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Beyond Shapes: Core Reduction Strategies in the Magdalenian of Cova Gran de Santa Linya (NE Iberia)

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Abstract

Core reduction provides insight into the technical actions involved in knapping sequences, one of the central elements in technological analysis. By examining reduction phases, cognitive and operational aspects of the management of lithic resources can be explored, and the technical behaviours of human groups reconstructed.

This paper presents a technological and morphometric analysis of cores from the Magdalenian sequence of the Cova Gran de Santa Linya (SE Pyrenees), which ranges from 23 to 16 k cal BP. The knapping strategies suggest two types of lithic exploitation: one on nodules using semi-circumferential methods and the other on thick flakes using burin-core methods. Five knapping modalities were identified through the study of reduction sequences and the analysis of technical attributes, which highlights the technical diversity of lithic production systems.

The data collected are supported by statistical analysis and reveal significant differences at the diachronic level and among the lithic assemblages. This study aims to suggest a reference model with which to characterise Magdalenian cores in technological terms. This model can broaden our understanding of the diversity of technical behaviours that appear from the beginning of LGM-b to the end of MIS 2 in the north-eastern Iberian Peninsula.

Highlights

- Cores were classified based on specific reduction strategies and the analysis of technical attributes.
- The analysis of cores indicates a ramification of the chaîne operatoire to achieve the lithic production goals.
- Semi-circumferential and burin-core methods are the mainly used during LGM-b occupations from Cova Gran de Santa Linya.
- Core reduction strategies in the Magdalenian of Cova Gran de Santa Linya are mainly oriented to blade and bladelet production.
- The core classification model presented allows amplifying our understanding of the technological and technical behaviour of human groups during the LGM-b.

Extended author information available on the last page of the article

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Keywords North-eastern Iberian Peninsula · Magdalenian · Lithic technology · Core reduction · Cova Gran de Santa Linya

Introduction

The study of lithic technology allows cognitive and organisational aspects of of human behaviour to be reconstructed and is essential for understanding technical diversity in stone tool production (Tixier et al., 1980; Tixier, 1984; Pelegrin, 1986; Inizan et al., 1995; Andrefsky, 2008) .

In this regard, cores hold much of the technological information of lithic assemblages and are critical for reconstructing the technical behaviour (Boëda, 1994; Cattin, 1997). The study of cores includes actions and technical gestures in the reduction phase, as well as the analysis of knapping sequences and the products of that process. The interaction between production and maintenance phases also sheds light on how the different actions interact to achieve the production goals. The study of diacritic schemes and refits also provides insight into the technical processes involved in knapping strategies (Cahen, 1980; Delagnes & Roche, 2005; Castañeda, 2009; Scerri et al., 2015, Roussel et al., 2016).

Reduction systems have been studied in depth in the Middle Palaeolithic (Boëda, 1991; Casanova et al., 2008; Mourre, 2003; Slimak, 2008), in the Middle to Upper Palaeolithic transition (Bordes & Teyssandier, 2012; Soressi & Roussel, 2014; Roussel et al., 2016) and the Early Upper Palaeolithic (Le Brun-Ricalens et al., (2005); Bon, 2006; Conard & Bolus, 2006; Bordes et al., 2007; Bataille & Conard, 2018b; Falcucci & Peresani, 2018; Sánchez-Martínez et al., 2021), describing a series of knapping strategies and methods that underpin the technical genesis of lithic technology. These analytical categories allow the hierarchical organisation of lithic exploitation schemes, providing an excellent frame to the study core reduction strategies (Geneste, 1991; Karlin, 1991b).

From the second half of the Late Glacial Maximum (LGM-b) (Maier et al., 2021; Yokoyama et al., 2018), blade technology diversifies, acquiring greater flexibility in the strategies and technical actions used (Duches et al., 2018; Pelegrin, 2000). This diversity of laminar knapping strategies was described in pioneering works on lithic industry and *chaînes opératoires*, which have been crucial for understanding previously little-explored cognitive and socio-organisational aspects (Pigeot, 1987; Pelegrin et al., 1988; Geneste, 1989; Boëda et al., 1990; Karlin et al., 1991a; Pigeot, 1991; Ploux et al., 1991; Aura et al., 2020).

Typological approaches in which retouched artefacts serve to guide the characterisation of technocomplexes are still common, although these approaches have limitations in interpreting the archaeological record (Dibble et al., 2016; Reynolds & Riede, 2019). In the Iberian Peninsula, different approaches have provided a general overview of the Magdalenian from a chronometric, environmental and social perspective (Álvarez-Fernandez et al., 2019; Mas et al., 2021; Utrilla et al., 2012), while specific technological studies have been recently undertaken aiming at organising the lithic variability during the Magdalenian (Langlais, 2007; Roman, 2015). Stone tool variability, within other elements of the material culture, has been used to

highlight the diachronic and technological differences in the composition of Magdalenian assemblages (Deschamps et al., 2019). In this line, different works carried out in northern and southern Pyrenees evaluated the diversity of the assemblages from processes of technical rupture and continuity (Langlais & Ducasse, 2013; Straus & Langlais, (2020), giving rise to the emergence of a variety of cultural traditions integrated in the regional chronometric framework (Langlais et al., 2020; Utrilla et al., 2012).

This work aims to explore if there is a break or a continuity in core reduction systems during the Magdalenian, which allows us to observe the persistence or disappearance of specific technical decisions involved in the lithic production. To test this idea, we examine cores from the Magdalenian occupations of the Cova Gran from a technological and morphometric perspective, and we define a set of knapping strategies, methods and core types. Due to the time span of the Gran Cova archaeological sequence, the data collected allow for comparative analyses with other lithic assemblages as well as the evaluation of the technical evolution of reduction systems throughout the LGM-b.

Stratigraphic and Contextual Position of the Magdalenian at Cova Gran

The Cova Gran de Santa Linya is a rockshelter located in the north-eastern Iberian Peninsula on the south-eastern side of the Pyrenees. The site has yielded evidence of human occupations attributed to the Middle Palaeolithic, Middle to Upper Palaeolithic Transition, Early Upper Palaeolithic, Late Upper Palaeolithic, Neolithic and Early Bronze that allow for the characterisation of the human presence in southwestern Europe over the past 50 k years (Benito-Calvo et al., 2009; Mora et al., 2011).

This paper presents the Magdalenian levels of Cova Gran, which are concentrated in two main sectors , Test Pit EA and Test Pit 4, found in the areas defined as the transition zone (T) and the internal platform of the shelter (P) (Mora et al., 2011) (Fig. 1).

Test Pit EA

In Test Pit EA, which measures 38 m^2, different archaeological levels have been documented ranging from the Late Neolithic to the initial phases of the Magdalenian. Test Pit EA is on the interior platform of the shelter (Platform P, see Mora et al., 2011), in the area next to the cave's rear wall. Excavations in this sector have revealed a sequence of three levels separated by stratigraphic disconformities. At the top, the upper unit (N) (2980 ± 30 BP–6020 ± 50 BP) consists of a sequence of fine sediments with high organic content interpreted as pen deposits (Burguet-Coca et al., 2020; Polo Díaz et al., 2014) that present interstratified levels of sands and gravels, indicating erosional processes. This unit overlies unit M (9810 ± 40–9930 ± 40 BP), which consists of several layers with thicknesses ranging from 10 to 30 cm to 1–1.4 m. At the sedimentary level, it is composed of loose calcareous cobble

