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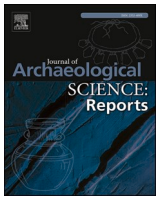

Long-distance movements during the Last Glacial Maximum in the Pyrenean mountain Range: Fresh insights for Montlleó archaeological site (Prats i Sansor, Cerdanya, Spain)

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ABSTRACT

The archaeological work developed at the site of Montlleó for more than twenty years has allowed documenting a long sequence of human occupation that begins during the LGM, around 23000 cal BP and ends after the LGM, around 17000 cal BP. To the obtained radiocarbon dates and the typological variability of the lithic industry, we can now add recent studies on micro-spatial distribution that have allowed documenting at least three horizons of human occupation linked to three chronocultural periods: the Upper Solutrean, the Badegoulian and the Lower Magdalenian.

While the Lower Magdalenian occupation has been extensively studied and published, data regarding earlier occupations remains very limited to date. Therefore, in this paper, we will present a specific analysis of lithic industries, focusing on the study of the Upper Solutrean and Badegoulian markers. We have undertaken a complete archaeopetrological approach, that has included LA-ICP-MS geochemical analyses, and a technological approach on a selection of typological tracers from both periods (raclettes and notched points). The results have allowed us to confirm the stratigraphic and chronocultural succession between the Upper Solutrean and the Badegoulian and we have been able to identify different technological traditions and a wide variety of chert types exploited, whose origin is located on both sides of the Pyrenean Mountain range. Thus, these results are evidencing the existence of divergences between the territoriality of the Upper Solutrean and the Badegoulian groups.

1. Introduction

Lithic artefacts are among the best-preserved items in Paleolithic archaeological sequences from Western Europe. The characterization of lithic raw materials involved in their production is essential to determine the origin of the rocks exploited by Pleistocene hunter-gatherers, and thus to make inferences regarding the mobility patterns of these human groups. Due to its geographic location and harsh environmental conditions, the Pyrenean Mountain range is a key area for studying past human mobility and territoriality. The Pyrenees are a mountain chain located in south-western Europe and naturally divides the Iberian Peninsula from the rest of continental Europe along the S-N axis. It extends for almost 500 km from the Bay of Biscay to the Gulf of Lion.

Traditionally, it had been considered that mobility during the Upper Paleolithic had been restricted to the extremes of the mountain chain (Jordá Cerdá, 1958). However, environmental studies carried out in the last decades have demonstrated that ice retreat in the Pyrenees was earlier than expected, being the chronology of the Pyrenean Last Glacial Maximum (LGM) somewhat out of synchronization with the global LGM (Calvet et al., 2011; Delmas et al., 2020; Reixach et al., 2021), and thus making human occupation of this mountain range feasible during the Upper Paleolithic. It has been nowadays recognized that, at least, two main natural corridors were frequented by past human groups to cross the mountain chain: the so-called Basque crossroad on the Western Pyrenees (Arrizabalaga et al., 2021) and the Cerdanya valley on the eastern Pyrenees (Sánchez de la Torre et al., 2019; Utrilla and Mazo,

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1996).

Archaeological work in the Pyrenean Mountain range has demonstrated that human populations adapted to the changing mountain environment (Arrizabalaga and Rios-Garaizar, 2012; Deschamps, 2017; Peña-Monné et al., 2022) and settled in areas that had initially been considered to be permafrost. In this sense, the discovery and the excavation of the open-air site of Montlleó (Prats i Sansor, Cerdanya, Spain) have proven that human occupations in high altitude open-areas during the LGM were not just a possibility, but a reality (Fullola et al., 2019; Mangado et al., 2019).

In this paper, we present the results of recent studies related to the oldest occupations at the Montlleó archaeological site. We conducted an archaeopetrological analysis of the retouched lithic industry, allowing us to identify changes in behavior regarding raw material acquisition and management across the different human occupations. Additionally, we performed geochemical analyses using LA-ICP-MS and a techno-typological approach on specific tools that are considered tracers from the Upper Solutrean (notched points) and the Badegoulian period (raclettes). These analyses revealed that the groups that settled at the Montlleó site during the LGM followed opposing strategies in terms of raw material procurement for their lithic tool production.

2. Montlleó: The archaeological site and stratigraphic sequence

The archaeological site of Montlleó is placed in the Eastern Pyrenees, at 1144 m asl, in the Cerdanya valley, which is the largest high-attitude valleys in the Pyrenees and a natural pathway to cross this chain in the oriental area following the Têt River to the north and the Segre River to the south. The site, situated atop a small hill in the heart of the plain, was discovered due to a sedimentary fracture associated with mining activity carried out in the immediate vicinity until the 1980 s. The natural exposure enabled the discoverer to retrieve the initial artefacts before the beginning of excavations in 2000. The site has been since then annually excavated by a team from the SERP research group from the University of Barcelona (Mangado, 2018). Three excavation areas have been opened (sectors A, B and C), being sector B the richest in terms of recovered archaeological material (Fig. 1).

The excavation work carried out in the first decade of the 2000 s revealed evidence of human occupations during the Lower Magdalenian period. In addition to various radiocarbon dates from charcoal and horse teeth, which placed the occupation between 20,000 and 17500 cal BP, there was a lithic industry where bladelets with inverse retouch were found alongside mostly blade debitage domestic tools, including scrapers, burins and other elements of simple and abrupt retouch.

However, for several years now, lithic elements suggesting a prior occupation by distinct cultural groups have been recovered, based on the typology of the lithic industry. These lithics evidences were complemented by new radiocarbon dating results that effectively confirmed the existence of older archaeological occupations, dating between 23,000 and 21000 cal BP. The inability to establish precise stratigraphy at the site, due to the sedimentary characteristics of the location −where macroscopically uniform sediment spans the entire sequence- and considering the presence of a steep natural slope, led us to conduct microspatial studies in an effort to identify these cultural horizons using geographic information systems tools.

In order to establish a stratigraphic sequence of the materials recovered at the Montlleó site, a north–south section projection was carried out for all the coordinated materials in sector B (Fig. 2). The

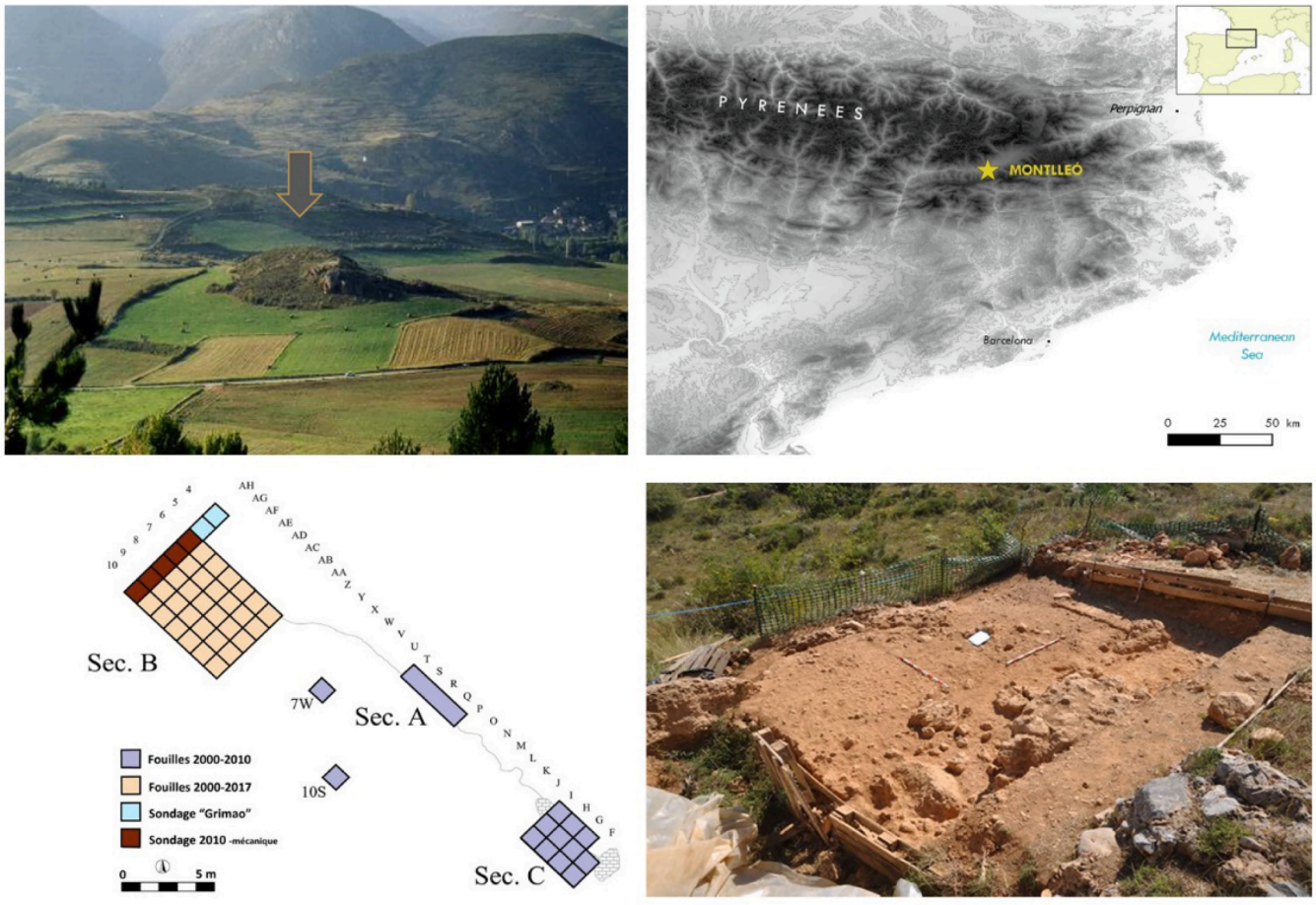

Fig. 1. Location of Montlleó (top) and detail excavation area of sector B (bottom).

