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ORIGINAL PAPER

Variability of limestone knapping methods in Middle Palaeolithic levels M and Ob of Abric Romaní (Barcelona, Spain)

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Abstract

This paper presents the limestone reduction sequences documented in levels M and Ob at Abric Romaní from a technological point of view. At level M, a recurrent knapping system has been identified, resulting in the frequency of pseudo-Levallois blanks. At archaeolevel Ob, the presence of Levallois methods are observed in association with this knapping system. In both cases, retouched tools are rare and dominated by notches and denticulates. Although it is not well-known the degree of similarity and difference between the two levels in relation to occupational patterns is not well understood, Neanderthals employed more opportunistic knapping strategies, investing less time and energy in the procurement of raw materials including for chert. In level Ob, although limestone is still collected in the local fluvial deposits, differences in raw material procurement have been identified for chert. Results show the plasticity and versality that Neanderthals had and how they took advantage of the different abiotic resources they had around them. In this paper, we discuss the limestone technology at Abric Romaní in the context of the Iberian Peninsula.

Keywords Limestone · Petrographic characterisation · Lithic technology · Occupational patterns · Middle Palaeolithic · Iberian Peninsula

Introduction

The use of limestone as a raw material for knapping is documented throughout the Middle Palaeolithic at different sites in the Iberian Peninsula. The primary locations are in the Cantabrian (El Castillo, Amalda, Esquilleu and Hornos de la Peña) and the Mediterranean area (Teixoneres, Abrigo de la Quebrada, Bolomor, Cova Negra, Cueva Antón, Vanguard's Cave and Gorham's Cave), with special emphasis on the central peninsular area and on the Atlantic façade (Altuna et al. 1990; Walker 2001; Baena et al. 2005; Manzano et al. 2005; Fernández Peris 2007; Zilhão and Villaverde 2008; Rios-Garaizar 2010; Giles et al. 2012; Shipton et al. 2013; Bargalló et al., 2014; Eixea 2015; Eixea et al. 2016, 2020a; Talamo et al. 2016). The high percentage of Mesozoic and Cenozoic calcareous geological zones in both regions makes the abundance of this rock possible. It is also easy to obtain although there are different petrological varieties that differ in quality and quantity. Most are micritic fine-grained limestones which are of good quality and aptitude for knapping; they are also frequent in certain Triassic and Jurassic facies that have a wide distribution throughout the Iberian

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Peninsula (Fernández Peris and Villaverde 1996, 2001; Eixea et al. 2011; Cuartero et al. 2015; Eixea et al. 2016; Gómez de Soler 2016; Rios-Garaizar 2016).

The variety of raw materials in the knapping systems used by the European populations of the Middle Palaeolithic confirms that there is no direct relationship between complex type management, such as the Levallois method, and a particular lithology, such as chert or flint (Bargalló 2008; Eren et al. 2011; Eixea et al. 2016; Romagnoli et al. 2016). In these cases, environmental determinism (i.e. lack of chert surrounding the site or its poor quality) by itself does not explain the choice of knapping strategy, which opens a debate around the versatility of the behaviours of the Neanderthal groups. In addition, numerous sites reveal diverse limestone tool components (sidescrapers, denticulates, points, endscrapers, etc.), showing a focus beyond *façonnage* tasks (choppers and chopping-tools or trihedral) or a use only as hammerstones. Instead, the production of microlithic elements and the application of Levallois, Quina and discoid methods to limestone discredit the static and homogeneous vision of this raw material (Baena et al. 2005; Fernández Peris 2007; Zilhão and Villaverde 2008; Rios-Garaizar 2010; Giles et al. 2012; Shipton et al. 2013; Eixea 2015; Eixea et al. 2016; Talamo et al. 2016).

In the current work, our main objective is to determine the reduction sequences of the limestones in the M and Ob levels of the Abric Romaní site. We also seek to establish how these production sequences fit within the context of the Iberian Peninsula where the exploitation of this rock is quite recurrent. Furthermore, we will provide a technological and cultural explanation for the production sequences that allows us to delve into the diversity of the Neanderthal groups that inhabited the Iberian Peninsula between the MIS 5 and 3.

It should be noted that this work is a technological study that analyses the reduction strategies of limestone. The use of limestone and its function in other contexts (such as limestone cobbles linked to hearths) are not part of this work because they are included in other ongoing investigations.

Material and methods

Abric Romaní

The Abric Romaní site is located in the north-eastern Iberian Peninsula, in the town of Capellades near Barcelona. It is situated in the travertine cliff of the Cinglera del Capelló (Fig. 1). The karst system is rich in natural shelters (e.g. Balma de la Costa de Can Manel, Abric Agut, Balma dels Pinyons and Abric de la Consagració, among others), which have yielded archaeological finds dating from the Middle Palaeolithic to the Mesolithic (Vaquero et al. 2013). The stratigraphic sequence is composed of 50-m-thick sedimentary sequence dated by uranium series (U-series) and radiocarbon between 110 and 40 ka BP (Bischoff et al. 1988; Vallverdú et al. 2012a, 2012b; Vaquero et al. 2013; Sharp et al. 2016). The sedimentary dynamic is based on the formation of travertine, a rapid formation process that produced a clear vertical separation between the human occupation separated by sterile travertine platforms (Vallverdú et al. 2012a; Vaquero et al. 2013). Depending on the archaeological level, sedimentary rates vary between 17 and 130 cm/ka (Sharp et al. 2016). Except for level A, all the archaeological units along the sequence correspond to the Middle Palaeolithic.

The archaeological levels considered in this study are levels M and Ob. The palaeoenvironmental conditions of levels M and Ob are characterised by short and abrupt oscillations of warmer and wetter episodes in intervals of 1 ka, and the period which marks the beginning of MIS 3 (Burjachs et al. 2012). The anthracological analysis confirms a predominance of *Pinus type silvestris/nigra* attesting to the presence of an open forest environment (Burjachs et al. 2012; Allué et al. 2017). The tufa layer above level M has been dated by U-series to 51,800 ± 1400 BP, whereas the underlying tufa has been dated with a result of 54,900 ± 1700 BP, 54,100 ± 1600 BP and 55,800 ± 2300 BP (Vaquero et al. 2013). It has yielded abundant faunal and lithic remains, wood imprints and combustion structures (Fernández-Laso et al. 2011; Picin 2014; Allué et al. 2017; Solé et al. 2013). The taphonomic and zooarchaeological examination identified six main activity areas (Fernández-Laso 2010, 2020; Marín et al. 2017a, 2017b; Vaquero et al. 2017). Chert is the most exploited raw material along the sequence and the lithic assemblage is characterised by the discoid bifacial method and a low frequency of denticulate and notched tools (Picin et al. 2011; Chacón et al. 2013; Picin 2014; Gómez de Soler 2016; Romagnoli et al. 2018; Gómez de Soler et al. 2020b). The total number of lithic remains is 6084. In relation to level O, following stratigraphic analysis, three archaeolevels (Oa, Ob and Oc) are differentiated (Bargalló 2014; Bargalló et al. 2016). Due to the low density of limestone remains in archaeolevel Oa ($n=79$) and Oc ($n=2$), it has been decided to focus primarily on level Ob, which is the most diagnostic and has the most remains ($n=1133$). The U-series dating are of 54.6 ± 0.4 ka BP for the travertine above the archaeolevel and 54.24 ± 0.42 ka BP for the travertine below it. It has yielded a huge assemblage of faunal and lithic remains, together with wood imprints and combustion structures (Vallverdú et al. 2012b; Chacón et al. 2013; Bargalló, 2014; Bargalló et al. 2016). The lithic collection is characterised by the use of the Levallois method in the preferential and centripetal recurrent modes, especially on microlithic productions, whereas retouched artefacts comprise denticulates, notched tools and sidescrapers (Picin et al. 2011; Chacón et al. 2013; Bargalló et al. 2014; Eixea et al. 2020b).

