Testing a hypothesis about the importance of the quality of raw material on technological changes at Abric Romaní (Capellades, Spain): Some considerations using a high-resolution techno-economic perspective

Francesca Romagnoli [1, 2], Amelia Bargalló [3], Maria Gema Chacón [1, 2, 4, 5], Bruno Gómez de Soler [1, 2], Manuel Vaquero [1, 2]

1. IPHES, Institut Català de Paleoecologia Humana i Evolució Social, Campus Sescelades URV (Edifici W3), 43007 Tarragona, Spain. Email: Romagnoli: f.romagnoli2@gmail.com; Chacón: gchacon@iphes.cat; Gómez de Soler: bgomez@iphes.cat; Vaquero: manuel.vaquero@urv.cat
2. Area de Prehistoria, Universitat Rovira i Virgili (URV), Avinguda de Catalunya 35, 43002 Tarragona, Spain.
3. Institute of Archaeology, University College of London, Gordon Square 31-34, WC1H0PY London, U.K. Email: ameliabarg@gmail.com
4. UMR 7194 – Muséum national d'Histoire naturelle (CNRS - MNHN - UPVD - Sorbonne Université), 1 rue René Panhard, 75013 Paris, France.
5. Musée de l'Homme, 17 Place du Trocadéro, 75016 Paris, France.

Abstract:

Technological changes have been identified in several European Middle Palaeolithic sites. Specifically, the turnover in discoid and Levallois knapping methods has traditionally been explained by raw material constraints that are usually related to foraging areas and mobility strategies of Neanderthal groups. While Levallois production requires high homogeneous blocks, predominant discoid techno-complexes have generally been interpreted as better adapted to the scarcity of high quality raw material, not only for the lowest degree of control in products morphology, but also for their multitask characteristics. Nevertheless, the impact of the quality of raw material has never been systematically studied. Furthermore, technological analyses usually consider the lithic assemblage as a whole and do not dissect assemblages to identify single events, which are units that are needed to interpret relationships between technological organisation, human mobility, economic strategies, and settlement patterns. Here, we present an application of technological analysis with a high-resolution approach to investigate, in detail, how raw material quality affected production and how Neanderthals managed the low quality of Sant Martí de Tous chert within Levallois and discoid concepts. We used Raw Material Units and refits as units of analysis with a diacritical approach. The results suggested that the Levallois organisation of the reduction sequence in layer O included a phase of selection of the block and its systematic cutting-down, as well as quite standardised productive procedures and a high fragmentation of the productive sequence within the landscape. In layer M discoid sequences showed a high internal variability as a response to raw material constraints, and most of the production was usually manufactured at the site. Data implied that factors others than the quality of raw material determined the technological turnover at Abric Romaní, suggesting that social organisation and settlement patterns have most probably played a more significant role than foraging area.

Journal of Lithic Studies (2016) vol. 3, nr. 2, p. xx-xx doi:10.2218/jls.v3i2.1443

Published by the School of History, Classics and Archaeology, University of Edinburgh
ISSN: 2055-0472. URL: http://journals.ed.ac.uk/lithicstudies/

Keywords: Neanderthal; Middle Palaeolithic; Raw Material Unit analysis; diacritic approach; lithic technology; formal and informal technology; discoid; Levallois

1. Introduction

In several European Middle Palaeolithic sites, technological changes have been recognised between overlapped archaeological layers (*e.g.*, Faivre *et al.* 2014; Fernández Peris *et al.* 2008; Peresani 2011; Romagnoli *et al.* 2016a). The reasons for changes in knapping strategies have been identified in climatic and environmental fluctuations (Rolland & Dibble 1990), landscape exploitation changes with consequences on raw material availability (Geneste 1985), mobility strategy shifts related to foraging activities (Delagnes & Rendu 2011), presence of human groups with different cultural backgrounds (Moncel & Daujeard 2012), and risk assessment of the activities carried out at the sites (Romagnoli 2015). In the last years, researchers clearly showed that many factors contributed to the variability of Neanderthal behaviour. The organisation of technology is strictly related to the studied area, making it impossible to generalise the interpretation of technical behaviour. The assumption is that comprehension of the relationships between shared knowledge and economic strategies on one the hand and the adaptation to a specific environment, resource availability, and social organisation of tasks on the other can be obtained at a local high-resolution scale of analysis to understand mechanisms that have driven human behaviour.

In lithic studies, it is usually assumed that the ability to perform formal technology is strictly related to the high quality of raw material and its abundance (Andrefsky 1994; 2009; Bamforth 1986; 1991). The quality of raw material is usually determined by the degree of elasticity, homogeneity, and isotropy (Crabtree 1967; Goodman 1944; Inizan *et al.* 1999: 21-23). The greater these characteristics, the better the control of the conchoidal fracture originated by knapping and, consequently, the control of products and core geometry. These observations mean that raw material blocks with geodes, other inclusions, or cleavage planes are less suitable for knapping and are used for “simple”, informal methods. This assumption has been especially emphasised for Levallois technology, in which the control of the results of each removal on core geometry is usually considered to be unavoidable (*e.g.*, Boëda 1994; 1995; Dibble 1985; Kuhn 2011; Otte 1991). Nevertheless, the impact of the quality of raw material has never been systematically studied. Recent experimental works have suggested that the variability of Middle Palaeolithic lithic assemblages and, more specifically, of Levallois production was not related to a “determinism” of raw material (Eren *et al.* 2011): other variables, such as the edge durability of the artefacts, were probably more important for ancient hominids when selecting raw material. However, some authors have suggested that the quality of raw material could have also facilitated the cutting edge features (Terradillos-Bernal & Rodríguez-Álvarez 2017).

In this paper, we present a high-resolution analysis of the chert assemblage at Abric Romaní (Capellades, Spain). We analysed a sample of Raw Material Units (RMUs) identified in layers O and M. Layer O was mainly characterised by centripetal recurrent Levallois production, while in layer M, chert was mainly exploited with classical bifacial discoidal, uni-facial recurrent centripetal and multi-facial, multi-directional strategies (Chacón *et al.* 2013). In other words, level O exhibits a highly organised, formal reduction method, while level M is characterised by a markedly expedient behaviour that produces a high variability in core morphology. A previous study linked the technological rupture between layers O and M to climatically driven changes in the foraging radius (Picin & Carbonell 2016). According to the authors, the use of Levallois technology was directly linked to higher quality resources collected at a greater distance. In contrast, discoid technology was driven by reduced human mobility that obliged solving needs using local resources of lesser quality and maximising the exploitation of limited homogeneous supplies. We tested this hypothesis at a short scale of analysis, using single technical events to interpret technical behaviour.

The aim of this study was to determine how the raw material quality affected (i) the organisation of removals on the core to maintain its geometric construction and (ii) the application of different knapping methods.

1.1. The site

Abric Romaní rockshelter is located in the town of Capellades, approximately 50 km west of Barcelona (41º32'N, 1º41'E) (Figure 1). It is 280 m above sea level and set in the Cinglera del Capelló travertine cliff that rises on the right bank of the Anoia River at the intersection between different, rich ecosystems. The archaeological sequence is composed by approximately 20 meters of sediments and is characterised by anthropic layers separated by sterile travertine platforms and archaeo-levels vertically well delimited. The site has been investigated over more than 200 m^2. Actually layer Q is under investigation. The whole archaeological sequence have been dated by U-Series also through new sedimentary core samples. It covers a chronology between 40 kyr and 110 kyr BP (Vaquero *et al.* 2013; Sharp *et al.* 2016). Except for layer A, all the stratigraphic units are related to Middle Palaeolithic frequentation of the site. The palaeo-ecological analysis of the whole sequence allowed to identify five pollen zones (Burjachs *et al.* 2012). Each layer preserves a very rich archaeological record of animal bones, lithic remains, woody remains (Solé *et al.* 2013) and many hearts (Cabanes *et al.* 2007; Vallverdú *et al.* 2012). Taphonomic analyses have shown that the archaeological record is well preserved, and Neanderthal activity is the main cause of animal bone deposition (Cáceres *et al.* 2012; Gabucio *et al.* 2016). Hunting was mainly directed to horse and deer (*Equus ferus* and *Cervus elaphus*) occasionally associated with the exploitation of other large mammals and small preys. The study of charcoals and phytoliths suggested an almost exclusive exploitation of *Pinus* sp as fuel for combustion and the presence of open forest environment in the chronological range of human occupation at the site (Allué 2002; Cabanes *et al.* 2007). In the whole sequence, chert was the main raw material exploited usually being at least 80% of the whole lithic assemblage, followed by limestone and quartz that cover fluctuating percentage along the deposit. Chert was mainly collected in primary or sub-primary position.

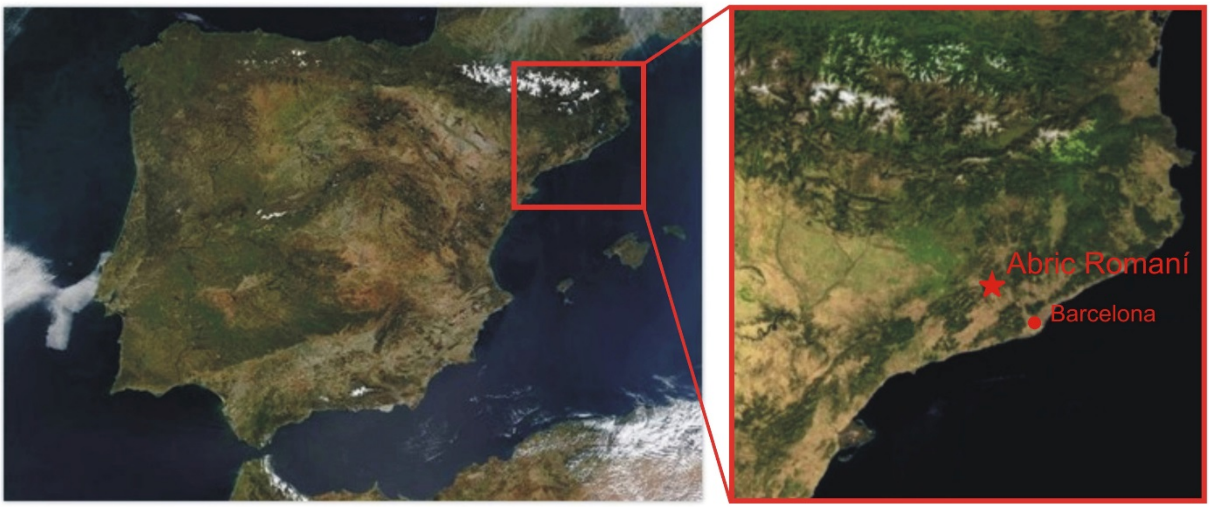

Figure 1. Location of Abric Romaní site.

Layers O and M fall within pollen zone 3, which was characterised by short and abrupt climatic shifts at the beginning of MIS 3 (Burjachs *et al.* 2012). Retouched tools were little represented and were mainly denticulated, notches and scrapers (Chacón *et al.* 2013). In both the layers retouched tools were less than 1% of the assemblage. The archaeological levels are vertically well delimited (Bargalló *et al.* 2015; Vaquero *et al.* 2015).