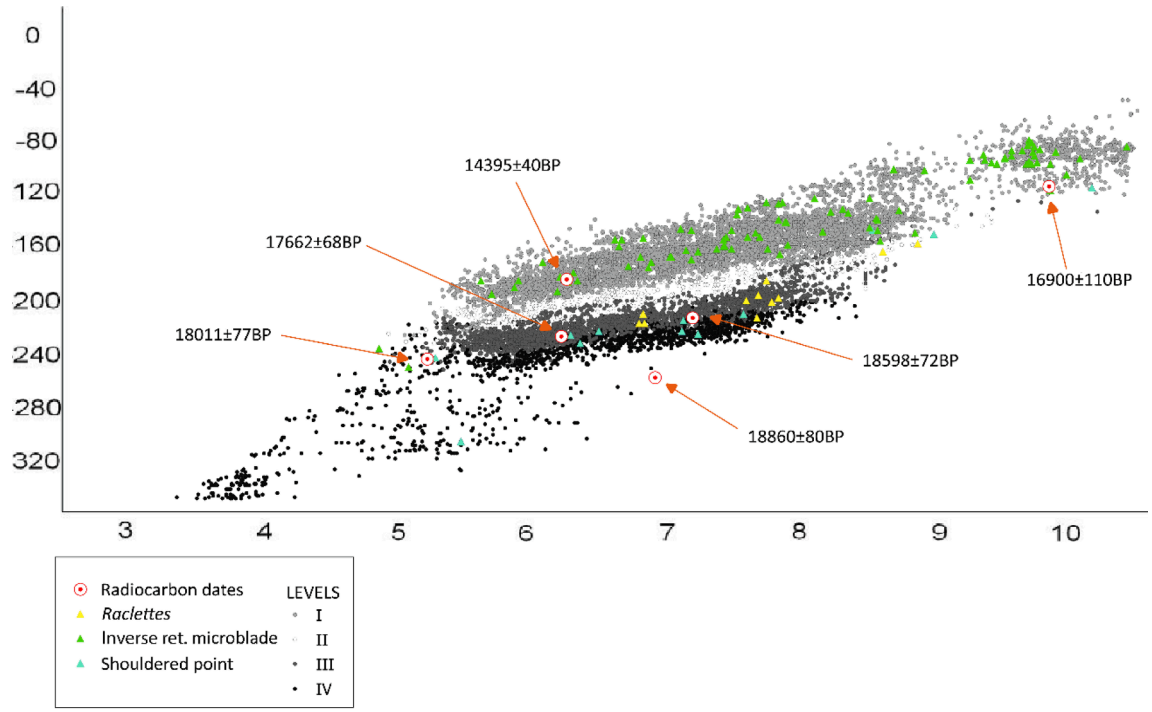

Fig. 2. Archaeological materials from sector B' dispersion with the different archaeological levels and the location of the main representative lithic industry and radiocarbon dates.

result of this GIS-based approach clearly identifies a final occupation horizon (Level I) characterized by the abundance of bladelets with inverse retouch, attributed to the Lower Magdalenian period (Langlais, 2010). Additionally, the most recent carbon-dated samples were recovered from this level. Below this layer, there is an occupational hiatus (Level II), which is more visible in the grid lines of the lower rows (6 and 7). Beneath Level II lie the older occupations of the site (Levels III and IV). Firstly, we observe a horizon (defined in the figure by a dark gray color) that we have designed as Level III. This corresponds to the Badegoulian occupation, dated between 22,000 and 21000 cal BP. Within this level, raclettes –typological elements with abrupt retouches traditionally associated with Badegoulian occupations- are identified. Below Level III, in black, we find what we refer to as Level IV. This level corresponds to the Upper Solutrean occupation, with radiocarbon dates ranging from 23,000 to 22000 cal BP, and it is characterized by the presence of notched points.

In recent excavation campaigns, we carried out two test-pit on the southwest and southeast margins of sector B with the purpose to identify whether there were any earlier occupations below the Upper Solutrean occupation horizon. The test-pit results seem to validate that the Upper Solutrean occupations were the earliest at the site.

The calibration curve obtained indicates a nearly continuous occupation from 23000 cal BP to 17500 cal BP, with at least three chronocultural horizons represented (Table 1; Fig. 3). The earliest human groups that settled in the Montlleó mount did so during the Upper Solutrean, approximately between 23,000 and 22000 cal BP. They were followed by communities of the Badegoulian chronoculture, which carried out their activities between 22,000 and 21000 cal BP. Finally, the last occupation of the site occurred during the Lower Magdalenian, with radiocarbon dates ranging from 20,000 to 17500 cal BP.

3. Materials and methods

The lithic industry of Montlleó is comprised of more than 25,000 pieces, of which 2107 constitute finished tools and cores. An archaeopetrological study of these 2107 finished tools and cores has been done following a macroscopic approach. A visual and micropalaeontological description of each sample has been undertaken at the SERP laboratory placed at the University of Barcelona using a binocular microscope Olympus SZ61 (from 6.7 to 45 x magnification). We have taken images using a coupled Olympus SC30.

Then, a selection of 24 finished tools from levels III (Badegoulian) and IV (Upper Solutrean) were geochemically analyzed. From level III we chose 11 raclettes while from level IV 13 notched points were selected (Table 2, Fig. 4). These 25 pieces constitute almost the entire set from these typological tools recovered until now, having discarded these

Table 1
Radiocarbon dates from samples recovered at sector B from Montlleó and calibrated with OxCal Online Program v 4.4 with the IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (Reimer et al., 2020).

Reference	Material	Date BP	cal BP (2 σ)	$\delta^{13}C$ (‰)	Level
ETH-110104	Faunal bone	14395 ± 40BP	17800–17363	−19,6	I
OxA-9017	Horse molar	15440 ± 80BP	18886–18364	−19,9	I
ETH-112146	Faunal bone	15295 ± 40BP	18745–18310	−19,7	I
Beta-648155	Wood charcoal	16050 ± 60BP	19531–19182	−22,1	I
ETH-112147	Faunal bone	16363 ± 41BP	19877–19579	−19,6	I
OxA-X2234-52	Horse molar	16900 ± 110BP	20751–20141	−19,92	I
CNA-6403	Wood charcoal	17662 ± 68BP	21727–21049	−21,4	III
CNA-6402	Wood charcoal	18011 ± 77BP	22175–21479	−29,1	III
CNA-6405	Wood charcoal	18598 ± 72BP	22810–22347	−22,5	IV
CNA-6407	Wood charcoal	18680 ± 50 BP	22866–22416	−20,2	IV
OxA-23973	Wood charcoal	18860 ± 80BP	22977–22533	−23,96	IV

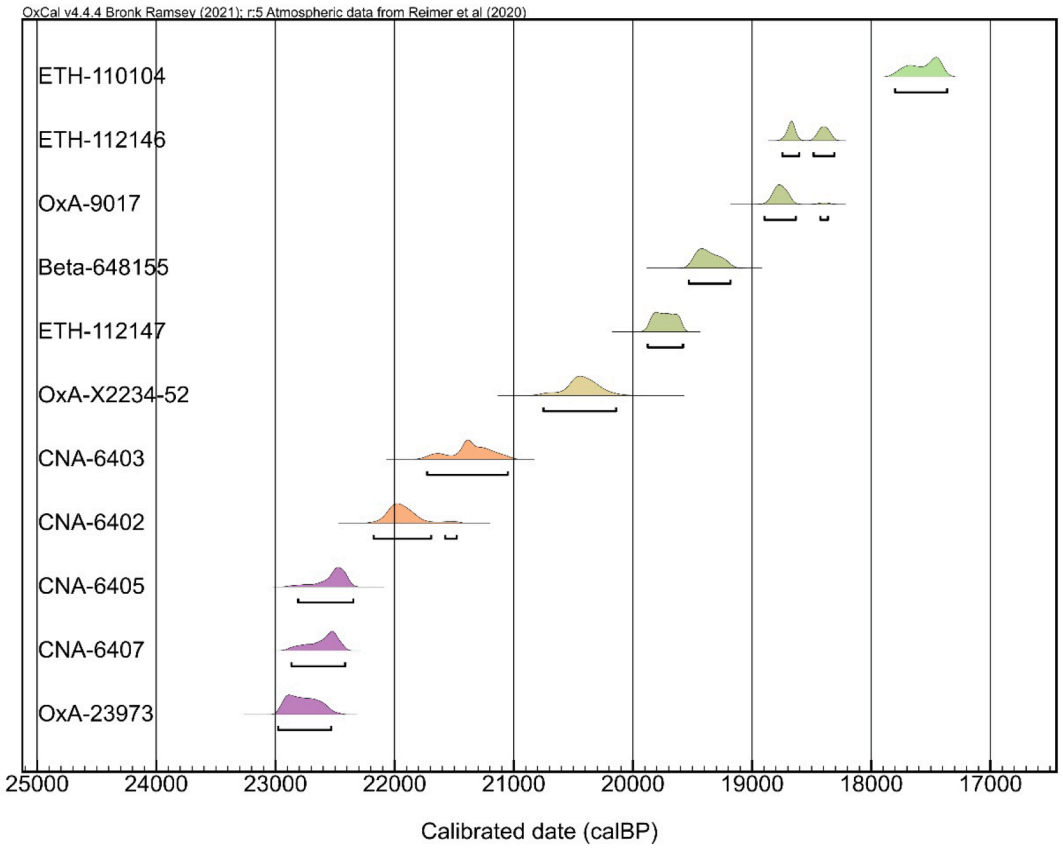

Fig. 3. Calibration curve obtained with Oxcal v.4.4 (Ramsey 2021) with the radiocarbon dates from sector B and atmospheric data from Reimer et al. 2020. Green: Lower Magdalenian; Orange: Badegoulian; Purple: Upper Solutrean. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

samples that were highly altered.

With the aim of comparing results obtained after the analysis of archaeological tools, geological formations with cherts having similar characteristics to those of the artefacts were sampled and analyzed. It involved up to 26 outcrops from 14 geological formations, with more than 450 samples being selected for geochemical analyses (Table 3, Fig. 5). Only primary and subprimary outcrops were considered for this study. To improve analysis time and to avoid surface alterations, geological samples were prepared in squares of 5 x 5 mm removing cortex surfaces.

The 24 archaeological tools and a comparison geological set composed of 457 samples were geochemically analyzed to quantify components so as to be able to compare the archaeological tools with those from known geological outcrops.

To quantify major, minor and trace elements, we used laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at the IRAMAT laboratory, Orleans, France. Elements were quantified using a Thermo Fisher Scientific Element XR mass spectrometer associated with a Resonetics Resolution M50e ablation device. This spectrometer has the advantage of being equipped with a dual mode (counting and analogue modes) secondary electron multiplier (SEM) with a linear dynamic range of over nine orders of magnitude, associated with a single Faraday collector which allows an increase in the linear dynamic range by an additional three orders of magnitude. This feature is particularly important for laser ablation analysis of lithic samples, as it is possible to analyze major, minor and trace elements in a single run regardless of their concentrations and their isotopic abundance. The ablation device is an excimer laser (ArF, 193 nm), which was operated at 7–8 mJ and 20 Hz and only if saturation was observed were conditions reduced to 10 Hz. A dual gas system with helium (0.65 l/min) released at the base of the chamber, and argon at the head of the chamber (1.1 l/min) carried the ablated material to the plasma torch. Ablation time was set to 40 s: 10 s pre-ablation to let the ablated material reach the spectrometer and 30 s collection time. Laser spot size was set to 100 μm, and only reduced to 80 or 50 μm if saturation was detected, and line mode acquisition was chosen to enhance sensitivity. Background measurements were run every 10–20 samples. Fresh fractures were analyzed on geological samples to reduce potential contamination. Priority was given to characterizing large samples; thus, only one ablation line was carried out per specimen. However, if element spikes due to the presence of inclusions or heterogeneities were observed during analysis, results were discarded and a new ablation location was selected.

Calibration was performed using standard reference glass NIST610 which was run periodically (every 10–20 samples) to correct for drift. NIST610 was used to calculate the response coefficient (k) of each element (Gratuze, 1999, 2014), and the measured values of each element were normalized against 28Si, the internal standard, to produce a final percentage. Glass Standard NIST612 was analyzed independently of calibration to provide comparative data. 30 elements were quantified (Li, Be, B, Mg, Al, Si, Ca, Ti, V, Cr, Fe, Ga, Ge, As, Rb, Sr, Y, Zr, Nb, Cs, Ba, La, Ce, Pr Nd, Sm, W, Bi, Th and U).

