C. R. Palevol 16 (2017) 865–877

Contents lists available at ScienceDirect

Comptes Rendus Palevol

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Human Palaeontology and Prehistory

Exploring Neanderthal skills and lithic economy. The implication of a refitted Discoid reduction sequence reconstructed using 3D virtual analysis

Exploration des aptitudes et de l'économie lithique de l'homme de Néandertal. Implication d'une reconstitution de la séquence de réduction discoïde par utilisation de l'analyse virtuelle 3D

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ARTICLE INFO

Article history:
Received 12 February 2017
Accepted after revision 19 June 2017
Available online 31 August 2017

Presented by Marcel Otte

Keywords:
Knapped stone
3D visual technology
Refitting
Discoid technology
Neanderthal
Middle Paleolithic

Mots clés :
Pierre taillée
Technologie visuelle 3D
Reconstitution
Technologie discoïde
Néandertal
Paléolithique moyen

ABSTRACT

Lithic refitting studies have consistently contributed to address two specific research aims: the intra-site mobility and identification of preferential areas or latent structures, and the in-depth analysis of the knapping technologies and core reduction strategies. Multiple refits, in particular, can produce highly detailed data on knapped stone technology. Elucidating human skills and lithic economy, a potential still rarely evaluated for Discoid technology: a stone knapping method largely spread across the Middle Paleolithic of Europe. The opportunity to explore Neanderthal knapping behavior is provided from the remarkable discovery of a primary lithic waste concentration in the Mousterian Discoid level of the Grotta di Fumane, Italy, dated to at least 47.6 ky cal BP. With a combined approach that included the 3D virtual interaction, we were able to reproduce a complete reduction sequence that supports the technological analysis conducted on the lithic assemblage. Results lead to a better comprehension of the knapper's technological and technical behavior, including the detection and quantification of economic objectives and productivity.

RÉSUMÉ

Les études de reconstitution lithique ont considérablement contribué à la poursuite de deux objectifs de recherche: la mobilité intrasite et l'identification d'aires préférentielles ou de structures cachées et l'analyse en profondeur des techniques de taille et des stratégies de réduction de nucléus. Des reconstitutions multiples, en particulier, peuvent fournir des données très détaillées sur les techniques de taille des pierres. L'élucidation des aptitudes humaines et de l'économie lithique est un potentiel de ces méthodes encore rarement évalué dans la technologie discoïde: une méthode de façonnement de la pierre

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http://dx.doi.org/10.1016/j.crpv.2017.06.008

largement répandue au cours du Paléolithique moyen en Europe. L'opportunité d'explorer le comportement de taille de la pierre chez l'homme de Néandertal est fournie par la remarquable découverte d'une concentration de débris lithiques primaires dans le niveau discoïde moustérien de la grotte de Fumante, datant au moins de 47,6 ka cal BP. Une approche combinée incluant l'interaction virtuelle 3D nous a permis de reproduire une séquence compète de réduction, qui corrobore l'analyse technologique réalisée sur l'assemblage lithique. Les résultats obtenus conduisent à une meilleure compréhension du comportement technique et technologique du « tailleur de pierre », avec la détection et la quantification des objectifs économiques et de la productivité.

1. Introduction. Technological and behavioral contribution of lithic refitting; perspectives in the Middle Paleolithic of western Eurasia

Lithic tools and assemblages (the most common and preservable finds along the Paleolithic) have always been used to define culturally hunter-gatherer human groups and species. Within the Middle Paleolithic, in particular, the contrast between the apparent technical stability and the wide variety of tool sets and knapping methods attracted contributions from several scholars, each one with different analytical paths. Only in the last decades, the technological approach allowed us to investigate and understand in detail the behavioral strategies in terms of human adaptation (Bamforth and Bleed, 1997; Inizan et al., 1999; Nelson, 1991; Odell, 2001), especially when studies on knapped stones have been integrated with sourcing studies, refittings, use-wear traces, microresidue analysis, and taphonomy.

Refits in particular can produce highly detailed data on technological evolution, human skills, natural and cultural formation processes, lithic economy and human land use (Cziela et al., 1990; Delagnes & Ropars, 1996; Roebroeks, 1988; Skar & Coulson, 1986; Vaquero et al., 2007). In more recent years, the discovery of multiple refits in the European Middle Palaeolithic archaeological record has provided opportunities for direct comparison with analytic theories, also serving as a "control test" for the technological approach to the study of lithic assemblages. In this case, the use of mental refitting has thus made a fundamental contribution to the understanding of the technical gestures aiming to explore further their variability. Mental refittings should thus be confirmed if possible through real refittings, when extensive and complete, although this evidence rarely occurs and relates to specific events. Refittings may be equally useful in coming to an understanding of the more conceptual stages of flaking, such as, for example, the predetermination of flaking products. Thanks to these discoveries, it is also possible to ascertain the ramifications of the core reduction strategies, which in some cases intertwine with the exploitation of flake supports.

While, most of the refitting evidence concerns assemblages created using the Levallois method (Delagnes and Ropars, 1996; Roebroeks, 1988), a range of knapping methods were used by Neanderthals in Western Eurasia; one of the most intriguing is Discoid technology, which covers a wide range of cultural contexts (see Delagnes and Rendu, 2011; Peresani, 2003). Examples of multiple refits are rare within Discoid lithic assemblages (Carbonnel ed., 2012; Deschamps et al., 2016; Faivre, 2011; Locht & Swinnen, 1994), probably due to the spatial and temporal fragmentation that characterizes the operating chains of these industries (Turq et al., 2013), which in turn correlates to the economic behaviors that are expected of human groups with an elevated level of mobility (Delagnes and Rendu, 2011). Consistent with that observed for the Levallois, and even for the Discoid core itself, the technology provides a consistent source of first-choice products, which could be part of the toolkit of hunters aiming to maximize the potential utility-to-weight ratio.

The meaning of the word "discoid" has had a long metamorphosis from the tool to the core to the knapping method. The definition has been impacted by methodological and critical trends in lithic studies, from the typological to the technological approach, and finally experimental comparisons. In this manner, following the determination of some morpho-technical features of the cores, an elaboration of a series of technical criteria adhering to a flaking method has been determined (Boëda, 1993; Gouëdo, 1990). The new approach has made use of the analyses of noted archaeological collections, turning to the so-called mental refitting in order to reconstruct the volumetric design and architecture of core reduction. New light was shed on the method over the course the '90s and 2000. The variability of the technical criteria was better defined, leading to a more complete understanding of the complex dynamics that led to the formation of the archaeological lithic sets (Peresani (Ed.), 2003). An opportunity to explore this particular knapping technology is provided here from the remarkable discovery of a primary lithic waste concentration in the Mousterian Discoid assemblage of the Grotta di Fumane.

