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ORIGINAL PAPER

Flexibility within Quina lithic production systems and tool-use in Northern Italy: implications on Neanderthal behavior and ecology during early MIS 4

Davide Delpiano[1] · Andrea Zupancich[2,3] · Stefano Bertola[1] · Eva Francesca Martellotta[1,4] · Alessandra Livraghi[1,5] · Emanuela Cristiani[2] · Marco Peresani[1,6]

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Abstract

The Quina Mousterian is one of the well-defined Middle Paleolithic techno-complexes. Despite the pivotal research carried out in south-western France, the presence of this techno-complex across the rest of Europe is still poorly documented. Here we apply a techno-functional approach, combining technological and use-wear analyses, for reconstructing lithic core-reduction, tool-reduction, and tool use at De Nadale Cave, a single-layered Mousterian site with Quina features located in northern Italy and dated to the early MIS 4. Our results indicate that the flexible core reduction strategies identified at De Nadale show some similarities with the Quina knapping method, in addition to the adoption of centripetal methods on single surfaces. Variations of this scheme identified at De Nadale are the exploitation of lateral and narrow fronts which are aimed to the production of elongated, small blanks. A parallel, ramified reduction is applied to *limace* cores and Quina or demi-Quina scrapers having diversified purpose (mixed matrix). These blanks are exploited as tools and cores-on-flakes from which thinner, usable flakes or bladelets are detached. The use-wear identified on both scrapers and *reaffutage* flakes further confirm this behavior, demonstrating the use of both tools, albeit for different tasks (i.e., scraping and cutting). We discuss the ecological implications of this behavior within the Quina Mousterian. The high frequency of retouched tools and Quina or demi-Quina scrapers seems to accompany the highly mobile human groups associated with this techno complex and their seasonally organized subsistence strategies. Finally, by combining available multidisciplinary data on paleoenvironment, subsistence, and chronology, we were able to embed the neanderthal settlement of De Nadale in a regional and Western European frame, underlining the importance of the Quina Mousterian in Western Eurasia between MIS 4 and early MIS 3.

Keywords Lithic technology · Use-wear analysis · Quina scraper · Neanderthal behavior · Human ecology · Mousterian

✉ Davide Delpiano
davide.delpiano@unife.it

1 Dipartimento Di Studi Umanistici, Sezione Di Scienze Preistoriche E Antropologiche, Università Degli Studi Di Ferrara, Corso Ercole I d'Este, 32, 44121 Ferrara, Italy

2 DANTE - Diet and ANcient TEchnology Laboratory, Dipartimento di Scienze Odontostomatologiche e Maxillo Facciali, Università di Roma - La Sapienza, Via Caserta 6, 00161 Roma, Italy

3 Institución Milá Y Fontanals, Consejo Superior de Investigaciones Científicas (IMF-CSIC), Barcelona, Spain

4 Australian Research for Human Evolution, School of Environment and Science, Griffith University, 170 Kessels Road, Nathan, QLD 4111, Australia

5 Departament d'Història i Història de l'Art, Universitat Rovira I Virgili (URV), Avinguda de Catalunya 35, 43002 Tarragona, Spain

6 Istituto di Geologia Ambientale e Geoingegneria, Consiglio Nazionale delle Ricerche, Piazza della Scienza 1, 20126 Milano, Italy

Introduction

The debate around Neanderthal cultural and behavioral expressions received constant attention from Paleolithic archeologists since the second half of the XXth century. Thanks to the continued renewals arose by the diverse methodological and epistemological approaches utilized over the decades, this topic resulted in multiple interpretative theories (Binford and Binford 1969; Bordes and De Sonneville-Bordes 1970; Dibble 1987; Mellars 1965; Rolland 1981). Whichever approach is preferred, the entire dispute is based on the recognition, before the interpretation, of the ensembles of techno-cultural features named with expressions which have entered by right the accustomed vocabulary of specialized scholars. Among these, the Quina labeling properly summarizes the historiographical misunderstandings derived from the different and subsequent lines of research on lithic assemblages. Born from the eponymous site of La Quina (Dordogne, France), the meaning of this term was initially referred to the identification of a Mousterian Facies in the "sensu *Bordes*," specific of the Charentian, characterized by the high frequency of retouched tools, absence of Levallois "technique," and presence of transverse scrapers with scaled and deep retouch (Quina-type scrapers) (Bordes 1984; Bordes and Bourgon 1951). Over the last quarter century, the technological approach concurred to refresh the definition of the Quina complex on a technological base. The result was the identification of a specific volumetric design of cores clearly distinguishable from the most commonly used during the Middle Paleolithic. According to A. Turq (1992) and L. Bourguignon (1997), the Quina was a very distinct and flexible techno-economic concept.

The flexibility of the Quina system is expressed by the variability of the reduction strategies, applied to a wide set of blanks. Core-reduction strategies have been analyzed in depth after reference works mainly addressed to South-Western France archeology. Overall, these papers have pointed out the low degree of core preparation, the alternated and concatenated production on sub-parallel and secant surfaces, and the volumetric optimization through invasive detachments (Bourguignon 1997; Turq 1992, 1989). In addition to this, a notable feature of the Quina system is the flake-oriented reduction strategy: The Quina flake, thick, asymmetric, and often characterized by a thick natural edge, represents the most suitable mobile blank, since it can support repeated stages of reuse and recycle. This potentially long-life perspective usually leads to the manufacture of the so-called Quina scraper. This tool normally provides evidence of long and complex biographies, thus being at the same time a possible volume of material from which to detach flakes, according to a branching concept (*ramification* s.l.) (Bourguignon 2001; Bourguignon et al. 2004; Cuartero et al. 2015; Faivre et al. 2017; Hiscock et al. 2009; Meignen 1988; Rios-Garaizar et al. 2015). Use-wear analysis on retouch flakes strengthens this hypothesis, since it attests direct utilization for animal butchering (Claud et al. 2012). As an alternative to the Quina cores, the Quina scraper can be furtherly reduced through bifacial retouching, bulb thinning, and triangular shaping at the end of its exploitation (Bourguignon 2001, 1997; Lemorini et al. 2016). These different aspects recall the reduction concepts of the Middle Paleolithic bifacial tools, which were possibly strategical elements that fulfilled the requirements of potentially high mobile systems (Delpiano and Uthmeier 2020; Soressi 2002).

Following the dualism derived by the apparently "expedient" core-reduction and, on the other hand, by the remarkable tool curation, one of the diagnostic elements of Quina assemblages and tools is the "Quina retouch," a scaled and invasive retouching procedure performed with soft-hammers such as bone, wood, or antler tools (Blasco et al. 2013; Bourguignon 2001; Jéquier et al. 2012; Martellotta et al. 2021, 2020; Mozota 2015). Retouch scars commonly present hinged or stepped terminations and, due to the numerous retouching phases, they concur to shape the typical concave-convex delineation in cross-section (Bourguignon 1997; Lemorini et al. 2016). Because of its peculiar geometry, this working could represent more than a simple edge retouching, thus implying the shaping and re-shaping of a typical techno-functional unit on thick blanks (Meignen 1988; Turq 1989). This was useful for a wide range of activities, from processing animal carcasses to working vegetal resources, animal hide, or bone (Bourguignon et al. 2004; Claud et al. 2012; Lemorini et al. 2016; Zupancich et al. 2016). The Quina concept of the functional edge applies to different raw blanks and materials, for instance, the case of the widespread exploitation of *Callista chione* shells in southern Europe for the manufacturing of retouched tools, whose potential use is similar to the Quina scrapers (Romagnoli et al. 2017, 2016).

Overall, despite its variability, the Quina techno-economical system correlates to intense human mobility, likely in situations lacking natural resources? Faunal assemblages are mainly mono-specific, suggesting that subsistence was mostly based on the exploitation of migratory and gregarious species such as reindeers and bisons, as Strontium isotope analyses attest as well (Britton et al. 2011). The necessary planning of subsistence activities also results in the organization of settlements, structured in specialized kill sites in the surroundings of the main camp site (Costamagno et al. 2006; Delagnes and Rendu 2011; Discamps et al. 2011; Meignen et al. 2009; Rendu et al. 2012; Rios-Garaizar and Garcia-Moreno 2015).

According to the above assumption, the emergence and the disappearance of the Quina complex might be related to climatic fluctuations. The latter would have directly caused variations in the biomass, therefore forcing the Neanderthals to adapt exploiting large herbivores rather than other prey. Apparently, the Quina blank, with its potential use, and the curation of the mobile tool kit would derive from these needs. As a matter of fact, both these elements show strong propensities towards adaptive versatility, which is expressed throughout the reduction sequences development and the extended portability of the blanks. Yet, the economic value of the Quina blanks is a distinctive parameter that must have acted as a main objective. Therefore, the interpretation of the emergence and diffusion of the Quina concept must not ignore the close relationship between the targeted blank and its high reuse potential, a distinctive feature which reflect the needs of the human group that conceived and manufactured it. In turn, the archeological data must take in account the broad techno-economic variables that may affect the quantitative representation of the operational chain on site. In fact, Mousterian reduction sequences are more or less intensely fractionated in a spatial and geographical way, according to different behavioral and mobility strategies (Turq et al. 2013). Quina Mousterian is no exception, often bearing witness of tools brought from long distances, as direct evidence of high mobility of human groups and raw materials (Turq et al. 2017).

From a global perspective, could this mobility have enhanced the spreading of the Quina concept? A certain geographical and chronological consistence confines most of the Quina assemblages in Western Europe between MIS 4 and the beginning of MIS 3 (Frouin et al. 2017b, a; Jaubert et al. 2011; Lahaye and Guérin 2016; Monnier and Missal 2014; Richter et al. 2013), with some studies which tend to frame them in MIS 3, especially in Aquitaine region (Guibert et al. 2008) and in Cantabria region (Rios-Garaizar 2017). However, in its wider sense, the first attestations of Quina retouch date back to MIS 11 in the Levant, where it has its roots in the Amudian and especially the Yabrudian contexts (Barkai and Gopher 2013; Parush et al., 2016); in Europe, proto-Quina complexes have been associated to MIS 9 (Delpech et al. 1995) or even more ancient contexts (Rose 1992), historically interpreted as "Tayacian" or "Clactonian." Between MIS 9 and MIS 7, the Quina method has also been identified along with Levallois, bifacial and other technologies in South-Western France (Bourguignon et al. 2008), South-Eastern France (Carmignani et al. 2017), and the Balkans (Mihailović et al. 2022). But what are the differences and modalities of the spreading and the adoption of the Quina concept? Could it have represented a culturally homogeneous complex? Or conversely, did substantial differences accompany the spread of classical Quina? It is well established that some techno-cultural aspects might have been transmitted within these highly mobile complexes, such as shell technology in Southern Europe (Romagnoli et al. 2016).

This paper presents an extensive study of a MIS 4 lithic assemblage with Quina features located in the Berici Hills in the North of Italy, an important refuge area that may have been the scene of cultures and techno-behavioral features crossing and diffusion during the cooling episodes of the Pleistocene, when the Po Plain much extended southwards thus favoring the connections between continental Italy and the Western Balkans. In this area, we are currently investigating Grotta De Nadale, a small cavity settled during MIS 4 by the makers of the lithic industry that we analyzed to reconstruct core reduction, tool reduction, and tool use with the aim of exploring the Quina Neanderthal behavior. The presentation of the lithic assemblage and the use-wear on a sample of Quina scrapers and *reaffutage* elements is followed by a discussion of the prerogatives implied by the Quina system, such as productive flexibility and potential of portability. The atypical features of the analyzed assemblage are also presented and discussed, with the final aim of sequencing lithic techno-complexes on a macro-regional scale.

De Nadale Cave: geographical and chronological setting

De Nadale cave (45° 25′ 16″ N; 11° 29′ 22″ E) is located in the Southern slope of the Berici Hills, a karst plateau situated halfway between two similar formations, the Lessini Mounts and the Euganean Hills. The Berici Hills have been intensively archeologically investigated over the half century, as they turned out to be extremely rich in evidence dating back to the Middle Paleolithic. In fact, over 20 open-air sites, caves, or shelters have been discovered (Fig. 1) (Bertola and Peresani 2000; Duches and Peresani 2009; Fiore et al. 2004; Leonardi and Broglio 1962; Peresani 2015, 2001), with additional sites and findings in the Euganean Hills (Duches et al. 2008; Peresani 2013; Peresani and Perrone 1999). Caves and shelters are exclusively set along the eastern side of the Berici Hills, where Broion Cave, Broion rockshelter, Paina Cave, Col de la Stria Cave, and San Bernardino Caves lie (Fig. 1). Apparently, it was the Levallois knapping method that dominated the lithic industries founded at all these sites (Peresani 1995–96; Peresani and Porraz 2004; Picin et al. 2013). Nonetheless, the technological and typological features of De Nadale lithic assemblage showed marked differences with the Mousterian of the rest of northern Italy.

De Nadale Cave is a small cavity developed in Eocene limestones that lie at 80 m a.s.l., overlooking the narrow Calto valley, a lower area rich in springs. Eight excavation campaigns—carried out from 2014 until 2021—exposed a short stratigraphic sequence, including one single Mousterian layer (unit 7) embedded between sterile levels (units 6

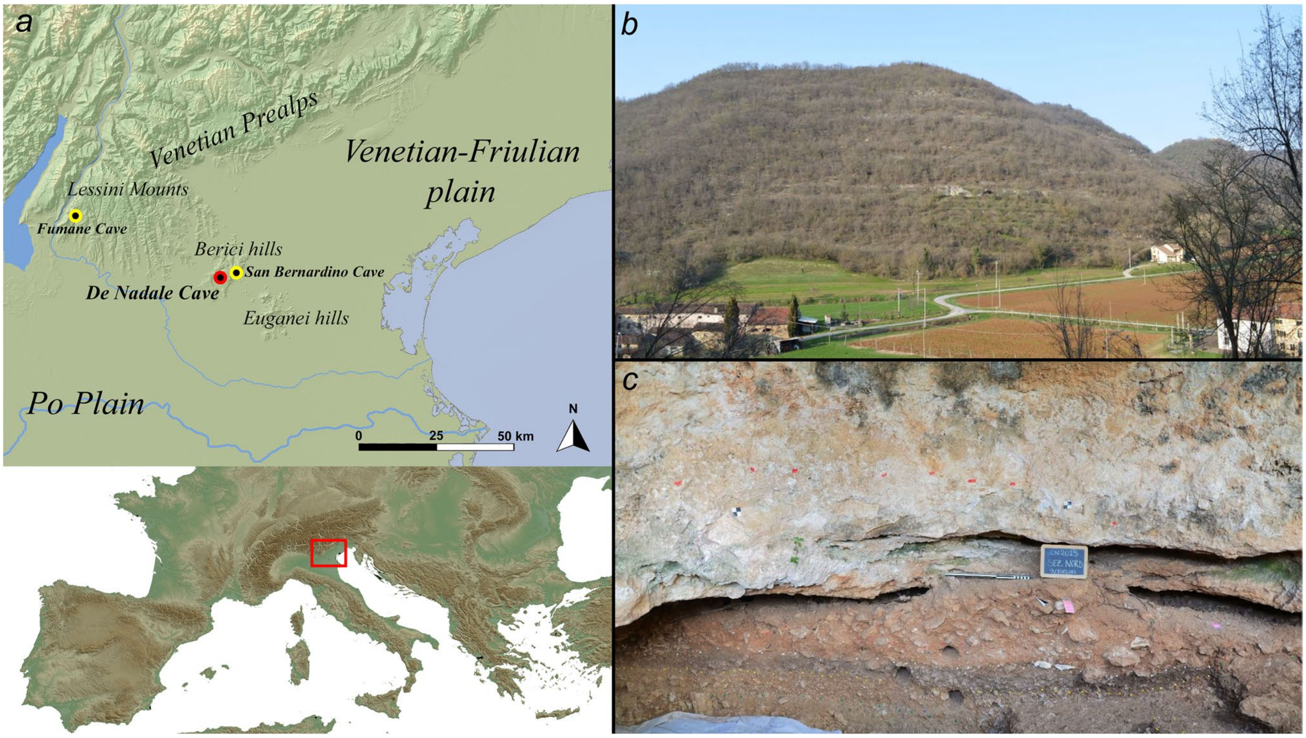

Fig. 1 North-Eastern Italy with the location of De Nadale cave and a couple of major regional sites (**a**); the souther slope of Berici plateau in the Liona valley (**b**) and the section of the deposit, with the visible dark SU 7 (**c**)

and 8). Unit 7 consists of dark brown-gray silt loam with medium-small-sized stones sub-rounded by surface corrosion; it is well preserved, and extends into the cave (Jéquier et al. 2015). Moreover, unit 7, investigated for a total of 20 m^2, has yielded thousands of fragmented bones, flint implements, few tiny fragments of charcoal, and a Neanderthal deciduous tooth (Arnaud et al. 2017); it is U/Th dated to 70.2 + 1/-0.9 ka BP (minimum age; Jéquier et al. 2015). Two charcoal accumulations were found in the north-eastern area of the cave and were interpreted as dumping areas or residual fire places. This unit was also disturbed by badger dens, partially emptied during the last two excavations (units 12, 13, 14, 15, and 16).

The zooarcheological assemblage of unit 7 is largely of an anthropogenic nature, including mainly remains of red deer (*Cervus elaphus*), giant deer (*Megaloceros giganteus*), and bovids (*Bison priscus* and *Bos primigenius*) (Livraghi et al. 2021; Terlato et al. 2019). It is important to emphasize the presence of over 300 bone retouchers manufactured on bones of large cervids and bovids (Martellotta et al. 2021).

The paleoenvironmental and paleoclimatic context of unit 7 is currently identified with a cold climate phase, characterized by a landscape presenting open woodland formations and open dry meadows, suggested also by the study of small mammals (López-García et al. 2018), and anhtropogenic charcoals (Vidal-Matutano et al. 2022). Taking into account the chronology of the site, this has been associated with the very beginning of MIS 4.

Materials and methods

Technological analysis

For the present study, we analyzed the whole lithic assemblage recovered from De Nadale cave. We considered all the artifacts exceeding a certain threshold size: module (length + width) ≥ 30 mm or major axis ≥ 20 mm. We choose this threshold since the lowest dimensional class includes small fragments, flakes and *debris*, artifacts not distinctive for a technological analysis. The only exception is retouch flakes, whose small fraction could however be confused with the undiagnostic *façonnage/débitage* products which we will discuss afterwards. These pieces have been viewed and counted but not examined in detail.

Therefore, we implemented a database compiled with quantitative and qualitative data, including 1176 artifacts. To a large extent, the anthropogenic lithic materials are attributable to unit 7, from which 687 artifacts have been found. Neighboring units yielded 54 (unit 6) and 12 (unit 8) lithic artifacts that may be ascribed to the contact/interface areas with the archeological layer 7. The units that have been reworked by badgers or modern-day humans' activities include many finds, in particular unit 1 ($n=114$), unit 13 ($n=186$), and unit 14 ($n=64$).

The assemblage presents consistent taphonomic patterns: artifacts are usually characterized by small size, both the unretouched blanks (23.5 × 20.3 × 5.4 mm the average of intact pieces), the retouched tools (32.1 × 24.2 × 8.1 mm), and the cores (34.7 × 27.7 × 14.3 mm). The fragmented pieces represent about 42% of the whole (495 out of 1176), and 11% ($n=131$) show traces of thermal alteration. Lithic artifact edges are usually well preserved: macro-detachments are present only in few pieces, mainly founded in the reworked units.