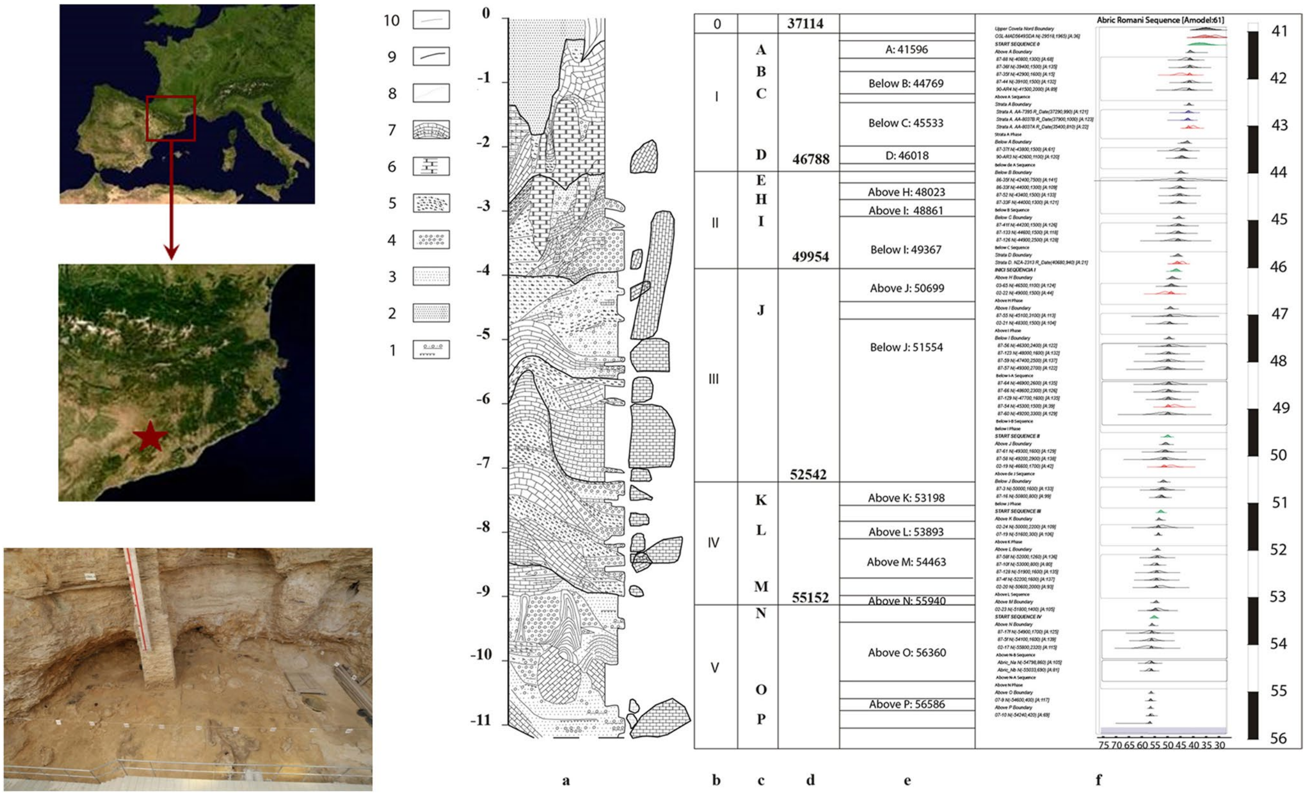

Fig. 1 **a** Geographical location map of the Abric Romaní (https://visibleearth.nasa.gov/); (**b**) General view of archaeological level O (Photo ©IPHES). Coveta Nord Stratigraphy from Abric Romaní rockshelter. Lithofacies legend: 1, bedded calcitic sands and travertinic gravels; 2, siliciclastic and calcitic muddy sands; 3, calcitic sands; 4, travertine gravels and calcitic sands; cristalitic gravels and sands; 6, cristalitic lamination; 7; microbreccia, calcarenite and stromatolithe lamination; 8, archaeological level; 9, boundary sequence; 10, diasteme. Commentaries table: a, lithostratigraphy; b, sequence number; c, letters of archaeological layers; d, bayesian dates for the start of the Abric Romani sequences; e, bayesian dates for Abric Romaní archaeological layers; f, U-series, radiocarbon and luminescence dates of the Abric Romaní sedimentary samples (Vaquero et al. 2013; Vallverdú, 2018)

Methods

Lithic assemblage was studied according to the *chaîne opératoire* approach (Cresswell 1982; Lemonnier 1986; Karlin et al. 1991), with the aim of recognising various stages in lithic tool making and investigating the basic conceptual processes that underlay the sequence of manufacturing steps in stone tool production. Accordingly, we regard the production of stone artefacts as a dynamic process, from the acquisition of raw material to the discard of used tools. It thus aims at re-establishing the lifecycle of the stone tools. In this process, there are four main phases: raw material acquisition, production, utilisation and discard (Tixier et al. 1980; Boëda et al. 1990; Julien 1992; Texier 1996).

Refitting analysis was used to determine the variability within the production sequences and the temporal relation between the archaeological clusters. All finds taken into consideration to establish different kinds of knapping activities (exploitation, configuration, retouching, fracturing) and the distances between the elements were quantified, as was their location in space (Newcomer and Sieveking 1980; Cziesla, 1990; Cziesla et al., 1990; Kvamme 1997; Vaquero et al. 2017, 2019). Moreover, refitting can provide information about the temporal relationships between the archaeological accumulations in which the refitted artefacts are located. Refits were often used to demonstrate that different accumulations were contemporaneous, although it now seems clear that the simple connection between two artefacts is not enough to argue that two activity areas were formed during the same occupation episode (Cahen and Keeley 1980; Larson and Ingbar 1992; Vaquero et al. 2014).

Retouched pieces (including retouched pseudo-Levallois points and pieces with macro-use wear) were classified using the Bordes' type-list (1961).

Regarding the lithic taphonomic approach, flake fragmentation, conservation and representativeness have been carried out following the work of Hiscock (2002) and adapted by Santamaria (2006 and 2012). In this study, it is intended to identify and characterise the fragmentation patterns present in the sample (i.e. the distribution of lithic fragments and the fragmentation and representativeness indices of each techno-typological group), and examine the potential causes of this distribution. These can be due to internal factors: lithological and/or technological factors (i.e. quality of the raw material, knapping methods used, morphology of the substrates) and external ones: behavioural factors or those derived from interstratigraphic contaminations.

Finally, the data from the levels analysed are compared with other sites in the same geographical area, the Iberian Peninsula, and with chronologies ranging from MIS 5 to 3. The selection criteria have been those linked to the use of limestone in knapping activities; not considering the assemblages in which the limestones are associated to other types of domestic activities. Special attention is paid to the percentage of limestone in the record of each site and what is the main reduction strategies used. The aim is to obtain a regional perspective on systematic use of limestone by Neanderthal groups, which has not been an important line of studies so far. Also, the use of non-flint raw materials, especially limestone, is an interesting point to be assessed in connection with the length of occupations of the sites and the activities carried out therein.

Results

Lithic raw materials and the petrographic characterisation of limestones

Regarding the raw materials procurement, the most exploited raw material is chert (80% for level M and 91% for archaeolevel Ob), with the Sant Martí de Tous variety the most represented type (93% and 84% respectively). These source areas are located approximately 16 km north-west from the Abric Romaní site and are included within the Sant Genís formation, a Priabonian-aged evaporitic formation of the Ebro Basin margin (Gómez de Soler 2016; Gómez de Soler et al. 2019, 2020a) (Fig. 2).