2. Materials and methods

2.1. The archeological context and the finding of the lithic concentration

Fumane cave is a south Alpine site well known for its Middle and Early Upper Palaeolithic sequence with Mousterian (units A11 to A5), Uluzzian (A4, A3) and Aurignacian levels (A2 to D1c) (Broglio et al., 2006; Obradović et al., 2015; Peresani, 2012; Peresani et al., 2008, 2016). Within the late Mousterian sequence, the unit A9, explored extensively in the last years, is an ensemble of thin levels and

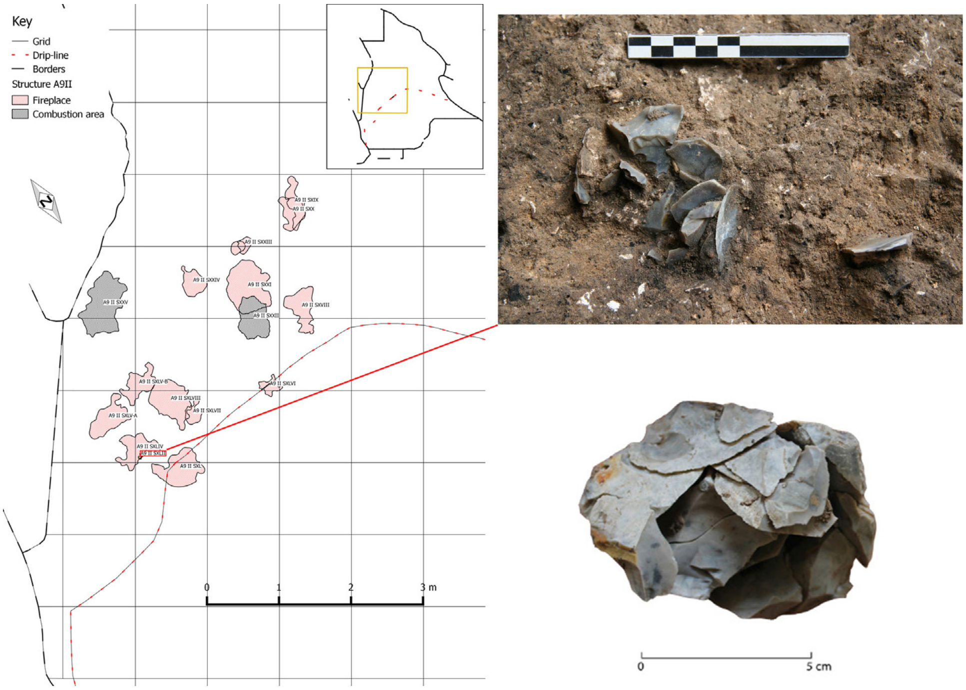

Fig. 1. The context of Structure A9II_SXLII. Left, map of the cave with position of the hearths and combustion areas discovered in layer A9II (drawing: E. Cocca); the position of structure A9II_SXLII is indicated. Top right, view of structure A9II_SXLII after its discovery and the partial removal of the first unearthed artifacts; bottom right, refitted flakes and core from the structure.

Fig. 1. Contexte de la structure A9II_SXLII. À gauche, carte de la grotte avec la position des foyers et des aires de combustion découvertes dans le niveau A9II (dessin : E. Cocca). La position de la structure A9II_SXLII est indiquée. En haut à droite, vue de la structure A9II_SXLII après sa découverte et le transfert partiel des premiers artefacts déterrés ; en bas à droite, écailles et nucleus reconstitués à partir de la structure.

lenses composed of frost-shattered breccia and Aeolian silt, diffused with sands and dark sediments because of intense anthropogenic accumulation. Thousands of knapped stones, micromammal, mammal, bird, bones (Fiore et al., 2016; López-García et al., 2015; Peresani et al., 2011; Romandini et al., 2014, 2016) human remains (Benazzi et al., 2014) and dwelling structures with hearths and toss-zones have been brought to light; currently, A9 has produced over 50 structures, mostly hearths, scattered at the cave entrance, with more in the western than in the eastern zone, in proximity to the present-day drip-line. The chronometric position of A9 is provided by only one reliable date among a few other measurements of 47.6–45.0 ky cal BP (Higham et al., 2009; Peresani et al., 2008).

A9 records the appearance of an exclusively Discoid industry sandwiched between two Levallois cultural units: A10 below and A6 above, with the sterile layer A7 in between (Peresani, 2012). The production system was structured in two reduction sequences, a main one and a secondary one, with the same shared goal of producing short, strong, and sometimes pointed implements, as evidenced by pseudo-Levallois points, backed flakes, and subcircular, quadrangular or triangular flakes (Peresani, 1998). The former system exploited blocks and nodules, whereas the latter, which was simpler and less productive, used flake-cores either originating from by-products (cortical flakes) or introduced directly onto the site. The cores began to yield usable blanks right from the initial steps, with the outline gradually changing from unidirectional to Discoid.

The 2012 archaeological campaign explored the western section of the atrial zone, which was limited to the west by the currently visible section at the entrance to gallery A. In proximity to this section, Unit A9II, a thin anthropogenic level containing lithic artifacts, bone, charcoal, and several combustion structures and overlying the A10 stratigraphic complex was removed. The density of the lithic artifacts in that area is two to three times higher than in the adjacent areas. No particular concentrations or preferential distributions of specific artifact categories were identified during excavation, with the exception of structure A9II_SXLII, a concentration of a dozen flakes in sq. 68 g (Fig. 1). Within the assemblage, which covered a few cm^2, the peripheral flakes sloped towards the center of the structure; some, especially those to the south, were nearly vertical, while those toward the east sloped to the west. This arrangement seems to be due to post-depositional deformation attributable to freezing-thawing mechanisms, but requires confirmation from soil-micromorphological analyses. The size of the artifacts, comparable with each other, the gray Maiolica flint and their state of conservation seem to indicate that the flakes originated from the same core, which was also recovered during the structure's excavation. Therefore, it was simple to refit the entire concentration to form a single reduction sequence. Among the flakes, small fragments and chunks made of the same grey flint, were found.