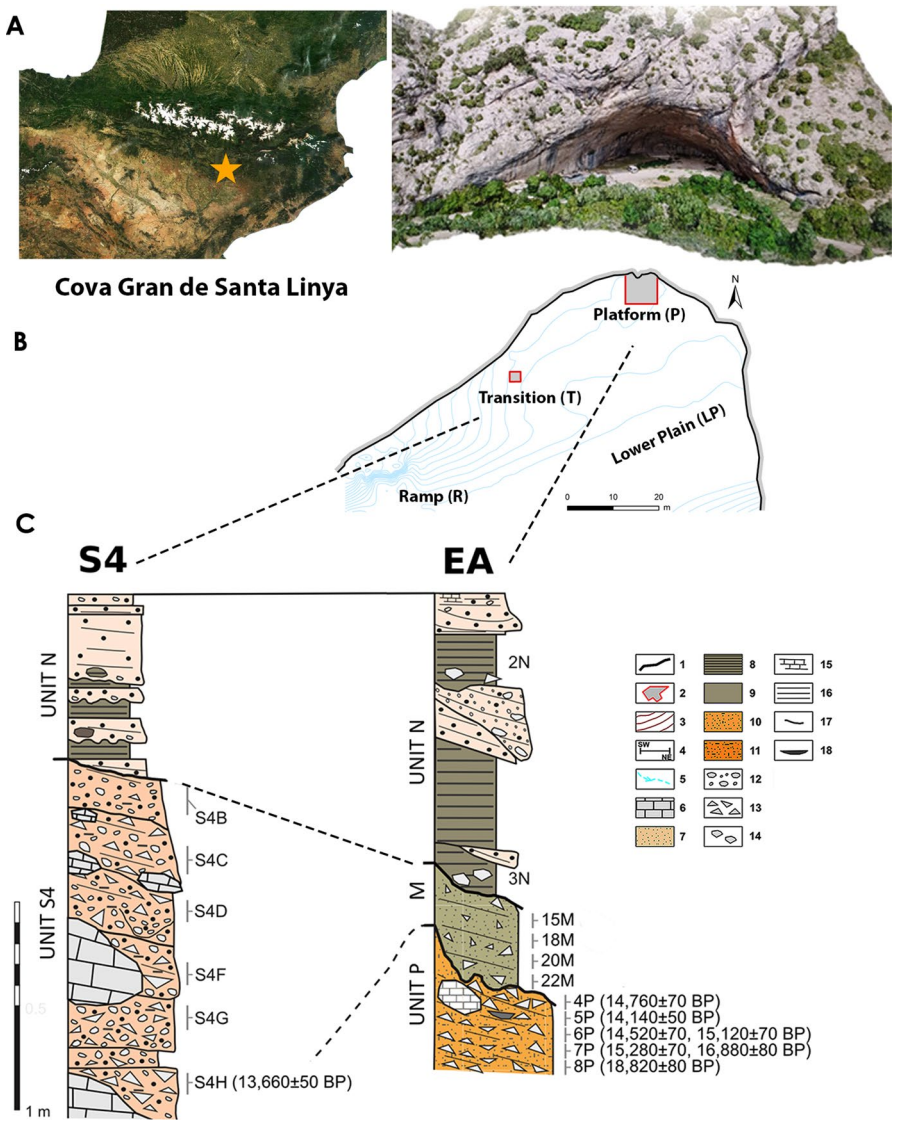


Fig. 1 **A** General context of the Cova Gran de Santa Linya site. Location in southeastern Pyrenees and general drone view of the rock shelter. **B** Topography and excavated areas of Cova Gran de Santa Linya. Sectors analysed in this paper (transition and platform) are marked in red. **C** Stratigraphic sequence of the excavated areas EA and 4 (extracted by Mora et al., 2011). Legend: (1), limestone bedrock; (2), excavated areas; (3), topographical contours (0.5 m); (4), geomorphological section; (5), drainage lines; (6), limestone blocks; (7), sands; (8), fumiers; (9), sand and clays; (10), clays and sands; (11), sands, clays and silts; (12), rounded and subrounded clasts; (13), angular and subangular clasts; (14), archaeological blocks; (15), carbonate concretions; (16), bedding; (17), discontinuity; 18, hearths

breccias and brown sands of massive or coarsely stratified structure, including scattered angular or subangular clasts. Unit M is distributed in the outer-central part of the test pit (to the south), while to the north, it tapers and disappears. This unit is interpreted as a product of the deterioration of the roof and wall of the shelter and erosion of the lower unit by gravitational processes and runoffs of local origin. Unit M rests on top of the lower unit (P). This unit, of estimated chronology between 14,760 ± 70 BP and 18,820 ± 80 BP (Fig. 1), consists of clastic-bearing, coarsely stratified breccias composed of clasts and subangular limestone blocks with a sparse orange sandy-loamy matrix.

Test Pit 4

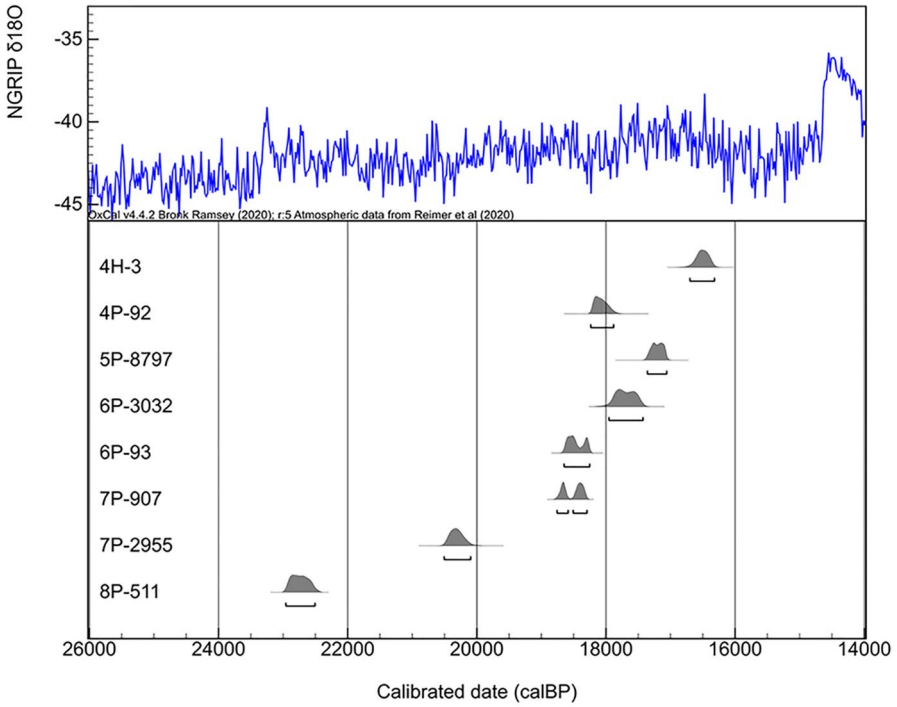
Test Pit 4 is located in the transition zone (T), which connects the ramp (R) with the shelter's interior platform (P). It has an excavated surface area of 4 m^2, with six documented archaeological levels delimited by sterile strata (Fig. 1). The sediments described in this test pit are divided into two main levels. The upper unit, called N (4380 ± 40 BP–4410 ± 40 BP), consists of a series of sandy runoff levels intercalated between fine sediments attributed to pen deposits of approximately 0.5 m in thickness (Mora et al., 2011). Meanwhile, lower unit S4 is approximately 2 m thick, and is composed of a sequence of 10–40 cm thick beds tilted slightly to the east. These layers are composed of sandy matrix sediments with sub-rounded clasts, indicating runoff processes from the western part of the rockshelter, and angular clasts and blocks, indicating gravitational inputs from the roof of the rockshelter. The base of unit S4 has been dated to 13,660 ± 50 BP (Mora et al., 2011; Vega Bolívar et al., 2013) and rests on a large limestone surface that could be the base of the rockshelter or a large block detached from the cavity.

Chronometric Data of the Magdalenian Technocomplex

14C AMS radiocarbon data for archaeological levels from Test Pit EA and Test Pit 4 are provided here, which update the chronostratigraphic context of the site discussed in previous works (Mora et al., 2011; Vega Bolívar et al., 2013) (Fig. 2). Level 6P has been dated to 14,520 ± 60 BP and level 7P to 15,280 ± 60, both more recent dates than those previously published. Level 8P, which is the base of Test Pit EA, has been dated to 18,820 ± 80 BP. Upper levels 4P/5P were not included in this study because their contextual position is under review, although their attribution to the end of MIS 2 is consistent. Current chronometric data place the levels studied between the beginning of LGM-b and the end of MIS2 in the range between 23 and 16 k cal BP.

These dates were calibrated with IntCal20 (Reimer et al., 2020) and expressed as cal BP intervals with 2∂, whose chronometric ranges are represented with OxCal v4.4 (Bronk Ramsey, 2016).

The aim of this article is not to discuss the chrono-cultural levels presented herein, but to provide a contextual overview of them. However, it is necessary to specify that the level 8P has been included in this study despite the antiquity of its dating because



Sector	Level	Reference	Sample type	Sample	BP	σ	cal BP p (95%)
S4	S4H	4H-3	Charcoal	Beta-187424	13660	50	16700-16319
EA*	4P/5P	4P-92	Charcoal	Beta-259273	14760	70	18235–17882
EA*	4P/5P	5P-8797	Charcoal (hearth)	Beta-311103	14140	50	17358-17058
EA	6P	6P-3032	Charcoal (hearth)	Beta-311104	14520	60	17953-17426
EA	6P	6P-93	Charcoal	Beta-265984	15120	70	18647-18251
EA	7P	7P-907	Charcoal (hearth)	Beta-311105	15280	60	18757-18294
EA	7P	7P-2955	Charcoal	Beta-233606	16800	80	20505-20094
EA	8P	8P-511	Charcoal	Beta-333057	18820	80	22957-22505

Fig. 2 **A** Chronometric chart of the units attributed to the LGM-b in sectors EA and 4 from Cova Gran de Santa Linya. **B** Radiometric series for the archaeological units analysed in this paper. *Units under evaluation for its contextual position. All data correspond to AMS dates. Datings have been calibrated using IntCal20 (Reimer et al., 2020)

the analysis of the cores showed technical features consistent with the Magdalenian tradition. Further discussions to decide whether this unit should be attributed to the Solutrean or Badegoulian tradition are addressed in ongoing studies.

Material and Methods

This paper analyses the cores from the Magdalenian levels of Test Pit EA (8P, 7P and 6P) and Test Pit 4 (S4B, S4C, S4D, S4F, S4G and S4H). The analysis was performed based on the consideration that the technical attributes of the cores are a

reflection of the last knapping scheme used. As such, establishing early or advanced reduction stages or identifying the application of different reduction methods within the same knapping sequence is an added challenge for analysis. Core fragments were counted but left out of the analysis (Table 1).

The lithic materials were analysed using a techno-typological approach and contextualised from studies on lithic *chaînes opératoires* (Geneste, 1991; Pelegrin et al., 1988; Soressi & Geneste, 2011). The cores and reduction sequences were analysed based on previous works in blade technology (Cattin, 1997; Karlin, 1991a; Pelegrin, 1985; Pigeot, 1987; Ploux et al., 1991) and core reduction sequences (Langlais, 2007; Naudinot, 2010; Falcucci & Peresani, 2018). A number of qualitative variables and technical actions based on core attribute analysis were also characterised in order to gain insight into technical aspects of the reduction phases (de Araujo Igreja & Pesesse, 2006). Systematic refits were performed for the levels analysed to understand the technical actions involved in the knapping strategies (Fig. 9).

Raw materials were analysed based on the macroscopic characterisation of the assemblage by attributes such as colour, texture and impurities previously applied to Cova Gran (Mora et al., 2020; Roy-Sunyer, 2016).