The technological analysis is based on the identification of the processes used to obtain the supports, as well as on the recognition and description of the retouching configurations of each piece. Given that these elements are characterized by their standardization, the regularity of the edges, the number of transverse edges and their placement on the piece have been taken into consideration. Lastly, though not less importantly, technometric analyses were conducted on the parts that configure the pieces: the stem, notch, and body of the points, in the case of Solutrean samples; and for the raclettes attributed to the Badegoulian period, morphometric characteristics, as well as the configuration and delineation of the abrupt retouches, were also considered.

Table 2
Chronocultural markers from the Badegoulian and Upper Solutrean levels from Montlleó. In italics, samples not analyzed by geochemistry.

Sample reference	Level	Chronoculture	Typology	Lithology	Nature
MO-311	IV	Upper Solutrean	Notched point	Chert	Evaporitic
MO-334	IV	Upper Solutrean	Notched point	Chert	Marine
MO-335	*IV*	*Upper Solutrean*	*Notched blade*	*Jasper*	–
MO-336	IV	Upper Solutrean	Notched blade	Ryolite	–
MO-337	IV	Upper Solutrean	Notched blade	Chert	Lacustrine
MO-338	IV	Upper Solutrean	Notched point	Ryolite	–
MO-339	IV	Upper Solutrean	Notched point	Chert	Marine
MO-340	IV	Upper Solutrean	Notched blade	Chert	Lacustrine
MO-343	*IV*	*Upper Solutrean*	*Notched point*	*Chert*	*Undefined*
MO-344	IV	Upper Solutrean	Notched blade	Chert	Marine
MO-345	IV	Upper Solutrean	Notched point	Ryolite	–
MO-347	IV	Upper Solutrean	Notched blade	Chert	Lacustrine
MO-348	IV	Upper Solutrean	Notched point	Chert	Lacustrine
MO-352	III	Badegoulian	Raclette	Chert	Lacustrine
MO-353	III	Badegoulian	Raclette	Chert	Lacustrine
MO-354	III	Badegoulian	Raclette	Chert	Lacustrine
MO-355	III	Badegoulian	Raclette	Chert	Evaporitic
MO-356	III	Badegoulian	Raclette	Chert	Evaporitic
MO-357	III	Badegoulian	Raclette	Chert	Evaporitic
MO-359	III	Badegoulian	Raclette	Chert	Evaporitic
MO-360	III	Badegoulian	Raclette	Chert	Evaporitic
MO-361	III	Badegoulian	Raclette	Chert	Evaporitic
MO-364	III	Badegoulian	Raclette	Chert	Evaporitic
MO-365	III	Badegoulian	Raclette	Chert	Evaporitic

4. Results

4.1. Archaeopetrological approach to the assemblage of tools and cores

Of the 2107 configured tools and cores recovered in sector B of Montlleó, 1359 have been assigned to level I (Lower Magdalenian), 275 to level III (Badegoulian) and 303 to level IV (Upper Solutrean). The remaining 170 tools were recovered from transitional levels (II and III/IV) and their assignment to a specific archaeological layer remains impossible. Therefore, they have been excluded from the presentation of results.

The lithic tool assemblage at Montlleó is characterized by its polylithological nature, a feature observed both in the finished tools and the cores. Despite being chert the most extensively exploited rock across the three chronocultural horizons, its percentage varies significantly. In the Upper Solutrean, chert represents only 58 % of the retouched tools and cores assemblage. During the Badegoulian, this percentage slightly increases to 70 %. Similarly, in the Lower Magdalenian, chert tools and cores account for 78 % of the total.

Excluding chert, rhyolites dominate the lithic representation in all three cultural horizons. In the Upper Solutrean they constitute 30 %, whereas in the Badegoulian they represent just the 15 %. This decrease it is also observed during the Lower Magdalenian, where rhyolites represent the 14 % of the set. Additionally, quartz and quartzites are identified, albeit with much lower percentages. In Level IV they account for 3 % and 4 % respectively, whereas in level III their representation rises to 7 % and 4 %. Finally, in level I they decrease to 3 % and 1 %. Occasionally, other rocks such as jasper, lydite, limestone, rock crystal and metamorphic rocks are documented across the studied chronocultural horizons (Fig. 6A).

The archaeopetrological analysis of the chert industry has allowed the identification of up to eight distinct types based on inclusions and micropalaeontological content observed under a binocular microscope (Fig. 6B). Additionally, there is a group of indeterminate pieces, which cannot be classified into any specific group due to significant alterations. We are going to briefly define the characteristics of these different groups and their relative average to the total tool assemblage for each archaeological horizon. A detailed description of the different types can be found in (Sánchez de la Torre and Mangado, 2016; Sánchez de la Torre et al., 2019).

- Type 1: these are cherts originating in a lacustrine continental environment, characterized by the inclusions of carbonate relicts and metal oxides and the presence of charophyte algae and gastropod sections. Silicification of this type appears in similar percentages across all three archaeological levels, approximately 30–33 %. Six geological formations of chert with identical macroscopic characteristics are known from the north and the south of the Eastern Pyrenees. In the Corbières Massif, lacustrine cherts from the Oligocene-Aquitanian outcrop within the G3m1 unit, whereas in the southern Pyrenees, the main lacustrine chert formations are placed in the Middle Ebro basin (Cinca Unit, Lanaja-Castejón Unit, Bujaraloz-Sariñena Unit and Pallaruelo-Sora Unit) and the contact between the Catalan Central Depression and the first Pre-Pyrenean foothills (Castelltallat formation).
- Type 2: cherts originating in an evaporitic continental environment. They are characterized by the absence of bioclastic content and the presence of gypsum lenticules, occasionally accompanied by metal oxides. This chert type experiences variations based on the archaeological level: during the Upper Solutrean is the most exploited chert type (45 %), decreasing its average to 37 % during the Badegoulian, and to 18 % during the Lower Magdalenian. Parallels can be drawn between this raw material with Danian cherts outcropping in the northern Pyrenean slopes (*Petites Pyrénées*) and sources from the Tremp formation, in the southern Pyrenees.
- Type 3: these cherts originated in a marine environment and are characterized by inclusions of metal oxides and detrital quartz crystals. They also possess sponge spicules and, in some cases, macroforaminifera such as *Omphalocyclus macroporus* and *Siderolites* are identified. This chert type represents 7 % in level IV and a similar average in level III (9 %), being however more abundant in level I (13 %). This chert type can be related to two chert formations outcropping in the northern slopes of the Central Pyrenees, namely the Montgaillard flysch cherts (Turonian-Santonian) and the Montsaunès-Buala cherts from the Nankin formation (Middle Maastrichtian).
- Type 4: cherts originated in a marine sedimentary environment, being characterized by abundant detrital quartz crystals and rhombohedral calcite or dolomite crystals. Additionally, they may contain amorphous organic matter and sponge spicules and globigerinid microforaminifera. The percentage of this type is lower in level IV, with only 4 % of the analyzed assemblage, whereas in level III increases to 9 % and in level I constitutes 8 %. This chert type is macroscopically similar to cherts from the Agua-Salenz formation (Conacian), outcropping in the southern slopes of the Central Pyrenees, near the Turbón Massif.
- Type 5: these cherts originated in a marine sedimentary environment and are characterized by the presence of metal oxides and abundant sections of alveolinids. This chert type exclusively appears in level I, with a limited average (1 %, 6 pieces). Therefore, it represents a sporadic arrival that is only identified

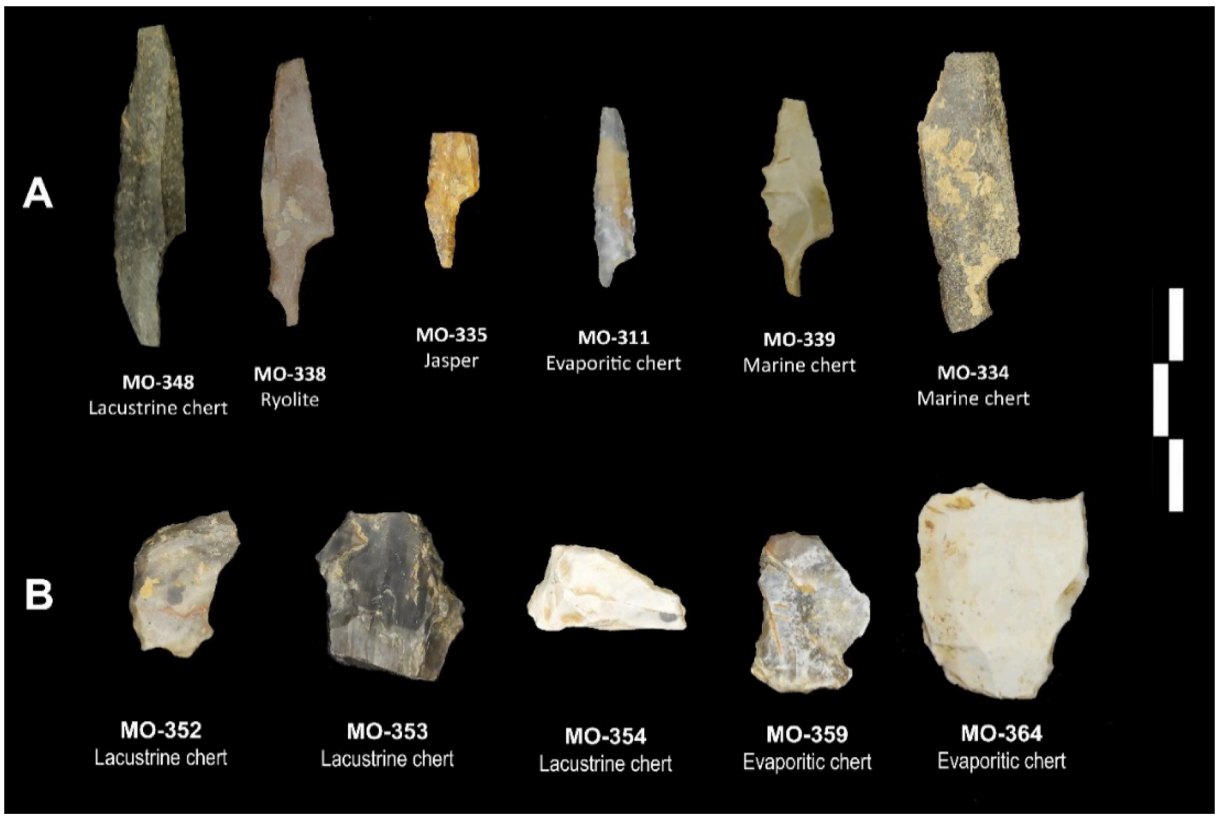

Fig. 4. Significant sample of the set of notched points (A) and raclettes (B) recovered at Montlleó and analyzed by LA-ICP-MS.

Table 3
Geological lithic outcrops with the number of samples geochemically analyzed.