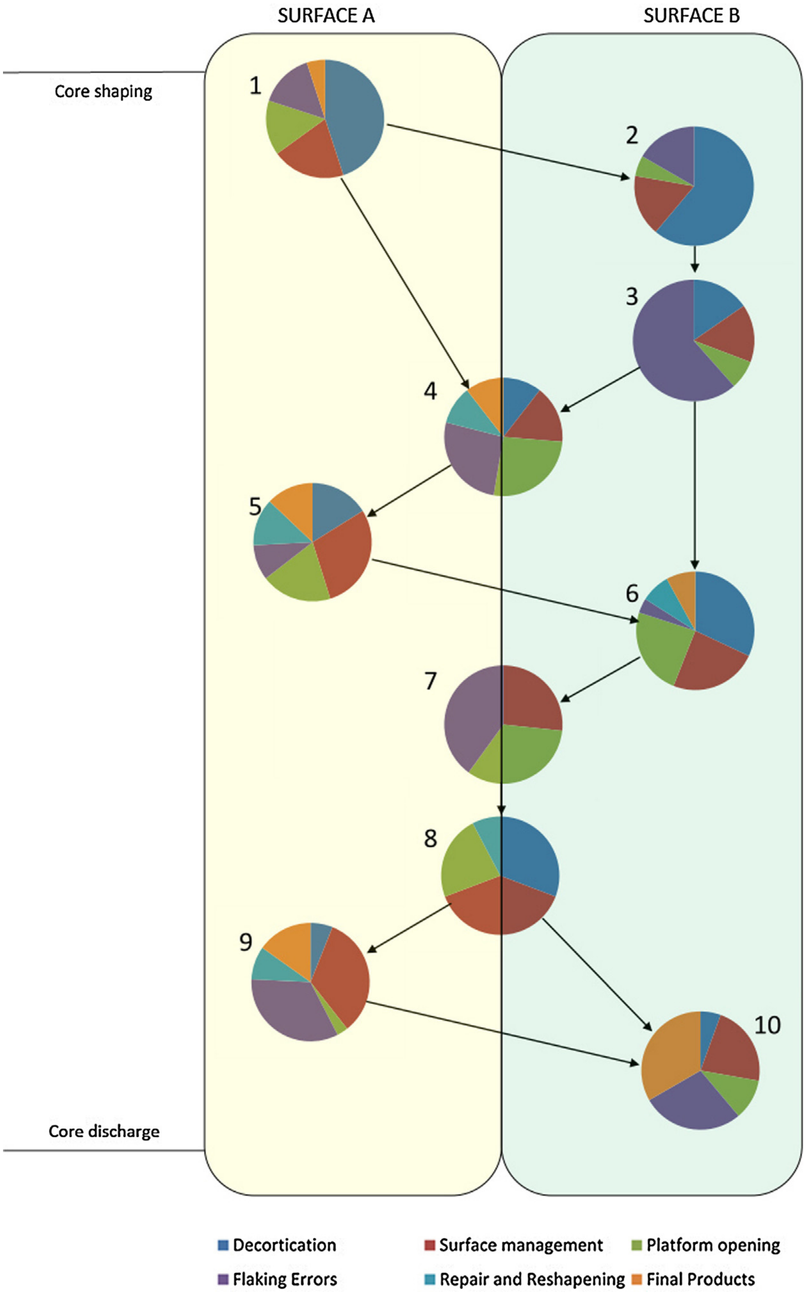

Fig. 2. The ten stages of the reduction sequence showing the exploited surface and the technical effects on the knapping economy.

Fig. 2. Les dix étapes de la séquence de réduction, montrant la surface exploitée et les effets techniques sur l'économie de la taille.

2.2. *Analytical methods: traditional and virtual approaches*

Refitting was performed primarily with the traditional method, reconstructing the sequence according to the direct consequential position determined by scars and negatives. However, problems soon arose due to the complexity of the task and the need for a punctual analysis. For these reasons, we tried a different approach obtaining three-dimensional templates of the artifacts, in order to be able of analyze them more easily on a virtual system. As previously established in papers on lithic technology and other disciplines within prehistoric archaeology (Bretzke & Conard, 2012; Clarkson & Hiscock, 2011; Lin et al., 2010; Richardson et al., 2013), the analysis of three-dimensional models can be used to obtain morphometric data that would be otherwise inaccessible with the traditional method. For lithic refitting, the analysis is focused

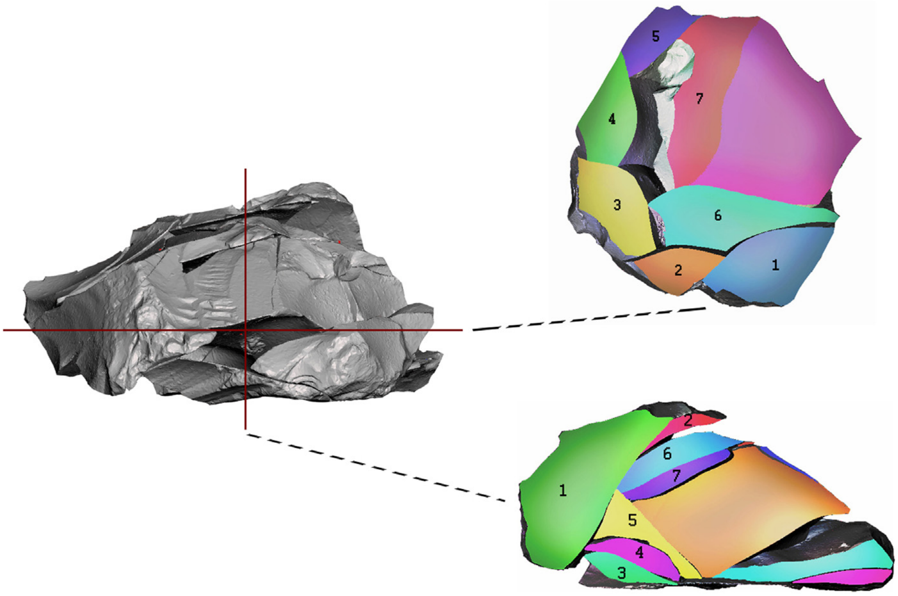

Fig. 3. Cross-sections of the refitted core: the upper one shows the progression of the core reduction viewed from the upper surface (surface A), with the detached flakes succession showing a turning exploitation pattern in a clockwise sense, strictly following the peripheral edge according to a discoid concept. The lower one shows the division between surfaces A and B, marked by the peripheral edge along which the production is organized.

Fig. 3. Coupes du nucleus reconstitué : la première montre la progression de la réduction du nucleus à partir de la surface (surface A), avec la succession d'éclats détachés montrant un patron d'exploitation tournant dans le sens des aiguilles d'une montre. La seconde coupe montre la division entre les surfaces A et B, marquée par le tranchant périphérique le long duquel la production est organisée.

on analyzing not only the pieces found but also to investigate the three-dimensional gaps produced by absent pieces. This method also allows the analysts to bypass preservation and handling issues through an ease of interaction that, in a space without gravity, removes real-world limitations (Gartski, 2016). To obtain the scans, we used a structured light scanner, Breuckmann SmartScan 3D, developed by AICON 3D systems, already performed with excellent results for prehistoric cave sites and artifacts (Breuckmann et al., 2009; Pastoors & Cantalejo, 2014; Pastoors & Weniger, 2011; Tusa et al., 2013), including lithic samples (Slizewski & Semal, 2009). Details on the instruments and the procedure used for achieving and elaborating the 3D images are presented in Delpiano et al. (2017), who have determined that the 3D approach is very useful to integrate the whole study (in these cases), but not to replace it entirely.

3. Results

3.1. Reconstruction of the reduction sequence

Thanks to this approach, it has been possible to analyze the *chaîne opératoire* in its entirety recognizing at least 64 detachments that have been set-up in time and space in a matrix. The reassembled flakes construct almost the original shape of the raw material pebble. Few missing artifacts indicate that the gray Maiolica flint cobble has been carried into the site intact or only partially tested after possible collecting in the streambed located a few hundred meters from the site.

