Quaternary International 721 (2025) 109686

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Reassessing the Middle Palaeolithic lithic technology of Grotta Romanelli (Lecce, southern Italy)

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A R T I C L E I N F O

Keywords:
Italian peninsula
Grotta Romanelli
Middle Palaeolithic
Mousterian
Lithic technology

A B S T R A C T

Located in the southernmost part of the Italian Peninsula, specifically the Salento area in the Apulia region, Grotta Romanelli (Lecce) is one of Italy's most significant Palaeolithic sites. It shows evidence of human occupation from the Middle to the late Upper Palaeolithic.

This study presents a re-analysis of historical lithic collections and also includes a new analysis of artefacts from recent excavations within Middle Palaeolithic Inside Stratigraphic Unit 3 (ISU3). This unit, formerly referred to as level G or "terre rosse", is dated to at least the MIS 5 interglacial period.

Our findings offer a revised perspective on past interpretations of Grotta Romanelli's Middle Palaeolithic lithic industry. Interpretations of this industry have varied over time, especially regarding the presence of Levallois core technology — an important cultural and chronological marker.

The initial classification in the 1970s described the assemblage as Charentian Mousterian of Quina type, characterized by the absence of Levallois technology and the exclusive use of local materials. However, studies from the 2000s suggested a predominance of Levallois technology, along with a noteworthy, albeit limited, use of non-local materials.

Our lithic analysis suggests instead a focus on expedient flake production using exclusively locally available raw materials, with no evidence of the Levallois method.

These results contrast with previous hypotheses, indicating a distinctive role for Grotta Romanelli's lithic technology within the Middle Palaeolithic cultural framework of southern Italy.

1. Introduction

The emergence of the Levallois method, traditionally marking the transition from the Lower to the Middle Palaeolithic, represents a fundamental technological innovation (e.g., Adler et al., 2014; Baena et al., 2014; Fontana et al., 2013; Moncel et al., 2011; White and Ashton, 2003; Wiśniewski, 2014). It coincides with changes in subsistence strategies and the first appearance of early Neanderthal anatomical traits (Moncel et al., 2020; Zanolli et al., 2018).

Early Levallois technology is usually dated in Europe to the end of MIS 9 and the beginning of MIS 8. However, recent research points to an early emergence of prepared core technology in Western Europe, from MIS 12 to MIS 9 (Moncel et al., 2020).

In Italy, the Levallois method appears asynchronously. With the exception of the Guado San Nicola site in Molise, dated to MIS 11-10 (Muttillo et al., 2014; Peretto et al., 2016), the method appears from MIS 9-8 onwards in northern and central Italy. Examples include Cave dall'Olio in Emilia-Romagna (Fontana et al., 2013), San Bernardino cave in Veneto (Picin et al., 2013), and Sedia del Diavolo and Monte delle Gioie in Lazio (Soriano and Villa, 2017). In southern Italy, the Levallois

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https://doi.org/10.1016/j.quaint.2025.109686
Received 2 November 2024; Received in revised form 13 January 2025; Accepted 24 January 2025
Available online 21 February 2025

method does not appear before MIS 5 (Aureli and Ronchitelli, 2018).

Reconstructing the chronology of the prepared core technology in Salento, the southernmost part of the Italian Peninsula, is even more challenging. This is due to the lack of high-resolution chrono-stratigraphies. While Mousterian industries are abundant in cave sites in Salento, only few sites can rely on radiometric dating (Table 5).

An attempt to establish a chronology was made using lithic typological data combined with paleontological and geological information (Spinapolice, 2018a, 2018b; Palma Di Cesnola, 2001).

The Campanian Ignimbrite tephra level (~40 ka; Giaccio et al., 2017), present at the top of the Grotta del Cavallo, Grotta Uluzzo C, and Grotta Mario Bernardini sequences, was used as a *terminus ante quem* for human frequentation (Zanchetta et al., 2018). Meanwhile, the last interglacial sea-level high stand (MIS 5e, ~125 ka), identified at the base of the stratigraphic sequence of most of the sites in Salento, including Grotta Romanelli, was used as a *terminus post quem*.

Therefore, the Mousterian assemblages in Salento are generally bracketed between MIS 5 and MIS 3 (e.g., Ranaldo et al., 2022; Spinapolice, 2018a, 2018b).