The first step of this work was to list every artifact included in the analysis within its scheme of technological production. For this purpose, each piece was individually examined through the recording of technical and morphological data and technological features. The conceptual and analytical approach applied on the technological study of knapped stones was based on the parameters defined by Inizan et al (1995) and Andrefsky (2007), among others. The identification of knapping methods and core-reduction systems represented at the site relies on the information recorded on the matrices, such as the terminal sequences of core exploitation, and the technical attributes visible on the knapping products, for instance, the type of platform, the knapping angle, the inclination of the knapping surface, the chronological and directional schemes of the negatives (scar pattern) on the dorsal surface, and the transversal cross-section of the blank. This step was particularly challenging since diverse reduction systems are present and hardly clustered in De Nadale assemblage. The technological branching and the frequent intersection in the cores and tool reduction complicates the picture, such as the presence of s.l. *façonnage* on cores. Morpho-technical analyses also were necessary for better understanding the role and the position of each product along the specific sequence of production, in a diachronic perspective and according to the knapping concept of the *chaîne opératoire*, also useful for the application of the so-called mental refittings (Geneste 1991, 1988, 1985; Leroi Gourhan 1964; Pelegrin et al. 1988; Tixier 1978). A summary of the technological attribution of each blank is available in Table 1, while the counting and stratigraphical attribution of retouched tools is indicated in Table 2.

Due to the intense reduction of the "full production" blanks and core tools (the latter, considered "mixed matrix," different to the "*façonnée* tool" meaning derived from Anglo-German tradition), some of these parameters were difficult to record. However, the waste from knapping activities proved to be particularly important in this regard. As a matter of fact, the products whose primary function is the management of core convexities usually bear direct witness about the strategies performed during the development of the knapping schemes.

Table 1 Tecnological attribution of De Nadale lithic assemblage to the recognized reduction systems

	n
Quina ramification B-C core tools	19
Quina cores	5
Plan-secant (Quina?) cores	3
Quinoid tools	54
Quinoid flakes	24
Retouch flakes type III (Q. Tools)	45
Recyclage flakes types IV-V-VI	40
Total Quina ramification system	**169**
Atypical surfacic cores	16
Atypical surfacic tools	35
Atypical surfacic flakes	77
Total atypical surfacic system	**119**
Centripetal cores	9
Other cores on surface	5
Tools from cores on surface	31
Flakes from cores on surface	96
Total surface-oriented system	**141**
Retouch flakes type 0	47
Façonnage s.l. flakes	129
Bladelets	55
Total débitage/façonnage	**231**
Kombewa-type flakes	**79**
Undetermined tools	52
Cortical flakes	112
Cortical fragments	68
Non cortical fragments	113
Knapping errors	66
Other/undetermined	26
Undiagnostic	**437**
TOT	***1176***

Sub-totals are shown in bold, while total in italic bold

The determination of *stricto* sensu tools was based on an empirical-inductive approach through the identification of the technical investment observed on the cutting edge, aimed at effective functional reasons as retouching. Tool manufacturing and reduction/resharpening was also analyzed taking into consideration all the blanks showing detachments from retouching and thinning operations. Technical features such as the position, localization, distribution and extent of the retouch, the delineation of the retouched edge, and the morphology of the retouch negatives have been recorded, as well as the typology of the final tools as defined by F. Bordes' typological list of the European Middle Paleolithic (1961). Flake tool reduction cycles could be observed through the numerous retouching flakes, whose amount, however, must

Table 2 Stratigraphical and typological characterization of the retouched tool's assemblage of De Nadale

Retouched tools	Stratigraphic provenance							TOT	Quina retouch	
	Unit 7	Unit 6	Unit 8	Unit 1	Unit 13	Unit 14	Other reworked units		Demi-Quina	Quina
Scrapers	90	6	4	15	20	11	10	152	38	21
Simple	*28*	*1*	*2*	*3*	*8*	*3*	*2*	*47*	*9*	*4*
Transversal	*13*	*1*	–	*4*	*1*	–	*2*	*21*	*7*	*1*
Double	*12*	*2*	–	*3*	*2*	*1*	–	*20*	*6*	*1*
Déjeté	*4*	–	–	*2*	*1*	*3*	–	*10*	*2*	*3*
Convergent	*14*	*1*	–	–	*1*	–	*2*	*18*	*4*	*4*
Marginal	*4*	–	–	*1*	*4*	*2*	–	*11*	*1*	–
Inverse	*1*	–	–	–	–	*2*	–	*3*	–	–
Bifacial	*3*	–	–	–	–	–	–	*3*	*2*	–
Triple	*3*	–	–	–	–	–	–	*3*	*1*	*1*
Other/undiff	*1*	*1*	–	*2*	–	–	*3*	*7*	*1*	–
Denticulated scraper	*3*	–	*2*	–	*3*	–	*1*	*9*	*2*	*1*
Limaces	6	–	1	–	2	–	–	9	3	6
Denticulated tools	4	–	2	1	1	1	3	12		
Notches	10	–	–	1	1	1	2	15		
Retouched points	3	1	–	1	3	1	2	11		
End-scrapers	2	–	–	–	2	1	–	5		
Backed tools	2	–	–	–	–	–	–	2		
Other retouched flakes	11	2	–	2	5	1	–	21		
Other retouched fragments	20	–	1	2	4	–	1	28		
Total	143	9	8	22	38	16	18	255		

Scrapers' sub-types are shown in italic

be considered a downward estimate due to their generally small size.

Finally, we recorded data regarding the exploitation of stone resources and their impact on the formation of De Nadale lithic assemblage. This includes the macro- and microscopic identification of the reference chert formations at the level of lithological facies, but also the recording of the type and nature of the cortex displayed by natural surfaces. Still, the relevant information about this topic will not be discussed here in detail; in fact, those data will be the focus of a dedicated work, which is currently under preparation.

Use-wear analysis

Use-wear analysis was performed at the Diet and ANcient TEchnology (DANTE) laboratory at Sapienza University of Rome and consisted in the observation of both edge damage and micro wear. A sample ($n=28$) of the Quina assemblage from De Nadale cave was analyzed. Edge damage features, such as micro scar termination, orientation, and distribution along the edges of the tool as well as edge rounding, were observed at low magnifications (7×–80×) using a ZEISS AxioZoom digital stereomicroscope. Edge damage characteristics provide information in terms of hardness of the worked material (i.e., soft, medium, hard) and the motion (i.e., longitudinal, transversal, mixed gestures) of the performed activity (Gijn 2010; Odell and Odell-Vereecken 1980; Rots 2010; Tringham et al. 1974). Along with the observation of use-related edge damage, the analysis of the scrapers at low magnifications permitted to assess the state of preservation of the material and to identify potential post depositional modifications (PDMs). Macroscopic PDMs affecting the tools may include extensive edge and surface rounding, fractures, macro striations, and surface abrasions etc. caused by mechanical and tribo-chemical agents (Burroni et al. 2002; Caux et al. 2018; Galland et al. 2019). Tools characterized by diagnostic edge damage ($n=20$) were selected for further analysis at higher magnifications. Micro wear, including micro polishes, abrasions, and striations have been analyzed using magnifications ranging between 100× and 400× using a ZEISS AxioScope metallographic microscope. Features observed at high magnifications include micro polish topography and texture, micro polish orientation and distribution, and micro striae morphology and orientation. Micro wear characteristics allow to identify with higher details the nature of the worked material giving the possibility to distinguish between animal, vegetal, and mineral material, and providing information concerning its state (fresh, dry, etc.) (Gijn 2010; Keeley 1980; Rots 2010). The observation of the specimens at high magnifications permitted also to recognize micro PDMs including surface alterations such as micro abrasions and micro striations and patina affecting the surfaces of the tool and not associated with their use.

To ensure the correct interpretation of the edge damage and micro wear identified on the tools from De Nadale cave, the experimental use-wear collection housed at the DANTE laboratory, which included more than 50 Quina and demi-Quina scraper replicas employed for different activities, was used as a reference by the analyst (AZ). Before being observed under the microscope, the tools were gently washed by hand in hot water. After this first stage, the tools were subjected to an ultrasonic bath in a 2% solution using a neutro detergent soap (Derquim) for 15 min and finally rinsed using hot water. Micro photographs of edge damage and micro wear were taken using a ZEISS AxioCam 305.

Lithic production systems: matrices and products

The core-reduction procedures attested within De Nadale lithic assemblage highlight a remarkable variety of technical systems, with the presence of Quina technology and Quina-type ramification which is expressed in a large number of mixed matrix blanks and by-products. Beside this, other kinds of technological branching are presents (e.g., the exploitation of cores on flake) as well as knapping systems organized on the exploitation of surfaces, both Levallois and non-Levallois, with a predominance of the latter. The marked reduction of cores and blanks, related to recycle and over-exploitation, complicates the identification of lithic production systems. For the sake of convenience, we will first present the Quina cores and products, including all the artifacts which revolve around the Quina ramification l.s. and then the surface-oriented systems, associating to these procedures, if possible, the obtained products.

Mixed matrix: Peripheral core/tools and *limaces*

The volume of these core tools is strictly organized around two secant planes shaping a rather narrow angle (between 50° and 70°), whose surfaces can be exploited hierarchically or interchanging their roles. The flat surface, A, located on the upper plane, usually bears negatives of wide, invasive flakes. The steep surface, B, is organized in turn in different faces, which are located on the lower plane, peripherally and around surface A. Surface B is characterized by detachments of flakes developing towards the distal convexity. These removals usually are wide and short flakes or pseudo-bladelets. The latter are mainly obtained through the exploitation of the narrow sides or the fronts (Fig. 2a, b). As reduction develops, rather short and curved bladelets are produced, due to the reduced thickness of the residual core. Flakes as wide as long are detached from the larger lateral surfaces, presenting a high number of hinged flakes in the last phases (Figs. 2 and 3). The bifacial *façonnage*, in the last phase, could shape a tool rather than a core, but the two functions could be also alternating.

Many of these blanks resemble "*limace*" core tools. Here, surface A corresponds to the ventral surface of the original blank, which is maintained flat to be used as striking platform for B. The latter is knapped along the blank thickness in a carinated-like concept. Usually, surface B is intensively exploited for the production of wide flakes and, seldom, (micro) bladelets, which are obtained on the blank extremities, sometimes after the narrowing of the front (Fig. 2b). In fact, these core tools are rather narrow and elongated (Fig. 2c, d). Overshot bladelets removed the maximum convexity of surface B, then flattened by small oval flakes. In some cases, surface A may be characterized by flat and invasive detachments, through which it is possible to maintain a steady inclination with surface B, for the purpose of using the tool as cutting or/and scraping implement (Fig. 2e).

These core tools are extremely exploited and abandoned at a very reduced volume (Figs. 2 and 3). De Nadale peripheral cores-*limaces* may be compared with the volumetric structure of some of the alternating-method cores defined by L. Bourguignon (1997) in the classical Quina sites of South-Western France, especially the ones characterized by a surface B covering the whole periphery of the core without the opening of alternative striking platforms. However, despite sharing the same knapping organization, some of these cores could manifest relevant differences during surface exploitation and regarding the objectives of production and the knapping techniques may be to be referred to their mixed purpose. In other words, the two surfaces could be hierarchized, with the production insisting just on one of them, which often is surface B. When these kinds of cores are obtained from flakes, surface A usually coincides with the flattest ventral surface. In this way, the intersection edge, characterized here by a lower angle, could represent the cutting edge of the tool core, likely displaying retouch scars. Detachments on these core tools are thin and invasive, probably obtained through soft percussion within *façonnage* operations. This is a substantial difference with classical Quina cores, which is also expressed in the lower thickness of the by-products. As lithic production develops, peripheral core tools may attest the rotation of the knapping axis, which

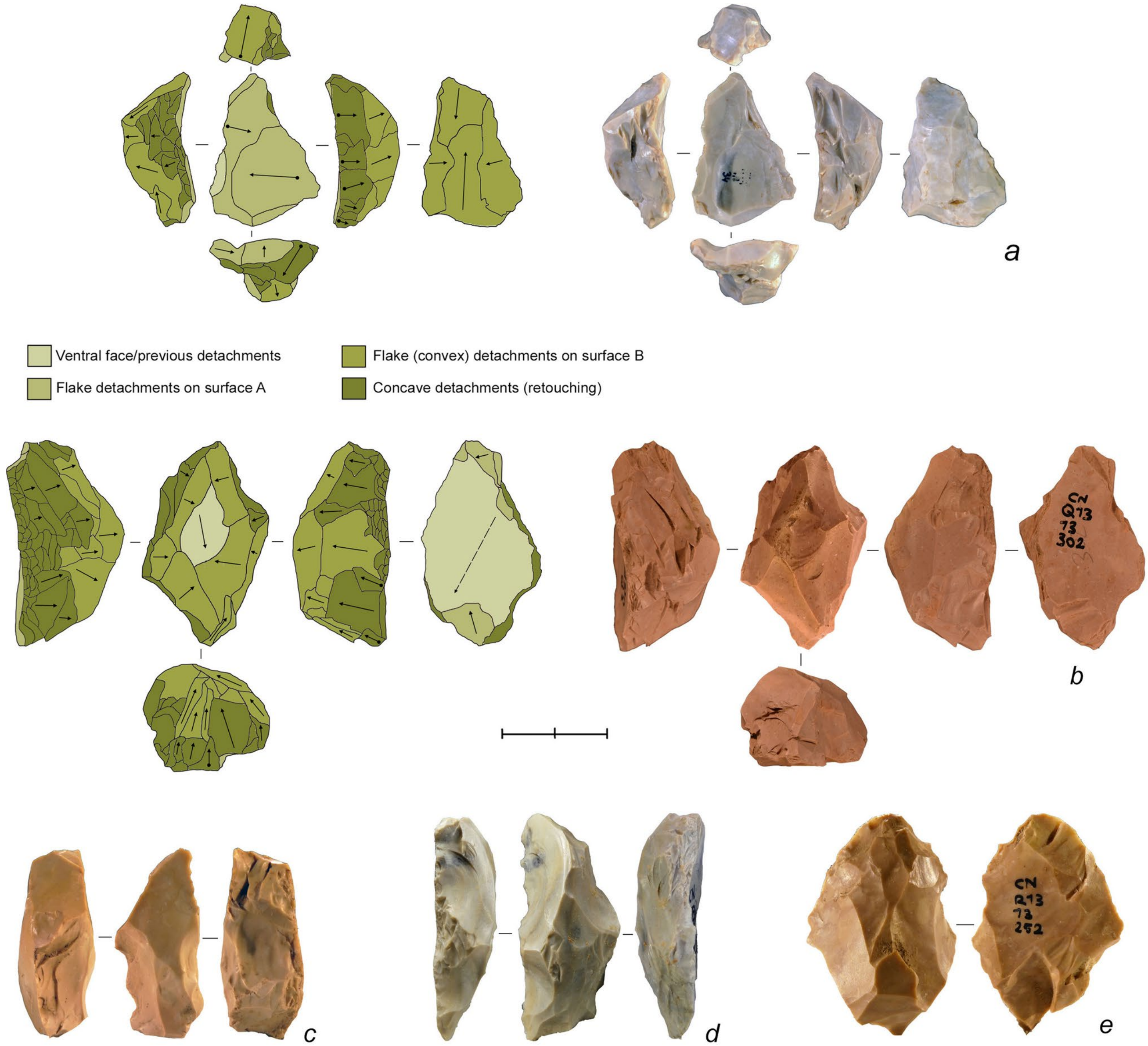

Fig. 2 Mixed matrix, peripheral core tools on *limaces*, organized on a flat surface **A** opposed to a steep and peripheral surface **B**, distributed on wide and narrow fronts for the production of flakes or bladelets. These artifacts are characterized by a last phase of edge retouching consistent with their function as a tool

is noticeable in the opening of adjacent and orthogonal surfaces. From these new plans, surface B can be exploited along its length, beside and in parallel with "surface A." A significant example of this halfway peripheral-multifaceted concept on a mixed matrix is core tool no. 648 (Fig. 3c). In this situation, bladelets were initially obtained after the knapping of surface B, from which a new striking platform was opened for the removal of a large flake invading most of the length of surface B. The latter detachment, peripheral to surface A, concurred to thin and resharpened the edge between the two surfaces that was subsequently retouched and potentially used as a tool.

Knapping system on surface and lateral planes

The same technological criteria of peripheral cores are partially shared by other core types, although they are applied to a different exploitation of the surfaces. As a matter of fact, several cores are knapped on a single surface starting from a dihedron and circumscribed on a usually narrow and constrained surface inclined to the striking platform (Fig. 4).

These cores are sequentially knapped through the production of invasive and overshot flakes (also elongated flakes and bladelets? See Fig. 4). Their exploitation mainly follows unipolar patterns, although bipolar (Fig. 4a) or centripetal

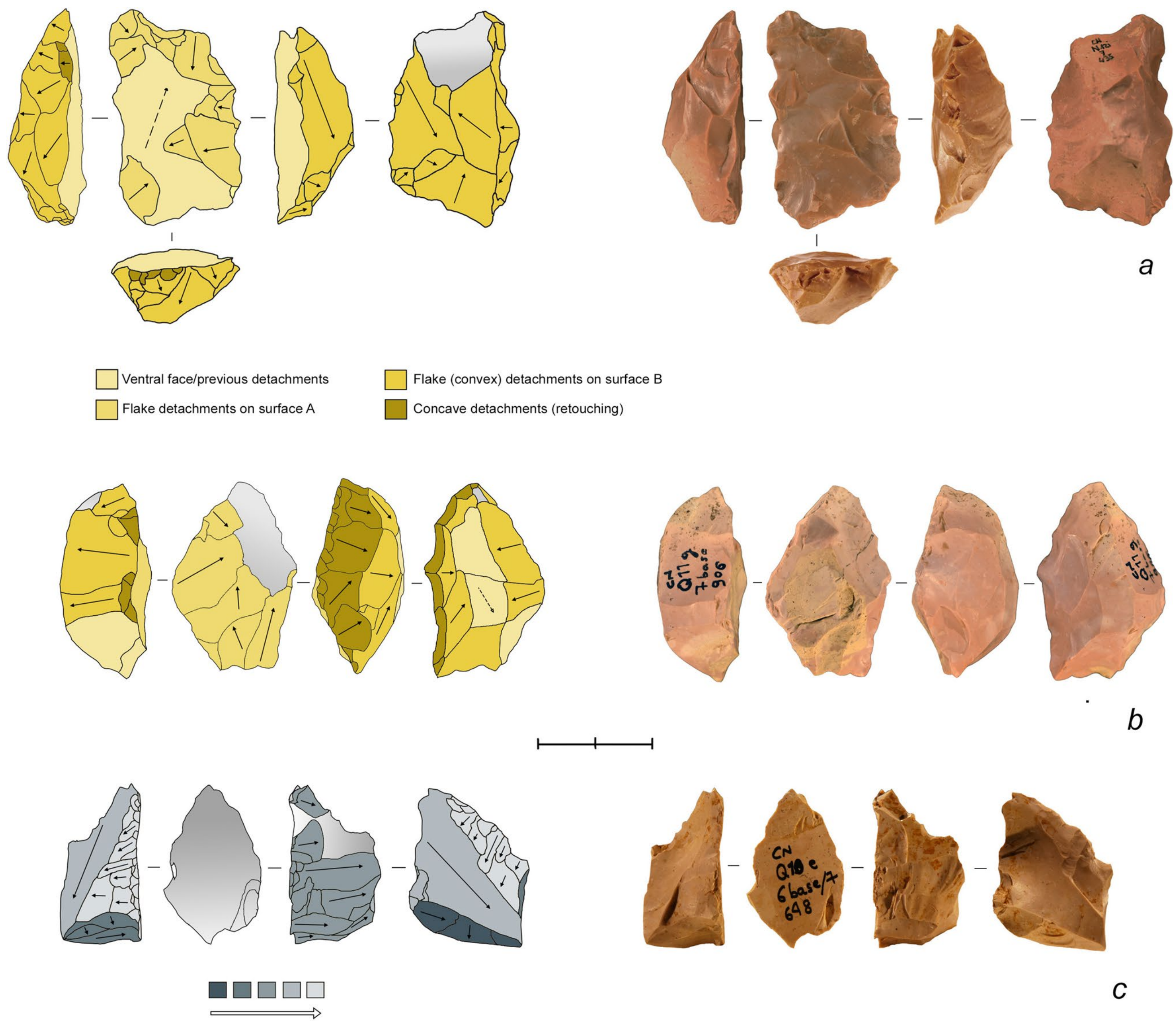

Fig. 3 Mixed matrix, peripheral core tools; **a** and **b** artifacts are characterized by a last phase of exploitation consistent with their function as a tool; **c** is a peripheral-multifaceted core without the knapping of flat surface A, and the opening of a lateral, secant surface, before tiny detachments were probably aimed to retouching the functional edge

schemes are attested as well. On these occasions, blows are struck from the lateral or the opposite platform based on a "double dihedron" (Fig. 4d).