The cobble was originally squared shape with smoothed edges and a pronounced convexity on one surface, which was considered appropriate for the application of the Discoid technology. The reduction sequence took place totally at the site as demonstrated from the artifacts produced during the first decortication stages up to the last phase of exploitation and the discard of the core. All the refitted pieces come from structure A9II_SXLII and we did not find any refitted element from other excavated areas.

The morphometric features of each detachment (measurements, edges, presence of cortex or hinged terminations) and the technological position along the reduction sequence frame a list of technical effects designed for each flake obtained. These include decortication, maintenance of knapping faces convexities, creation of the striking platform, mistake reparations and the achievement of the first choice artifacts. The reduction sequence has been partitioned into ten major stages each one featured from specific objectives and consequences and related to the core face exploited (Fig. 2).

The overall development in the core reduction can be seen from the dissection of the available refitted flakes (Fig. 3). The knapper worked out his task with a reduction in a clockwise sense (with a view from the surface A) alternating the production on the two knapping faces, reaching an almost complete 360° turn around the core and along the peripheral edge removing much of cortical surface. However, not every detachment strictly follows the previous one in this sense but many shifts or rotations are present; nevertheless, a global trend can be noticed.

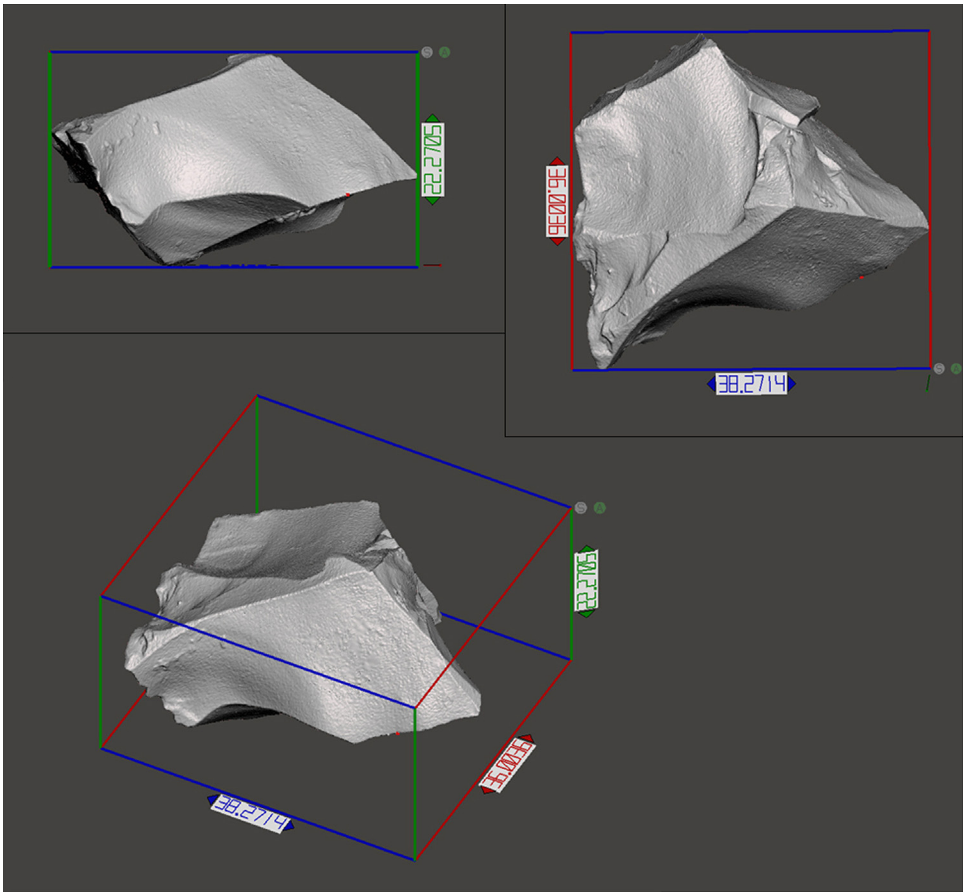

Fig. 4. Different views of the residual core with measurements (length, blue; width, red; thickness, green).

Fig. 4. Diverses vues du nucleus résiduel, avec ses mesures (longueur, bleue ; largeur, rouge, épaisseur, verte).

The refitted sequence is the expression of the knapper's decision to arrange the exploitation on two opposite, adjacent and secant faces from the earliest stage: the first blows (Stage 1) were designed to remove the cortex from face A, outline a peripheral edge following the natural block convexities and open a striking platform functional to the face B, exploited in the following stage (2). Therefore, the two faces maintain interchangeable roles. However, in these early stages face A appears much more convex than the almost flat face B.

Framed in this concept of non-hierarchical surfaces, the exploitation often insisted on the same striking platforms, wide and basically flat, that have been obtained by the detachment of large flakes mostly cortical and secant. The reduced preparation of the striking platform (a defining feature of Discoid knapping when compared with Levallois) is expressed by flat or convex butts and the platform left "brute", avoiding any further preparation. The impact points are systematically located on the proximal convex sides of each scar.

Though after the first phases of core design, the reduction proceeds within a fully Discoid concept, with the peripheral edge that is gradually exploited along its total extension by an apparently opportunistic production of secant flakes obtained through chordal or centripetal blows. However, almost all artifacts played the role of predeterminant products and of technical solutions aimed to maintain the central and peripheral convexities. Face B reveals a preferential exploitation: this side of the core is less convex than face A and was knapped for obtaining almost exclusively core-edge removal products, also with cortical back. This face was in fact intentionally worked along its peripheral edge for increasing the central convexity.

The key concepts remain unvaried across the sequence: blows are always practiced starting from the peripheral edge and never attest the intention to deviate from the exploitation of these knapping faces. Core size reduces but is unchanged in its features, being homothetic in accordance with the Boëda's design (2013). In other words, no evidence of a polyhedral tendency has been detected. When discarded, the core measured 38 × 36 × 22 mm (Fig. 4).