Possibly older (attributable to MIS 7) is the Mousterian industry of Grotta del Cavallo, based on the faunal association (Berto, 2020; Sala and Berto, 2020; Sarti, 2020; Sarti and Martini, 2020). However, the U/Th dating of the earliest Mousterian level (level N) indicated a more recent age, at MIS 5e (Zanchetta et al., 2020).

Even accepting the older chronology suggested for Grotta del Cavallo, the appearance of Levallois method (I level) would not be older than MIS 5 (Martini et al., 2020a).

Based on the typological analysis conducted during the 1960s–1980s by A. Palma di Cesnola, E. Borzatti von Lowerstern, and M. Piperno, the oldest lithic industries of the sites in Salento, including Grotta Romanelli, were attributed to the Charentian Mousterian of Quina type (*sensu* Bordes, 2002; Bordes and Bourgon, 1951) lacking Levallois concept. Prepared core technology would only emerge in the area at a later stage, marking an abrupt shift that hinted at the potential arrival of a different cultural tradition (Palma di Cesnola, 2001).

However, more recent revisions and analyses of most of the Salento sites (i.e., Grotta Romanelli, Grotta Torre dell'Alto, Grotta Uluzzo C, Grotta Mario Bernardini, and Grotta dei Giganti), overturns this scenario, revealing the significant and massive presence of the Levallois method in the oldest archaeological units (Spinapolice, 2012, 2018a, 2018b).

In this complex scenario, the recent chronostratigraphic reassessment of Grotta Romanelli prompts a reconsideration of the Mousterian lithic industry recovered in the Inside Stratigraphic Unit 3 (ISU3; Pieruccini et al., 2022, formerly known as "*terre rosse*", "*bolo*" or level G, *sensu* Blanc, 1920), now assigned to MIS 5 (Pieruccini et al., 2022).

Previously, ISU3's lithic industry was attributed to the Charentian Mousterian of Quina type, lacking Levallois elements, based on Piperno's analysis conducted in the 1970s (Piperno, 1974). Later, Spinapolice (2018a, 2018b) changed the interpretation of the lithic industry, identifying a predominance of Levallois technology, alongside minimal use of exotic raw material.

This discrepancy, along with the new dating results, necessitated a reanalysis. This paper offers a detailed revision of historical lithic collections and examines artefacts from recent excavations in ISU3. The study reassesses this lithic record within the updated chrono-stratigraphic framework (Pieruccini et al., 2022) and the broader context of the Mousterian in the southern part of the Italian peninsula.

2. Grotta Romanelli: geological background

Grotta Romanelli (40°00′58″N, 18°26′01″E) opens at 7.3 m asl on the south-eastern tip of the Salentine Peninsula (Apulia, Italy). This coastal sector of the Apulia carbonate platform is characterised by limestone to dolostone and calcarenite sequences ranging from the Upper Cretaceous to the Lower Pleistocene (Altamura Limestone, Torre Tiggiano Limestone and Castro Limestone Units, Porto Badisco Calcarenite, Andrano Calcarenite and Gravina Calcarenite Units) (Fig. 1) (Ricchetti and Ciaranfi, 2013).

The Castro Limestone Unit (Lower Chattian, Upper Oligocene) outcrops continuously along the coastline in the area of Grotta Romanelli. It consists of a reef to backreef limestone with clumps of corals, algae, macro foraminifers, and bivalves. In detail, clinoforms with a 30° inclination of calcarenites and calcirudites with fragments of corals, rudists and foraminifera characterize the reef facies sequences. The Castro Limestone Unit non-conformably overlies the Upper Cretaceous Altamura Limestone Unit that crops in the Romanelli Bay. In fact, Grotta Romanelli is situated within a coarse bioclastic calcarenite-calcirudite with fragments of rudists, corals, bryozoans, calcareous algae and large foraminifera, including orbitoids related to the Upper Cretaceous Ciolo Limestone (member of Altamura Limestone Unit) (Ricchetti and Ciaranfi, 2013; Schlüter et al., 2008).

Above the entrance of Grotta Romanelli, Middle Pleistocene coarse to very-coarse and cemented debris-slope deposits (OSU2, stratigraphic unit outside the cave) and shoreface pebbles (OSU1) are preserved (Pieruccini et al., 2022).