A refitting between two fragmented cores shows the technological shift from a knapping system on a single surface organized on orthogonal/centripetal plans to a different scheme (Fig. 5). A recurrent behavior is the exploitation of a lateral edge of cores, aimed at obtaining elongated flakes or blades. The detachment plane of these products is strongly inclined in respect to the original knapping surface, and the products obtained often are overshot or crested, sharing a convex or twisted profile. In the same sequence, after the breakage of the original core, one part was discarded whereas the other was exploited using the fracture itself as striking platform to reduce the opposite surface. Strikingly, small and hinged flakes were almost exclusively produced.

This lateral-oriented exploitation could focus on the edges and crests between the upper and lateral planes, so as to produce bladelets (Fig. 4a, b); nevertheless, on

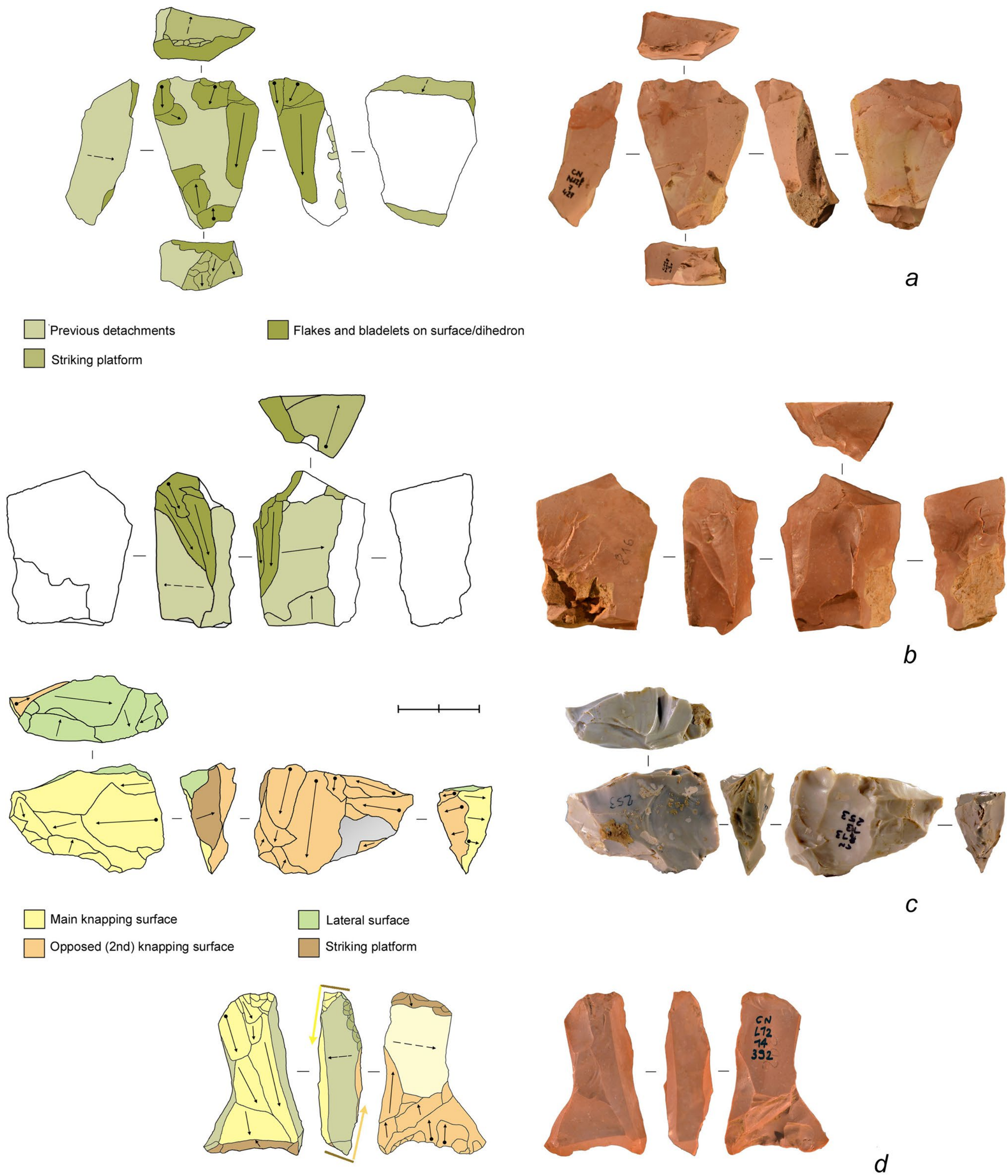

Fig. 4 Dihedral or double-dihedral cores exploited on single or diverse surfaces, with the production of lamellar blanks from narrow edges or lateral surfaces

several occasions, the progressive rotation of the plane where the main knapping surface was located could shift by raising the inclination to 90° in respect to the original surface. This is especially documented where a double exploitation of two non-hierarchized and opposite surfaces is present (the upper and the lower); in this way,

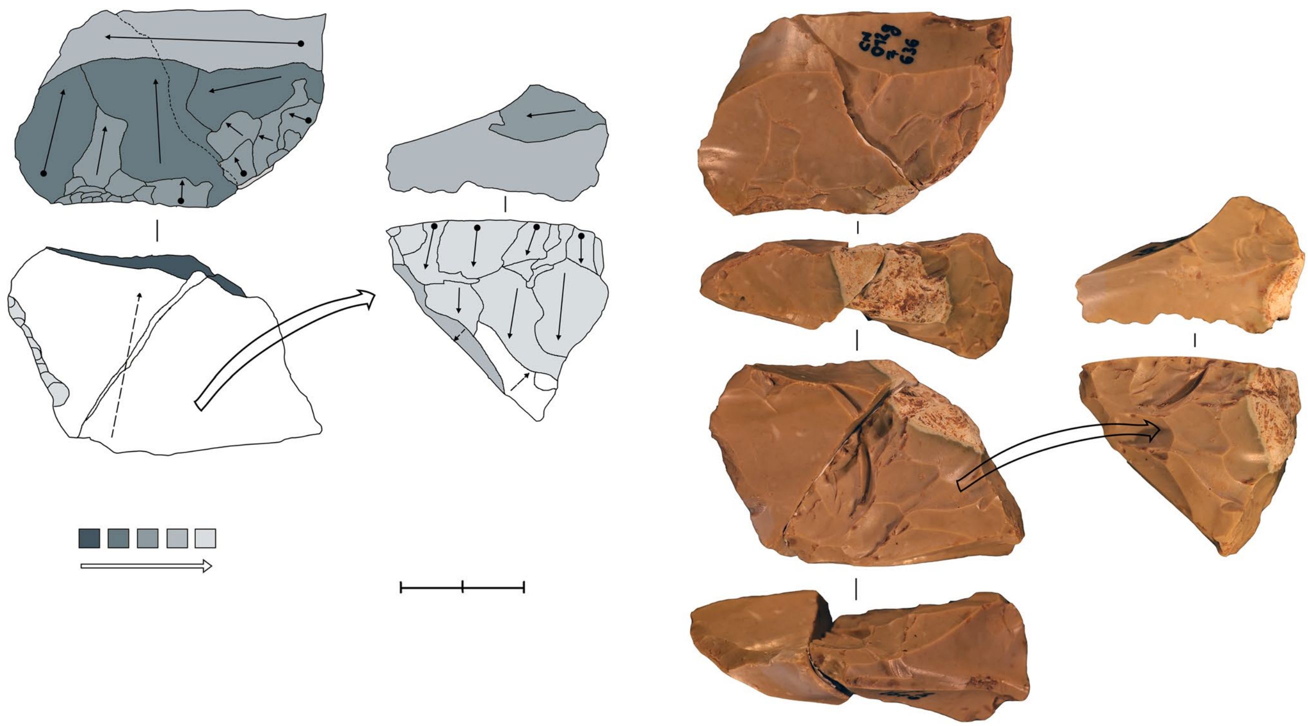

Fig. 5 Refitting of a fragmented core showing a surface centripetal exploitation, followed by the production of an elongated flake on a lateral, inclined plane. After the breakage, one of the two fragments is further reduced on the opposite surface, using the fracture as a striking platform

different types of blanks were obtained through the reduction of the two main surfaces and the narrower, lateral plane (Fig. 4c).

Polyhedral-multifaceted cores

During reduction, both peripheral and surface-oriented cores could develop towards more versatile and polyhedral-multifaceted schemes. As mentioned above, some peripheral cores attested the opening of a further face from an orthogonal plane. We observed that the same technological behavior was applied to dihedral cores and cores on surface: after a 90° rotation, a second striking platform was opened starting from a previous knapping removal.

As reduction proceeded, some of these cores displayed a multi-faceted scheme with the alternate knapping of orthogonal and opposed platforms, mostly exploited for producing laterally and distally invasive flakes in more advanced stages (Fig. 6). These cores are close to a more classic Quina volumetric scheme, having concatenated knapping surfaces which are sub-parallel and secant each other. Still, at least in the last reduction phase, it seems that hard and soft hammers were indiscriminately used through internal or more tangential blows. For these reasons, two kinds of products were obtained from these cores: on the one hand thick and laterally/distally invasive flakes, on the other hand thin, convex, and often hinged flakes from flat surfaces.

Levallois and Discoid reduction

Other knapping systems, oriented to the more typical exploitation of surfaces, are also attested. Certain cores are characterized by continuous detachments along a peripheral edge, oriented towards the intersecting plane designed on the edge in cross-section. The scars' direction and the limited trimming of the striking platform represent some of the criteria shared by the Discoid knapping method observed through several Middle Paleolithic assemblages (Peresani 2003). For instance, Discoid cores may exploit a single surface (Fig. 7c), or, occasionally, two opposed surfaces, following a bifacial scheme. These cores may record the shifting of the peripheral edge up to the opening of new surfaces in a pseudo-polyhedral scheme.

The Levallois knapping method is also attested by cores and by-products. Centripetal cores are the commonest, addressed to produce flakes until the exhaustion of the volume (Fig. 7a, b). This method is seldom applied to core flakes which always maintain two opposed and hierarchized surfaces, and an accurate trimming of the striking platform. However, we cannot exclude that both the surfaces of some of these cores were exploited throughout different knapping stages.

Furthermore, we have noted cores presenting prepared striking platforms and trimmed peripheral edges. Yet, they displayed a flexibility in the volumetric concept going

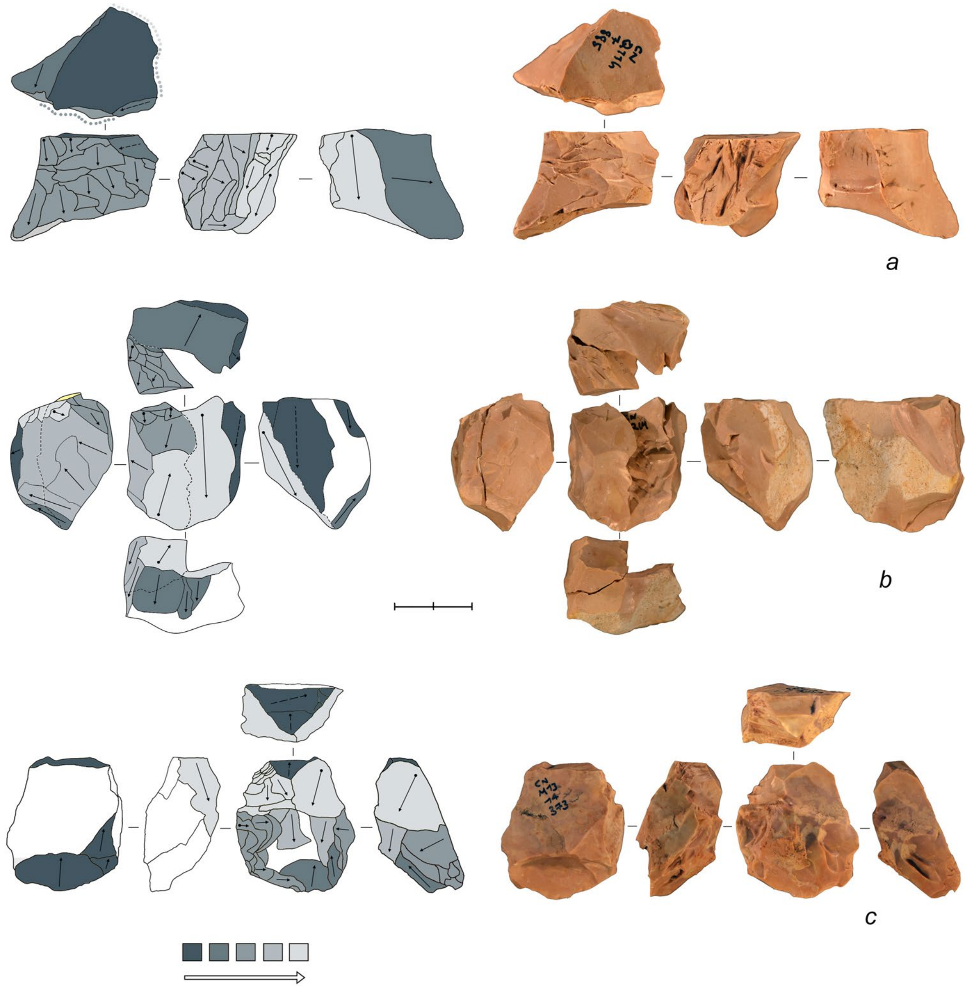

Fig. 6 Polyhedral-multifaceted cores knapped on orthogonal and secant surfaces to produce small and wide flakes or short bladelets, with evidence of a refitting (**b**)

beyond the strictness of the Levallois criteria. We observed as well that on these usually intensively exploited cores, surfaces were non-hierarchized, and that the knapping angles increased together with the inclination of the last removals. Still, cores displaying more complex patterns of exploitation were centripetally knapped on both surfaces, one of which was flatter than the other.

Other reduction systems

Cores on flakes were attested as well, which referred both to Quina ramification concept (see the "mixed matrix" blanks), and to less organized systems and ephemeral exploitations. These last ones were mainly directed to bulbs and ventral surfaces, in a Kombewa-like conception applied to the thick and short Quina blanks.

Another reduction system, weakly represented by cores and by-products, focuses on the exploitation of a wide and short surface through subsequent and parallel removals, often starting from the upper surface. An example is a thick flake with a Hertzian cone reduced by slice-knapping along its thickness (Fig. 8a). In the same way, small plaquettes could be progressively exploited on one side from the same surface. Occasional removals on secant planes were aimed to alternate the exploitation or shape the convexities (Fig. 8b). The result was knapped products under the form of thick, wide, and short invasive flakes, possibly slightly overshot, as attested by the presence of distal natural surfaces. The first core is conceptually comparable with Le Pucheuil method which, according to A. Delagnes (1993), is a secondary knapping method applied to cores-on-flakes: dorsal surfaces act as striking platforms and recurrent and parallel detachments slice the flake core along its thickness. Wide flakes have a "*concorde*" longitudinal profile, flat and large platform,

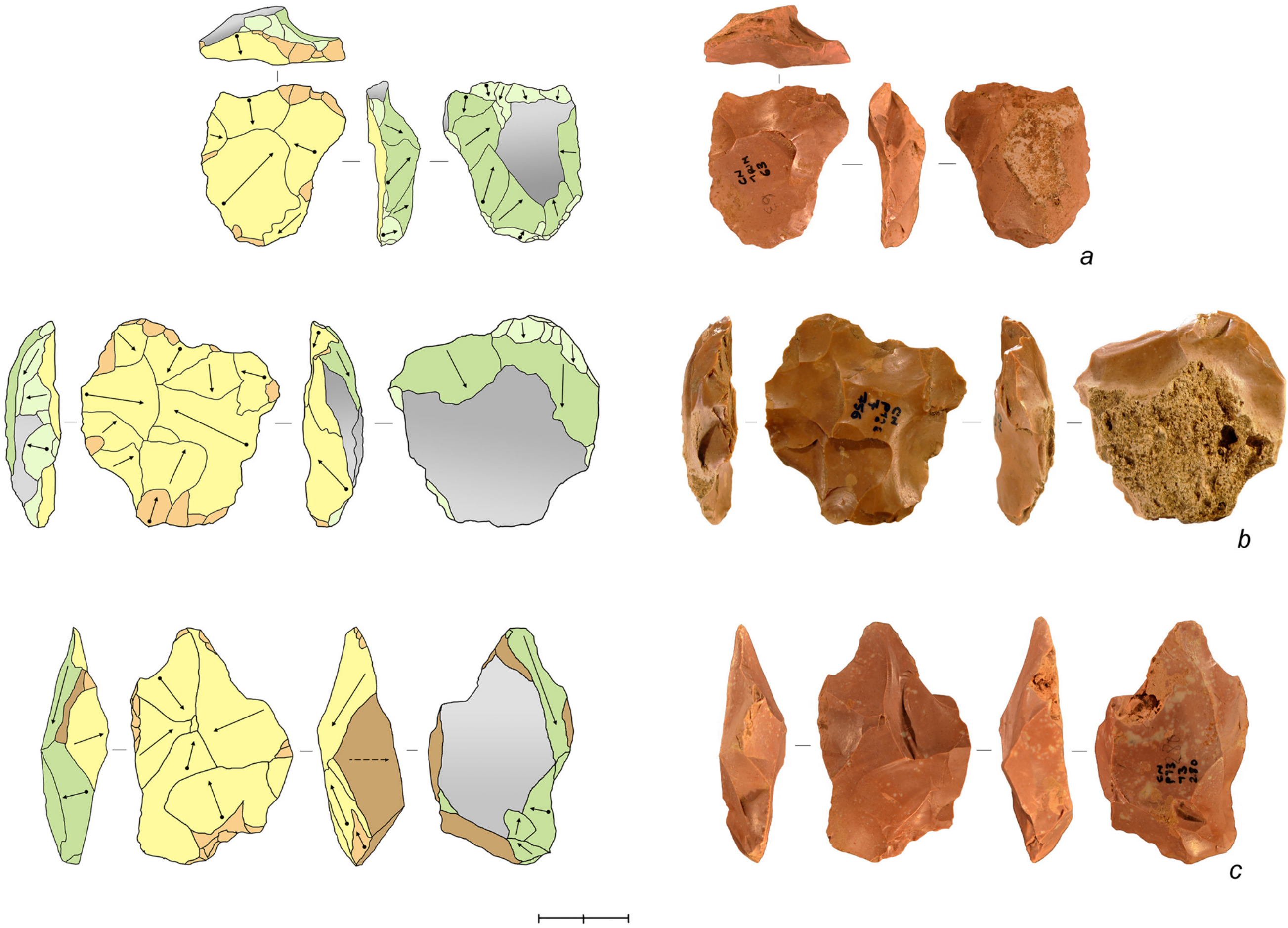

Fig. 7 Levallois recurrent centripetal cores (**a**, **b**), unifacial discoid core (**c**)

