Flint Recycling in the Lower Paleolithic Levant: A Microscopic Investigation of Small Recycled Flakes at Qesem Cave (Israel)

Feuerstein-Recycling im Altpaläolithikum der Levante: Eine mikroskopische Untersuchung kleiner recycelter Abschläge aus der Qesem-Höhle (Israel)

Flavia Venditti
Department of Archaeology and Ancient Near Eastern Cultures
Tel Aviv University
Tel Aviv 69978, Israel.
fv1@mail.tau.ac.il
flavia.venditti@gmail.com

Laboratory of Technological and Functional Analyses of Prehistoric Artefacts (LTFAPA)
Department of Classics
“Sapienza” University of Rome
Rome, Italy

ABSTRACT

Recycling is defined as a process in which waste materials can again become usable. In the common belief of many peoples, recycling is only considered a contemporary manifestation linked to the economic and ecological politics of industrialized societies. Both archaeological and historical records, however, prove that recycling has its roots back in time, being a common behavior of our ancestors as well as of many past societies. At the Late Lower Paleolithic site of Qesem Cave, Israel, research has identified a particular lithic trajectory oriented towards the production of small flakes by means of recycling, in the exploiting of old discarded flakes to be re-used as cores. The high density of this specific production throughout the stratigraphic sequence of the cave demonstrates that lithic recycling was a conscious and planned technological choice aimed at providing small and sharp items, most probably in order to meet specific functional behaviors. This particular lithic behavior persisted for some 200 kyr of human use of the cave and is not related to any shortage of flint, as the vicinity of the cave is exceptionally rich in flint sources. The exceptional conservation of use-wear signs and residues has allowed the author to reconstruct the functional role of this specific production, highlighting its specialized nature mostly related to the pro-

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cessing of animal carcasses through accurate and careful actions. The aptitude towards specialization in a tool's function and technology shows how advanced the cognitive capacities were of the Qesem hominins. Applying functional analysis based on the determination of wear on artifacts by means of optical light microscopes, scanning electron microscopy and chemical analysis (FTIR and EDX) provides a useful and effective approach for understanding the adaptive strategies of the Qesem Cave hominins who, while facing various situations, were able to find thoughtful solutions for different needs.

Keywords: Lower Paleolithic, Israel, stone artifacts, use-wear traces, residues, function, recycling

ZUSAMMENFASSUNG

Recycling ist als ein Prozess definiert, bei dem fortgeworfene Materialien wieder verwertbar gemacht werden können. Nach allgemeiner Auffassung vieler Völker wird Recycling nur als zeitgenössische Manifestation angesehen, die mit der wirtschaftlichen und ökologischen Politik der Industriegesellschaften verbunden ist. Im Gegensatz dazu belegen sowohl archäologische als auch historische Aufzeichnungen, dass Recycling seine Wurzeln in der Vergangenheit hat und sowohl bei unseren Vorfahren als auch in vielen früheren Gesellschaften ein weit verbreitetes Verhalten war. In der spätaltpaläolithischen Qesem-Höhle in Israel wurde eine bestimmte Entwicklungslinie in der Steinbearbeitung erkannt, die auf die Herstellung kleiner Abschläge durch Recycling ausgerichtet ist und alte aufgelassene Abschläge nutzt, die als Kerne verwendet werden. Die Häufigkeit dieser spezifischen Produktion über die gesamte stratigraphische Sequenz der Höhle zeigt, dass das Recycling von Steinartefakten eine bewusste und geplante technologische Wahl war, die darauf abzielte, kleine und scharfe Gegenstände bereitzustellen, höchstwahrscheinlich um bestimmte Funktionen damit auszuführen. Diese besondere Verhaltensweise dauerte über etwa 200.000 Jahre menschlicher Nutzung der Höhle an und ist nicht mit einem Mangel an Feuerstein verbunden, da die Umgebung der Höhle außerordentlich reich an Feuersteinquellen ist. Die außergewöhnliche Erhaltung von Gebrauchsspuren und Residuen hat es ermöglicht, die funktionale Rolle dieser spezifischen Produktion zu rekonstruieren und ihre Besonderheit hervorzuheben, die hauptsächlich mit der Verarbeitung von Tierkadavern mittels genau und sorgfältig ausgeführter Tätigkeiten zusammenhängt. Die Fähigkeit zur Spezialisierung auf die Funktion und Technologie des Werkzeugs zeigt, wie weit die kognitiven Fähigkeiten der Qesem-Menschen fortgeschritten waren. Die Anwendung der Funktionsanalyse, basierend auf der Bestimmung der Gebrauchsspuren von Artefakten mittels optischer Lichtmikroskope, Rasterelektronenmikroskopie und chemischer Analyse (FTIR und EDX), bietet einen nützlichen und effektiven Ansatz zum Verständnis der adaptiven Strategien der Menschen aus der Qesem-Höhle, sich verschiedenen Anforderungen zu stellen und durchdachte Lösungen für unterschiedliche Bedürfnisse zu finden.

Schlagwörter: Altpaläolithikum, Israel, Steinartefakte, Gebrauchsspuren, Residuen, Funktion, Recycling

Introduction

The term "circular economy" is a modern expression first theorized by Pearce and Turner (1990) to indicate an economic model based on the idea of reusing, repairing, refurbishing and recycling existing materials and products as long as possible. The concept of "circular economy" aims at keeping materials in use, whether as objects or as their raw components and offers an opposing model to that of the "linear economy" (make → use → dispose) which has remained dominant since the onset of the Industrial Revolution in Western societies (Korhonen et al. 2018).

Nowadays, in the common conception of most people, strategies of recycling are only considered contemporary manifestations of industrialized markets linked to the economic and ecological responses to the over-consumption of resources. Both archaeological and historical records, however, prove that recycling has its roots back in time, being fully integrated into the behavioral repertoire of many past societies, as well as in traditional hunter-gatherer groups (Horne and Aiston 1924; Gould 1977; Amick 2007, 2015). Just as a matter of example, in prehistoric times tiny flint tools were made from old discarded tools while unused vessels were often reduced to powder and used as clay for new pots and other objects. Ancient metal and glass makers frequently melted older artifacts and reconstituted them as new vessels, and so on (Amick 2015; Paynter and Jackson 2016).

Although the concept of recycling may have its origins in the Paleolithic period, contemporary and ancient concepts of recycling differ one from the other. Modern systems of recycling are largely designed to reduce global environmental damage. In contrast, our ancestors were far from being considered "ecologically noble," or at all sensitive toward the environment and the overconsumption of earth's resources (Amick 2015:14). In order to survive, they deeply exploited environmental resources and objects to the point of exhaustion before discarding them, polluting their surroundings, and creating, sometimes, massive amounts of waste (the classical period of Monte Testaccio in Rome is a clear example: Havlíček and Morcinek 2016). Several ethnographic and archaeological studies have identified the stockpiling of discards as an indicator of reuse and recycling behavior (Bradley 1988; Chang 1991; Kamp 1991; Rathje et al. 1992).

In prehistoric times, recycling seems to have been an integral part of the behavioral habits of our ancestors. Stones such as flint, quartz, chert and limestone, were the first raw materials to be exploited and potentially recycled by prehistoric hominins, facilitated by the reductive nature of lithic technology. Chipped stone tools and their waste products, in fact, could be potential raw material for further reduction sequences aimed at producing new usable flakes and tools.

According to M. Schiffer, who is the first to investigate the transformative processes of material culture, a lithic object during its life undergoes five stages or processes: procurement, manufacture, use, maintenance and discard (Schiffer 1972). After being discarded, the object may reenter the system and be reused or recycled, depending on changes in object use, user and the form of the artifact. The possibility for a discarded stone tool to enter cyclically in different lithic trajectories across time and space in an archaeological assemblage has often complicated the comprehension of the *chaîne opératoires* performed at sites. That is why lithic recycling is still an overlooked phenomenon among archaeologists due the complexity of recognizing it in the archaeological record and the multidisciplinary approach required to fully investigate it (Odell 1996).

Even though recycling of material culture has occurred as a constant of human behavior from prehistoric times until the present day, we know very little about the origin and the meaning of this practice in the past. After the seminal work of Michael Schiffer, who examined the main terminological issues (Schiffer 1972, 1976, 1977; Schiffer et al. 1981), recycling, and in particular, Paleolithic recycling, has not been investigated and discussed for some time now in the scientific community. Only recently the topic again began attracting the attention of researchers, with an international workshop held in Tel Aviv in October 2013 that was entirely dedicated to presenting evidence and discussing the significance of recycling behavior during the Old Stone Age (Amick 2014; Barkai et al. 2015 and references therein). Although the workshop was not conclusive, it was important in bringing together researchers to discuss the importance of studying and recognizing recycling in the archaeological record and in promoting the need to for a common methodological approach to define and distinguish recycling from other practices such as reuse and resharpening. In this respect, some of the major themes that emerged from the discussion included the challenges of dealing with fluctuating temporal indicators such as differential patination rates as a criterion for identifying recycling.

Patina, in fact, plays a central role in the recognition and identification of lithic recycling (Barkai et al. 2015; Efrati et al. 2019). Siliceous stone artifacts are frequently subjected to physical and chemical alterations over time and under particular environmental conditions, gradually leading to the formation of patina. Several types of patina exist as a result of a combination of factors, such as the structure and microstructure of the flint; the type, proportion and distribution of the flint's impurities; and environmental factors such as water or the lack thereof, the pH value of the soil and mineral agents (Hurst and Kelly 1961; Rottländer 1975; Schiffer 1983; Purdy and Clark 1987; Burroni et al. 2002; Amick 2015). During patination, the color of "fresh" flint changes. Weathering agents attack impurities in the flint; resulting in changes in the texture (Hurst and Kelly 1961). Some well-developed patinas can be distinguished by the naked eye; and "fresh" unpatinated surfaces (resulting from modification of patinated surfaces) can very easily be discerned from them by color, gloss and pattern differences.

According to Vaquero (2011), recycling is a temporal phenomenon, defined by a phase of discard between two or more different use events. A common and unanimously accepted criterion used to indicate a temporal gap between the two use-stages is the presence of double-patinated surfaces on lithic items. In fact, the use of previously discarded items is often more easily identified in those artifacts showing some type of surface alteration. The best examples include the artifacts showing patinated or thermally altered surfaces which are retouched or reduced after surface damage. These artifacts, also known as "double patinated artifacts" should be considered the best evidence of recycling because they clearly indicate a time span between the two use-events and a discard stage before recycling (Vaquero et al. 2015).

At the Late Lower Paleolithic site of Qesem Cave (420–200 ka), Israel, a particular lithic trajectory has been recognized, aimed at the production of small flakes by means of recycling while exploiting "old" discarded flakes and tools as cores. The repeated characteristics and intensity of this lithic trajectory throughout the stratigraphic sequence of the cave demonstrates that this was a planned technological choice aimed at providing small and sharp items to meet specific functional behaviors for some 200 ka in the human use of the cave.

The production and use of small items in Lower and Middle Paleolithic assemblages have been acknowledged but largely overlooked for many years. Flakes, and small flakes in particular, are usually viewed as by-products or debris of the knapping process rather than desired end-products manufactured in anticipation of a specific potential use. In recent years, the study of small tools has gained interest among researchers, especially those examining Lower Paleolithic contexts with a focus on technological aspects. But the functional role of these tiny tools remains poorly investigated (Barsky et al. 2013; Gallotti and Peretto 2015; Aureli et al. 2016; Santucci et al. 2016; Rocca et al. 2016).

I present here the results of a systematic and comprehensive study aimed at understanding the functional role related to the production of small recycled flakes at Qesem Cave through an innovative approach combining experiments, technology, use-wear and residue analyses. The methodological approach used in this study represents a unique opportunity to investigate the production and use of products of recycling in a well-dated and persistently occupied Late Lower Paleolithic site (see Barkai et al. 2017a, b).

The aims of this study also include the investigation of intra-site similarities and/or differences between the distinctive Amudian (blade-dominated) and the Yabrudian (scraper-dominated) assemblages represented at the cave, combined by spatial analysis. The possibility of sampling three distinct areas of the cave (the rock shelf, the central hearth area and the area south of the hearth) provides important information and insights regarding the way the inhabitants of Qesem conceived their activity areas and may provide information regarding social and spatial organization and the division of space in the cave.

Geological, chronological and archaeological setting: Qesem Cave

Qesem Cave is located 12 km east of Tel Aviv, Israel, at an elevation of 90 m a.s.l. on the western slopes of the Samaria Hill (Fig. 1a, b). It is a sediment-filled chamber cave discovered in 2000 when road construction crews cut through its southern and upper parts. The chamber is ~20 m x 15 m in size and ~10 m high. At the west, north and east sides of the cave, massive limestone bedrocks are exposed within the stratigraphy, while in the southern part the road-cutting has removed the bedrock wall (Frumkin et al. 2009).

Fig. 1: Qesem Cave, geographical setting.
a) location on map;
b) Qesem Cave (picture: Qesem cave Project);
c) the upper sequence during the 2009 archaeological excavation, looking east (after Barkai et al. 2013).

Abb. 1: Qesem-Höhle, geografischer Rahmen.
a) Lagekarte;
b) Qesem-Höhle (Bild: Qesem-Höhlenprojekt);
c) die obere Sequenz während der archäologischen Ausgrabung 2009, Blick nach Osten (nach Barkai et al. 2013).