ACRONYM	OUTCROP	FORMATION / UNIT	AGE	TYPE	SAMPLES
HOR	Campo Horgas	Lanaja-Castejón Unit	Miocene	Lacustrine	20
LM1	La Muela 1	Lanaja-Castejón Unit	Miocene	Lacustrine	10
LM2	La Muela 2	Lanaja-Castejón Unit	Miocene	Lacustrine	20
LT	La Torraza	Lanaja-Castejón Unit	Miocene	Lacustrine	13
SB1	San Borombón 1	Pallaruelo-Sora Unit	Miocene	Lacustrine	11
SB2	San Borombón 2	Pallaruelo-Sora Unit	Miocene	Lacustrine	20
SQ	Santa Quiteria	Pallaruelo-Sora Unit	Miocene	Lacustrine	12
PC	Puente Candasnos	Bujaraloz-Sariñena Unit	Miocene	Lacustrine	20
VALCU	Valcuerna	Cinca Unit	Miocene – Oligocene	Lacustrine	20
CDF	Castelló de Farfanya	Castelltallat Fm	Oligocene	Lacustrine	49
ED1	Étang du Doul 1	G3m1 Unit	Oligocene – Aquitanian	Lacustrine	15
ED2	Étang du Doul 2	G3m1 Unit	Oligocene – Aquitanian	Lacustrine	15
ED3	Étang du Doul 3	G3m1 Unit	Oligocene – Aquitanian	Lacustrine	14
PM1	Port Mahon 1	G3m1 Unit	Oligocene – Aquitanian	Lacustrine	15
PM2	Port Mahon 2	G3m1 Unit	Oligocene – Aquitanian	Lacustrine	25
CER	Cérizols	Blue tertiary	Danian	Evaporitic	17
ALI	Alins del Monte	Tremp Fm	Maastrichtian	Evaporitic	30
VSSM	Ves. Sud St Mamet	Tremp Fm	Maastrichtian	Evaporitic	21
SALIES	Salies de Béarn	Pelagic cherts unit	Campanian	Marine	10
TERCIS	Tercis	Pelagic cherts unit	Campanian – Maastricthian	Marine	10
AUDIGNON	Audignon	External marine platf. unit	Maastricthian	Marine	10
BASTENNES	Bastennes-Gaujacq	External marine platf. unit	Maastricthian	Marine	10
MONTS	Montsaunès	Nankin Fm	Maastrichtian	Marine	20
MONTG	Montgaillard	Flysch limestones	Turonian – Santonian	Marine	20
PADAR	Padarniu	Agua-Salenz Fm	Coniacian	Marine	20
PENDIS	Coll de Pendís	Prir Unit	Permian	Ryolite	10

in the Lower Magdalenian occupation. Until now we have not identified in the geological environment cherts with similar features, so we suggest this chert type could have been procured from regions at greater distance.

- Type 6: this silicification probably originated in a marine environment due to the presence of sponge spicules. This chert type is also characterized by the abundance of rhombohedral calcite or dolomite crystals, along with numerous internal fissures. It appears sporadically in level IV (2 pieces), is absent in level III and is identified again in level I with 12 pieces (1 %). This chert type is macroscopically similar to cherts from the

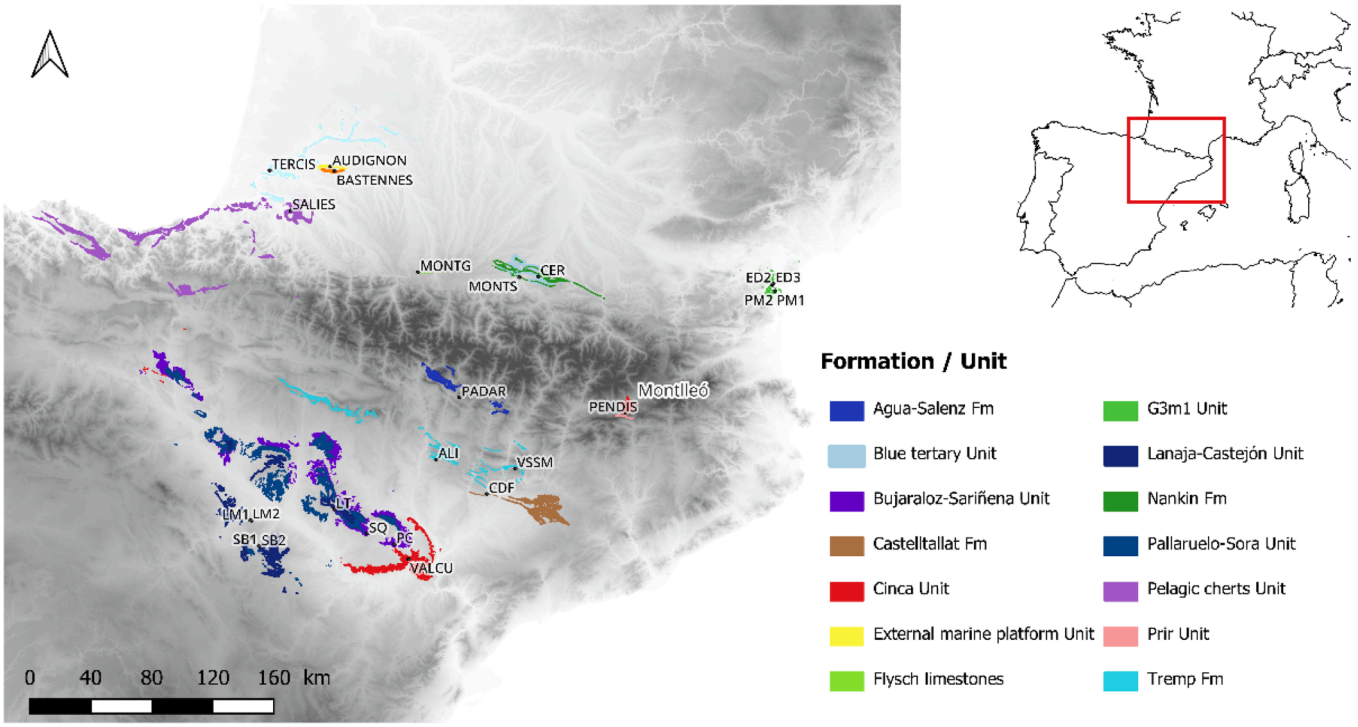

Fig. 5. Geological formations containing chert with macroscopic similarities to those found at the archaeological site of Montlleó.

Corones formation, outcropping in the southern slopes of the Cadí mountain range, near the Cerdanya valley.

- Type 7: cherts originating in a marine sedimentary environment, characterized by a homogeneous texture with the presence of scarce metal oxides and an abundance of macroforaminifera such as *Lepidorbitoides* and *Siderolites*, as well as Bryozoaires. This chert type is represented by only three pieces. Two of them are assigned to the Upper Solutrean occupation, while the other one is associated with the Lower Magdalenian occupation. This chert type is macroscopically similar to the Maastrichtian cherts outcropping in Audignon, where an association between *Lepidorbitoides*, *Siderolites* and bryozoaires has also been recognized.
- Type 8: these cherts originated from turbiditic formation within the flysch. They exhibit abundant sections of sponge spicules and rhombohedral calcite or dolomite crystals. This chert type has been exclusively identified in level IV and is represented by a total of three pieces. This chert type has direct parallels with the Cretaceous flysch formations observed in the northern Pyrenees from the Atlantic coast to the central part of the range.

4.2. Geochemical characterization of chronocultural tracers from the Upper Solutrean

The thirteen notched points from the Upper Solutrean were initially studied macroscopically. The macroscopic examination revealed that three of them were made from rhyolite, one from jasper, and nine from chert. Among these, four correspond to lacustrine cherts of type 1, one to evaporitic chert of type 2, two to marine cherts of type 7, one of marine chert of type 8 and the remaining one could not be identified due to its significant alteration (Fig. 4A).

Then, the thirteen notched points from level IV were geochemically examined. The LA-ICP-MS analyses allowed us to differentiate between geological sources and establish connections between archaeological specimens and specific geological formations (Fig. 7, top). Specifically, the four notched points macroscopically classified as lacustrine cherts were further divided into two groups using multivariate statistics. As previously presented for the raclettes, we firstly calculated the median value and the standard deviation for each measured element, trying to identify which were the elements that better discriminate between geological sources. Then, we developed a linear discriminant analysis using the elements that better discriminate between sources. The linear discriminant analysis, considering Ti, Sr and U values, associated three archaeological tools (MO-337, MO-340 and MO-348) with the lacustrine cherts found in the Corbières Massif (g3m1 Unit). On the other hand, the notched point MO-347 is situated near the dispersion area of the Bujaraloz-Sariñena Unit, which corresponds to outcrops in the Middle Ebro Basin. Additionally, a scatterplot comparing Ln As/U vs Ln B/U reinforces the previous findings, clearly distinguishing the most suitable geological formations and linking the archaeological samples to the previously identified geological units (Fig. 8).

One notched point was macroscopically identified as resembling type 2 evaporitic chert. In the Central-Eastern Pyrenees, two geological formations exhibit similar macroscopic characteristics: the Blue Paleocene cherts, which outcrop on the northern slope, and the Tremp formation cherts, which outcrop on the southern slope. The linear discriminant analysis, based on B and U values, effectively distinguishes between these two geological formations. However, the archaeological sample (MO-311) is situated in a central area between both units. Similarly, the scatterplot comparing Ln U/Sr vs B/Sr does not yield clear results, as the archaeological sample falls within an overlapping region between the two geological units (Fig. 7, middle).

Macroscopically, three notched points were attributed to marine cherts of types 7 and 8. We conducted a linear discriminant analysis using Li and B values, which allowed us, in broad terms, to differentiate potential geological formations (Fig. 7, bottom). Type 7 cherts are macroscopically similar to the cherts from the limestone formation of Dumes that outcrop between Audignon and Bastennes-Gaujacq, commonly known as Chalosse cherts. However, we also decided to include cherts from Tercis and Salies de Bearn from the Western Pyrenees, as well as cherts from the central Pyreneees (Montgaillard and Montsaunès cherts) to observe whether the macroscopic attributions truly aligned with chemical composition. Indeed, the two pieces defined as type 7 cherts (MO-339 and MO-344) are situated within the