The archaeostratigraphic levels were separated by sterile layers, following their dimensions and slopes. Lithic remains larger than 10 mm were collected, while smaller remains were recovered daily from 50 × 50 cm surfaces. All sediments were rinsed with water in 2- and 5-mm sieves to ensure that the smallest remains were not overlooked. Further information concerning recovery techniques can be consulted in previous works (Martínez-Moreno et al., 2011; Mora et al., 2010, 2014; Roda Gilabert & Mora Torcal, (2014); Sánchez-Martínez et al., 2021).

Analysis of Analytical Variables and Technical Attributes

For the technological analysis of the cores, a series of variables were used that allowed us to characterise the actions and technical gestures implicit to knapping sequences (Tab s1 and s2) (Tixier, 1984; Inizan et al., 1995; Le Brun-Ricalens & Brou, 2003; de Araujo Igreja et al., (2006). These actions might be common or specific to the knapping modes, which allowed us to establish convergence relationships between the different reduction phases.

Diacritic diagrams of the surfaces analysed were created to understand the phases of reduction and maintenance of the cores (Inizan et al., 1995; Pastoors & Tefelmaier, 2010; Roussel, 2011; Roussel, 2013; Pastoors et al., 2015; Falcucci & Peresani, 2018). Based on the diacritics, the visible removals of the knapping surface of the cores were measured to obtain dimensions of the products of the last knapping phase (Almeida, 2007; Casanova Martí, 2009; Castañeda, 2009).

Statistical Analysis

A combination of statistical tests was applied to evaluate the technological and morphometrical configuration of the assemblage dataset. Pearson's chi-squared test was used to determine statistical significance in core types from each archaeological

Table 1 Absolute and relative frequencies of cores by archaeological unit

Cores	8P	%	7P	%	6P	%	S4B	%	S4C	%	S4D	%	S4F	%	S4G	%	S4H	%	Total
Semi-circumferential sensu lato	4	19	4	6.7	14	14	6	30	5	18.5	3	17.6	1	12.5	0	0	0	0	**37**
Semi-circumferential narrow-sided	5	23.8	1	1.7	25	25	3	15	2	7.4	4	23.5	2	25	1	33.3	0	0	**42**
Semi-circumferential wide-faced	3	14.3	5	8.3	11	11	0	0	1	3.7	0	0	0	0	0	0	0	0	**20**
Preferential burin-core	3	14.3	28	46.7	26	26	5	25	12	44.4	6	35.3	4	50	1	33.3	0	0	**85**
Equivalent burin-core	0	0	7	11.7	6	6	2	10	1	3.7	1	5.9	0	0	0	0	0	0	**17**
Expedient	1	4.8	6	10	9	9	2	10	2	7.4	0	0	0	0	1	33.3	1	100	**22**
Multiplatform	3	14.3	2	3.3	3	3	1	5	0	0	0	0	0	0	0	0	0	0	**9**
Centripetal	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Centripetal unipolar	0	0	0	0	0	0	0	0	0	0	1	5.9	0	0	0	0	0	0	**1**
Hierarchical centripetal unipolar	0	0.0	0	0	0	0	0	0	1	3.7	0	0	0	0	0	0	0	0	**1**
Abrupt unipolar	1	4.8	1	1.7	1	1	0	0	0	0	0	0	0	0	0	0	0	0	**3**
Test core	1	4.8	0	0	1	1	1	5	0	0	0	0	0	0	0	0	0	0	**3**
Core fragment	0	0	6	10	2	2	0	0	3	11.1	2	11.8	1	12.5	0	0	0	0	**14**
Total	**21**	100	**60**	100	**100**	100	**20**	100	**27**	100	**17**	100	**8**	100	**3**	100	**1**	1	**257**

sector and between sectors. Correspondence analysis (CA) was performed to evaluate the correlation between core types and to observe tendencies within the lithic assemblage. CA is a multivariate statistical technique that provides a means of summarising a dataset in two-dimensional graphic forms (Beh & Lombardo, 2014; Greenacre, 2007). Core types with low representation were removed to the contingency tables to avoid outliers in data view (Tab s3). Morphometric variation in the core assemblage was tested with the Kruskal–Wallis test, a non-parametric method that determines if samples belong to the same distribution. Boxplots were made to represent the diachronic and morphometric variation among the core assemblage. These typometric and statistical analyses were performed using the Addinsoft XLSTAT statistical software and SigmaPlot 12.0.

Technological Analysis of Core Assemblage

Technological analysis of cores (249) and core fragments (8) yielded information on the technical actions involved in the reduction strategies based on the study of technical variables and attributes. The results were structured in two large blocks. In the first, qualitative reflections focusing on the knapping strategies identified were presented and framed within the discussion on Upper Palaeolithic laminar knapping systems. Subsequently, quantitative results were statistically tested to verify the soundness of the assertions established in the technological analyses.

Magdalenian Knapping Strategies

Based on the technological and morphometric analyses of the core assemblage, a series of strategies, methods and core types were identified that form an integral part of the organised knapping systems. At the same time, a group of cores included among the expedient systems were identified (Fig. 3).

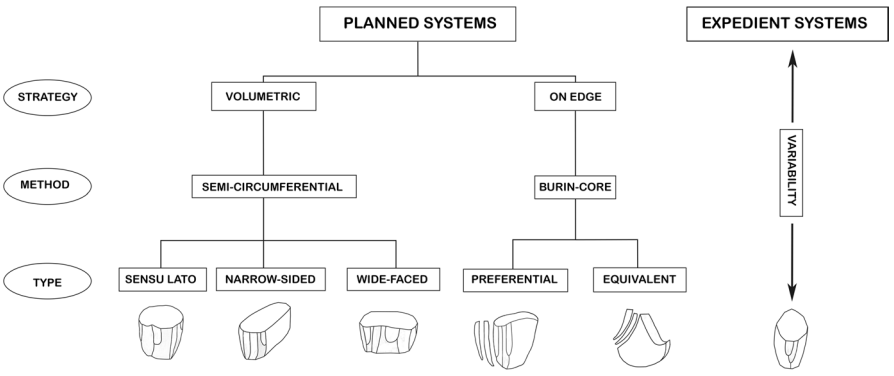


Fig. 3 Graphic scheme representing core reduction systems organised by strategies, methods and core types

Organised knapping systems are structured around complex technical behaviours that require a series of technical and cognitive skills (Binford, 1979; Romagnoli et al., 2018; Shott, 2018). The aim of these systems is to obtain predetermining shapes and products through the volumetric management of the core in which *débitage* and shaping phases alternate. In contrast, expedient systems are the result of low-cost behaviours that aim to reduce the time and energy expended in lithic production (Vaquero & Romagnoli, 2018). This allows predetermined products to be produced with a wide range of technical solutions.

Two types of knapping strategies are distinguished within the organised systems: volumetric and on-edge. Volumetric strategies are applied to fragments or nodules using two preferential planes where the platform and the knapping surface are located (Pigeot, 1987). The core cortex is generally found opposite the knapping surface. Full production phases are followed by core shaping and the actions focused on maintaining the lateral and distal convexity of the core (Ploux et al., 1991). This strategy includes the semi-circumferential methods, common in laminar technology, which comprise various sub-categories. On-edge strategies are organised on thick blanks (flakes, elongated flakes and fragments), using their laterals for the development of lithic production (Newcomer & Hivernel-Guerre, 1974). This process is used in the burin-core method, which comprises two main types: preferential and equivalent (Figs. 4 and 5).

Expedient systems employ volumetric and on-edge knapping strategies, but core maintenance requires a lesser investment of time. The morphological characteristics of the pieces, including their sides, are used to organise short reduction sequences.

In general, in these assemblages, cores structured around one knapping platform (217, 84.4%) are more abundant than two platforms (37, 14.3%) or more than two platforms (3, 1.1%). Sometimes knapping schemes are structured independently of the number of platforms involved, as is the case in cores with opposing platforms that share a knapping surface; while other cores may have different knapping schemes on their surfaces. Given the nature of the cores as a final product, identifying previous reduction phases poses a challenge. Cores may also retain several reduction schemes on their surfaces, which can be complementary or overlapping (Morales et al., 2013). Examples such as these help to give a sense of the flexibility required in interpreting the archaeological record and the complexity of attempting to analyse knapping sequences that may mask one another.

Semi-Circumferential Methods

These methods aim to obtain laminar and micro-laminar blanks from the semi-peripheral exploitation of the core (Aura Tortosa, 1997; Zilhão, 1997). Core maintenance is performed by rejuvenation of the lateral flanks, resulting in a lateral convexity of the flaked surface, and occasionally by opposing removals to carry out the core distal convexity. The progression of the knapping sequence can be linear consecutive (*sémi-tournant*) or linear alternated (Falcucci & Peresani, 2018). The sagittal plane remains unchanged during the reduction phase. Three types are