The second most exploited raw material is limestone, representing 9% and 5% of the total lithic assemblages at each level. Dolomitic limestones and tabulated dolomites of marine origin are found in the Muschelkalk facies of the Prelittoral ranges. Micritic marine limestones with alveolates have been located in the Ebro Basin at the Orpí formation (Eocene). Both limestone types are also found in

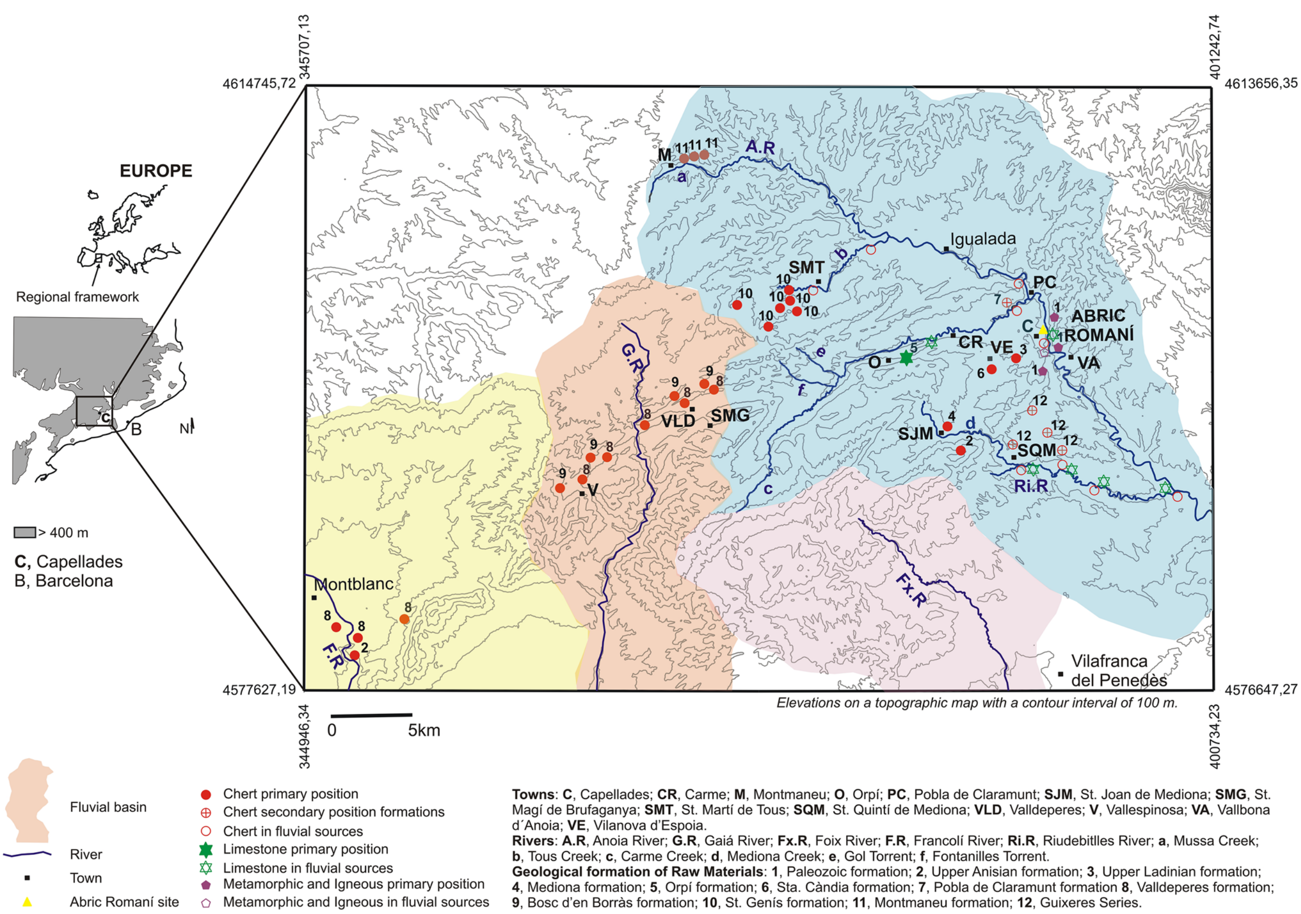

Fig. 2 Map showing the distribution of chert, limestone, metamorphic and igneous rocks outcrops. In yellow the Francolí river basin. Ochre-coloured the Gaià river basin. Greyish pink the Foix river basin. Bluish green the Anoia river basin

secondary position as part of conglomerates constituting the Pobla de Claramunt formation (Eocene) and Guixera Series (Pliocene). These outcrops can be found within an area < 10 km from the Abric Romaní site, suggesting local procurement strategies for this raw materials. Nevertheless, most of the limestone morphologies found in Abric Romaní are pebbles. Cortical surfaces indicate secondary procurement areas, with the Anoia River and, to a lesser degree, the conglomerate formations located within a < 5-km radius from the site as the most plausible sources (Gómez de Soler 2009; Vaquero et al. 2017; Vaquero et al. 2012; Bargalló et al., 2014; Gómez de Soler et al. 2020a).

The rest of the raw material assemblage is formed by igneous and metamorphic rocks, with quartz and schist as representatives. All are identified in primary position in the immediate surroundings of Abric Romaní.

Two petrological groups of limestones have been distinguished. The first is a group of grey to greyish-yellow and orange varieties of fine-grained micritic and dolomitic limestone with wackstone, packstone and, more commonly, grainstone of foraminifera (miliolids, orbitolinids, rotolids and alveolates) with conchoidal fracture. Its primary formation is ascribed to the Orpí formation (< 10 km from the site) of Ilerdian age (Lower Eocene) (Fig. 3). The second is a group of white to greyish varieties of medium-grained microsparitic and sparitic limestones with granular fracture, with a still-undetermined primary origin (Fig. 4). Both groups are very common as pebbles in the fluvial courses near the Abric Romaní site.

Both groups were collected in Quaternary deposits from the Anoia fluvial system (the Mediona-Riudebitlles River, Carme Creek and the Anoia River itself). The exploitation of the first group is chiefly attested for knapping and percussion activities, while the second group, due mainly by its poor aptitude for knapping (e.g. sparitic textures, granular fractures), is mostly used as structural elements; for example, delimiting hearths are a well-documented aspect of the Neanderthal occupations of the site.

Level M

A total of 6084 elements are assigned to this level, 566 of which are limestone (9.3%). Taphonomically, in limestone, both the Fragmentation Index (FI: 0.19) and the Representativeness Index (RI: 0.63) (FI & RI following Hiscock 2002) and adapted by Santamaría 2006 and 2012) are compatible with each other. These values indicate weak fragmentation. Thermal alterations, patinas and concretions are also