The travertine platform between layers O and M has been dated at 54.6±2.3 kyr BP (Bishoff *et al.* 1988). Layer O was characterised by an intense human occupation with diversified areas (Gabucio *et al.* 2014a). Hunting mainly targeted red-deer, aurochs and horses, but the occasional consumption of other animals, such as wildcat, has been identified (Gabucio *et al.* 2014b).

The travertine platform that covered layer M has been dated at 51.8±1.4 kyr BP (Bishoff *et al.* 1988). Hunting activity mainly focused on red-deer, horses and aurochs; macromammal remains showed intense bone processing and a high level of bone fragmentation related to Neanderthal subsistence (Fernandez-Laso *et al.* 2011). Macrofaunal dental wear analysis suggested that in this phase the site was occupied during autumn and early winter (Fernandez-Laso *et al.* 2010).

1.2. Geological context and time resolution set of problems

A 30-km radius from Abric Romaní was defined as the area to be prospected for abiotic resources (Gómez de Soler 2009; 2016: 105-107). According to numerous archaeological and ethnographic studies (Binford 1982; Féblot-Augustins 1999; Geneste 1992; Turq 1989) the majority of lithic raw materials exploited by Middle Palaeolithic hunter-gatherers are expected to have been collected in a local and semi-local area not far from a 30-km radius.

Along the archaeological sequence, chert was always the more exploited abiotic resource. It was mainly collected in semi-local areas (between 10 and 20 km from the site), with fluctuations in the percentage of chert collected in distant outcrops located approximately 30 km north-west (NW) from the site. A recent archaeo-petrographic investigation based on macroscopic (morphoscopic features), microscopic (thin sections), and complementary analysis (SEM, XRD, and μ-XRD) of archaeological and geological samples detailed the source areas exploited in layers M, O and P (Gómez de Soler 2016; Gómez de Soler *et al. in press*). The data show few changes in chert procurement between layers O and M. In both layers the predominant chert corresponds to the Sant Martí de Tous source (SMT; Figure 2), located approximately 15 km NW (layer O 78.5%; layer M 75.7%). However, the second most represented source, the Panadella chert (PAN) - collected at approximately 25 km NW - is more common in layer O (layer O 11.5%; layer M 2.0%). According to geo-petrographic analysis, the decrease in PAN chert in layer M was associated with the increase of secondary locally collected raw materials, mainly limestone and quartz (Gómez de Soler 2016: 306-308).

While PAN chert was usually characterised by a high homogeneity, SMT provided blocks with variable degrees of homogeneity. Noting this difference we faced two main research questions:

1. How did Neanderthals adapt to the heterogeneous grain-size and homogeneity of SMT chert blocks applying Levallois and discoid concepts?
2. How did they manage the low quality of SMT chert within the two different productive concepts?

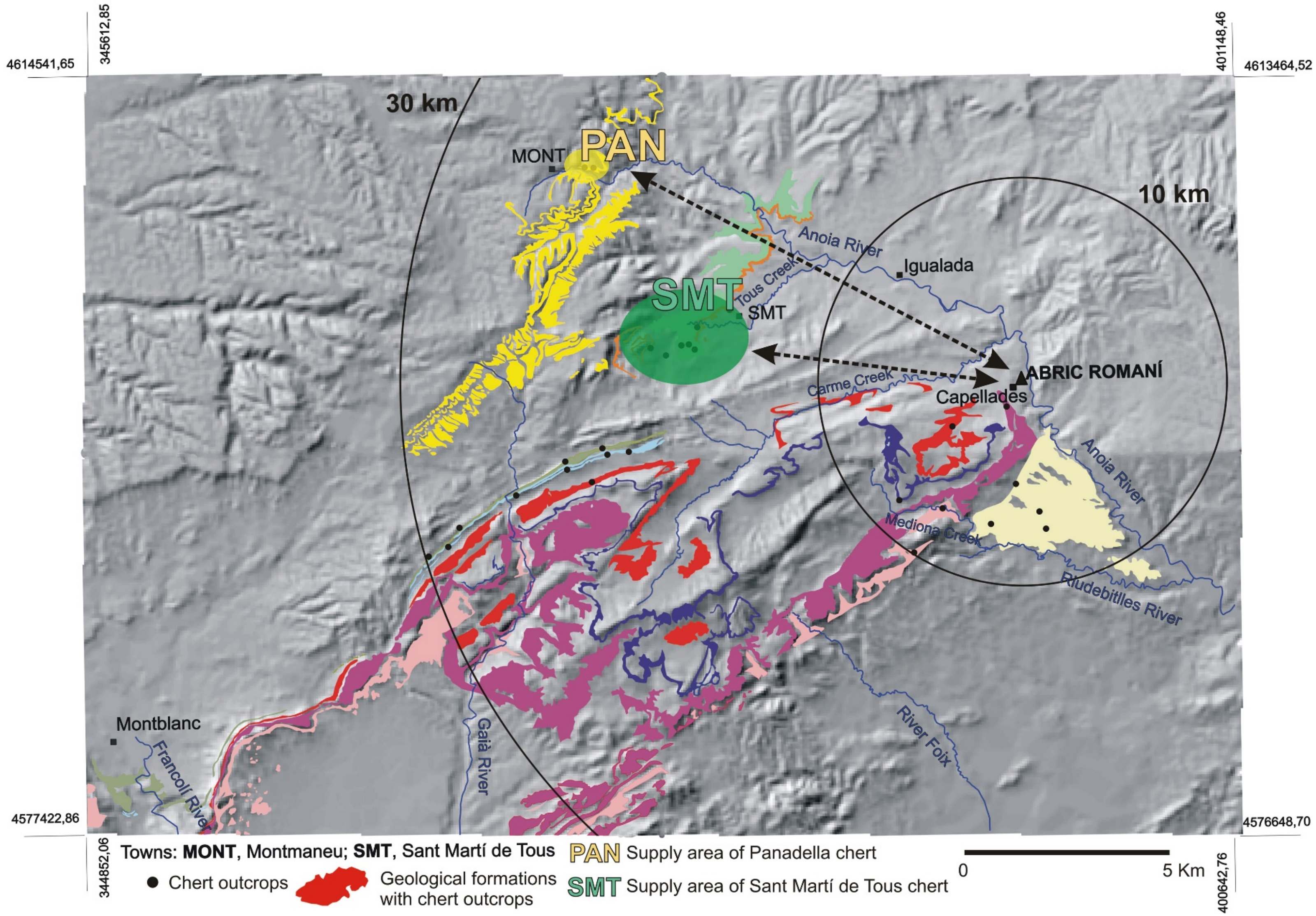

Figure 2. Location of the site (black triangle on the right) and of geological formations exploited by Neanderthals. Green (SMT) and yellow ovals (PAN) show the supply areas of chert formations analysed in the paper. Black dots show the chert outcrops analysed with macro- and microscopic archaeo-petrographic approach.

We assume that, being SMT the main exploited chert variety in layers O and M, in SMT outcrops Neanderthals found chert with the needed physical quality for production. If in layer O there was a 'determinism' of the raw material, we can expect low technological standardisation of SMT blocks and, in general, the highest Levallois variability in SMT supplies.

Until now, the variability of chert exploitation within each layer was not noticeable using a large scale of analysis. In previous technological studies (Chacón *et al.* 2013; Picin & Carbonell 2016), the lithic assemblages were considered as a whole, which means that they were a homogeneous set of materials produced by the same group during a phase of occupation at the site. This low temporal scale approach was the rationale for the comparison of macro categories in technical behaviour, such as Levallois *versus* discoid. The problem is that 'Levallois' and 'discoid' are not immutable definitions, and each technical system implied a variable degree of flexibility imposed by the variability of human responses to raw material and time-stress constraints. Several options were implemented by ancient hominins to adapt productive concepts to the volumetric characteristics of lithic supports. They included ramification and cores use-life, a variable degree of surface resharpening, and different strategies in the number and exploitation of the core surfaces (Bourguignon & Turq 2003; Dibble & Bar-Yosef 1995; Guette 2002; Peresani 2003; Slimak 2008; Vaquero *et al.* 2008; Villaverde *et al.* 2012; Wallace & Shea 2006). Moreover, internal variability and modification existed within Levallois and discoid technical systems because of their widespread geographical distribution and temporal endurance, as well as their association with other technical systems.

The possibility of perceiving behavioural variability in past technology lies in reducing the scale of analysis of the lithic assemblage and enlarging its temporal resolution. Analysing the assemblage as a whole, we obtained an "average behaviour" (Vaquero 2008). Several works have shown that archaeological assemblages were the result of a series of independent import, export, use, and discard events, and knowledge of the fragmented characteristics of production in the landscape is needed to understand and interpret site function, occupation length, planned behaviour, handling costs, and more in general techno-economic strategies (Machado *et al.* 2016; Turq *et al.* 2013; Vallverdú *et al.* 2005; Vaquero 2008).

2. Materials and methods

To test the hypothesis of differential uses of chert within each layer in relation to raw material heterogeneity, we sampled Raw Material Units (RMU) (Larson & Kornfeld 1997; Roebroeks 1988) from layers O and M mainly related to SMT chert sources and analysed them with a technological diacritical approach. Each RMU sampled included at least one core. We also included a RMU of PAN chert for comparison (Table 1). The complete refitting study of lithic assemblages is under way. RMU were identified using both macroscopic and microscopic criteria and comparisons with geological samples. Macroscopic criteria included texture related to the roughness of the surface to touch, cortex, impurities as geodes and mineral inclusions, transparency, presence of fissures and joins, sedimentary structures as indicative of depositional environment, and colour, while microscopic analysis took into account texture of α-quartz, presence or absence of non-epigenetic relict minerals, and the identification of authigenic minerals (Gómez de Soler 2016: 114-168; Soto *et al.* 2014).

Each element of the RMU was analysed with a diacritical approach reconstructing the logical sequence of technical gestures that determined its extraction from the core (Dauvois 1976; Inizan *et al.* 1999: 89-90). The same analysis allowed the identification of the technical procedures on cores. Removals were studied to identify temporal and directional orders of technical actions carried out during production. Later, techno-morphological characteristics of all of the elements were described. The association between diacritical and morpho-technical analysis allowed a detailed reconstruction of the productive concepts applied by Neanderthals and an understanding of the organisation of removals from the core to maintain its geometric construction in relation to raw material constraints.

Table 1. RMU analysed.