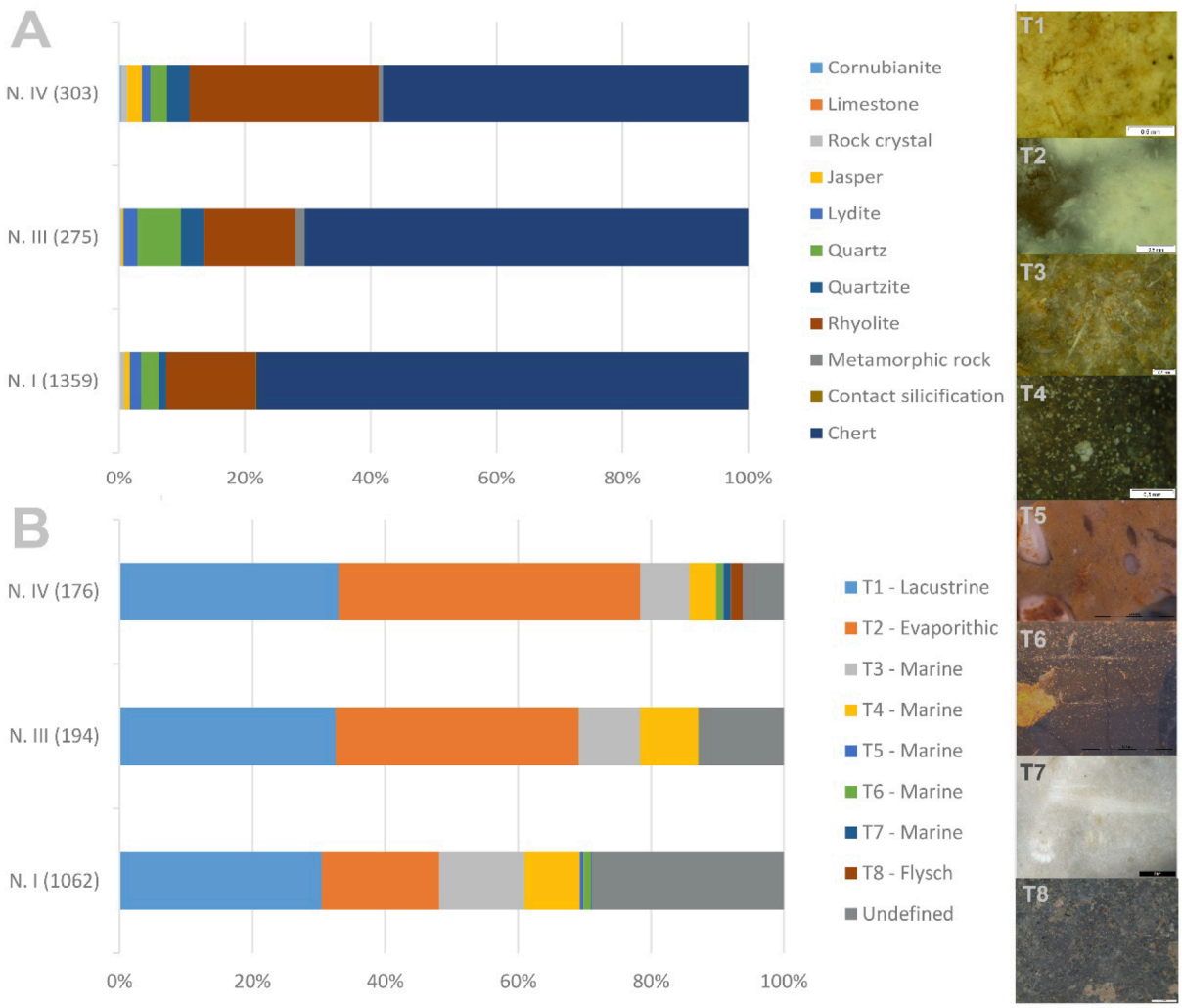

Fig. 6. Stacked bar charts showing the lithologies (A) and the chert types (B) identified in the assemblage of tools and cores from the three chronocultural horizons of Montlleó. At right, macroscopic view of each chert type.

dispersion area of the Audignon cherts, reaffirming the initial macroscopic connection based on micropalaeontological content. Additionally, we included in this analysis the chert defined as type 8 (MO-334), which is macroscopically similar to the flysch cherts that emerge in the Western Pyrenees. In this case, we are unable to directly compare it with geological samples from this geographical area. Therefore, we must exercise caution when interpreting the archaeological implications of these analyses. Based on the studied geological samples, this point chemically resembles the cherts from the Agua-Salenz formation, which we have classified as marine cherts of type 4 for the Montlleó samples. However, the macroscopic characteristics of this notched point differ from those of the Agua-Salenz cherts –although it is true that they are not entirely distinct- and more closely resemble the cherts from the flysch formations of the Western Pyrenees, not included in the geochemical study.

Finally, we conducted a principal component analysis using LA-ICP-MS data on all the measured elements to verify the macroscopic attributions of the three notched points as rhyolites (MO-336, MO-338 and MO-345) (Fig. 7, bottom). The results indicate that these three archaeological specimens differ from both the geological and archaeological cherts. Instead, they are more closely associated with the geological rhyolites found in the Prir unit, which outcrop in the Cadí Mountain Range, situated to the south of the Cerdanya valley. These findings confirm the local origin of the notched points.

4.3. Technological approach of chronocultural tracers from the Upper Solutrean

In general, given that these are fractured notched points –some of which are broken at both ends- it is difficult to establish groups based on the homogeneity of their lengths. However, the preservation of other elements, such as the cross-section or the notch that forms the tang, has allowed us to establish some technological correlations. Based on this, we have clearly identified five technological traditions converging at this archaeological site (Fig. 9).

The first group consists of seven elements (MO-335, MO-336, MO-337, MO-338, MO-340, MO-345 and MO-348) that exhibit identical characteristics to the well-documented Salpetrian-type notched points (Boccaccio, 2021): regular parallel-edged blades derived from cores with two opposed platforms. Additionally, these blades feature an abrupt retouch notch at the base that maintains the original width of the proximal area. Regarding the body of the points, we observe direct abrupt retouching on the left edge, while on the right edge, very marginal direct retouching can be distinguished.

The second group (MO-311 and MO-343), although reminiscent of those previously described, is characterized by the production of visibly smaller and narrower points. While the first group had dimensions ranging between 200 and 350 mm approximately, these do not exceed 230 mm. Additionally, both pieces originate from unipolar blade cores and feature a single central ridge that was used as a guide to define the

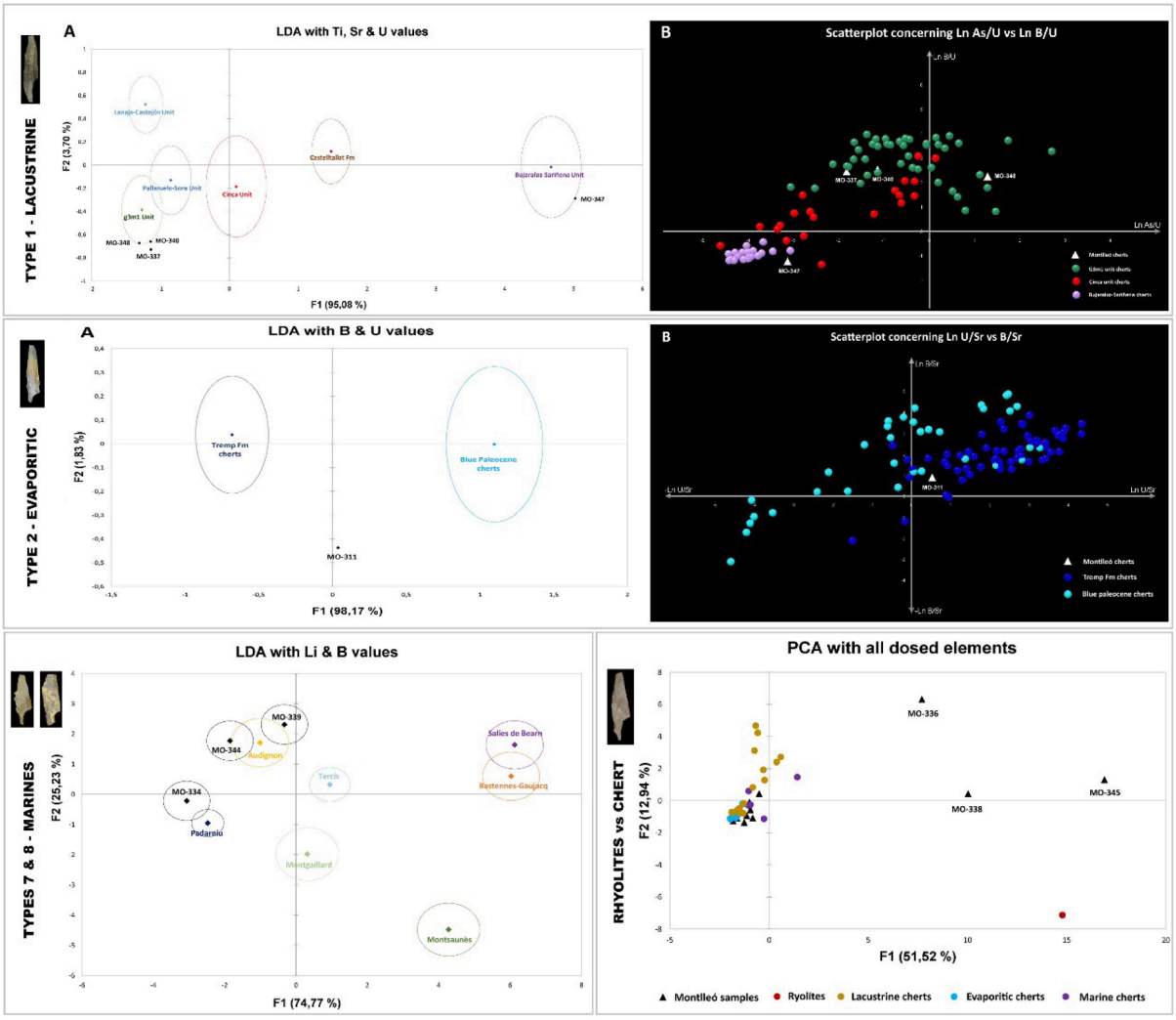

Fig. 7. In the top: linear discriminant analysis with Ti, Sr and U values (left) and scatterplot concerning Ln As/U vs B/U (right) for the type 1 lacustrine notched points and the geological comparison set with data obtained by LA-ICP-MS. In the middle: linear discriminant analysis with B and U values (left) and scatterplot concerning Ln U/Sr vs B/Sr (right) for the type 2 evaporitic notched point and the geological comparison set with data obtained by LA-ICP-MS. In the bottom: linear discriminant analysis with Li and B values (left) for the types 7 and 8 marine notched points and the geological comparison set with data obtained by LA-ICP-MS and principal component analysis (right) with all the dosed elements including all the analyzed notched points by LA-ICP-MS and the geological dataset.

notch. Finally, abrupt direct and marginal retouching is observed on both edges, which completes the final pointed shape.

The third typology consists of a single element (MO-347), which does not keep the characteristic notch; however, the body of the point allows us to include it within the broader category of notched points. Unlike the previous examples, this piece exhibits considerable thickness, which is further accentuated by its trapezoidal cross-section with two parallel ridges slightly offset to the right. The used blade was derived from a unipolar core with regular and parallel edges, which were modified to create a point through deep and abrupt direct retouching along the entire left side and the distal end of the right side.

The fourth grouping corresponds to pieces MO-339 and MO-344. Although MO-344 is fractured at the proximal end and what might correspond to the distal third, it is possible to recognize a bipolar debitage with opposed platforms, which facilitates the extraction of the blade along a single guiding ridge. Unlike the blades in the first group, these points exhibit a slight reduction in length, averaging around 250 mm.

Finally, the last piece (MO-334) deviates from the previously observed criteria, as it has significantly larger dimensions (approximately 370 mm in length). Although it has parallel edges, it does not appear to be shaped into a point. Moreover, the notch, although located on the right proximal side, shows no preparation, which suggests it could be what is known in the literature as a notched blade (Fullola, 1976). Lastly, it should be noted that the straight form was directly achieved during the core reduction process, rather than through configuration retouching.

4.4. *Geochemical characterization of chronocultural tracers from the Badegoulian*

The 11 raclettes from level III were initially macroscopically studied. Subsequently, they underwent geochemical analysis to better define their origin. The macroscopic examination revealed that the eleven raclettes correspond to chert, having identified only two siliceous varieties. Over 70 % of them are made from evaporitic chert of type 2, while the remaining three specimens were crafted from lacustrine chert of type 1 (Fig. 4B).