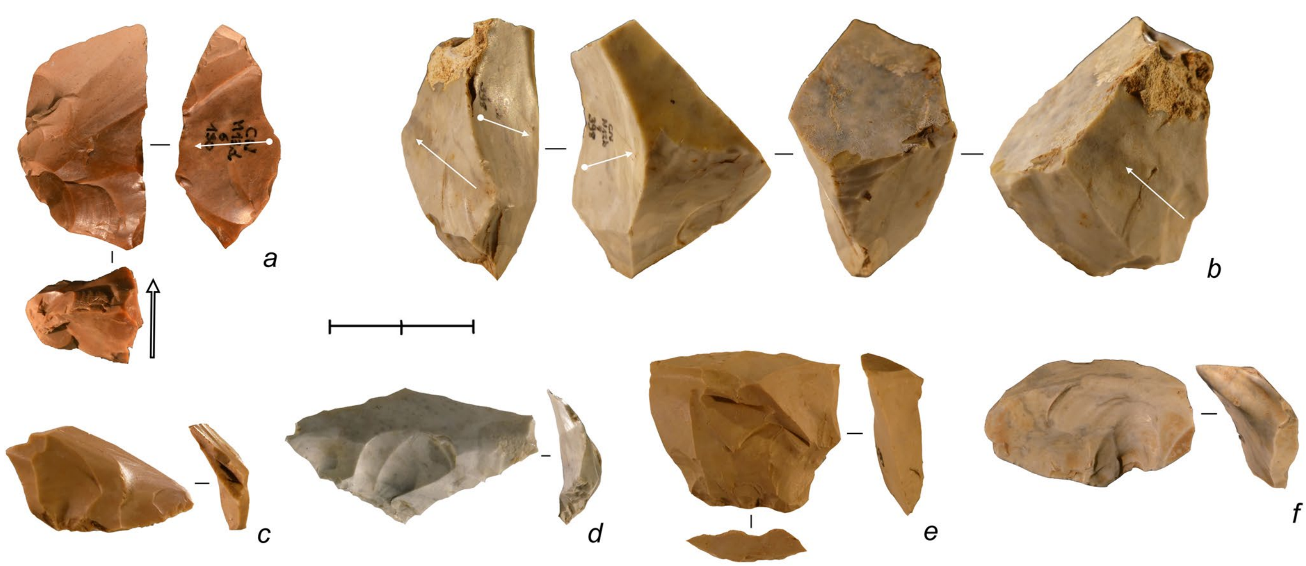

Fig. 8 Le Pucheuil-type core on a flake with hertzian cone (**a**), plaquette core with knapping on secant planes (**b**), flakes obtained from Le Pucheuil-type or Kombewa-type cores (**c**–**f**)

Fig. 9 Simple scrapers (**a**, **c**, **e**), transversal scrapers (**f**–**h**), double scrapers (**i**–**k**), denticulated scraper (**b**), simple scraper with retouched back (**d**), double scraper on a recycled Levallois flake (**l**), scraper tool with intense thinning of the lower surface (**m**); panels j and k are characterized by Clactonian notches

which was possibly distally corticated. Some by-products seem also to attest this knapping concept (Fig. 8c–f).

Objectives of technological production—products and by-products

In order to identify the technological goals within the occupation of De Nadale cave, we have employed a multi-scalar approach. First, we began with the techno-typological analysis of stricto sensu tools, then we carried out the technological analysis of blanks obtained from the identified core-reduction trajectories, and finally we concluded with the use-wear analysis applied to a sample of retouched tools and retouching by-products/*reaffutage* elements.

Retouched tools

Retouched tools amount to over 250 specimens (Table 2), including about twenty "mixed-matrix" blanks which, as we already highlighted, can be framed within the bifacially shaped tools, such as *limaces* and bifacial scrapers (Figs. 2 and 3).

Scrapers

We recognized 152 scrapers in the whole lithic assemblage, including a dozen of core tools made on scrapers or recycled as scrapers. These are fragmented in 2/3 of cases and they are often significantly reduced in size. The average dimensions of intact specimens are 33.4 × 25.1 × 9.3 mm. In some instances, several extremely reduced tools were abandoned since they were no more exploitable (Fig. 9a, b).

Table 3 Techno-typological characterization of the scrapers from De Nadale with information on the presence of Quina or demi-Quina retouch

Type of blank	Type of scraper								TOT	Quina retouch	
	Simple	Transversal	Double	Déjeté	Convergent	Marginal	Denticulated	Other		Demi-Quina	Quina
Cortical f	6	2	5	2	5	2	2	5	29	11	5
f. with natural back	8	6	–	2	–	–	–	–	16	7	4
Backed f	8	3	1	1	2	1	2	–	18	4	3
Quinoid f	3	1	2	1	3	2	2	3	17	3	4
Unidirectional f	3	–	6	–	2	1	–	–	12	3	
Kombewa-type f	3	2	–	–	–	1	–	–	6	2	
Levallois f	5	2	1	–	1	2	–	–	11		
Management f	–	2	2	1	1	2	1	1	10	2	1
Knapping errors	1	–	–	–	–	–	1	–	2		
Other/Undetermined	9	3	3	2	3	–	1	5	26	6	4
Retouching f	1	–	–	1	1	–	–	2	5		

Fig. 10 Convergent scrapers (**a**, **b**, **g**), *déjeté* scrapers (**c**–**e**), scrapers with intense thinning of the lower surface (**f**, **i**), bifacial scrapers (**h**, **j**, **k**), triple-edge scrapers (**l**, **n**), convergent convex scraper with a thinned base (**m**)

Considering the major length distribution, we noticed a large group of tools measuring about 20–30 mm, and a second concentration ranging between 40 and 50 mm. Conversely, width and thickness rather record unimodal distributions.

Scraper shapes and typologies are quite diversified (Table 3). Overall, simple types with lateral retouch on one side represent the relative majority ($n=47$) (Fig. 9a, c, e), followed by transversal scrapers ($n=21$) (Fig. 9f–h). Yet, more complex shapes with more than one edge retouched are quite common too: double ($n=20$) (Fig. 9i–l), convergent ($n=18$) (Fig. 10a, b, g), and lateral-transversal or *déjeté* ($n=10$) (Fig. 10c–e) scrapers are present, as well as some rarer and elaborated types such as some bifacial scrapers (Fig. 10h, j, k) and triple-edge (Fig. 10l, n) scrapers. Finally, about a dozen marginal types and as much denticulated scrapers complete the picture. Convergent and double scrapers were manufactured on longer blanks while transversal types were mainly set on short and wide flakes.

Retouched edges are almost equally distributed between rectilinear and convex delineations, even if convexity remains usually low. Transversal scrapers are mainly characterized by a straight, although oblique, retouched edge (Fig. 9f). Some concave retouched edges also exist, and we observed that rectilinear-convex combinations are particularly common within convergent and *déjeté* scrapers (Fig. 10b–d). Retouch is almost always direct, since only a handful specimens record inverse or bifacial detachments. Bifacial retouching is recorded in no. 345 tool, a convergent scraper/point with a broken tip (Fig. 10k); in this instance, a flat retouching is directed to the edges and especially to the base. A second bifacial scraper is still characterized by flat and invasive detachments; however, it is likely that it broke while being manufactured and then abandoned (Fig. 10j).

More than 20 scrapers record the typical Quina retouch at least on one edge (Figs. 9, 10 and Table 3): a scaled, stepped retouch defined by many resharpening cycles, mainly applied to thick blanks and shaping a straight to convex profile. Besides these, almost 40 scrapers may be identified as demi-Quina, including some variants (Table 3). The first and most common variant is characterized by usually scaled and stepped retouch applied to thinner blanks (6–8 mm). The second variant includes pieces that present an unusual shape and retouching profile.

Finally, thick flakes bearing witness of many retouching cycles but characterized by parallel or sub-parallel detachments were observed as well. Most of the scrapers record at least three cycles of retouching (the average on Quina and demi-Quina types are close to four cycles) (Table 4): the first one (the most recent) is very marginal, concave, and stepped; the second one is defined by scaled or sub-parallel detachments; and the third one (the oldest) is usually invasive and characterized by convex profile in cross-section. Overall, retouching is rather invasive, reaching an average of 12.3-mm depth within Quina scrapers; this value drops to 10.7 mm in the demi-Quina and 7 mm in the other scrapers (Table 4). The angle of the retouched edges is quite open, usually settling between 45° and 70°.

The most common blanks chosen for scrapers manufacturing are flakes with a thick lateral back, which in half of the cases is shaped by natural surfaces (Table 3 and Fig. 9a, c, f and 10b, c, i). In some specimens, these correspond to débordant flakes or *déjeté* points produced by centripetal (Levallois or Discoid) knapping schemes (Fig. 9e). Also, many of them match with the production of lateralized and invasive flakes on Quina cores, with which they share the thickness and the asymmetrical profile. Some elongated flakes with a convex profile were probably obtained from the atypical cores on surface where the lateral plane was exploited. Among the modified blanks, undifferentiated cortical flakes and Quinoid flakes are common too, while thin flakes and management products are also present, as well as predetermined Levallois flakes and unidirectional/laminar flakes. Six kombewa-type flakes complete the picture, together with 5 retouching/resharpening flakes that record further retouching after their obtaining (Table 3).

About 40% of scrapers bear cortical surfaces, raising up to 50% among Quina scrapers and 70% among demi-Quina (Table 4). While simple scrapers are less cortical than other types, a dozen tools (mainly demi-Quina scrapers) are manufactured on flakes having at least half of the dorsal surface covered by cortex, indicating a significant productivity in the very first phases of core shaping. Two scrapers are characterized by a double patina: the first one is a Levallois elongated blank with a previously made proximal fracture, then recycled through a bilateral direct retouching (Fig. 9l). The

Table 4 Detailed information on the scrapers from De Nadale in respect to the presence of Quina or demi-Quina retouch

	n	Retouching cycles (average)	Depth of retouch (average in mm)	Cortical blanks (%)	Thinned blanks (%)	Intact pieces (*n*)	Mediium length (mm)	Medium width (mm)	Medium thickness (mm)
Quina scrapers	21	3.81	12.3	47.6	23.8	12	33.8	24.3	13.3
Demi-Quina scrapers	38	3.65	10.7	370.6	26.5	19	34.8	23.5	11.4
Other scrapers	93	2.7	7.0	28.9	7.8	35	32.9	26.2	8

second one is a double scraper as well, set on an elongated but thicker blank and bearing an older patina only on a limited portion of the dorsal surface; in this case, it was the original core that had been probably recycled, rather than the retouched blank.

More than 25 scrapers show traces of lower surface thinning, which is rarely marginal and more often invasive and covering (Fig. 10f, h, i). This was sometimes aimed at removing or flattening the bulbar convexity. In most cases, however, the thinning was applied from the lateral, thick back. This arrangement could have had different goals, such as improving prehension by moving the symmetrical axis, inserting the tools into a handle by thinning out the passive portion, or producing small and usable flakes from the tool, again in a "mixed-matrix" concept. The latter is the case of no. 28 specimen, bearing large negatives aimed at detaching oval flakes and, at the same time, preparing the active edge for a new cycle of retouching (Fig. 10h). A convergent convex scraper with a thinned base must be mentioned as well: in this instance, the thinning was probably applied in order to allow the manipulation of the object on the left basal apex (Fig. 10m). Still, several cycles of thinning are recorded on specimen no. 584, which after the last covering flake detached along the ventral cutting-edge, it was retouched again on the dorsal surface (Fig. 9m). In this situation, the thinning was possibly conceived as mean of resharpening the tool maintaining the edge angle. At any rate, the association between demi-Quina and Quina scrapers and the deep thinning of lateral, adjacent margins is common (1/4 of tools), whereas it is rare in the other types (Table 4). On some scrapers and core tools, isolated "Clactonian" notches are present. There are some denticulated scrapers bearing three or four retouching cycles, the last of which is characterized by deeper detachments possibly aimed at renewing the edge angle and thus shaping the tool into a notched or denticulated profile. However, these notches might have had different and more functional-related purposes as well (Figs. 2c, d and 9j, k).

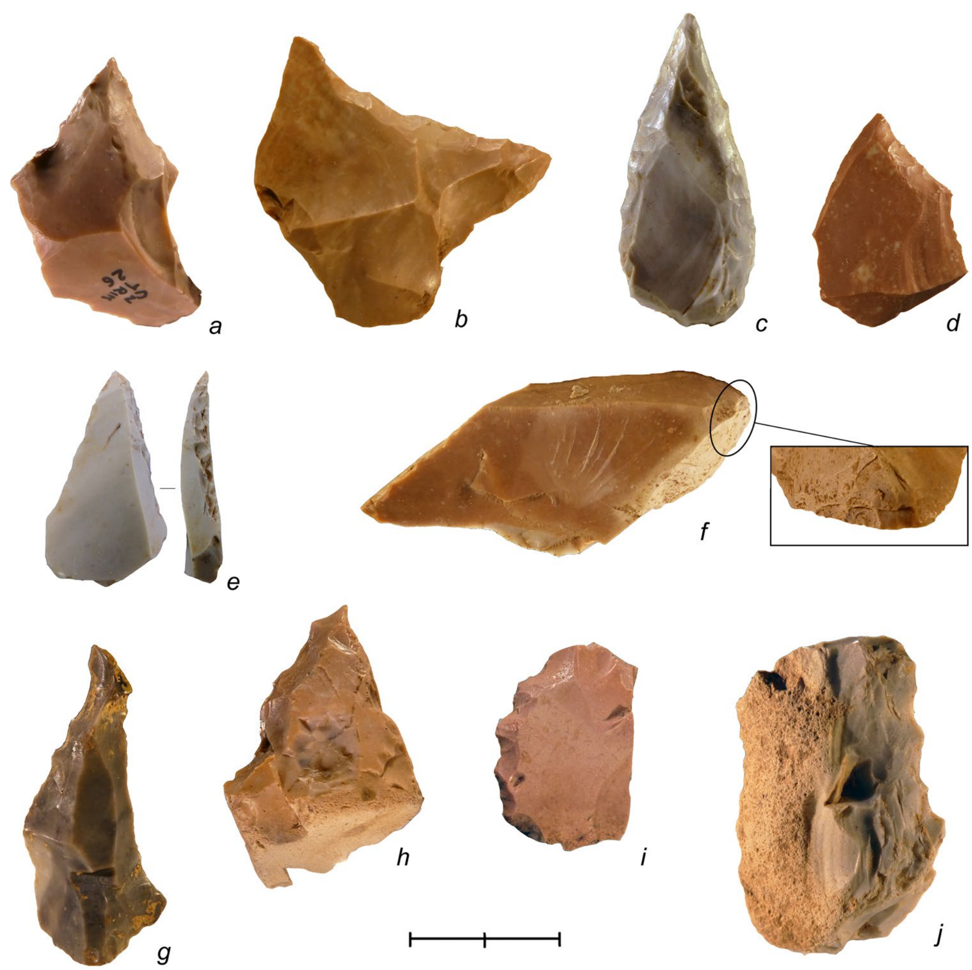

Fig. 11 Retouched points (**a**–**d**), flake with marginal abrupt retouch (**e**), marginal end-scraper (**f**), denticulated point (**g**), notches and denticulated tools (**h**–**j**)

Other retouched tools

The rest of the retouched assemblage includes a limited collection of shapes and types: among them, it is worth to mention a dozen retouched points usually manufactured on short and wide blanks, measuring 27.8 × 23.7 × 5.1 mm on average. Unlike convergent scrapers, these points are thinner, without necessarily being more acute. Probably, they were conceived to perforate the material. The points could be shaped either on irregular blanks (Fig. 11a), or sometimes on pseudo-Levallois points (Fig. 11b) although extremely refined points were present as well, showing a nearly total and peripheral retouching (Fig. 11c). The category of partially retouched points includes tools retouched on a single edge, while the other one could be affected by inverse and extremely marginal detachments (Fig. 11d). Still, several points bearing an extensive and long retouching on one edge might represent scraper points.

About 15 notches were identified in the assemblage. These were manufactured on very diverse blanks, including flakes with natural back and kombewa-type products. A dozen denticulated tools were realized on various blank types as well, even on short-maintenance flakes (Fig. 11g–l).

Among the other retouched implements (nearly 50 specimens), partially retouched pieces and marginal types are particularly present, together with fragmented and undifferentiated elements (Table 2). Only few other tools follow defined tool types, such as five end-scrapers with frontal, marginal, and abrupt retouching, mainly shaping a convex end. These were manufactured on unidirectional, thick flakes, on Levallois flakes, and on a large semi-cortical Quina flake (Fig. 11f).