Layer	RMU	Number of pieces	Chert variety
O	Sil-TA2	7	PAN
O	Sil-TS24	52	SMT
O	Sil-TS29	19	SMT
O	Sil-TS38	120	SMT
O	Sil-TS46	7	SMT
O	Sil-TS49	6	SMT
O	Sil-TS51	36	SMT
O	Sil-TS61	20	SMT
O	Sil-TS62	7	SMT
		Total 274	
M	Sil-011	10	SMT
M	Sil-020	48	SMT
M	Sil-025a	24	PAN
M	Sil-048	9	SMT
M	Sil-072	156	SMT
M	Sil-073	57	SMT
		Total 304	

Refits were carried out to identify single technical events within each RMU. A ‘technical event’ is defined as a sequence of actions aimed at modifying the raw materials that were carried out at the site over a continuous range of time. Analysing refitting from a technological point of view, three types of events were especially interesting: (i) knapping, (ii) import, and (iii) export events. Knapping events were informative about the primary aims of production (morpho-technical characteristics sought in the toolkit) and the variability of technical solutions applied to adapt to raw material constraints to obtain productive aims. The import events revealed the morphology in which the raw material was introduced into the site as (i) unrefined block, (ii) rough-cut block, (iii) partially exploited core, (iv) blank, or (v) a retouched tool. Import events were determined by the planning of activity and needs to be fulfilled at the site, the knowledge of the absence or availability and abundance of specific raw materials in proximity to the site, and production and transportation costs of technology. The export events, which were identified by the absence of pieces or sequence of pieces in RMU and refits, reflected the strategies of production and use of raw material from the site. They were related to the organisation of technology within the landscape, mobility strategies, time-stress constraints, and technological costs.

Analysing the variability of techno-economic behaviour, selection was another important concept in technology. Selection implied a human choice, the voluntary keeping of something and, consequently, the rejection of something else within a series of possible options. Selection was performed according to priority criteria that were used as a filter for choosing raw material. Criteria for selection may have included block dimensions, raw material quality, morphology of the block, exigence of knapping in terms of productivity (quantity and quality of toolkit needed), and skills of the knapper. Identifying a selection phase at the beginning of the productive sequence and understanding the criteria for selection was significant in reconstructing how Neanderthals adapted to the available resources and created technical options to address raw material constraints (Figure 3).

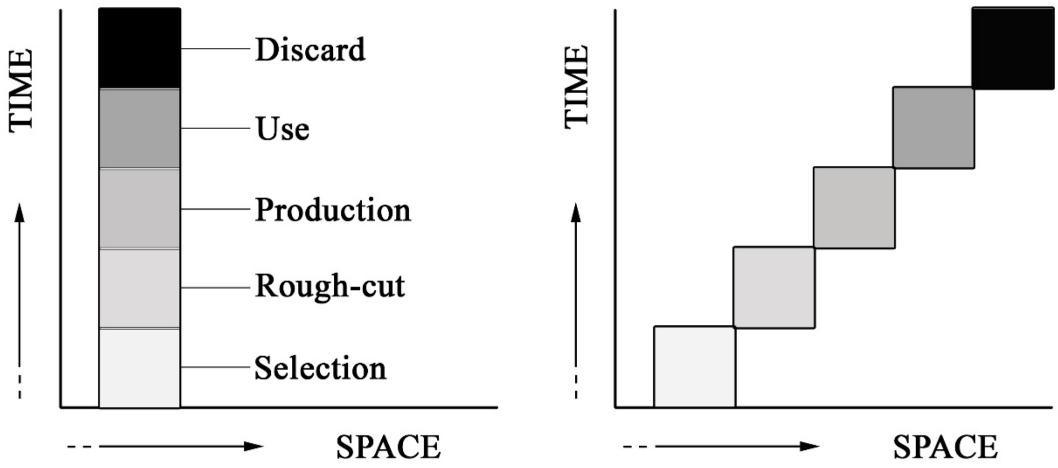

Figure 3. Spatial and temporal extreme strategies of the organisation of technology. The archaeological record usually shows a mix between these two opposite options depending on the technological costs, mobility of the group, and risk associated with the different phases of the productive sequence. Each phase symbolised here could have been realised by a single event or be split into several technical events.

3. Results

From a general point of view, the technological composition of SMT chert assemblages differed in two aspects. Layer O was characterised by a higher percentage of cores and a lower rate of fragmentation (Table 2).

Table 2. Technological categories in RMU of layer O and layer M.

RMU	Cores	Flakes	Fragments	Retouched tools	Total
Sil-TA2	1	4	2	-	7
Sil-TS24	8	25	17	2	52
Sil-TS29	1	9	7	2	19
Sil-TS38	9	76	35	-	120
Sil-TS46	1	4	2	-	7
Sil-TS49	2	2	2	-	6
Sil-TS51	7	19	9	1	36
Sil-TS61	7	10	3	-	20
Sil-TS62	2	2	3	-	7
Total	**38 (13.9%)**	**151 (55.1%)**	**80 (29.2%)**	**5 (1.8%)**	**Layer O 274 (100%)**
Sil-011	1	6	3	-	10
Sil-020	2	24	22	-	48
Sil-025a	1	14	9	-	24
Sil-048	2	4	3	-	9
Sil-072	3	84	69	-	156
Sil-073	4	17	35	1	57
Total	**13 (4.3%)**	**149 (49.0%)**	**141 (46.4%)**	**1 (0.3%)**	**Layer M 304 (100%)**

Both layers were characterised by the small size of artefacts, with an average size of 33 x 24 mm in layer O and 29 x 25 mm in layer M (Table 3; Figure 4). In both layers, the analysis of cortical surfaces suggested collection mostly in a sub-primary position.

Table 3. Length and width, summary statistics. Fragmented elements were not been counted. Measurements are in millimetres.

	Layer O 191 whole pieces		Layer M 163 whole pieces	
	Length	Width	Length	Width
Min	5	3	8	5
Max	100	95	116	83
Mean	32.51	23.62	27.87	25.23
Std. error	1.14	0.93	1.28	1.08
Variance	248.31	164.87	266.11	190.31
Stand. dev.	15.76	12.84	16.31	13.80
Median	29	20	24	22
25 percentile	20	15	16	16
75 percentile	45	32	37	31
Skewness	1.03	1.47	1.72	1.36
Kurtosis	1.34	4.23	5.07	2.16
Geom. Mean	28.99	20.58	23.97	22.01
Coeff. var	48.47	54.37	58.54	54.68

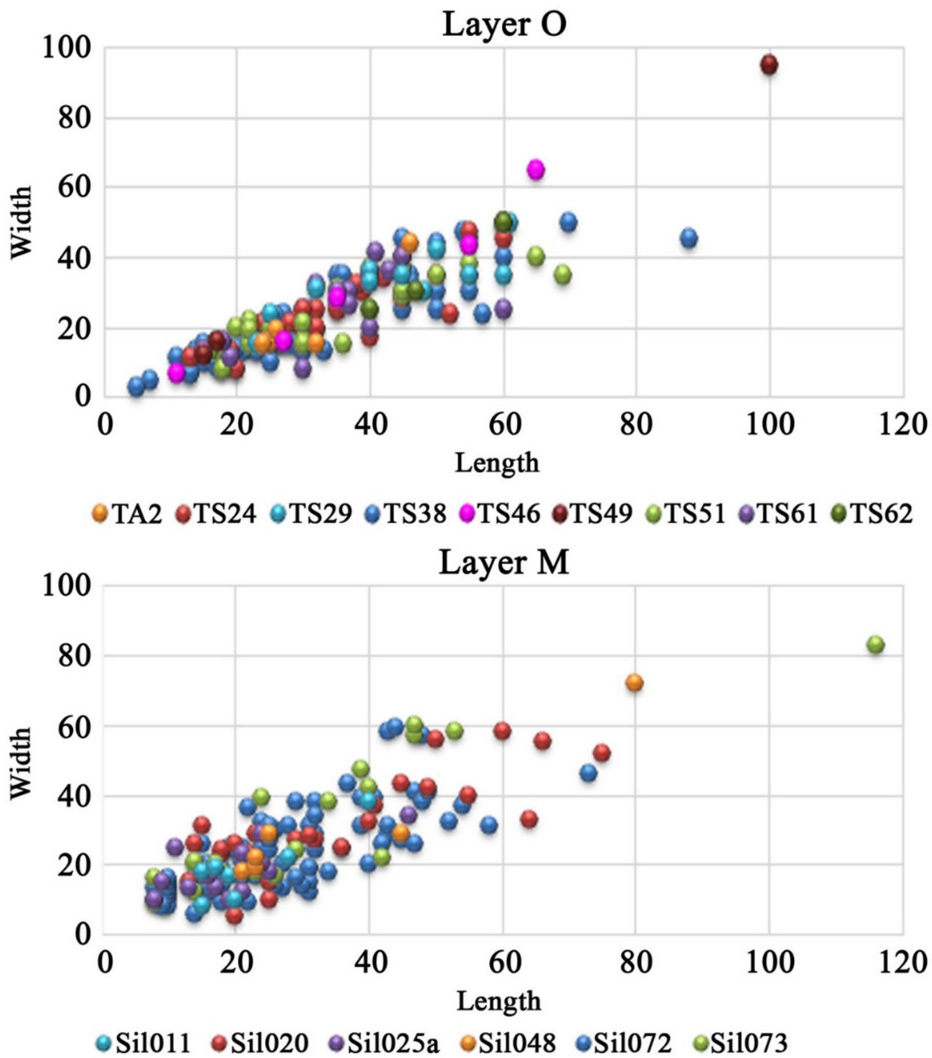

Figure 4. Length and width according to each RMU. Fragmented blanks were not been counted. Dimensions are in mm.

When analysing production, several differences can be highlighted. In layer O, the main knapping method was recurrent centripetal Levallois. Removals were geometrically linked to obtain two principal morpho-volumetric blanks: quadrangular and sub-triangular flakes. These last blanks were usually produced by detaching two adjacent, convergent removals aimed at preparing the needed arrises to extract a sub-triangular flake hitting between preparatory removals with a debitage axis toward the centre of the debitage surface. The knapping procedure exploited the whole periphery of the core. The PAN chert core sampled was exploited with this method. It measured 46 x 44 x 13 mm and was perfectly comparable with the other SMT cores (Figure 5).