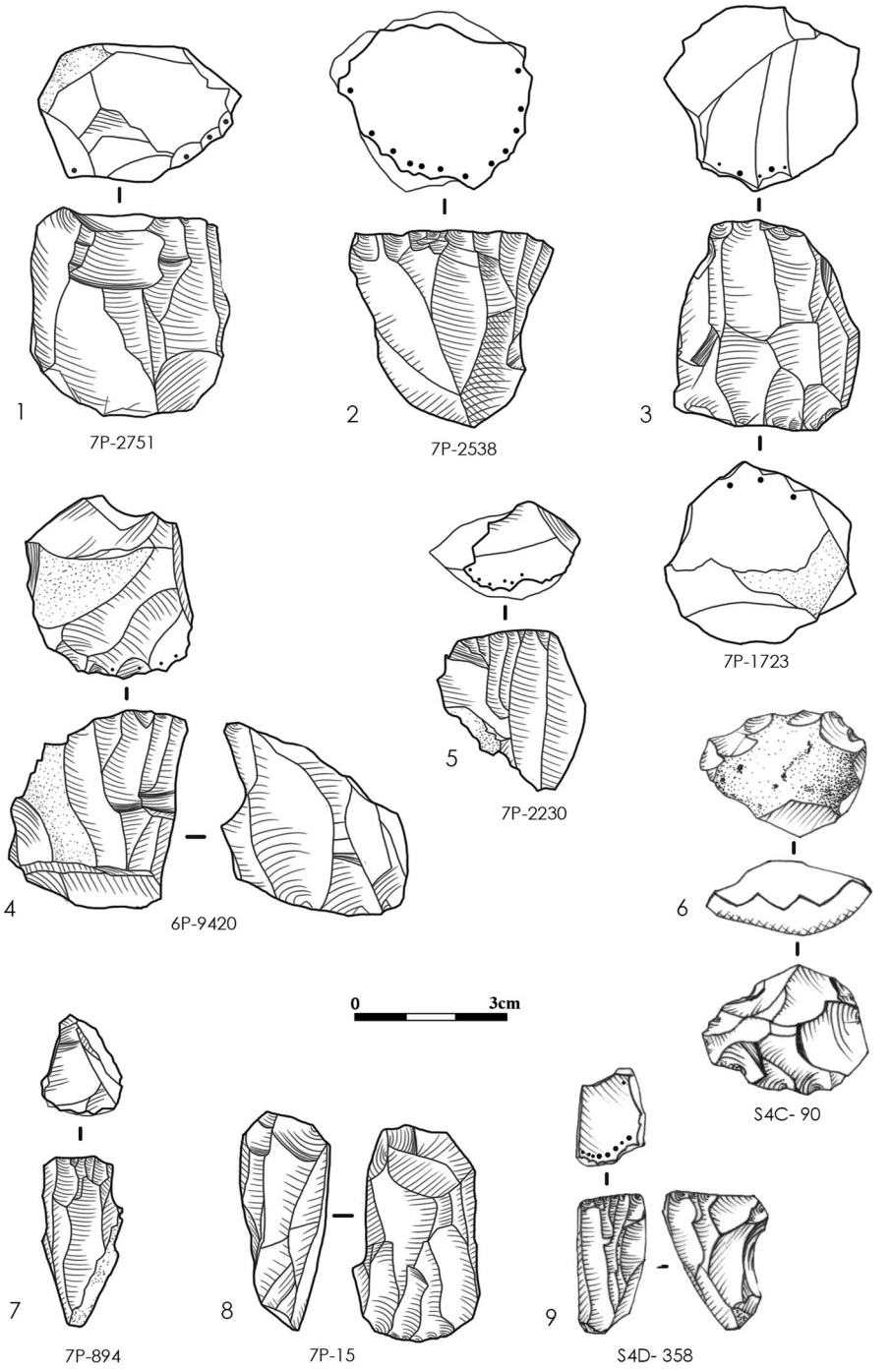


Fig. 4 Cores from Cova Gran de Santa Linya. Semi-circumferential sensu lato (1–3) Semi-circumferential narrow-sided (4–5), centripetal (6), preferential burin-cores (7–9) (Drawings: Mònica López)

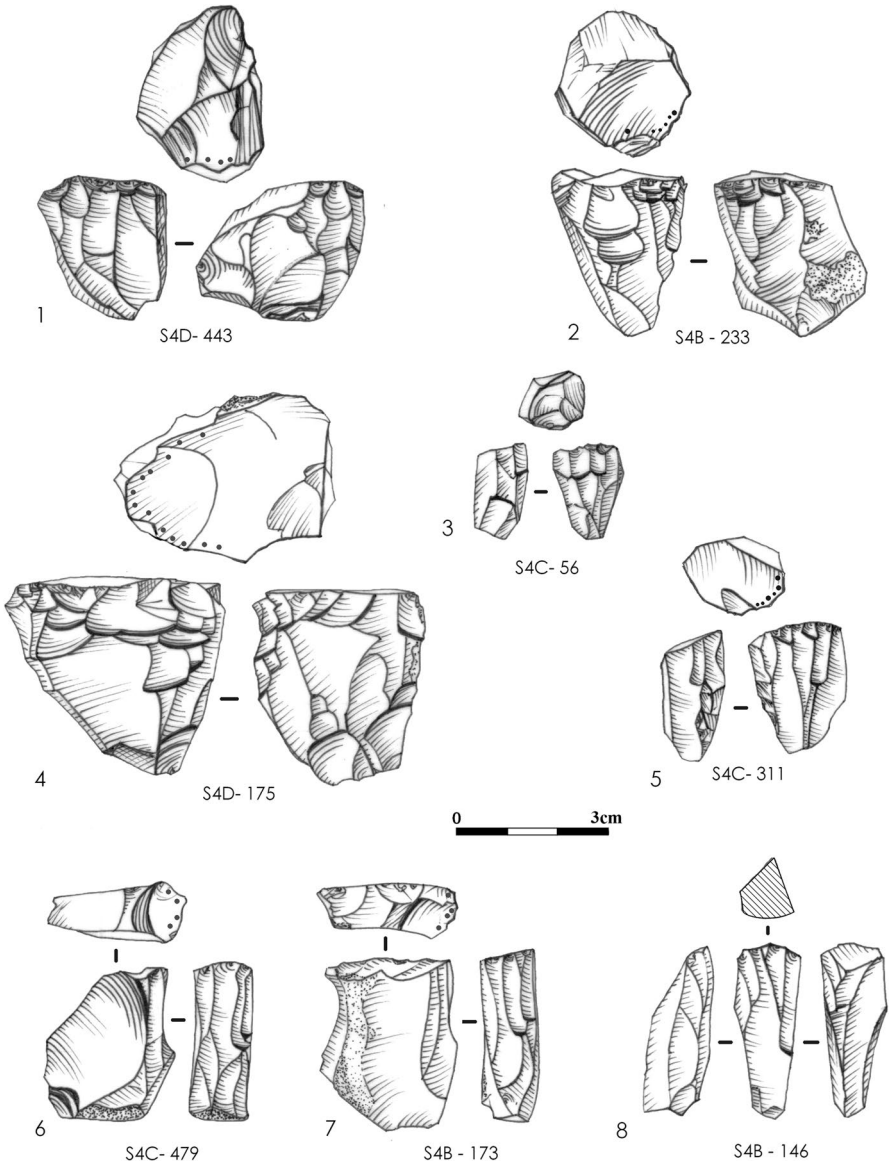


Fig. 5 Cores from sector 4 of Cova Gran de Santa Linya. Semi-circumferential sensu lato (1–4), semi-circumferential wide-faced (5), preferential burin-cores (6–8) (Drawings: Mònica López)

distinguished in the semi-circumferential knapping methods: sensu lato, narrow-sided and wide-faced.

The sensu lato semi-circumferential cores, present throughout the Upper Palaeolithic, are aimed at obtaining laminar blanks and are characterised by semi-circular delineation of the knapping platform created from converging blades on the flanks.

The knapping surface maintains a balance between full production and preparation phases, which facilitates maintenance of the reduction surface. These cores have been given different names: 'nucleiform end scraper'(Domingo et al., 2012; Le Brun-Ricalens & Brou, 2003), 'carinated end scraper'(Bicho, 2000; Demars, 1982; Gameiro & Almeida, 2004; Straus et al., 2016; Zilhão, 1997), 'dorsal-frontal core' (Roman, 2015) and 'unipolar/bipolar'(García Catalán et al., 2013) (Fig. 6 and Table 2).

The narrow-sided type (Le Brun-Ricalens et al., (2005); Falcucci & Peresani, 2018) includes cores with a narrow knapping surface which predetermines the morphometric characteristics of the blanks, generally bladelets. Narrowing of the knapping surface is achieved by removals on the lateral flanks of the core or by orthogonal removals. It may occur that one of the two flanks may be worked to reduce the width of the flaked surface. This category of core has been included in the 'orthogonal' schemes described for other assemblages in the Iberian Peninsula (Roman i Monroig 2004; García Catalán et al., 2013). The terms unipolar and bipolar have also been used to denote this type of exploitation (Fig. 7 and Table 2).

The wide-faced type (Falcucci & Peresani, 2018) is comprised of cores with a wide knapping surface parallel to the unknapped area of the core. The surface is slightly convex and is maintained by curved and convergent removals (Fig. 6). The success of this method lies in the use of the flake scar ridges to obtain continuous laminar or laminar-like blanks without the need to narrow the knapping surface as with narrow-sided cores. Occasionally, due to the extent of the lateral convexity of the core, non-laminar blanks and hinged removals are produced resulting in the abandonment of the core. The terms unipolar and bipolar have also been used to denote this type of exploitation (Roman i Monroig 2004).

Burin-Core Methods

Burin-core methods are structured around the lateral edges of blanks (flakes, elongated flakes and fragments) as semi-crests to initiate the reduction sequence (Bodu et al., 2007; Le Brun-Ricalens & Brou, 2003; Zilhão, 1997) (Fig. 8). These methods are aimed at obtaining bladelets and micro-bladelets (Almeida et al., 2004; Bicho, 2000) with specific morphometric characteristics stemming from the size constraint of the cores. Burin cores present complex reduction stages in which *débitage* and shaping processes alternate (de Araujo Igreja et al., (2006)). This begins with an initial shaping by means of lateral retouch to generate convex morphologies from which to open exploitation facets (Langlais, 2007). The knapping platform may be formed by retouch (like truncation) or serve as a starting point to create a facet (like a crested blade). The opening of the knapping surface is done in a similar manner. The names given to this type of exploitation are varied: burin, with its variations (nucleiform, Vachons and Busqué), 'burin-core' (de Araujo Igreja et al., (2006); Aura et al., 2012) and 'on edge' (Ducasse et al., 2020; Gameiro & Almeida., 2004; Goebel, 2002; Langlais, 2007; Roman, 2015). Burin-core methods include two main types: preferential and equivalent.