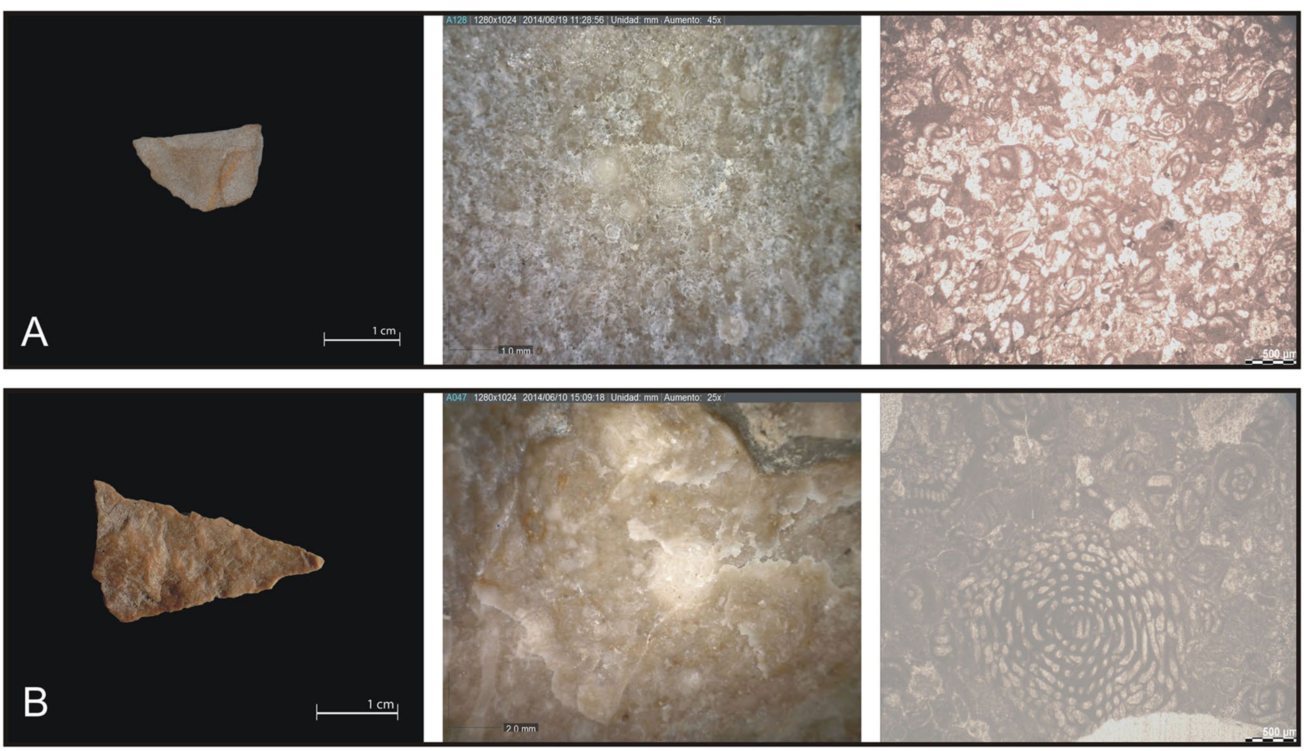

Fig. 3 Two examples of archaeological limestones adscribed to the Orpí formation. (**A**) From left to right, archaeological limestone AR'02_M_O46_7, detail with the stereoscopic microscope and image taken under a petrographic microscope with plane-polarised light (PPL) and 40×. (**B**) From left to right, archaeological limestone AR'02_M_U47_254, detail with the stereoscopic microscope and image taken under a petrographic microscope with PPL and 40×. In both cases can be observed the great number of foraminifera (mainly miliolids and aleveolines) conferring packstone-grainstone textures

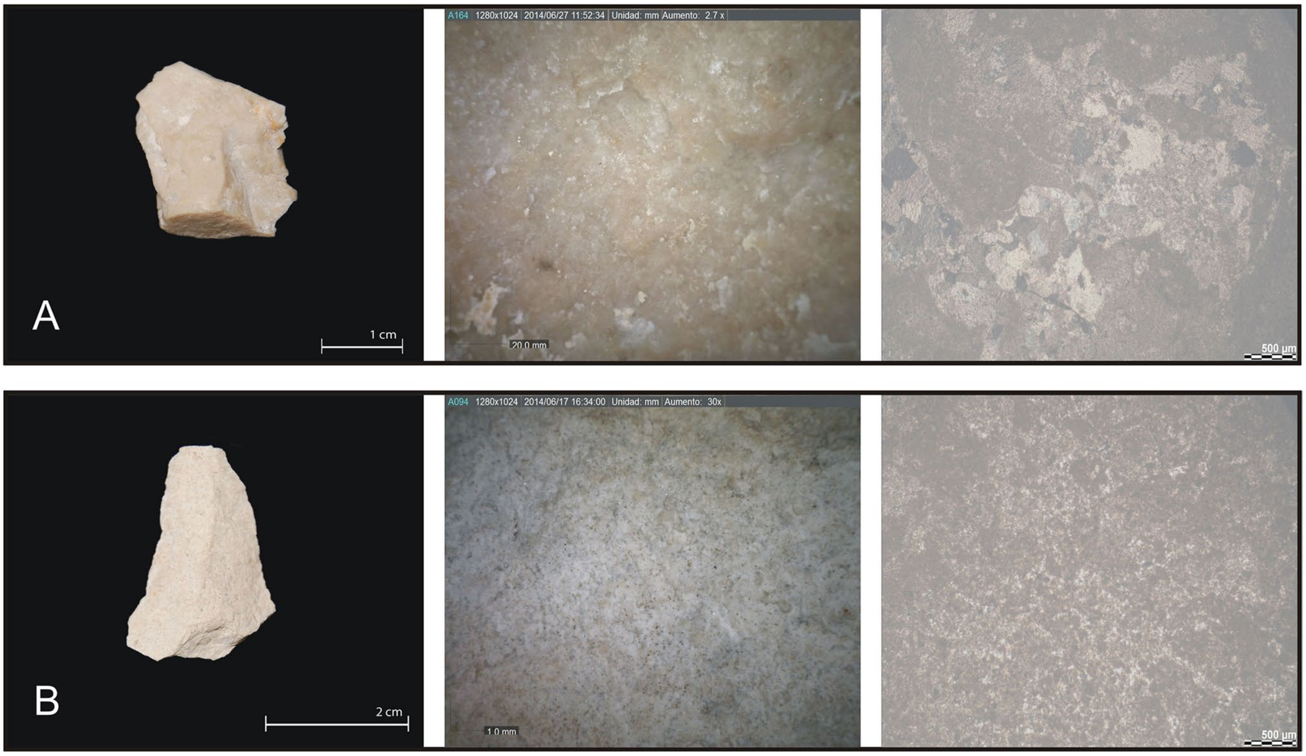

Fig. 4 Two examples of archaeological limestones grouped in the medium-grained microsparitic and sparitic limestones. (**A**) From left to right, archaeological limestone AR'02_M_O46_7, detail with the stereoscopic microscope and image taken under a petrographic microscope with cross-polarised light (XPL) and 40×. (**B**) From left to right, archaeological limestone AR'02_M_N43_50, detail with the stereoscopic microscope and image taken under a petrographic microscope with cross-polarised light (XPL) and 40×. In both cases can be observed the microsparitic matrix with mudstone texture

low. From these results, the existence of a single fragmentation pattern is observed, characterised by the predominance of complete pieces over fragmented ones.

Cores and blank production

In the limestone assemblage, flakes and flake fragments predominate (> 75%), followed by a much smaller quantity of elongated flakes and hammerstones (1.4%). Elements where it is not possible to precisely determine their morphology are low in number (18%) (Table 1).

Regarding cores, their geometric organisation shows the exploitation of multiple opposing platforms to obtain triangular and quadrangular flakes. Three cores correspond to discoid-type systems (two unifacial and one bifacial), one orthogonal and one multipolar. The surfaces show a marked convexity and a reduction that took place on the widest face.

Through the refitting sequences, we can observe how the management of the convexities is associated with overpassed flakes of pseudo-Levallois morphology (16.5%). There are no remarkable differences in the dimensions of the cores. Their length varies between 6 and 8 cm. Cores on fractured old hammerstones correspond to those that are larger in size.

With the exception of a multipolar core where the removals have more than one direction, the rest are exploited in a centripetal strategy following a trajectory towards the centre, in a short series composed of a few flakes ($n=8$–11) and in short formats which do not reach the entire surface of the core. Most of the cores have a quadrangular morphology, probably due to the successive use of opposing striking platforms and their central knapping direction. In turn, this is also found in the dorsal surface of the blanks in which the centripetal direction predominates in most of the assemblage. The dimension analysis indicates a predominance of flakes between 2 and 4 cm in length, with width and thickness around 1 cm (Fig. 5, Table 2).

The flakes are dominated by flat (42%) and cortical (11.8%) platforms. The time required to obtain the blanks is low, involving direct use of the natural platform without previous modification. All of these flakes have prominent bulbs showing the use of direct percussion with hard hammerstones. Most of the flakes have converging distal axes, a slightly curved and laterally flat longitudinal profile.

Table 1 Blank, Cores and Tools on limestone from levels M and Ob

BLANKS	M	%	Ob	%
Flake	141	24.9%	344	30.4%
Flake fragment	296	52.3%	382	33.7%
Elongated flake	3	0.5%	39	3.4%
Core	6	1.1%	16	1.4%
Tool	13	2.3%	4	0.4%
Hammerstone	5	0.9%	76	6.7%
Indet	102	18.0%	272	24.0%
Total	566	100.0%	1133	100.0%
CORES	M	%	Ob	%
Discoid	3	60.0%	10	62.5%
Bifacial	2	40.0%	8	50.0%
Unifacial	1	20.0%	2	12.5%
Levallois	-	-	2	12.5%
Recur. Unip.	-	-	1	6.3%
Recur. Centrip.	-	-	1	6.3%
Orthogonal	1	20.0%	2	12.5%
Multipolar	1	20.0%	-	-
Trifacial	-	-	2	12.5%
Total	5	100.0%	16	100.0%
TOOLS	M	%	Ob	%
Denticulate	4	30.8%	1	25.0%
Notch	3	23.1%	-	-
Sidescraper	-	-	2	50.0%
Retouched pseudo-Levallois point	2	15.4%	-	-
Endscraper	-	-	1	25.0%
Chopper	1	7.7%	-	-
Macro-use wear	3	23.1%	-	-
Total	13	100.0%	4	100.0%

A good representation of the morphological variety determined by flakes seems to be focused on the production of the discoid method, obtaining the typical pseudo-Levallois type elements (22%, Table 1). Kombewa-type flakes have been identified and would possibly come from the exploitation of large core-on-flakes. The rest do not seem to respond to a specific technological differentiation based on knapping strategies.