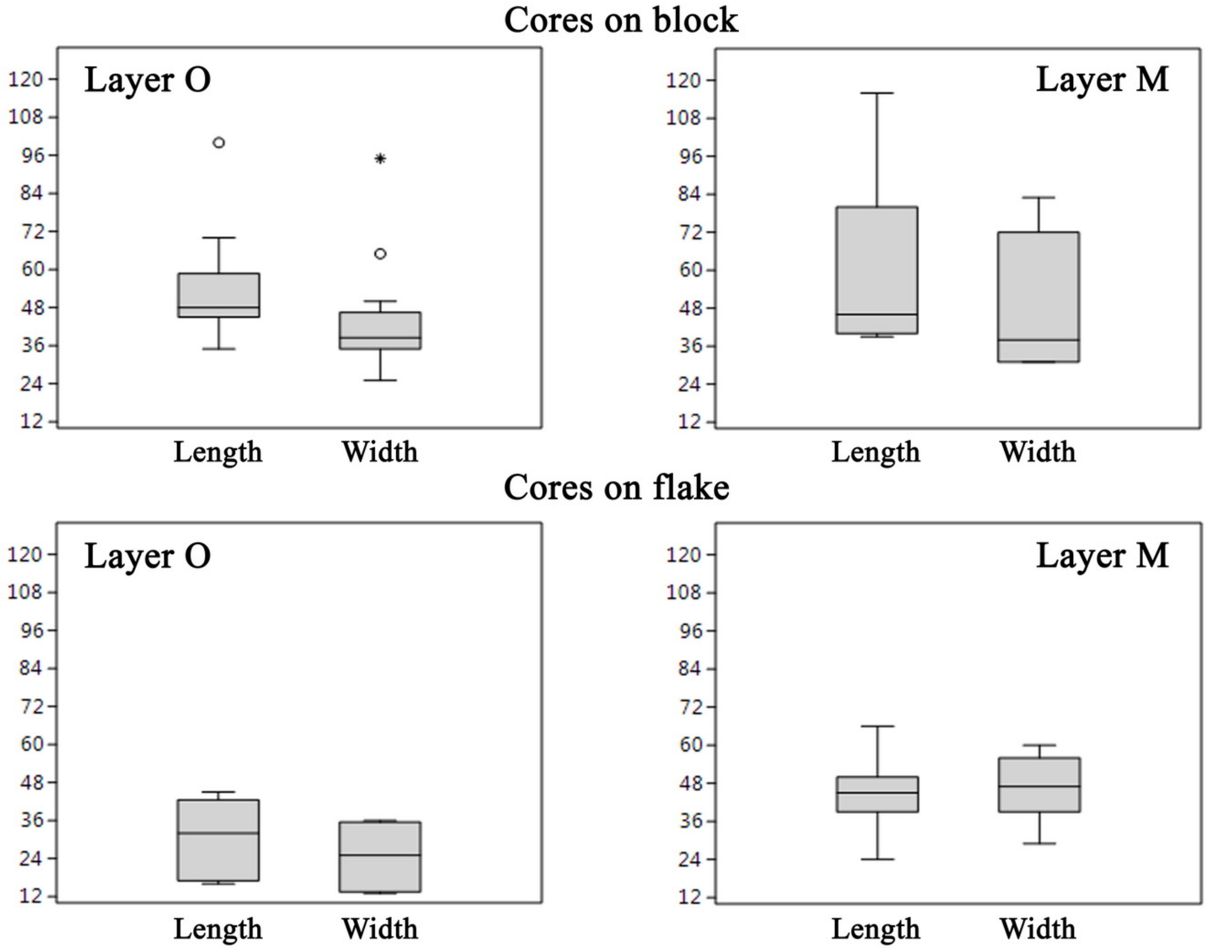

Figure 5. Length and width of cores. Dimensions are in mm.

A variation of this method was the organisation of removals according to the unipolar sequence. In this case, the preparatory flakes were located at the lateral extremities of the debitage surface and resulted in the extraction of naturally backed knives. In addition to preparing the arrises, their technological role was also to maintain the lateral convexities of the core surface.

Levallois reduction was associated with discoidal and multipolar, multidirectional sequences. Seven cores were identified as related to these secondary strategies. The association on the same core of bifacial, secant removals and alternating, abrupt removals (exploiting orthogonal surfaces) was attested on cores with volumetric constraints due to knapping accidents, to specific sequences of removals during knapping, or to volumetric constraints related to block morphology. The exploitation of one or two core surfaces was not systematic. The products related to these strategies were quadrangular.

Cores were usually short and exploited until the exhaustion of their productive volume (Figure 5). No dimensional differences were showed between the Levallois cores and those exploited according to different productive concepts. The only exception was a discoidal core depicted as an outlier in Figure 3. Approximately 10% of the cores attested ramification processes by the use of flakes as cores (Table 4). The analysis of Levallois cores suggested that usually, at least during the last phases of exploitation, Neanderthals rarely and only roughly prepared the point of impact and the striking platform. This datum was also supported by 46% of flakes that preserved a portion of the cortex on the butt.

Table 4. Core-on-flake.

RMU Layer O	Core-on-flake	RMU Layer M	Core-on-flake
Sil-TS51	2	Sil-020	4
Sil-TS61	1	Sil-048	1
Sil-TS62	1	Sil-073	3
Total	**4 (10.5%)**		**8 (53.3%)**

A reduced portion of internal fissures, geodes, or other inclusions was still visible on the SMT chert cores. These impurities partially affected the control of few removals, producing hinged flakes of fractures during knapping. However, cores generally showed quite a good degree of homogeneity (Figure 6).

Layer M was characterised by recurrent, alternating knapping sequences. The turnover of core surfaces was performed both with a slow alternating rhythm (a series of removals was performed on a surface; then, the core was shifted to produce a second series on the adjacent surface) and with a rapid rhythm (a continuous shifting between the core surfaces after each removal). These two strategies were also applied on the same core at different portions of the overhang. Cores showed, by turns, discoid exploitation (unifacial or bifacial) or an association on the same core between bifacial, secant sequences and the exploitation of alternating orthogonal surfaces.

Reduction sequences were located over the whole periphery of the core or on limited portions of the overhang because of specific raw material volumetric constraints. One core was exploited with a typical discoid concept (*sensu* Boëda 1993); at the end of its productive life, one extremity of the peripheral overhang had been removed to create a plane surface. That surface had been used as a striking platform for few adjacent, unipolar, final extractions. The PAN chert core sampled was exploited on portions of its peripheral overhang with a discoid hierarchical sequence. Along this exploitation the succession of removals was aimed to obtain triangular blanks. In this layer, during discoid exploitation radial blanks (*i.e.*, *débordant* (core-edge) flakes and pseudo-Levallois points) were often produced to guarantee the suitable convexities of the core. While radial removals produced sub-triangular flakes, centripetal sequences were aimed at quadrangular shaped extraction, and no systematic morpho-dimensional control was identified. Rather, products were characterised by a large variability. Recurrent, alternating productive sequences were associated with multipolar, multidirectional knapping. Neither Levallois cores nor products have been identified in the assemblage.

Cores showed a higher morphological variability than in layer O (Figure 5). Furthermore, the use of core on flakes is significantly consistent, representing more than 50% of the cores. Cores on flakes were mostly exploited for short alternating series of extraction.

Raw material blocks were characterised by a high inhomogeneity that was determinant in the high fragmentation rate and in frequent changes of flaking angles during production.

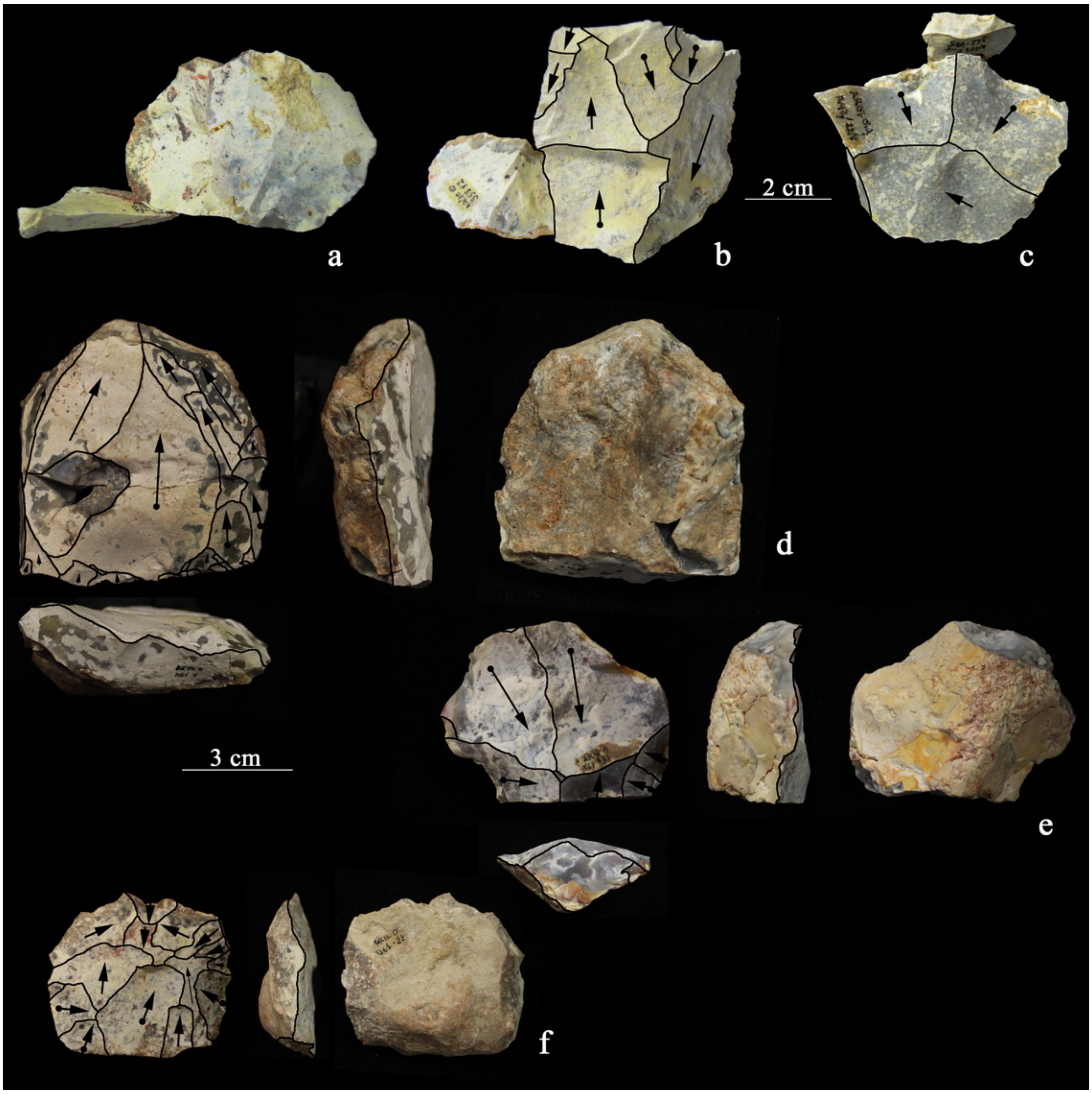

Figure 6. Layer O. (a, b, c): refits. Scale bar 2 cm. (d): Unipolar Levallois core for sub-triangular flake production; (e): centripetal Levallois core-on-flake; (f): centripetal Levallois core. Scale bar 3 cm.

Refitting analysis showed important differences in relation to import and export events. In refits from layer O, the first phases of the SMT chert knapping procedure were systematically absent. In this respect, it was interesting to detect the quite high rate of flakes that were partially corticated. Dividing the dorsal surface of flakes into four equivalent parts, four flakes had the whole dorsal surface corticated, 24 had a portion of the cortex corresponding to two thirds, and 71 had a portion of the cortex corresponding to one half or less. Furthermore, cores on flake were not refitted with the rest of the sequence, lacking quite a large portion of the sequence. The last phases of production, including the core, were preserved at the site. However, the main products were not found, and refits were composed of few elements, usually only four. No refit was identified with more than four RMUs (Table 5).

In layer M, refits have been identified in all of the RMUs sampled. There were 155 refitted elements, and several refits were composed of more than five elements (Table 5, Figure 7).

Table 5. Layers O and M, number of elements refitted in the RMUs analysed.

