to consider the assemblage as a single collection.

Analysis of the lithic remains encompassed all lithic components of this collection (debris, flakes, cores and tools) and a systematic approach was adopted, based on the raw material groups and archaeostratigraphic levels.

First, the raw material of each lithic component was determined and related to its potential geological source, simultaneously using macroscopic petroarchaeological methods (Grégoire, 2001), the regional flint repository of Languedoc-Roussillon (Grégoire et al., 2008) and data from new field surveys and samplings from the ancient Aude alluvial deposits for the crystalline rocks. The aim of this first analysis was to determine where Neanderthal groups found their lithic resources, with the dual purpose of identifying the morphology of the initial production matrix (blocks, slabs, nodules, pebbles) and defining land-use patterns related to each of the cave's occupation phases.

The next goal of lithic analysis is to identify, as accurately as possible, the steps of production, methods applied, technical objectives and mobility patterns associated with the lithic production activity in each phase of settlement. Our approach adopted the concept of the '*chaîne opératoire*' (Leroi-Gourhan, 1964; Inizan et al., 1995), to locate each artefact in its technical sequence and, if possible, in the fragmented technical scheme across time and space (Bourguignon et al., 2004; Kuhn, 2013; Turq et al., 2013). Systematic morphometric classical description was applied to define the technological artefact categories (Debénath and Dibble, 1994, Inizan et al., 1995) and the objects' status in the reduction sequence.

To diagnose the production methods applied to each raw material, several characteristic debitage concepts are used, such as Levallois (Boëda, 1994), discoid (Boëda, 1993, Peresani, 2003), SSDA (Ashton, 1992, Forestier, 1993), Quina (Bourguignon, 1997), prismatic laminar concepts (Carmignani et al., 2017) or cores-on-flakes (Tixier and Turq, 1999; Bourguignon et al., 2004), for the analysis of flakes and cores.

Retouched and shaped blanks were studied using Bordes' classical typological nomenclature for the Lower and Middle Palaeolithic (Bordes, 1981).

At this stage of the excavations, we still have only a partial view of the archaeological lithic record. Consequently, the results presented here are first trends which must be completed with the examination of the whole of the lithic record, whose collection from each Mousterian level is ongoing, thanks to the new excavation programme.

Stratigraphical correspondences

The only elements available for comparison with the old stratigraphic descriptions were Héléna's publication of the cave's stratigraphy, consisting of an article published in 1928 with a synthetic general stratigraphy profile and short descriptions of the layers observed in two places excavated in the middle of the cave, and a three-page letter from his final main excavations in 1930 at the rear of the cave. The layers' nomenclature changed between the two field descriptions, but the last was sufficiently precise as to identify in the still-preserved cross section cleaned during the 1995 pit and during the actual excavations (2016-2018), the three main Middle Palaeolithic layers—C6, C7 and C8—described in Héléna's 1930 stratigraphy. In the first excavations (Héléna 1928), one other layer (LJInf) was reported and marked on the remains, but was not yet identified in the stratigraphy because it is spread across different levels between the archaeological layers in Héléna's descriptions and drawings (sup. data Appendix 1).

3- Results

3-1 – Stratigraphy

The actual fill reaches 5 m (Fig. 3), and the two metres on top are highly brecciated by calcium carbonates (Saos, 2003). All of the soft sediment was removed by clandestine collectors, giving a tortuous shape to the profile and adding to the difficulty in distinguishing layers.

The cavity's basement has never been reached, and geophysical research by georadar prospection (Saos et al., 2017) did not facilitate determination of the infilling's maximum thickness. However, those results show that the first two metres were considerably disturbed and not as well stratified as the lower deposits, reflecting the extensive reworking to which the cave has been subjected.

The deepest levels are sterile between -500 cm and -600 cm under the 0 plane, known only in the 1995 pit, just under Héléna's main cross section of 1930 and 1946. The deposits consist of laminated clayed silts and well-sorted sand beds, indicating waterflows during karst activity (Fig. 3).

Layer C8 is approximately 50 cm thick, between -500 cm and -450 cm under the 0 plane. The top of the layer was reached during the last campaign, and several lithic artefacts were recovered.
The deposit comprises yellowish sand with two black levels attributed to hearths on the basis of the rich presence of charcoals and burned bones, also found in Héléna's collection.

Layer C7 is 70 cm thick, with a silty dark brown sediment that contains some limestone blocks. Three sub-layers can be described: regardless of the coarse fraction, they are identified simply as sedimentological layers, but each yielded osseous and lithic artefacts. These cannot be used to mark archaeostratigraphical layers, however, because few materials were found during excavation and these were limited to a few squares.

Layer C6, also referred to as the bear's layer, is 60 cm thick and consists of a yellowish sandy sediment with few limestone blocks. It was very rich in bear remains, as its name suggests. Sparse lithic remains were found, concentrated at the bottom of the layer.

Layer C5 at the top, between 330 and 300 cm under the 0 plane, is composed of silty brown sediment, with significantly more coarse elements than the deepest levels. This layer is not found universally across the site, but is patchy in its extent. In one area (square Q63), a small hearth (20 cm large) was found, identified by burned stones, bones and charcoals. Lithic material is rare at this level, with some typical Aurignacian tools (nosed-endscrapers).

Sand granulometry and composition and coarse fraction composition with karstic pebbles reveal a karstic input derived from waterflow, responsible for the deposit that originated from the inside of the karst. The contribution of the limestone also seems to have been important, as it delivered quartz grains and glauconite. Even some marine fossils may be found in the deepest layer, associated with a high percentage of rounded quartz typical of a shoreline deposit, as found on the plateau above the cave.
The waterflow was not sufficiently constant to disperse the remains, as demonstrated by the scant lithic debris found and some bone material that was found in anatomical connection (e.g., foetal bear remains).

The Upper Palaeolithic levels have yet to be studied as they are preserved only partially and have not been excavated. We may, however, observe the greater granulometry and richness in the coarse fraction in the main cross section (Fig. 3)

3-2. Datations

Initial radiocarbon results were obtained via AMS analysis of charcoal pieces extracted from sediment sampled on the Héléna cross section from 1995 in the Mousterian C8 layer (Table 1, Fig. 4). They did not come from a securely identified fireplace, but were selected as the only datable material. The age obtained for sample S6 (Poz-37967) at 49,776–44,805 cal BP is statistically indistinguishable from that of the deeper S2 sample (Poz-37966) at 48,025–43,861 cal BP. A bone determination (Poz-66106) appears somewhat later, at 44,436–41,566 cal BP, but, taken together, the results place this Mousterian layer between 49,7 and 41,5 ka cal BP

Further dates were obtained via AMS from horse bones selected from Héléna's collections. These bones carried no anthropic marks as we had decided to keep the rare examples that we had as it was the first attempt at dating the bone material from this cave. The three main layers—C6, C7 and C8—were sampled in addition to another layer not yet identified in the infilling (the 'Limon Jaune Inférieur'—LJInf—of the historical excavation). The results were highly variable (Table 1, Fig. 4), leading us to reject some ages as considerably too young for these Middle Palaeolithic layers (Table 1, Fig. 4). We are uncertain as to whether this variability is due to sample collection practices during old excavations, pre-treatment chemistry or post-depositional interference (contamination).

Two charcoals from a very small preserved hearth were analysed from the top of the actual excavation, corresponding to the first Upper Palaeolithic layer (layer C5). One (OxA-37665) was surprisingly young, at 12,638–12,371 cal BP (Table 1, Fig. 4), but the other (OxA-37723) provided an age of 38,430–37,331 cal BP, which overlaps with the age obtained from the modern human maxillary bone housed in Narbonne Museum (La Crouzade VI) at 36,014–34,402 cal BP, which has previously been dated (ERL 9415) to around the same age at 36,021–33,656 cal BP (Gambier and Sacchi, 2008).

We resampled both La Crouzade V (frontal bone) and La Crouzade VI (maxilla) in the Narbonne Museum. La Crouzade V yielded a small amount of collagen (610 mg gave 4.92 mg of ultrafiltered collagen), but the CN atomic ratio was 4.2, suggesting strongly that the sample was contaminated. We therefore did not obtain a date from this specimen. The possibility of unremoved contamination being present cannot be eliminated, and for this reason we gave the sample an OxA-X- prefix to indicate the high likelihood that this measurement is a minimum age: it might be accurate but it could be older. The only means of locating the result in its proper context would be to date it using a single amino acid method, after Devièse et al. (2018), but this would require additional sampling.

ESR and U-series methods were also applied to horse teeth from the Héléna collection layers C6 and C7. The results are presented in Tables 2 and 3: tooth CZ1401, which came from layer C6, yielded a result of 42 ± 3 ka (±1σ), and tooth CZ1402, from layer C7, gave a result of 41 ± 2 ka (±1σ). These results are indistinguishable, but are consistent with the radiocarbon determinations described above.

3-3. Lithic assemblage
Raw materials and lithic technology

The first vision of this industry was the typological study carried out by H. de Lumley (1971). Technological and techno-economic analysis was then proposed by F. Lebègue (2004, 2012). H. de Lumley identified in layers 6, 7 and 8 a Paracharentian-type industry described as homogeneous across all the three levels by de Lumley and subsequently by Lebègue. H. de Lumley (1971) typologically characterised the Paracharentian from these industries. The features used to determining this Mousterian cultural facies were typological attributes, including the presence of Quinson points and proto-limaces, the presence of atypical bifaces and quarter-circle scrapers and the high proportion of raised retouching.

Given the small number of objects resulting from the old excavations on which analyses had been only partially conducted, it was necessary to complete these first studies (Lebègue, 2012) and to obtain more data for a more refined characterisation.
The resumption of excavations in the middle Palaeolithic levels was partly motivated by this objective and has allowed the gradual completion of the historical 'Héléna' lithic collection and to reconsider the question of cultural characterisation in the light of a larger collection, in a well-understood deposit context.
Following three years of excavation, the lithic industries exhumed in levels C6, C7 and C8 bring the entire collection to a total of 1443 pieces attributable to the Mousterian.
The lithic material from current excavations, this time positioned spatially and with a clearer stratigraphical perspective, clarifies the technical and economic trends already observed (op. cit. Lumley 1971, Lebègue, 2004, 2012) and feeds the ongoing multidisciplinary study.
In this article, we revise the Héléna collection in addition to the material from the most recent excavations to expand the collection and thereby obtain a more accurate understanding of these Mousterian occupations.

Raw materials and their origins

Petroarchaeological study has demonstrated that three large families of rocks are represented throughout the lithic collection from the three levels. According to the regional flint repository and new data obtained by field surveys, it is possible to confirm that the vast majority of raw materials were sourced within a radius of 20 km around the cave (Grégoire, 2000).
Flint, represented by several facies (4), is the dominant material in all levels, followed by quartz and quartzite. Other raw materials are rare and are not represented in each level. The C7 level has the greatest diversity of rocks (Table 4).
Beyond this 20-km radius local and semi-local context, two allochthonous sources could be identified. Five pieces come from the debiting of at least two Bedoulian flint pebbles taken from the alluvial terraces of Costières du Gard, at a distance from the site of around 100 km as the crow flies (Grégoire and Bazile, 2005). Brown jasper, known from the regional Palaeolithic

(Arago, Ramandils, Arbreda) (Grégoire et al 2006, Boutié et al., 2004) and present in small quantities (n = 4) in the C7 layer, originating from the Canigou massif, could be found as pebbles in the Têt alluvium, reachable 60 km south of the site, in the Roussillon plain.
Apart from these two allochthonous supplies, most of the semi-local flint came from Oligo-Miocene deposits located between 14 and 20 km south of the site. The Miocene flint of Portel-des-Corbières and the Oligocene flint of Roquefort-des-Corbières were the most frequently selected (Grégoire et al, 2009). The Miocene flint outcropping on the Doul peninsula was also chosen to a lesser extent.
Other local flint facies, generally of poorer quality and whose extraction from the surrounding was not easy (Narbonne Jurassic chert, Barremo-Bedoulian of St Pierre la Mer), were used sporadically and were identified at this stage only within the historical collection.
Other rocks (quartz, rock crystal, quartzite, sandstone, quartzite sandstone, Lydian) came from the old alluvial deposits of Aude, accessible near the site to the southwest of the La Clape massif, less than 6 km from the cave as the crow flies.
The land use pattern drawn reveals a semi-local territory within a radius of around 20 km, from which most of the supply was sourced. In the C7 level, some pieces testify to allochthonous exploitation of the flint pebbles of Costières du Gard (op.cit. Grégoire et Bazile, 2005) and show a 'long distance' circulation of artefacts from north to south. In this same level, some pieces of Canigou jasper conversely indicate the arrival of end-products from 60 km to the south, the raw materials for which were sourced from the alluvial deposits of the Roussillon plain. For the C7 layer, the economic territory lies within the 20 km radius, with a few artefacts from distant sources located between 60 and 100 km away, which testifies to inter-territorial contacts and the high circulation level of certain kinds of product made using remarkable raw materials.

Techno- economic features

The first techno-economic study of the Héléna collection yielded the first observations (Lebègue, 2012) that are today possible to complete, thanks to the new excavations.
From a technical perspective, analysis of the completed collection made it possible to identify trends in each archaeological layer and to demonstrate that various debitage systems were applied in each level, even though Levallois production (Boëda, 1986) is dominant in all levels (Table 5). The latter develops only on flint and jasper.

The C6 layer is archaeologically quite poor in terms of lithic material because it corresponds to some very short periods of human activity alternated with the presence of bears. Dominated by Levallois, the primary mode of production, this level includes secondary productions applied to all types of material: one discoid, with characteristic short flakes and pseudo-Levallois points sometimes retouched, the other the SSDA reduction process (Ashton, 1992; Forestier, 1993), used for the production of numerous non-predetermined ordinary blanks of small dimensions. The tools produced in this level are mainly scrapers and notched tools (Table 6). Maintenance by-products are well represented and testify to in-situ and advanced-stage production (Table 5). From an economic perspective, the nucleus indicates intensive exploitation of the raw material whose source is not particularly local, with regard to the flint.

In the C7 layer, Levallois production is predominant (27%). The cores (n = 26) illustrate several Levallois modalities, including the preferential flaking modality (Fig. 5b) and the centripetal recurrent modality (Fig. 5c), pushed to the extreme and producing—in the final phase—flakes of reduced size. Non-predetermined products obtained via orthogonal flaking on SSDA cores indicate that the secondary modes of production were unorganised, varied (unipolar, semi-rotating) and quite opportunistic, based on the selected materials (Fig. 5a). Note the presence of a system close to the Quina concept (Bourguignon et al., 2008) that has been recognised in this level and which has the characteristic of producing small short-backed blanks, usually thick retouched scrapers, configurated by semi-Quina scalariform retouching (Fig. 5). The discoid flaking concept (Fig. 5d) and different methods of knapping on the flakes (i.e., on the underside or upper surface) (Fig. 5 e) were also recognised. In general, the small size of the

cores, their frequent recovery and their recycling as tools testify to optimised flaking in the cavity and the abandonment of exhausted and incomplete cores.
Although they are diversified in this layer (Table 6), the best-represented tools are scrapers. Most are lateral or transversal scrapers of small dimensions. Double scrapers are also attested. Their retouching is mainly simple on fine supports and scaly and scalariform of Quina or semi-Quina type on thick supports. Among the scrapers, a certain morphological recurrence may be observed. Noticeable similarities are observed on these lateral scrapers: they are of relatively small size; on their upper face they have a largely cortical part that opposes the retouching, indicating the voluntary maintenance of a certain thickness to obtain a tool back. Their bursting face is more or less flat; their retouching is abrupt and scalariform or scaly (i.e., Quina retouching). The latter have a triangular section that is fairly wide compared to the dimension of the flake. These small scrapers have become very short, following successive re-sharpening, and offer a very open dihedral angle (about 60°). This morphology suggests functions of scraping rather than cutting, and may testify either to a particular need defined by a use difficult to determine or to the pushed recycling of the original flake, causing it to become shorter and thicker with successive re-sharpening as it is used and reused until exhaustion of the support. The second most represented tools are the Mousterian points and the notches. Endscrapers are surprisingly common in this Mousterian context (Table 6).