LA-ICP-MS analyses were conducted to quantify major, minor and trace elements in the selected archaeological tools. These results were then compared to a database containing over 450 geological samples from 14 distinct geological formations. Regarding the 11 retouched tools

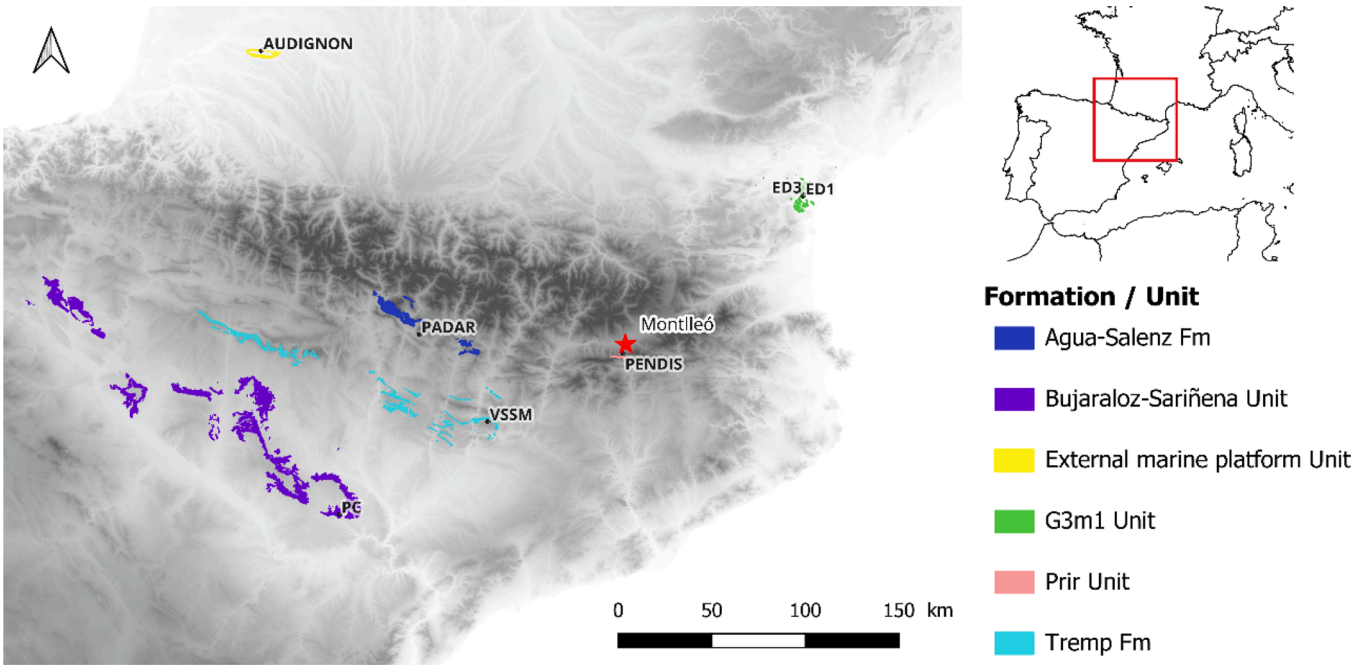

Fig. 8. Geological formations and outcrops containing chert geochemically similar to the studied notched points from the Upper Solutrean level.

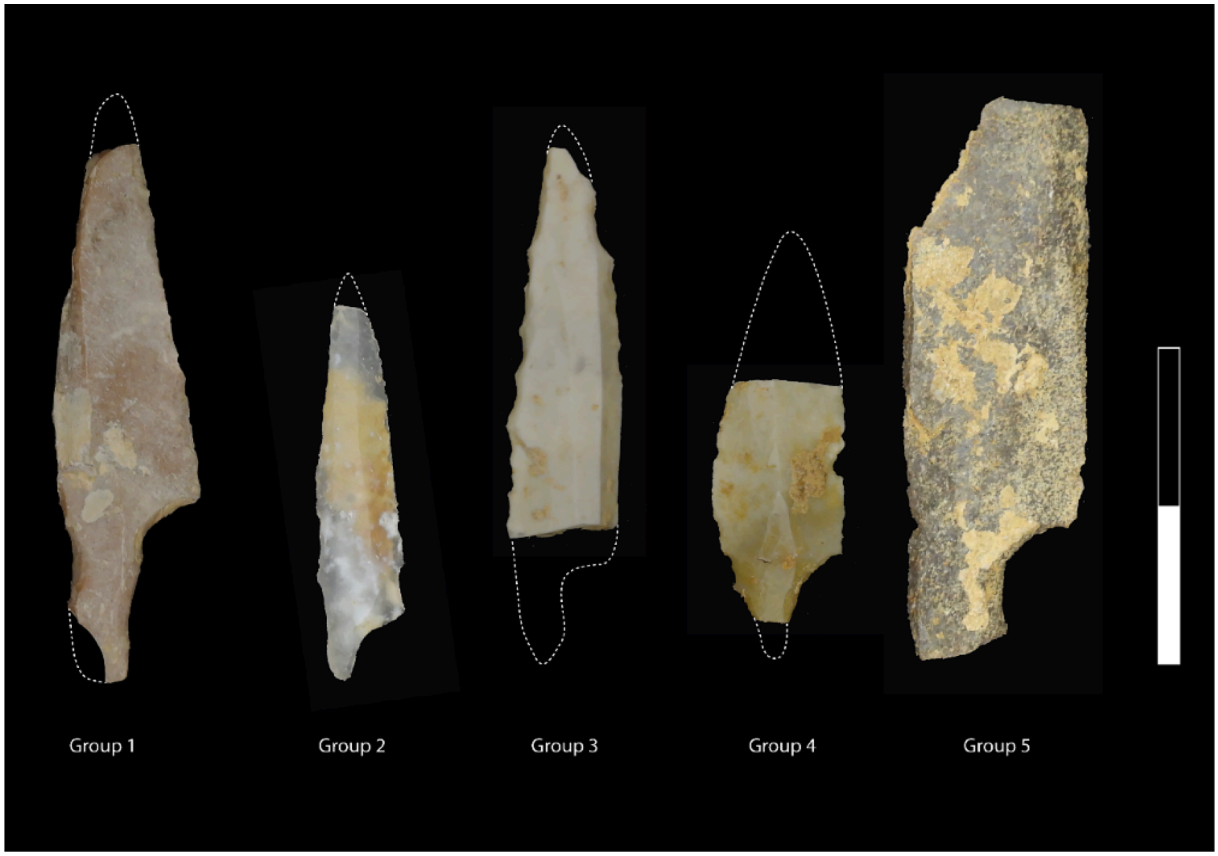

Fig. 9. Examples of each technological group of notched point described in the text.

recovered at level III, classified as raclettes, 8 of them were macroscopically identified as type 1 (lacustrine cherts). The LA-ICP-MS results suggest that certain trace elements may serve as distinguishing factors between different geological formations (Fig. 10, top). Specifically, up to six geological formations are exposed in various regions: in the Corbières Massif (g3m1 Unit), in the Middle Ebro Basin (Lanaja-Castejón Unit, Pallaruelo-Sora Unit, Cinca Unit and Bujaraloz-Sariñena Unit) and in the first foothills from the southern Pre-Pyrenees (Castelltallat formation). We developed multivariate analyses for firstly identifying differences between geological sources and then, trying to relate with the

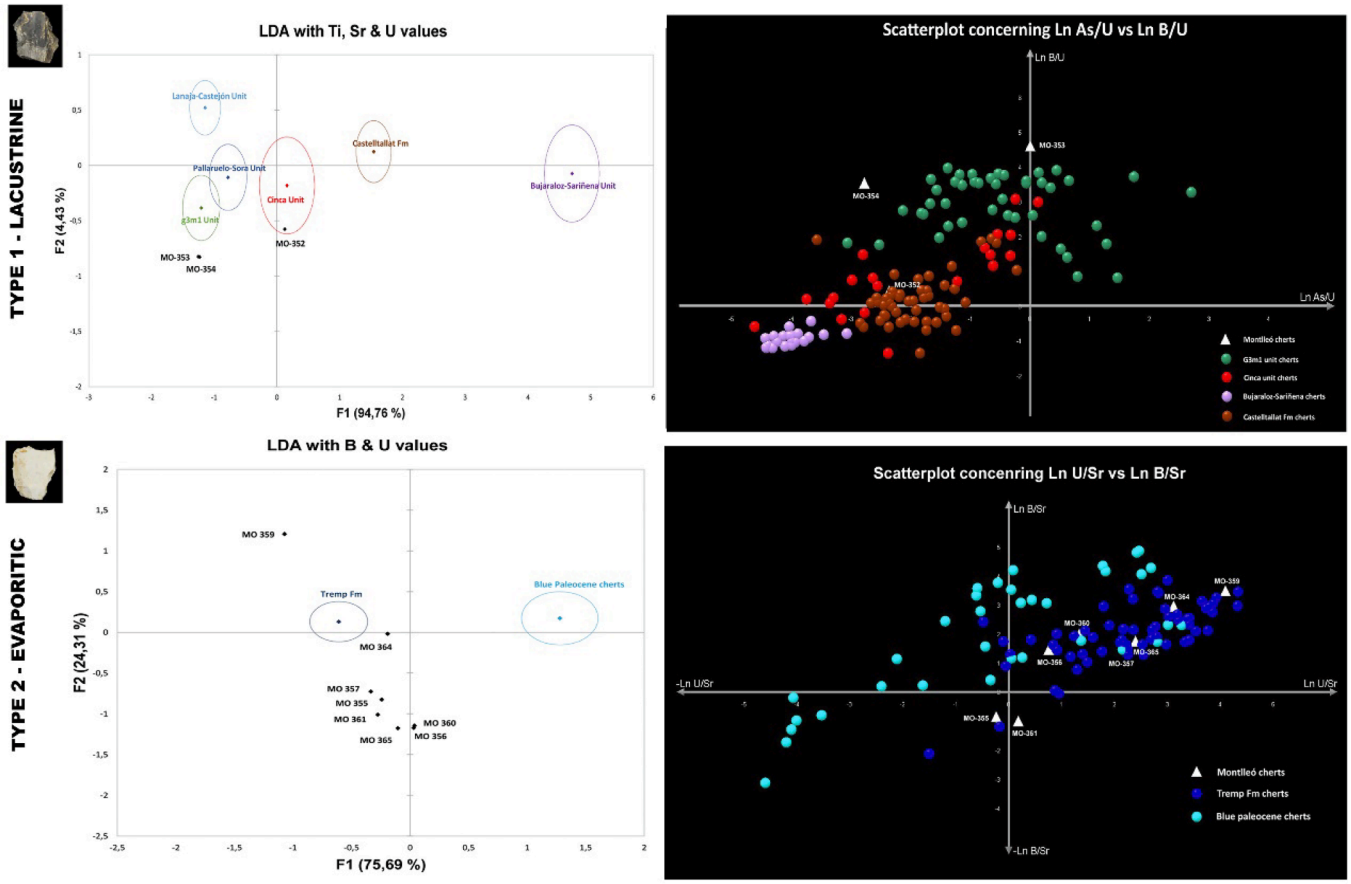

Fig. 10. In the top: linear discriminant analysis with Ti, Sr and U values (left) and scatterplot concerning Ln As/U vs B/U (right) for the type 1 lacustrine raclettes and the geological comparison set with data obtained by LA-ICP-MS. In the bottom: linear discriminant analysis with B and U values (left) and scatterplot concerning Ln U/Sr vs B/Sr (right) for the type 2 evaporitic raclettes and the geological comparison set with data obtained by LA-ICP-MS.