Several knapping accidents repeatedly affected and compromised the progress of the reduction sequence, especially in stages 3, 4, 7 and 9. These occurrences have been observed with more frequency on the same face, expressed in hinged fractures, overshoots or frequent

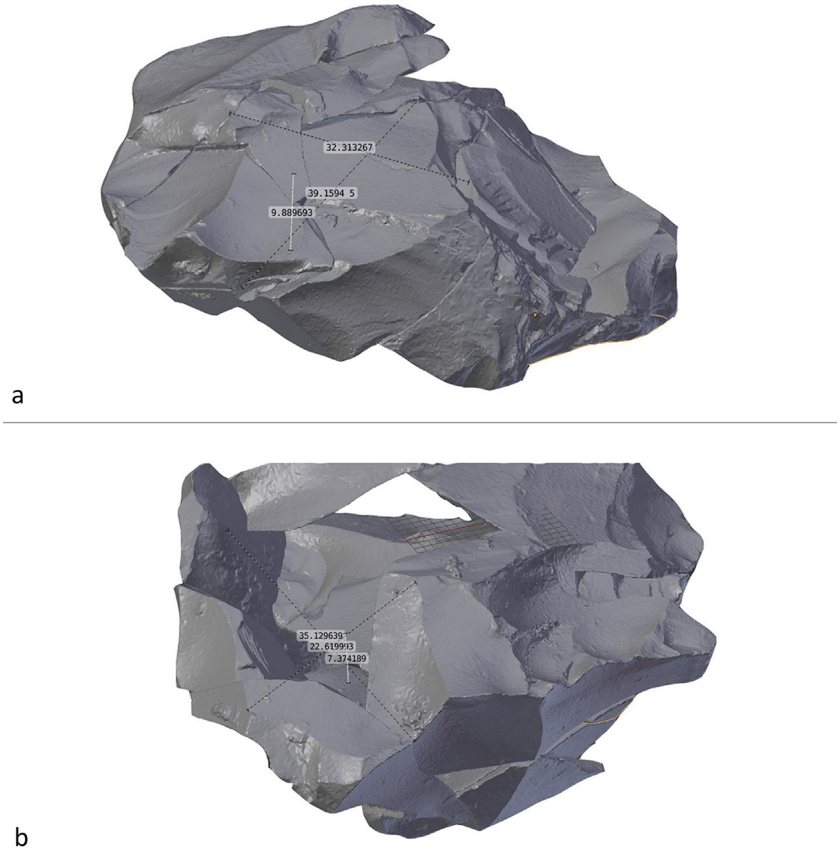

Fig. 5. 3D view and size of a flake, detached by a centripetal cortical blow from face A during stage 1 (a); 3D view and size of a centripetal flake, detached from face B during stage 5. It is probably one of the first fully usable products (b).

Fig. 5. Vue 3D et taille d'un l'éclat, détaché par un coup cortical centripète à partir de la face A pendant l'étape 1 (a) ; vue 3D et taille d'un éclat centripète n°11, détachée de la face B pendant l'étape 5. C'est probablement l'un des premiers produits qui soit complètement utilisable.

fragmentations due to reiterated blows on improperly prepared zones. This pattern denotes an odd and unexplainable insistence in working these areas and could be related to approximate preparation, poor accuracy and misapplication of the technical skills, if available. As a consequence, the knapper rearranged the core through reparatory flakes, which ablated and removed the errors following the same pattern and direction of the previous detachments.

Finally, it has to be noted that the first choice products were poorly represented in the refitted assemblage. This bias is a consequence of the using these products in the cave or in another site, with these tools subsequently lost. In this case, the three-dimensional approach provides clues for depicting and quantifying these missing artifacts.

Summarizing, flake scar patterns combined with the reduction development seen in the virtual model suggest that knapping was organized via unidirectional exploitation until stage 3. Later, until stage 5, the pattern shifted to bidirectional knapping: normally patterned by means of chordal and centripetal detachments, almost perpendicular to each other, which corresponds to the beginning of the core rotation along its peripheral edge. Finally, as the reduction advances, the multidirectional centripetal and convergent pattern reaches its full expression on both the core faces and knapping becomes more structured, completing the first turn of reduction around the core. At last, the final stages show another round of reduction, which produces the smallest amount of flakes making it hard to track a pattern. This exploitation arrangement creates the final classic Discoid core shape with bifacial exploitation.

3.2. *Missing pieces*

The missing flakes are non-uniformly distributed across the reduction sequence: selection increased gradually up to the end in relation to the full achievement of the technical objectives.

The major missing artifacts are estimated to number 14, derived especially from stages 1, 5, 6, 9 and 10. Decortication by-products (stage 1) of the core face A is missing, apart from the first one detached. These missing artifacts, obtained undoubtedly in situ, are four cortical flakes with natural or flat butt; only one of which was large (at least 40 × 30 mm) (Fig. 5a). These flakes may have been exploited as a core-on-flake or as a tool equipped with a sharp edge (18 mm long on the left side).

During stage 4, when decortication temporarily stops and the finishing of some peripheral convexities starts, some profitable artifacts were detached and selected. We