Layer O **ID Refit**	**SilTA2**	**SilTS24**	**SilTS29**	**SilTS38**	**SilTS46**	**SilTS49**	**SilTS51**	**SilTS61**	**SilTS62**
1		2	3	6			2	2	
2		2		2			2	2	
3				2					
4				2					
5				2					
6				2					
7				3					
8				3					
Total	**-**	**4**	**3**	**22**	**-**	**-**	**4**	**4**	**-**

Layer M **ID Refit**	**Sil011**	**Sil020**	**Sil025a**	**Sil048**	**Sil072**	**Sil073**
1	7	2	2	9	2	37
2		2	8		2	
3		2	2		2	
4		2			2	
5		2			4	
6		3			16	
7		5			8	
8					15	
9					21	
Total	**7**	**18**	**12**	**9**	**72**	**37**

Refits showed that the first phases of extraction were frequently made at the site, where the whole block was usually introduced. It was possible to refit core on flakes with the main sequence from which they were extracted. At least a *débordant* flake or a pseudo-Levallois point were found within quite each refit.

4. Discussion and conclusions

Layer O and layer M SMT chert assemblages differed not only in the predominant productive method applied but also in the general organisation of technology. In layer O, the Levallois techno-complex was characterised by a high standardisation of procedures that implied quite simple sequences of extractions to maintain control of the core geometry, mainly obtained through *débordant* flakes and often with a corticated back. It is interesting to notice that these products, well identified through the diacritical analysis, were often exported from the site at least concerning the sample analysed in this study. The predominant method was recurrent centripetal. Cores were exploited to obtain quadrangular and sub-triangular flakes. Other secondary methods, such as discoid, orthogonal and multipolar, and multidirectional, have been identified. In the sampled materials, the first phases of production were almost never identified at the site. Raw materials were usually introduced at two different manufacturing stages: as prepared cores or as flakes. Rarely, such flakes were exploited as a core within the site. Export events also significantly affected the composition of the SMT lithic assemblage, and several main products were transported and used elsewhere. It is significant to observe that this productive fragmentation would have been unperceived if analysing the sampled assemblage as a whole. Indeed, the few cortical blanks were isolated from refitted series or related to the low preparation of the core periphery and shaping out.

Similarly, the presence of Levallois first choice products was attested to in the assemblage, but mostly, they were isolated pieces rather than elements included in multi-element RMUs.

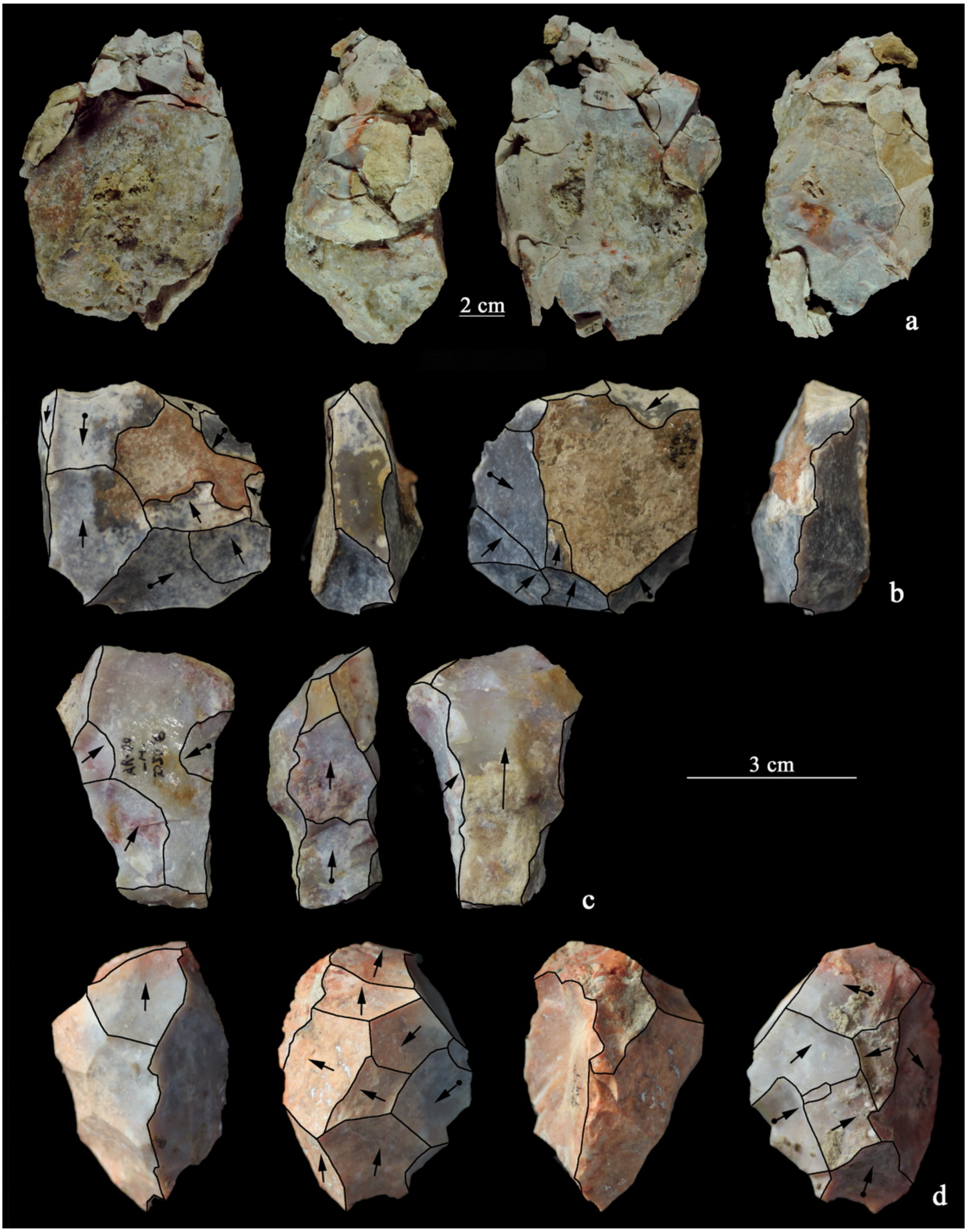

Figure 7. Layer M. (a): refit. Scale bar 2 cm. (b): discoidal unifacial core; (c): core-on-flake; (d): diacoidal bifacial core. Scale bar 3 cm.

The layer M SMT chert assemblage was characterised by discoid sequences, and neither Levallois products nor waste were identified. However, the definition of 'discoid' is not completely satisfactory according to the high variability of procedures that were shown and that seem to have been expressed during a continuous knapping sequence, as attested by refits. The problem in the definition of this techno-complex from a technological point of view is that few studies have detailed the flexibility of alternating, recurrent, bifacial sequences and further analysis will be needed to take into account the highest number of refits from this archaeological layer that are actually under study. Contrary to layer O, in layer M, it was not infrequent that a quite long portion of the production sequence was produced at the site, including ramification and the first phase in which the cortex was removed.

In relation to the quality of raw material, two opposite behaviours were displayed. In layer O, the productive sequence started with a high investment in raw material selection. Due to the heterogeneity in SMT chert outcrops, it is possible to hypothesise that the first productive phase, which is absent at the site, was expressly made near the collecting areas to cut-down the blocks and keep the most homogeneous parts of each one. In this way, the exploitable volume was diminished, but the shaping out of cores was quite standardised, simplifying the procedure to maintain volumetric control of the core and reduce variability within production. In this respect, it is interesting to note that similar Levallois recurrent centripetal procedures have been identified on limestone pebbles, suggesting that Neanderthals perfectly adapted their technological choices during production to other raw materials (Bargalló 2016: 103; Bargalló *et al.* 2015). In this layer, a portion of the fragmentation of productive sequences was probably due to the need to adapt the first phases of exploitation to the variable morphologies and homogeneities of the block and to obtain their most suitable portion. The high selection was most likely reflected in the short dimensions of cores and cores on flake and the generally short dimensions of products. At present, it is not possible to discuss the complementarity between SMT and chert from other outcrops in relation to the functional potential and dimensional constraints of the toolkit. Waiting for the complete analysis of the assemblage, it is not possible to exclude that the dimensional limits imposed by SMT chert cutting-down have obliged humans to exploit other more homogeneous resources. Refitting of the whole assemblage is in progress, and preliminary data suggest that the largest flakes, approximately 30-40 mm long and related to all of the chert varieties, were often introduced into the site ready to be used. The cutting-down of the block guaranteed a low fragmentation rate and minimised the risk associated with raw material impurities. Other knapping concepts were applied to SMT chert, enlarging the suitability of this resource. Although these concepts were characterised by a reduced degree of formal control, import and export events as well as selection and cutting-down of blocks directed their spatial and temporal organisation in the same way.

In layer M, no selection has been identified at the beginning of the SMT chert productive sequence. However, the organisation of extractions on the same core along alternating bifacial and secant, and bifacial and orthogonal series of extractions was clearly an efficient response to raw material constraints. This flexibility allowed Neanderthals to exploit blocks of different morphologies and dimensions, deal with uncontrolled fractures caused by the raw material heterogeneity, and systematically introduce ramification processes within manufacturing. The low control over the morpho-dimension of products and the high fragmentation rate were most likely supplied by the high productivity of the sharpened cutting edge. Furthermore, the technical organisation also implied the import into the site of pseudo-Levallois points and *débordant* flakes as response to specific planned activity and *in-situ* recycling and production of these techno-types as a consequence of differentiated raw material procurement strategies, including intra-site supply (Vaquero *et al.* 2015). Also in layer M, the imported products (including all of the chert varieties) were usually more than 40 mm long, attesting to anticipation and planning in relation to raw material constraints.

In both layers, *in situ* production of SMT chert flakes shorter than 30-40 mm was significant. In the last few years, the production of dimensionally reduced toolkits were commonly identified in Middle Palaeolithic sites in the Iberian Peninsula, western Europe, and the Levant and often related to ramification processes and Kombewa-type production (*e.g.*, Bourguignon *et al.* 2004; Cortés 2007; Fernández Peris 2007; Galván *et al.* 2009; Giles Pachego *et al.* 2012; Kuhn 1995; Romagnoli 2015). These short products had specific functional characteristics related to their short dimensions and to the highly sharpened edge and were most probably used in a variety of activities in which the accuracy of the gesture to be performed was a priority for the task to be successful (Barkai *et al.* 2010; Lemorini *et al.* 2015). Also in Levallois techno-complexes, even if less systematically studied, 'micro' production has been described in the Cantabrian region (Rios- Garaizar 2010; 2017); in the Valencian region (Villaverde *et al.* 2012); in France (Molés & Boutié 2009; Turq *et al.* 2008), Switzerland (Le Tensorier 1998), Greece (Koumouzelis *et al.* 2001); and in the Levant (Goren-Inbar 1988). Usually, this production has been interpreted as an adaptation to raw material dimensional constraints. The case studies presented in this paper suggest an alternative interpretation, with microlithisation as a technological process related to a specific shaping out strategy. It seems logical to us to hypothesise that, as part of the organisation of the technical system, the production of short blanks was also a response to specific functional constraints and probably to site function and social organisation, as proposed at the Abrigo de la Quebrada (Villaverde *et al.* 2012). In layer M, the search for short products was mostly related to informal, secondary productions using core on flakes.