After its discovery in 2000, a salvage excavation was conducted in 2001, with the cave later systematically excavated from 2004 until 2016 by archaeologists from Tel Aviv University (Gopher et al. 2005). Excavations have exposed ~10.5 m-thick archaeological deposits containing gravel, clays and a large ash component, together with rich faunal and lithic assemblages (Gopher et al. 2005; Karkanas et al. 2007; Barkai and Gopher 2011; Blasco et al. 2014).

The Qesem Cave deposit contains a combination of natural and anthropogenic sediments, such as flint and bone fragments, as well as ash-rich material (Shahack-Gross et al. 2014), which has been subjected to subsidence, erosion, fracturing, deposition, and the cementation of various sediments. The deposit is divided into two major stratigraphic units: an upper sequence (~4.5 m thick) consisting of cemented sediment with a large ashy component (Fig. 1c) and a lower sequence (~6 m thick) consisting of sediments with clastic content gravel and clays (Karkanas et al. 2007).

Speleothems and burnt flints dated by U-series, TL, and ESR indicate that hominin occupation at the cave began ca. 420 ka and ended somewhat before 200 ka (Barkai et al. 2003; Gopher et al. 2010; Mercier et al. 2013; Falguères et al. 2016).

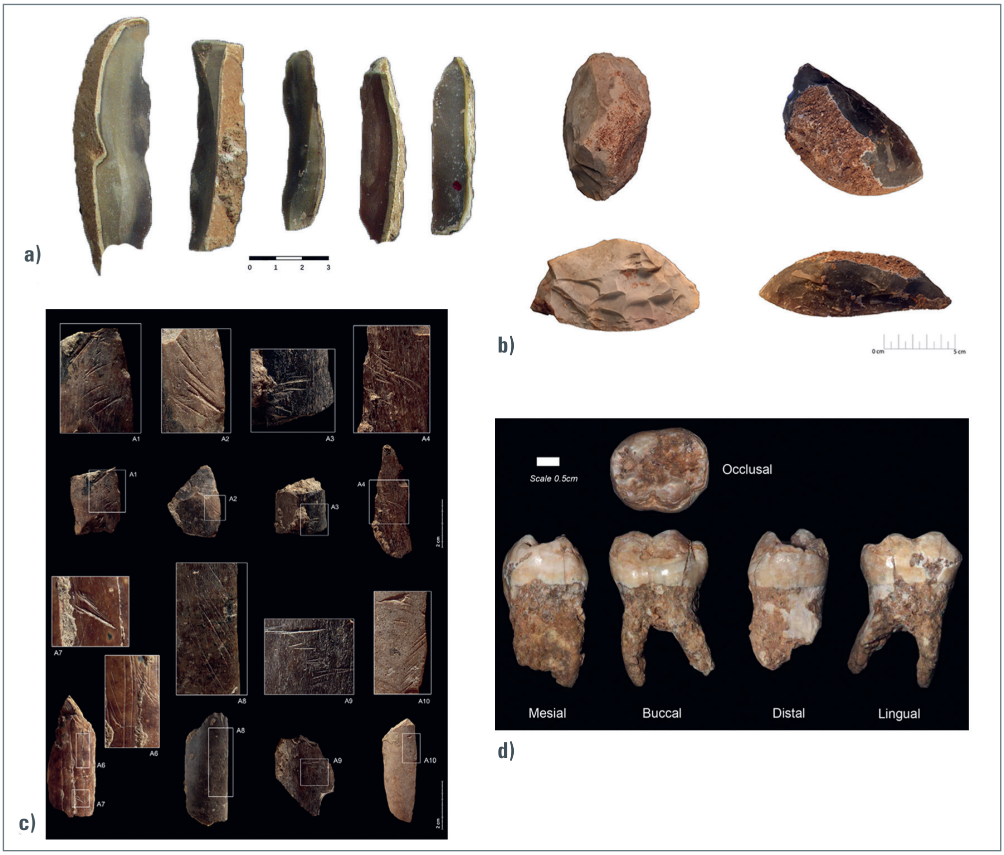


Fig. 2: Examples of Qesem Cave findings. a) typical Amudian blades; b) typical Yabrudian Quina scrapers (courtesy of A. Zupancich); c) limb bone fragments showing cut-marks (after Blasco et al. 2014); d) lower left second deciduous molar (after Hershkovitz et al. 2011).

Abb. 2: Beispiele für Funde aus der Qesem-Höhle. a) typische Klingen des Amudien; b) typische Quina-Schaber des Jabrudien (mit freundlicher Genehmigung von A. Zupancich); c) Fragmente von Extremitätenknochen mit Schnittspuren (nach Blasco et al. 2014); d) unterer linker zweiter Milchmolar (nach Hershkovitz et al. 2011).

The archaeological deposits in the cave are rich and well preserved and entirely assigned to the Acheulo-Yabrudian Cultural Complex (AYCC) of the late Lower Paleolithic period in the Levant (e.g., Gopher et al. 2005). The AYCC is characterized by the production of handaxes, thick scrapers and blades (Rust 1950). This cultural horizon shows similarities with Acheulian lithic production and is completely lacking in Levallois technology and systematic prismatic blade production, typical of Levantine Mousterian sites (Shimelmitz 2015). These differences suggest that the transition between the Acheulian and the Mousterian phases involved some important changes, probably linked to the populations who brought the lithic material to the site (Valladas et al. 2013). Therefore, the transition from the Lower to the Middle Paleolithic in the Levant represented a crucial event in human evolution.

The lithic industries in the cave reflect the Acheuleo-Yabrudian technocomplex: the Amudian Industry, which is clearly dominant, is characterized by a well-established blade production technology (Fig. 2a), while the Yabrudian Industry, dominated by Quina and demi-Quina scrapers (Fig. 2b), appears in only three stratigraphically and spatially distinct areas of the cave (Barkai et al. 2009; Shimelmitz et al. 2011). Nevertheless, it should be emphasized that the Yabrudian and Amudian industries share techno-typological features that differ mainly in the frequency of their appearance.

Faunal remains include fallow deer as the most represented hunted prey (*Dama* cf. *mesopotamica*), followed by aurochs (*Bos*), red deer (*Cervus elaphus)*, horse (*Equus*, caballine form), wild pig (*Sus scrofa*), tortoise (*Testudo* cf. *graeca*; see Blasco et al. 2016b), wild ass (*Equus* cf. *Hydruntinus*), and different bird species (Sánchez-Marco et al. 2016). Rhinoceros (*Dicerorhinus hemitoechus*), porcupine (*Hystrix indica*) and small ungulates (goat [*Capra aegagrus*] and roe deer [Capreolus capreolus]) are present, but rare.

Different types of cut-marks were detected on Qesem bones. Many of the recognized breaks on bones are from butchering and marrow extractions through hominin activity. In fact, the well-preserved faunal remains showed evidence of cut-marks (incisions, sawing and scraping marks, chop-marks) made by flint tools, together with typical cone fractures for marrow extraction (Fig. 2c). Gnawing damage from carnivores as well as hyena coprolites are present, but quite rare (Stiner et al. 2011).

Data from different areas of the cave testify to a selective choice of specific animal body parts brought into the cave. The high proportions of head and limb parts, and the low proportions of axial bones and acropodia, are common not only in the hearth unit but also throughout the Qesem sequence (Stiner et al. 2009, 2011; Blasco et al. 2014).

Among the innovative behaviors recognized at Qesem Cave, it is worth noting the habitual and systematic use of fire, identified throughout the sequence through wood ash remnants and burnt bones and flints (Karkanas et al. 2007; Stiner et al. 2009, 2011; Mercier et al. 2013). The hearth area is characterized by two superimposed use cycles, each one composed in turn of shorter episodes, located in the central part of the cave and dated about 300 ka (Shahack-Gross et al. 2014).

The systematic production of small and sharp flakes from the ventral face of old discarded flakes and tools is another significant hallmark of Qesem Cave. This lithic trajectory is aimed at the specific manufacture of small thin flakes/blades with convex edges (regular flakes) on the one hand, and elongated flakes (blades), mostly cortically backed with straight regular and sharp edge (lateral flakes), on the other (Parush et al. 2015). The production of small sharp flakes by means of lithic recycling is part of a more general recycling behavior identified at the site through other recycling trajectories that are present in significant quantities in all contexts of the cave.

Human occupation at the site is documented through several permanent and deciduous teeth, the morphologies of which indicate that the hominins who inhabited the cave were not *H. erectus* but rather similar to later modern populations (Fig. 2d; e.g., those of Skhul and

Qafzeh) of the Levantine region who also exhibited some Neanderthal affinities (Hershkovitz et al. 2011, 2016; Fornai et al. 2016; Sarig et al. 2016; Weber et al. 2016). Some researchers have suggested that biological and cultural changes occurred in the Levant some 400 ka that led to the replacement of *H. erectus* by a new hominin lineage as the result of the disappearance of elephants and the need to hunt large numbers of medium-sized ungulates (Ben-Dor et al. 2011; Barkai and Gopher 2013).

Lithic recycling for the production of small sharp items at Qesem Cave

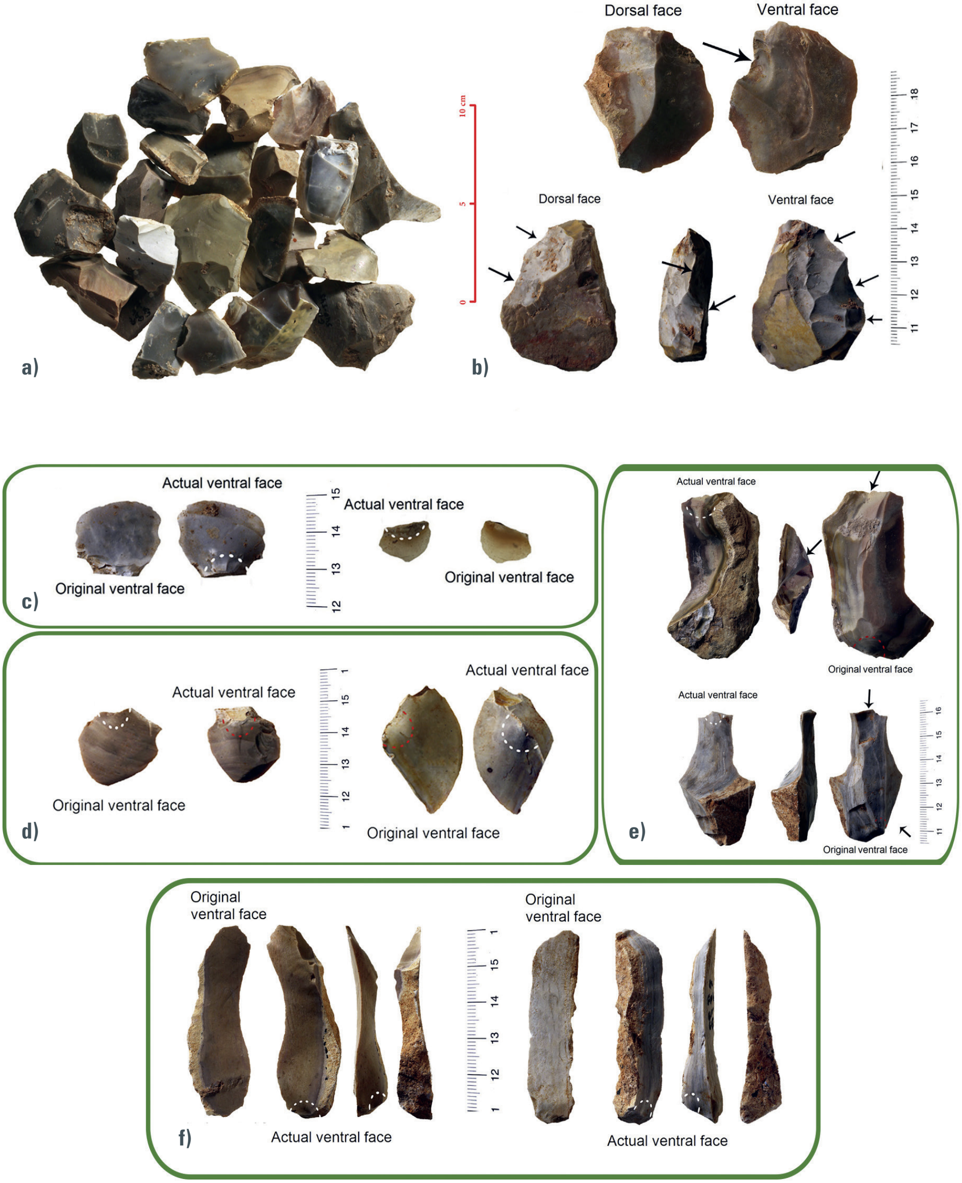
Recycling is a widespread behavior at Qesem Cave and is significantly present in all the archaeological contexts of the cave. Thousands of recycled items have been identified during the techno-typological analysis of the material and five different recycling modes have been reconstructed: 1) Handaxes recycled as cores, 2) Patinated blanks recycled into side scrapers, 3) Side scrapers recycled into cores, 4) Patinated cores recycled or reused as "regular" cores, 5) Production of small sharp items from cores-on-flakes (the focus of this work).