Fig. 12 Large Quinoid flakes with basal or lateral thick or cortical portions (**a**–**f**), centripetal flake (**g**), *débordant* flake (**h**), Levallois flake with facetted platform (**i**), short bladelets with convex profile (**j**, **l**–**q**, **v**), twisted or straight bladelets (**k**, **t**, **u**, **w**, **x**), bladelets from volumetric knapping (**r**, **s**)

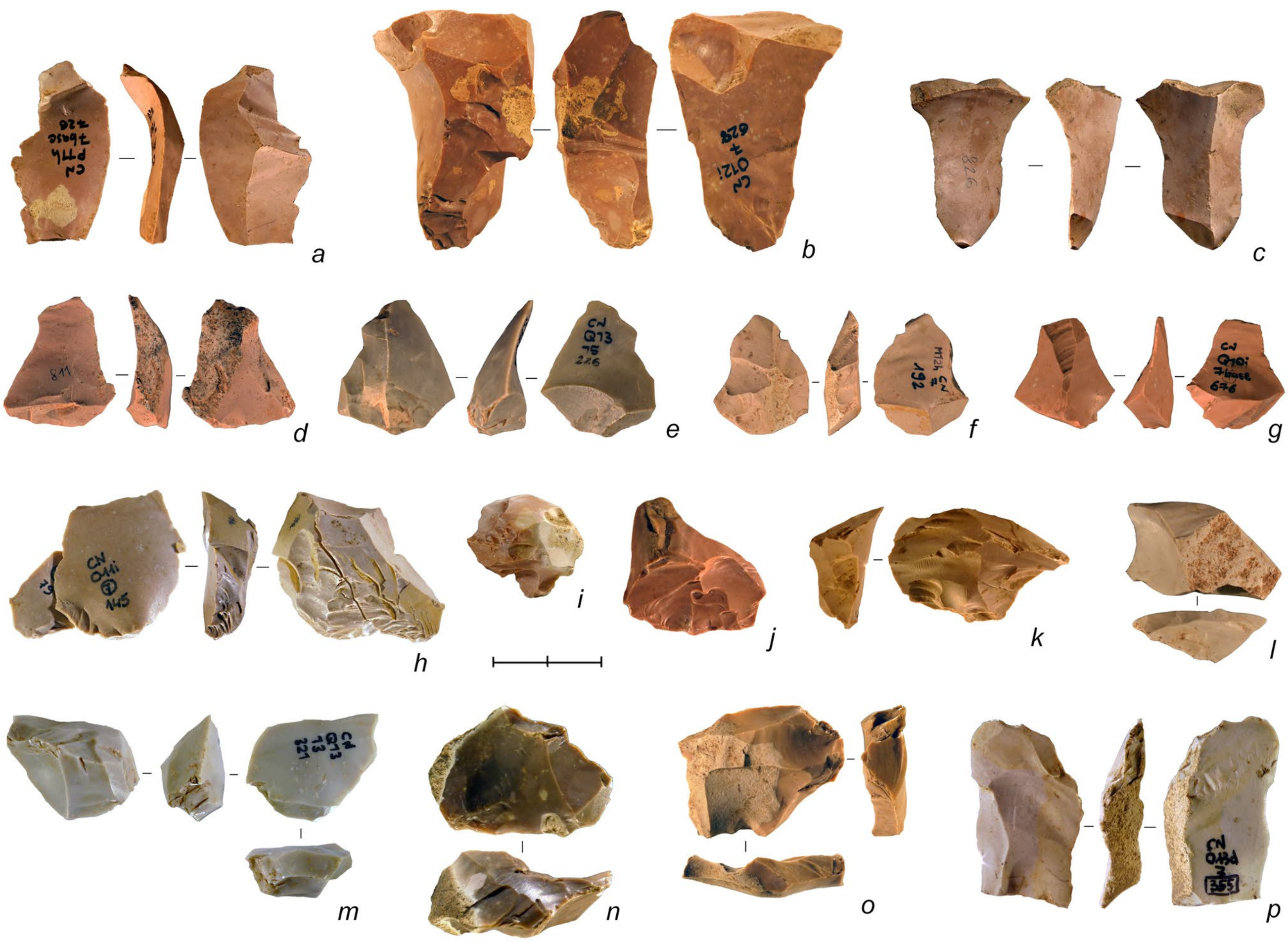

Fig. 13 Technical or maintenance products of the attested reduction sequences. Overshot flakes (**a**–**c**), short flakes with thick platform (**d**–**g**), flakes shifting back the striking platform (**h**–**k**), flakes with transverse dihedral platform (*talon à pans*) (**l**–**n**), orthogonal flake (**o**), flake with very inclined natural back (**p**)

Some techno-functional misunderstandings might arise from fragmented elements bearing abrupt retouching opposed to cutting or scraping edges, which may recall prepared backed tools. In fact, marginal abrupt retouching may affect also small and intact flakes on the thicker and, presumably, passive portion in order to allow and improve tool handling (Fig. 11e).

Non-retouched blanks

Flakes

A large part of the knapping products consists of flakes obtained during the aforementioned core-reduction trajectories. According to a technological and deductive approaches, these blanks could include both first-choice and second-choice artifacts, thanks to a series of techno-functional features (regularity, dimensions, ergonomics, functionality) and their analogy/difference with the retouched blanks. The majority of first-choice artifacts was presumably retouched. Among the non-retouched flakes, we can recognize different types of blanks, such as wide and lateralized flakes from Quina cores presenting thick platform and, often, natural surfaces on proximal or lateral portions (Fig. 12a–d and 13p), as well as flakes with thin or convex profile which might result both from flat surfaces of polyhedral cores and lateral planes of cores exploited on surface, sometimes attesting the rotation of the platform (Fig. 12e–g). Some flakes, usually larger and thinner, are typical of centripetal exploitation of Discoid or Levallois-like cores (Fig. 12h, i).

The arrangements or preparation of the striking platforms are well-exemplified by the variety of the flake platforms: considering the whole assemblage, the platforms are mainly flat ($n=307$), followed by punctiform ($n=97$), facetted ($n=79$), linear ($n=66$), cortical ($n=62$), and dihedral ($n=43$). Quina technical systems are well represented especially by flat platforms and, more rarely, dihedral *à pans* detaching flakes with open knapping angle (110° on average, with cases of 120° and 130°). Surface-oriented and centripetal technical systems bear flat, facetted, and dihedral impact points together with flakes with very different knapping angles, from 90°–100° (Levallois flakes) to 110°–120° (other reduction systems).

Among the technical products, several types of flakes attest the significance of recurrent technological criteria. For instance, the angle of the dihedral edge is essential, both on peripheral and on surface cores, for obtaining a continuous series of products. To maintain this angle, percussions were usually inclined and parallel to each other, thus resulting in invasive and overshot blanks (Fig. 13a–c). Nevertheless, several circumstances may lead to narrow the angle and, as a result, the dihedral edge gets thinner. In these situations, it is necessary to detach short products with thick platform to restore the appropriate angle (Fig. 13d–g). Conversely, when the angle between the two secant surfaces widens too much, it usually causes the flattening of the knapping surface. The result is the production of hinged percussions which compromise the further exploitation of the surface. This really common mistake becomes emphasized especially when cores reach small sizes. As a way to solve this impasse, the production of thick reparatory flakes is well attested, therefore shifting back the striking platforms addressed to repair the knapping surface (Fig. 13h–k). The exploitation of surfaces from lateral or opposite platforms is supported by the presence of many knapping products displaying orthogonal scar patterns on their dorsal surface (Fig. 13j–l, o), while centripetal scars are rare/less than common. When core-reduction reaches the last stages, orthogonal flakes increase in number and they constitute the majority of products, thanks to the rotation of the cores and to the alternated exploitation of lateral planes as striking platforms or exploitation/flaking surfaces. Finally, semi-crests are also realized by shifting the inclination of the knapping surface on the lateral plane, as we recorded from many cores on surface. Twisted flakes or bladelets can also derive from this kind of exploitation. Their production is a hint of the interconnection of two orthogonal striking platforms or of a gradual rotation of the knapping surface to converge distally on the cores. Twisted flakes are usually employed to manage the latero-distal convexities of the core, where a perpendicular surface is opened.

Retouching flakes and undiagnostic *façonnage/débitage* products

Diagnostic retouching or resharpening flakes were identified with about 130 pieces (Table 1), probably widely underestimated because of size limitation, as also confirmed by the high frequency of bone retouchers (more than 300: Martellotta et al. 2021) and by the observation of lithics < 20 mm in length. Those that have been recognized are mainly represented by the types II–III, which are detached from scrapers' edges after other retouching cycles, and types IV–V or *reaffutage* elements as described by Bourguignon (2001) (Fig. 14). These flakes are characterized by proximal lip, large and linear platform, very open knapping angle, convex or arched profile, wide and oval shape or fan-shaped, and evidence of previous detaching negatives on the dorsal surface. In some cases, these flakes concur to remove large portions of edges or tips belonging to simple or convergent scrapers (type IV

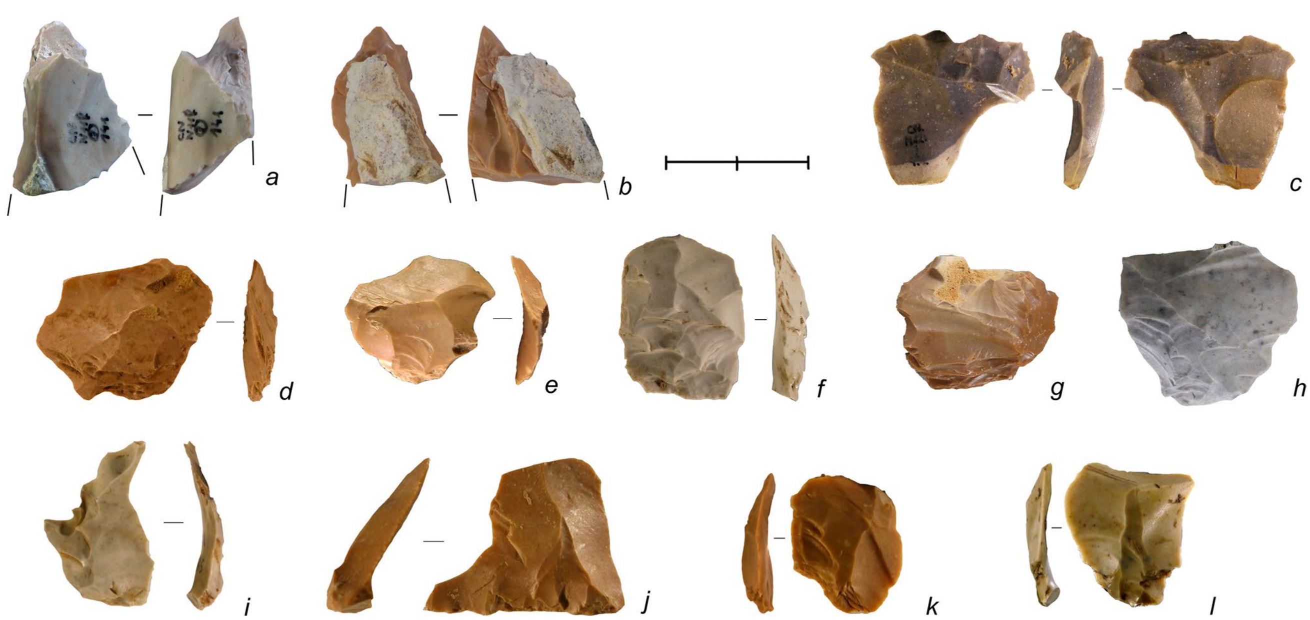

Fig. 14 Rejuvenation/resharpening flakes (**a**, **b**) and retouching flakes (**c**–**l**)

reaffutage flakes: Fig. 14a, b); in the same way, resharpening flakes having flat and thicker platform would considerably affect the edges of the interested tools by forming large notches (type V *reaffutage* flakes: Fig. 14f, j). These cases could represent retouching errors that, as a result, make the tool unusable, or they were more probably intended to totally renovate and recycle the tool, thus changing its first function.

The variety of knapping systems attested in De Nadale gave life to a wide range of bladelets or thin flakes from flat and wide surfaces, presenting linear or punctiform platforms but not directly associated to tools' retouching. Most of these blanks is obtained through direct percussion carried out with soft hammer possibly made of limestone or, alternatively, the same bone tools used for retouching. In fact, at least 230 knapping products displaying the intact proximal end show clear features related to this technique, including prominent lips and flat percussion bulbs. It should be mentioned that these flakes are, on average, thinner than the others (24.9 × 21.4 × 5.8 mm), and only few of them bear traces of retouch. These blanks have been defined as undiagnostic *façonnage/débitage* products, since they can be referred to both the exploitation of mixed matrices core tools, and to the knapping of surface-oriented cores as well as atypical Quina cores. In fact, also the latter were sometimes knapped through soft hammer, possibly giving birth to comparable flakes.

Bladelets

About 55 bladelets or lamellar flakes are present in De Nadale lithic assemblage (Fig. 12j–x). Generally, these are rather small, short, and relatively wide, measuring on average 26.9 × 11.1 × 4.1 mm. Some recurrent types have been recognized:

- The first type includes short bladelets with a convex, distal profile, and open knapping angle. These blanks are obtained from retouched core/tools (*limaces*) and peripheral Quina cores, especially from the narrow fronts, thus exploiting the available thickness and referred convexity of the original blank source (Fig. 12j, l–q, v).
- The second type concerns bladelets obtained from the exploitation of lateral edges or planes on surface-oriented cores. These frequently have one thicker side or a triangular cross-section, since they are obtained from prominent ridges. In several situations, they are hint of the migration of the exploitation on these surfaces: in these cases, they record a considerable lateral twist (Fig. 12k, t, u, w, x).
- Rare bladelets, bigger but always fragmented, recall volumetric core-knapping possibly on earlier stages of reduction; however, they are not documented in the De Nadale core assemblage (Fig. 12r, s).

Use-wear analysis

Use-wear analysis was performed on a total of 28 artifacts, including Quina scrapers ($n = 11$), demi Quina scrapers ($n = 7$), and *reaffutage* flakes ($n = 10$). In 20 cases out of 28 diagnostic traces were identified, only in 2 cases the observed wear was not considered diagnostic, while on 5 implements any use-related damage was recognized (Tables 5 and 6). Within the utilized tools ($n = 20$), in 7 cases out of 21, functional analysis comprised the examination of both edge damage and micro wear, while for the remaining 14 items the state of preservation of the surfaces allowed only the analysis of edge damage.

The most common PDM observed is a glossy appearance of the surfaces. This kind of surface alteration is due to both chemical and tribological disturbances affecting the artifacts during their deposition (Burroni et al. 2002; Caux et al. 2018; Galland et al. 2019). In particular, pedogenic processes, such as solifluction and bioturbation, are commonly associated to glossy appearance (Burroni et al. 2002; Caux et al. 2018; Galland et al. 2019). Other kinds of PDMs observed at De Nadale include surface patination, specifically white patina caused by the presence of water in the archeological deposit, as well as soil sheen and thermal alterations.

Quina and demi-Quina scrapers

At De Nadale, Quina and demi-Quina scrapers were mostly ($n = 9$) employed through transverse gestures related to scraping activities. Instead, evidence of longitudinal motions, associated to cutting activities, are identified on 3 scrapers, while only in one case (tool 141) it was not possible to assess the gesture performed. The characteristics of micro scarring and the degree of edge rounding observed on the tools indicate that most of the Quina and demi-Quina scrapers were utilized on materials of soft ($n = 5$), medium soft ($n = 3$), or medium hardness ($n = 4$). Feather terminating scars along with low degree of edge rounding are hints of the processing of soft tissues. In one case (tool 4), a band of micro polish with smooth texture and a domed topography has been recognized, suggesting the contact with medium/soft materials of animal origin, possibly hide (Fig. 15a). Low degree of edge rounding with small feather and step scars with transverse orientation are related to the working of medium/hard matters (Fig. 15c). On tools, 28 feather terminating micro scars and a medium/high degree of edge rounding are combined with the presence of a band of micro polish with a smooth texture and a domed topography, features

Table 5 Quina and demi-Quina scrapers with diagnostic use-wear. *St* straight, *Cx* convex, *Cv* concave, *Ir* irregular

Artifact ID	Type	Status	PDM	FA morphology (delineation /cross-section)	Edge damage	Micro wear	Use-wear location	Gesture	Worked material
3	Quina scraper	Preserved	Severe glossy appearance	St / Cx-Cx	Small feather scars with a transverse orientation Low degree of edge rounding	NA	Dorsal edge surface	Transverse	Soft
4	Quina scraper	Preserved	Severe soil sheen	St / St-St	Small feather and step terminating scars with transverse orientation High degree of edge rounding	NA	Dorsal edge surface	Transverse	Medium soft
148	Quina scraper	Preserved	Severe glossy appearance	St / St-St	Small feather scars with a transverse orientation Low degree of edge rounding	NA	Dorsal edge surface	Transverse	Soft
213	Quina scraper	Preserved	Light glossy appearance	Cx / St-St	Small feather scars with an oblique orientation Medium degree of edge rounding	NA	Dorsal and ventral edge surfaces	Longitudinal	Soft
401	Quina scraper	Fractured	Severe glossy appearance	Ir / Cv-Cx	Feather and step terminating scars with transverse orientation High degree of edge rounding	NA	Dorsal edge surface	Transverse	Soft
411	Quina scraper	Preserved	Soil concretion	St / St-St	Small feather scars with a transverse orientation High degree of edge rounding	NA	Dorsal edge surface	Transverse	Medium soft
656	Quina scraper	Fractured	Light white patina	Ir / St-St	Step and feather terminating scars with oblique orientation Medium degree of edge rounding	Band of smooth domed micro polish	Dorsal and ventral edge surfaces	Longitudinal	Soft animal material

Table 5 (continued)

Artifact ID	Type	Status	PDM	FA morphology (delineation /cross-section)	Edge damage	Micro wear	Use-wear location	Gesture	Worked material
28	½ Quina scraper	Preserved	White patina	St / St-Cx	Small feather and step scars with an oblique orientation High degree of edge rounding	Band of smooth domed micro polish	Dorsal and ventral edge surface	Longitudinal	Soft animal tissues
106	½ Quina scraper	Preserved	Severe glossy appearance	Cx / St-St	Step and feather scars with a transversal orientation Medium degree of edge rounding	NA	Dorsal edge surface	Transverse	Medium
141	½ Quina scraper	Fractured	Severe glossy appearance	Cx / St-St	Overlapping step scars with a transverse orientation High degree of edge rounding	NA	Dorsal edge surface	Transverse	Medium hard
413	½ Quina scraper	Preserved	Severe glossy appearance	St / Cv-Cx	Small feather and step scars with a transverse orientation High degree of edge rounding	NA	Dorsal edge surface	Transverse	Medium
501	½ Quina scraper	Preserved	Glossy appearance	St / St-St	Small feather and step scars with a transverse orientation High degree of edge rounding	Band of smooth domed-reticulated micro polish	Dorsal edge surface (edge damage) Ventral edge surface (micro wear)	Transverse	Medium vegetal material
949	½ Quina scraper	Preserved		Cv / Cv-St	Small step scars with a transverse orientation High degree of edge rounding	Band of smooth domed-cratered micro polish	Dorsal edge surface (edge damage) Ventral edge surface (micro wear)	Transverse	Medium vegetal material

Table 6 *Reaffutage* flakes with diagnostic use-wear. *St* straight, *Cx* convex, *Cv* concave, *Ir* irregular

Artifact ID	Type	Status	PDM	FA morphology (delineation /cross-section)	Edge damage	Micro wear	Use-wear location	Gesture	Worked material
141	Reaffutage flake	Preserved	Severe glossy appearance	Cx / St-Cx	Overlapping step scars with a transverse orientation High degree of edge rounding	NA	Dorsal edge surface	Transverse	Medium
17	Reaffutage flake	Preserved	White patina	St / Cv-St	Small feather and step scars with an oblique orientation Low degree of edge rounding	NA	Dorsal and ventral edge surfaces	Longitudinal	Soft
118	Reaffutage flake	Preserved	White patina	Cx / St-Cx	Small feather scars with an oblique orientation Low degree of edge rounding	Band of smooth domed polish	Dorsal and ventral edge surfaces	Longitudinal	Soft animal tissues
186	Reaffutage flake	Preserved	White patina	St / St-St	High degree of edge rounding	NA	Dorsal and ventral surfaces	Indeterminable	Medium hard
865	Reaffutage flake	Preserved	Severe glossy appearance	St / St-Cx	Step scars with an oblique orientation Medium degree of edge rounding	NA	Dorsal and ventral edge surfaces	Longitudinal	Medium
905	Reaffutage flake	Preserved	Severe glossy appearance	St / St-Cx	Feather and step scars with an oblique orientation Medium degree of edge rounding	NA	Dorsal surface	Longitudinal	Medium
958	Reaffutage flake	Preserved	Glossy appearance	St / St/Cx	Small step and feather scars with an oblique orientation Medium degree of edge rounding	Band of smooth domed micro polish	Dorsal and ventral edge surfaces	Longitudinal	Soft medium animal tissues