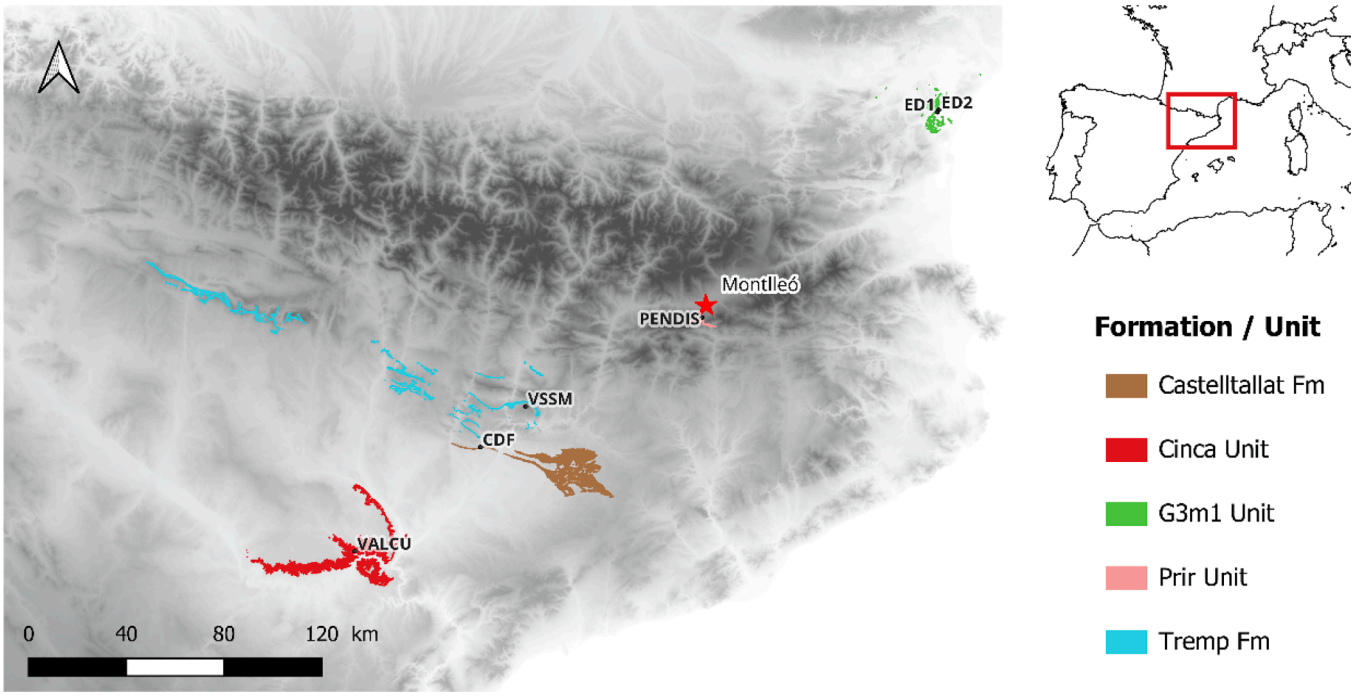

Fig. 11. Geological formations and outcrops containing chert geochemically similar to the studied raclettes from the Badegoulian occupation.

archaeological samples. We first calculated the median value and the standard deviation of each measured element by LA-ICP-MS. Then, we selected those elements that better discriminate the geological sources. After that, we calculated a linear discriminant analysis (LDA) using Ti, Sr and U values, that effectively distinguishes these six geological units. In the LDA, two of the archaeological samples (MO-353 and MO-354) closely align with the dispersion area of the Corbières Massif (g3m1 Unit). However, the remaining archaeological specimen (MO-352) is situated within the dispersion area of the Cinca Unit cherts, which outcrop in the Middle Ebro Basin (Fig. 11).

Similarly, the scatterplot comparing Ln As/U vs Ln B/U partially aids in differentiating between the most similar geological formations, as determined by the previous LDA. In this case, geological samples from the Cinca Unit and the Castelltallat formation exhibit slight overlap, with the MO-352 archaeological chert falling into the overlapping region. Meanwhile, the two raclettes previously associated with the g3m1 Unit (MO-353 and MO-354) once again align with the dispersion area of this geological formation found in the Corbières Massif.

Regarding the eight raclettes which were macroscopically classified as evaporitic cherts (type 2), a linear discriminant analysis using B and U values successfully differentiated between the two primary geological formations that share similar cherts: the Blue Paleocene cherts, which outcrop in the northern slope of the Eastern Pyrenees; and the Tremp formation cherts, which outcrop in the southern slope of the Central-Eastern Pyrenees. The entirety of the archeological samples closely aligned with the dispersion area of the Tremp formation. Similarly, the scatterplot comparing Ln U/Sr vs Ln B/Sr revealed distinct differences between these two geological formations. Once again, the archaeological samples predominantly coincided with the dispersion area of the southern Pyrenean formation (Fig. 10, bottom, Fig. 11).

4.5. Technological approach of chronocultural tracers from the Badegoulian

The technological characteristics of eleven pieces found at the site allow us to accurately discuss the classic raclettes described by Cheynier (1930). The Montlleó raclettes were analyzed using technometric criteria, examining the dimensions of the blanks and determining the features of the retouching that typify this type of diagnostic element.

The total sample correspond to abrupt-edge elements with varying delineations, although most are rectilinear. While the blanks are also varied (flakes or blades), the most notable feature is that six of them were shaped on blanks resulting from core cleaning (core flanks), as well as have been described in other cases (De la Rasilla et al., 2019; Ducasse et al., 2021). The remaining five pieces correspond to truncated elements resulting from core reduction or the intentional fracturing of some blanks.

The studied assemblage does not exhibit homogeneity in its configuration; rather, it involves the utilization of waste blanks, which have been modified through abrupt retouching on various faces. In one case, we also observe the combination of irregular flat retouching, likely aimed at reducing the thickness of the blank, with abrupt lateral retouching applied in both direct and indirect directions (Fig. 12).

5. Discussion

One of the initial inquiries we wish to address in this article concerns the stratigraphic differentiation between the Upper Solutrean assemblage and the one associated with a Badegoulian occupation. Researchers have observed that, in specific archaeological sites such as Le Cuzoul de Vers in Quercy, raclettes and notched points appear at the same stratigraphic level. This assemblage, dated between 23.5 and 23 ka cal BP, implies the coexistence of both typological traditions within the same archaeological context. However, it has been treated as a singular occurrence (one-shot), without recognized parallels. Additionally, at Le Cuzoul de Vers, alongside the use of locally sourced alluvial cherts, a diverse range of raw materials is documented, including unidentified exogenous cherts. This further underscores distinct technological traditions within the same archaeological assemblage (Ducasse et al., 2021).

The case of Montlleó aligns well with this differentiated tradition between Badegoulian manifestations, dated in that case between 22.1 – 21 ka cal BP. In this context, raclettes appear stratigraphically and chronologically separated from notched points, which represent an

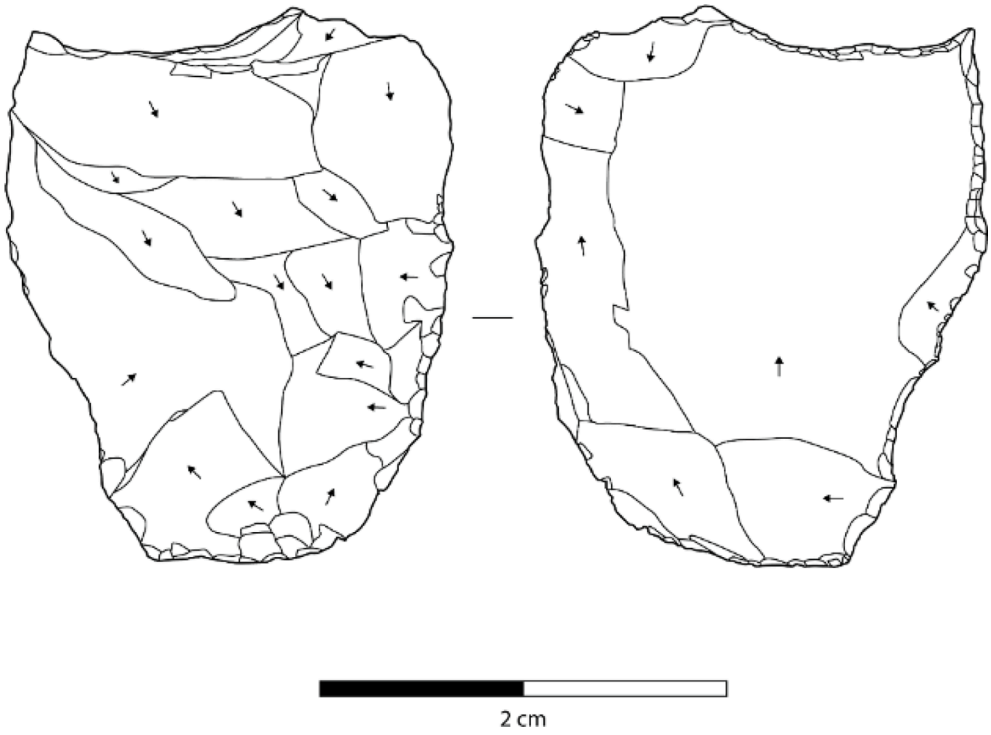

Fig. 12. Example of a raclette combining flat thinning removals with abrupt configuration retouching.

earlier occupation dated for Montlleó at 23 – 22.5 ka cal BP. In fact, a brief hiatus is documented between these two occupations. Similarly, although unfortunately lacking abundant radiocarbon dates, the Petite Grotte de Bize, in Aude, also documents a Badegoulian occupation following a previous Upper Solutrean level, providing evidence for the stratigraphic succession between these chronocultural phases (Ducasse et al., 2021). The study presented in this work would confirm this succession, serving as a new example with stratigraphic data and absolute dating.

The stratigraphic and chronocultural differentiation between the Upper Solutrean and the Badegoulian occupations at Montlleó is also reflected in the nature of exploited raw materials, which correspond to notably distinct exploitation territories. While, for the Badegoulian, the nature of raclettes indicates more intensive use of evaporitic cherts from the southern slopes of the Pyrenees, alongside less abundant lacustrine cherts from the Corbières massif and the Middle Ebro valley, the exploitation territories for lithic raw materials during the Upper Solutrean appear to be much broader. This likely includes the existence of exchange networks.

If we analyze the Upper Solutrean occupation of Montlleó, the geochemical analysis of the notched points indicates a wide territory for acquiring lithic raw materials or, at least, a broad territoriality where different traditions converge. Additionally, the analysis of the notched points from Montlleó reveals the coexistence of other technological and typological traditions within the same site, which intersect with diverse origins of the raw materials. The techno-typological study has identified up to five distinct varieties based on the configuration of the supports, their morphometry and their *châine opératoire*. These varieties are closely linked to the origin of the raw materials.

The relationship between technological groups and the source of raw materials is particularly interesting, as there is a correlation between these criteria. When focusing on elements that deviate from the classical Salpetrian tradition (group one), we observe a trend towards imitating the technological characteristics typical of the northern Pyrenees through the use of local materials, as seen in technological group two. The same pattern emerges when comparing the morphotechnical relationships of traditions found in the Cueva de Chaves, Montlleó, and La Salpêtrière site.