Tools

Retouched limestone tools are rare, composing only 2.3% of those found at Abric Romaní, although they are more common compared with other raw materials such as chert (0.7%), quartz (0.3%) or slate (1.3%). The predominant group is composed of notches and denticulates (> 50%), followed by retouched pseudo-Levallois points and a chopper. A proportion of flakes (23%) with macro-use wear (e.g. micropolishes, cracked, edge deformations), as observed with an × 50 microscope lens, was also identified. This highlights there was a clear selection of pseudo-Levallois type blanks to transform through retouch (notches and denticulates) or used directly raw (Fig. 6).

Typometrically, retouched pieces vary between 2 and 4 cm in length and 2 and 6 cm in width, presenting quadrangular morphologies with a tendency to a greater widening in the entire piece, which is common on this type of pseudo-Levallois format. Retouch is simple and mainly located on the distal edge which entails retouching from either the lateral flank (*meplat*) or the proximal part to get a good grip to use the piece.

Archaeolevel Ob

The number of elements is 1133, which represents 93.5% of the limestone remains from level O in full. At the taphonomic level, the analysed sample presents a good preservation in which concretions, patinas and post-depositional processes are minimal. The incidence of fire does not exceed 5% of the whole. If we focus on fragmentation, the FI is low (0.17) within a reliable RI (0.78). This indicates a weak alteration of the analysed assemblage.

Cores and blank production

Lithic production is orientated to obtaining flakes, which compose more than 60% of the assemblage. Although the numbers are much smaller, the elongated formats are found in greater amounts than at level M (3.4%). There is a good proportion of hammerstones ($n = 76$) and the indeterminate elements are higher than in the previous level (24%).

A total of 12 elements have been documented, among which the discoid type is dominant ($n = 10$). Within these, the bifacial variant ($n = 8$) predominates. Both surfaces are alternately exploited in a centripetal direction as has been identified through refits. Both exploitation surfaces are convex, asymmetric and secant delimited by a plane of intersection. There is no hierarchy between them and they are used equally as striking and exploitation surfaces. The surface is prepared by establishing a peripheral convexity with the aim of obtaining predetermined products. The axis of knapping is perpendicular to the edge of the core. In the unifacial remains ($n = 2$), similar criteria are observed but with the exception that one of the surfaces is exploited while the other is used as a percussion platform. Depending on the axis of the blank and the back, the identified products are classified as plunging flakes, pseudo-Levallois points or centripetal flakes. Typometrically, there is no variation with the other knapping methods used for other raw materials in the level M. Pieces have dimensions that range between 2 and 4 cm in length and 2 to 3 cm in width, with a thickness

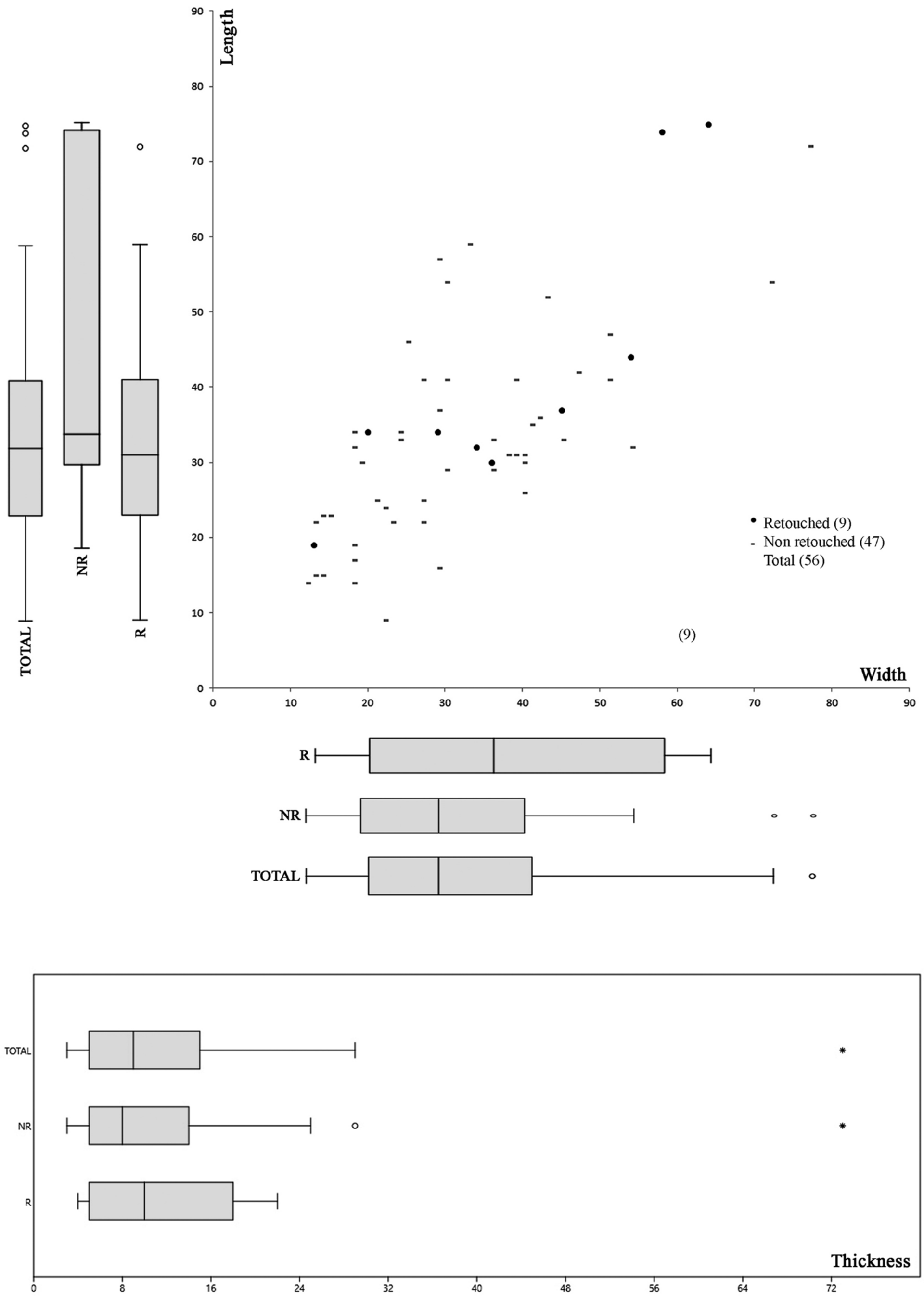

Fig. 5 Level M scatter plot (length, width and thickness, in cm) of retouched and unretouched flakes. The box plots represent the average (central bar), 50% of the cases (rectangle), 95% of the cases (whiskers) and outliers (dots)

Table 2 Level M: distribution of the typometrical variables (*N*, minimum, maximum, average and standard deviation)

	Length retouched	Width retouched	Thickness retouched	Length non-retouched	Width non-retouched	Thickness non-retouched
N	9	9	9	47	47	47
Min	1.9	1.3	0.4	1.4	1.2	0.3
Max	7.5	6.4	2.2	7.2	7.7	2.9
Average	4.2	3.9	1.2	3.3	3.1	1.1
Stand. dev	1.9	1.7	0.6	1.3	1.4	0.5