3. Grotta Romanelli: archaeo-stratigraphical context

Fieldwork at Grotta Romanelli began with Stasi and Regalia at the beginning of the 20th century and continued with Blanc during the 1920s (Stasi et al., 1904; Blanc, 1920, 1928). Later, it was carried out by Cardini in the 1960s and 1970s. Systematic excavations, interrupted for over 40 years, were resumed in 2015 by *Dipartimento di Scienze della Terra of Sapienza Università di Roma* (Sardella et al., 2018, 2019).

The stratigraphy of the cave infilling was primarily described at the beginning of the 20th century (Blanc, 1920) and has recently been revised after new excavation campaigns. Based on a recent litho-morpho-, and chrono-stratigraphical re-assessment, supported by new U/Th dates, the chronology of the lowermost part of the deposit is significantly older than previously known (Pieruccini et al., 2022).

From bottom to top, the following stratigraphic units inside the cave (named ISU) were recognized (Pieruccini et al., 2022) (Fig. 2A–B).

- ISU1 (formerly layer K, *sensu* Blanc, 1920), made of marine rounded and subrounded polygenic limestone gravels, pebbles, and boulders with variable amounts of sandy-silty matrix, resting over the bedrock and related to a marine high stand. In this unit, only two limestone artefacts were recovered, associated to fire features and scarce faunal remains. Previously attributed to the Last Interglacial (MIS 5e) (Blanc, 1920, 1928), this unit is now ascribed to MIS 9 (Pieruccini et al., 2022).
- ISU2 (formerly layers H and I, *sensu* Blanc, 1920), consisting of layers of angular to subrounded coarse-grained monogenic cemented limestone gravels, pebbles, and boulders, with a sandy-silty matrix, covered by irregular flowstones. In this unit very few lithics ($n = 6$) and faunal remains were recovered. According to the new U/Th ages, comprised between 360 ± 87 ka and 218.8 ± 34 ka, ISU2 provided the oldest geochronological constraint for the whole succession, bracketed between MIS 9 and MIS 7 (Pieruccini et al., 2022).
- ISU3 (formerly layer G called "*terre rosse*" or "*bolo*", *sensu* Blanc, 1920), composed of clays and silts with variable amounts of fine to coarse-grained quartz sands. The sedimentary facies are typical of alternating and recurrent sheet-floods and lack of significant features associated to weathering or soil formation processes, such as cracks or other features related to biological activity. This unit yielded a consistent Mousterian limestone industry (Piperno, 1974; Spinapolice, 2018a) associated to a diversified vertebrate fauna (Mecozzi et al., 2024).
- ISU4 (formerly layer F, *sensu* Blanc, 1920) is a roofspall made of mono-genic limestone boulders and gravels, which is covered by a flowstone dated starting from 112.5 ± 1 ka (Pieruccini et al., 2022).