In layer C8, despite the low quantity of data for this level, scarcely reached by the excavations, Levallois and discoid production are identified, and, once again, the Levallois production is dominant but not exclusive. Both systems are associated with SSDA debitage, producing non-predetermined flakes. Scrapers are also the dominant tools at this level, and raw materials are less diversified than in other levels. At this stage of the excavation, it is difficult to advance the description of the lithic production in this layer any further.

The layer LJInf was not found during the most recent excavations. However, the historic collection indicates that it is rich in material with a high proportion of Mousterian-type laminar products, sometimes produced using Levallois methods (Carmignani et al., 2017) and sometimes using a unipolar method associated with a fairly significant Levallois flake production. Scrapers are also dominant, and no shoulder or nose-endscrapers are attested. Few bladelets are identified in the collection from this layer. We are thus prompted to ask whether it is a Mousterian layer, unrecognised within the current stratigraphy on the actual location of the excavation? Does it correspond to a lateral variation of one of the three Mousterian levels (C6,7,8) or is it a mix of all three? Or does the level containing a mixture of Mousterian and Upper Palaeolithic material ? Given the technological composition, it would be logical to dismiss the latter hypothesis and to consider this distinct layer in analysis of the Mousterian levels.

On the whole, the lithic series of these levels are characterised by predominantly Levallois production, while the initialisation products are poorly represented among the material. Cores also appear to be deficient: only part of the Levallois production at an advanced stage of the '*chaîne opératoire*' (non-cortical flakes, maintenance flakes, exhausted cores, absence of many end-of-sequence products, possibly exported) and a ramification of this primary production (Bourguignon et al., 2004) are represented in the cave. The resumption of new reduction processes from the first sequence is visible on core flakes and Kombewa flakes resulting from various production systems, including Kombewa methods (exploitation of the lower volume) and Nahr Ibrahim technique (exploitation of the upper volume) (Soleki et al, 1970), following a secondary reduction sequence. The latter replaced a Levallois management (Dauvois, 1981) that can no longer develop on flakes that have become too small, leading to 'micro-production', particularly on flint.
Levallois products' flakes or blades are generally small (average l:37mm, w: 26mm, t:10mm for the flakes), and in 80% of cases were turned into tools by fine retouching.

In the C7 layer only, thick triangular-section blanks, sometimes produced by a system close to the Quina flaking concept (Bourguignon, 1997) (Fig. 5f, 5g, 5h), that we may term 'Quina-type production' are turned into tools by Quina retouching on a cutting edge opposite a natural back. In many cases, successive re-sharpening steps on already short supports, increasingly reduced (Fig. 5i and 5j), and the frequent lateral or proximal thinning of the tools (Fig. 5g) make it difficult to clearly identify this production method.

Upper Palaeolithic lithic material

In layer C5, lithic and faunal material have been coordinated and appear to correspond to Sacchi level 10 (Sacchi, 1986), containing the Aurignacian material. Sacchi described a poor lithic series made exclusively from flint and dominated by tools on blade and on flakes. The most widely represented are careenated endscrapers, nosed-endscrapers and retouched Aurignacian blades, some of which are strangled.
No Dufour bladelets have been identified. These lithic elements and the bone industry found in this layer during the historical excavations led Sacchi to attribute this level to the Aurignacian period without any greater precision.
The current excavations, whose primary objective is to excavate Middle Palaeolithic levels, have crossed this layer partially preserved in some areas, and have permitted the collection of some additional lithic material, helping to refine its attribution.
Partly made on blades obtained by rotating unipolar debitage, the lithic material is also characterised by flake production, some of which served as cores for the production of curved bladelets. These techno-cultural elements, such as nosed-endscrapers, shoulder endscrapers and perhaps a curve-shaped blade, would attribute this material to a former Aurignacian rather than Proto-Aurignacian phase.

3-4 Palaeontological results

Revision of the old collections and analysis of the remains resulting from the new excavation campaigns make it possible to identify in the Mousterian levels (C8-C6, LJInf) the following large mammalian species (Table 7, Fig. 6), which complete the list originally proposed by Gerber (1973): *Lynx* sp., *Panthera pardus, Panthera spelaea, Crocuta crocuta spelaea, Vulpes vulpes, Canis lupus*, *Meles meles*, *Ursus spelaeus*, *Ursus arctos*, *Stephanorhinus* sp., *Equus ferus germanicus*, *Equus hydruntinus davidi*, *Bison priscus*, *Bos primigenius*, *Capra caucasica praepyrenaica*, *Rupicapra* sp., *Saiga tatarica*, *Capreolus capreolus*, *Cervus elaphus*, *Rangifer tarandus*, *Megaloceros giganteus* and *Sus scrofa*.
In terms of the number of identified specimens (NISP), the faunal list is dominated by horse, reindeer and ibex in equivalent proportions (Table 7). The cave bear is the most abundant Carnivore species in the assemblage, notably in layer C6, where the cave was used as a den, as indicated by the numerous perinate and juvenile remains found, particularly naturally fallen deciduous teeth. The cave hyena is identified in all Mousterian levels (and up to layer C5). Occupation of the cave is clearly attested in the C7 layer by the presence of numerous coprolites.
The Upper Palaeolithic (C5-C4) levels have a comparable faunal list with some new taxa, such as the woolly rhinoceros (*Coelodonta antiquitatis*) and a smaller horse. However, some species identified in the Mousterian levels have not to date been found in the upper layers (*Panthera pardus, Meles meles, Bison priscus, Saiga tatarica, Capreolus capreolus, Megaloceros giganteus*). The wild cat (*Felis silvestris*) has also been reported in the assemblage but without stratigraphic attribution.

The C8 association seems slightly different, with higher proportions of horse, deer and megaloceros. This assemblage may be correlated with the Tournal Mousterian layers: more humid and corresponding to a closed environment (Magniez, 2010).

Biochronology

The biochronological significance of the Carnivore species from La Crouzade cave remains relatively limited, since their presence in Western Europe covers a large timeframe, from the Middle Pleistocene until the end of the Late Pleistocene. Wolf size may be a good chronological marker (Argant, 2009; Boudadi-Maligne, 2011) but the small sample does not yet permit any accurate evaluation. The cave bear is large in size, similar to other southern populations of the same age (e.g. Tournal, Arbreda; Quiles, 2003). Although the sample is too limited to be statistically significant, dental morphotypes (see among others Rabeder and Tsoukala, 1990; Argant, 1995) agree with the MIS 3.

Among the large herbivores, the biochronological study of equids and ibex yields information that helps to position the Middle Palaeolithic infilling in the MIS 3. The size of the horse (*E. ferus germanicus*) in the Mousterian levels (LJInf, layers C8 to C6) aligns well with the general trend of decrease, observed in this group, during the Late Pleistocene (Magniez and Boulbes, 2014). The body size exhibits affinities with series dated to MIS 3 (Fig. 7). Variability Size Index (VSI) calculated for LJInf is lower than layers C8–C6 ($p=0{,}0251$, Mann-Whitney U test). They are respectively close to the horses from Tournal Cave's Mousterian levels (levels B/C and D1/D2) and Portel-Ouest layers F. The VSI is conversely higher than the Aurignacian level from Tournal (E) and the regional series correlated to the MIS 2. The dental morphotype of La Crouzade cave *Equus hydruntinus* (elongated protocone) also differs from that of the Ramandils (MIS 5, Rusch et al., 2019) small equid, and seems close to the subspecies *Equus hydruntinus davidi* (Boulbes, 2009), a particular form recorded in the south of France from the second half of the Late Pleistocene, particularly during and after MIS 3 ('Würm II', Prat, 1968; Guadelli and Delpech, 2000; Boulbes, 2009).

The ibex of La Crouzade cave has been assigned to *Capra caucasica praepyrenaica* (Crégut-Bonnoure, 2002; Crégut-Bonnoure, 2007; Magniez, 2009). The skull discovered during the new excavations in layer C7 (Fig. 6) exhibits proportions close to the Pyrenean lineage. The phylogeny of western European *Capra* remains a matter for debate: recent studies on ancient DNA support a monophyletic origin for the Alpine ibex and the Iberian wild goat and observe no close relationship with *Capra caucasica* (Urena et al., 2018). A similar morphotype to that of La Crouzade cave can be found in France, in the south Mediterranean area, notably in the Portel-Ouest, Hortus and Arche caves or in the Mousterian levels of Tournal Cave (Rivals and Testu, 2006; Magniez, 2009). Further analyses, including those populations dated to the MIS 3, are required to clarify their problematic status. A typical Pyrenean morphotype is found at MIS 2 in several regional deposits (Les Conques, Castel 2, Belvis, Gazel; Crégut-Bonnoure, 1992; Pernaud et al., 2004; Magniez, 2009).

Furthermore, analyses of reindeer (*Rangifer tarandus*) body size variations support a cold phase in MIS 3 (Magniez, 2010).

Archaeozoology

The archaeozoological study of the artiodactyls of La Crouzade cave was conducted on Héléna's collection and allowed us to identify some regularity in the occupation of the site by Palaeolithic hunters. Seasonality was studied from dental series and isolated teeth of young cervid and bovid individuals. The ibex remains coming from the Mousterian layer LJInf allow us to estimate an occupation at the end of autumn. Age estimates from *Bos* and *Bison* confirm this hypothesis and extend the periods of occupation in late summer-early fall and winter (Bachellerie, 2017).

The data obtained from dental remains of reindeer from layers C7 and LJInf indicate a clear seasonality, with occupation during the winter period. As reindeer carcass accumulation was concentrated over a very short period of time, the site would have been used as a winter hunting halt specialising in that species.

The systematic analysis of reindeer, deer and ibex bones revealed various carcass-processing operations: skinning, evisceration, disarticulation, dismemberment and defleshing. These activities were noted in all the levels studied (sup. data Appendix 2), indicating a certain homogeneity in butchering activities. Recurrent behaviours are evident, including a high concentration of cut marks on reindeer and ibex humerus epicondylar ridges. The treatment of reindeer carcasses, however, remains more systematic and comprehensive: each part of the skeleton has been exploited (Bachellerie, 2016).

The fracture pattern is similar in all Mousterian levels. A predominance of spiral fractures, typical of anthropogenic activity, may be observed. A specific and systematic treatment of tibias and metatarsals of ibex and reindeer could be highlighted. This systematisation in the treatment of long bones is more particularly visible on the remains of ibex (sup. data Appendix 3) and reindeer humerus (complete epiphysis, with spiral fracture above the epicondylar crest) (sup. data Appendix 4).

Finally, the presence of burned bones was noted, particularly in layer C8. The bones most affected by calcination are those of bovids (up to 14.8% of the NISP in the layer LJInf). However, the percentage of burned elements, with respect to the frequency of other modification types (e.g., cut marks, fracturation), remains low. The bones were therefore not used as fuel.

All these elements allow us to hypothesise a site used as a reindeer hunting halt in winter, with complete and systematic treatment of carcasses. The cave would also have been used as a temporary camp in late summer/early autumn for a more diversified hunt, with a particular focus on bovids. It is particularly interesting to note the considerable homogeneity in the treatment of carcasses across the different Mousterian levels.

3-5 Human remains

Here, we present the situation at La Crouzade in terms of human remains. New studies are in progress. Previously, ten samples of human remains were found in a Palaeolithic context at La Crouzade (Table 8): six from the Mousterian levels and four from the Upper Palaeolithic levels (i.e., Aurignacian, Gravettian (?), Magdalenian). No human remains were found in a Palaeolithic level during the recent excavation.

Six samples of human remains attributed to Neanderthal come from three distinct Mousterian levels (from 6 to 8): one clavicle (CX), two humerus (CI and CIX) and three manual phalanges (CII, CIII and CIV), including one infant (three months) and one adolescent (Fig. 8). Henceforth, the largest humerus (CI) is considered to belong to an adolescent and not an adult as proposed by Lumley (1973). It should be noted, however, that Lumley (1973) concluded that the phalange CIII probably belonged to an adolescent. The clavicle (CX) and one humerus (CIX, three months) are unpublished. The latter samples were found in levels 8 and 7, respectively. Four Neanderthal remains (CI, CII, CIII and CIV) were studied by M.A. Lumley (1973) and two others (CIX and CX) were analysed by Bertrand (1999) in an unpublished master's thesis. As it stands, including our observations (*study in progress*) and Lumley's study (1973), we have no morphological features that permit us to securely assign these remains to the Neanderthal species, largely due to the bones' conservation (Crouzade CI), the bone types and the preserved anatomical regions. However, the phalanges are similar to those found in Hortus Cave, and the humeral diaphyses are compatible with Neanderthal morphology (Lumley, 1973).

Currently, only five well-preserved humerus samples have been assigned to very young Neanderthals (Mezmaiskaya, Moustier 2, Ferrassie 4B, Amud 7 and Kiik-Koba 2; see respectively in Golovanova et al. 1999; Maureille, 2002; Heim, 1982; Hovers et al., 1995; Bonch-Osmolovski, 1925). Thus, the Crouzade IX humerus (three months) is particularly significant in enhancing the Neanderthal sample to better assess their morphological variation. Additionally, it offers the opportunity to investigate the developmental pattern of the trabecular and cortical bones in Neandertal (*study in progress*).