At Qesem Cave, cores-on-flakes (COFs) were used in order to produce new sharp items, the products of the recycling procedure. These artifacts are an integral and distinctive component of the lithic *chaîne opératoire* practiced at the cave and appear in all lithic assemblages and archaeological contexts in significant numbers. COFs were made on a variety of blanks and former tools, with differences in size and patination (Fig 3a). Unlike ramification (where flakes are produced in a planned and intentional reduction strategy in order to allow the further production of smaller items; see Bourguignon et al. 2004 for an overview), varied products at Qesem from a primary reduction stage, as well as collected older items, are used in order to obtain new small, sharp items (Fig. 3b). The selection preferences of blanks to be used as COFs show high variability and the chosen and collected blanks were not produced with an apparent preconceived intention to be transformed into COFs, but rather were transformed into COFs in the course of a recycling process after their discard (Parush et al. 2015).

After selection, these items constitute a starting point for a new specific *chaîne opératoire* for the production of small sharp items. The results from a preliminary study combining the techno-typological analysis with functional interpretation show that COFs were rarely used and only expediently while the small detached blanks were the final desired end-products. When used, evidence for processing materials of medium and hard hardness were observed in the new edges created by the intersection of the negative of the recycling flake (Lemorini et al. 2015). They are characterized by regular and very sharp edges, a rather standardized morphology, and areas that allow for a comfortable grip. These products of recycling are divided into four types by their morphology and by the area from which they were removed:

1) Regular double-ventral items

Characteristically, these items have two ventral faces and one bulb on the last ventral face – the actual ventral face of the item. These blanks usually exhibit a flat dorsal face and rather sharp lateral edges. Some items are hinged or stepped at their distal end because of the force


a)
Dorsal face
Ventral face
10 cm
5
0
18
17
16
15
14
13
12
11
Dorsal face
Ventral face
b)
Actual ventral face
Original ventral face
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14
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of the blow directed towards a flat surface devoid of ridges that would have guided the blow (Fig. 3c). They have an average length of 1.6 cm and average width of 1.8 cm (Parush 2014; Parush et al. 2015).

2) Double-bulb, double-ventral 'Kombewa' items

These flakes are characterized by two ventral faces and two percussion bulbs, one for each of the two ventral faces. They are double convex in profile and sharp and thin at the edges. These items are similar to those produced with the Kombewa technique (Parush 2014; Parush et al. 2015). They have an average length of 2.6 cm and average width of 2.2 cm. This category is infrequent in both assemblages considered in this study (Fig. 3d).

3) Double-bulb, double-ventral face 'non-Kombewa' items

These items exhibit two ventral faces and two bulbs of percussion, one on each of the two ventral faces. They have an average length of 4.5 cm and average width of 1.8 cm. Furthermore, most of the items are overshots, taking a larger part of the ventral face of the core-on-flake, with the original bulb of percussion and striking platform at their distal end (Fig. 3e). This study was useful in exploring whether these items were the results of knapping mistakes while removing small flakes from COF, or the intentional products of a specific recycling method (Parush 2014; Parush et al. 2015)

4) Lateral double-ventral face

These are items with two ventral faces removed from a lateral edge and part of the ventral face of the COF. The percussion bulb is present in the ventral face of the item. These items were knapped along the longitudinal axis of the COF/FF at an obtuse angle, taking the lateral edge of the COF and creating a backed item, in many cases cortically backed (Parush 2014; Parush et al. 2015). They have an average length of 3.8 cm and average width of 1.6 cm. These items are laminar in shape, showing a straight angle cross-section that is triangular or trapezoidal. A characteristic of these objects is their cortical back, creating a comfortable grip (Fig. 3f). This is the most common category among the blanks produced from COF in the Amudian and Yabrudian contexts alongside the regular double-ventral items.

Fig. 3: Qesem Cave lithic recycling.
a) a group of core-on-flakes (after Parush et al. 2015); b) two core-on-flakes; c) regular double-ventral item; d) double-bulb double ventral Kombewa item; e) double-bulb double ventral non-Kombewa item; f) lateral double-ventral item.

Abb. 3: Lithisches Recycling in der Qesem-Höhle.
a) eine Gruppe von Kernen an Abschlag (nach Parush et al. 2015); b) zwei Kerne an Abschlag; c) regelmäßiger Abschlag mit doppelter Ventralfläche; d) Abschlag mit zwei Bulben und doppelter Ventralfläche in Kombewa-Technik; e) Abschlag mit zwei Bulben und doppelter Ventralfläche ohne Kombewa-Technik; f) seitlicher Abschlag mit doppelter Ventralfläche.

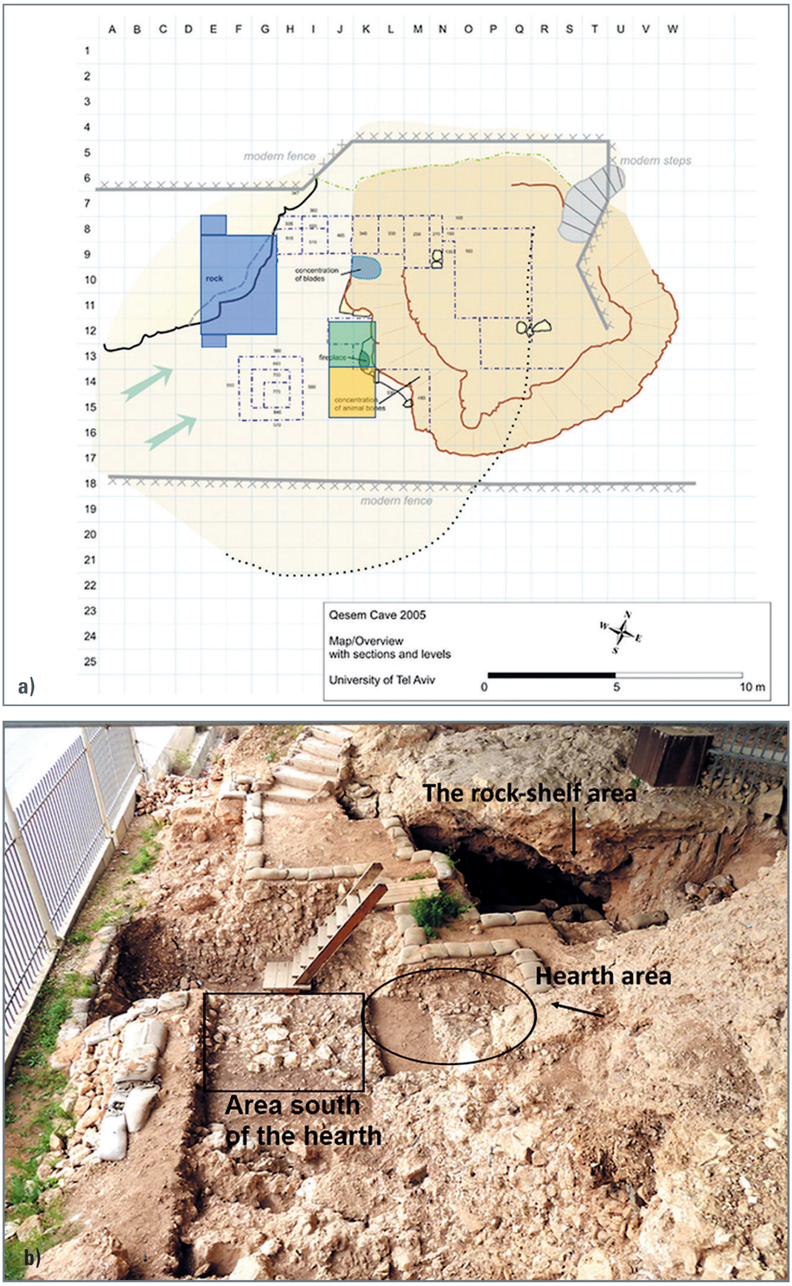


Fig. 4: a) Qesem Cave map (modified after Shahack-Gross et al. 2014);
b) Qesem Cave general view, looking west with the highlighted sampled areas.

Abb. 4: a) Plan der Qesem-Höhle (modifiziert nach Shahack-Gross et al. 2014);
b) Gesamtansicht der Qesem-Höhle mit Blick nach Westen mit den hervorgehobenen Beprobungsarealen.

Materials and Methods

The archaeological sample presented here consist of 609 small flakes retrieved respectively from the rock-shelf area (hereafter the shelf), the hearth area and the area south of the hearth (Fig. 4a, b) and it was equally divided among the four categories of identified recycled artifacts (for details see Venditti 2019). The items originating from the shelf belong to both the Amudian and Yabrudian layers, while the hearth and the area south of the hearth were Amudian. The three areas of the cave have been thoroughly studied under different aspects such as raw material procurement (Wilson et al. 2016), faunal analysis (Blasco et al. 2013, 2014, 2016a, b, 2019), lithic analysis (Lemorini et al. 2006, 2015, 2016; Parush et al. 2015; Zupancich et al. 2016, 2017), and density analysis (Gopher et al. 2016), thus allowing a comprehensive and multifaceted understanding of human behaviors at the cave. Moreover, the three assemblages are roughly contemporaneous and belong to the upper part of the lower half of the stratigraphic sequence of the cave, dated to ca. 300 ka (Gopher et al. 2010; Falguères et al. 2016).

An experimental and traceological approach was used in analyzing the specimens. The use-wear analysis, conducted applying the high and low power approach (Tringham et al. 1974; Keeley 1980; van Gijn 1990, 2010; Rots 2010) was complemented by the morphological observations of residues along with their spectroscopic analysis through two independent techniques: Fourier transform infrared spectroscopy (micro-FTIR) and energy dispersive X-ray spectroscopy (EDX).

The study began with a preliminary qualitative analysis employing the naked eye and using a stereomicroscope Nikon SM with a 1x objective, a 10x ocular, and a 0.75–7.5x magnification zoom in reflected light in order to notice any presence of physical alteration (fractures, cracks, pits, ridge rounding) including the presence of patination with particular attention to type (color patina, white patina, glossy and sheens), degree of development and location. Overall, the sample was considered in a good state of preservation even if differences were recorded in patination and degrees of alteration (for details see Venditti 2019). Along with evaluating the state of preservation, this analysis identified the edge damage (e.g., micro-chipping and localized rounding) derived from use. Edge damage is used to infer tool function, and, more precisely, the motion carried out and the generic hardness of the worked material, with hardness designated as a large category of "consistence" (soft, soft to medium, medium, and hard materials).

The more powerful metallographic Nikon Elite microscope in reflected light with a 10x ocular and 10x, 20x and 50x objectives equipped with a reflected differential interference contrast (DIC) was then used to reach magnification up to 1000x in order to investigate the micro traces developed on the lithic surface. This analysis allows the observation of micro use-wear (e.g., polishes, striations, pits, grooves and micro-rounding) which reveals more precise information concerning the exact nature of the worked materials (e.g., bone, meat, hide, wood). The objects are finally scrutinized under a last generation Scanning Electron Microscope (SEM) Hitachi TM3000 equipped with an EDX probe.

The analyses of possibly preserved use-related residues on the archaeological flint tools were performed combining two approaches: 1) the morphological observation by means of optical and digital microscopes, and 2) the chemical detection by means of two spectroscopic techniques: the Fourier transform infrared spectroscopy (micro-FTIR) and the energy dispersive X-ray spectroscopy (SEM-EDX). Both techniques allow the chemical characterization of the specimens of interest: the FTIR identifies chemical bonds in a molecule by producing an infrared absorption or spectrum. Molecules, in fact, absorb frequencies that are characteristic of their structure since the absorbed radiation matches the vibrational frequency (Smith 2011). The EDX analysis identifies the composition of materials by producing an energy spectrum showing the peaks corresponding to the elements composing the sample (Frahm 2014).

FTIR spectra were collected with a Bruker Optic Alpha-R portable interferometer with an external reflectance head covering a circular area of about 5 mm in diameter. The samples were placed directly in front of the objective and spots were selected for analysis. The recorded spectral range was 7500–375 cm^{-1}, acquired with 250 scans or more, with a resolution of 4 cm^{-1}. Spectra reported in the text, however, show only the spectral range where absorption bands were observed (4000–375 cm^{-1}). Infrared measures were taken on specimens at least on three points (proximal, medial and distal) along the dorsal and ventral surface according to the used edge, and at least on two points on the inner dorsal and ventral surface of each item.

EDX spectra were collected with the Hitachi SEM equipped with the SwiftED3000 energy dispersive X-ray spectrophotometer. Different accelerating voltages were used during the analysis of residues: 5 Kv was used to characterize topographic and textural traits while the 15 Kv mode provided elemental information through grayscale images according to the atomic number using the high sensitivity backscattered electron detector. Electron dispersive X-ray spectroscopy was performed on each identified residue with two or three measurements taken on different spots of the same residue at 15 kV accelerating voltage in BSE mode with a magnification from 500x to 800x and an acquisition time of 400 s.

The two methods proved to be highly suitable for chemically characterizing organic and inorganic residues on stone tools because they are non-invasive techniques that do not require chemical or mechanical pre-treatment of the investigated sample. They also provide the additional advantage of revealing very small spots directly on the artifact surface (Monnier et al. 2017, 2018; Pedergnana and Ollé 2018).