The technical rupture at Abric Romaní was previously correlated with differences in mobility strategies determined by environmental, climatically driven changes (Picin & Carbonell 2016). However, new archaeo-petrographic analyses suggested a different scenario. Raw materials were mainly selected by Neanderthals for abundance, probably during the foraging transfer of the group (Gómez de Soler 2016: 299-313; Gómez de Soler *et al. in press*). SMT chert is characterised by a large dimensional and morphological variability, as well as variable degree of homogeneity (Gómez de Soler 2009; Soto *et al.* 2014). At present is not possible to exclude differences in mobility at short scale of analysis that could have affected the variability of the quality of the collected blocks. However, the systematic catchment of raw material in primary or sub-primary position suggests similar behaviour in the landscape. Furthermore, the geo-petrographic study has identified similar percentage of SMT chert in layer O (78.5%) and layer M (75.7%). Although the analyses were carried out on a sample, at present these new data show that is not possible to highlight any important change in mobility areas and pathways between these two layers, at least according to raw material exploited outcrops (Gómez de Soler 2016: 306-312). Differences could be identified in the exploitation of the strictly local resources, mostly limestone and quartz, which are more abundant in layer M. The higher variability of resources could have been facilitated by the flexibility of the technical system in this layer that allowed to easily exploit block of different morphology, dimension, and homogeneity.

Although the complete technological analysis of the lithic assemblages with a high-resolution approach is still in progress, and the data presented here were related to an early stage of the project, our results allow for a rejection of *a priori* raw material determinism with respect to its suitability and physical characteristics. Recent studies have shown that the relationship between technology and environment (including in this concept both biotic and abiotic available resources) is not necessarily a satisfactory element for interpreting past human behaviour. That is evident in the unvaried faunal assemblage associated with technological shifts at Combe-Grenal (Quina - Levallois techno-complexes) or in the persistence of the Quina production system in a layer of the same site in which faunal assemblage is completely different from the overhead and underlying layers (Faivre *et al.*

2014). Similarly, a recent analysis of the Middle Palaeolithic in eastern Cantabria has shown that Neanderthal groups were able to design their strategies to made them less dependent on resource availability (Rios-Garaizar 2017; Rios-Garaizar & García-Moreno 2015). In the same way, raw material quality was not necessarily the main factor that drove technological choices (Eren *et al.* 2011; Romagnoli, 2015; Romagnoli *et al.* 2016b), and neither was the distance to the source adequate to predict and explain techno-economic behaviour (Moreau *et al.* 2016; Romagnoli *et al.* 2016a). In layers O and M at Abric Romaní, faunal assemblages were characterised by red-deer, aurochs and horses, and in both layers, macromammal remains showed intense bone processing and high bone fragmentation due to anthropic subsistence activity (Fernandez-Laso *et al.* 2010; 2011; Gabucio *et al.* 2014a). The technological changes seem to have been associated with differences in the housing spaces within the site and in spatial patterns. The archaeological record was hearth-related in both layers, but while layer M was characterised by activity areas that were spatially quite well delimited (Vaquero *et al.* 2015), in layer O, the intense human occupation resulted in a rich palimpsest with areas attesting to different use of fire and different settlement patterns (Bargalló *et al.* 2015; Vallverdú *et al.* 2012). These data suggested that at Abric Romaní, as in the cases cited above, technological choices applied by Neanderthal groups seem to represent adaptations driven by factors other than the environment, such as social dynamics, occupation span, site function, demography, and cultural behaviour. At present, is not possible to interpret the technological rupture at this site, as in general in the whole Iberian Peninsula where Middle Palaeolithic variability seems not to show chronological patters (de la Torre *et al.* 2013). Our results suggest that a future method is to enlarge the temporal resolution of the analysis to identify and interpret single events. In this way, the formation of the archaeological record would be observed in all of its complexity and variability, and it would be possible to also include in the scenario aspects that would be otherwise unperceived or underestimated, such as micro production, fragmentation of productive sequences into the landscape, intra-site spatial patterns, and behavioural strategies. These aspects are essential to outline site function, the number of recurring occupational events, the whole techno-economic organisation, and long-term social and demographic dynamics. We should therefore take into account that changes in human behaviour, in the past as well as in the present, were linked to several factors and that each human group did not necessarily meet its own needs in the same way.

In conclusion, in both layers at Abric Romaní, the technical system was adapted to overcome the raw material constraints of SMT chert, which was most exploited probably in relation to similar pathways and mobility areas. However, while in the case of Levallois, the adaptation implied a high technical investment at the beginning of the productive sequence to guarantee morpho-dimensional and procedural ‘standardisation’, in layer M, Neanderthals opted in favour of a more informal and flexible system. In this way, the low quality of the raw material and high fragmentation rate were supplied by diminished geometric control, high production of asymmetric flakes with functional edge opposed to a back, and high productivity. These different choices were most likely linked to specific social needs, settlement patterns, and demography rather than environment and climatic shifts. Future detailed high-resolution analyses applied to the whole collection would allow a better understanding of this technical rupture and interpretation of behavioural factors affecting assemblage variability.

Acknowledgements

This research was funded by the European Union’s Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No. 653667

(F.R.). A.B. is funded by the H2020 Marie Sklodowska-Curie grant agreement No. 702584. M.G.C. has been supported by HAR2013-48784-C3-1-P from the Spanish Ministry of Economy and Competitiveness (MINECO). The authors are grateful to the Departament de Cultura of Generalitat de Catalunya, Diputació de Barcelona, Ajuntament de Capellades, and Arts Grafiques Romanya-Valls S.A. that provided support for the Abric Romaní excavations.

Authors contribution

Conceived and designed the paper: F.R. Performed the diacritical, technological analysis: F.R, A.B. Performed the lithic refits: F.R., A.B., M.G.C., M.V. Performed the archaeo-petrographic analysis for the identification of RMUs and of their related outcrops: B.G.S. Written the paper: F.R, B.G.S. Results have been discussed by all the authors.

References

Allué, E. 2002, Preliminary issues regarding the taphonomic study of archaeological charcoal upon the record from the Abric Romaní (Capellades, Spain). In: *Current topics on taphonomy and fossilization* (Renzi, M., Pardo, M.V., Belinchón, M., Peñalver, E., Montoya, P., & Marquez-Aliaga, A., Eds.). Ajuntament de Valencia, Col·lecció Encontres, Valencia: p. 447-452.

Andrefsky, W.Jr. 1994, Raw-material availability and the organization of technology. *American Antiquity*, 59: 21-34. doi:10.2307/3085499

Andrefsky, W.Jr. 2009, The analysis of stone tool procurement, production, and maintenance. *Journal of Archaeological Research*, 17: 65-103. doi:10.1007/s10814-008-9026-2

Bamforth, D.B. 1986. Technological efficiency and tool curation. *American Antiquity*, 51: 38-50. doi:10.2307/280392

Bamforth, D.B. 1991. Technological organization and hunter-gatherer land use: a California example. *American Antiquity*, 56: 216-234. doi:10.2307/281416

Bargalló, A. 2016. *Análisis tecnológico de los asentamientos Neandertales del nivel O: Abric Romaní (Barcelona, España).* Publicia Publications, Saarbrücken, 260 p. (in Spanish) ("Technological analysis of layer O: A Neanderthal settlement at Abric Romaní (Barcelona, Spain")

Bargalló, A., Gabucio, M.J., & Rivals, F. 2015, Puzzling out a palimpsest: testing an interdisciplinary study in level O of Abric Romaní. *Quaternary International*, 417: 51-65. doi:10.1016/j.quaint.2015.09.066

Barkai, R., Lemorini, C., & Gopher, A. 2010, Palaeolithic cutlery 400 000-200 000 years ago: tiny meat-cutting tools from Qesem Cave, Israel. *Antiquity, Project Gallery*, 84 (325). URL: http://www.antiquity.ac.uk/projgall/barkai325/

Binford, L.R.1982, The Archaeology of place. *Journal of Anthropological Research*, 1(1): 5-31. doi:10.1016/0278-4165(82)90006-x

Bischoff, J.L., Julia, R., & Mora, R. 1988, Uranium-series dating of the Mousterian occupation at the Abric Romani, Spain. *Nature*, 332: 68-70. doi:10.1038/332068a0

Boëda, E. 1993, Le débitage discoide et le débitage Levallois recurrent centripète. *Bulletin de la Société préhistorique française*, 90: 392-404. (in French) ("Discoidal and recurrent centripetal Levallois debitage") doi:10.3406/bspf.1993.9669

Boëda, E. 1994, Le concept Levallois: variabilité des méthodes. CNRS, Monographie du CRA, 9, Paris, 290 p. (in French) (“Levallois concept: variability of methods”)

Boëda, E. 1995, Levallois: a volumetric construction, methods, a technique. In: *The definition and interpretation of Levallois technology* (Dibble, H.L., & Bar-Yosef, O., Eds.), Prehistory Press, Madison, Wisconsin: p. 41-68.

Bourguignon, L., & Turq, A. 2003, Une chaîne opératoire de débitage discoïde sur éclat du Moustérien à denticulés aquitain: les exemples de Champ Bossuet de Combe-Grenal c. 14. In: *Discoid Lithic Technology: Advances and* Implications, (Peresani, M., Ed.), BAR International Series Vol. 1120. Archaeopress, Oxford: p. 131-152. (in French) (“A core-on-flake discoidal productive sequence in the denticulated Mousterian in Aquitania: the examples from Champ Bossuet de Combe-Grenal c.14”)

Bourguignon, L., Faivre, J.P., & Turq, A. 2004, Ramification des chaînes opératoires: une spécificité du Moustérien? *Paléo*, 16: 37-48. (in French) (“Ramification of productive sequences: is it a Mousterian specificity?”)

Burjachs, F., Lopez-Garcia, J. M., Allue, E., Blain, H-A., Rivals, F., Bennàsar, M., & Expósito, I. 2012, Palaeoecology of Neanderthals during Dansgaard-Oeschger cycles in northeastern Iberia (Abric Romani): from regional to global scale. *Quaternary International*, 247: 26-37. doi:10.1016/j.quaint.2011.01.035

Cabanes, D., Allué, E., Vallverdu, J., Cáceres, I., Vaquero, M. & Pastó, I. 2007, Hearth structure and function at level J (50 kyr, BP) from Abric Romani (Capellades, Spain): phytolith, charcoal, bones and stone-tools (Part 3: Applications in Archaeology). In: *Plants, People and Places: Recent studies in Phytolithic analysis* (Madella, M., & Zurro, D., Eds.), Oxbow Books, Oxford: p. 98-106.

Cáceres, I., Bennàsar, M., Huguet, R., Rosell, J., Saladié, P., Fernández-Laso, M.C., Gabucio, M.J., Ibáñez, N., Martín, P., Muñoz, L., & Rodríguez-Hidalgo, A. 2012, Taphonomy of level J of Abric Romaní. In: *High Resolution Archaeology and Neanderthal Behavior. Time and Space in Level J of Abric Romaní (Capellades, Spain)* (Carbonell, E., Ed.), Springer, New York: p. 159-187. doi:10.1007/978-94-007-3922-2_6

Chacón, M.G., Bargalló, A., Gómez de Soler, B., Picin, A., Vaquero, M., & Carbonell, E. 2013, Continuity or discontinuity of Neanderthal technological behaviours during MIS 3: level M and level O of the Abric Romaní site (Capellades, Spain). In: *Pleistocene foragers on the Iberian Peninsula: their culture and environment* (Pastoors, A., & Auffermann, B., Eds.), Festschrift in honour of Gerd-Christian Weniger for his sixtieth birthday. Wissenschaftliche Schriften des Neanderthal Museum Vol. 7, Mettman: p. 55-84.