Prior to 1930, several (probably) modern human remains were mentioned in the literature (Sicard, 1900; Ph. Héléna, 1928; Ph. and Th. Héléna, 1930; see in Gambier and Sacchi, 1991). Some are related to modern human cultural contexts (Magdalenian, Aurignacian) while others are without known context. Henry-Gambier and Sacchi (2008) emphasise that, of these human elements observed in the past by M. Boule, only those that we know as Crouzade V and VI (a frontal bone and a maxilla, respectively) exist. These two human remains were found in 1918 by Héléna in an Aurignacian level F, now called level 5 or C5 (Sacchi, 1986; Gambier and Sacchi, 1991; Henry-Gambier and Sacchi, 2008). The frontal bone (Crouzade V) is composed of two parts glued together (Fig. 9). It belongs to an adult whose precise age and sex are not determinable (Henry-Gambier and Sacchi, 2008). The maxilla presents four permanent teeth (Crouzade VI) with low occlusal wear in agreement with a young adult (Fig. 10). No anatomical argument for assigning the maxilla and the frontal bone to the same individual exists. However, they were found together by Héléna (Héléna, 1928), who paid particular attention to archaeostratigraphy. Based on this information, Henry-Gambier and Sacchi (2008) assume that both bones belonged to the same archaeological level. These remains are clearly attributed to modern humans based on their morphology, which is consistent with their archaeological context. These remains are associated with an early phase of the Aurignacian period (though not the earliest phase) (Sacchi, 1986). The maxillary bone was dated to approximately 31,000 BP by Henry-Gambier and Sacchi (2008) and to 31200 ± 400 BP (Higham in this study). Consequently, these fossils are among the oldest modern humans exhumed in France (although with several caveats, as mentioned above), and they are 10–15 kyr younger than the earliest anatomically modern humans in Europe (Benazzi et al., 2011, 2015; Higham et al., 2011). According to Henry-Gambier and Sacchi (2008), the large width of the interorbital space is the only archaic feature found in Crouzade V. As the other features of Crouzade V, the morphology of Crouzade VI incorporates the early modern human variation. To better characterise these specimens, new analyses are being undertaken on the structure of the frontal bone and teeth.

4-Discussion

La Crouzade cave is regularly cited as a comparison site in major syntheses, often simply as a point on a map, in work on assemblages of Mousterian Western Europe (Eixea 2018), the emergence of *Homo sapiens* in Mediterranean Europe, (Hublin, 2015)—notably due to maxillary dating (Davies, 2015) or funerary practices (Pigeaud, 2017)—archaeological and paleoclimatic chronologies (Discamp et al., 2011), fauna, particularly ungulates (Alvarez Lao et al., 2017) or the phylogeny of certain species, such as wild goat (Urena et al., 2018, Sauqué et al., 2018). However, although it contained a precious material, it suffered from a reduced collection and an unclear stratigraphic context. The last notes of the principal excavators in 1930, in the form of a few pages of manuscript, did not permit us to locate precisely in the stratigraphy essential fossils, such as human remains, sometimes recognised as such after the excavations or having been unearthed in a hurry. It is surprising, for example, to find no mention in these works of bioturbations associated with burrowing animals, frequently encountered in new excavations and easily identifiable.

Indeed, rabbits' and badgers' burrows are relatively numerous, and the question of their effects on the reliability of previous excavations may be raised, the taphonomic impact of these burrowing animals having been demonstrated (Pelletier et al., 2017).

The main disturbances encountered are the result of ancient and clandestine excavations that mainly affected the upper Palaeolithic layers. These are only found in tatters, and the poorly preserved hearth has provided a date compatible with the dated maxillary attributed to *Homo sapiens*. The robust overlapping of these ages confirms that this remains belongs to layer 5.

Although the main archaeological levels of the Middle Palaeolithic are now well identified (layers C6, C7 and C8), this is not the case for the so-called LJInf layer, from which a large portion of the material of the historical excavations originates.

Several hypotheses are permitted, among which it is not currently possible to choose the most likely.

It may be a limited extension layer, perhaps present only towards the centre of the cavity where it was initially described (Héléna, 1928), and it may not exist in the currently excavated area. It may also correspond to one of the Mousterian strata resembling this facies (Layer 6, 7 or 8) or present below that, which does not seem the case, since only sterile levels have been found (Saos, 2003). Finally, it may be a mixture of all or part of the Middle Palaeolithic levels that were not individualised in the first version of the stratigraphy.

The chronological analyses of bone slices of this level and those of well-referenced layers do not provide an answer (Fig. 4), with the bones exhibiting a contamination responsible for a rejuvenation of ages.

The similar faunal procession tends to bring the LJInf layer closer to the C6 and C7 layers; however, the lithic material does not permit this connection, the LJInf being distinguished by the abundance of laminar products.

The VSI obtained from horses from the C8-C7-C6 layers, compared with the LJInf layer and with Late Pleistocene standard sites, indicates a slight downward trend for the LJInf layer, which might be interpreted as a distinct younger layer, supported by AMS datation spread between 28434-27690 cal BP and 35787-34181 cal BP.

As things stand, and although it could not be found in the new excavations, we consider the LJInf layer as a separate, probably later, mousterian layer, but with dates to refine. An extension of the excavation, pits and cores and new accurate dates could confirm this hypothesis.

The dates obtained on the Mousterian layers situate these occupations between 49,8 and 41,5 ka cal BP through AMS 14 C on the C8 layer and at 41 ± 2 ka and 42 ± 3 ka for the C7 and C6 layers respectively by U/Th-ESR. We may be more confident regarding the 49,8–43,9 ka BP interval for the C8 layer, obtained with AMS dates on charcoals as we collected the samples ourselves on the main cross section, rather than regarding the bone dating results, which samples were collected in 1930 with no certitude of their exact provenience, including the possibility of post-depositional disturbance. Moreover, we are unsure as to the anthropic origin of the bones, as opposed to the charcoals, as they come from a rich layer of burned bones.

These ages are in line with palaeontological data, which reveal a fauna typical of MIS 3, and are supported by the biochronological data, notably obtained on the evolution of the size of the horse and the morphotypes of the cave bear, *E. hydruntinus* and the ibex.

These late dates are in agreement with the results obtained in the nearly Mediterranean area (Table 9) and more generally in Western Europe, which indicate that the Neanderthal's demise occurred within the time range 40,8–39,2 ka cal BP (Higham et al., 2014).

However, to situate the Mousterian occupations of La Crouzade cave at a regional scale is quite difficult because contemporaneous sites are rare and their chronological contexts are often unclear.
In the area (sup. data Appendix 5), Ramandils Cave situated at Port-la Nouvelle is older, dated to MIS 5 (Rusch et al., 2019) and is associated with a micro-Mousterian industry (Moles and Boutié, 2009), mostly produced in local flint (Boutié et al., 2004).

Tournal Cave (Bize-Minervois) also presents the Middle-Upper Palaeolithic transition, but yielded few coherent dates (Tavoso, 1987), which were not really accurate: 35 ± 7 ka, mean of three methods (Yokoyama et al., 1987). The lithic artefacts from Mousterian layers are made mostly in quartzite and correspond to the Denticulate Mousterian (Tavoso, 1987; Chacon, 2009; Lebègue, 2012). An early Aurignacian presence was identified in unit III, with Dufour bladelets and a typical Aurignacian assemblage dominated by endscrapers (Sacchi, 1986; Tavoso, 1987).

We are obliged to move further north-east, towards the Ardèche region, to find similar dates for a Late Mousterian securely dated site, such as the Saint-Marcel cave, dated by ^{14}C AMS at 42–42,8 ka cal BP (Szmidt, 2010).

Hortus Cave does not have physical dates; the latest Middle Palaeolithic layer (layer V) shows a typical Mousterian assemblage dominated by Levallois production on local flint (Lumley, 1972; Lebègue et al., 2010) in a specialised Ibex hunting camp context, alternately with an *Ursus spelaeus* den.

In the south-west, Portel Cave may offer an interesting site of comparison, as it also shows the Middle to Upper Palaeolithic transition and Late Mousterian occupations, dated from 44 ± 6 ka by ESR in the F levels (Tissoux, 2004). Lithic industries are qualified as meridional Charentian Mousterian, made quasi-exclusively in quartz. (Prince, 2000)

Further south, the Arbreda site in the southern Pyrenées also contains this chronocultural transition, with a typical Mousterian in the last middle Palaeolithic layer, layer I, dated at 42–43 ka cal BP, dominated by discoid and Levallois production in quartz, quartzite, porphyry and flint (Maroto et al., 2012).

Typical Mousterian layers of those sites may be compared with layers C6 and C8 of La Crouzade cave, rather than the C7 layer, according to Lumley (Lumley, 1971), which may be compared with sites where meridional Charentian, Paracharentian or Quina facies are mentioned (Bazile, 2012; Prince, 2000).

Lumley defined the Paracharentian cultural facies from La Crouzade compared to the Languedoc sites of Esquicho Grapaou and St Vérédème, which he describes as Charentian. Its main characteristics are a medium Quina index, a low Levallois index, non-Levallois thick flakes, high proportions of raised retouching, the presence of Quinson points and proto-limaces and the presence of atypical bifaces and quarter-circle scrapers.
Actual analysis of the entire lithic collection of La Crouzade did not clearly identify all these features and showed only in the C7 layer a high proportion of raised retouching (demi-Quina) and the presence of non-Levallois thick flakes produced by a 'Quina-like' method associated with a dominant Levallois production.

However, the C7 lithics' features, compared to the other two layers, exhibit a greater diversity of raw materials, a wider diversity of production systems, with the emergence of the Quina concept, and objects showing practices of economy, such as recycling and re-sharpening of blanks, lending this series a Charentian or Paracharentian aspect *sensu* Lumley (Lumley, 1971).
With the exception of the technical Quina concept, applied essentially to quartz, producing

small, short and thick flakes and frequently retouched (Fig. 5 f,g,h), the only criterion for identifying the Paracharentian techno-culture, found in the recent analysis, is the Quina index described by Lumley, based on the ‘semi-Quina’ retouch style. In the case of La Crouzade, this criterion would be a more functional—even economic—than typological characteristic.
Furthermore, this Quina-like technique is used only in the C7 Layer in complement with a dominant Levallois method (Fig. 5), which is rather atypical. All these features lead us to conclude that the attribution of the La Crouzade lithic assemblage to the Paracharentian techno-complex must be reconsidered in the light of more material, thanks to the continuation of the excavations, particularly with regard the C6 and C8 layers, where the Levallois production is dominant, but also for the C7 occupation, which remains the closest to the Charentian cultural roots (Lumley, 1971) with the use of the Quina debitage method.

The techno-typological peculiarities are not, however, linked to a lithological determinism, since the three Mousterian layers result from the exploitation of the same geological environment.
In the C7 layer, the other raw materials that complete the usual flint-quartz duo originate from nearby alluvial deposits, denoting more expedient opportunistic supplies.

In this context, we may ask which specific activities might have been carried out and which would have led to the development of modes of production and consumption of tools that differed from those used at other levels and which were more varied. The impact of a harsher climate identified in this layer could be a limiting factor for the supply of raw materials of semi-local or distant origin, and would have compelled the human occupants to move less and use their tools optimally by re-sharpening and recycling them until exhaustion during their stay in the cave. The hypothesis of limited mobility causing the use of a larger panel of local raw material may explain a more important adaptative behaviour than on the other occupation levels, resulting in a wider range of production techniques and longer and branched ‘*chaînes opératoires*’, including more maintenance and/or recycling phases. The faunal analyses indicate that hunting was mostly oriented towards reindeer during rough seasons, but the butchering mode is identical to that observed in C6’s ibex exploitation. During the cooler climate oscillation, reindeers migrate towards south coastal plains and Neanderthals occupied this area to hunt these herds.

Conclusion

La Crouzade cave, on the Mediterranean edge of the Occitanie region in the south of France, is a site that has in the past yielded valuable but scant collections from the Middle and Upper Palaeolithic. The resumption of excavations on this deposit completes the lithic and faunal corpus of the Mousterian layers C6, C7 and C8, the only layers still extensively present at the site, and brings new insights to these collections, thanks to the multidisciplinary data obtained and the establishment of a clear chronostratigraphic framework.
The dates obtained via two methods, AMS ^{14}C and ESR-U series, highlight Late Mousterian occupations, between 49,8 and 41,5 ka cal BP. This result makes it possible to situate La Crouzade cave among the last Mousterian regional occupations of southern France. Biochronological data, notably those provided by the sizes of the horse remains and the dental morphology of *hydruntinus*, support these results.
The result of new dating from the modern human maxillary, collected from a layer surmounting the Mousterian layers, gives an age of 36,0–34,4 ka cal BP, confirming the antiquity of this fossil, among the oldest known from France. The recovery of this date with that resulting from the dating of a charcoal from layer C5 confirm the stratigraphic origin of this fossil.
Thanks to the resumption of excavations, analysis of enriched archaeological collections allows us to draw some preliminary conclusions regarding human behaviours.
La Crouzade cave is a natural shelter overlooking a freshwater point (La Goutine ravine) close to good quality flint outcrops and alluvial pebble deposits at the Aude outlet, in a limestone massif acting as a promontory within a vast coastal plain. Given the quantity of allochthonous

raw materials abandoned in this cavity, it may be interpreted as a hunting halt in a vast territory extending from the Rhone Valley to the foot of the Pyrenées, on which these groups lived.

The circulation of raw materials observed at this site place it at the centre of a Mediterranean cultural space (Lebègue, 2012), which extends from the piedmont of the central massif, where another distinct cultural space has been ascribed (Vaissier et al., 2017) to the Iberian foothills of the Pyrenean chain.
This space is characterised by a relative technical unit built around the Levallois facies and low cultural diversity compared to the southwest.

All these elements allow us to hypothesise a site used as a reindeer hunting ground in winter, where complete and systematic treatment of carcasses was performed. The cave would also have been used as a temporary camp at the end of the summer/early autumn for a more diversified hunt, with a particular focus on bovines.

These first results and the resumption of the excavations at La Crouzade cave promise more data that will allow us to understand in greater detail the temporal and environmental contexts of the replacement of Neanderthal with modern humans.

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Appendix. Supplementary data

Supplementary data: stratigraphic correlations (annexe 1), zooarchaeological results (annexes 2-3-4) and a map of mentioned sites (annexe 5).

References

Álvarez-Lao, D.J., Rivals, F., Sánchez-Hernández, C., Blasco, R., Rosell J., 2017. Ungulates from Teixoneres Cave (Moià, Barcelona, Spain): Presence of cold-adapted elements in NE Iberia during the MIS 3 Palaeogeography, Palaeoclimatology, Palaeoecology 466, 287–302.
Ajaja, O., 1994 – Datation de quelques sites moustériens de Catalogne et du Languedoc par la méthode U-Th. Comparaisons avec la méthode ESR. Phd Thesis, MNHN, Paris, 149 p.
Ambert, P., 1993. Preuves geologiques de l'insularite du massif de la Clape (Aude) pendant la transgression flandrienne. Comptes Rendus Académie des Sciences, Paris, 316, 237–244.
Argant, A., 2009. Biochronologie et grands mammifères au Pléistocène moyen et supérieur en Europe occidentale: l'apport des canidés, des ursidés et des carnivores en général. Quaternaire 20 (4), 467-480.