It is worth noting that residues (when detected) were used to reinforce and corroborate the functional interpretations based on the use-wear results obtained on the archaeological specimens. The presence of residue does not necessarily prove the utilization of an object, since residues may be the result of post-depositional accumulation or modern contamination. The use-wear evidence on these items is thus critical for their analysis. FTIR and EDX sample control spectra were also collected on archaeological stone tools during the analysis to compare the spectroscopic results obtained on spots with and without presence of micro-residues.

To guarantee the validity of the functional interpretations, the observation of the archaeological materials ran parallel to an experimental protocol for both use-wear and residues (results of the reference collection are available in Venditti 2019 and Venditti et al. 2019a). Modern replicas of the archaeological flint tools were created and used in various activities in order to test their efficiency and the development of use-wear and residues after the material processing. Replicas of the small recycled implements were produced following the technological procedures identified at Qesem Cave and using the same geological flint sources used by the Qesem inhabitants for this lithic trajectory. Later, F. V. performed experiments and manipulated flakes by using longitudinal and/or transversal motions on a variety of materials considered as potentially having been processed by the Qesem hominins: fresh meat, fresh and dry hide, fresh and dry bone, fresh and dry wood, fresh woody plants, herbaceous plants and tubers (Fig. 5). After the practical activities, experimental artifacts were observed under microscopes in order to characterize, on a morphological level, the residues adhering to the lithic surface. Later, they were subjected to FTIR and EDX analysis prior to cleaning. Finally, they were chemically washed in order to observe and describe the use-wear traces.

Experiments played a major role in this work, as using the replicas made it possible to test directly the efficiency of the tools, their manipulation, and to record the development of use-wear throughout use time. At the same time, it is possible to characterize the micro-residues on a morphological and chemical level that result from the processing of the different materials worked in the reference collection for the use-wear traces. In this way, a use-wear and a residue comparative collection was produced and exploited to accompany and support the results obtained from the analysis of the archaeological assemblages (Fig. 6). Ancient residues found on archaeological stone tools are always subjected to degradation processes during their burial period, and sometimes it is difficult to interpret them based only on observing their morphology. In order to give more strength to the interpretation, the residues were double-checked through FTIR and EDX techniques which proved to provide reliable results also on degraded residues (Hayes and Rots 2019; Monnier and May 2019). The interpretation of the residues was considered reliable if at least one of the two spectroscopic techniques showed results matching the use-wear interpretation. The experiments and use-wear and residue analyses were performed at the "Laboratory of Technological and Functional Analysis of Prehistoric Artefacts" at "Sapienza" University of Rome.

The cleaning protocol for the archaeological tools included a bath in fresh water to remove the soil deposits and a subsequent bath in deionized water in an ultrasonic tank for 10 min. Experimental replica were subjected to a quick bath under tap water before residue analysis. Patches of residues were still firmly attached on the lithic surface after this procedure and were chemically analyzed and recorded. In order to carry out the functional analysis, the items were subsequently subjected to a chemical bath that began by soaking the objects for 15 min in 3 % acetic acid (CH_3COOH) followed by another 15 min in 3 % sodium hydroxide ($NaOH$). Finally, the objects were washed with deionized water in an ultrasonic tank for 10 min. In order to prevent, as much as possible, the formation of any type of grease on the lithic surface, the cleaning protocol included the use of powder-free sterile gloves during the manipulation of the cleaned objects and the use of Parafilm (a laboratory film) to wrap the modeling clay supporting the pieces on the microscope stage.

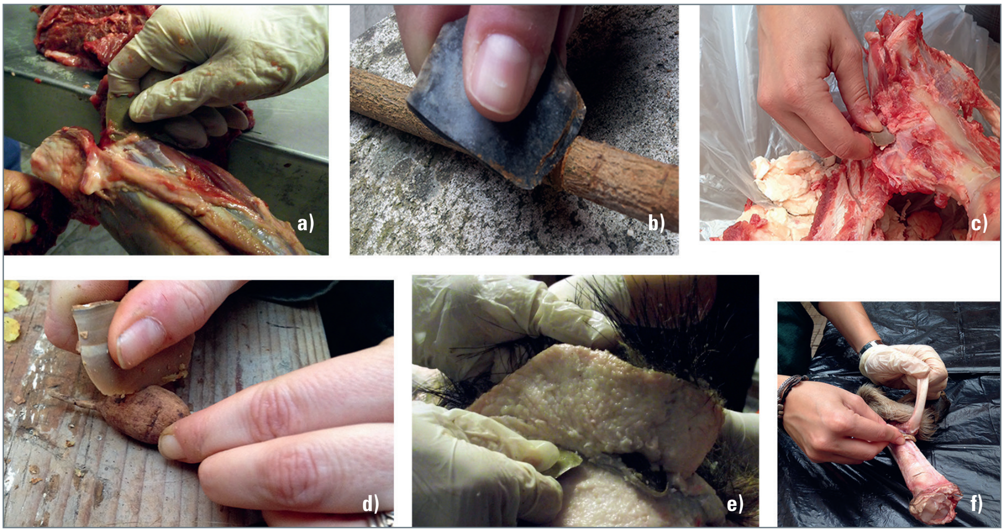
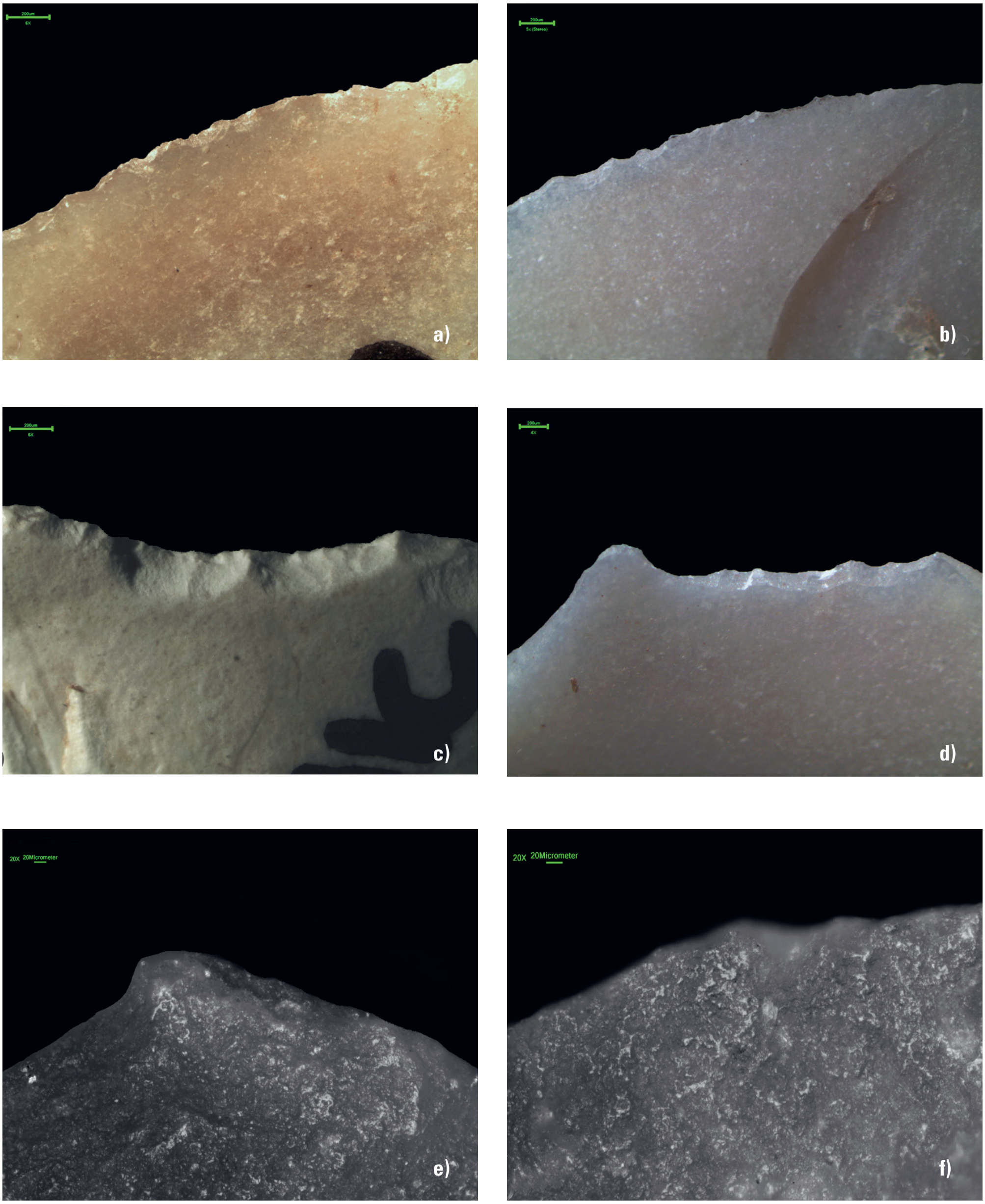


Fig. 5: Representative images of controlled experiments carried out to develop the reference collection.
a) wild-boar butchery; b) sawing wood; c) cleaning bone from meat and fat; d) cutting tubers; e) skinning;
f) tendon removing.

Abb. 5: Repräsentative Abbildungen kontrollierter Experimente zum Aufbau der Referenzsammlung.
a) Wildschweinzerlegung; b) Sägen von Holz; c) Reinigen eines Knochens von Fleisch und Fett; d) Schneiden einer Wurzelknolle; e) Häuten; f) Entfernen von Sehnen.

Fig. 6 (right): Examples of archaeological (left) and experimental (right) use-wear traces.
a) archaeological edge-damage related to butchery activity; b) experimental edge-damage related to butchery;
c) edge-damage interpreted as butchery on a regular small recycled flake; d) edge-damage resulting from butchery activity on a small recycled flakes replica; e) archaeological micro-polish interpreted as butchery;
f) experimental micro-polish after butchering metapodials.

Abb. 6 (rechts): Beispiele für archäologische (links) und experimentelle (rechts) Gebrauchsspuren.
a) Kantenbeschädigungen im Zusammenhang mit Schlachtaktivitäten an archäologischem Artefakt;
b) experimentelle Kantenbeschädigungen im Zusammenhang Schlachtaktivitäten; c) Kantenbeschädigungen, die als Schlachtspuren auf einem regelmäßigen kleinen recycelten Abschlag interpretiert werden;
d) Kantenbeschädigungen infolge Schlachtaktivitäten auf der Nachbildung eines kleinen recycelten Abschlags;
e) archäologische Mikropolitur, die als Schlachtspuren interpretiert wird; f) experimentelle Mikropolitur nach dem Schlachten von Metapodien.


200um
6X
a)
200um
5x (Stereo)
b)
200um
6X
c)
200um
4X
d)
20X 20Micrometer
e)
20X 20Micrometer
f)

Results

A total number of 609 archaeological items were subjected to use-wear and residue analysis. Considering the specimens showing traces related to use (168 out of 609), the combination of use-wear traces and residues revealed that animal resources are the most exploited, constituting 45 % of the entire sample (Fig. 7).