Cortés, M., (Ed.), 2007, *Cueva Bajondillo (Torremolinos). Secuencia cronocultural y paleoambiental del Cuaternario reciente en la Bahía de Málaga.* Centro de Ediciones de la Diputación de Málaga, Malaga, 546 p. (in Spanish) (Bajondillo Cave (Torremolinos). Chrono-cultural and paleoenvironmental sequence of Late Quaternary in Bahía de Málaga”)

Crabtree, D.E. 1967, Notes on experiments in flintknapping: 3. The flintknapper’s raw materials. *Tebiwa*, 10: p. 8-24.

Dauvois, N. 1976, *Précis de dessin dynamique et structural des industries lithiques préhistoriques*. Fanlac, Perigueux, 262 p. (in French) (“Précis of dynamic and structural drawing of prehistoric lithic industries”) de la Torre, I., Martínez-Moreno, J., & Mora, R. 2013, Change and stasis in the Iberian Middle Paleolithic. Considerations on the significance of Mousterian technological variability. *Current Anthropology*, 54: S320-S336. doi:10.1086/673861

Delagnes, A., & Rendu, W. 2011, Shifts in Neandertal mobility, technology and subsistence strategies in western France. *Journal of Archaeological Science*, 38: 1771-1783. doi:10.1016/j.jas.2011.04.007

Dibble, H.L. 1985, Raw-material variation in Levallois flake manufacture. *Current Anthropology*, 26: 391-393. doi:10.1086/203286

Dibble, H.L, & Bar-Yosef, O., (Eds.), 1995, *The definition and interpretation of Levallois technology*. Prehistory, Madison, 502 p.

Eren, M.I., Lycett, S.J., Roos, C.I., & Sampson, C.G. 2011, Toolstone constraints on knapping skill: Levallois reduction with two different raw materials. *Journal of Archaeological Science*, 38: 2731-2739. doi:10.1016/j.jas.2011.06.011

Faivre, J.P., Discamps, E., Gravina, B., Turq, A., Guadelli, J.L., & Lenoir, M. 2014, The contribution of lithic production systems to the interpretation of Mousterian industrial variability in south-western France: the example of Combe-Grenal (Dordogne, France). *Quaternary International*, 356: 227-240. doi:10.1016/j.quaint.2014.05.048

Féblot-Augustins, J. 1999, La mobilité des groupes paléolithiques. *Bulletins et Mémoires de la Société d'anthropologie de Paris*, Nouvelle Series, 11: 219-260. (in French) ("The mobility of Palaeolithic groups") doi:10.3406/bmsap.1999.2551

Fernández Peris, J. 2007, *La Cova del Bolomor (La Valldigna, Valencia). Las industrias líticas del Pleistoceno medio en el ámbito del mediterráneo peninsular*, Trabajos Varios del Servicio de Investigación Prehistórica Vol. 108, Valencia, 463 p. (in Spanish) ("Bolomor Cave (La Valldigna, Valencia). The Middle Pleistocene lithic industry in the framework of peninsular Mediterranean area") URL: http://www.museuprehistoriavalencia.es/web_mupreva/publicaciones/?q=es&id=139

Fernández Peris, J., Barciela, V., Blasco, R., Cuartero, F., & Sañudo, P 2008, El Paleolítico Medio en el territorio valenciano y la variabilidad tecno-económica de la Cova del Bolomor. *Treballs d'Arqueologia*, 14: 141-169. (in Spanish) ("The Middle Palaeolithic in the territory of Valencia and the techno-economic variability of Cova de Bolomor")

Fernandez-Laso, M.C., Chacon, M.G., Garcia-Anton, M.D., & Rivals, F. 2011, Territorial Mobility of Neanderthal groups: a case study from Level M of Abric Romaní (Capellades, Barcelona, Spain). In: *Neanderthal lifeways, subsistence and technology* (Conard, N.J., & Richter, J. Eds.), Heidelberg, Springer: p. 187-202. doi:10.1007/978-94-007-0415-2_17

Fernandez-Laso, M.C., Rivals, F., & Rosell, J. 2010, Intra-site changes in seasonality and their consequences on the faunal assemblages from Abric Romani (Middle Paleolithic, Spain). *Quaternaire*, 21: 155-163. doi:10.4000/quaternaire.5525

Gabucio, M.J., Cáceres, I., Rosell, J., Saladié, P., & Vallverdú, J. 2014a, From small bone fragments to Neanderthal activity areas: the case of Level O of the Abric Romaní (Capellades, Barcelona, Spain). *Quaternary International*, 330: 36-51. doi:10.1016/j.quaint.2013.12.015

Gabucio, M.J., Cáceres, I., Rodríguez-Hidalgo, A., Rosell, J., & Saladié, P. 2014b, A wildcat (Felis silvestris) butchered by Neanderthals in the Level O of the Abric Romaní site

(Capellades, Barcelona, Spain). *Quaternary International*, 326-327: 307-318. doi:10.1016/j.quaint.2013.10.051

Gabucio, M.J., Cáceres, I., Rivals, F., Bargalló, A., Rosell, J., Saladié, P., Vallverdú, J., Vaquero, M., & Carbonell, E. 2016, Unravelling a Neanderthal palimpsest from a zooarcheological and taphonomic perspective. *Archaeological and Anthropological Sciences*, online first: 1-26. doi:10.1007/s12520-016-0343-y

Galván, B., Hernández, C.M., Ortega, F., Molina, F.J., & Tarriño, A. 2009, La producción lítica del Abric del Pastor (Alcoi, Alicante). Un ejemplo de variabilidad musteriense. *Tabona*, 17: 11-61. (in Spanish) ("The lithic production of Abric del Pastor (Alcoi, Alicante)") URL: http://riull.ull.es/xmlui/handle/915/2302

Geneste, J.M. 1985, *Analyse lithique d'industries moustériennes du Périgord: une approche technologique du comportement des groupes humains au Paléolithique moyen*, PhD Dissertation, Université de Bordeaux I, Bordeaux, 571 p. (in French) ("The lithic analysis of Mousterian industries in Perigord: A technological approach to the behaviour of human groups in Middle Palaeolithic")

Geneste, J.M. 1992, L'approvisionnement en matières premières dans les systemes de production lithique: la dimension spatiale de la technologie. In: *Tecnología y Cadenas Operativas líticas* (Mora, R., Terradas, X., Parpal, A., & Plana, C., Eds.), Treballs d'Arqueologia, 1: 1-31. (in French) ("Raw materials supply in lithic production systems: the spatial characteristic of technology") URL: http://www.raco.cat/index.php/TreballsArqueologia/article/view/50042

Giles Pacheco, F.G., Giles Guzmán, F.J., Gutiérrez, J.M., Santiago, A., Finlayson, C., Rodríguez, J., Finlayson, G., & Fa, D. 2012, The tools of the last Neanderthals: Morphotechnical characterization of the lithic industry at level IV of Gorham's Cave, Gibraltar. *Quaternary International*, 247: 151 161. doi:10.1016/j.quaint.2011.02.026

Gómez de Soler, B. 2009, Àrees de captació, tecnologia lítica i estratègies d'aprovisionament de reques silicies em el nível L de l'Abric Romaní (Capellades, Barcelona). *Quadern de Prehistòria Catalana*, 17: 11-56. (in Catalan) ("Catchment areas, lithic technology, and raw materials supply strategies in layer L at Abric Romaní (Capellades, Barcelona)") URL: http://www.raco.cat/index.php/QuadernPrehistoriaAAG/article/view/225534/306888

Gómez de Soler, B. 2016, *Procedencia del aprovisionamiento lítico durante el Paleolítico medio en el yacimiento del Abric Romaní (Capellades, Barcelona). Niveles M, Oa y P*, PhD Dissertation, Universitat Rovira i Virgili, Tarragona, 408 p. (in Spanish) ("Lithic supply in Middle Palaeolithic at Abric Romaní (Capellades, Barcelona). Layers M, Oa, and P")

Gómez de Soler, B., Vallverdú, J., Soto, M., Allué, E., Bargalló, A., Campeny, G., Chacón, M.G., Gabucio, M.J., Marín, J., Saladié, P., Romagnoli, F., Vaquero, M., Carbonell, E. *in press*, Afloraments silicis a la Catalunya Central i àrees de captació dels neandertals de l'Abric Romaní (Capellades, Anoia). Els cas dels nivells M, Oa i P. In: *Jornades de Arqueologia de la Catalunya Central 2015-2016*, Museu Diocesà i Comarcal de Solsona, Solsona (Spain): 8 p. (in Catalan) ("Siliceous outcrops in Central Catalonia and catchment areas of the Neanderthals of Abric Romaní (Capellades, Anoia). The cases of the levels M, Oa and P")

Goodman, M.E. 1944, The physical properties of stone materials. *American Antiquity* 9: 415-433. doi:10.2307/275093

Goren-Inbar, N. 1988, To Small To Be True? Reevaluation of Cores on Flakes in Levantine Mousterian Assemblages. *Lithic Technology*, 17: 37-44. doi:10.1080/01977261.1988.11754524

Guette, C. 2002, Révision critique du concept de débitage Levallois à travers l'étude du gisement moustérien de Saint-Vaast-la-Hougue/le Fort (chantiers I-III et II, niveaux inférieurs) (Manche, France). *Bulletin de la Société préhistorique française*, 99: 237-248. (in French) ("Critical revision of Levallois debitage concept through the study of Saint-Vaast-la-Hougue/le Fort Mousterian site (chantiers I-III et II, lower layers) (Manche, France)") doi:10.3406/bspf.2002.12655

Inizan, M.L., Reduron-Ballinger, M., Roche, H., & Tixier, J. 1999, *Technology and terminology of knapped stone*, CREP, Nanterre. URL: http://www.mae.u-paris10.fr/prehistoire/IMG/pdf/Technology_and_Terminology_of_Knapped_Stone.pdf

Koumouzelis, M., Kozlowski, J.K., Escutenaire, C., Sitlivy, V., Sobczyk, K., Valladas, H., Tinesrat-Laborde, N., Wojtal, P., & Ginter, B. 2001, La fin du Paléolithique moyen et le début du Paléolithique supérieur en Grèce: la séquence de la Grotte 1 de Klissoura. *L'Anthropologie*, 105: 469-504. (in French) ("The end of Middle Palaeolithic and the beginning of Upper Palaeolithic in Greece: the sequence of Cave 1 of Klissoura") doi:10.1016/s0003-5521(01)80049-2

Kuhn, S.L. 1995, *Mousterian lithic technology. An ecological perspective*, Princeton University Press, Princeton, 224 p. doi:10.1515/9781400864034

Kuhn, S.L. 2011, Neanderthal technoeconomics: an assessment and suggestion for future developments. In: *Neanderthal lifeways, subsistence and technology: one hundred fifty years of Neanderthal study* (Conard, N.J., & Richter, J., Eds.), Springer, Dordrecht: p. 99-110. doi:10.1007/978-94-007-0415-2_10