Up to seven notched points of Salpetrian tradition have been identified in Montlleó, being configured with local (rhyolites) or regional rocks (lacustrine cherts from Corbières Massif and probably Canigou jasper). Salpetrian culture has been defined as a post-Solutrean culture due to the distinctive morphological variability of the notched points compared to the notched points of the Upper Solutrean in southwestern France, and the absence of bifacial retouch (Boccaccio, 2021). However, it presents a chronological framework that broadly aligns with the Upper Solutrean of the Cantabrian and Mediterranean regions in Iberia, potentially being considered as distinct facies in Languedoc. Radiocarbon dates associated with the Salpetrian coincide with those obtained from the Upper Solutrean level at Montlleó. In La Salpêtrière site, AMS dates from Level 5 of the central porch (22,8 – 22,2 ka cal BP) and Level 6b of the central porch (23,6 – 22,5 ka cal BP) are nearly identical to those obtained for Level IV at Montlleó. In the Petite Grotte de Bize, the notched points from Level 6 are similar to Salpetrian points, despite the level being identified as part of the Upper Solutrean (Utrilla, 1989 in (Boccaccio, 2021). In Bize, as in Montlleó, this Salpetrian-Upper Solutrean horizon is followed by a significant Badegoulian occupation.

The fact that a selection of notched points from the Salpetrian tradition has been identified at the Montlleó site, and that the AMS dates from La Salpêtrière are nearly identical to those obtained from Level IV at Montlleó, lead us to consider whether the Salpetrian phenomenon could have extended beyond southeastern France and reached the southern slope of the Eastern Pyrenees, as previously suggested by Boccaccio and Utrilla (2013). In this regard, the identification of Salpetrian notched points in Level 1c of Cueva de Chaves, with dates very close to those obtained at Montlleó (24 – 22,9 ka cal BP), more typical of the Upper Solutrean, could support this hypothesis, with Montlleó playing a key role in demonstrating the connection between Aragón and Languedoc.

The presence of notched points from the Salpetrian tradition at Montlleó, which were made from local materials (rhyolites) or regional materials (jasper and lacustrine cherts from Corbières) is a clear indicator that the Solutrean groups settled in Montlleó were well acquainted with the Salpetrian tradition (perhaps even their own tradition). It is highly likely that they elaborated these notched points at the same site, using local materials such as rhyolites. Consequently, we should probably consider that the territory annually frequented by the Solutrean groups in Montlleó may have encompassed areas of eastern Languedoc.

Until now, the extension of the Salpetrian tradition in the Mediterranean arch has not been determined. However, in the Upper Solutrean layers of Cueva Ambrosio and Parpalló, notched points with abrupt retouch have also been identified. Although these points exhibit morphological differences from those of the Salpetrian tradition and are smaller than the French ones, we should consider that they belong to a distinct tradition, that is not yet represented in the variability observed in Montlleó. Additionally, there is no evidence of traditions originating further south, such as those described by Villaverde and Peña (1981) from Valencia.

The presence of notched points in the lithic record probably linked with different technological traditions and various lithic materials indicates the existence of broad territorial permeability among the groups that frequented Montlleó during the Upper Solutrean period. This even leads us to consider the hypothesis that the site could have played a strategic role in the encounter and exchange of materials and traditions between different regional groups.

The wide territorial permeability of Solutrean groups in Montlleó is also documented in other Upper Solutrean assemblages. Least-cost path analysis reveals an extensive network of raw material sources for the lithic materials recovered from various Upper Solutrean occupations in Atlantic Europe (Aubry et al., 2015). For example, at Le Fourneau du Diable in Dordogne, several specimens of notched points from the Salpetrian tradition have been identified. Similarly, at the open-air site of La Rouvière in Ardèche, a notched point from the Atlantic tradition was found, likely confectioned with Turonian chert from the Cher basin (Delvigne et al., 2017 in (Ducasse et al., 2021).

Regarding the Badegoulian set, recent synthesis studies on Badegoulian manifestations have confirmed that it is a broader and more complex phenomenon than initially expected (Banks et al., 2011). It is evident that we are dealing with a chronoculture that represents a significant departure from the Upper Solutrean (Ducasse et al., 2021). We are in a phase of high climatic instability, covering the early part of the Last Glacial Maximum for Badegoulian occupations, thus corresponding to a cold and humid period (GS1.1c) (Ducasse et al., 2021).

The Badegoulian horizon at Montlleó, based on radiocarbon dates obtained to date, aligns with the Late Badegoulian, dated between 22,5 and 20,5 ka cal BP. In fact, the dates obtained for the nearby Lassac locus 1 site (21,5 – 21 ka cal BP) closely coincide with those from Montlleó. Chronometrically, Montlleó's dates are similar to those obtained for levels 8b and 8c at Pégourié in Quercy (22 – 20,9 ka cal BP), level 4 at Petit Cloup (also in Quercy, 21,9 – 21 ka cal BP) and level NA4 at Casserole (in Dordogne-Poitou, 21,9 – 21,1 ka cal BP), all attributed to Late Badegoulian occupations (Ducasse et al., 2021). During this phase, there is an increasing diversification of lithic and osseous hunting equipment. Additionally, in the southern Pyrenees, Montlleó's dates are similar to those obtained for level III at Aitzbitarte IV (Gipuzkoa, 21,8 – 21,2 ka cal BP) in the western Pyrenees (Altuna, 1972 in (Aura et al., 2012) and the sup-B level at l'Arbreda (Girona, 21,5 – 20,1 ka cal BP) in the Eastern Pyrenees (Delibrias *et al.*, 1987 in (Aura et al., 2012). In the Ebro Valley, the Gato 2 site (Zaragoza, 21,4 – 21 ka cal BP) presents dates that align well with the Montlleó occupation, although it is important to note that raclettes have not been identified at the Aragonese site (Blasco and Rodanés, 2009; Sánchez de la Torre et al., 2023).

In the Iberian Mediterranean, the dates obtained for Montlleó are similar to those of level 4 at Parpalló (València, 22–6 – 20,1 ka cal BP) and level 8c at Nerja (Málaga, 22,2 – 21 ka cal BP) (Aura et al., 2012). At Parpalló, the analysis of lithic industry within the Magdalenian – Solutrean sequence indicates a continuous decline in blade production and an increase in undifferentiated and short-wide flakes during the Badegoulian period (Aura et al., 2012).

In the Cantabrian region, we have several examples of stratigraphic succession between Upper Solutrean and Late Badegoulian occupations, such as Llonín Cave in Asturias (De la Rasilla et al., 2019). There, Upper Solutrean occupations (Level IV) are followed by Level III, which corresponds to the Late Badegoulian period. The radiocarbon dates closely align with those from Montlleó. The Badegoulian phase is dated between 22,4 – 20,7 ka cal BP, while the Upper Solutrean occupation spans from 23,5 – 22,9 ka cal BP. Regarding raw materials, the Badegoulian level is characterized by a predominant use of locally or regionally sourced cherts, with limited evidence of long-distance materials. A preliminary macroscopic analysis indicates the exploitation of local materials such as quartzites, radiolarites and local black cherts. Moreover, tertiary silicifications within a radius of 40 to 100 km are also exploited. Three specimens of possible Treviño chert have tentatively been identified, representing the most distant procurement source (De la Rasilla et al., 2019). These procurement strategies do not differ from the ones observed at Montlleó.

To conclude, the wide territorial permeability of the groups settled in Montlleó is also evident through the analysis of malacological resources, partially published (Fernández-Marchena et al., 2019; García-Argudo et al., 2019). Within the site, species of mollusks originating from the Mediterranean predominate. The identification of various well-preserved and unperforated specimens, belonging to different taxa, has led us to consider that these elements were used as raw materials, either for crafting ornaments within the same site or for later exchange with other groups. In this context, the appearance of several specimens of *Homalopoma sanguineum*, a strictly Mediterranean species, documented not only in Magdalenian levels of other Iberian sites such as Cova del Parco (Alòs de Balaguer, Lleida) (Garcia-Argudo, 2015) and Cova Alonsé (Estadilla, Huesca) (Montes and Domingo, 2013) on the southern side of the Pyrenees, but also in the Grotte de la Vache (Ariège), Grotte de Tournal (Aude), Espélugues (Hautes-Pyrénées) and Mas d'Azil (Ariège) (Taborin, 1993, in (García-Argudo et al., 2019) on the northern side of the Pyrenees, supports the hypothesis of extensive networks of contacts among Pyrenean groups.

The evidence of wide territorial connections extends beyond the Pyrenean region and also encompasses the Cantabrian arch. For instance, the appearance of *Homalopoma sanguineum* specimens in Magdalenian levels at El Mirón (Varela, 2014 in (Fernández-Marchena et al., 2019) and El Horno (Vanhaeren *et al.*, 2005 in (Fernández-Marchena et al., 2019) (Ramales de la Victoria, Cantabria), as well as at Tito Bustillo (Álvarez-Fernández, 2002 in (García-Argudo et al., 2019) (Ribadesella, Asturias), would show this broad territorial permeability during the Upper Palaeolithic. Additionally, a recent study on seashell procurement, focusing on territoriality during the Solutrean and Badegoulian periods in western France, concludes that Solutrean seashell provisioning areas were extensive and involved the exploitation of seashells from various regions. In western France, seashells appear to widely circulate, ranging from the Loire and Charente basins to the Dordogne and Garonne basins, with a notable reduction in frequented areas during the Badegoulian period (Peschaux, 2021). In this sense, the identification of various specimens of *Litorina obtusata* and *Tritia heynemanni* at the Upper Solutrean level in Montlleó, currently considered exclusively Atlantic species (Eriksen, 2002), reinforces connections with the Atlantic territory. While some researchers suggest that these species could have colonized the Mediterranean during colder periods, the discovery of two notched points made from Chalosse cherts (Audignon) and one of flysch, technologically and typologically distinct from the main set of notched points from Montlleó, attests to the existence of potential contact networks with Atlantic groups.

6. Conclusions

The study presented in this article allows us to conclude that during the last part of the Upper Paleolithic period in the Pyrenees, the different chronocultures that passed through the Montlleó site had similar economic territories regarding the exploitation of lithic raw materials, with some variations. These variations were probably influenced by interactions with other groups, which seemed to be more extensive during the Upper Solutrean and the Lower Magdalenian periods. However, the exploitation of local rocks is quite similar across the three studied chronocultures, as are the types of chert exploited. The visible break in technical traditions could be the result of an influx of new human populations that nevertheless exploited the same territories as previous groups, as proposed by Banks and colleagues (Banks et al., 2011).

Undoubtedly, analyzing other similar assemblages in the Pyrenean region using geochemical approaches to lithic industries and GIS models will be of great utility in gaining a better understanding of the human groups that frequented the Pyrenean Mountains during the Last Glacial Episode.

CRediT authorship contribution statement

Marta Sánchez de la Torre: Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Visualization, Validation, Supervision, Investigation, Funding acquisition, Data curation. **Eulàlia Rafart:** Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis. **Cynthia González-Olivares:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Bernard Gratuze:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Formal analysis. **Xavier Mangado:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Investigation, Funding acquisition, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2024.104905.

Data availability

Data will be made available on request.

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