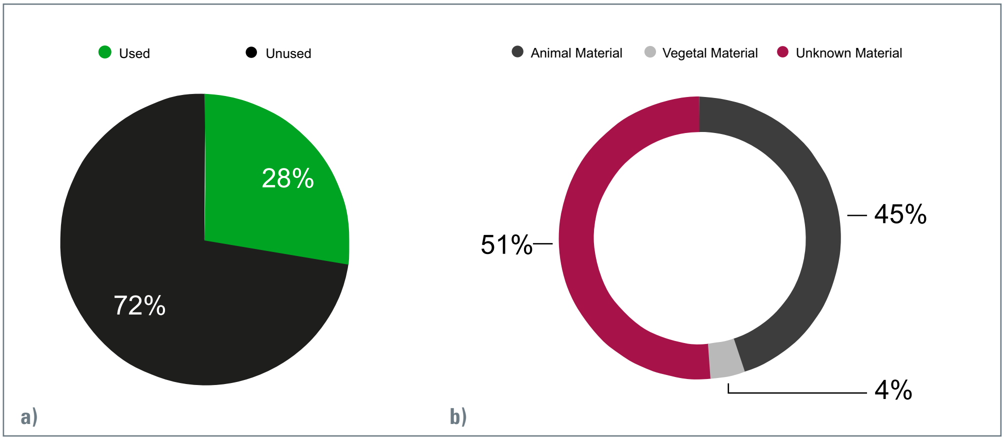
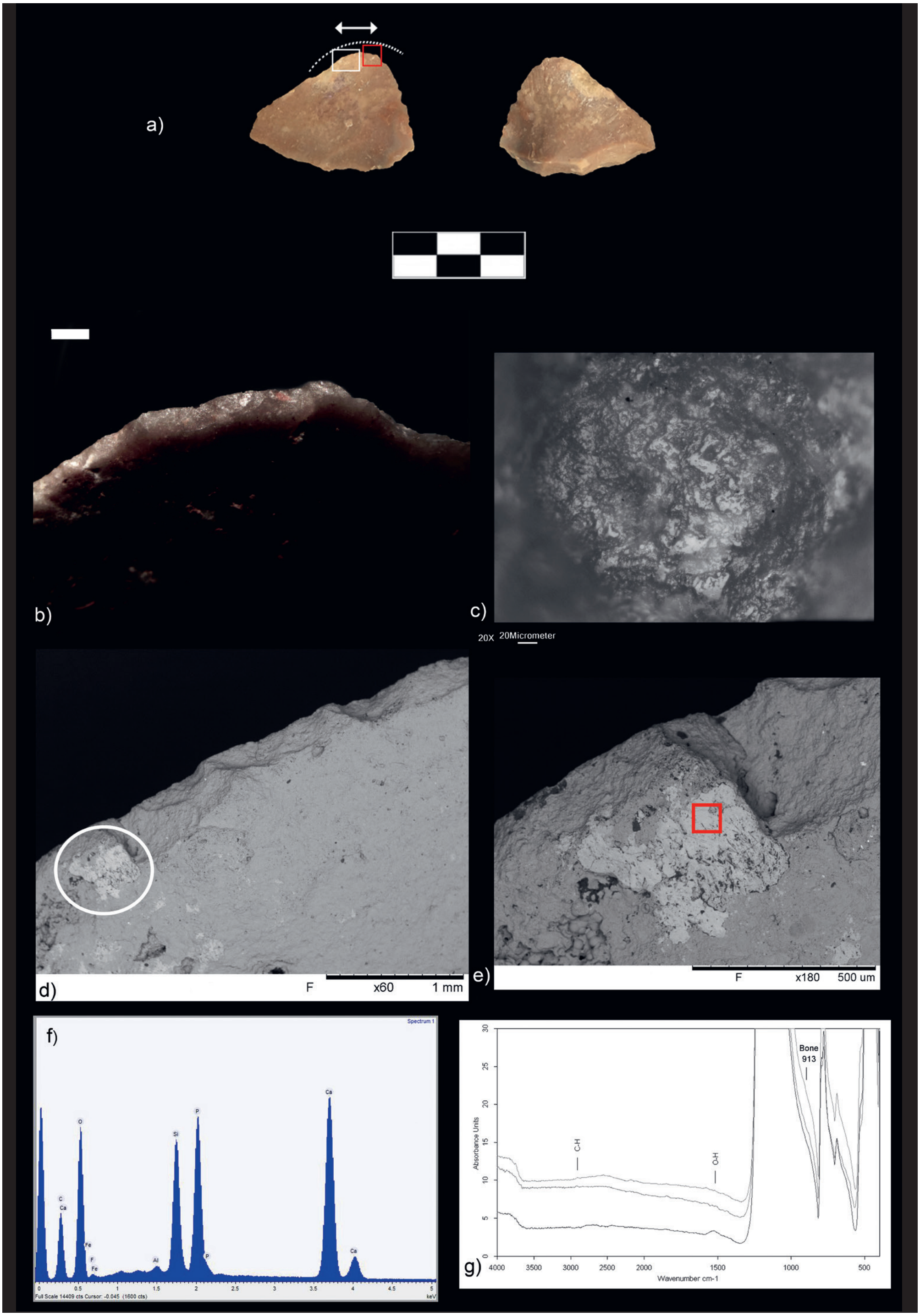


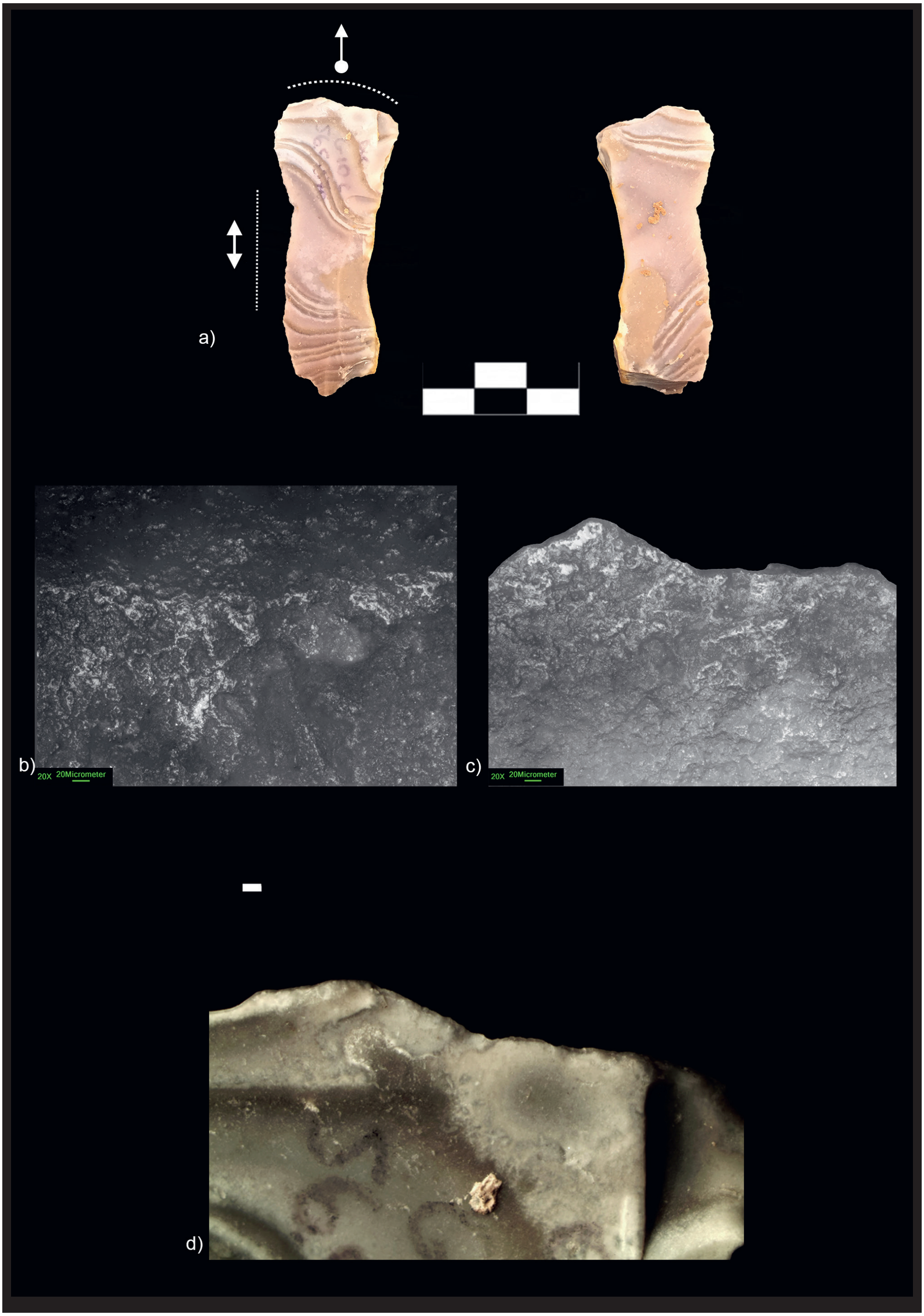
Fig. 7: Charts.
a) chart showing the percentage of used and unused analyzed items;
b) chart showing the percentage of used items according to the worked material.

Abb. 7: Kreisdiagramme.
a) Diagramm mit dem Prozentsatz der benutzten und nicht benutzten der analysierten Stücke;
b) Diagramm, das den Prozentsatz der bearbeiten Materialien bei den benutzten Stücken zeigt.

Fig. 8: Use-wear and SEM-EDX results:
a) specimen E12b 580-595; b) edge damage; c) polish located on the dorsal edge surface interpreted as cutting fresh animal tissues + bone; d, e) SEM micrograph of the dorsal edge surface showing bone residue (secondary electrons; 5 Kv; mag=60X and 180X); f) EDX-histogram showing the high percentages of phosphorus (P) and calcium (Ca); g) micro-FTIR spectrum showing the peak of bone microresidue. Red squares indicate the EDX sampling point, white square indicates the FTIR sampling area.
White scale bar = 1 mm.

Abb. 8: Gebrauchsspuren und SEM-EDX-Ergebnisse:
a) Stück E12b 580-595; b) Kantenbeschädigungen; c) Politur auf der dorsalen Kantenoberfläche, interpretiert als Spuren vom Schneiden von frischem Tiergewebe + Knochen; d, e) REM-Mikroaufnahme der dorsalen Randfläche mit Knochenresiduen (Sekundärelektronen; 5 Kv; mag = 60X und 180X); f) EDX-Histogramm, das die hohen Prozentsätze von Phosphor (P) und Calcium (Ca) zeigt; g) Mikro-FTIR-Spektrum, das den Peak der Knochenresiduen zeigt. Die roten Quadrate zeigen den EDX-Abtastpunkt an, das weiße Quadrat zeigt den FTIR-Abtastbereich an.
Weißer Maßstab = 1 mm.


a)
b)
c)
20X 20Micrometer
d)
F x60 1 mm
e)
F x180 500 um
f)
Spectrum 1
C
Ca
O
Fe
F
Fe
Al
Si
P
P
Ca
Ca
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5
Full Scale 14409 cts Cursor: -0.045 (1600 cts)
keV
g)
Absorbance Units
0 5 10 15 20 25 30
C-H
O-H
Bone
913
4000 3500 3000 2500 2000 1500 1000 500
Wavenumber cm-1

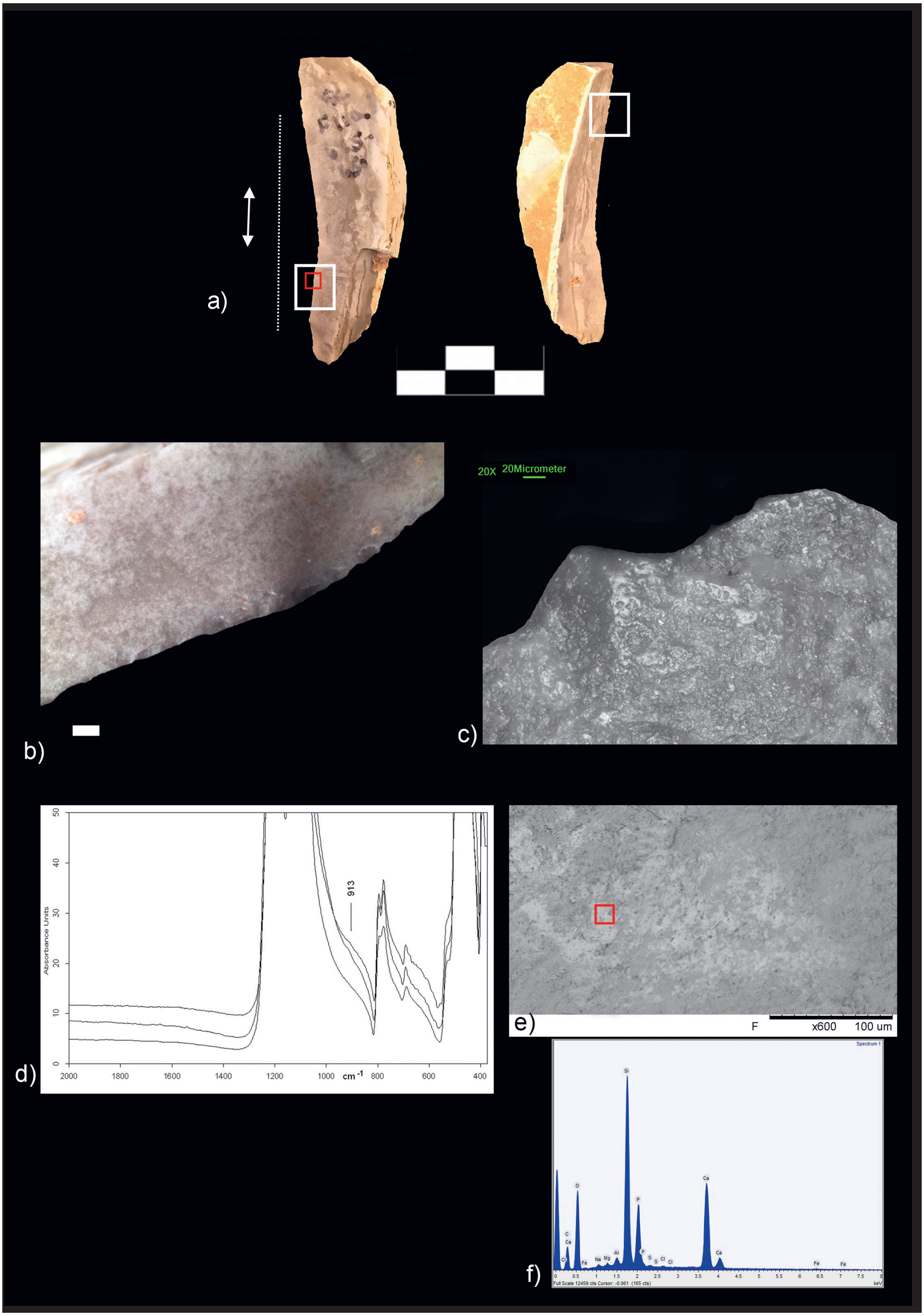

a)
b)
20X 20Micrometer
c)
20X 20Micrometer
d)

In particular, regular and lateral items (32 %) were the most recycled products used during the processing of animal carcasses for activities of dismembering, cleaning bones, and filleting meat. This is confirmed by evidence of micro-traces (i.e. polish) interpreted as contact with fleshy and greasy animal tissues and sporadic and accidental contact with bone (Fig. 8c). The edge damage corresponds to half-moon scars and scars with bending initiation and feather termination (associated with fleshy tissues) and hinge and step scars (associated with contact to hard material) together with different degrees of the edge rounding (mainly low or medium; Fig. 8b). The use-wear interpretations were confirmed by FTIR and SEM-EDX residue analysis on 30 tools and in several cases the two techniques provided complementary results. FTIR detected micro-residues of Hydroxyapatite ($Ca_5(PO_4)_3(OH)$) at the frequency of ~913 cm^{-1}(Fig. 8g), adipocere at the frequencies of 1575–1536 cm^{-1} assigned to the C-O stretching of calcium salt carboxylate of saturated acids, often in association with the C-H stretching mode of generic organic material. Particularly outstanding and remarkable is the presence of the bands associated with Amide I, at ~1645 cm^{-1} found along the ventral edge of a unique tool, along with the doublet typical of micro-residues of adipocere at the frequencies ~1575 and 1536 cm^{-1}. The presence of these peaks derived from the proteinaceous and fatty component of animal tissues testifying to its use during the butchery process (for details see Venditti et al. 2019a).