Larson, M.L., & Kornfeld, M. 1997, Cjipped Stone Nodules: Theory, Method, and Examples. *Lithic Technology*, 22: 4-18. doi:10.1080/01977261.1997.11754530

Lemorini, C., Venditti, F., Assaf, E., Parush, Y., & Barkai, R. 2015, The function of recycled lithic items at late Lower Paleolithic Qesem Cave, Israel: an overview of the use-wear data. *Quaternary International*, 361: 103-112. doi:10.1016/j.quaint.2014.07.032

Le Tensorer, J.-M. 1998, *Le Paléolithique en Suisse*. J. Million, Grenoble, 500 p. (in French) ("The Palaeolithic in Switzerland")

Machado, J., Molina, F.J., Hernández, C.M., Tarriño, A., & Galván, B. 2016, Using lithic assemblage formation to approach Middle Palaeolithic settlement dynamics: el Salt stratigraphic Unit X (Alicante, Spain). *Archaeological and Anthropological Sciences*, 29 p. doi:10.1007/s12520-016-0318-z

Molés, V., & Boutié, P. 2009, Contribution à la reconnaissance d'une microproduction au Paléolithique moyen: les industries de la grotte des Ramandils (Port-La Nouvelle, Aude, France). *L'Anthropologie*, 113: 356-380. (in French) ("Contribution to the identification of a Middle Palaeolithic micro production: the lithic industries of Ramandils Cave (Port-La Nouvelle, Aude, France)") doi:10.1016/j.anthro.2009.04.002

Moncel, M.H., & Daujeard, C. 2012, The variability of the Middle Palaeolithic on the right bank of the Middle Rhône Valley (Southeast France): technical traditions or functional choices? *Quaternary International*, 247: 103-124. doi:10.1016/j.quaint.2010.10.030

Moreau, L., Brandl, M., & Nigst, P.R. 2016, Did prehistoric foragers behave in an economically irrational manner? Raw material availability and technological organisation at the early Gravettian site of Willendorf II (Austria). *Quaternary International*, 406: 84-94. doi:10.1016/j.quaint.2015.11.123

Otte, M. 1991, Evolution in the relationships between raw materials and cultural tradition in the European Palaeolithic. In: *Raw material economies among prehistoric hunter-gatherers* (Montet-White, A., & Holen, S., Eds.), University of Kansas: p. 161-167.

Peresani, M. 2011, Fifty-thousand years of flint knapping and tool shaping across the Mousterian and Uluzzian sequence of Fumane cave. *Quaternary International*, 247: 1-26. doi:10.1016/j.quaint.2011.02.006

Peresani, M., (Ed.), 2003, *Discoid Lithic Technology: Advances and Implications*, BAR International Series 1120. Archaeopress, Oxford, 275 p.

Picin, A., & Carbonell, E. 2016, Neanderthal mobility and technological change in the northeastern of the Iberian Peninsula: the patterns of chert exploitation at the Abric Romaní rock-shelter. *Comptes Rendus Palevol*, 15: 581-594. doi:10.1016/j.crpv.2015.09.012

Rios-Garaizar, J. 2010, Organización económica de las sociedades neandertales: el caso del nivel VII de Amalda (Zestoa, Gipuzkoa). *Zephyrus*, 65: 15-37. (in Spanish) ("Economic organisation of Neanderthal societies: the case study of layer VII of Amalda (Zestoa, Gipuzkoa)") URL: http://gredos.usal.es/jspui/handle/10366/100641

Rios-Garaizar, J. 2017, A new chronological and technological synthesis for Late Middle Palaeolithic of the Eastern Cantabrian Region. *Quaternary International*, 432(B): 50-63. doi:10.1016/j.quaint.2016.02.020

Rios-Garaizar, J., & García-Moreno, A. 2015, Middle Paleolithic Mobility Patterns and Settlement System Variability in the Eastern Cantabrian Region (Iberian Peninsula): a GIS-Based Resource Patching Model. In: *Settlement Dynamics of the Middle Paleolithic and Middle Stone Age* vol. 4, (Conard, N.J., & Delagnes, A., Eds.), Kerns Verlag, Tübingen: p. 329-360.

Roebroeks, W., 1988, *From Find Scatters to Early Hominid Behaviour. A Study of Middle Palaeolithic Riverside Settlements at Maastricht-belvedere (Netherlands)*. Analecta Praehistorica Leidensia 21, University of Leiden, Leiden, 175 p.

Rolland, N., & Dibble, H.L. 1990, A New Synthesis of Middle Paleolithic Assemblage Variability. *American Antiquity*, 55: 480-499. doi:10.2307/281279

Romagnoli, F. 2015, A second life: recycling production waste during Middle Palaeolithic in Southern Italy. The lithic assemblage of layer L at Grotta del Cavallo (Lecce, South Apulia). *Quaternary International*, 361: 200-211. doi:10.1016/j.quaint.2014.07.033

Romagnoli, F., Trenti, F., Nannini, L., Carmignani, L., Ricci, G., Lo Vetro, D., Martini, F., & Sarti, L 2016a, Raw material procurement and productive sequences in the Palaeolithic of southern Italy: the Tyrrhenian and the Ionian areas. In: *Ressources lithiques, productions et transferts entre Alpes et Méditerranée* (Tomasso, A., Binder, D., Martino, G., Simon, P., Porraz, G., Simon, P., & Naudinot, N., Eds.), Société Préhistorique Française, Les Séances de la SPF 5, Paris: p. 177-197. URL: http://www.prehistoire.org/offres/file_inline_src/515/515_P_40036_578298164ec72_8.pdf

Romagnoli, F., Baena, J., & Sarti, L. 2016b, Neanderthal retouched shell tools and Quina economic and technical strategies: an integrated behaviour. *Quaternary International*, 407: 29-44. doi:10.1016/j.quaint.2015.07.034

Sharp, W.D., Mertz-Kraus, R., Vallverdú, J., Vaquero, M., Burjachs, F., Carbonell, E., & Bishoff, J.L. 2016, Archaeological deposits at Abric Romaní extend to 110 ka: U-series dating of a newly cored, 30 meter-thick section. *Journal of Archaeological Science: Reports*, 5: 400-406. doi:10.1016/j.jasrep.2015.12.015

Slimak, L., 2008, ¿Qué sistemas de talla, qué conceptos, qué límites para el Paleolítico Medio? *Treballs d'Arqueologia*, 14: 9-26. (in Spanish) ("Which knapping systems, which concepts, which limits in Middle Palaeolithic?")

Solé, A., Allué, E., & Carbonell, E. 2013, Heart-related wood remains from Abric Romaní layer M (Capellades, Spain). *Journal of Anthropological Research*, 69: 535-559. doi:10.3998/jar.0521004.0069.406

Soto, M., Gómez de Soler, B., Vallverdú, J, & Vaquero, M. 2014, Potential siliceous sources during Prehistory: Results of prospecting in the East margin of the Ebro Basin (NE Iberian Peninsula). *Journal of Lithic Studies*, 1(1): 293-318. doi:10.2218/jls.v1i1.772

Terradillos-Bernal, M., & Rodríguez-Álvarez, X.P. 2017, The influence of raw material quality on the characteristics of the lithic tool edges from the Atapuerca sites (Burgos, Spain). *Quaternary International*, 433(A): 211-223. doi:10.1016/j.quaint.2015.10.122

Turq, A. 1989, Exploitation des matières premières lithiques et exploitation du sol: l'exemple du Mustérien entre Dordogne et Lot. *Cahiers du Quaternaire*, 13: 179-204. (in French) ("The exploitation of lithic raw materials and of soil: the example of Mousterian between Dordogne and Lot")

Turq, A., Faivre, J.-P., Goldberg, P., McPherron, S., & Sandgathe, D. 2008, Le Moustérien du Périgord Noir: quoi de neuf ?. In: *Les sociétés du Paléolithique dans un Grand Sud-ouest de la France: nouveaux gisements, nouveaux résultats, nouvelles méthodes* (Jaubert, J., Bordes, J.-G., & Ortega, I., Eds.), Société préhistorique française, Paris: p. 83-93. (in French) (Mousterian of Périgord Noir: What's new?")

Turq, A., Roebroeks, W., Bourguignon, L., & Faivre, J.P. 2013, The fragmented character of Middle Palaeolithic stone tool technology. *Journal of Human Evolution*, 65: 641-655. doi:10.1016/j.jhevol.2013.07.014

Vallverdú, J., Allué, A., Bischoff, J.L., Cáceres, I., Carbonell, E., Cebrià, A., García-Antón, D., Huguet, R., Ibáñez, N., Martínez, K., Pastó, I., Rosell, J., Saladié, P., & Vaquero, M. 2005, Short human occupations in the Middle Palaeolithic level I of the Abric Romaní rock-shelter. *Journal of Human Evolution*, 48: 157-174. doi:10.1016/j.jhevol.2004.10.004

Vallverdú, J., Alonso, S., Bargalló, A., Bartrolí, R., Campeny, G., Carrancho, A., Expósito, I., Fontanals, M., Gabucio, J., Gómez, B., Prats, J.M., Sañudo, P., Solé, A., Vilalta, J., & Carbonell, E. 2012, Combustion structures of archaeological level O and mousterian activity areas with use of fire at the Abric Romaní rockshelter (NE Iberian Peninsula). *Quaternary International*, 247: 313-324. doi:10.1016/j.quaint.2010.12.012

Vaquero, M. 2008, The history of stones: behavioural inferences and temporal resolution of an archaeological assemblage from the Middle Palaeolithic. *Journal of Archaeological Science*, 35: 3178-3185. doi:10.1016/j.jas.2008.07.006

Vaquero, M., Allué, E., Bischoff, J.L., Burjachs, F., & Vallverdú Poch, J. 2013, Environmental, depositional, and cultural changes in the Upper Pleistocene and Early Holocene: the Cinglera del Capelló sequence (Capellades, Spain). *Quaternaire*, 24: 49-64. doi:10.4000/quaternaire.6481

Vaquero, M., Bargalló, A., Chacón, M.G., Romagnoli, F., & Sañudo, P. 2015, Lithic recycling in a Middle Paleolithic expedient context: evidence from the Abric Romaní (Capellades, Spain). *Quaternary International*, 361: 212-228. doi:10.1016/j.quaint.2014.05.055

Vaquero, M., Chacón, G., García-Antón, G., & Gómez De Soler, B. 2008, Variabilidad de los conjuntos en el Paleolítico Medio del Abric Romaní (Capellades, Barcelona). *Treballs d'Arqueologia*, 14: 195-212. (in Spanish) ("Variability of lithic assemblages in Middle Palaeolithic at Abric Romaní (Capellades, Barcelona)")

Villaverde, V., Eixea, A., Rios, J., & Zilhão, J. 2012, Importancia y valoración de la producción microlevallois en los niveles II y III del Abrigo de la Quebrada (Chelva, Valencia). *Zephyrus*, 70: 13-32. (in Spanish) ("The importance and valorisation of micro-Levallois production in layers II and III at Abrigo de la Quebrada")

Wallace, I.J., & Shea, J.J. 2006, Mobility patterns and core technologies in the Middle Paleolithic of the Levant. *Journal of Archaeological Science*, 33: 1293-1309. doi:10.1016/j.jas.2006.01.005