Argant, A., 1995. Un essai de biochronologie à partir de l'évolution dentaire de l'ours des cavernes. Datation du site de La Balme à Collomb (Entremont-le-Vieux, Savoie, France), Quaternaire 6 (3-4), 139-150.
Ashton, N., 1992. The High Lodge flint industries. In *:* Ashton N., Cook J., Lewis S.J., Rose J. (Eds.), *High Lodge. Excavations by G. de Sieveking, 1962-8, and J. Cook, 1988.* British Museum Press, 124-168.
Bachellerie, M., 2016. Les cervidés de la grotte de la Crouzade (Gruissan, Aude), caractérisation des populations, exploitation par les hommes du Pléistocène supérieur et modifications par les prédateurs. Master Thesis, Université de Perpignan, 55 p.
Bachellerie, M., 2017. Les artiodactyles de la grotte de la Crouzade (Gruissan, Aude) : Taphonomie, caractérisation des populations et exploitation par les hommes du Pléistocène supérieur. Master Thesis, Université de Perpignan, 112 p.
Bahain, J.J., Laurent, M., Falgueres, C., Voinchet, P., Farkh, S., Tissoux, H., 2002. Datation par résonance paramagnétique électronique (RPE) des formations fluviatiles pléistocènes et des gisements archéologiques ou paléontologiques associés, Quaternaire, 13, 91-103.
Banes, L., 1996. Les restes dentaires de la faune des Grottes des Ramandils (La Nouvelle – Aude) et de la Crouzade (Gruissan - Aude), Master Thesis, Université Paul Valéry, Montpellier III, 138 p.
Bazile F., 2002. Le premier Aurignacien en France méditerranéenne. Un bilan. Espacio, Tiempo y Forma, Série I, Prehistoria y Arqueologfa 15, 215-236.
Bazile F., 2006. Le premier Aurignacien en France méditerranéenne. Un bilan. *In* : F. Bon, J.M. Maillo Fernandez et D. Ortega i Cobos (Eds.), Autour des concepts de Protoaurignacien, d'Aurignacien archaïque, initial et ancien. Unité et variabilité des comportements techniques des premiers groupes d'hommes modernes dans le Sud de la France et le Nord de l'Espagne. Madrid, UNED, Serie I, Prehistoria y Arqueologia 15, 215-236.
Benazzi, S., Douka, K., Fornai, C., Bauer, C. C., Kullmer, O., Svoboda, J., Pap, I., Mallegni, F., Bayle, P., Coquerelle, M., Condemi, S., Ronchitelli, A., Harvati, K., Weber, G. W., 2011. Early dispersal of modern humans in Europe and implications for Neanderthal behavior. Letter to Nature, 479, 525–528.
Benazzi, S., Slon, V., Talamo, S., Negrino, F., Peresani, M., Bailey, S. E., Sawyer, S., Panetta, D., Vicino, G., Starnini, E., Mannino, M.A., Salvadori, P.A., Meyer, M., Pabo, S., Hublin, J. J., 2015. The makers of the Protoaurignacian and implications for Neandertal extinction. Science 348, 793–796.
Bertrand, B., 1999. Néandertaliens du Midi-Méditerranéen de la France, La Crouzade, Tournal, Le Portel, Pié-Lombard, Master Thesis, Institut de Paléontologie Humaine.
Bird, M. I., L. K. Ayliffe, L. K. Fifield, C. M. Turney, R. G. Cresswell, T. T. Barrows and B. David, 1999. Radiocarbon dating of "old" charcoal using a wet oxidation, stepped-combustion procedure. Radiocarbon 41 (2), 127-140.
Boëda, E., 1986. Approche du concept Levallois et évaluation de son champs d'application à travers trois gisements saaliens et weichséliens de la France septentrionale. PhD Thesis, Université Paris X-Nanterre.
Boëda, E., 1993. Le débitage discoïde et le débitage Levallois récurrent centripète. Bulletin de la Société préhistorique française 90, 392-404.
Boëda, E., 1994. Le concept Levallois : variabilité des méthodes. Monographie du CRA, n°9, CNRS Editions, 280 p.
Bonch-Osmolovski, G.A. 1925. Neanderthal remains in Crimea. American Journal of Physical Anthropology 8, 114–115.
Bordes, F., 1961. Typologie du Paléolithique ancien et moyen. Publications de l'Institut de Préhistoire de l'Université de Bordeaux, mémoire n°1, Delmas, 85 p.
Boulbes, N., 2009. Etude comparée de la denture d'*Equus hydruntinus* (Mammalia, Perissodactyla) dans le Sud-Est de la France. Implications biogéographiques et biostratigraphiques. Quaternaire 20 (4), 449-465.
Bourguignon, L., 1997. Le Moustérien de type Quina : nouvelle définition d'une entité technique. PhD Thesis, Université Paris X-Nanterre.

Bourguignon, L., Faivre, J.Ph., Turq, A., 2004. Ramification des chaînes opératoires : une spécificité du Moustérien ? Paleo 16, 41-61.
Bourguignon, L., Djema, H., Bertran, P., Lahaye, C., Guibert, P., 2008. Le gisement saalien de Petit-Bost (Neuvic, Dordogne) : à l'origine du Moustérien d'Aquitaine ?. In : Jaubert J., Bordes, J.G. et Ortega, I. (Org.), Les sociétés du Paléolithique dans un grand Sud-Ouest : nouveaux gisements, nouveaux résultats, nouvelles méthodes, séances de la SPF, 24-25 novembre 2006, Bordeaux, Bulletin de la Société Préhistorique Française, mémoire XLVII de la SPF, pp. 41-56.
Boutié, P., Ajaja, O., Banès, L., Molès, V., Kabiri, L., Grégoire, S., 2004 – Le gisement moustérien des Ramandils (Port-la-Nouvelle, Aude). Archéologie de la France-Informations, Languedoc-Roussillon. Online, 26 p.
Brock, F., Higham, T.F.G., Ditchfield, P & Bronk Ramsey, C. 2010. Current Pretreatment Methods for AMS Radiocarbon Dating at the Oxford Radiocarbon Accelerator Unit (ORAU). Radiocarbon 52 (1), 103-112.
Bronk Ramsey, C.,2017. Methods for Summarizing Radiocarbon Datasets. Radiocarbon, 59 (2), 1809-1833.
Brugal, J.P., Boudadi-Maligne, M., 2011. Quaternary small to large canids in Europe: Taxonomic status and biochronological contribution. Quaternary International 243, 171-182.
Capaldo, S.D., Blumenschine, R.J., 1994. A Quantitative diagnosis of notches made by hammerstone percussion and carnivore gnawing on bovid long bones. American Antiquity 59 (4), 724-748.
Carmignani, L., Moncel, M.H., Fernandes, P., Wilson, L., 2017. Technological variability during the early Middle Paleolithic in Western Europe. Reduction systems and predetermined products at the Bau de l'Aubesier and Payre (South-East France). *PLoS ONE* 12, 6, 49 p.
Chacón, M.G., 2009**.** The Middle Paleolithic in southwestern Europe: Abric Romaní (Capellades, Barcelona, Spain) Payre (Rompón, Ardèche, France) and Tournal (Bize, Aude, France). PhD. Thesis, Rovira i Virgili University (Tarragona, Spain) and Muséum National d'Histoire Naturelle (Paris, France).
Couturier, M., 1961. Détermination de l'âge du bouquetin des Alpes (*Capra aegagrus ibex ibex*) à l'aide des dents et des cornes. Mammalia 25 (4), 453-461.
Crégut-Bonnoure, E., 1992. Intérêt biostratigraphique de la morphologie dentaire de Capra (Mammalia, Bovidae). Annales Zoologici Fennici 28, 273-290.
Crégut-Bonnoure, E., 2002. Les Ovibovini Caprini et Ovini (Mammalia, Artiodactyla, Bovidae, Caprinae) du Plio-Pléistocène d'Europe : systématique, évolution et biochronologie. Thèse de Doctorat d'Etat, Université Claude Bernard Lyon I, 429 p.
Crégut-Bonnoure, E., 2007. Apport des Caprinae et Antilopinae (Mammalia, Bovidae) à la biostratigraphie du Pliocène terminal et du Pléistocène d'Europe. Quaternaire 18 (1), 73-97.
Dauvois, M., 1981. De la simultanéité des concepts Kombewa et Levallois dans l'Acheuléen du Maghreb et du Sahara nord-occidental.In: Préhistoires africaines. Mélanges offerts au doyen L. Balout, Paris, Editions ADPF, 313-321.
Davies, W., White, D., Lewis, M., Stringer C., 2015. Evaluating the transitional mosaic: frameworks of change from Neanderthals to Homo sapiens in eastern Europe. Quaternary Science Reviews 118, 211-242
Debénath, A., Dibble, H.L., 1994. Handbook of Paleolithic Typology: Lower and Middle Paleolithic of Europe. University Museum, University of Pennsylvania, Philadelphia.
Defleur, A., Valladas, H., Radulescu, C., Combier, J., Arnold, M., 1990. Stratigraphie et datation carbone-14, en spectrometrie de masse par accelerateur, du Mousterien recent de l'abri du Ranc de l'Arc (Ardeche France). C. R. Acad. Sci. Paris, Ser. II 311, 719–724.
Defleur, A., Bez, J.F., Cregut-Bonnoure, E., Fontugne, M., Jeannet, M., Magnin, F., Talon, B., Thinon, M., Combier, J., 1994b. Industries, biostratigraphie, restes humains et datation du gisement mousterien de la Baume Neron (Soyons Ardeche). C. R. Acad. Sci. Paris, Ser. II 318, 1409–1414.
Deviese, T., Comeskey, D., McCullagh, J ., Ramsey, C.B., Higham, T. 2018. New protocol for compound specific radiocarbon analysis of archaeological bones. Rapid Communications in Mass Spectrometry 32, 373-79.

Discamps, E., Jaubert, J., Bachellerie, F., 2011. Human choices and environmental constraints: deciphering the variability of large game procurement from Mousterian to Aurignacian times (MIS 5-3) in southwestern France Quaternary Science Reviews 3, 2755-2775.
Duran, J-P., Soler, N., 2006. Variabilité des modalités de débitage et des productions lithiques dans les industries moustériennes de la grotte de l'Arbreda, secteur alpha (Serinyà, Espagne). In: Bulletin de la Société préhistorique française, tome 103, n°2, 2006, 241-262
Eisenmann, V., 2018. http://www.vera-eisenmann.com/
Eixea, A., 2018. Middle Paleolithic lithic assemblages in western Mediterranean Europe from MIS 5 to 3 Journal of Archaeological Science: Reports 21, 643–666.
Forestier, H., 1993. Le Clactonien : mise en application d'une nouvelle méthode de débitage s'inscrivant dans la variabilité des systèmes de production lithique du Paléolithique ancien. Paleo, n°5, 53-82.
Gambier, D., Sacchi, D., 1991. Sur quelques restes humains leptolithiques de la grotte de la Crouzade, Aude. L'Anthropologie, 95, 155-180.
Gerber, J.P., 1973. La faune de grands mammifères du Würm ancien dans le Sud-Est de la France. Travaux du Laboratoire de Géologie historique et de Paléontologie de l'Université de Provence, Centre Saint-Charles, 310 p.
Golovanova, L.V., Hoffecker, J.F., Kharitonov, V.M., Romanova, G.P., 1999. Mezmaiskaya Cave: A Neanderthal occupation in the northern Caucasus. Current Anthropology 40, 77–89.
Goslar, T., 2018. Description of procedures of AMS ^{14}C dating used in the Poznań Radiocarbon Laboratory. https://radiocarbon.pl/en/sample-preparation/
Grégoire, S., 2000. Origines des matières premières des industries lithiques du Paléolithique pyrénéen et méditerranéen. Contribution à la connaissance des aires de circulation humaines. PhD. Thesis, Université de Perpignan.
Grégoire, S., Bazile, F. 2005**.** La diffusion du silex des Costières du Gard au Paléolithique supérieur. C.R. Palevol 4, 413-419.
Grégoire, S., Barsky, D. et Byrne, L. 2006**.** The Caune de l'Arago : an example of middle Pleistocene flint exploitation (Tautavel, Pyrénées-Orientales, France). Stone age, mining age. Der Ansmitt, Beiheft 19, 2005-VIII° International Flint Symposium, 13-17 september 1999, Bochum, Allemagne.
Grégoire, S. et Bazile, F. 2009. La lithothèque des matières premières siliceuses en Languedoc-Roussillon. Un outil pour la reconstitution des territoires. Els Pirineus i las arees circumdants durant el Tardiglacial. Mutacions i filiacions tecnoculturals, evolució paleoambiental (16000-10000 BP). Homenatge al professor Georges Laplace. XIV Col.loqui international d'arqueologia de Puigcerdà. Institut d'Estudis Ceretans Editor, 227-238.
Grün, R;, Katzenberger-Apel, O., 1994. An alpha irradiator for ESR dating, Ancient TL, 12, 35–38.
Guadelli, J.L., Delpech, F., 2000. Les Grands Mammifères du début du paléolithique supérieur à Temnata. In B. Ginter, J.K. Kozlowski, J.L. Guadelli, H. Laville (ed.), Temnata Cave. Excavation in Karlukovo Karst Area, Bulgaria, 53-158.
Guérin, G., Mercier, N., Adamiec, G., 2011. Dose-rate conversion factors: update. Ancient TL, 29, 5–8.
Heim, J.L., 1982. Les Enfants Néandertaliens de La Ferrassie. Masson et Cie, Paris.
Héléna, P., 1928. La stratigraphie de la grotte de la Crouzade (Commune de Gruissan, Aude), Bulletin de la Commission archéologique de Narbonne, T XVII, 1926-1927, 5-50.
Héléna P. and Héléna T., 1930. Rapport succinct des fouilles exécutées dans la grotte de La Crouzade (Aude) du 9 juillet au 6 août 1930. Institut de Paléontologie Humaine de Paris, 8p.
Henri-Gambier, D., Sacchi, D., 2008. La Crouzade V-VI (Aude, France) : un des plus anciens fossiles d'anatomie moderne en Europe occidentale. Bulletins et Mémoires de la Société d'Anthropologie de Paris 20, 1-2, 79-104.
Higham, T., Compton, T., Stringer, C., Jacobi, R., Shapiro, B., Trinkaus, E., … Fagan, M., 2011. The earliest evidence for anatomically modern humans in northwestern Europe. Nature, 479, 521-524.