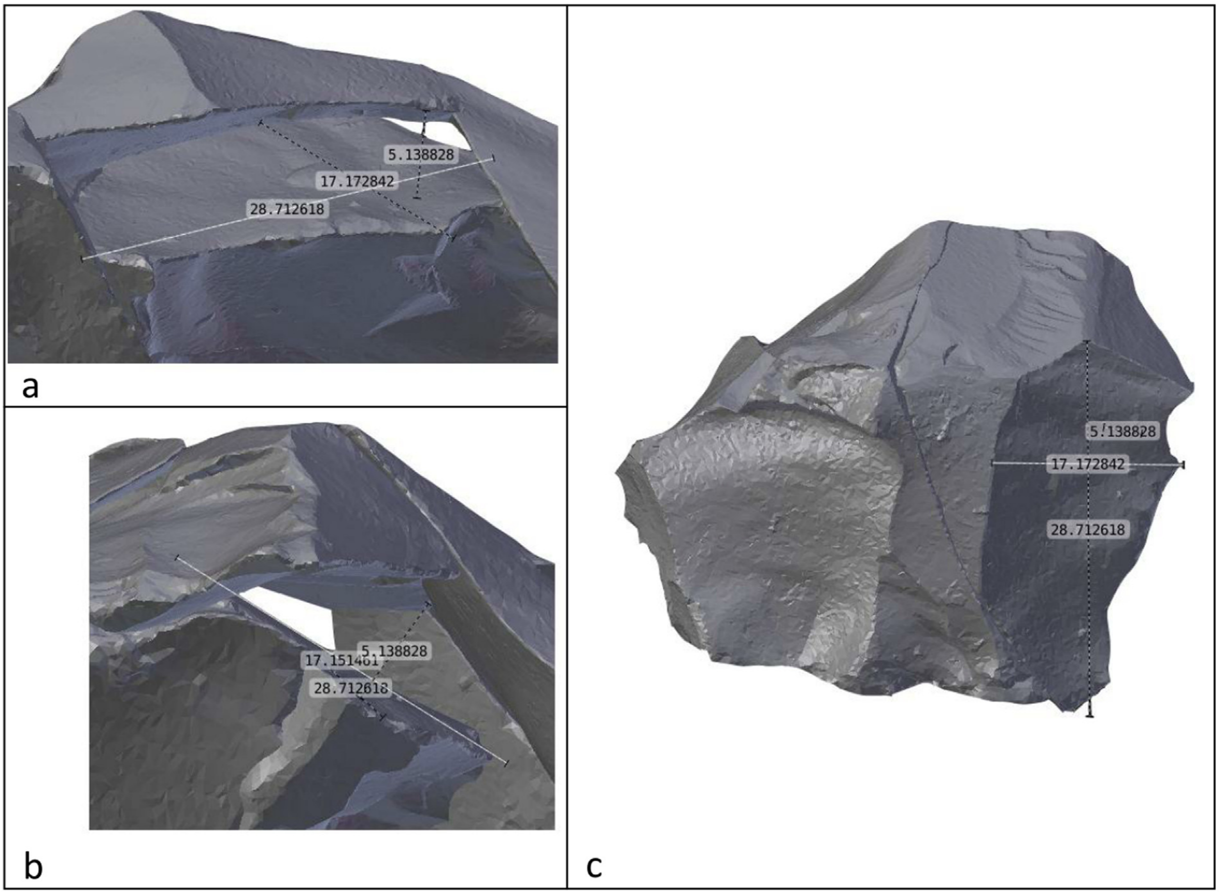

Fig. 6. 3D view and size of a flake, exposed from the right side (a), the impact point (b) and the top (c). This fine core-edge removal flake with right backed side opposite to left thin cutting edge is likely to be considered one of the best products obtained from face A during stage 9.

Fig. 6. Vue 3D et taille d'un éclat, exposé à partir du côté droit (a), du point d'impact (b) et du sommet (c). Le fin éclat d'arrachement à la bordure du nucleus, avec le côté arrière opposé au bord gauche de la coupe mince est probablement à considérer comme l'un des meilleurs produits obtenu à partir de la face A pendant l'étape 9.

identified a semi-cortical core-edge-removal flake issued from face B, short and thick in the proximal zone, although provided with a cutting edge on its right side. It also opened a striking platform that was intensively exploited shortly after, according to the concatenation of the two core faces.

In stage 5, the first fine Discoid products are mostly obtained from face A, which after the (unsuccessful) detachment of a pseudo-Levallois point, was deactivated. Knapping shifted to face B, already decorticated, and produced a fine flake through centripetal percussion (Fig. 5.b). It has an asymmetrical triangular section and an oval and elongated shape predetermined from the detachment of lateral flakes.

Stage 6 entails a few blows to face A following the detachment of a somewhat irregular centripetal flake from face B. In this and especially the following stages, fine artifacts were detached and selected, making the volumetric reconstruction tricky. The finest and most easily traceable is a core-edge removal flake with non-cortical left back and right cutting edge (Fig. 7a).

Stage 9 was targeted to achieve first choice products from face A by means of centripetal detachments, but also produced a large number of errors, then repaired. However, an oval flake was taken for its suitable shape. The last artifact of this stage is a core-edge-removal flake achieved by chordal percussion on face A and then picked up. This flake is regular and 5 mm thick, 28 × 17 mm large and equipped with a convex left cutting (30–40°) edge at least 25 mm long (Fig. 6). It certainly represents the most successful product up to this stage of the sequence.

Finally, stage 10 entails the last two detachments on face B before the core is depleted by the last refitted element, which was discarded. The first artifact (Fig. 7b) is a 35 × 26 mm large core-edge removal flake with sharp (45°) and straight left edge. The right back is convex due to previous detachments. The second flake (Fig. 7c) is cross-oriented to the first and overpasses the core-edge. It has a right knapped back, and a left thin and long (28 mm) edge. For this highly functional *trenchant*, it was selected.

3.3. Productivity

The productivity rate of the complete sequence remains low. Based essentially on the 3D morphology, it seems that only six or seven gestures might have produced usable blanks: four are finely shaped core-edge removal flakes