The limited portion of the used edge and the low degree of edge rounding suggests that small flakes were utilized for rather short activities but such that necessitate accuracy, precision and specific gestures. This is especially true for the very small and sharp regular flakes, which do not need any modification (e.g., retouch) in order to be efficient. According to my butchery experiments, regular flakes are perfectly suitable to process animal body parts with very small amounts of meat, such as the metapodials of medium or small-sized animals. They prove to be very useful for removing hide, meat, tendon, or the periosteum from bone fragments. These data fit well with the abundant cut-marks related to skinning, dismembering, disarticulation, fleshing, periosteum and tendon removal found on hundreds of bone fragments at the cave. It is also worth noting that the metapodials comprise a fairly high percentage of the long bone fragments found in small and medium-sized ungulates at the cave (Blasco et al. 2016a, 2019; Barkai et al. 2017a, b).

Fig. 9: Use-wear trace results:
a) specimen G10c-565-570; b–c) polish on the dorsal surface interpreted as cutting bone; d) edge damage.

Abb. 9: Ergebnisse der Gebrauchsspurenuntersuchung:
a) Stück G10c-565-570; b–c) Politur auf der Dorsalfläche, interpretiert als Spuren vom Schneiden von Knochen; d) Kantenbeschädigungen.


a)
b)
c)
20X 20Micrometer
d)
Absorbance Units
0
10
20
30
40
50
913
2000
1800
1600
1400
1200
1000
cm -1
800
600
400
e)
F
x600
100 um
f)
Spectrum 1
Si
O
C
Ca
Cl
Fe
Na
Mg
Al
P
S
Ca
Fe
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
Full Scale 12459 cts Cursor: -0.061 (165 cts)
keV

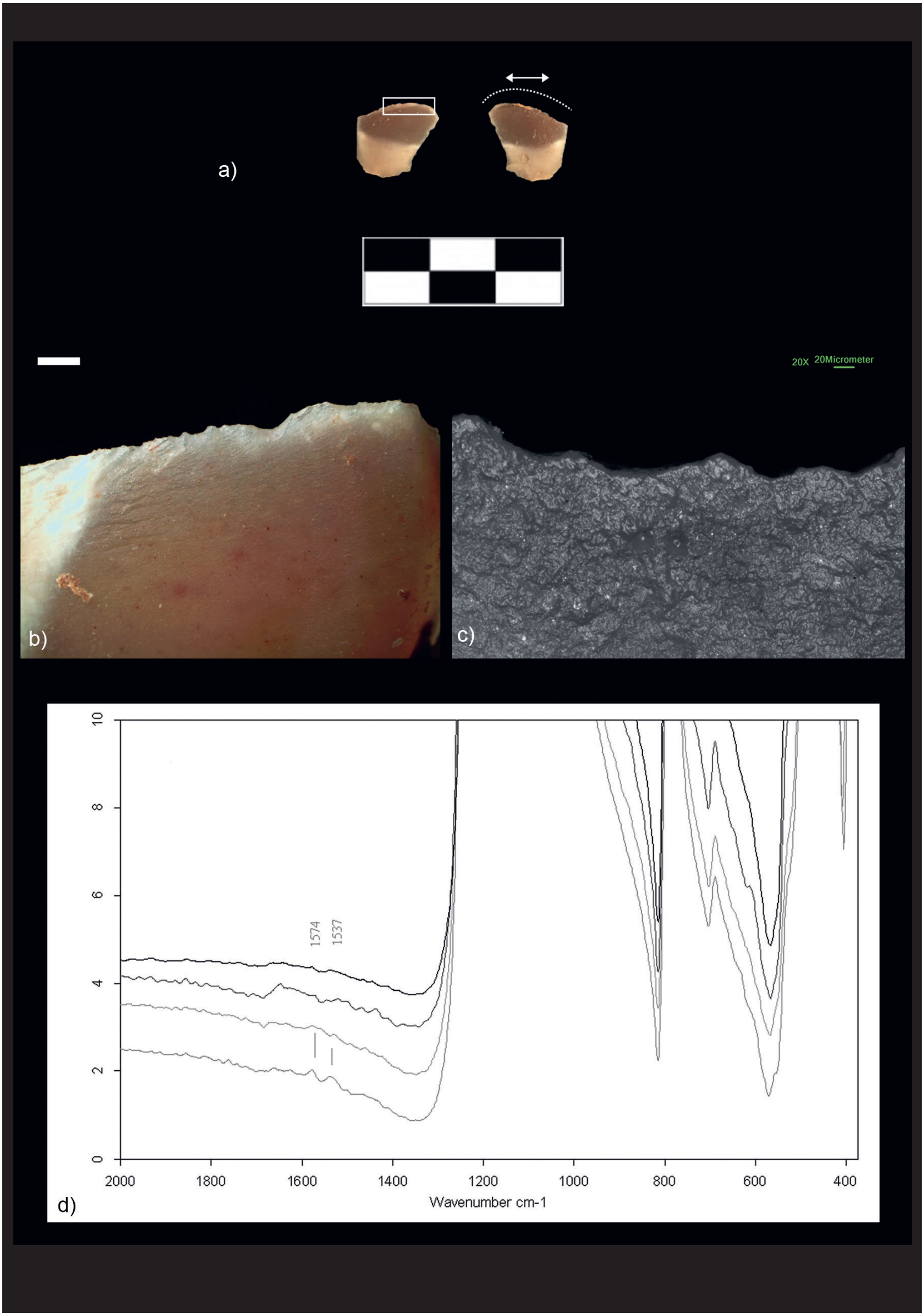
A small part of the sample (5 %) is interpreted as having had intentional, more prolonged and intensive contact with bone, with or without the weak presence of meat that covered it. Bone processing is associated with thicker and stronger edges of lateral and Kombewa items suitable to affect such hard material (Fig. 9). Bone micro residues confirmed the use wear interpretation detected on these items: the FTIR spectra showed peaks around 913 cm^{-1} which are assigned to residues of the mineral part of bone, namely the Hydroxyapatite (Fig. 10). The most intense peak of hydroxyapatite unfortunately lies around 1030 cm^{-1} and it is no more visible when FTIR is performed on in-situ residues because it is overlapped by the Si-O stretching mode of silica (Prinsloo et al. 2014; Monnier et al. 2017). However, the presence of bone produces a broadening in the lower frequency side of this mode and, in addition, a shoulder around 913 cm^{-1} (Taylor and Donnelly 2020). Through SEM-EDX observations it was possible to notice the presence of circular or linear matte-textured whitish masses of residues below or along the functional edge of the tools. The two typical bone elements of P and Ca at the proper atomic ratio (around 2:1 according to our experimental reference collection and to Christensen 1997) confirmed their origin. Bone is the most recurrent residue found at Qesem Cave, and its preservation was facilitated by the alkalinity condition of the sediment caused by the rich carbonate water percolating into the cave (Frumkin et al. 2009; Venditti et al. 2019a).

Fresh hide-processing is observed on 14 items (8 %), confirmed by a combination of edge damage, hide-like polish and micro-residues of adipocere identified by the typical doublet absorption bands at ~1575 cm^{-1} and ~1538 cm^{-1} assigned to the to the C-O stretching of calcium salt carboxylate of saturated fatty acids (Fig. 11).

The morphological observation at SEM performed on one item showed dark greyish residues attached along the ventral edge of the tool, consisting mainly of S associated with Na, Cl and K, which are the typical chemical components of meat/hide (see Venditti 2019). Although sulphur may also be found in EDX measurements of micro-skin flakes deposited after modern manipulation, I want to stress here that the residues interpreted as animal

Fig. 10: Use-wear trace and FTIR results:
a) specimen F11a-645-650; b) edge damage; c) polish on the edge ventral surface associated with cutting bone; d) Micro-FTIR spectrum showing the microresidue of bone; e) SEM micrograph on the ventral surface showing bone residues (secondary electrons; 5 Kv; mag=600x); f) EDX-histogram showing the high percentages of phosphorus (P) and calcium (Ca). Red squares indicate the EDX sampling point. White squares indicate the Micro-FTIR sampling areas.
White scale bar equals 1 mm.

Abb. 10: Gebrauchsspuren und FTIR-Ergebnisse:
a) Stück F11a-645-650; b) Kantenbeschädigungen; c) Politur an der Kante der Ventralfläche, die auf das Schneiden von Knochen zurückgeht; d) Mikro-FTIR-Spektrum, das die Mikroresiduen von Knochen zeigt; e) REM-Aufnahme auf der Ventralfläche mit Knochenresten (Sekundärelektronen; 5 Kv; mag = 600x); f) EDX-Histogramm, das die hohen Prozentsätze von Phosphor (P) und Calcium (Ca) zeigt. Rote Quadrate zeigen den EDX-Abtastpunkt an. Weiße Quadrate geben die Micro-FTIR-Abtastbereiche an.
Der weiße Maßstab entspricht 1 mm.


a)
b)
c)
20X 20Micrometer
d)
1574
1537
0
2
4
6
8
10
2000
1800
1600
1400
1200
1000
800
600
400
Wavenumber cm-1

tissues do not show the typical distribution and morphological features of skin flakes when observed at the SEM (Pedergnana and Ollé 2016). To the contrary, strict morphological resemblance was found with the micro-remains of animal tissues after animal processing observed in the reference collection (light grey tonalities and irregular amorphous shapes). Its interpretation was considered reliable in light of the hide-like polish observed on the active edge of the tool.

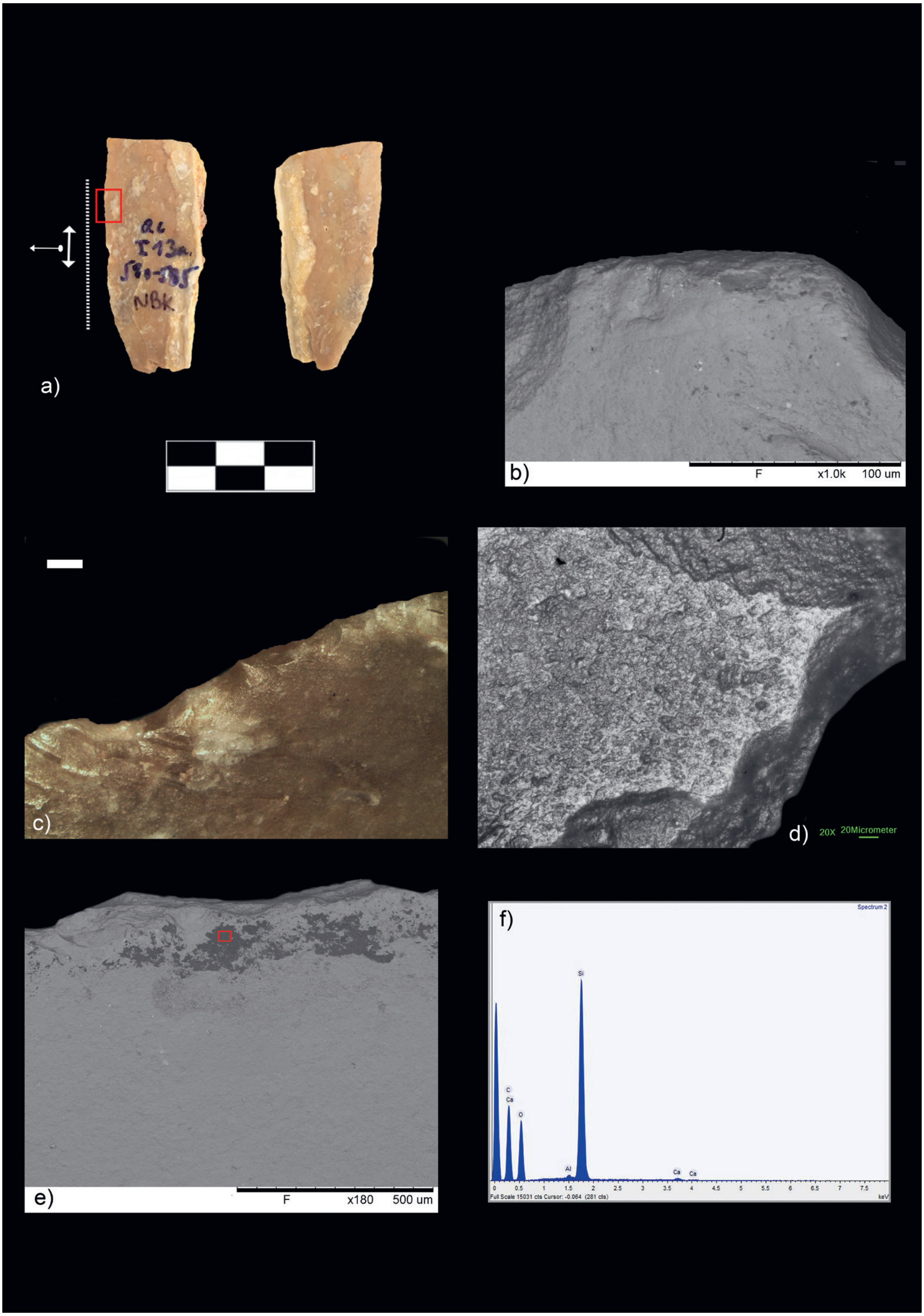
The exploitation of vegetal resources is much less represented (4 %), confirmed by the processing of tubers and wild plants, demonstrating that other types of resources were also consumed or utilized by the Qesem Cave inhabitants (Fig. 12). Residues detected through SEM-EDX observation consisted in micro-remains of tuber flesh possibly mixed with soil (Fig. 12e, f) found on two items and a fragmented phytolith on a flake that came in contact with wild plant and bone (Venditti et al. 2019a SI). Morphological and elemental characterization of the archaeological residues are consistent with tuber residues found on experimental replica. EDX measurements performed on the pure flesh of three different tuber species show calcium as the major compositional element. However, it should be stressed that calcium may also be related to micro-particles of soil embedded in the tuber flesh after processing unpeeled tubers, as shown in the reference collection (Venditti et al., 2019a).