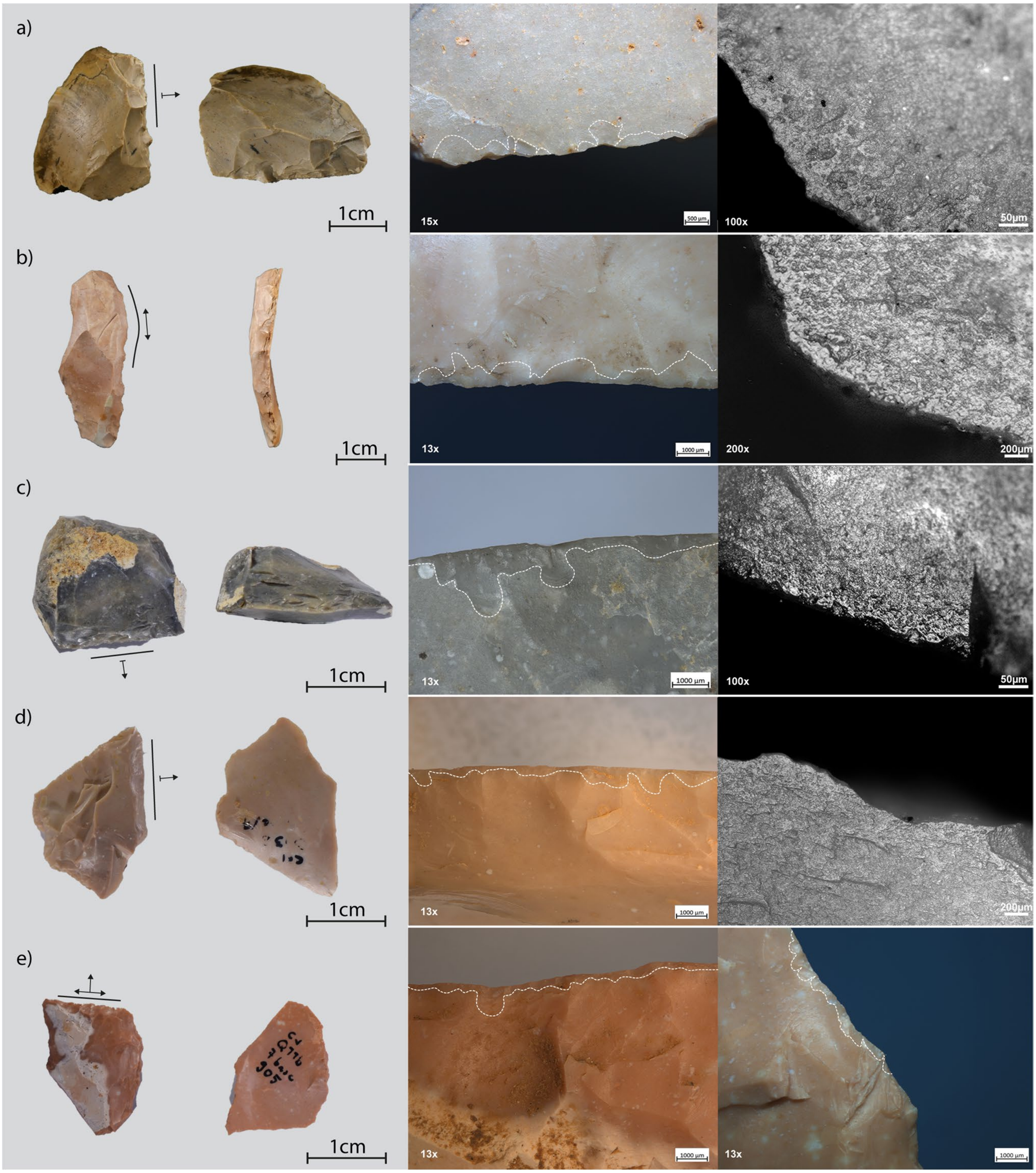

Fig. 15 Example of edge damage and micro wear identified on Quina scrapers and *reaffutage* elements from Nadale Cave. **a** Quina scraper used for scraping hide; **b** Quina scraper used to cut vegetal matter; **c** Quina scraper used for scraping material of medium hardness; **d** *reaffutage* elements used for scraping animal tissues; **e** *reaffutage* element used to work soft materials through mixed gestures

related to the working of animal skin at a fresh state. Step terminating scars and a high degree of edge rounding are typical of medium and medium hard matters. In two cases, on tools 501 and 949, these edge damage patterns are associated with a smooth micro polish with a domed/reticulated topography related to the processing of vegetal materials such as wood or woody plants (Fig. 15b).

Reaffutage elements

Traces of use have been identified on 7 *reaffutage* flakes coming from De Nadale cave. In all the instances, the wear is localized over the "new" edge of the flake and not on the "original" Quina one. The distribution and orientation of the wear identified on the tools indicate that 6 out of 7 tools were used to perform longitudinal gestures associated to cutting. In one case (tool 958), wear characteristics reveal the use of the tool in mixed gestures involving both longitudinal and transverse motions (Fig. 15e). As in the case of Quina and demi-Quina scrapers, the functional interpretation is based on edge damage, due to sever PDMs affecting the artifacts surfaces, which limited the identification of micro wear to three implements (tools 14, 118, and 958). The majority ($n=5$) of the *reaffutage* flakes were used on materials of medium hardness. Two implements were employed on medium soft and medium hard substances, respectively, while 2 flakes exhibit traces associated with the working of soft materials.

Step terminating micro scars associated with medium to high edge rounding degree are related to the processing of medium materials (Fig. 15d). In one case (tool 14), edge damage is associated with micro polish characterized by a smooth texture and a domed topography generated by the contact with animal tissues. Small feather terminating scars and a low to medium degree of edge rounding are related with the working of soft materials. In one instance, tool 118, micro wear has been identified along the edge, consisting in a band of micro polish with a smooth texture and a smooth topography. Such a combination suggests the working of soft and medium soft animal tissues.

Points of discussion

Technological trajectories at De Nadale in the Quina context

Some core reduction procedures recognized at De Nadale display similarities with the Quina knapping method, particularly with the alternate knapping systems described by Bourguignon (1996; 1997). Among the common criteria shared by the peripheral and polyhedral cores, we emphasize the construction on two or more adjacent surfaces, one of which (surface B) is strongly inclined compared to the first. These two planes form a rather narrow dihedron whose angle is maintained by percussive detachments of artifacts characterized by open knapping angles and inclined planes; these artifacts are both technical products and end-products which exploited the major axis of the core. According to known behaviors, at the beginning, the two surfaces are perpendicular and then one gradually tilts forming the asymmetrical dihedron (Bourguignon 1997).

The alternating and concatenated exploitation of the two main surfaces, having different roles within the reduction system, is consistent with the documented already existing about Quina method (Bourguignon 1997, 1996; Hiscock et al. 2009; Turq 1992). However, compared with the main French sites, some important variations must be mentioned. In these cases, surface A is often characterized by intense exploitation, yielded from many peripheral poles and percussion planes with equally numerous series of products; on the contrary, surface B is rarely exploited on the entire periphery, since a natural, decentralized cortical part is often left over (Bourguignon 1997: page 91). At De Nadale, considering peripheral and *limace* cores, surface B is peripherally and deeply exploited while surface A, being flat, rarely produced blanks and was mainly used as striking platform (Figs. 2 and 3). However, the main difference regards the productive stage, which implies different gestures as well. In De Nadale, the thick blanks derived from the lateralized and invasive exploitation of surfaces are few represented from the last stages of core knapping, deriving probably from earlier stages. At the end, mainly thin and convex flakes are obtained from cores that often have a double core-tool function. The strictly Quina blanks could represent the first stage of these core tools, as well as of many scrapers or other retouched tools; however, they are introduced in De Nadale possibly already detached and modified, and there finally exploited. The Quina reduction of cores, intended in all of its strict criteria, is carried out only to a lesser extent within the site.

In the western European sites, the production in alternate lateralized series is emphasized as one of the main criteria of the Quina production (Bourguignon 1997; Folgado Lopez 1994). Lateralized knapping on the surfaces is hardly recognizable at De Nadale due to covering detachments on the surfaces, extremely small cores and lack of articulated refittings, among others. For this reason, it is not always possible to reconstruct the phases of primary production outside the site, although the lateralization of the products is confirmed by several flakes with natural or technical back on one edge. Some rare asymmetrical dihedral platforms and the typical "*talon à pans*," shaped as a consequence of this action, are also present at De Nadale (Fig. 13m, n). These data lead us to think of an episodic adoption of this technical criterion, probably due to the difficulty to apply it to the De Nadale small-sized blanks, and to the different strategies characterizing the final exploitation of blanks as core tools.

As a matter of fact, the most evident feature shared between De Nadale and the Quina systems is the ramification cycle, especially the type-C ramification, for which the same long-lived blanks (mainly *limaces* or Quina scrapers) are considered both cores and tools. This is a typical behavior recorded within Quina techno-economic systems (Bourguignon et al. 2004), besides retracing the Quina production in the volumes and in the relationship between knapping faces, even not in the gestures and knapping techniques.

Core-reduction strategies are varied, including different adaptations to surface-oriented expoitations, which share with the Quina systems the recurrent opening of orthogonal and lateral planes. Within Quina cores, this behavior is leading up to the so-called polyhedral cores and concurs to create a new asymmetrical dihedron between the surfaces (Figs. 4–5). This variant is akin to the definition of Bourguignon's "third alternative" (1997: page 110), consisting in the opening of surface B from another pole of the block, adjacent or opposite to the first one. The multidirectional cores of Combe Grenal level 22 and Roc de Marsal also attest an analogous behavior (Turq 1992): this "organized *débitage*" pivots on the frequent displacement of the striking platform either positioned on the same planes or on different ones, on roughly perpendicular surfaces. Sometimes, the exploitation is rather opportunistic, while others is organized in consecutive detachments with different technological value. Although this concatenation of orthogonal planes is present at De Nadale, sometimes it applies on cores previously knapped on single surfaces, with the already mentioned variant of a lateral edge/plane. This variant is especially applied on a final stage, with the production of curved or twisted elongated flakes and bladelets whose detachment follow the original striking platform.

These cores could also show technical behaviors that are interconnected with other systems: at Combe Grenal, when a peripheral plane is no longer exploitable, the block is broken on purpose in order to create a new striking platform from the fracture. A refitting from De Nadale from a core exploited on surface, then with lateral exploitation and finally on a fragment of the original core attests this practice, although it is not possible to know whether the fracture is intentional (Fig. 5).

Productive implication and technological branching

In the classical Quina assemblages, a special importance is given to the final objective of the technical systems: thick and short flakes. However, this same goal is shared with some non-Quina systems, such as the Clactonian/SSDA and the Tares *débitage* (Bourguignon 2001, 1996; Forestier 2009; Geneste and Plisson 1996; Hiscock et al. 2009; Turq 1992), as well as the discoid technology (Delpiano and Peresani 2017; Peresani 2003). This type of flake, characterized by a markedly asymmetrical triangular cross-section and, often, by a natural or knapped back, is not the only type of product obtained in De Nadale. The set of Quina or not-Quina blanks is wider, including also several thin flakes and bladelets (Fig. 12). This toolkit, fully attested at De Nadale, allowed the production of a diversified set of usable or potentially retouchable blanks obtained in different ways.

First of all, in classical Quina systems, flat surface A and steep surface B, having distinct purposes in the technological system, usually generate different types of blanks (Bourguignon 1997). This variety can also take place consequentially during the various stages of production. For instance, the two sequential production stages recognized at Roc de Marsal and Mas Viel are oriented towards different objectives: in the first site backed flakes (with natural, knapped, or "enveloppant" back) were the goal, while in the second, undifferentiated flakes and *debris* were produced (Turq 2000). Moreover, looking at De Nadale assemblage, it is evident the double productive value of the attested production systems, empirically recorded on the variety of the flake blanks (Figs. 12, 13 and 17). This dualism was also due to the knapping techniques used: namely, direct percussion with hard hammer and direct percussion with soft hammer. The flakes obtained showed different techno-morphological features:

- Thicker products, with flat or natural platform, often equipped with a back and wide and asymmetrical triangular cross-section. The knapping technique is the direct percussion with hard hammer. For their potential of retouching and the fact that they were almost always chosen to be retouched, these are considered long-life implements.
- Wide and thin products with a convex section, often characterized by thin and linear platform, wide knapping angle, and a prominent lip. These features suggest a soft hammer percussion. These blanks are considerably less suitable to be retouched. In some cases, their shape could be more elongated or bladelet-like, especially when produced after the narrowing of the surfaces or on pronounced edges. Conversely, these are considered to be short-life implements.

This double and diversified productive value has to be correlated both on the organization of the reduction systems on different surfaces or different lateral and orthogonal planes, and on the variety between the reduction systems. However, it is the technological branching of core tools which above all is at the basis of this differentiated productivity.

As a matter of fact, a way to obtain a wide range of blanks is the reduction and thinning of the largest flakes and tool cores (Fig. 16). At the most-known Quina sites, the initial flakes, obtained from the core initialization or after the turning of the striking platform, were often reduced as cores,

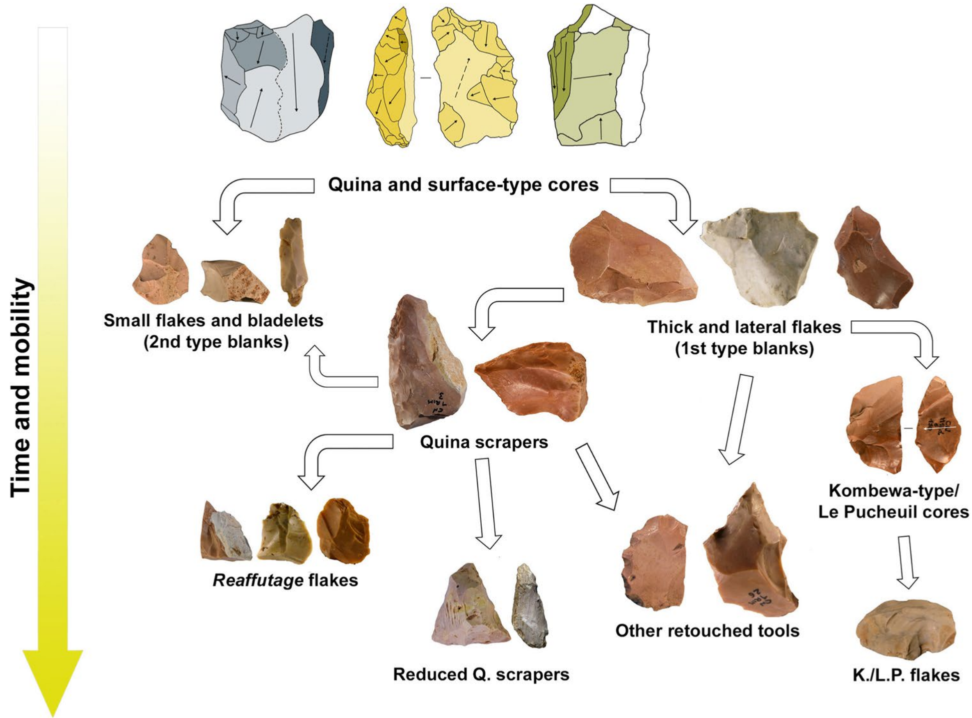

Fig. 16 Scheme reassuming the development and interconnection of core and flake-blank reductions in De Nadale, showing the concept of branching within the Quina knapping systems. The productive potentiality of different types of cores is gradually replaced by large flakes and Quina scrapers, able to originate diverse blank types

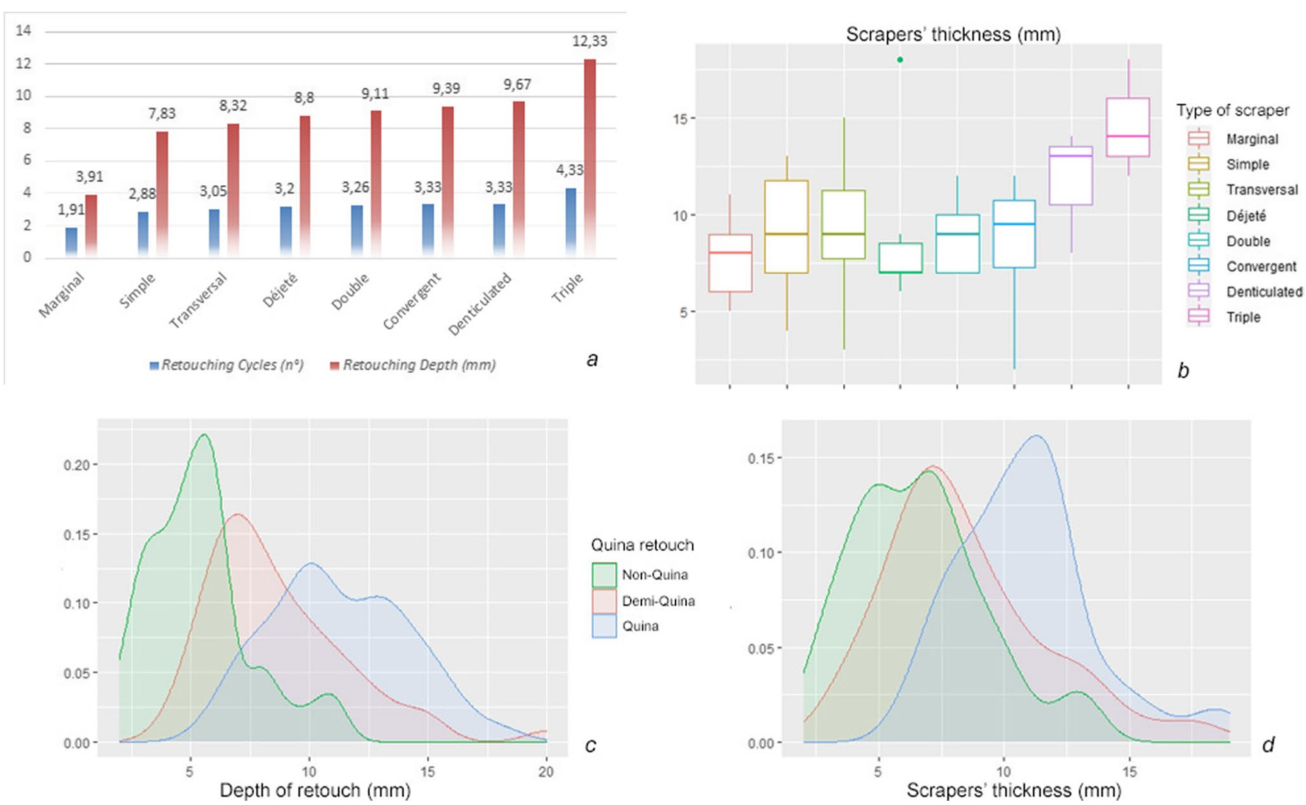

Fig. 17 Depth of retouch recorded on scrapers in respect to typology (**a**) and presence of Quina or demi-Quina retouch (**c**); thickness of scrapers in respect to typology (**b**) and presence of Quina or demi-Quina retouch (**d**)

both on the ventral surface (Kombewa-type method) and on the flake thickness (Le Pucheuil method). Flake cores could also be reduced in accordance with the classical alternating modalities ("production 2" for Bourguignon et al. 2004). The conception of flakes as productive matrices is especially attested at Combe Grenal level 22, where 27% of the total cores are flakes. These are frequent also at Roc de Marsal liv. 2–4 (Turq 1992), as well as at La Quina, Petit Puymoyen, Hauteroche, Combe Grenal, La Combette, and Mas Viel. All of these sites show very different behaviors regarding the reduction of blanks and the manufacture of retouched tools (Bourguignon 1997; Texier et al. 1998; Turq 2000). The two main classes of blanks derived from the first productive diversification are in this way intertwined: the first type of flakes is exploited to produce the second type, as in the first level of Quina technological branching or "production 1" (Bourguignon et al. 2004), also called "Type C ramification," considerably recorded in De Nadale.