Higham, T., Douka, K., Wood, R., Bronk Ramsey, C., Brock, F., Basell, L., Camps, M., Arrizabalaga, A., Baena, J., Barroso-Ruíz, C., Bergman, C., Boitard, C., Boscato, P., Caparros, M., Conard, N.J., Draily, C., Froment, A., Galvan, B., Gambassini, P., Garcia-Moreno, A., Grimaldi, S., Haesaerts, P., Holt, B., Iriarte-Chiapusso, M.J., Jelinek, A., Jorda Pardo, J.F., Maíllo-Fernandez, J.M., Marom, A., Maroto, J., Menendez, M., Metz, L., Morin, E., Moroni, A., Negrino, F., Panagopoulou, E., Peresani, M., Pirson, S., de la Rasilla, M., Riel-Salvatore, J., Ronchitelli, A., Santamaria, D., Semal, P., Slimak, L., Soler, J., Soler, N., Villaluenga, A., Pinhasi, R., Jacobi, R., 2014. The timing and spatiotemporal patterning of Neanderthal disappearance. Nature 512, 306-309.
Hovers, E., Kimbel, W.H., Lavi, R., Rak, Y., 1995. Hominid remains from Amud Cave in the context of the Levantine middle Paleolithic. Paléorient 21(2), 47-61.
Hublin, J.J., 2015. The modern human colonization of western Eurasia: when and where? Quaternary Science Reviews 118, 194-210.
Inizan, M.-L., Reduron, M., Roche, H., Tixier, J., 1995. *Technologie de la pierre taillée.* Préhistoire de la pierre taillée, t. 4, C.R.E.P., 199 p.
Khaska, M., Le Gal La Salle C., Lancelot, J., ASTER team, Mohamad A., Verdoux, P., Noret, A., Simler, R., 2013. Origin of groundwater salinity (current seawater vs. saline deep water) in a coastal karst aquifer based on Sr and Cl isotopes. Case study of the La Clape massif (southern France). *Applied Geochemistry* 37, 212-227.
Klein, R.G., Wolf, C., Freeman, L.G., Allwarden, K., 1981. The use of dental crown heights for constructing age profiles of Red Deer and similar species in archaeological samples, Journal of Archaeological Science 8, 1-31.
Kuhn, S. L., 2013 : Roots of the middle Paleolithic in Eurasia. *Current Anthropology*, *54*, S8, 255-268.
Klein, R.G., Allwarden, K., Wolf, C., 1983. The calculation and interpretation of Ungulate age profiles from dental crown heights. In G. Bailey dir., Hunter-gatherer economy in Prehistory: a European perspective, Cambridge University Press, Cambridge, 47-57.
Lebègue, F., 2004. Les industries moustériennes du Languedoc : Etude techno-typologique des gisements de La Crouzade et de Montou. Mémoire de DEA du Muséum d'Histoire Naturelle de Paris.
Lebègue, F., Boulbes, N., Gregoire, S., Moigne, A.-M., 2010. Systèmes d'exploitation, exploitation des ressources et mobilité des néandertaliens de l'Hortus. In ; Conard N., Delagnes A. (eds), Settlement dynamics of the Middle Paeolithic and Middle Stone Age, vol. III, 455-483.
Lebègue, F., 2012. Le Paléolithique moyen récente entre Rhône et Pyrénées. Approche de l'organisation techno-économique des productions lithiques, schémas de mobilité er organisation du territoire. PhD. Thesis, Université de Perpignan Via Domitia,
Leroi-Gourhan, A., 1964. Le geste et la parole. Tome 1 : Technique et langage*.* Albin Michel, 326 p.
Lespinasse, P., Aloisi, J.C., Barruol, J., Durand-Delga, M., Got, H., Monaco, A., Marchal, J.P., 1982. Notice explicative, Carte geologique de France (1/50 000), feuille Narbonne (1061). BRGM Ed, Orleans. 51 p.
Longin, R.,1971. New Method of Collagen Extraction for Radiocarbon Dating. Nature 230 (5291), 241-242.
Lumley-Woodyear de, H., 1971. Le Paléolithique inférieur et moyen du Midi de la Méditerranée dans son cadre géologique, t. I, Bas Languedoc-Roussillon-Catalogne, V° Supplément Gallia préhistoire, Presse du CNRS, Paris, 463 p.
Lumley-Woodyear de, H., 1972. La grotte de l'Hortus (Valflaunès, Hérault). Les chasseurs néandertaliens et leur milieu de vie. Elaboration d'une chronologie du Wurmien II dans le midi méditerranéen. Etudes Quaternaires 1, 668 p.
Lumley-Woodyear de, M. H., 1973. Anténéandertaliens et néandertaliens du bassin méditerranéen occidental européen. Etudes Quaternaires Géologie, Paléontologie, Préhistoire. Mémoire n°2. Editions du Laboratoire de Paléontologie Humaine et de Préhistoire. Université de Provence, Marseille, 569-573.

Magniez, P., 2010. Incidence des fluctuations climatiques sur la taille du renne (*Rangifer tarandus*) au Pléistocène supérieur. Quaternaire 21 (3), 259-279.
Magniez, P., 2009. Nouvelles données sur le genre *Capra* Linné, 1758 (Mammalia, Bovidae) du Pléistocène supérieur de la Grotte Tournal (Bize-Minervois, France) : implications biochronologiques et évolutives. Quaternaire 20 (4), 509-525.
Magniez, P., Boulbes, N., 2014. Environment during the Middle to Late Paleolithic transition in southern France: The archaeological sequence of Tournal Cave (Bize-Minervois, France). Quaternary International 337, 47-63.
Maroto, J., Vaquero, M., Arrizabalaga, A., Baena, J., Baquedano, E., Jordá, J., Julià, R., Montes, R., Van Der Plicht, J., Rasines, P., Wood, R., 2012. Current issues in late Middle Paleolithic chronology: New assessments from Northern Iberia, Quaternary International 247,15-25.
Maureille, B., 2002. A lost Neanderthal neonate found. Nature 419, 33.
Moigne, A.M., 1983. Taphonomie des faunes quaternaires de la Caune de l'Arago, Tautavel. PhD Thesis, MNHN et Université Pierre et Marie Curie, Paris 6.
Moigne, A.M., Baills, H., Grégoire, S., 1998. Les magdaléniens de la grotte des Conques: caractérisation du site d'après l'outillage et les restes osseux. In Economie préhistorique : les comportements de subsistance au Paléolithique. Acts of the XVIIIth Rencontres Internationales d'Archéologie et d'Histoire d'Antibes. October 23th-25th 1997, APDCA Ed., 397-411.
Moles, V., Boutié, P., 2009. Contribution à la reconnaissance d'une microproduction au Paléolithique moyen : les industries de la grotte des Ramandils (Port-La Nouvelle, Aude, France). L'Anthropologie 113, 356-380.
Mourer-Chauviré, C., 1980 - Le gisement pléistocène supérieur de la grotte de Jaurens, à Nespouls, Corrèze, France : les Equidés (Mammalia, Perissodactyla). Nouvelles Archives du Muséum d'Histoire Naturelle de Lyon, 18, 17-60.
Pelletier, M., Royer, A., Holliday, T.W., Discamps, E., Madelaine, S., Maureille, B., 2017. Rabbits in the grave! Consequences of bioturbation on the Neandertal "burial" at Regourdou (Montignac-sur-Vezere, Dordogne) Journal of Human Evolution 110, 1-17.
Peresani, M., 2003. Discoid Lithic Technology. Archaeopress. *Bar International Series, Oxford*.
Pernaud, J., Quiles, J., Rivals, F., 2004. La faune de la fin du Pléistocène dans la haute vallée de l'Aude : L'exemple de la grotte du Castel 2 à Bessède-de-Sault (Aude, France). In Secrétariat du Congrès (Ed.), Acts of the XIVth UISPP Congress, section 3: Paléoécologie/Paleoecology. University of Liège, Belgium. British Archaeological Reports S1271, Archaeopress, Oxford, 31-37.
Perrenoud, C., 1995. Trou de La Crouzade (Gruissan, Aude) campagne de prélèvements 1995, 21 Mars-21 Avril, site n° 11.170.002.P, Unpublished, Service Régional de l'Archéologie du Languedoc-Roussillon, 30p.
Pickering, T.R, Egeland, C.P., 2006. Experimental pattern of hammerstone percussion damage on bones: implications for inferences of carcass processing by humans. Journal of Archaeological Science 33, 459-469.
Piotrowska, N. and T. Goslar, 2002. Preparation of bone samples in the Gliwice Radiocarbon Laboratory for AMS radiocarbon dating. Isotopes Environ Health Stud 38 (4), 267-275.
Pigeaud, R., 2017. L'Homme préhistorique et la Mort. C. R. Palevol 16, 167–174.
Prat, F., 1968. Recherches sur les Equidés pléistocènes de France. PhD. Thesis, Université de Bordeaux 1, 622 p.
Prescott, J.R., Hutton, J.T., 1994. Cosmic ray contributions to dose rates for luminescence and ESR dating: large depths and long-term time variations, Radiation Measurements, 23, 497–500.
Prince, G., 2000. Contribution à l'étude des industries de la grotte du Portel-Ouest. Etude techno-typologique des industries moustériennes. PhD. Thesis, Université de Perpignan.
Quiles, J., 2003. Les Ursidae du Pléistocène moyen et supérieur en Midi méditerranéen. Apports paléontologiques, biochronologiques et archéozoologiques. PhD. Thesis, Muséum National d'Histoire Naturelle, Paris.
Rabeder, G., Tsoukala, E., 1990. Morphodynamic analysis of some cave-bear teeth from Petralona cave (Chalkidiki, North-Greece). Beiträge zur Paläontologie Österreich 16, 103-109.

Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., Grootes, P.M., Guilderson, T.P., Haflidason, H., Hajdas, I., Hatt, C., Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M., & van der Plicht, J., 2013. IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0-50,000 Years cal BP. Radiocarbon, 55 (4), 1869–1887.
Riglet, P.H., 1977. Contribution à l'étude de l'âge du Cerf élaphe (*Cervus elaphus* L.). Thèse de l'École nationale vétérinaire d'Alfort 104, 75 p.
Rivals, F., Testu, A., 2006. Un nouveau gisement paléontologique à *Capra caucasica praepyrenaica* : la grotte de l'Arche à Bugarach (Aude, France). Comptes Rendus Palevol 5, 711-719.
Rousseau, T., 1874. Habitation préhistorique de La Crouzade, Bulletin de la Société d'Histoire Naturelle de Toulouse 8, 363-372.
Ruebens, K., McPherron, S. J. P., Hublin, J. J., 2015. On the local Mousterian origin of the Châtelperronian: Integrating typo-technological, chronostratigraphic and contextual data Journal of Human Evolution 86, 55-91.
Rusch, L., Boulbes, N., Lartigot-Campin, A.S., Pois, V., Testu A., Bahain, J.J., Falguères, C., Shao, Q., Moigne, A.M., Saos T., Boutié P., 2019. Contexte paléoenvironnemental et chronologique des occupations néandertaliennes de la grotte des Ramandils (Port-la-Nouvelle, Aude, France). Apport des restes de grands mammifères. Quaternaire, 30 (2), 151-165.
Sacchi, D., 1986. Le Paléolithique supérieur du Languedoc Occidental et du Roussillon, Supplément à Gallia-Préhistoire 21, CNRS, 284 p.
Saos, T., Grégoire, S., Moigne, A.-M., Testu, A., Boulbes, N., Bachellerie, M., Alladio, A., Billy, J., Raynal, O., Ortega-Cordellat, M.I., Bahain, J.J., Shao, Q., Falguères, C., Dainat, D., Milizia, C., 2017. Grotte de La Crouzade (Gruissan, Aude), rapport de fouille programmée triennale 2016-2018, rapport intermédiaire 2017. Unpublished, Service Régional de l'Archéologie, Montpellier, 76 p.
Saos, T., Grégoire, S., Moigne, A.M., Testu, A, Boulbes, N., Perrenoud, C., Pois, V., Rusch, L., Lartigot-Campin, A.S., Chevalier, T., Becam, G., Lebreton, L., Celiberti, V., Alladio, A., Bachellerie, M., Milizia, C., Bahain, J.J., Falguères, C., Voinchet, P., Shao, Q., Elalouf, J.M., Marsolier-Kergoat, M.C., Moncel, M.H., Bourguignon, L., Chacon Navarro, M.G., Barsky, D., Magniez, P., Molès, V., Duran, J.P., Ivorra, J., Dainat, D., 2016 - Rapport du Programme Collectif de Recherches "Le monde moustérien méditerranéen entre Rhône et Pyrénées", Année 2016. Unpublished. Service Régional de l'Archéologie, Montpellier, 232 p.
Saos, T., 2003. Cadre stratigraphique, paléoclimatique et géochronologie du Languedoc-Roussillon au cours du Pléistocène supérieur d'après l'étude des remplissages de grottes. PhD. Thesis, Université de Perpignan.
Sauqué, V., García-Gonzalez, R., Rabal-Garces, R., Galan J., Núnez-Lahuerta, C., Gisbert, M., Cuenca-Bescos, G., 2018. Los Batanes: A trap for the Pyrenean wild goat during the Late Pleistocene (Spain) Quaternary International 48, 75-90.
Szmidt. C.C., Moncel. M.H., Daujeard C., 2010. New data on the Late Mousterian in Mediterranean France. C.R Palevol 9, 185-199.
Shao, Q, Bahain, J.J, Dolo, J.M, Falgueres, C, 2014. Monte Carlo approach to calculate US-ESR ages and their uncertainties, Quaternary Geochronology, 22, 99-106
Sicard G, 1900. L'Aude préhistorique ou inventaire des monuments et découvertes préhistoriques du département de l'Aude, Carcassonne, Bonnafous-Thomas, 104 p.
Slimak. L., 2007. Le Neronien et la structure historique du basculement du Paleolithique moyen au Paleolithique superieur en France mediterraneenne. C. R. Palevol 6, 301–309.
Solecki, R.L., Solecki, R.S., 1970, A new secondary flaking technique at the Nahr-Ibrahim cave site, Lebanon. Bulletin du Musée de Beyrouth 23, 137-142.
Szmidt, C.C., Daugeard, C., Moncel, M.H., 2010. New data on the Late Mousterian in Mediterranean France: First radiocarbon (AMS) dates at Saint-Marcel Cave (Ardeche). C. R. Palevol 9, 185-199.

Tavoso, A., 1987. Le remplissage de la grotte Tournal à Bize-Minervois (Aude). *Cypsela*, 6, 23-25.
Tissoux, H., 2004. Datation par Uranium-Thorium et par résonance paramagnétique électronique de quelques gisements paléolithiques du Pléistocène supérieur de Catalogne (Espagne) et du sud de la France. PhD. Thesis, Muséum national d'histoire naturelle, Paris.
Tixier, J., Turq, A., 1999. Kombewa et alii. Paléo 11, 135-143.
Turq, A., Roebroeks, W., Bourguignon, L., Faivre, J.Ph., 2013. The fragmented character of Middle Paleolithic stone tool technology. Journal of Human Evolution 65, 641-655.
Urena, I., Ersmark, E., Samaniego, J.A., Galindo-Pellicena, M.A., Cregut-Bonnoure, E., Bolívar, H., Gomez-Olivencia, A., Rios-Garaizar, J., Garate, D., Dalen, L., Arsuaga, J.L.,
Valdiosera, C.E., 2018. Unraveling the genetic history of the European wild goats. Quaternary Science Reviews 185, 189-198.
Valladas, H., Chadelle, J.P., Geneste, J.M., Joron, J.L., Meignen, L., Texier, P.J., 1987. Datations par la thermoluminescence de gisements mousteriens du Sud de la France. L'Anthropologie 91, 211–226.
Valladas, H., Mercier, N., Falgueres, C., Bahain, J.J., 1999. Contribution des methodes nucleaires a la chronologie des cultures paleolithiques entre 300,000 et 35,000 ans BP. Gallia Prehistoire 41, 153–166.
Vaissié, E., Delvigne, V, Faivre, J.-P., Fernandes, P., Turq, A., Raynal, J.P., 2017. Techno-economy and cultural significance of the upper Mousterian occupation from Baume-Vallée (Haute-Loire). C. R. Palevol 16, 804–819.
Valensi, P., Psathi, E., 2004. Faunal exploitation during the Middle Paleolithic in South-Eastern France and North-Western Italy. International Journal of Osteoarchaeology 14 (3-4), 256–272.
Yokoyama, Y., Nguyen, H.V., Quaegebeur, J.P., Jean-Pierre, F., 1987. Datation par la spectrométrie gamma non destructive et la résonance de spin électronique (ESR) du remplissage de la grotte Tournal à Bize. Cypsela VI, 145–149.