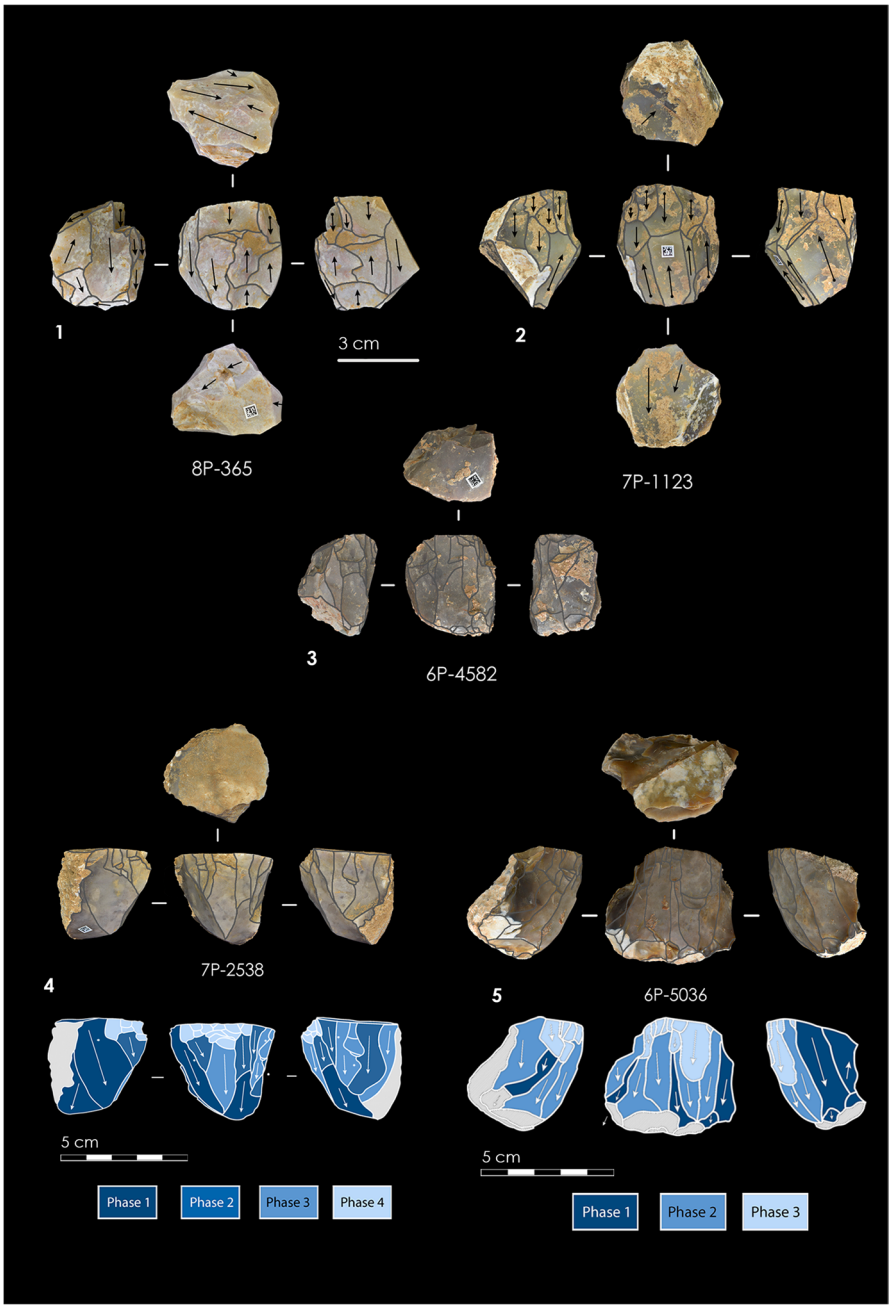


Fig. 6 Cores from Cova Gran de Santa Linya. Semi-circumferential sensu lato (1–2 and 4), semi-circumferential wide-faced (3 and 5). Diacritic diagrams and reduction phases are detailed in examples (4) and (5)

Table 2 Technical attributes identified in semi-circumferential and burin-core methods, and their derived types

	Planned systems					**Expedient**
Strategy	**Volumetric**			**On edge**		**Volumetric / On edge**
Method	**Semi-circumferential**			**Burin-core**		/
Type	***Sensu lato***	**Narrow-sided**	**Wide-faced**	**Preferential**	**Equivalent**	**Expedient**
Ideal scheme representation						
References	Ploux (1991) Pelegrin (1995) Langlais (2007)	Falcucci et al (2018)	Falcucci et al (2018)	Pigeot (1987) De Araujo Igreja et al. (2006)	De Araujo Igreja and Pesesse (2006)	Langlais et al (2010)
Equivalent references	Nucleiform end-scraper (Bourlon et al. 1912, Pradel 1962) Dorsal frontal (Román, 2015)	Orthogonal (García-Catalán, 2013; Román 2004, 2015)		Sur tranche (Langlais,et al 2004, 2010) On edge (Goebel, 2002; Gameiro, 2004 Román, 2004, 2015)	Dihedral burin (Demars and Laurent 2001)	Sur tranche (Langlais, et al 2004, 2010) On edge (Román, 2004; Aura 2007)
	Prismatic / Bladelet cores (Tixier et al. 1980, Andrefsky, 2008, Utrilla et al. 2008; Montes et al. 2013; Corchón et al. 2016; Straus et al. 2016)			Nucleiform burin/ Vachons burin (Demars and Laurent 2003)		
	Unipolar/Bipolar (Román 2004, García-Catalán, 2013, Rodríguez, 2014)			Burin core (De Araujo Igreja et al. 2006; Bodu et al. 2007)		
Blank	Nodule and fragments	Nodule and fragments	Nodule and fragments	Blade and flake	Blade and flake	Blade, flake, fragments
Hyerarchical	Yes	Yes	Yes	Yes	No	Yes
Débitage	Flakes, elongated flakes, blades and bladelets	Blades, bladelets	Flakes, elongated flakes, blades and bladelets	Bladelets, microblades (burin bladelets)	Bladelets, microblades (burin bladelets)	Flakes, elongated flakes and bladelets
Shaping	No	No	No	Lateral retouch	Lateral retouch	No
Core maintenance	Convergent and opposed removals	Opposed and lateral removals	Convergent and removals	Truncatures and crested bladelets	Truncatures and crested bladelets	No
Reduction	Intense and very intense	Intense and very intense	Intense and very intense	Intense and low	Intense and low	Low
Progression /Rhythm	Linear consecutive or alternated	Linear consecutive or alternated	Linear consecutive or alternated	Frontal, linear consecutive or alternated	Frontal	Frontal, linear consecutive or alternated
Examples on this paper	Fig.4 (1-3) Fig.5 (1-4) Fig.6 (1,2,4)	Fig.4 (4-5) Fig.7 (1, 3-5)	Fig.5 (5) Fig.6 (3 and 5)	Fig.4 (7-9) Fig.5 (6-8) Fig.7 (2) Fig.8 (2,3,5 6)	Fig.8 (1 and 4)	/

Preferential burin cores are structured around a platform and a main knapping surface from which a unidirectional series of bladelets are organised. The knapping sequence may have a linear consecutive, linear alternated or frontal

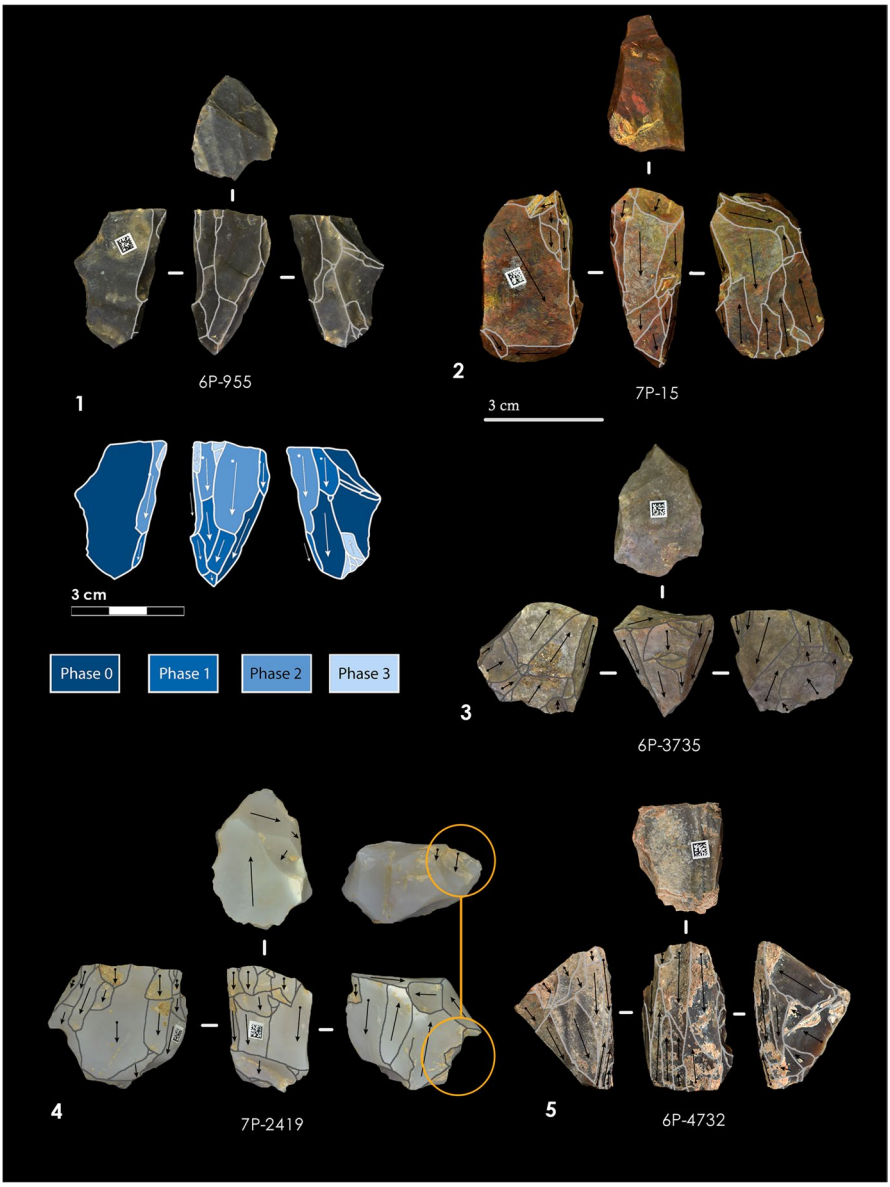


Fig. 7 Cores from Cova Gran de Santa Linya. Semi-circumferential narrow-sided (1, 3–5), preferential burin-core (2). Orange circles indicate the position of marks attributed to resting percussion activities (4). Diacritic diagram and reduction phases are detailed in example (1)

progression (de Araujo Igreja & Pesesse, 2006) and proceeds from the lateral edge towards the interior of the piece (Pigeot, 1987). This category is equivalent to the 'sur tranche' cores described in previous works (Langlais, 2007).