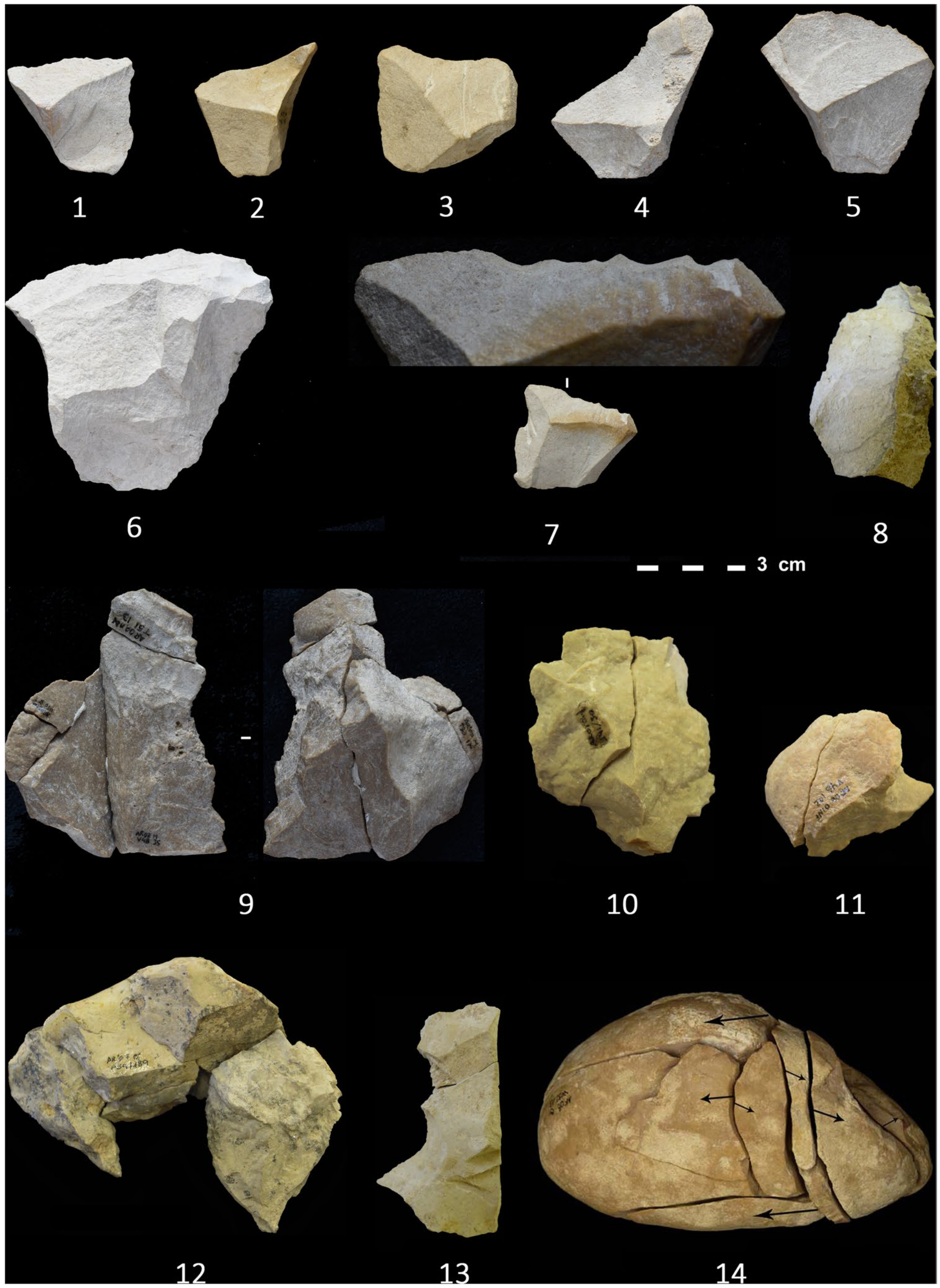

Fig. 6 Cores, blanks and tools assemblage: 1–6, Pseudo-Levallois points (level M); 7, Denticulate (level M); 8, Simple convex sidescraper opposite to natural back (archaeolevel Ob); 9, Refitting of a reduction sequence (level M); 10–12, 14, Refitting of a reduction sequence (archaeolevel Ob); 13, *Débordant* flake (archaeolevel Ob)

around 1 cm. There is a tendency for the larger blanks to be transformed by retouch (> 6 cm in L and 3 in W) (Fig. 7, Table 3). Comparing both levels (M and Ob) from a statistical point of view, an ANOVA test has been performed on length ($p = 0.713$), width ($p = 2.252$) and thickness ($p = 0.412$) of the items. The results show that there are no significant differences between both samples.

Regarding the Levallois strategies, a difference with level M can be determined in both the cores and the blanks obtained. There are no major technological differences between its use in chert, which is the dominant raw material, and limestone. In both cases, cores have one convex surface opposite to the other and an asymmetric profile: one of the surfaces is higher than the other and the main surface is flaked around its perimeter, either continuously or not. On the surface, several flake scars and a large flake scar can be seen, with multiple traces detached before the last flake. Regarding documented Levallois blanks, they are always obtained by direct percussion and have a regular morphology with a longitudinal symmetry axis, sharp edges, a dorsal surface showing several scars related to the preparation of the knapping surface (lateral and distal convexities) and

Fig. 7 Archaeolevel Ob scatter plot (length, width and thickness, in cm) of retouched and unretouched flakes. The box plots represent the average (central bar), 50% of the cases (rectangle), 95% of the cases (whiskers) and outliers (dots)