Overall, longitudinal motions are the most represented within the sample in all the analyzed areas while transversal and mixed activities are less common and are mainly performed with lateral flakes.

Due to preservation conditions it was only possible to assess the hardness of the worked material for 51 % of the items in the sample on the basis of the characterization of edge damage and edge rounding. The processing of soft-medium material through longitudinal motions is prevalent in all the analyzed areas, while transversal and mixed motions on soft or medium material are represented by a low percentage of use (Fig. 13). It should be said that several items recognized as being used on soft/medium materials were, quite certainly, used for activities involving animal materials. These were, therefore, the most important tasks carried out with such implements.

Fig. 11: Use-wear traces and micro-FTIR results:
a) specimen F10b 635e640; b) edge damage; c) polish located on the ventral edge surface interpreted as the result of cutting fresh hide; d) micro-FTIR spectrum showing the measurements on the dorsal edge surface with presence of adipocere microresidue. White square indicates the FTIR sampling area.
White scale bar = 1 mm.

Abb. 11: Gebrauchsspuren und Mikro-FTIR-Ergebnisse:
a) Stück F10b 635e640; b) Kantenbeschädigungen; c) Politur an der Kante der Ventralfläche, interpretiert als Ergebnis des Schneidens von frischem Fell; d) Mikro-FTIR-Spektrum, das die Messungen an der Kante der Dorsalfläche bei Vorhandensein von Adipocere-Mikroresiduen zeigt. Das weiße Quadrat zeigt den FTIR-Abtastbereich an.
Weißer Maßstab = 1 mm.


Q6
I 13a.
580-585
NBK
a)
b)
F
x1.0k
100 um
c)
d)
20X
20Micrometer
e)
F
x180
500 um
f)
Spectrum 2
Si
C
Ca
O
Al
Ca
Ca
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
Full Scale 15031 cts Cursor: -0.064 (281 cts)
keV

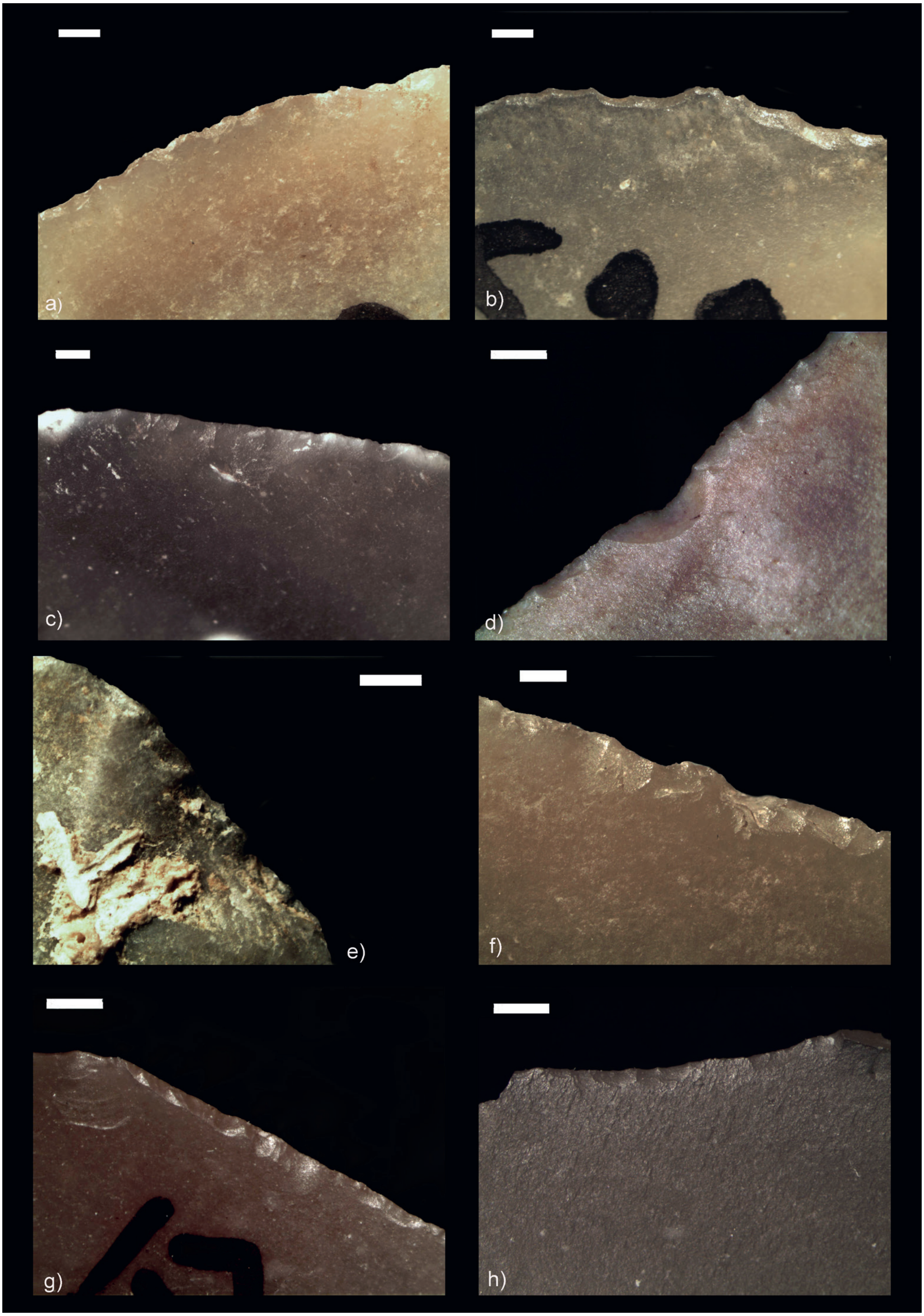
The general distribution of the use-wear traces along the functional edge of the items attests to a free hand manipulation, which has proved to be the best handling mode. Micro-polish possibly related to hand-held use was found on 16 specimens exhibiting well-preserved lithic surfaces, while no traces of hafting were observed in any of the artifacts in the sample. Traces were localized around the bulb area or along the ridge of the flint surface (Venditti 2019). According to my experimental work, it appears that certain tool mobility during the manipulation of the flakes is required in order to perform fine cutting activities and to allow a change in edge angle and edge portion following the required needs of accuracy (Venditti 2019).

Along with the reconstruction of the exploited resources and the tasks carried out by the inhabitants of Qesem Cave, this work also included the investigation of the spatial distribution of hominin activities in the cave. The density maps in Figure 14 clearly show a spatial interpretation of tool use in the Yabrudian and Amudian contexts of the cave.

The wide distribution throughout the analyzed areas of the items interpreted as used during the processing of animal carcasses (with a higher concentration in the shelf area as well as in the hearth, especially in square J13; Fig. 14b), confirms that butchery was the most common activity performed at the site. The processing of bone was almost exclusively performed in the shelf area (except for one item found in the area south of the hearth) along with hide which does not appear to be exploited in the hearth area (Fig. 14a, c). More interesting is the fact that the exclusive contact with fresh hide (only one case has shown traces of semi-dry hide in transversal motion) was observed with a much higher frequency in the Yabrudian rather than Amudian assemblages under the shelf (Fig. 15). The fact that Yabrudian contexts are dominated by the production of Quina scrapers may indicate, in a functional perspective, some sort of activity that necessitated the use of scraping tools. In fact, scrapers are the best suitable tools for defleshing and softening hide, as evidenced by experimental and ethnographic data (Christidou and Legrand 2005; Beyries and Rots 2008). It is no coincidence that the use-wear analysis conducted by Andrea Zupancich on the Quina and demi-Quina scrap-

Fig. 12: Use-wear and SEM-EDX results:
a) specimen I13a 580-585; b) SEM micrograph showing the high degree of rounding on the dorsal edge (secondary electrons; 5 Kv; mag=1000X); c) edge damage; d) polish located on the dorsal edge surface associated with mixed motion on tubers; e) SEM micrograph showing micro-tuber flesh residues along the dorsal edge (secondary electrons; 5Kv; mag=180X); f) EDX-histogram showing the presence of Aluminum and Calcium (Al, Ca). Red squares indicate the EDX sampling point.
White scale bar equals 1 mm.

Abb. 12: Gebrauchsspuren und SEM-EDX-Ergebnisse:
a) Stück I13a 580-585; b) REM-Mikroaufnahme, die den hohen Verrundungsgrad an der Dorsalkante zeigt (Sekundärelektronen; 5 kV; mag = 1000X); c) Kantenbeschädigungen; d) Politur an der Kante der Dorsalfläche, die mit verschiedenen Tätigkeiten auf Wurzelknollen verbunden ist; e) REM-Aufnahme, die Mikroresiduen von Wurzelknollen entlang der Dorsalkante zeigt (Sekundärelektronen; 5 kV; mag = 180 ×); f) EDX-Histogramm, das das Vorhandensein von Aluminium und Calcium (Al, Ca) zeigt. Die roten Quadrate zeigen den EDX-Abtastpunkt an.
Der weiße Maßstab entspricht 1 mm.


a)
b)
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g)
h)

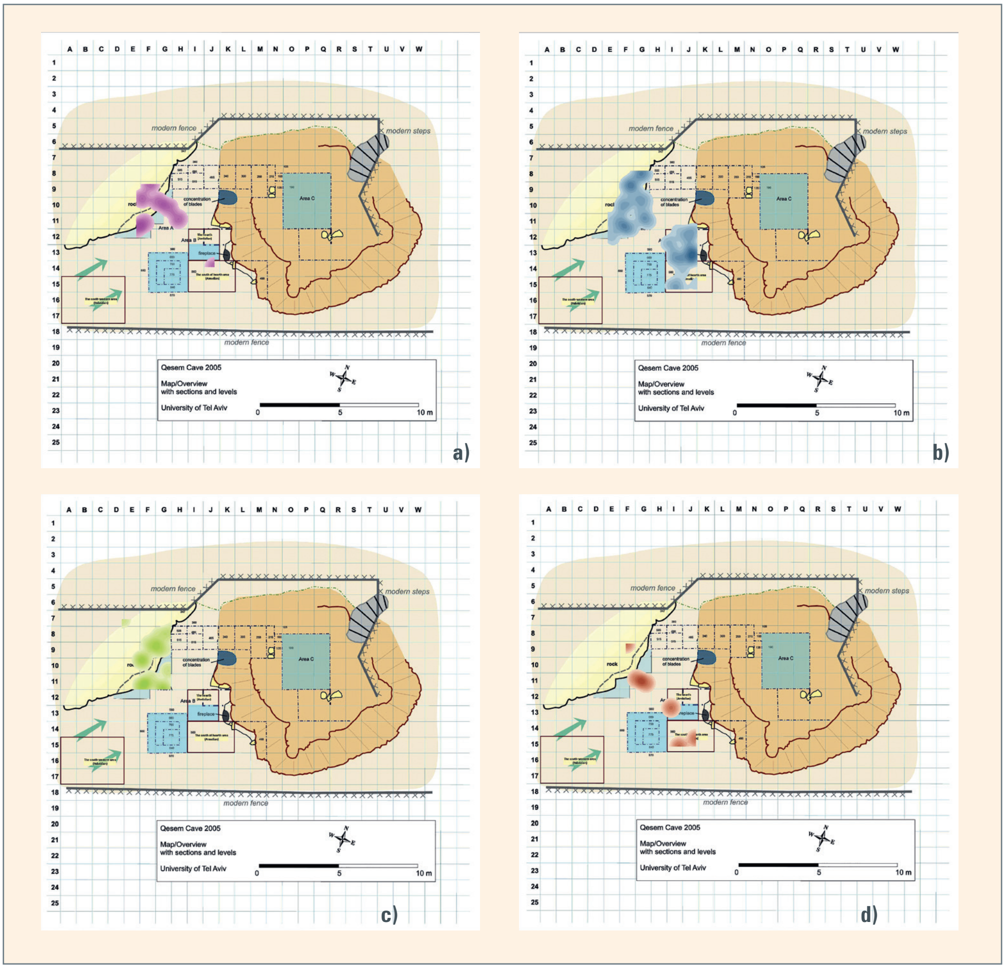

Fig. 13 (left): Edge damage interpreted as having been in contact with soft, medium and soft/medium materials: a) specimen E11b 690-695; b) E11b 660-665; c) G9c 605-610; d) G10b 650-655; e) G11c 560-565; f) I13c 590-595; g) J13b 570-575; h) J14b 595-600. White scale bar equals 1 mm.