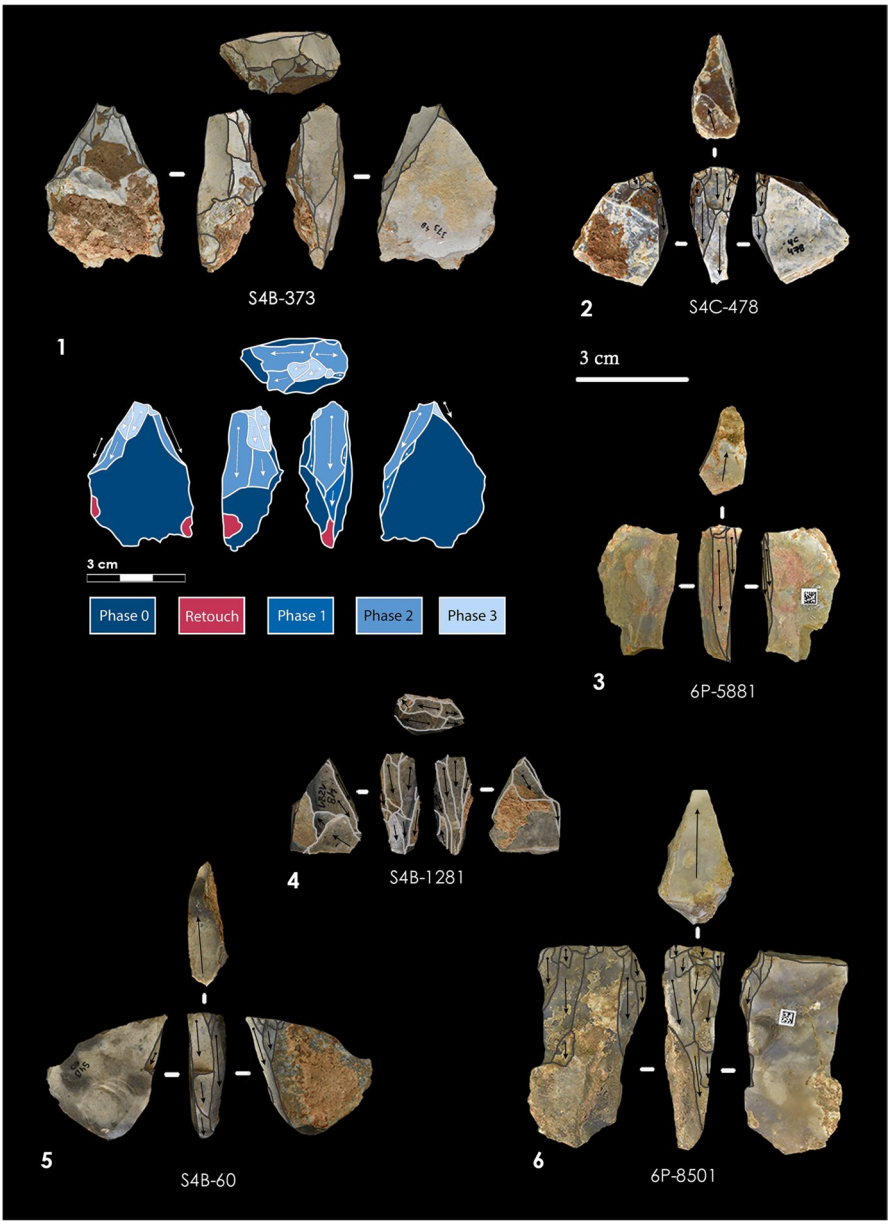


Fig. 8 Burin cores from Cova Gran de Santa Linya. Equivalent burin-cores (1 and 4), preferential burin-cores (2, 3, 5 and 6). Diacritic diagram and reduction phases are detailed in example (1)

Equivalent burin cores are organised from two contiguous facets that form a dihedral angle and are exploited in succession. During knapping, preliminary removals serve as platforms for subsequent removals (de Araujo Igreja & Pesesse, 2006), resulting in non-hierarchical cores. These artefacts have traditionally been analysed

as dihedral burins because of the bevel created between the two opposing lateral facets. Although we accept the existence of dihedral burins, those with a long lithic production sequence are within the realm of the equivalent burin core.

Technological information collected from the analysis of technical attributes was complemented with refits (Fig. 9). The refits validate the integrity of the archaeological record and provide insight into technical aspects related to reduction strategies.

Expedient Systems

Expedient cores are characterised by short knapping sequences, a lack of surface preparation and little-planned knapping schemes. These attributes show a lesser investment of time and energy in lithic production and are included among the expedient technologies (Vaquero & Alonso-Fernández, 2020; Vaquero et al., 2015). In general, these are cores that were not prepared or maintained, with no more than

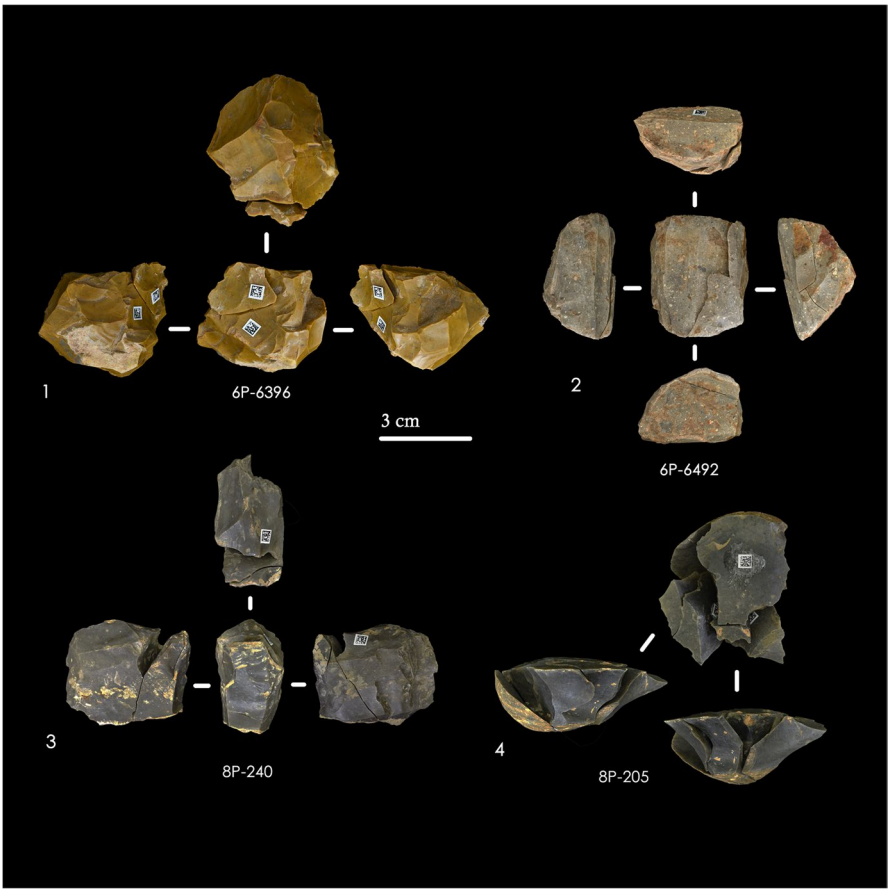


Fig. 9 Refitted cores from Test Pit EA of Cova Gran de Santa Linya

three removals and with morphological constraints. The cores in this group will be addressed tangentially as their exploitation systems are beyond the scope of this paper.

Statistical Analysis of the Assemblage

Statistical analysis of the cores was performed using a combination of descriptive, inferential and multivariate statistics to analyse relationships within the assemblage. The core assemblage (249) contains a wide variety of core types in the archaeological level analysed. Preferential burin cores (85) are abundant among the archaeological sequence (excepting 8P) and account for 30% of the total assemblage. Narrow-sided (42) and sensu lato (37) cores comprise the other third of the assemblage, while expedient (22) and wide-faced (20) cores are less abundant. Other cores, oriented towards flake production, have a lesser representation (Table 1).

Pearson's chi-squared test revealed significant differences in core composition between Test Pit EA and Test Pit 4 (χ^2 (30) = 46.47 p = 0.02) (Tab s4) and helped to identify correlations between core types and archaeological levels (Tab s5 and Fig s1). The main correlations found are in levels 6P, 7P and S4B. Levels 6P and 7P show contrary tendencies in the representation of narrow-sided cores and preferential burin cores. Narrow-sided cores are significant in 6P, while they are not in 7P. However, preferential burin cores are significant in 7P, while low significant values were documented for this category in 6P. Semi-circumferential sensu lato cores were also strongly correlated with the level S4B. The application of this test showed specific tendencies that should be further analysed via multivariate statistics.