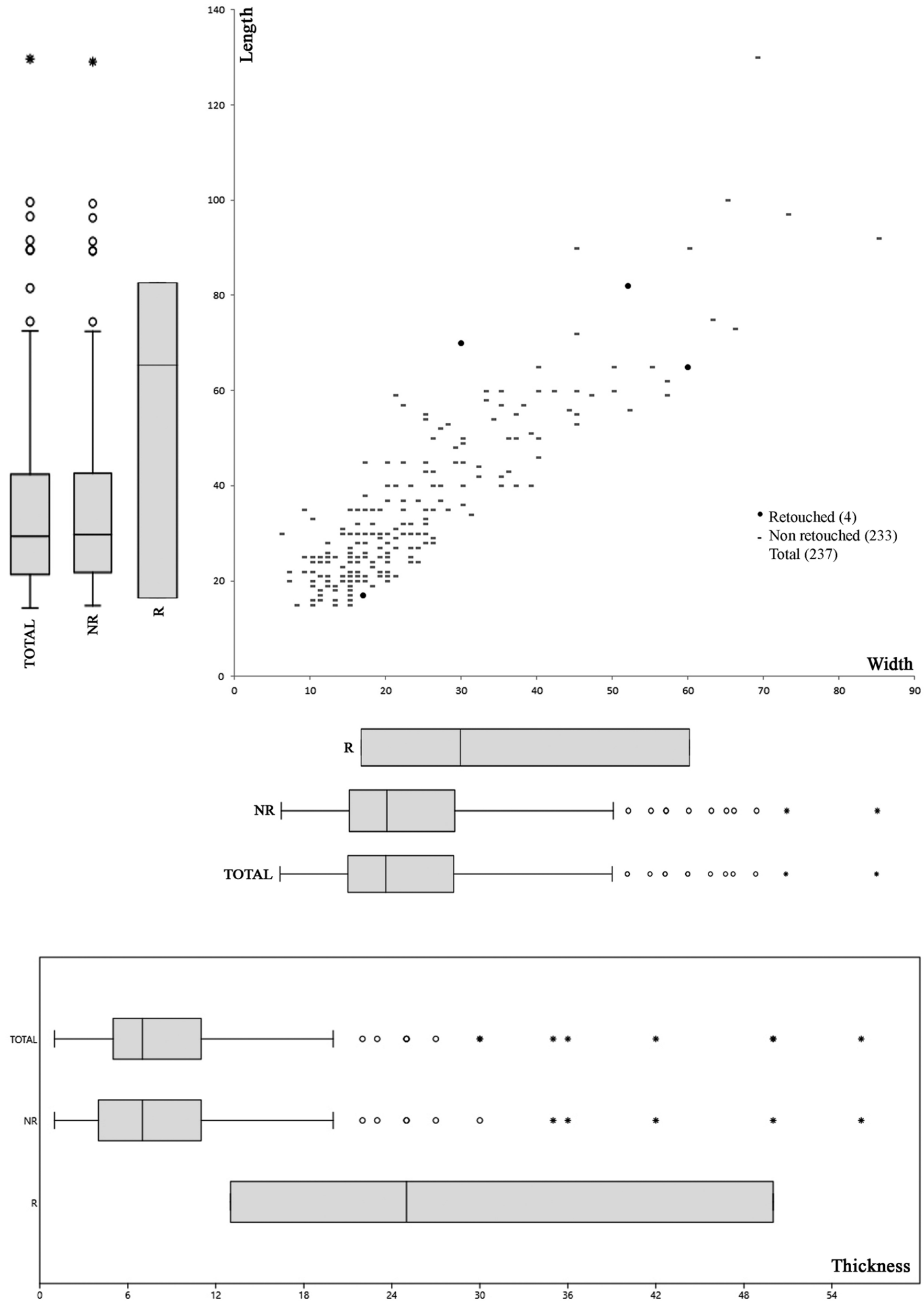

Table 3 Level Ob: distribution of the typometrical variables (*N*, minimum, maximum, average and standard deviation)

	Length retouched	Width retouched	Thickness retouched	Length non-retouched	Width non-retouched	Thickness non-retouched
N	4	4	4	233	233	233
Min	1.7	1.7	1.3	1.5	0.6	0.1
Max	8.2	6	5	13	8.5	5.6
Average	5.8	3.9	2.9	3.4	2.3	0.9
Stand. dev	2.8	1.9	1.5	1.7	1.3	0.7

dihedral and faceted butts (Boëda 1994; Boëda et al. 1990). The secondary blanks whose dorsal side also showed one or more invasive scars, interpreted as extractions from previous phases of knapping (recurrent unipolar, bipolar and centripetal method), have also been included. Typometrically, unlike the discoid blanks, they tend to be slightly longer (between 3 and 5 cm in length) and narrower and, above all, are much thinner, not exceeding 1 cm.

Finally, in relation to the other reduction methods documented in this lithology, the trifacial ($n=2$) and orthogonal ($n=2$) stand out. Following Boëda et al. (1990), trifacial method documented are characterised by three exploitation surfaces, two opposite wide surfaces and one shorter side. The produced blanks have trihedral sections and are frequently plunged. In orthogonal methods, the extractions are located on two or three surfaces but with the difference that the direction follows an orthogonal order when viewing the dorsal surface. The blanks have wide and short morphologies and are also frequently plunged.

Tools

Four retouched tools were found in this archaeolevel, composing 0.4% of the record. Comparing these data with the degree of transformation by retouch in the other main raw materials, the character of the retouched tools in the limestone is lower than general and decreases (2.3 in level M and 0.4 in level Ob). Chert (1.3%) and quartz (1%) increase slightly.

The tool types are sidescrapers ($n=2$) and, in particular, lateral opposite to natural back ones, followed by one denticulate and one endscraper. In all cases, retouch is simple, direct and marginal, forming a shallow edge that does not give a very marked appearance.

In relation to the dimension of these pieces, there is no significant difference in size between tool categories. Although one of the sidescrapers has a microlithic component in that the length and the width are below 2 cm, the other retouched tools are made on the largest blanks of the assemblage (6–8 cm in length, 3–5 cm in width and 2–3 cm in thickness).

Discussion and conclusion

This paper has sought to define the limestone production sequences used in levels M and Ob. The procurement area of these lithologies are local for both levels, originating at a distance of hundreds of metres from the site. Its introduction as pebbles confirms its secondary procurement in the river courses, mainly the Anoia River near the site (Gómez de Soler 2009, 2016). There are differences within each level from a technological point of view and with regard to other raw materials, especially chert (Chacón 2009; Chacón et al. 2013; Bargalló, 2014; Romagnoli et al. 2018). On the one hand, at level M, chert is mostly characterised by non-hierarchical strategies where these strategies resulted in the high variability of the final morphologies of the cores. The majority of the cores are asymmetrical and the angles of the striking platforms are essentially abrupt and semiabrupt, with symmetrical bi-pyramidal morphologies are rare (Chacón et al. 2013; Romagnoli et al. 2018). On the other hand, the limestone reduction strategies are predominantly discoid, exploited in a unifacial or bifacial way, and the obtained formats are essentially plunged flakes and pseudo-Levallois points. Although the number of remains is low, unifacial, trifacial and multifacial cores were also recovered. The sizes are usually small to medium, and the degree of transformation by retouche is low, consisting primarily of notches and denticulates and, to a lesser extent, some retouched pseudo-Levallois points. In relation to archaeolevel Ob, chert technology is focused on hierarchical strategies, in which one surface of the core is preferentially exploited and the other is used to prepare the percussion points. As opposed to chert from level M, these strategies resulted in less variability in the final morphologies of the cores. The majority of them are also asymmetrical and the angles of the striking platforms are essentially semi-plane/simple semi-abrupt. The angle varies depending on whether it is the first or second surface to be exploited, which is consistent with the hierarchy typical of Levallois strategies (Chacón et al. 2013; Bargalló, 2014; Bargalló et al., 2016). Limestone technology is characterised by a discoid method with characteristics similar to those previously seen, but with a difference that also demonstrates the presence of a well-defined Levallois method, both in cores and refitted blanks as well as some classic *débordant* flakes. This illustrates how the same technical criteria applied to chert can also be carried out on limestone (i.e. hierarchy of surfaces, preparation of convexities). As in level M, the transformation through retouch continues to be very low and it is mainly the non-Levallois flakes that are retouched.

The reason for this change could be a technological change in the culture, or it may simply indicate a change in the economy of the occupation patterns, with level M occupations being more opportunistic, while those in archaeolevel Ob were longer and more complex, involving a greater degree of planning in their subsistence activities. Within this variation, changes in chert procurement have been identified in level Ob with more presence of chert formation from La Panadella which is located 24 km from the site (Chacón et al. 2013; Bargalló et al., 2016; Romagnoli et al. 2018; Gómez de Soler et al. 2020a, 2020b). Group mobility and variation in the quality of the raw materials available in the site's immediate area could have influenced selection patterns. The use of limestones in different productions therefore needs to be assessed in connection with the length of occupation and the activities carried out therein. For instance, in places of seasonal occupation and in the context of short-duration activities like in Abric Romaní level M, raw material procurement could have been more focused on local and semilocal resources. As a result, any suitable raw material available could have been chosen for the production of blanks (discoid, Levallois, orthogonal, etc.). Recycling, whether flakes or hammerstones, has been identified through the technological and spatial analysis of refitted sequences, attesting to the use of the internal area of the rock shelter as a procurement area (Vaquero et al. 2014, 2017, 2019; Romagnoli and Vaquero 2016; Romagnoli et al. 2018).

In these cases, we observe that in level M long journeys to obtain a particular raw material would not have been economical profitable because the group only stayed at the site for a shorter period than in level Ob and the lithic tools produced there were used for a limited amount of time. This is even more likely when, as at Abric Romaní, cobbles of fine-grained quartz with a homogeneous structure and an adequate size, as well as of suitable limestone and reasonable quality chert, exist in the immediate surroundings. The choice of a given method could have been influenced by cultural tradition, but assessing the impact of this factor is, in our opinion, a difficult task. Therefore, other factors must be considered first. The fact that although retouched tools are low at Abric Romaní, discoid blanks are more often transformed than Levallois ones may be a particular indication of the importance of functional factors, since the more expedient nature of the discoid method is consistent with occupations of a more temporary or seasonal nature, as the archaeological and ethnographical data reveals (Luedtke 1984; Parry and Kelly 1987; Chase 1999; Delagnes and Rendu 2011; Eixea et al. 2016). In such instances, re-sharpening and recycling of blanks available on-site would have been more economically profitable than producing ex novo from suitable nodules whose acquisition, even at a short distance, would nonetheless have demanded an investment in time.