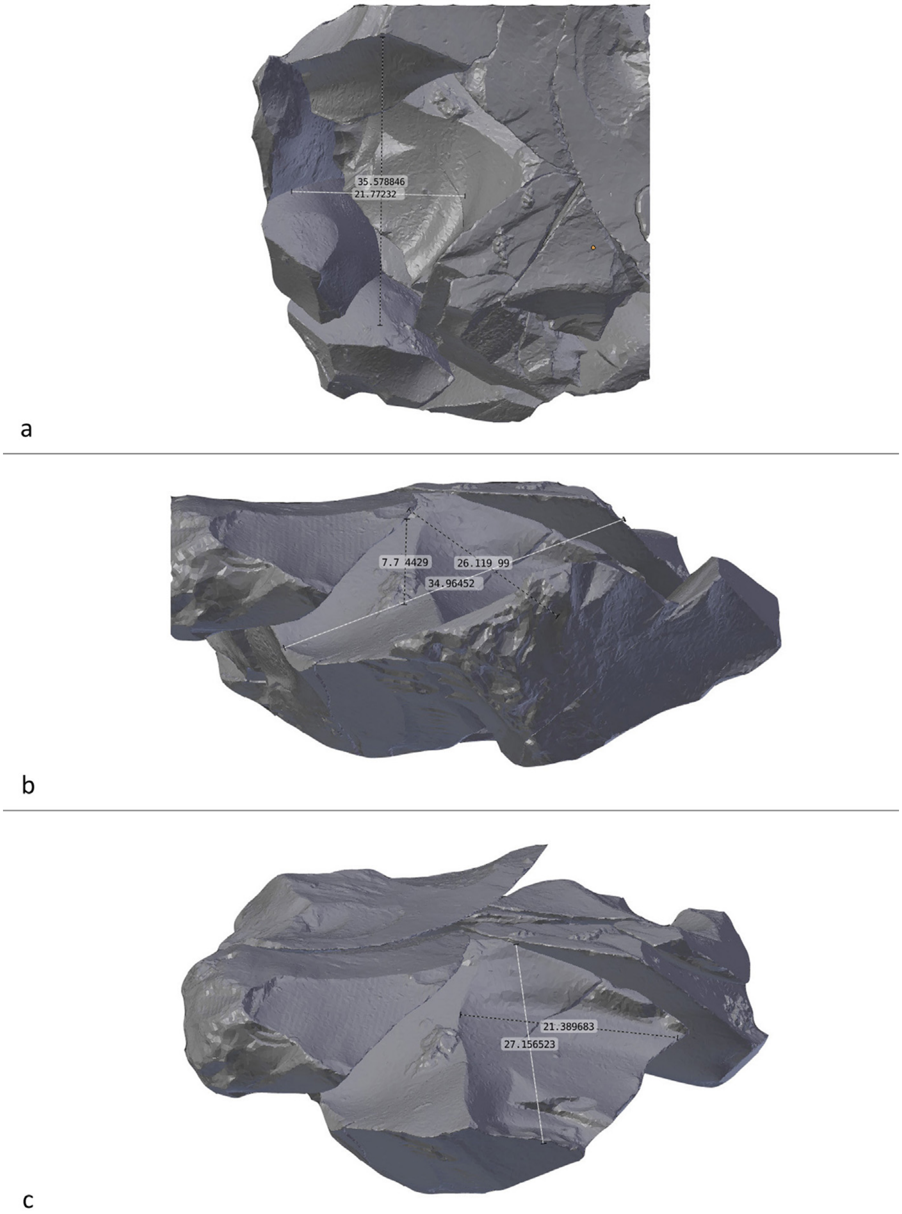

Fig. 7. 3D view and 2D size of a core-edge removal blow with left knapped back and right cutting edge detached from face A during stage 6. It represents one of the best products achieved and presumably used (a); 3D view and size of a core-edge removal blow with sharp left margin obtained from face B during stage 10 (b); 3D view and 2D size of a core-edge removal blow with right back opposed to left sharp edge, obtained from face B during stage 10 (c).
Fig. 7. Vue 3D et taille 2D d'un coup d'arrachement au bord du nucleus, avec un arrière gauche façonné et un bord de coupe droit détaché de la face A pendant l'étape 6. Ceci représente l'un des meilleurs produits achevé et sans doute utilisé (a) ; vue 3D et taille d'un coup d'arrachement en bordure du nucleus, avec une marge gauche tranchante, obtenue à partir de la face B pendant l'étape 10 (b) ; vue 3D et taille 2D d'un coup d'arrachement en bordure du nucleus, avec un arrière droit opposé au bord gauche tranchant obtenu à partir de la face B pendant l'étape 10 (c).

with knapped backs opposed to sharp and convex cutting edges and two are centripetal oval or quadrangular shaped flakes with single or double thin edge. Finally, a thick cortical centripetal flake seems to be the only blank suitable as a core-on-flake for the secondary reduction sequence. Experimental comparisons on Discoid technology testified to an average of seven pseudo-Levallois points obtained from each bifacially knapped core (Bourguignon et al., 2011; Brenet et al., 2009); however, these tools did not appear to have been the main objective of A9II_SXLII sequence: only one point was obtained and discarded *in situ*.

Comparing the productivity of the entire A9 lithic industry made on Maiolica flint to the refitting experiment (Table 1) found that at least 30 products (4 cm length + width) were issued from the reduction sequence of A9_SXLII, while the techno-economic structure of the A9 Maiolica industry records an average of 35 artifacts per core on block (therefore excluding the cores-on-flakes).

Table 1
Flake-per-core productivity recorded for the whole A9 lithic assemblage on Maiolica flint compared to the reconstructed reduction sequence of A9I_SXLII.
Tableau 1
Productivité en éclat par nucleus, pour l'ensemble de l'assemblage lithique A9 sur le flint Maiolica, comparée à la chaîne opératoire reconstituée de A9I_SXLII.

	A9 Maiolica assemblage	Reconstructed *chaîne opératoire*
Cores (*n*)	102	1
Total flakes mod > 4 cm (*n*)	3528	30
Flakes per core	35	30
Flakes with cortex	1704 (48%)	21 (70%)

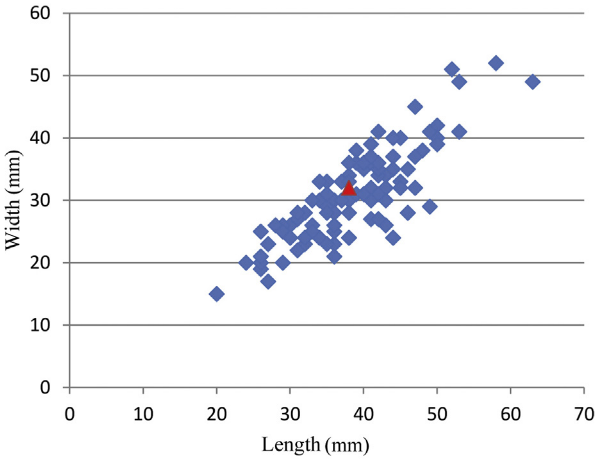

Fig. 8. Distribution of Maiolica Discoid cores sizes compared to the core of structure A9_SXLII (red triangle).
Fig. 8. Distribution des tailles de nucleus discoïdes, comparés au nucleus de la structure A9_SXLII (triangle rouge).

This data remains analogue even if we consider the fragmented, reused, or recycled flakes (Peresani et al., 2015). The A9_SXLII reduction sequence, however, displays a high rate of corticated products: 70% as compared to about 50% of the whole lithic assemblage. This data is related to the bifacial variant of exploitation and to decisions based on knapping design that led the core to maintain cortical portions until its discard. Overall, the frequency of the techno-typological categories of A9_SXLII suggests that this production is fully comparable to the A9 lithic industry (Table 2). In addition, the A9_SXLII core has been discarded at a degree of reduction on line with the cores from A9 (Fig. 8).

The only discrepancies concern the centripetal flakes, which are quite rare in A9_SXLII, probably a consequence of misshapen core convexities or flaking mistakes created when the knapper wanted to make these blanks: errors (and reparations) are in fact higher than the average in A9. The same holds for the cortical backed flakes: we consider that this data could be affected by the strong incidence of these products on the early stages of decortication of face B. As already mentioned, this surface initially appears much flatter, requiring intense knapping on the peripheral edge for shaping the central convexity. As shown by the evolution of the core shape (Fig. 9), the convexity of face B develops throughout the reduction sequence from the onset to deactivation. In accordance with the concatenated exploitation of the surfaces, the need to raise the peripheral edge can be ascribed to the opportunity to exploit non-hierarchical core faces in a coherently Discoid way by also taking advantage of the variability of the method. The preferential exploitation of face B may have been designed to exploit the block in a more flexible and less constricted way by bifacially knapping it. This type of production appears therefore directly related to the applicability and efficiency of Discoid method.

In conclusion, productivity for the Discoid method is not inherently low but it requires high technological investment aimed to maximize flake production on both faces. The core is modified to yield a recurrent series of first choice artifacts. The reality of this method however, is that it can lead to more mistakes and bad technical choices, which bring down the productivity.

4. Discussion and conclusion

The refitting technique is made here more accurate by the use of the 3D analytical method and virtual support (Delpiano et al., 2017). This methodological approach, used here for the first time for tackling questions of preservation and handling of a complex multiple refitting, turned out to be a significant analytical tool, to be queried and exploited, adding to the traditional analyses. This method adds a high levels of confidence thanks to its reality of representation and permits researchers to enter absolute and precise morphometric features that would be otherwise inaccessible (cross-sections, volumes) making it an innovative tool with high potential when associated with natural-scale observations, especially in circumstances like these, where multiple artifacts are involved.

Table 2
Incidence of the morpho-technical categories of the A9 lithic assemblage computed on Maiolica flint and compared to the reconstructed sequence.
Tableau 2
Incidence des catégories morpho-techniques de l'assemblage lithique A9 informatisées sur le flint Maiolica et comparées à la chaîne opératoire reconstituée.