Figures legends:

Fig 1 : Geological map and location of La Crouzade cave (modified from Khaska 2013)

Fig. 2 : Cave plan and location of Héléna's excavations (1, 2, 2') and trench (3, purple) and new excavation (grey)

Fig. 3: La Crouzade cave transversal stratigraphic section in 68/69 bands.

Fig. 4: La Crouzade cave AMS radiocarbon dating results (bone and charcoal) and ESR-UTh ages (teeth)

Fig. 5: Lithic material from new excavations; a: CZ Q68 C7a n° 6 Diacritic sketch of orthogonal flaking core in Miocene flint; b: CZ Q64-C7c n° 140 Preferential Levallois core in Miocene flint; c: CZ S68-C7b n° 117 Centripetal recurrent Levallois core in Miocene flint; d : CZ S68-C7c n° 99 Discoid core in Miocene flint; e: CZ R64-C7b n° 220 Core on flake in Miocene flint; f: CZ Q65 C7a. n°1 transversal scraper in quartz; g: CZ S68 C7b n°76 scraper-bec in Oligocene flint; h : CZ Q64 C7a n° 97 lateral scraper in Miocene flint; i: CZ S68 C7b n° 88 Levallois flake in Miocene flint; j: CZ Q64 C7c n° 214 limace in Miocene flint. Diacritical sketch a: Alex Alladio; drawings b, c, d, e, f, g, h, i, j : Christelle Milizia.

Fig. 6. Selected large mammal remains from La Crouzade cave, Mousterian levels. A: *Capra praepyrenaica* cranium in lateral view (CZQ64.C7.79, B: *Equus hydruntinus davidi* first phalanx in dorsal view (CZ Q68.C7.88), C: *Cervus elaphus* second phalanx in lateral view (CZ

S60.C6.1), D: *Equus ferus germanicus* capitatum in proximal view (CZ Q68.C7.176), E: *Crocuta spelaea* coprolite (CZ R64.C7.213), F: *Panthera spelaea* first phalanx I in dorsal view (CZ Q68.C7.217), G: *Panthera pardus* left distal fibula in lateral view (CZ S68.C7.49), H: *Ursus spelaeus* right lower first molar in lingual view (CZ Q63.C6.21). Scale bar 1 cm.

Fig. 7 - Variability Size Index (VSI) of Late Pleistocene horses. Standard site: Jaurens (Eisenmann, 2018 ; Mourer-Chauviré, 1980). N = number of specimens.

Fig. 8: Neanderthal remains from La Crouzade cave.

Fig 9: The anatomically modern human frontal bone from La Crouzade cave.

Fig. 10: The anatomically modern human maxilla from La Crouzade cave.

Tables legends :

Table 1: La Crouzade cave AMS radiocarbon dating results (bones and charcoals).

Table 2: Radioelements contents of La Crouzade cave sediments.

* a K factor (alpha efficiency) of 0.13 ± 0.02 has been used (Grün & Katzenberger-Appel, 1994). The gamma dose was measured in situ with TL dosimeters (mean of four measurements) and the cosmic dose was calculated using Prescott and Hutton's (1994) tables; ** age uncertainties were calculated using a Monte Carlo approach (Shao et al*.*, 2014).

Table 3: Palaeodose, uranium uptake parameters, contributions of the various radiations in the dose rate and ESR/U-series ages obtained for La Crouzade (Aude) samples.

Table 4: La Crouzade cave raw materials composition by layers (all material) and by distinguishing pieces <2 cm (uncoordinated)

Table 5: Main categories of identifiable products by layers from former and current excavation (CE*) and by distinguishing pieces <2 cm (uncoordinated) from La Crouzade cave.

Table 6 : Main categories of tools in number and percentage, by layer (all materials)

Table 7 : Faunal list and large mammals number of identified specimens (NISP) from La Crouzade cave.

Table 8: Human remains from La Crouzade cave.

Table 9 : Dates of Late Mousterian comparison sites in the nearby Mediterranean area.
AAR: amino acid racemisation; 14C: radiocarbon; AMS: accelerator mass spectrometry; Conv.: conventional; ESR: electron spin resonance; TL: thermoluminescence; U-Pa: uranium-protactinium; U-Th: uranium-thorium. The radiocarbon calibrated dates were obtained using the OxCal 4.3.2 calibration curve (Bronk Ramsey, 2017), based on the IntCal13 dataset (Reimer et al., 2013)

Appendix legends

Appendix 1: Stratigraphical correlations (Héléna 1928, 1930; de Lumley 1971; current excavation)
All profiles have the same orientation, facing the back of the cave.

Héléna's synthetic stratigraphy made in 1928 near the middle of the cave; Héléna's levels in 1928 A: Iron age to Historical period; B: Neolithic; C: Azilian; D: Magdalenian; E: Upper Aurignacian; F: Typical Aurignacian; G: Lower Aurignacian; L: Yellow silt; S: Stones

Héléna's levels in 1930 towards the back of the cave (no cross section)
1: Neolithic to Gallo-Roman; 2: Neolithic; 3: Upper Azilian; 4: Azilian; 5: Middle Aurignacian; 6: Lower Aurignacian; 7: Upper Mousterian; 8: Typical Mousterian

De Lumley's Levels in 1971 in a synthetic cross section observed in Héléna's last excavation
1: La Tène; 2: Néolithique; 3: Azilian; 4^1: Magdalenian V; 4^2: Upper Perigordian; 5^1: Gravettian; 5^2: Aurignacian; 6: Paracharentian Mousterian; 7: Paracharentian Mousterian; 8: Paracharentian Mousterian

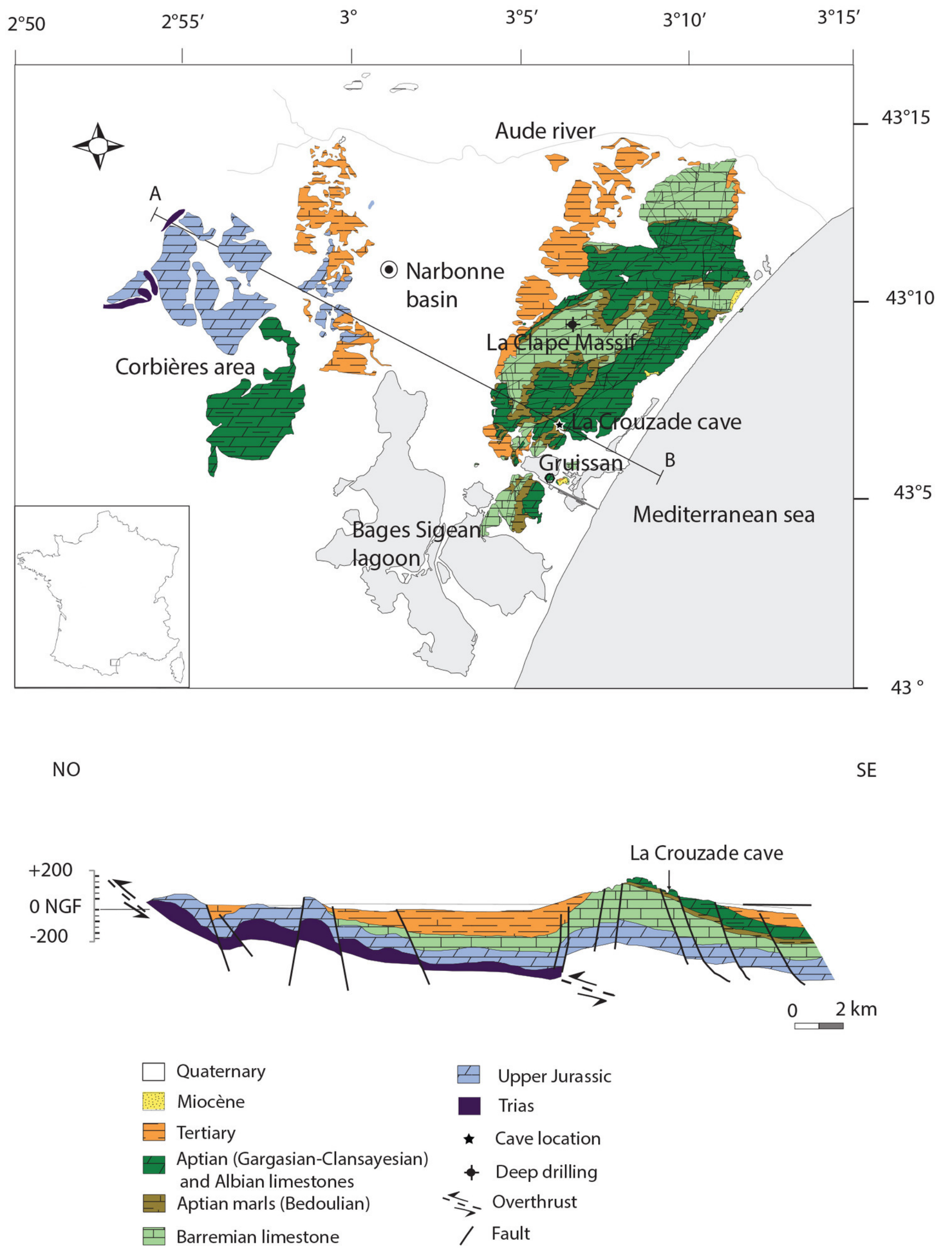
68/69 transverse stratigraphic section visible in current excavation, highlighting the three main Middle Palaeolithic layers (C6, C7 and C8).

Appendix 2: Archaeozoological data from the most representative animals from all mousterian layers in La Crouzade: reindeer (*Rangifer tarandus*), ibex (*Capra praepyrenaica*) and horse (*Equus c. germanicus*).
Traces are classified with anatomical origin: gnawing, including grooves, striation, scores or pits related to carnivorous activities. Green fractures are related to fresh fragmentation on long bones mostly attributed to human activities. Impact notches are linked to bone breakage attributed to carnivore or human activities. Cutmarks to striations made with lithic tools. Tools are mostly retouchers.

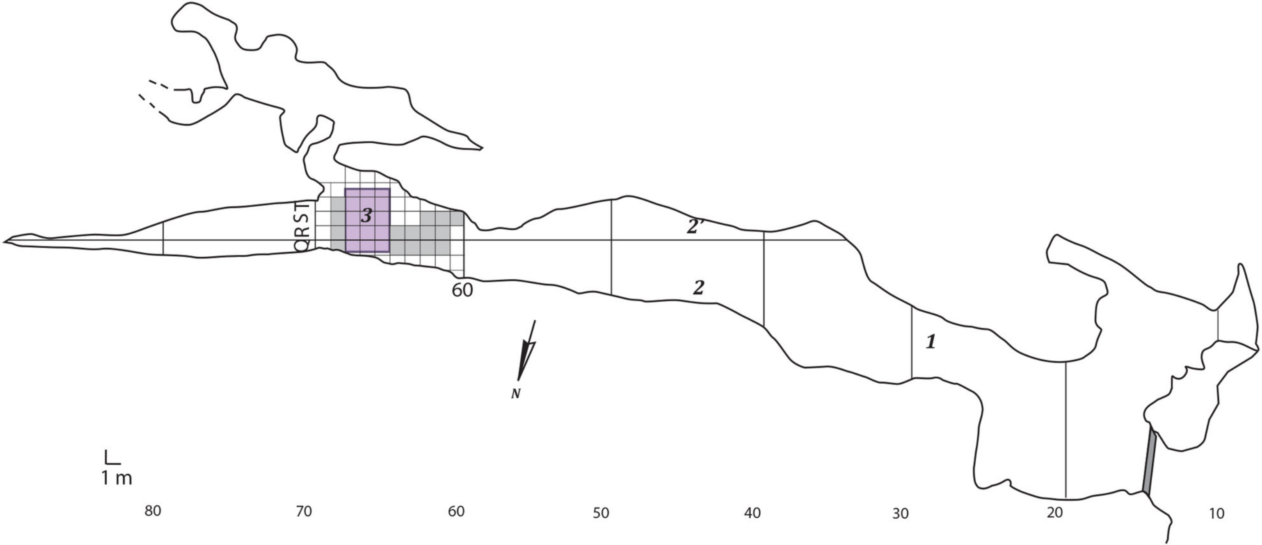
Appendix 3:
Preserved elements of ibex humerus from Limon Jaune Inférieur layer
A: Cranial view, B: Caudal view, C: Lateral view

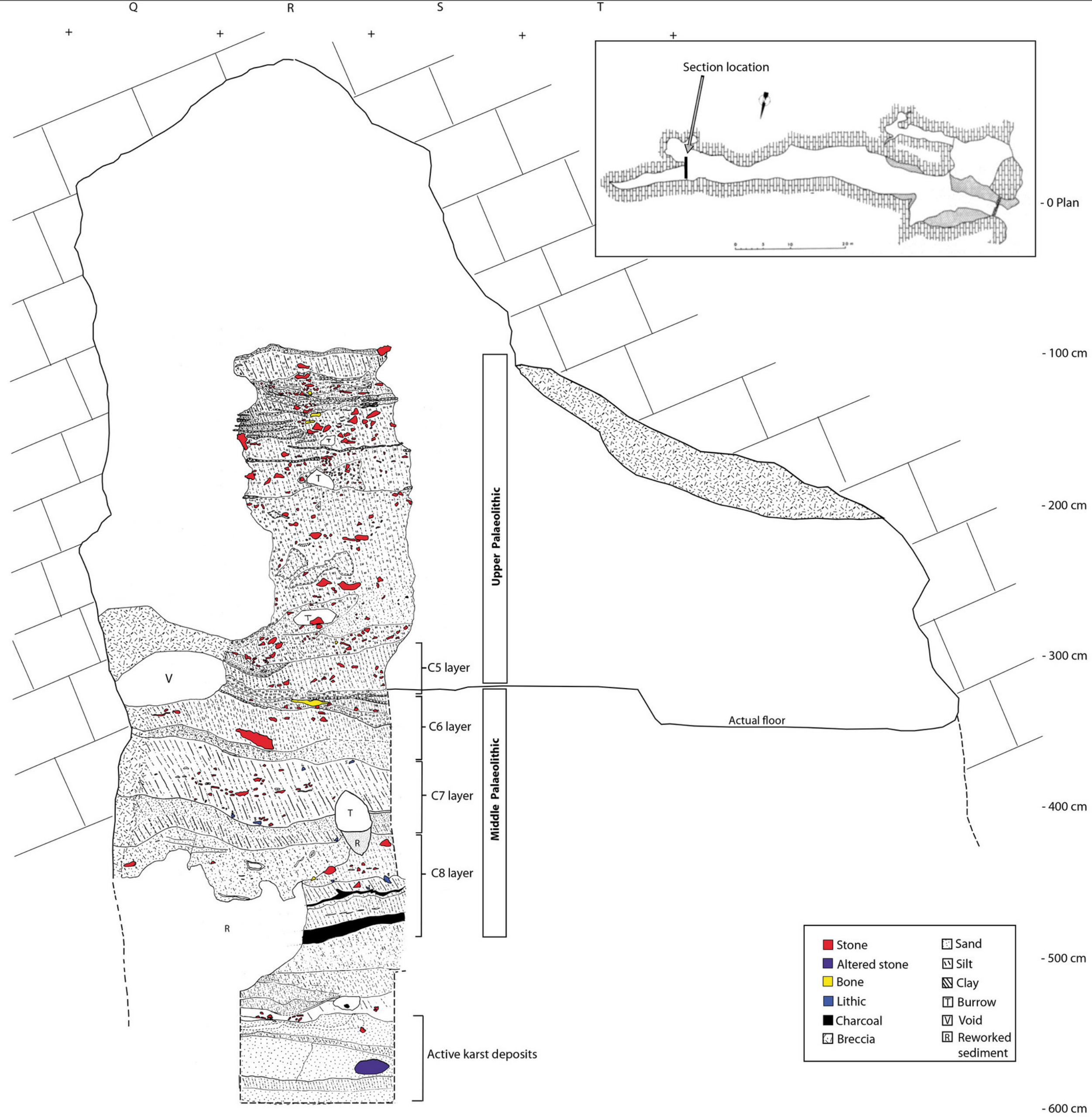
Appendix 4:
Preserved elements of Reindeer Humerus from all Middle Palaeolithic layers combined
A: Medial view, B: Caudal view, C: Cranial view, D: Lateral view