The correspondence analysis (CA) was performed according to core types with an inertia of 79.87% represented in Factor 1 (59, 7%) and Factor 2 (20, 1%) (Tab s6 ad Fig s2). The multivariate test displays the dataset in a two-dimensional plot, indicating the most significant correlations between the core assemblage and the archaeological levels studied (Fig. 10). The CA shows the levels of Test Pit EA at the top and the levels of Test Pit 4 at the bottom, the burin-core methods on the left, and the semi-circumferential methods on the right. This indicates that the distribution of variables is not random but ordered. Furthermore, the CA indicates a strong correlation between on-edge knapping strategies and level 7P; narrow-sided cores and levels 6P and 8P; and *sens*u *lato* cores and level S4D, which highlights the type of preferential exploitation at these levels.

The statistical tests revealed that the levels of Test Pit EA (8P, 7P and 6P) are independent of one another, indicating technological differences. In contrast, the levels of Test Pit 4 (S4B, S4C, S4D, S4F, S4G and S4H) are dependent and strongly correlated with each other, which indicates they share features and so behave in a statistically similar manner. These results support the conclusion that this lithic assemblage is technologically homogeneous throughout the sequence.

Morphometric analysis was conducted to determine whether the knapping systems were related to the final size of the cores and whether these changes were perceptible at the diachronic level. For this, a series of quantitative variables were analysed using the Kruskal–Wallis test. The Kruskal–Wallis test assesses whether the sample data have

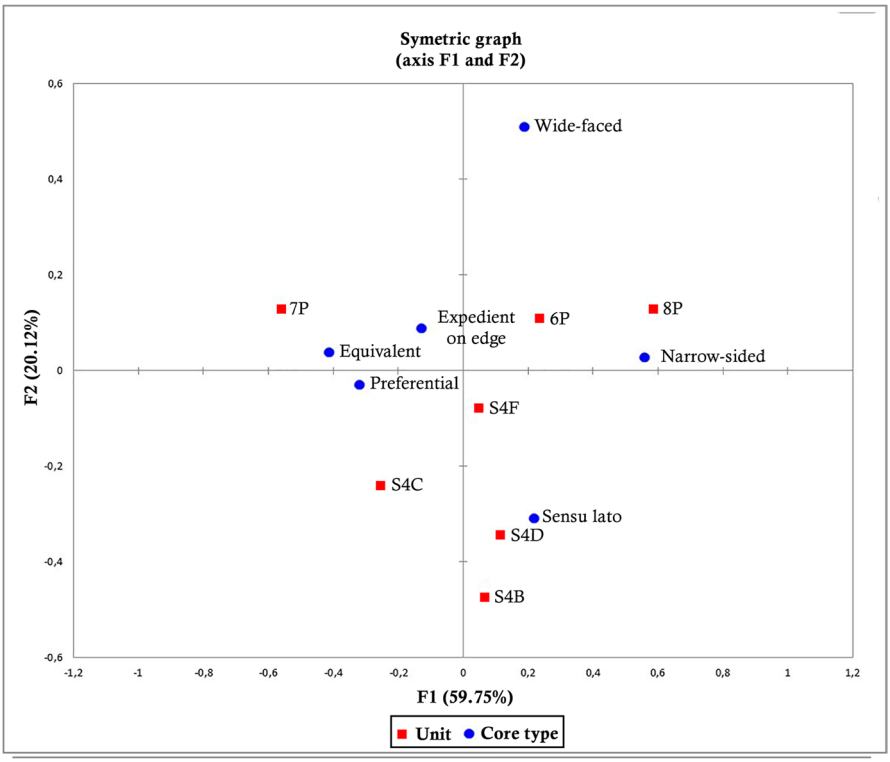


Fig. 10 Correspondence analysis with a 79.9% of trust between core types (blue dots) within the archaeological units (red squares)

the same distribution or if they belong to different populations. The result for length ($p=0.0044$), width ($p=0.0019$), thickness ($p=0.0001$) and weight ($p=0.0001$) indicated that the samples come from distinct populations (Tab s7 and s8). Furthermore, the test indicated significant variation in the dimensions of the cores from a diachronic perspective as can be seen in the boxplots (Fig. 11) (Tab s9, s10, s11 and s12). Boxplot shows differences in the lower part of the sequence (8P) and the upper part (S4). Level 7P has the lowest metric values in Test Pit EA, similar to those obtained in Test Pit 4, where a general reduction in core size is observed. This could be related to a progressive microlithisation of the cores and their knapping products, as has been suggested for the Mediterranean coast (Aura Tortosa, 1997).

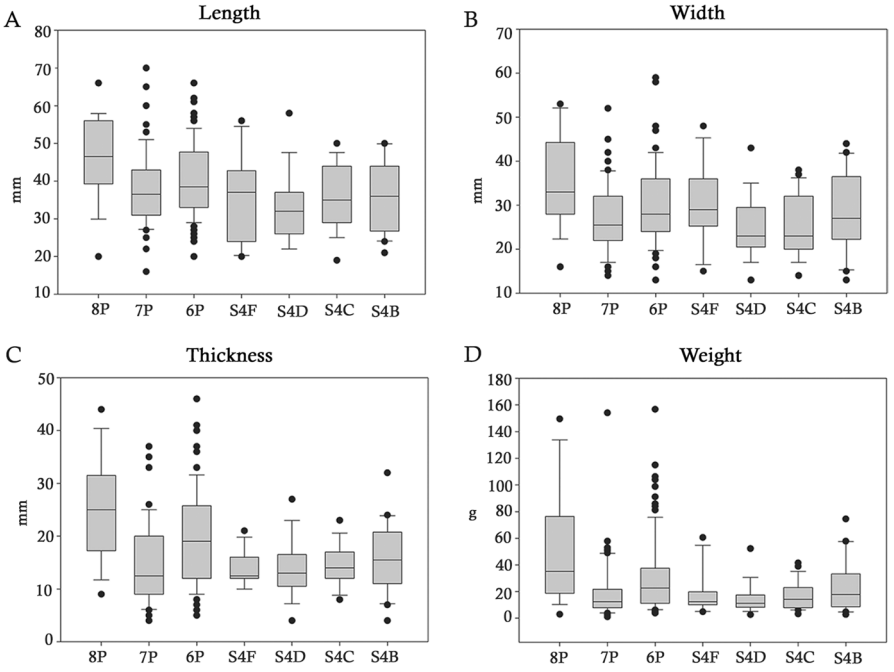


Fig. 11 Boxplot representing quantitative variables (**A** = Length, **B** = Width, **C** = Thickness, **D** = Weight) of the core assemblage. The units represented in *Y* axis has been organised chronologically from left (oldest) to right (more recent)

Discussion

Exploring Technical Diversity in Cova Gran de Santa Linya

The analysis presented in this paper highlights the technical variability in core reduction during the Magdalenian technocomplex of Cova Gran de Santa Linya. The core assemblage was classified according to technical and morphometric attributes, identifying specific production goals and constraints. The study of the reduction phases shows divergence and convergence patterns in lithic production among the core assemblage and reveals a wide variety of technical solutions in blade knapping strategies.

This diversity is also evident from a diachronic point of view, which indicated specific technical choices and behaviours among the archaeological levels, leading to the establishment of a reference model for comparison with other Magdalenian core assemblages in the Iberian Peninsula (Table 2).

Five core types were identified in the assemblage resulting from semi-circumferential methods (sensu lato, narrow-sided and wide-faced) and burin-core methods (preferential and equivalent).

Semi-circumferential methods refer to laminar reduction schemes common throughout the Upper Palaeolithic (Karlin, 1991a; Slimak & Lucas, 2005; Tixier, 1984). The differences in maintenance and production goals among these methods are due to the internal variability of the assemblages (Falcucci & Peresani, 2018; Langlais, 2007). However, other analyses focusing mainly on the morphological characteristics of the cores were unable to recognise these technological differences (Roman, 2015).

The burin-core methods are structured from the lateral edges of thick blanks. These methods, better known in recent chronologies (Inizan & Lechevallier, 1994a; Inizan & Lechevallier, 1994b; Quintero & Wilke, 1995), are also common in the Magdalenian (de Araujo Igreja et al., (2006); Langlais, 2007; Ducasse, 2012; Montes & Domingo, 2013; Utrilla & Mazo, (2014)), although they were not defined in depth.

One difference between these methods is that burin-cores take advantage of the predetermined morphometry of the blanks to obtain laminar products, while with semi-circumferential methods, the core surfaces must be prepared and maintained to apply laminar knapping strategies. This occurs because burin-cores are organised on blanks, while semi-circumferential cores are structured on raw material fragments or blocks.

The two methods share the same production goals but function differently. Full production phases alternate with maintenance phases in semi-circumferential cores, resulting in a discontinuous *débitage* rhythm (Boëda, 1993; Boëda et al., 1990; Slimak, 2008). In contrast, with burin-cores, the rhythm is continuous since maintenance is performed prior to the reduction sequence. The differences in *débitage* rhythms are related to the morphological constraints of the blanks. For example, starting with a larger volume—as in the case of semi-circumferential cores—allows for greater technical investment (time and effort) to ensure the success of lithic production. Thus, because of these attributes, semi-circumferential methods follow linear alternating and consecutive knapping rhythms. Burin cores, in contrast, are organised on smaller blanks, which present limitations for resolving possible knapping errors. For this reason, initial shaping is performed to adapt the morphometry of the blank and thus, ensure successful knapping. As such, on-edge cores are considered efficient (Le Brun-Ricalens & Brou, 2003; de Araujo Igreja et al., (2006)), since they accomplish laminar production goals using volumetrically limited blanks (Bataille & Conard, 2018a). That is the reason why burin-core methods are mainly organised following a frontal knapping rhythm, and, occasionally, in the case of thicker blanks, linear alternating or consecutive rhythms (Tab s13).