Summarising, we can highlight how the Neanderthal groups from the Abric Romaní showed an important behavioural complexity and flexibility in relation to landscape management. The variability of their behaviour is explained as the existence of different cultural traditions, maintained through time, as an adaptation to different circumstances (landscape, climate, demography, etc.), or as the result of the historical processes of Neanderthal communities (Hovers and Belfer-Cohen 2006; Rios-Garaizar 2008, 2020; d'Errico and Stringer 2011). This type of flexible strategy was very useful for high-mobility populations covering wide territories, with a wide range of biotopes from where they collected different variety of resources (marine animals, rocks, grassland and forest macromammals, and probably other resources as fish, small mammals, birds, fruits, plants, etc.) on a seasonal or annual cycle. This flexibility of resource (biotics and abiotics) acquisition and consumption, together with high residential mobility inside a wide territory, can be the consequence of a quick reduction of the available resources in an area (Venkataraman et al. 2017).

With the analysis of the data from levels M and Ob at Abric Romaní, we can place them in the context of the Iberian Peninsula where other groups use limestone as a raw material, allowing us to establish three types of sites (Table 4):

- Firstly, knapping is sporadic at those sites in which the use of limestones is documented in both percussion and macrotools (*façonnage*). For example, in Amalda VII, in a context dominated by flint and discoidal and Levallois reduction sequences, some massive tools appear sporadically (Rios-Garaizar 2008, 2010). The same occurs in Gorham's Cave where a cobble tool is associated with a single unifacially flaked limestone core (Giles et al. 2012; Shipton et al. 2013).
- Secondly, there are sites in which the activities related to the use of this lithology as percussion are linked with the development of well-documented technological management and sporadic macrotooling. For example, in Cueva Antón III, the limestone domain as a raw material affecting all the documented blanks but, above all, the Levallois and discoid strategies (Zilhão and Villaverde 2008). In Bolomor IV, Levallois production strategies and, to a lesser extent, trifacial in chert, are combined with a recurrent centripetal Levallois and orthogonal methods on the limestones from which notches and denticulates are obtained (Fernández Peris 2007; Hortelano 2016). This is also the case in Abric Romaní where the presence of hammerstones and macrotools is combined with the development of discoid and orthogonal strategies (level M) and Levallois and trifacial flakes (archaeolevel Ob) (Bargalló et al., 2014), with the aim of obtaining raw, ready-to-use blanks and, in other few cases, transforming into denticulates, notches and sidescrapers.
- Finally, the third group corresponds with those in which the only use of limestone is documented for knapping. We have examples from the Late Middle Pleistocene and the beginning of the Upper Pleistocene, as is the case of Arlanpe, Quebrada VIII and Vanguard's Cave (Lower Horizon), and more advanced (MIS 3), such as Cuco VII, Esquilleu (III, XVII, XVIII, XXI–XXIV), Teixoneres III, Quebrada II–V and Vanguard's Cave (Upper and Intermediate Horizons). It is worth noting that chert is the main raw material in Quebrada, where it is found in large quantities. Despite the prevalence of chert, limestone represents an important lithology both in the number of remains and in the strategies applied to it (Levallois sensu stricto, Levallois ramified and discoid).

Table 4 Chronological, raw material and technology data regarding from Iberian Peninsula main sites cited in the text

Site	Level	MIS	Main raw material	%	Main knapping method	Main raw material tools	% limestone	Knapping technique	Limestone tools	Catchment	Levallois limestone	References
Amalda	VII	4	Flint	> 90	Discoid/Levallois (ramified)	Sidescrapers	Anecdotic	Discoid/façonnage	Macro-tools	Local	N	Altuna et al. 1990; Rios-Garaizar 2008; Rios-Garaizar 2010
Arlanpe	IV (sector entrada)	7 – 5e	Lutite	55	Indet	Natural backed knifes	2.8	Indet	Natural backed knife	Local	N	Rios-Garaizar 2013
Cuco	VII	3	Flint	> 95	Ramified Levallois strategy	Sidescrapers and denticulates	Anecdotic	-	-	Local	N	Gutiérrez-Zugasti et al. 2018
Esquilleu	III	3	Quartzite	59	Discoid (on flake)		17.5	Discoid	-	Local	Y	Baena et al. 2005; Manzano et al. 2005
	XVII			57	Levallois (unipolar)	Sidescrapers	9.2	-				
	XVIII			59			9.3					
	XXI			66	Discoid/Levallois		18					
	XXII			83	Discoid (hierarchical)		6					
	XXIII			77	Discoid		9					
	XXIV			71			11					
Teixoneres	III	3	Quartz	42	*Tranche de saucisson*	Sidescrapers	8.5	Unidirectional/centripetal	-	Local	N	Talamo et al. 2016
Bolomor	IV	5	Chert	84	Levallois/trifacial	Notch/denticulates	14.6	Levallois (centr. rec)/orthogonal	Notch/denticulates	Local	N	Fernández Peris 2007
Quebrada	II	5–3	Chert	76	Levallois/discoid	Sidescrapers	12	Discoid/Levallois	Notch/denticulates/sidescrapers	Local	Y	Eixea 2015
	III	5		68			12					
	IV			61	Discoid/Levallois		17.4	Discoid	Notch/denticulates			
	V			63	Levallois/discoid		16.2		Notch/denticulates			
	VIII			86	Discoid		8.5		Sidescraper		N	
Cueva Antón	III	3	Limestone	Dominant	Levallois/discoid	Notch/denticulates	-	-	-	Local	Y	Zilhão and Villaverde 2008
Vanguard's cave	Upper Horizon	4–3	Quartzite	59	-	-	13	Discoid/multiplatform	Core	Local	N	Shipton et al. 2013
	Intermediate Horizon			44			11	Multiplatform				
	Lower Horizon	5		81	Discoid/Levallois		5	-	-			

Table 4 (continued)

Site	Level	MIS	Main raw material	%	Main knapping method	Main raw material tools	% limestone	Knapping technique	Limestone tools	Catchment	Levallois limestone	References
Gorham's cave	IV	3	Chert	58	Levallois (centr. rec)/ orthogonal	Sidescrapers	Anecdotic	Unifacial	Chopper	Local	N	Giles et al. 2012; Shipton et al. 2013

In the same way, a duality is observed between sidescrapers mostly made in chert while the notches and denticulates are in limestone. In addition, a good proportion of preferential Levallois blanks made from limestone is documented at Quebrada site (Eixea et al. 2016). At sites such as Arlanpe, Esquilleu, Teixoneres and Vanguard's Cave, the absence of good quality flint in the vicinity means that the use of other rocks such as quartzite, shale or quartz is of greater importance. This clearly affects the use of limestones. It is seen a greater proportion but with the difference that Levallois type criteria will not be applied and the degree of transformation through retouch will be almost non-existent. The record is composed of only a few indeterminate blanks and some unidirectional, multipolar and centripetal cores.

To conclude, the technological analysis carried out in this paper and its comparison with the Middle Palaeolithic sites in the Iberian Peninsula has provided new information regarding the use of limestone as a raw material for knapping. Based on this and other further studies, we will be able to better address the existing problem that surrounds the identification and technological characterisation of limestone. Also, deepen the petrographic study, as well as the location of most of the primary formations of the different types of limestones, with the intention of having a better regional perspective of all the possible sources of lithic raw materials. In the same way, it is also necessary to open new lines of research. Firstly, from a traceological point of view (use wear and residues analysis). Although the literature on this subject is scarce (Hortelano 2016), it is possible that a wide range of actions and worked materials was given (Paixão et al. 2021). As seen in other lithologies such as quartzite and quartz, we might think that the presence of multiple use episodes reveals us activities linked with cutting, scraping and cutting-scraping actions for the processing of animal carcass (hide, flesh and bone) and wood resources. Secondly, a deeper technological perspective, including experimental knapping and use-wear programmes, is in process for the Abric Romaní limestone assemblages which would determine the physical characteristics of this raw material more accurately and the activities developed with this stone resource.

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