Although cores on flakes, even considerably reduced, are generally present in Quina assemblages, 1st- and 2nd-generation kombewa-like flakes are comparably few (Turq 2000). At De Nadale, the collection counts about eighty kombewa-like flakes and a dozen of Le Pucheuil-derived flakes. The formers were retouched in 15% of cases and, occasionally, they were modified in simple or transversal scrapers (and a retouched point). The retouched Kombewa-type flakes were chosen among the largest and thickest blanks (6 mm on average). Most of them, left unretouched, responds to the features of short-life tools. Even Le Pucheuil–type flakes are not retouched, according to the concept of a technological system with immediate potential/quickly exploitable, although aimed at producing blanks useful for diversified activities (Lazuén and Delagnes 2014). In any case, this is a system rarely employed at De Nadale, attested by few products and, possibly, only a single core on a percussion cone, exploited in the cross-section taking advantage of its thickness (Fig. 8). Aiming to the optimization of the available volume of raw material, this instance is consistent with the behavior identified at the eponymous site, where even maintenance flakes or knapping errors were exploited for this purpose (Delagnes 1993).

Besides large flakes reduction, at De Nadale, mostly a double exploitation of blanks as tools and cores is attested, following both alternating and replacing modalities. An emblematic example is limace cores (Figs. 2 and 3). These follow the volumetric criteria of the Quina alternated cores but display techno-functional features proper of retouched tools, also confirmed by the technical investment on their working edges. In the same way, several cores were transformed into active tools after the sudden change of functionality of edges through the retouching (Fig. 3c). On the contrary, other retouched tools underwent to a change of function as they were recycled into cores, as attested by the last detachments (Fig. 3a, b). However, the most representative blanks with this double purpose are Quina and demi-Quina scrapers, many of which probably worked as matrix/cores during their use-life as a tool (Fig. 16). The production of suitable flakes from Quina scrapers, sometimes further transformed into retouched tools, is a technical trait attested in all the classic Quina sites (Bourguignon 2001, 1997; Bourguignon et al. 2006, 2004; Cuartero et al. 2015; Faivre et al. 2014; Geneste and Plisson 1996; Lemorini et al. 2016; Lenoir 2004; Meignen 1988; Rios-Garaizar et al. 2015; Turq 2000). This behavior is confirmed at De Nadale by the large detachments on the upper and lower faces of scrapers, and obviously by the use-wear found on seven retouching flakes and by the retouch on some *reaffutage* elements. Moreover, some retouching flakes are similar to the thin ones produced from the wide and flat surfaces of atypical Quina and surface-oriented cores, following the same curved profile: the steeper angle between the platform and the dorsal surface, together with the lack of retouching scars on the same surface, helps to differentiate the two classes of flakes. However, thin flakes from diverse cores reduction resemble "type 0" *reaffutage* elements as described by Bourguignon (2001). Their similarity is due to the aforementioned volumetric analogy between cores and Quina scrapers, and to the use of soft hammer percussion technique (Martellotta et al. 2021). In fact, in most of the Quina assemblages, the dualism hard hammer/soft hammer characterizes the *débitage* and the retouching stages, while at De Nadale it is present throughout the whole reduction systems. For these reasons, only few conceptual differences distinguish the reduction of cores and thick blanks. Thus, long-life tools (*limaces*, Quina, and demi-Quina scrapers) replaced cores as well-prepared and mobile elements to be reduced with the same techno-economic systems (Bourguignon 1997; Bourguignon et al. 2006; Meignen 1988; Turq et al. 2013). This allows to obtain short-life tools at different times, while long-life tools were produced at the beginning of reduction sequences, relatively few represented in De Nadale, becoming themselves the pivot of technological investment. Finally, the diversification of goals at De Nadale is also fulfilled by the adoption of other methods in addition to the Quina and ramification-based ones. Some of these systems, particularly the surface-oriented ones, could produce the same thin blanks. The last stage of these cores often concerns the reduction of lateral edges, which allows the production of elongated flakes and bladelets. In many cases, these blanks are not distinguishable from those derived from type C ramification.

Other Centripetal reduction systems on surface are present, such as the Levallois and a rarer Discoid, recorded with both the unifacial and bifacial variants. In some instances, the Quina and Discoid methods coexist in the same assemblages, like at Sous les Vignes (Turq et al. 1999) and Espagnac (Jaubert et al. 2001). The recurrent centripetal Levallois, here relatively common, usually represent a faint minority in the western European Quina assemblages, when it is not lacking at all. In particular, the Levallois system is present at Cova Negra (throughout the sequence), Combe-Capelle bas layers 4–5, Mas Viel, La Combette (Dibble and Lenoir 1997; Folgado Lopez 1994; Texier et al. 1998; Turq 2000; Turq et al. 2011). Furthermore, it is documented at Esquicho Grapaou and Petit Puymoyen—although intrusive—where isolated blanks and cores are not considered to be relevant for the technological classification of the assemblages (Bourguignon 1997). Levallois technology is more common within the Eastern Charentian, a "catch-all" term identifying Mousterian complexes in the Balkan peninsula characterized also by the presence of Quina tools. Charentian assemblages dated from the end of MIS 5 and the beginning of MIS 3 can be found between the northern Balkans and the Pannonian basin. These lithic industries share some techno-typological features with De Nadale, such as the layer 4 of Pesturina cave (Mihailović et al. 2021) or the assemblage from Erd, which attests a Quina technology on pebbles together with a more surface-oriented, "discoid" technology (Daschek and Mester 2020). In eastern Hungary, the Quina complex is reported in Subalyuk layer 11, dated approximately to MIS 4 (Mester 2004). Although the Levallois is absent within the main western European sites defining Quina techno-complex while it is present in the less specialized assemblages, it must be specified that in the Italian peninsula, the few documented Quina assemblages (Fumane BR4, BR5-BR6 and Paglicci external rockshelter layer 2) lack of Levallois traits (Galiberti et al. 2008; Lemorini et al. 1998-9; Peresani 2012). At De Nadale, there is possibly a partial intrusive feature of Levallois sequences, even if it is certainly present: about 20 centripete Levallois blanks are retouched (i.e., the large majority of the flakes), while the few cores found are largely exploited. Moreover, some of these products could also derive from exogenous introduction or reuse: this is the case of a scraper characterized by a double patina, manufactured on a recycled Levallois flake (Fig. 9l). This evidence is similar to the evidence from Fumane and other Levallois or Discoid technologically featured sites found in the same region of De Nadale (Peresani et al. 2015).

Functional meaning of Quina products and by-products

Given these premises, what were the objectives of the Quina technological systems? Despite the variability of the obtainable blanks, the interest is polarized by the high percentage of retouched tools. The blanks chosen for this further working were mostly those showing a high retouching potential, i.e., the aforementioned "first type" blanks (Table 3). Speaking of percentages, it is difficult to quantify how much of the whole assemblage was retouched. Considering the products of the entire reduction sequence—including cortical flakes and the "second type" blanks—less than half of the artifacts are retouched. Instead, without counting the flakes obtained with soft hammer percussion and the thin pieces (less than 8 mm), the retouch ratio raises to about 2/3 of the available blanks. Most of the products that did not undergo this working were in fact small and thin maintenance elements or cortical flakes, which lacked the volume needed to manage further edge resharpening. This ratio falls fully within the percentages of retouched flakes in the Quina assemblages, calculated from the half to ¾ of the total blanks (Turq 1992), or even more if we consider only the Quina technological flakes (Turq 2000). This also is significant in relation to the main activities carried out at the site, as confirmed by the remarkable presence of bone retouchers (more than 300) and about 230 large retouching and resharpening flakes (> 2 cm) of type 0–II–III–IV "*Bourguignon* sensu" (Bourguignon 2001; Martellotta et al. 2021). A topic worth addressing is the retouched tools typology, especially in relation to function: are these two aspects actually related or tools manufacture depended on other dynamics? Scrapers represent the large majority of tools, with an eloquent ratio with the denticulated tools of six to one (Table 2).

It must be specified that many of the denticulate/notches are scrapers (see denticulated scrapers), where the denticulated edge was the result of the detachment of deeper "type V" resharpening flakes (Bourguignon 2001). This process is aimed to produce usable flakes or recycle the scraper by changing its primary function, following the so-called scraper denaturation (Claud et al. 2012). However, some scholars suggested that such flakes could be produced during the ordinary resharpening process, i.e., for creating a suitable convexity of the working edge (Rios-Garaizar et al. 2015). In any case, the two tool-type manufacturing could be deeply intertwined, being part of the system of long-life implements/matrices.

This group of tools is perfectly represented, as already pointed out, by the Quina and demi-Quina scrapers whose incidence within the total amount of scrapers is moderately high (slightly less than 40%) (Table 2). This situation is alike of few less than those Quina techno-complex assemblages where the reduction of raw materials and blanks is quite significant (Mas Viel, Marillac, La Quina, and Petit Puymoyen) but greater than sites with little tool reduction such as Roc de Marsal (Bourguignon 1997; Turq 2000). Similarly, complex tools are well represented at De Nadale: among these, scrapers which highly retouched edges or diverse types of retouching, such as backed tools/scrapers, the aforementioned scraper cores, and a bifacially worked, convergent scraper. It is worth to mention the 25 thinned scrapers, mainly demi-Quina or Quina types, whose typical working on the lower surface could possibly serve to improve manual or mechanical prehension, or again to obtain functional products.

Therefore, on one hand, a clear preference for long-life curated tools (sensu Binford 1979)—represented here by scrapers bearing several stages of retouch and resharpening—can be found at De Nadale. The variety in their shape is a consequence of these working-recycling stages but it also depended on specific morpho-functional goals (Dibble 1987; Hiscock et al. 2009; Hiscock and Clarkson 2017; Mellars 1992). For instance, Mas Viel's flat flakes were chosen for double-convergent or *dejété* scrapers, while thick cortical quinoid flakes were modified/transformed into simple or transversal Quina scrapers (Turq 2000). At De Nadale, composite scrapers present, on average, more retouching cycles and a more profound retouch on the dorsal surface if compared to the "simple"-type scrapers, suggesting that a more complex use-life led to their forms (Fig. 17a). However, the typological choice might also be related to the initial blank morphology and to the availability and position of the functional edges. Backed flakes were preferred for simple or transversal types (reduced sometimes in *dejété* type), while cortical and unidirectional flakes for double scrapers. Quinoid flakes were used for all the scraper types, whereas simple scrapers are usually manufactured on a large variety of blanks (Table 3). Among these, the Quina and demi-Quina scrapers were obviously produced on the thickest blanks, mainly chosen among backed flakes, cortical flakes, or undifferentiated Quinoid flakes (Tables 3 and 4 and Fig. 17d).

The frequency of Quina and demi-Quina scrapers at De Nadale and other similar assemblages must be discussed in relation to their functionality. According to published data, there seems to be no functional consistency: different purposes are identified, mainly including them in the category of tools employed in heavy duty tasks. In several occasions, this multifunctionality is documented on the same specimens: large Quina scrapers with edges with different functions coexisting within the same tool have been recognized at La Combette (Texier et al. 1996). However, unretouched flakes were selected for butchering, while traces on scrapers suggest transverse movements on hide (in the different working phases, from wet to dry hide) and vegetal materials. The same functions have been recognized on the scrapers from Jonzac (Claud et al. 2012) and on medium-large size Quina and demi-quina scrapers from Fumane. These were selected for working (both scraping and cutting) hard/resistant materials such as wood and dry skin; in less cases, they were used for butchering mostly small size preys, where the contact with the carcass and therefore with hard materials is more common (Lemorini et al. 1998-9). The diversification in their function is supported by the variety of the conformation of the working edge (whose cutting angle ranges from 40° to 75° and more) and their shapes: convex edges were preferred for scraping, while straight edges (and rectilinear-concave in section) for cutting, as found both at Fumane and Fond des Blanchards (Lemorini et al. 1999; Lhomme et al. 2007). With regard to processed materials, use-wear from La Quina site pinpoint to especially hard/high silica matters—as wood and herb processing and also gymnosperm tissue residues (Hardy 2004). Scrapers from Combe Grenal (levels 21–24), many of which bear Clactonian notches, confirm the scraping and planning of wood but also hide working and especially the processing of coloring materials, of which they sometimes preserve residues. This peculiar use has been connected to the working of animal skin as well (Beyries and Walter 1996).

In the De Nadale lithic assemblage, the analyzed sample of Quina and demi-Quina scrapers confirms their use in transversal motion activities, recognized on 9 out of 12 tools where it was possible to assess the use gesture (Table 5). In these cases, their employment was focused on soft or medium hardness materials, and especially on soft tissue as suggested by feather terminating scars and by the low degree of edge rounding. In one case, animal's soft materials were recognized, and in another instance micro-wear features might relate to the working of animal skin at a fresh state. In two occasions, the traces of medium hardness matter led to hypothesize the processing of vegetal materials such as wood or woody plants. The functional goals and the processed materials are consistent with the published data from other sites, with a local preference for the processing of soft materials at the fresh state. The scrapers used with transverse motion have a diverse kind of edge shape, bevel, and cutting angles, while the three scrapers used with longitudinal motion are characterized by straight cutting edge, straight-straight bevel in cross-section, and more acute working angle, shaped by scaled, fan-shaped, and very invasive retouching scars.

This situation is strongly similar to the scrapers from Jonzac. At this site, scaled or marginal retouch, double-flat and symmetrical cross-section, and narrow cutting angles characterized the specimens used for skin cutting; instead, typical Quina retouch is less recorded for this function (Claud et al. 2012). Furthermore, experimentations based on the scrapers from the Acheulo-Yabrudian site of Qesem cave showed that, while Quina scrapers were often hafted and used for the scraping of medium-hard material such as wood and dry skin, less standardized demi-Quina tools were preferentially used freehand for the scraping or the cutting of meat, skin, and vegetal materials (Agam and Zupancich 2020; Lemorini et al. 2016).

Hence, it is clear that Quina scrapers do not have a fixed function. As a matter of fact, the Quina retouch permits the user to adjust the edge angle, bevel, and shape, and therefore to modulate the effectiveness of scrapers with respect to the needed function. It has also been suggested that Quina retouch was suitable for cleaning and removing of soft tissue or fatty matters after butchering or hide processing (Preysler and Santafé, 2003). Some scholars proposed that this peculiar type of retouch, together with the thickness of the quinoid blank, allowed to maintain a constant cutting angle thanks to the combination of a flat and a convex surfaces on the bevel, sometimes achieved through the thinning on the lower surface (Bourguignon 1997; Iovita 2014; Lemorini et al. 2016). It has also been suggested that the typical detachment of stepped and hinged flakes on the retouched surface produce a concavity that helped to maintain the acute angle of the edge (Lemorini et al. 2016). Other scholars have shown that with different retouching cycles, the cutting angle increases while maintaining functional attitudes. In this way, they related the manufacturing of Quina scrapers to ecological and functional reasons (Lin and Marreiros 2021). In fact, this type of retouching permits an optimization of the use of the volume and thickness of the blank allowing more retouching potential (Turq 1989).

This feature is linked to the second purpose of these blanks: the matrix/volume of raw material. In fact, where Quina and demi-Quina scrapers are not directly functional, they can originate flakes with different functionality (Fig. 16). In this sense, a nice example is still provided by the site of Jonzac, where beds of faunal remains derived from the butchering of animal carcasses are widespread. The main activities attested here are cutting soft and hard material recorded on implements used in all the phases of reindeer carcass processing (Claud et al. 2012). The productive diversification of Quina systems, allowed by the branching at several levels, is well suited to the different needs thanks to the utilization of several *reaffutage* elements (retouching flakes, scrapers' denaturation flakes) for cutting and similar activities. On the other hand, scrapers were used, besides cutting and processing skin, even for percussion (likely to open bones for marrow extraction). Then, they were abandoned after the detachment of deep and internal flakes (Claud et al. 2012). Therefore, a limited but adaptable toolkit could be obtained from these versatile blanks.

At De Nadale, *reaffutage* flakes and minor elements (other retouched and few unretouched flakes) compensate for the heavy duty/scraping function of the scrapers allowing the effective performing of other activities, albeit recognized on a limited number of specimens. These all concerned the cutting of soft to medium hardness materials (Table 6). Animal soft tissues have been recognized among the processed materials, suggesting that these implements could have been highly effective during animal skinning and meat cutting, activities which required sharp and even small flakes with acute edges.

Once again, these data highlight a technological dualism typical of Quina-related complexes and associated to the productive branching: the separation between high potential and low potential products (Fig. 16). The former is thick quinoid flakes, which either could be used as different tools depending on their functional areas or the reduction stages according to the working edge, or could be reduced as a core/matrix. This is why the thick flake, transformed into Quina and demi-Quina scraper, was an independent source of a hypothetically complete toolkit. Low potential products are expedient and immediately usable items, which were usually not retouched. However, even these products were important in the economics of Quina production systems and for the activities carried out in the site. Despite the high percentage of retouched tools, the concept of the tool must not be limited to the retouched piece only (Texier et al. 1996): use-wear confirms this assessment, as well as the empirical analysis of knapping objectives. Retouching, especially the Quina type, concurs to identify the "curated/well-prepared" tool, which is transported or heavily transformed for functional or morphological purposes.

Finally, in some cases, even the second type blanks can be retouched, mainly with marginal or partial retouching. At Jonzac, unretouched small flakes were preferred for butchering and cutting meat. Instead, the tools used to work hide, even the smallest ones, were rigorously retouched to regularize the edge and prevent the hide from being damaged, and also to reshape the edge since hide processing is a highly wearing activity (Claud et al. 2012). If the frequency of the first-type blank suggests important ecological and mobility implications, the second type emphasizes the very high productivity requested by these assemblages, and the contingencies which led to a clear maximization of productive and functional efficiency. The main reasons probably must have to be found in the ecological and environmental context where the assemblages of Quina techno-complex are typical that is the topic of the next paragraph.