Cova Gran Core Assemblage in Magdalenian Technological Trends

The knapping systems in the Magdalenian technocomplex in the Iberian Peninsula are geared towards obtaining elongated flakes, blades and bladelets (Aura Tortosa, 2007; Straus et al., 2016; Utrilla et al., 2012) but also thick flakes aimed at obtaining bladelets (Fullola i Pericot et al., 2012; Mangado et al., 2010). Laminar technology requires a high level of technical skill and the application of a series of actions

to ensure successful knapping. As such, it has been suggested that the most complex and technically developed reduction processes also depend on the use of high-quality raw material, since it is easier to work with and minimises knapping errors. In line with this idea, some authors have pointed out that knapping strategies and lithic production objectives are influenced by raw material constraints (Domènech, 1998; Cacho Quesada & Martos Romero, 2004; Roman i Monroig 2004; Soto, 2014; Vadillo, 2018; Vaquero & Alonso-Fernández, 2020) (conversely, Montes et al., 2013). Therefore, the characteristics of the raw materials condition the technical decisions involved in the management of lithic resources.

This tendency was not identified at Cova Gran, where production goals developed independently of the raw material used (Tab s14). The two main varieties used are Garumnian chalcedony and Serra Llarga flint, both limited to a local supply less than 20 km from the site (Roy-Sunyer, 2016). The Garumnian chalcedony appears in the form of medium-sized blocks of variable quality, while the Serra Llarga flint appears in the form of small-sized blocks of good quality for knapping. The habitual use of both types shows that the quality of the raw material and its size did not condition the use of one knapping method or another. As such, we believe that the differences in knapping strategies and production goals observed in Magdalenian occupations are related to technical and organisational decisions and not determined by the raw material constraints.

At Cova Gran, the lithic *chaîne opératoire* was oriented towards obtaining blades and bladelets from the exploitation of semi-circumferential cores. At the same time, we identify a ramification of the main *chaîne opératoire* where bladelets are seeked by exploiting the lateral edges of thick flakes (Tab s15). This divergence is a characteristic feature of the period (Pelegrin, 1997; Langlais, 2007; Naudinot & Jaquier 2014; Renard & Ducasse, 2015; Ducasse et al., 2017; Bataille & Conard, 2018b; Aura et al., 2020) and may be an indicator of the efficiency of Magdalenian knapping strategies.

The concept of efficiency includes the cost of manufacture—measured in terms of time and technical skill—and the utility of the object. This term has been used mainly to calculate tool-efficiency in human evolution (Bamforth, 1986; Key & Lycett, 2015; Pastoors et al., 2015) and to a lesser extent in knapping strategies (Jennings et al., 2010; Pastoors & Tafelmaier, 2010; Pastoors et al., 2015). At Cova Gran, semi-circumferential methods were defined as efficient because the cost of the maintenance of core convexity was equivalent to the result of an extended series of *debitage* (Naudinot, 2013; Bataille & Conard, 2018b). Burin-core methods are not usually maintained and have morphological constraints, but they produce morphometrically similar products and so are also understood to be efficient. The efficiency of expedient technologies, in contrast, is difficult to assess due to the lesser investment of time and skill required to exploit them.

Burin cores also produce homogeneous burin bladelets, whereas lithic production on semi-circumferential cores generates more morphometrically diverse laminar blanks. This blank diversity provides flexibility in stone tool manufacturing, which allows different production goals to be met.

In our analysis, we distinguished a series of technologically simpler cores that point to a lower investment of time in the reduction process. We included these

cores within the expedient knapping systems (Vaquero & Romagnoli, 2018). Expedient knapping systems can be structured on volumetric and on-edge strategies, and follow simplified schemes based on one or two removals. These schemes have been partially related to the initial reduction stages (Vaquero & Romagnoli, 2018), stressful situations/environmental constraints (Corchón Rodríguez et al., 2015; Soler et al., 2021) or different levels of learning (Assaf, 2019; Bodu et al., 1990; Bril et al., 2010; Högberg, 2008; Pelegrin, 1991). Although the presence of expedient knapping systems cannot be denied, these studies show that the investment of time in core maintenance is one of the most defining features of Magdalenian technology.

Core preparation with semi-circumferential methods begins by opening the knapping platform with a large removal and progressively creating lateral convexity by removals from the sides of the core. These actions are inherent to laminar knapping systems and are found in technocomplexes identified in western Europe from the Aurignacian (Bataille & Conard, 2018b; Bordes et al., 2011; Falcucci et al., 2017) and the Gravettian (Falcucci and Peresani, 2020; Sánchez-Martínez et al., 2021), introducing the idea that a series of technical principles persisted throughout the Upper Palaeolithic (Bar-Yosef & Kuhn, 1999). Core maintenance is fundamental to control lateral and distal convexity (Tab s16 and s17) and plays an important role in blade technology, although it is an optional feature in on-edge strategies (Tab s18).

Core preparation in burin-core methods starts with the shaping of the blank. Shaping is done by lateral retouch or truncations that modify the initial morphology of the blank, which allows for the removal of crested bladelets (de Araujo Igreja et al., (2006); Pesesse & Michel, 2006). Crested bladelets are characterised by retouch on the lateral edge of the blank that allows lateral facets to be opened to produce micro-bladelets (Bataille & Conard, 2018a). In preferential mode, bladelet production is hierarchical, with one of the lateral facets playing the role of a platform and the other the role of a knapping surface. In equivalent mode, the reduction sequence has an alternated sequence (de Araujo Igreja & Pesesse, 2006) similar to that identified in the discoid method (Boëda, 1993; Mourre, 2003), in which the two lateral facets can be both platform and knapping surface, resulting in a non-hierarchical production of bladelets. The different knapping sequences in preferential and equivalent burin cores affect core morphology. In the preferential mode, the angles between the knapping platform and the core surface tend to be 80–90°, while in the equivalent mode, the angles are more acute (de Araujo Igreja & Pesesse, 2006). From the refits, we know that reshaping phases take place as well as the rejuvenation of the platform by means of short removals perpendicular to the knapping surface (Le Brun-Ricalens & Brou, 2003).

This diversity of knapping methods and core maintenance is a constant throughout the Magdalenian. The presence of both varies diachronically, due to a variety of factors, leading to debate about the continuity or rupture of technical traditions in the Magdalenian (Ducasse, 2013; Langlais, 2007). Whether these behaviours indicate technical innovations that define temporal changes or if they are the result of site-specific organisational actions is a subject that needs further examination. To explore diachronic differences in technical management of the cores in the assemblage, we used additional quantitative data collected from the analysis of the technical attributes (Tab s19, s20, s21, s22, s23 and s24).

The Cova Gran core assemblage revealed technical homogeneity in the management and exploitation of laminar cores. At the base of the sequence, in Level 8P (c. 23 ka), the knapping systems were geared towards obtaining elongated flakes and bladelets with a low degree of standardisation. Likewise, we identified on-edge knapping strategies, already described in other lithic assemblages at the beginning of LGM-b (Aura et al., 2012). The widespread use of on-edge strategies appears in level 7P (c. 20 ka), where burin cores play a significant role in the production of bladelets. In the upper level, 6P (c. 18 k), narrow-sided cores are prevalent (these are a minority in the lower sequence) and, together with on-edge strategies, are the preferred method for obtaining bladelets. Lastly, Test Pit 4 (c. 16 k) exhibits a combination of semi-circumferential and burin-core methods, which are notable for their smaller size. This microlithisation, which is also present in the knapping products, does not seem to be the result of a progressive reduction of core volumes, but rather of the selection of small blanks (Falcucci et al., 2017) .

Different reduction schemes in the Cova Gran LGM-b sequence were recognised showing the wide technical diversity of blade technology. The intensive maintenance processes also show attention to the morphological characteristics of the cores, whose role in devising laminar knapping strategies is unquestionable. These indicators suggest that human groups have a broad operational range (Guilbaud, 1996; Mahaney 2014) whose uneven diachronic representation may affect the interpretation and characterisation of the Magdalenian technocomplex. It needs to be further explored whether the trends observed at the diachronic level in the use and management of cores are common throughout Magdalenian or if they are due to organisational factors within human occupations.

Conclusions

The data presented in this paper place the Cova Gran de Santa Linya as a reference site for the study of the Magdalenian in the Iberian Peninsula. The archaeological sequence provides new data on the lithic technology and technical traditions of the human groups during the LGM-b period.

The technological and morphometric analysis of the cores has allowed us to characterise the technical diversity of Magdalenian knapping systems and to assess the appearance and evolution of specific technical core reduction behaviours.

The core reduction strategies are geared towards obtaining elongated and narrow blanks using semi-circumferential and burin-core methods. Burin-core methods are based on on-edge exploitation and represent a technical innovation in Magdalenian technology. Semi-circumferential methods follow the basic principles of blade technology and support the persistence of common technical traditions throughout the Upper Palaeolithic.

Significant diachronic differences in cores have not been identified, suggesting there is a technical homogeneity in core reduction systems during the Magdalenian which support the idea of technical-cultural continuity during this period. However, the rhythm and development of blade knapping systems give rise to specific forms of variability (core types) which are explained by the application of

technical decisions in tool production and the emergence of site-specific organisational factors.

This variability is presented by means of a classification model for Magdalenian knapping strategies and the principal technical features observed in the core assemblage, providing a new reference for evaluating technological variation among lithic assemblages during the end of MIS 2.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s41982-022-00115-x.

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Declarations

Conflict of Interest The author declares no competing interests.

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