	A9 Maiolica assemblage	Reconstructed *chaîne opératoire*	S.A	S.B
Cortical flakes	1437 (40.3%)	11 (36.7%)	7	4
Cortical backed	267 (7.5%)	6 (20.0%)	2	4
Backed (no cortex)	505 (14.1%)	4 (13.3%)	2	2
Centripetal	464 (13.0%)	2 (6.7%)	1	1
Errors/repair	357 (10.0%)	4 (13.3%)	3	1
Other	431 (12.1%)	1 (3.3%)	1	0

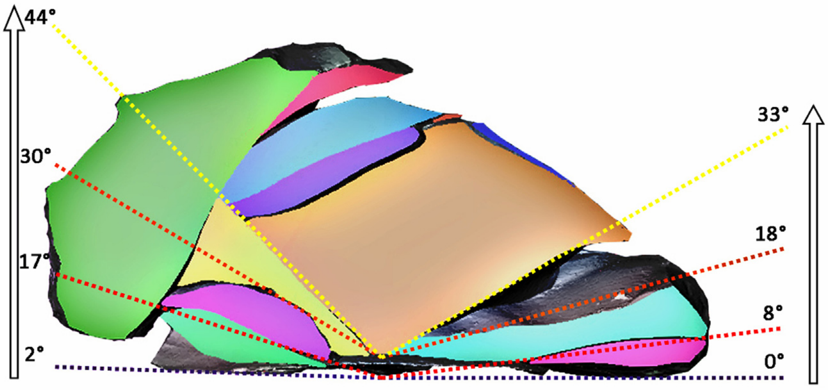

Fig. 9. Progressive evolution of the core shape. A gradual increase of the central convexity is clearly evident for face B.

Fig. 9. Évolution progressive de la forme du nucleus. Une augmentation graduelle de la convexité centrale est tout à fait évidente sur la face B.

Therefore, this analysis allowed us to better explore the informative potential of multiple refitting techniques, to learn about Neanderthal behavioral economy, knapping skills and theoretical and practical concepts.

All of the steps of the reduction sequence from initialization until discard took place in minutes on site, possibly in the zone where structure A9_SXLII has been unearthed. This type of economic behavior fits with data collected from the techno-economic analysis of the local knappable rocks exploited, especially the Cretaceous flint from Maiolica limestones, which was not subjected to any fragmentation of the reduction sequence (Delpiano, 2014).

It should also be emphasized that the refitting does not entail artifacts collected in the surrounding of structure A9II_SXLII; furthermore, the structure contains equally large products and debris. Given this spatially limited scatter, it cannot be excluded that the cobble was knapped on a skin then cleaned and freed of un-useful flakes in place. Furthermore, the elevated density of artifacts in this zone of the cave could be connected to a possible garbage zone, in proximity of the fireplaces and of other knapping zones under the rock shelter (Fig. 1).

Further, we have determined that the knapper's technical criteria and the reduction concepts are fully compatible with Discoid technology: the arrangement of the knapping operations based on two opposed, convex and not hierarchic core faces is set up already after their decortications. These surfaces, moreover, are separated by a peripheral edge that shows a convexity along which the core is exploited, through a turning and complete modality, with secant and steeped detachments.

These technical issues reflect the main Discoid operational chain recognized in the A9 lithic assemblage in a previous, pioneer study (Peresani, 1998). The A9_SXLII reduction sequence is, indeed, a confirmation to this sense and points out the reliability of the technological analysis based on mental refitting, a useful tool for increasing awareness of the method's rules, here followed in a rigid, "manual" way. However, given its uniqueness, the A9_SXLII sequence does not reveal the ample variability envisaged on several levels across this technological procedure. The ramification of the production in two juxtaposed operational chains, for example, is not documented here but is certainly present in A9 unit; on the contrary, the notable refits from the French site of Les Fieux record the flexibility of the Discoid method in which the objectives, represented by core-edge-removal flakes and pseudo-Levallois points, remain almost the same (Faivre, 2011; Turq et al., 2013). In our case, however, the possibility that some cortical flakes (we assumed one) were exploited for the secondary reduction sequence cannot be excluded. Flexibility in Discoid knapping may also lead the core to maintain the original shape of the cobble, where asymmetric convexities make the core comparable to a Levallois volume exploited by a preferential or centripetal pattern. This is the case at Abric Romaní, layer J (Carbonnel (Ed.), 2012), but it has not been observed at Fumane.

Knapping at structure A9_SXLII was also affected by careless technical gestures that are at odds with clear technical know-how. The virtual reconstruction allowed us to unravel an evident behavior: the knapper wanted to adapt the cobble morphology for technological purposes aimed at diversifying the production, probably in order to maximize knapping and make it more flexible and versatile. These actions are reflected in the specialized exploitation (mostly chordal) of the face B that results in an increased central convexity, shaping the discoidal core. Little attention is paid to the gestures that seem typical of less experienced individuals, but instead the knapper seems fully aware of the Discoid concept design and planning depth, so indicative of the work of a "master." Thence, the whole sequence may be an example of cultural transmission. Know-how is transmitted through a pedagogical behavior in a society that uses quite complex technologies to design tool. Discoid technology, in its basic criteria, remained unchanged over long periods and great distances. It is unlikely that the know-how was transmitted only by emulation, imitation or using so-called procedural memory, where a lack of comprehension of the gestures quickly gave rise to spatiotemporal changes, but it is far more likely that a real teaching and learning system could exist (Tehrani and Riede, 2008). However, in the whole Middle Palaeolithic there is an absence of spatial knapping clusters in the archaeological record that might suggest that teachers were involved. In this case, this argument is supported only by the contrast between theoretical knowledge and knowledge put into practice. Actually, we know that the economic objectives were at least partially achieved, thanks to the production and probable utilization of four core-edge-removal flakes and two centripetal flakes. Comparing to the results of an experimental study designed to quantify the Discoid productivity on the base of the knapper's expertise (Brenet et al., 2013), we observed that our example is halfway between skilled and low experienced individuals. In addition, in this particular case, the educational purpose of a knapping product made, finished, and discarded in situ (also with excellent knappable stones) appears much higher than the supposed economic purpose, weakly documented (Pigeot, 1990); another point in favor of the teacher/learner hypothesis.

Refittings like that one achieved from this specific context confirm once again their utility in providing data concerned with different field of investigation, cultural, behavioral, taphonomic and methodological. Widely known to be time-consuming, this practice should be more implemented by using 3D imaging technology in order to facilitate the search of virtual refits and large-scale connections also of materials different than stone in the archaeological records.

Acknowledgments

Research at Fumane is coordinated by the Ferrara University in the framework of a project supported by the Ministry of Culture–Veneto Archaeological Superintendency, public institutions (Lessinia Mountain Community–Regional Natural Park, Fumane Municipality) and private associations and companies. The Breuckmann SmartScan 3D used for this work is based at the Neanderthal Museum in Mettmann (Germany). The authors thank Kristen Heasley for the translation and Jamie Hodgkins for the revision of the English text and two anonymous reviewers for providing contribution to considerably ameliorating the manuscript.

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