Appendix 5 : Location map of mentioned sites

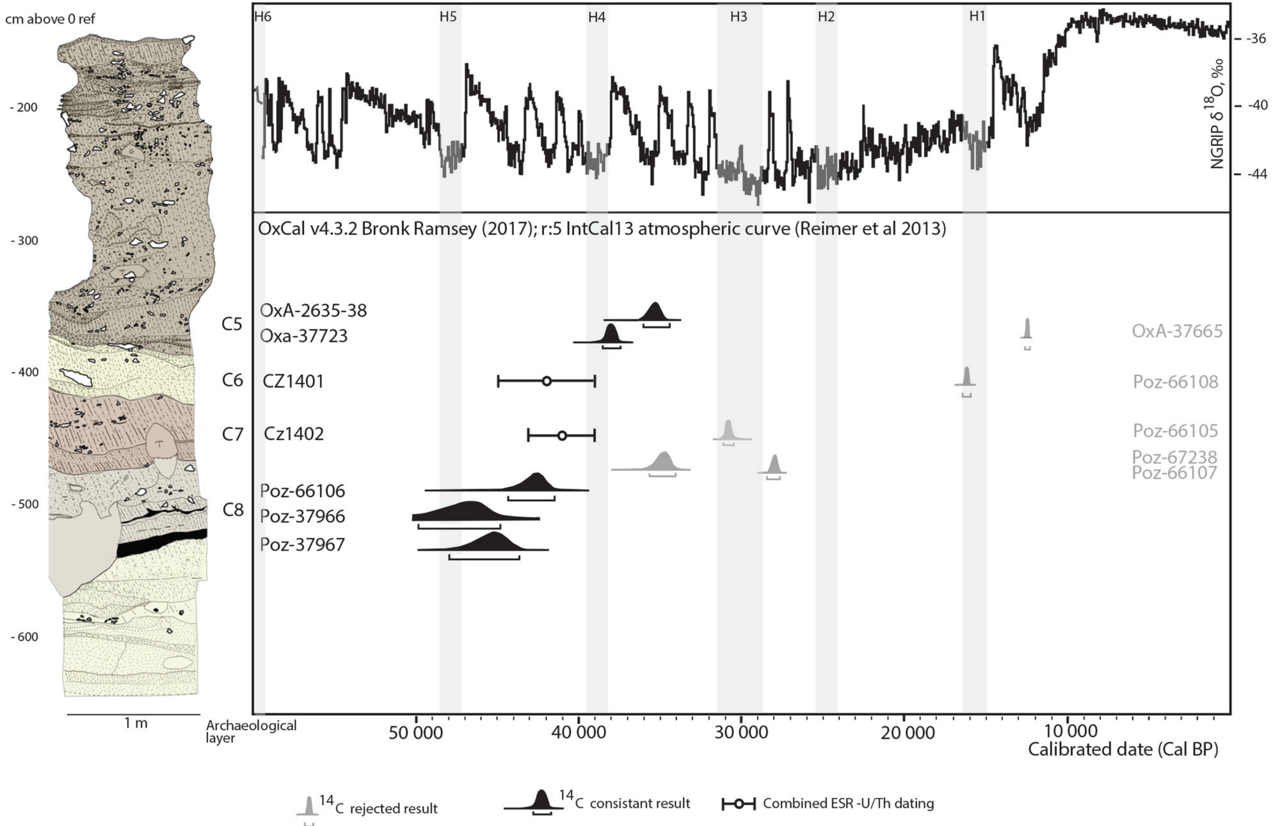


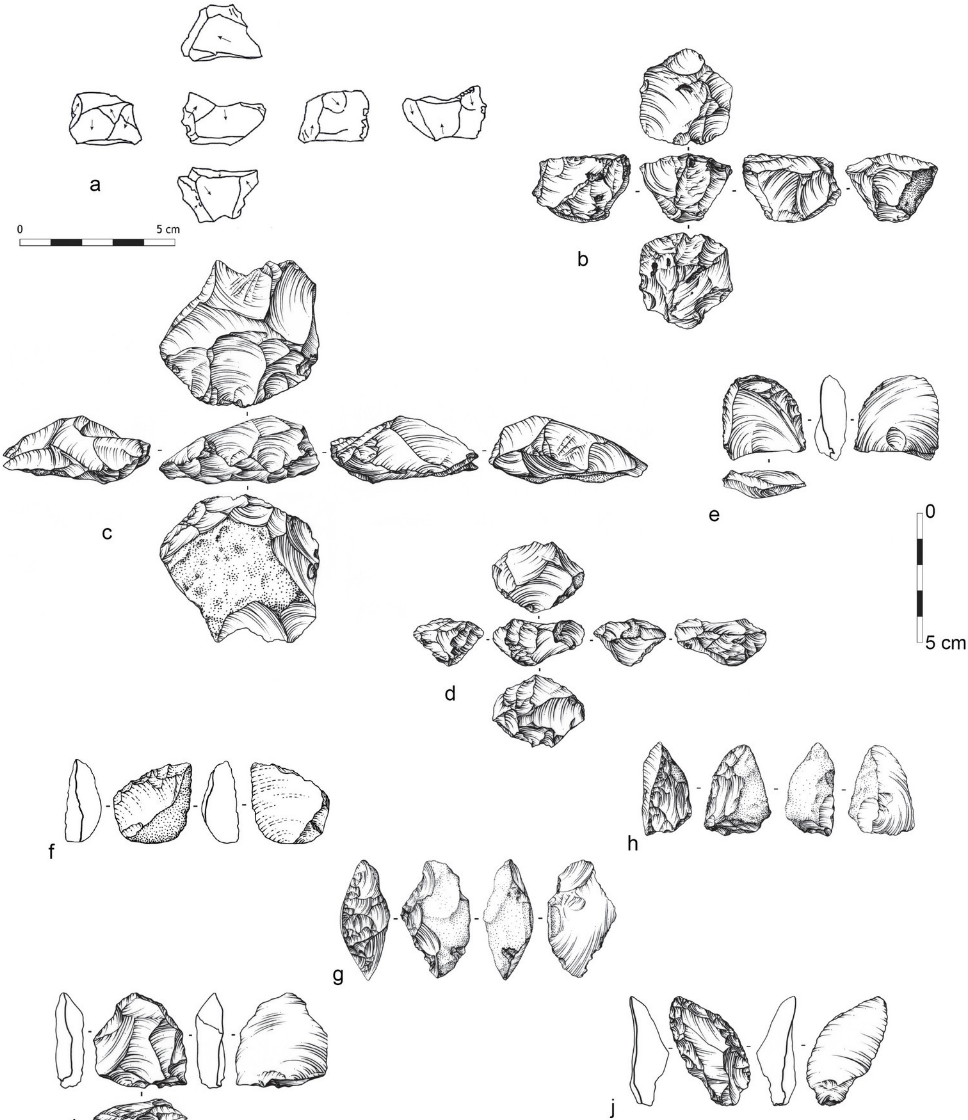
2°50
2°55′
3°
3°5′
3°10′
3°15′
43°15
43°10
43°5
43 °
Aude river
A
B
Narbonne
basin
Corbières area
La Clape Massif
La Crouzade cave
Gruissan
Mediterranean sea
Bages Sigean
lagoon
NO
SE
+200
0 NGF
-200
La Crouzade cave
0
2 km
Quaternary
Miocène
Tertiary
Aptian (Gargasian-Clansayesian)
and Albian limestones
Aptian marls (Bedoulian)
Barremian limestone
Upper Jurassic
Trias
Cave location
Deep drilling
Overthrust
Fault

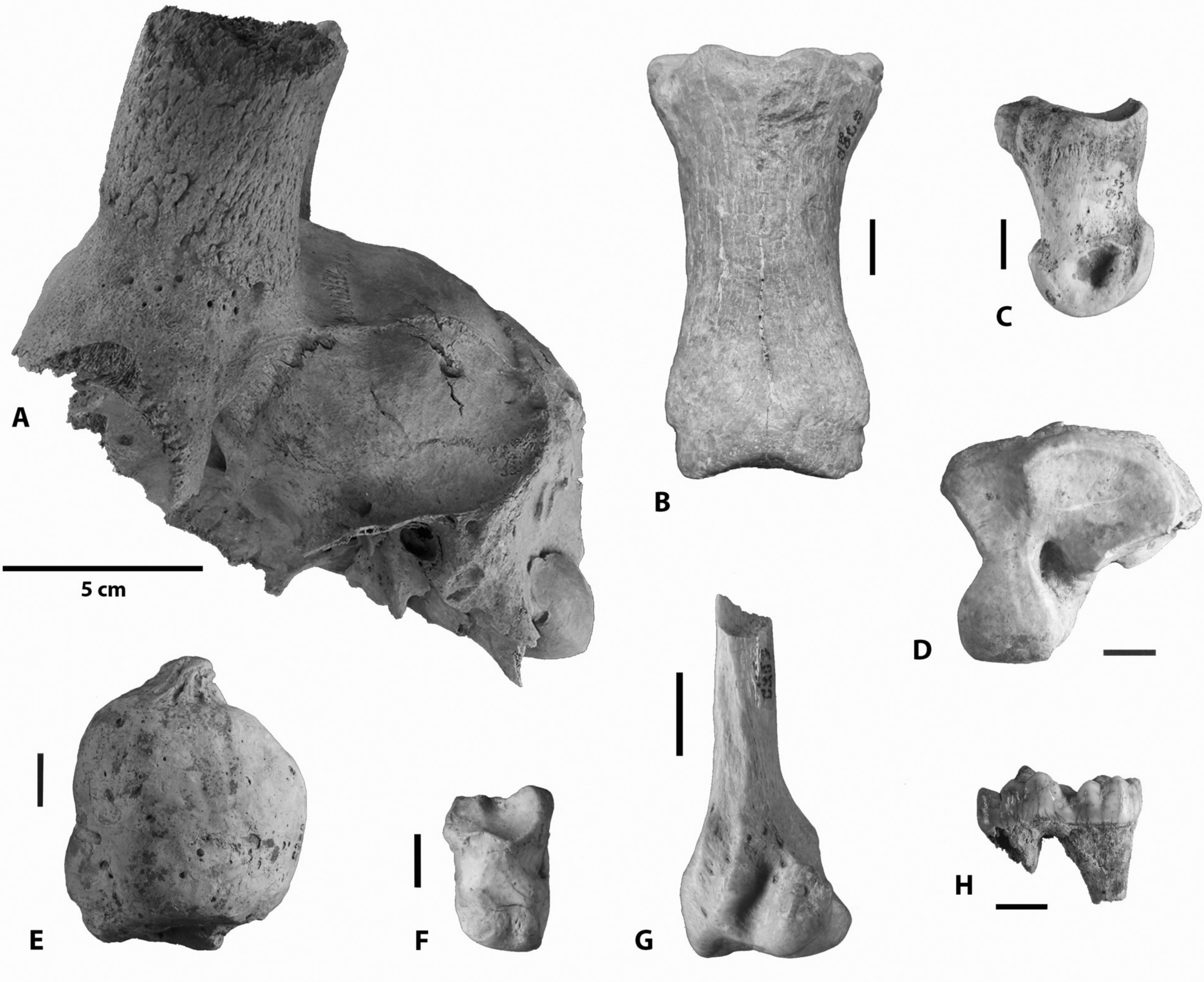

QRST
3
2'
2
1
60
N
1 m
80
70
60
50
40
30
20
10



Q
R
S
T
Section location
- 0 Plan
- 100 cm
- 200 cm
- 300 cm
- 400 cm
- 500 cm
- 600 cm
Upper Palaeolithic
Middle Palaeolithic
C5 layer
C6 layer
C7 layer
C8 layer
Active karst deposits
Actual floor
V
T
R
Stone
Altered stone
Bone
Lithic
Charcoal
Breccia
Sand
Silt
Clay
Burrow
Void
Reworked sediment


cm above 0 ref
- 200
- 300
- 400
- 500
- 600
1 m
Archaeological layer
H6
H5
H4
H3
H2
H1
NGRIP δ 18O, ‰
-36
-40
-44
OxCal v4.3.2 Bronk Ramsey (2017); r:5 IntCal13 atmospheric curve (Reimer et al 2013)
C5
OxA-2635-38
Oxa-37723
OxA-37665
C6
CZ1401
Poz-66108
C7
Cz1402
Poz-66105
Poz-67238
Poz-66107
C8
Poz-66106
Poz-37966
Poz-37967
50 000
40 000
30 000
20 000
10 000
Calibrated date (Cal BP)
14C rejected result
14C consistant result
Combined ESR -U/Th dating


a
0
5 cm
b
c
e
0
5 cm
d
f
h
g
i
j


A
5 cm
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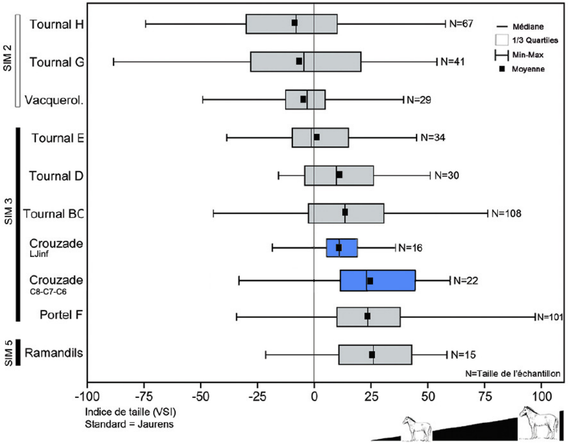
SIM 2
Tournal H
Tournal G
Vacquerol.
SIM 3
Tournal E
Tournal D
Tournal BC
Crouzade
LJinf
Crouzade
C8-C7-C6
Portel F
SIM 5
Ramandils
N=67
N=41
N=29
N=34
N=30
N=108
N=16
N=22
N=101
N=15
Médiane
1/3 Quartiles
Min-Max
Moyenne
N=Taille de l'échantillon
-100
-75
-50
-25
0
25
50
75
100
Indice de taille (VSI)
Standard = Jaurens


CX
CI
CIX
CIV
CII
CIII


0 1 2 3 4 5 cm

Table 1: La Crouzade AMS radiocarbon dating results (bones and charcoals).