Ecological implications

Within the Quina assemblages, the high rate of retouched tools and the frequency of the eponymous type of scraper have considerably influenced the functional, ecological, and techno-economic interpretation of each human occupations, generally associated to high mobility and predetermined and organized subsistence strategies (Delagnes and Meignen 2006; Mellars 1996; Rios-Garaizar and Garcia-Moreno 2015; Rolland 1981). This seems to be particularly true since Quina sites, in south-western France, are usually characterized by monospecific faunal assemblages, specialized on gregarious and migratory species with seasonal rounds. In particular, reindeers were by far the preferred prey in most of Quina sites (Marillac levels 9–10, Roc de marsal, Combe Grenal levels 17–26, Pech de l'Azé IV, Jonzac levels 9–10-18–20-22–24, Hauteroche, Vaufrey), followed by horses (dominant in Puycelci and present together with reindeer in Espagnac and La Rouquette), and bovids, which are the most abundant prey at Sous-Les-Vignes and Mas Viel (see Delagnes and Rendu 2011 and Discamps et al. 2011 for review). Reindeers were largely dominant in Charente and Perigord regions, while in the southern plateaux of Quercy region, they were replaced by equids and bovids, probably following the local availability of game (Discamps et al. 2011). In any case, food resource management shows that the Quina system was adapted to high seasonal mobility based on the planned acquisition of migrating large ungulates (Delagnes and Rendu 2011). On the other hand, lithic raw materials indicate that local resources were preferably exploited, while non local materials increased with the deterioration of climate conditions, as it is recorded in Combe Grenal, Roc de Marsal, and Espagnac assemblages (Jaubert et al. 2001; Turq et al. 2017). Seasonal scheduling of mobility patterns does not necessarily correspond on the high distance but rather on the frequency of the regional displacements (Delagnes and Rendu 2011). On the other hand, in the Quina layers of Axlor site (B and D), in Cantabria region, human groups possibly planned their catchment strategies, moving around an extended territory in order to select game and lithic raw materials which would hardly be found in the surrounding of the site (Rios-Garaizar and Garcia-Moreno 2015).

Therefore, the relationship between the techno-economic behavior and the surrounding environment must be of primary importance. Paleoecological data contextual to human occupation at De Nadale describe a landscape characterized by open woodland formation and open dry meadows. This is suggested by large cervids and bovids (Livraghi et al. 2021), and small mammal association which includes *Microtus arvalis*, but also *Chionomys nivalis* and *Microtus agrestis*, two indicators of harsh climatic conditions (Amori et al. 2008; López-García et al. 2018). However, human groups settled the Berici area in MIS 4 at De Nadale and possibly at San Bernardino Maggiore cave, where the ephemeral traces of human frequentation dispersed in the loess sediments of unit IV have been framed within late MIS 5–MIS 4 through ESR dates and micro-mammal analysis (Gruppioni 2003; López-García et al. 2017; Peresani 1996). The terrestrial pollen sequences from the nearby Fimon Lake (Pini et al. 2010) and from Azzano Decimo in Friuli region (Pini et al. 2009) reveal for MIS 4 a mosaic of open forest and steppe with predominance of Pinus-Picea and abundance of Betula and herbaceous plants. Anthracological data from De Nadale reveal the preferential use of spruce/larch (Picea-Larix) as firewood together with cryophilous pines (*Pinus* tp. *sylvestris*) and birch (*Betula* sp.), but also a specimen of dogwood (*Cornus* sp.) (Vidal-Matutano et al. 2022). A persistent afforestation is documented in North-Eastern Italy, even during the Early to Middle Würm. Especially Berici hills may have favored the preservation of thermophile vegetation (*Tilia* and *Abies* sp.) and a certain related biodiversity, acting as a refuge area (Pini et al 2010). In addition, De Nadale cave opens towards the south on a tributary of a long valley cut (Val Liona) in the middle of the Berici hills, dominating valley bottoms and in proximity of the wide plateau above. This favorable location could have been suitable to control the movements of grazing large herbivores, such as aurochs and bisons, giant deers, and red deers, here attracted from water springs and bodies located at the valley bottoms (Livraghi et al. 2021).

The combined use of cementochronology and dental tooth analyses (meso- and microwear analyses) recently added some new information about the seasonality and the extent of the human occupation at De Nadale Cave. The study, carried out on a sample of large sized ungulate teeth, confirmed the paleoenvironmental reconstruction and indicated that the accumulation event(s) that lead to the formation of the faunal assemblage at the site lasted for a limited period in a time span of a year, less than or equal to a season. Thanks to the cementochronology techniques, these limited periods of time have been linked to the cold season, namely winter, with some minor frequentation during the good season (spring and summer) (Livraghi et al. 2022). The availability of food resources even in the sharpest phases acted as a strategic reason for the occupation of the region and site. Biodiversity also includes other kinds of foods, such as herbaceous plants. In fact, the oral microbiome of De Nadale's deciduous tooth contains streptococci that bind particularly to starches, suggesting a diet of starch-rich foods, possibly modified by cooking (Fellows Yates et al. 2021); moreover, the presence of an incipient caries suggests a diet that includes cariogenic carbohydrates (Arnaud et al. 2017).

The correlation with the site function is also necessary in order to embed the type of settlement within the territorial strategic system, which concur to shape the composition of the lithic assemblage, as the introduction and the carrying away of functional elements. Based on the currently available data, De Nadale does not seem to be a particularly specialized site: butchering activities are highly represented, as an over-representation of faunal remains in relation to lithic artifacts is documented, accompanied with the selective introduction of parts of carcasses of large cervids and bovids already disarticulated (Livraghi et al. 2021). A marked difference is therefore attested in respect to killing sites, such as Jonzac, where carcasses are represented in their entirety (Niven et al. 2012); similarly, differences are documented in intermediate/transit sites like Marillac, characterized by great number of prey and presence of poorest portions of not intensively exploited carcasses, indices of secondary butchery site (Costamagno et al. 2006). By contrast, De Nadale represents a site where the ultimate processing and consumption of meat and other nutritional parts are suggested by the selective introduction of the richest body parts of hunted game and the fragmentation of the spongy portions of bones (Livraghi et al. 2021). The site attests to a residential, short-term human occupation, which occurred after a regionally developed mobility, where the extreme reduction and finally the exhaustion of lithic raw materials took place, with the aim of processing animal remains. The human deciduous tooth also gives us information on the composition of the human group, which must have been complete, even if, given the size of the shelter, small in number (Arnaud et al. 2017). This seasonal camp site is therefore characterized by maintenance rather than extraction activities Binford sensu (Binford and Binford 1969).

An important aspect related to site function concerns the exploitation of lithic blanks, which is always intense. A specific feature of De Nadale lithic assemblage is the extreme reduction of cores and retouched tools, accompanied by the high rate of blanks transformed into tools. This may depend partly on the distance from the lithic sources and the relative scarcity of suitable materials in the strictly local area, with import from 10 to 15 km to the east, in the Berici-Euganei flint district, or from 30 to 50 km to the west, in the Lessini Mounts (Bertola 2016, 2001; Porraz and Peresani 2006). This marked reduction is thus indicative of a maximization of volume and productive potential, which is typical of Quina Mousterian and it is once again associated with strategies of intense territorial mobility (Delagnes and Rendu 2011; Turq 2000).

In this sense, it is significant the case of the most long-lived and portable elements, the Quina and demi-Quina scrapers. These tools were mainly produced before their introduction to the site, in the early stages of core reduction, as pinpointed by the high rate (between 50 and 70%) of cortical blanks used for their manufacture, which decrease to 20–30% among the other retouched tools and the *débitage* by-products (Table 4). Conversely, a technologically comparable site such as Roc de Marsal, although yielding all the stages of core-reduction on site, generally shows a higher cortical rates (between 70 and 80%), besides the presence of many retouched tools but not extremely reduced (Hiscock et al. 2009; Turq 1992). We think that at De Nadale both cores and tools—which were part of the portable toolkit—arrived on site already quite small/reduced, given the average size of debitage by-products (between 20 and 25 mm) and of retouched tools (up to 30 mm). This data may be due to several reasons, possibly related to the distance from the primary sources of raw material and to the cyclic and seasonal mobility systems which led the Neanderthals to the Berici hills from the Pre-Alps or the Lessini Mounts during the bad season. Therefore, while the production of starting and full *débitage* blanks is here poorly attested, the most common technological activities carried on site were the production of final *débitage* and resharpening/*reaffutage* elements, implying core-on-flake or core-on tool branching (Fig. 16). Likely, there is a tool preparation intended to be used within the cave or during the hunting-gathering expeditions nearby. The over 300 bone retouchers recovered in the site show a great percentage of concentrated and superposed percussion marks, indicative of an intense use of the bone blanks in retouching and/or knapping activities. Together with the hundreds of retouching by-products, these data suggest that the site was occupied when intense tool-wearing activities were being carried out, although, as we suggested, bone retouchers were probably useful both for the knapping of small cores and for tools' shaping (Martellotta et al. 2021).

The main activities performed on site or nearby, as displayed by the use-wear, were the processing, cutting, and scraping of mainly medium-soft and medium-slightly hard materials of animal origin and more rarely of vegetal origin. It is possible to guess that all the phases deriving from the processing of carcasses and related by-products mainly occurred at a fresh state. Faunal studies also suggest the intense fragmentation of bones' epiphysis possibly aimed at the extraction of fat or used as fuel (Livraghi et al. 2021), which is consistent with the hypothesis that during cold phases Neanderthal were processing faunal remains more intensively, as a response to increased nutritional stress (Hodgkins et al. 2016). In any case, systematic and wearing activities must have taken place, for which also the retouching of a few tens of bones diaphysis as scrapers was intended to be necessary, although their functionality still needs to be tested. The residential vocation (camp site) of the site is also suggested by the variety of blanks obtained with the Quina technology but also with other minor systems that allowed the production of flakes and bladelets, used unretouched or after further working on the functional edges.

Reference chronologies for Quina-related industries

Given the specificity of the technological and cultural traditions attested at De Nadale, it is clear how these differ from the fully Levallois Mousterian sites recorded in the Berici Hills, recalling at the same time more distant assemblages which are similar from a chronological and paleoenvironmental points of view. De Nadale layer 7 is, in fact, the first documented example of Quina Mousterian on the Berici Hills, albeit being atypical for the "classical" Quina complexes. However, the local chrono-cultural picture for MIS 4 is still sketchy/fragmentary. The most complete stratigraphic sequence in the area, San Bernardino cave, attests repeated frequentations of Levallois Mousterian during the final Middle Pleistocene (MIS 7 and 6) and MIS 3, while unit IV, dated between MIS 5b and early MIS 4, is archeologically poor (Gruppioni 2003; Peresani 1996). The sequence of Broion cave, in the north-eastern sector of Berici hills, should also cover the entire Wurmian cycle from MIS 5 to MIS 3, but the pedosedimentary data are not consistent with paleobotanical ones, which do not record the cold phase of MIS 4 (Cattani and Renault-Miskovsky 1983-4; Cremaschi 1990). In any case, the entire Broion sequence is characterized by few retouched artifacts mostly on Levallois blanks (Peresani and Porraz 2004). In the same region but 50 km to the north-west, in the Lessini Mountains, the long stratigraphy of Fumane cave includes the upper BR (breccias) levels, framed in MIS 4 after geopedological and faunal data, which show a replacement of cervids by caprids (Cassoli and Tagliacozzo 1991; Cremaschi and Ferraro 2006). Furthermore, BR 4–5-6 levels mark a clear caesura in the Levallois tradition previously attested at the site. They also differ from the subsequent Levallois and Discoid levels, confirming the presence of a Quina Mousterian characterized by a high retouching rate of flakes. The Quina knapping method is mainly recognized through the obtained blanks, defined by wide and flat platforms, orthogonal secant surfaces, asymmetrical triangular section, and often cortical backs (Lemorini et al. 1998-9; Peresani 2012).

Nearby Fumane, typical Quina scrapers are reported from the Ghiacciaia cave, inside layers of breccias attesting to an open forest environment. These and the upper loessic layers may be dated to the last glacial cycle, even if further investigations are needed (Bertola et al. 1999). Extending the reference area to the Italian peninsula, the Quina Mousterian is rarely attested. Its most significant example is the level 2 of Grotta Paglicci external rockshelter; despite that it has not being dated yet, the geopedological data might refer to an advanced moment of MIS 5 (Galiberti et al. 2008).

Quina technology is attested in some sites in northern Spain such as El Esquilleu Cave (layers XV to XI) and Axlor B and D (Cuartero et al. 2015; Rios-Garaizar and Garcia-Moreno 2015). Based on few dates and multi-layered sequences, Quina Mousterian should characterize a late phase of the local Middle Paleolithic, more or less around 50–45 ky (Rios-Garaizar 2017). However, the most substantial reference sites provided with a solid chronological framework are once again located in southwest France, despite some of these have been discussed. Nonetheless, Quina Mousterian can be found in recurring stratigraphical positions within the main and more complex sequences, prompting the creation of chronological models of Mousterian variability by Mellars (1969), which were then resumed by Jaubert et al. (2011) and Discamps et al. (2011). The first statistical chronological models based on limited sets of dates obtained with different dating methods have led some scholars to propose a chronological overlap between the Quina and the other Mousterian techno-complexes, especially during MIS 3 (Guibert et al. 2008; Vieillevigne et al. 2008). Recently, after extensive dating campaigns, other researchers have argued that the comparison of dates obtained with different methods, or after different preparations, can lead to the creation of erroneous models (Jacobs et al. 2016). The former one places the Quina Mousterian fully in MIS 3, between 57–54 and 43–39 ky (Guibert et al. 2008; Vieillevigne et al. 2008). According to this first thesis, there would have been any substantial differences with other techno-complexes such as the debated "MTA." However, "MTA" layers are always above Quina layers when both are present in the same sites, defining an abrupt change of faunas from reindeer to species characteristic of a more temperate environment (Delpech 1996; Discamps et al. 2011). In fact, new data resulting from chronological and stratigraphic revisions disagree with this first model, confirming the recurrence of the Quina Mousterian in more ancient phases at many sites, especially between MIS 4 and the beginning of MIS 3.

Among these, within the ensemble of sites of Pech de l'Azé, a clear trend with temporal patterning and succession of facies is recognizable (Jacobs et al. 2016). The Quina, although poor and not very distinctive, is framed between the very end of MIS 4 and the beginning of MIS 3 (57.3 ± 2.8 ky). To the same chronological interval belong the Quina layers of Marillac, dated through TL (57.6 ± 4.8 ky) (Frouin et al. 2017a), and La Quina Amont. In this site, the Quina layers from the southern area have been dated with OSL, TL, and IRFC (average age 63–56 ky), before the Levallois and Discoid techno-complexes attested in the northern area during MIS 3 (Frouin et al. 2017b). On the other hand, at Combe Grenal, the Quina Mousterian covers the second half of MIS 4 (Faivre et al. 2014), and the TL dates from Jonzac place the human occupation in the early MIS 4 (Richter et al. 2013). Finally, it is worth to mention the case of Roc de Marsal which, after TL and OSL dating campaigns, returned to record the Quina occupation (layers 4–2) fully within MIS 3, although curiously accompanied by an entrance of cold fauna with the predominance of reindeer (Guérin et al. 2017). In the south-west of France, after the "St Germain II" moment dated to about 80 ky with alternation between boreal forest and temperate forest, a progressive cooling at the beginning of MIS 4 is documented in correspondence with some Quina sites such as Jonzac (Sánchez Goñi et al. 2013). Subsequently, between 70 and 65 ky, the cold steppe tundra increases and, perhaps, a hyatus in human occupation occurred at the cold peak, the H6 event, or Villars cold phase (Genty et al. 2010; Guiter et al. 2003; Sánchez Goñi et al. 2013). A certain (re)population took place between the final MIS 4 and the initial MIS 3, with the Quina techno-complex widely attested in reliable contexts like Marillac, La Quina, Pech de l'Azé IV, Combe Grenal, and Roc de Marsal. These are all characterized by faunal (both macro and micro) distinctive of cold tundra environment (Delagnes and Rendu 2011; Discamps and Royer

2017; Royer et al. 2013). Therefore, any apparent climatic ameliorations were contextual to this possible repopulation. However, it must be stressed that human occupations could occur during short, milder phases, still characterized by the same harsh environments. This hypothesis is supported by the study of stable oxygen isotopes in the tooth enamel of preys hunted at La Ferrassie, which allowed to remodel the seasonal temperatures present at the time of human occupation (Pederzani et al. 2021).

Conclusions

To summarize, the marked chrono-environmental and geographic consistency among the main Quina assemblages of south-west France permitted to infer the presence of a techno-complex restricted between MIS 4 and the beginning of MIS 3. Its cultural value is better defined compared to the Mousterian techno-complexes characterized by Levallois, Discoid, or blade technologies, which are more pan-European and present throughout the Middle Paleolithic, besides being associated to diverse ecosystems and land-use strategies. However, the ecological foundation of Quina Mousterian could be proposed, according to a planned management of (minerals and food) resources as a response to rigid and constraining environmental conditions. The updated analysis of De Nadale technological and functional activities, which integrates the studies on subsistence tasks, allows us to define some Quina-related knapping methods used at the site, however along with other knapping technologies. In addition, there is a strong presence of lithic ramification cycles, mainly displayed by "mixed-matrix" blanks, by several cores on tools, and by some cores on flakes. Besides, we highlight the relative frequency of the eponym scrapers, the type of retouching and their contextual association with cold environments, and the hunting and processing of gregarious and migratory game. Hence, we can advance the hypothesis of the existence of a Quina techno-complex outside its main area located in western Europe but located in the Mediterranean region, specifically in the upper Adriatic and Subalpine area around early MIS 4, which may be connected to the point-like but recurrent evidences in the Balkans, where Quina is attested between MIS 5 and MIS 3 (Mester and Moncel 2006; Mihailović et al. 2021) and signaled in the Late Middle Paleistocene, where connections with the Levant have been proposed (Mihailović et al. 2022). However, the differences between De Nadale and the "classic" Quina complexes of South-Western France are mainly evident in the flexibility of lithic production, which includes the presence of surface-oriented reduction systems and the adoption of diverse core-knapping techniques: that is, the direct percussion with hard hammer and with soft hammer, possibly the bone retouchers themselves. As a result, a wide set of diverse objectives, going beyond the classical Quina tool-set, are here manufactured. Among these, it is necessary to mention bladelets and small and thin flakes. Use-wear analysis confirm that the tool is beyond the evidence of edge retouching, even if the high retouching rate and number of bone retouchers stress the importance of this practice. Despite this, the concept of the tool must not be limited to the retouched piece only, since the reduction sequences and the use-wear analysis agree in suggesting that both retouched implements for heavy-duty activities and non-retouched implements for precision activities are present, mainly addressed to different functional purposes. Some of these features concur to identify De Nadale assemblage as atypical Quina Mousterian. Differences and local adaptations could have characterized the emergence and spread of Quina concept during the last glacial cycle. In this sense, there may be connections with the so-called Eastern Charentian or the *Rhodanien* assemblages, where some of the Quina features are represented along with surface-oriented knapping methods (such as Levallois and Discoid) and very peculiar knapping or branching objectives such as bladelets which, conversely, do not appear in the regional context until late Mousterian (Peresani et al. 2013, Peresani et al. 2022).

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Declarations

Conflict of interest The authors declare no competing interests.

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