Abb. 13 (links): Kantenbeschädigungen, die auf Kontakt mit weichen, mittleren und weichen/mittleren Materialien zurückgehen:
a) Stück E11b 690-695; b) E11b 660-665; c) G9c 605-610; d) G10b 650-655; e) G11c 560-565; f) I13c 590-595; g) J13b 570-575; h) J14b 595-600. Der weiße Maßstab entspricht 1 mm.

Fig. 14 (top): Kernel density map showing the spatial distribution of inferred activities in relation to the grid system of Qesem Cave. Spatial distribution reflects the results of several occupation stages. a) bone working (8 items); b) processing of animal carcass (52 items); c) hide working (14 items); d) vegetal working (6 items).

Abb. 14 (oben): Kernel-Dichtekarte, die die räumliche Verteilung der erschlossenen Aktivitäten in Bezug auf das Grabungsraster der Qesem-Höhle zeigt. Die räumliche Verteilung spiegelt die Ergebnisse mehrerer Besiedlungsphasen wider. a) Knochenbearbeitung (8 Belege); b) Verarbeitung von Tierkadavern (52 Belege); c) Fellbearbeitung (14 Belege); d) Bearbeitung pflanzlichen Materials (6 Belege).

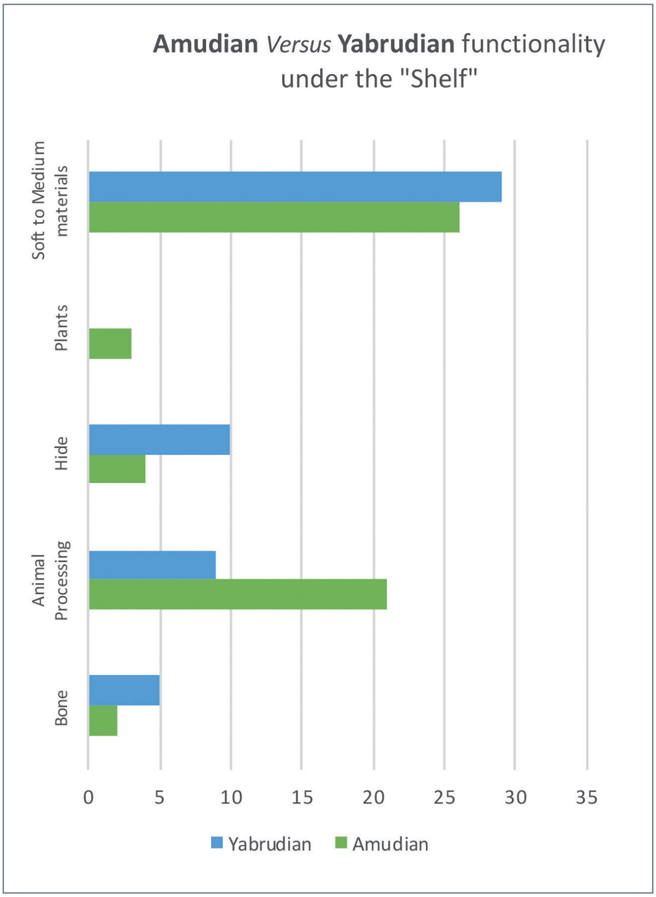

Fig. 15: Chart showing the Yabrudian versus Amudian functionality under the "shelf."

Abb. 15: Diagramm mit der Gegenüberstellung der ausgeführten Funktionen im Jabrudien und im Amudien unterhalb des „shelf"-Bereiches.

ers under the shelf shows that scraping activities on hide were the main tasks carried out in the Yabrudian contexts under the shelf (Zupancich, personal communication). To the contrary, functional data on the small recycling flakes show that they were exclusively used in longitudinal motion for carrying out cutting activities during specific moments of hide processing. According to the results of the experimentations, small recycled flakes proved to be very powerful during the initial phase of the process, when the fresh hide (with the hair on) has to be separated from the animal carcass. The sharp and thin edges are entirely suitable for making deep and precise cuts during the skinning process. In the same way, once the hide is softened with the use of a scraper, the small blanks can be used to cut strips of fresh hide that will be subsequently soaked in agents for tanning. After the drying process, strips of leather may be used for further needs, including as wrapping material in hafting or binding.

Following this evidence, I suggest that the small recycling flakes were used by the Qesem hominins in a complementary way along with the use of other tools during the same or different working process. In this way, scrapers and small flakes constitute different possibilities within the available tool-kits to be used at the most appropriate time. This behavior testifies to planning mechanisms put in place to reach specific goals, including the realization of specific tasks and the deliberate production of different tools (Venditti 2019; Venditti et al. 2019).

The absence of traces related to the processing of wood either in the Yabrudian or in the Amudian industries under the shelf is another interesting aspect of the Yabrudian versus Amudian variability observed at Qesem Cave. It is highly likely that the exploitation of vegetal resources, including woodworking, was realized to a greater extent with other types of tools, in which the Quina and demi-Quina scrapers are definitely included, as confirmed by the use-wear analysis on this category of objects (Lemorini et al. 2016; Zupancich, personal communication). In fact, only scant evidence of tuber and plant working was identified at Qesem Cave, and that evidence was only related to the Amudian context of the cave.

Discussion and conclusion

The data obtained so far testify that the products of recycling hold technological and functional features belonging to a targeted production aimed at obtaining specific tools to satisfy immediate and particular needs. Functional results show that small sharp flakes produced by lithic recycling were mostly used in exploiting animal carcasses after selected body parts were brought to the cave for butchery purposes and food sharing, notably around the fire (Stiner et al. 2011). Few cases of processing vegetal resources were recognized as well.

The comparison between Amudian and Yabrudian assemblages shows that animal body parts were similarly processed in both and in all the areas studied, demonstrating that small flakes were commonly produced for carrying out this task at all times and places at the cave. In addition, bone processing is almost exclusively practiced in Yabrudian contexts under the shelf, while hide working is performed only under the shelf with no evidence in the fireplace areas. This might hint towards a specialized activity area of animal by-products under the shelf, with the hearth area being the center for the consumption of animal and vegetal resources, undoubtedly also generating social interaction between group members. Conversely, vegetal resources appear to be exploited by recycled flakes only in the Amudian context of the cave, while the Yabrudian context in the shelf area lacks such evidence. The results originating from the shelf area and from the hearth areas support a spatially related interpretation of the Yabrudian and Amudian variability at Qesem Cave, suggesting different activity areas within the cave characterized by an emphasis on specific tool-kits.

Despite a good percentage of tools being used for a specific activity on targeted materials, there was also a large quantity of unused items, especially within the regular, lateral and non-Kombewa categories. The latter category has recorded a higher percentage of unused tools, especially in Amudian contexts under the shelf, where their production was common. Following the functional results, it could be argued that the non-Kombewa items resulted from knapping mistakes made during production of lateral pieces. This interpretation is supported by the fact that most of them are overshot and that the non-Kombewa tools are more abundant in Amudian than Yabrudian assemblages, where laminar production is more consistent.

The regular and the lateral were the most produced types of tools and, consequently, they account for a major number of uses. But they also account for a fairly high percentage of unused items. In my opinion these data get to the heart of the recycling question: the recycling phenomenon is linked to fast production methods that do not necessarily result in tools best suited to particular demands and needs (Venditti 2019). We must still bear in mind, though, that some recycling tools interpreted as unused may have had very short and fast contact with soft materials, and as such, they might exhibit negligible macro- or micro-wear signs. This feature was also noticed by other scholars who worked on the functional reconstruction of small tool assemblages in Middle Pleistocene sites (Mosquera et al. 2015; Aureli et al. 2106).

The adoption of a recycling procedure has often been related to contexts where raw materials are scarce. It is a way to obtain quickly and easily raw material for a new line of production. This behavior has also been considered expedient in nature (Vaquero et al. 2015). However, this was not the case at Qesem Cave, where close (up to 5 km) and distant flint sources (up to 15 km) were known and used by the Qesem hominins (Wilson et al. 2016). This was also the case for deeply buried materials used in the production of more complex tools such as handaxes and Quina scrapers (Boaretto et al. 2009).

The contribution of use-wear and residue analysis has demonstrated that the recycling trajectory was addressed to maximize and optimize lithic production to satisfy specific functional practices, rather than a result of flint shortage. This planned execution of adaptive strategies is outstanding and considerably reverses the idea that the adoption of lithic recycling by hunter-gatherers is fundamentally linked to environmental constraints.

However, the deliberate and well-executed manufacture of the products of recycling at Qesem Cave can be seen as expedient, to the extent that the production was clearly done quickly and provided sharp cutting tools that required no further modification of the edges to be useful. However, it does not seem appropriate to categorize Qesem lithic recycling as strictly expedient. Although the recycled products are apparently simple ready-made tools, produced through a short reduction sequence without need of further modification before use, this does not imply there were no reasoned choices or technological complexity behind their production. To the contrary, it was a conscious and deliberate behavior that allowed the Qesem hominins quickly to obtain simple sharp tools with little effort to be used in a specific way for meticulous practical activities (Venditti 2019).

According to my experimental work and the results obtained on the archaeological material, I suggest we consider the small recycled flakes as non-versatile tools. This conclusion is based on their technological features (small dimension, short edges), by their short time of utilization, and by the fact that no superimposed activities or materials were observed on the archaeological flakes. I suggest that the small flakes were used for activities not involving high force but for those requiring more precision, such as the collecting of meat and fat during the butchery process, the cutting of hide for removing the subcutis, the tendon and periosteum removal for cleaning the bone, the defleshing/filleting of small amounts of meat etc. In this scenario, small flakes probably constituted an important addition to the Paleolithic tool-kit alongside larger and more massive tools (e.g., handaxes, scrapers, naturally backed knives) used for activities involving more force applications or energetic actions, probably of a less precise nature. That is why I suggest considering these recycled small flakes as "finishing touch" tools, used in a complementary way with other types of tools mainly during the processing of animal materials. These data clearly show how features such as edge morphology, worked material, and the motion employed are strictly related and dependant in this category of tools (see also Venditti et al. 2019b). The technological and functional aspects of the small recycled flakes indicate a high level of know-how demonstrated by the development of structured activities (e.g., hide working, butchery) within different actions (e.g., skinning, defleshing, filleting meat, periosteum removal), realized by accurate gestures and specific tool-types. The production of small flakes at Qesem Cave is part of a varied lithic production and repertoire including many thousands of artifacts such as blades, scrapers and backed knives used in specific activities according to their technological characteristics. This diversification of the tool-kit according to the anticipated needs of the cave's inhabitants demonstrates a high level of cognitive complexity in planning their activities both in terms of lithic production and use.

If we add these results to the set of novelties already recognized at Qesem Cave (e.g., laminar and Quina production, systematic use of fire, meat roasting, raw material selection, storage and delayed consumption of marrow; see Shahack-Gross et al. 2014; Blasco et al. 2016a, 2019; Lemorini et al. 2016, 2020; Barkai et al. 2017b) it is clear that "something new" occurred in the Levant around 420 ka which has no parallels in the preceding Acheulian.

Who were the hominins bringing with them this set of novelties and why did they replace *Homo erectus* in the Levant at this specific time is still an open question. The geographical position of Qesem Cave in the Levant is exceptional as a connection between the Asian, African and European continents. The Levantine Corridor was one of the most important contact zones between Africa and Eurasia during the Pleistocene, and thus constitutes a potential area in which to detect population dispersals. This is a crucial aspect concerning the types of *Homo* once living in this area who conceived the innovative behaviors related to the AYCC.

It has been suggested that the changes occurring during this period resulted from the disappearance of elephants from the Levant around ca. 400 ka which might have caused a need to hunt an increased number of smaller and faster animals to maintain an adequate level of fat in the hominin diet. This subsistence adaptation led to the emergence of lighter, more agile and cognitively capable hominins (Ben-Dor et al. 2011). This idea is confirmed by the fact that the disappearance of elephants in the Levant and the emergence of new cultural behaviors coincided in time. Moreover, the morphometrical results of Qesem teeth analyses have revealed that they do not belong to *H. erectus*, highlighting, conversely, a general similarity to Upper Pleistocene local populations of Skhul and Qafzeh Caves, on the one hand, and Neanderthal populations, on the other (Hershkovitz et al. 2011, 2016; Weber et al. 2016). These data demonstrate that new cultural and biological transformations took place during the AYCC period in the Levant. The deliberate production and use of the small recycled flakes are an important part of this new mode of adaptation which allowed the Qesem hominins to survive and thrive for 200,000 years (Barkai and Gopher 2013).

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