Sample name	Lab Code	Dating year	Material	Discovery year	level	Conventional radiocarbon age (BP)	Calibrated age (2σ) OxCal 4.3.2- cal BP (Reimer et al, 2003)
La Crouzade S2	Poz-37966	2010	charcoal	1995	C8	42200 ± 1000 BP	48025-43861
La Crouzade S6	Poz-37967	2010	charcoal	1995	C8	43400 ± 1400 BP	49776-44805
CZC8-76104	Poz-66106	2014	bone	1946	C8	38700 ± 900 BP	44436-41566
CZC7-76103	Poz-66105	2014	bone	1928	C7	26660 ± 230 BP	31183-30503
CZC6-76102	Poz-66108	2014	bone	1928	C6	13430 ± 70 BP	16397-15914
CZLJInf-76105	Poz-66107	2014	bone	1928	LJInf	23950 ± 180 BP	28434-27690
CZLJInf-76108	Poz-67238	2014	bone	1928	LJInf	31000 ± 400 BP	35787-34181
CZQ63C541	OxA-37665	2018	charcoal	2017	C5	9340 ± 45 BP	12638-12371
CZQ63C561	OxA-37723	2018	charcoal	2017	C5	32060 ± 250 BP	38430-37331
La Crouzade VI	OxA-X-2635-38	2015	human bone	1928	C5	31200 ± 400 BP	36014-34402
La Crouzade VI	ERL-9415 *	2008	human bone	1931?	C5	30640± 640 BP	36021-33656

ERL-9415 *: Henri-Gambier and Sacchi, 2008

SRa
ZR

Sample name	P Code	Quantity of material used (mg)	Yield (mg)	%Yld	%C	δ^{13}C (‰) (VPDB)	% N,% C	C/N at
CZC8-76104	**AF**						15,5%N; 44,4%C	3.34
CZC7-76103	**AF**						14,9%N; 43,1%C	3.37
CZC6-76102	**AF**						16%N;43,6%C	3.17
CZLJInf-76108	**AF**						14,5%N; 40,7%C	3.28
CZQ63C541	YR	62	3.01	4.9	52.2	-25.2		
CZQ63C561	YR	76	7.41	9.8	77.8	-22.4		
La Crouzade VI	AF	130	4.94	3.8	43.1	-19.2		

P Code refers to pretreatment code; AF is ultrafiltered collagen (for bone) and YR is reduced carbon (for charcoal)[1]. Yield denotes the weight of carbon (for charcoal) and ultrafiltered gelatin (for bone) in milligrams. %Yld is the percent yield as a function of the starting weight of the sample. %C is the carbon present in the combusted gelatin or charcoal sample. Stable isotope ratios δ^{13}C and δ^{15}N are expressed in per mil (‰) relative to vPDB and AIR, respectively, with a mass spectrometric precision of ± 0.2‰[2]. C/N denotes the atomic ratio of carbon to nitrogen and is acceptable if it ranges between 2.9-3.5 in the case of collagen.

1 F. Brock, T. Higham, P. Ditchfield and C. Bronk Ramsey, *Radiocarbon* , 2010, **52**, 103-112.

2 B. Coplen Tyler, *Journal* , 1994, **66**, 273-276.

Site	Echantillon	^{238}U (ppm)	^{230}Th (ppm)	^{40}K (%)
Crouzade cave	Layer 6	3,04 ± 0,09	7,55 ± 0,12	1,13 ± 0,02
Crouzade cave	Layer 7	3,30 ± 0,10	5,81 ± 0,13	1,53 ± 0,02

sample	Nature	Paléodose (Gy)	U-uptake parameter p (US model)	Da (µGy/an)	ESR-U-series ages *** (US model) (ka)
CZ1401	Enamel	59,38 ± 0,62	-0,729 ± 0,081	1414 ± 102	**42 ± 3**
(C6 71008)	Dentine		-0,062 ± 0,131		
CZ1402	Enamel	44,39 ± 1,03	-0,945 ± 0,045	1083 ± 59	**41 ± 2**
(C7 81054)	Dentine		- 0,107 ± 0,087		

Raw material	C6	NC<2 cm	Total C6	C6 %	C7	NC< 2cm	Total C7	C7%	C8	NC<2 cm	Total C8	C8%	Total LJ inf	LJinf %	Total
Flint	69	87	156	**61%**	546	688	1234	**84.9%**	138	10	**148**	**54.0%**	**315**	**88%**	**1853**
Jasper			0	**0%**	4		4	**0.3%**			**0**	**0.0%**			**4**
Lydian	2		2	**1%**			0	**0.0%**			**0**	**0.0%**			**2**
Limestone			0	**0%**	10	1	11	**0.8%**			**0**	**0.0%**	**9**	**3%**	**20**
Hornfels			0	**0%**	4		4	**0.3%**			**0**	**0.0%**			**4**
Quartz	52	29	81	**32%**	59	74	133	**9.1%**	69	5	**74**	**27.0%**	**10**	**3%**	**298**
Sandstone	10	2	12	**5%**	5	2	7	**0.5%**			**0**	**0.0%**			**19**
Quartzite sandstone			0	**0%**	7		7	**0.5%**			**0**	**0.0%**	**5**	**1%**	**12**
Quartzite	4	2	6	**2%**	53		53	**3.6%**	51		**51**	**18.6%**	**19**	**5%**	**129**
Schist			0	**0%**	1		1	**0.1%**			**0**	**0.0%**			**1**
Rhyolite			0	**0%**			0	**0.0%**	1		**1**	**0.4%**			**1**
Total	137	120	257	**100%**	689	765	1454	**100.0%**	259	15	**274**	**100.0%**	**358**	**100%**	**2343**

Kind of products	**C6 Hélena**	**C6 CE***	**NC (<2cm)**	**Total C6**	**Total C6%**	**C7 Héléna**	**C7 CE***	**NC (<2cm)**	**Total C7**	**Total C7 %**	**C8 Héléna**	**C8 CE***	**NC (<2cm)**	**Total C8**	**Total C8%**	**Total Ljinf**	**Total Lj inf %**
Raw blocks		1		**1**	**0%**	8	1		**9**	**1%**				**0**	**0%**	**4**	**1%**
Initialisation products	7	5		**12**	**5%**	49	38		**87**	**6%**	44	2		**46**	**17%**	**27**	**8%**
Levallois products	14	5		**19**	**7%**	164	21		**185**	**13%**	69	2		**71**	**26%**	**62**	**17%**
laminar products				**0**	**0%**		4		**4**	**0%**	7			**7**	**3%**	**183**	**51%**
Discoid products	17			**17**	**7%**	34	6		**40**	**3%**	57			**57**	**21%**	**7**	**2%**
Quina products				**0**	**0%**	45	6		**51**	**4%**				**0**	**0%**		**0%**
Kombewa products				**0**	**0%**	7	4		**11**	**1%**	3			**3**	**1%**	**2**	**1%**
Non predetermined products	5	10		**15**	**6%**	47	39	42	**128**	**9%**	34	2		**36**	**13%**	**15**	**4%**
Retouch and re-sharpening flakes	1	25	38	**64**	**25%**	17	72	254	**343**	**24%**	3	2	3	**8**	**3%**	**13**	**4%**
Debris, undifined by-products	19	28	82	**129**	**50%**	41	86	469	**596**	**41%**	21	13	12	**46**	**17%**	**45**	**13%**
Total	63	74	120	**257**	**100%**	412	277	765	**1454**	**100%**	238	21	15	**274**	**100%**	**358**	**100%**

Tools	C6	C6 %	C7	C7 %	C8	C8 %	LJ inf	LJ inf %
Bec	3	12.5%	8	4.0%	1	1.3%	2	4.5%
Notche			14	7.0%	2	2.6%	4	9.1%
Denticulate	2	8.3%	5	2.5%	9	11.7%	3	6.8%
Limace			2	1.0%		0.0%		0.0%
Quinson pt			4	2.0%	1	1.3%		0.0%
Point			13	6.5%	4	5.2%		0.0%
Convergent scraper			4	2.0%	2	2.6%	2	4.5%
Scraper	2	8.3%	6	3.0%	6	7.8%	1	2.3%
Sidescraper	6	**25.0%**	75	**37.7%**	31	**40.3%**	18	**40.9%**
Canted side scraper	4	16.7%	28	14.1%	10	13.0%	1	2.3%
Double side scraper	2	8.3%	9	4.5%	1	1.3%	1	2.3%
Triple scraper			1	0.5%		0.0%		0.0%
Endscraper	1	4.2%	8	4.0%	2	2.6%	3	6.8%
Burin			3	1.5%	4	5.2%	1	2.3%
Troncation			1	0.5%		0.0%		0.0%
Percoir			1	0.5%		0.0%		0.0%
Knife					1	1.3%		0.0%
Raclette			1	0.5%		0.0%		0.0%
Multiples	4	16.7%	14	7.0%	4	5.2%	6	13.6%
Various			2	1.0%	1	1.3%	2	4.5%
Total	**24**	100%	**199**	100%	**77**	100%	**44**	100%

	Upper Pal. level	Mousterian levels			Upper Palaeolithic levels			Mousterian levels			
	C5	**C6**	**C7**	**C8**	**C2**	**C4**	**C5**	**C6**	**C7**	**C8**	**LJ inf**
		Excavation T. Saos			*Former excavations*						
***Lynx* sp.**	1	1	3					1			
Panthera pardus			1								
Panthera spelaea		1	6							1	
Crocuta crocuta spelaea	12	7	42				1	4	5	1	8
Vulpes vulpes	2	1	4		3		1	5	2	1	2
Canis lupus	9	2	4						3		2
Meles meles								1	3		1
Ursus spelaeus	26	119	19			2	1	103	46	14	19
Ursus arctos								2	1	1	1
Equus ferus germanicus		4	27	1				39	57	102	136
***Equus ferus* ssp.**	20					15					
Equus hydruntinus davidi	1		1			1		3	4	1	17
Coelodonta antiquitatis							2				
***Stephanorhinus* sp.**							1				
Bison priscus			1				1	1	1	6	8
Bos primigenius	3	1	4		1			8	5	7	15
Bovinae indet.	5	1	1					7	2	3	29
Capra praepyrenaica	25	14	31	1		3	1	34	34	18	105
***Rupicapra* sp.**		1						8	3	2	12
Saiga tatarica									1		3
Capreolus capreolus			1								1
Cervus elaphus	12	5	15			6		8	19	14	35
Rangifer tarandus	11	18	12		2	18	5	33	69	23	154
Megaloceros giganteus			1							1	
Sus scrofa	1						1	3	1		2
Total	128	175	173	2	6	45	14	260	256	195	550

	Bone/Teeth	Level from Héléna (1930)	Level from Lumley (1972)	Paleolithic context	Taxon	References
Crouzade I	Humerus	G	8	Mousterian	*H. neanderthalensis*	de Lumley, 1973
Crouzade II	Phalange	G	7	Mousterian	*H. neanderthalensis*	de Lumley, 1973
Crouzade III	Phalange	G or L	Inf. (8-7-6)	Mousterian	*H. neanderthalensis*	de Lumley, 1973
Crouzade IV	Phalange	L	g 6	Mousterian	*H. neanderthalensis*	de Lumley, 1973
Crouzade V	Frontal bone	F	5	Aurignacian	*H. sapiens*	Gambier and Sacchi, 1991
Crouzade VI	Maxilla	F	5	Aurignacian	*H. sapiens*	Gambier and Sacchi, 1991
Crouzade VII	M^3	D	4	Magdalenian	*H. sapiens*	Gambier and Sacchi, 1991
Crouzade VIII	Fragmentary skull	E?	5?	Gravettian?	*H. sapiens*	Gambier and Sacchi, 1991
Crouzade IX	humerus	G	7	Mousterian	*H. neanderthalensis*	Bertrand, 1999
Crouzade X	clavicle	G	8	Mousterian	*H. neanderthalensis*	Bertrand, 1999

Location	Site	Layer	Dating method(s)	Material dated	Age	14C Calibrated date using OxCal 4.3,2 (95,4 % probability) in cal BP	Industry	Laboratory number	References	Notes
Ardèche, France	Mandrin	B	TL	Flint	35000 ± 1600		Post-Neronian	Gif, no number	Slimak, 2007	average of 5 samples
Ardèche, France	Mandrin	6	^{14}C (AMS)	Bone	33300 ± 230	38356-36460	Neronian	Lyon2755OxA	Slimak, 2007	
Ardèche, France	Néron	III	^{14}C (Conv.)	Charcoal (pine)	43,000 ± 1100	49076-44561	Quina Mousterian	Gif/LSM9132	Defleur et al., 1994	
Ardèche, France	Ranc de l'Arc	5	^{14}C (AMS)	Charcoal	41300 ± 1900	49266-42508	Typical Mousterian	Gif, no number	Defleur et al., 1990	
Ardèche, France	Ranc de l'Arc	4 and 5	TL	Flint	46100 ± 3900		Typical Mousterian		Valladas et al., 1999	average of five samples
Ardèche, France	Saint-Marcel	f	^{14}C (AMS)	bone	37850 ± 550	42924-41385	Discoide Mousterian	OxA-19623	Szmidt et al., 2010	
Ardèche, France	Saint-Marcel	f	^{14}C (AMS)	bone	41300 ± 1700	48947-42571	Discoide Mousterian	OxA-19624	Szmidt et al., 2010	
Ardèche, France	Saint-Marcel	f	^{14}C (AMS)	bone	37850 ± 600	43011-41306	Discoide Mousterian	OxA-19625	Szmidt et al., 2010	
Gard, France	Ioton	Ag	TL	Flint	48000 ± 3000		Quina Mousterian	Gif, no number	Valladas et al., 1987	average of 7 samples
Gard, France	Esquicho Grapaou	CC2 and BR2	AAR		39996 ± 2570		Quina Mousterian		Bazille, 2002	
Aude, France	Tournal	E	U-Pa, U-Th and ESR	Bone	35000 ± 7000		Denticulate Mousterian		Yokoyama et al., 1987	average of three methods
Ariège, France	Portel Ouest	B1A	ESR		36300 ± 5400		Chatelperronien		Tissoux, 2004	
		F2-F3	U/Th		38400 ± 6000		Charentian mousterian		Ajaja 1994	
		F1	ESR	teeth	44400 ± 6600		Charentian mousterian		Tissoux 2004	
		F2	ESR	teeth	44000 ± 6600		Charentian mousterian		Tissoux 2004	
		F3	ESR	teeth	44900 ± 6700		Charentian mousterian		Tissoux 2004	
Catalonia, Spain	Arbreda	I	^{14}C (AMS)	Charcoal	38350 ± 400	41068-39977	Typical mousterien	OxA-19994	Maroto, 2012	

42924-41385
48947-42571
43011-41306