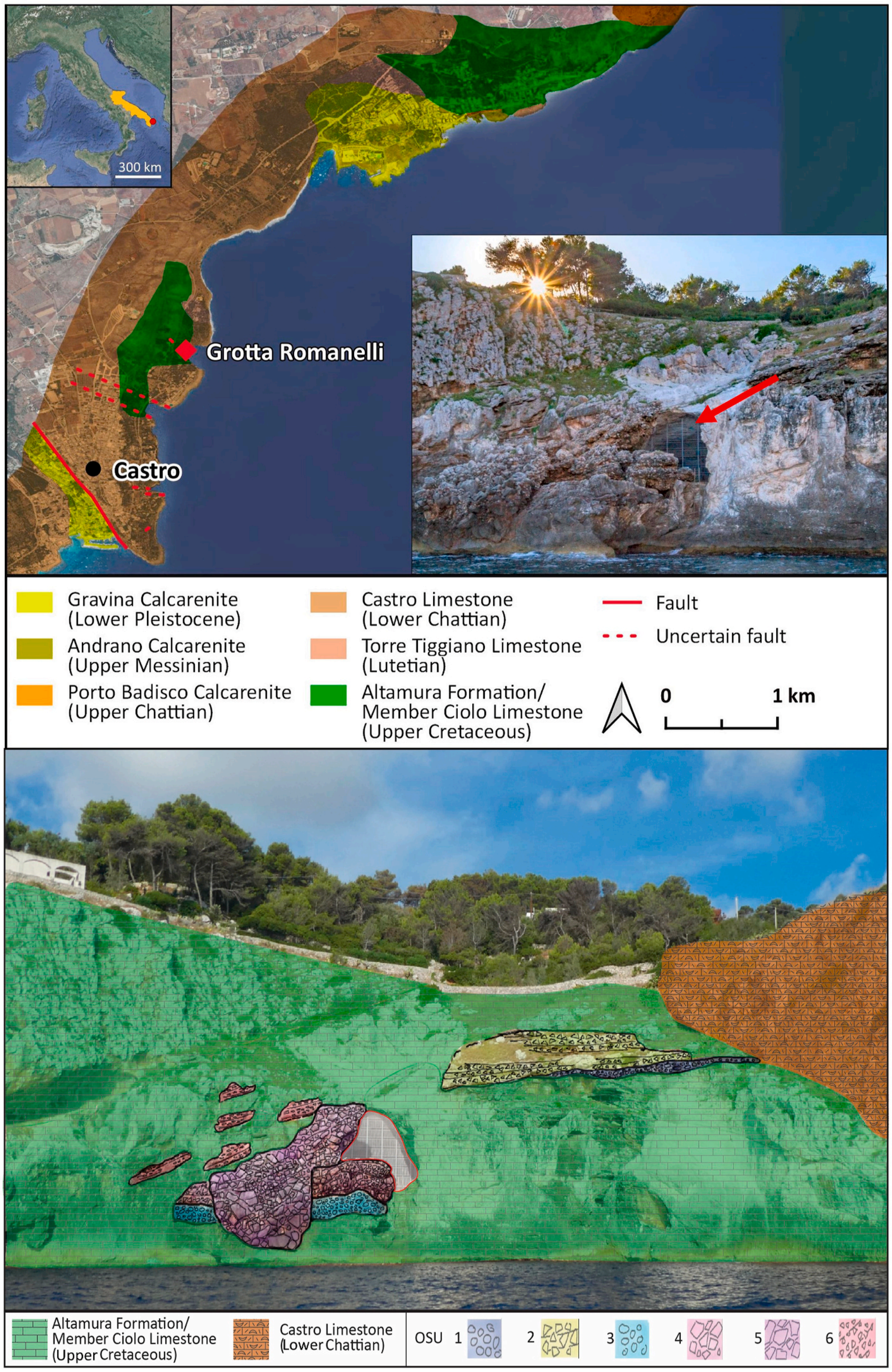

Fig. 1. Geological map of the coastal sector neighbouring Grotta Romanelli (at the top) (modified from Bosellini et al., 1999 and adapted from Ricchetti and Ciaranfi, 2013), with the panoramic view on the Romanelli Bay and the Grotta Romanelli entrance (red arrow). Geological and geomorphological line drawing of the Romanelli Bay (modified from Pieruccini et al., 2022) (at the bottom).

- ISU5 (layers A-E, called "*terre brune*", *sensu* Blanc, 1920), consisting of thinly to medium layered sands, silts, and clays, rich in upper Palaeolithic tools and faunal remains. According to recent ^{14}C dating, this unit was dated between 13.6 cal ka BP and 11.4 cal ka BP (Calcagnile et al., 2019; Sigari et al., 2021).

4. Inside Stratigraphic Unit 3 (ISU3)

This unit was excavated in 1963, 1964, and 1970 in a trench located in the southern sector of the cave (Fig. 2C), during the Cardini excavations. ISU3 deposit was divided in three principal artificial sub-units (G1, G2, and G3 from the top to the bottom) and excavated through 13 artificial layers, each 10 cm thick. The typological homogeneity of the lithic components, combined with the recovery of five refittings composed of 15 artefacts across the subunits, suggested limited occupation events. This is further supported by the scarcity of faunal remains, and the absence of structured hearths. ISU3 was therefore interpreted as the result of a single or a few occupation events (Piperno, 1974; Spinapolice, 2018a, 2018b).

The sandy and silty sediments of this unit were flushed and redistributed into the cave by run-off waters. These sediments, made of quartz derived from the erosion of older continental deposits and

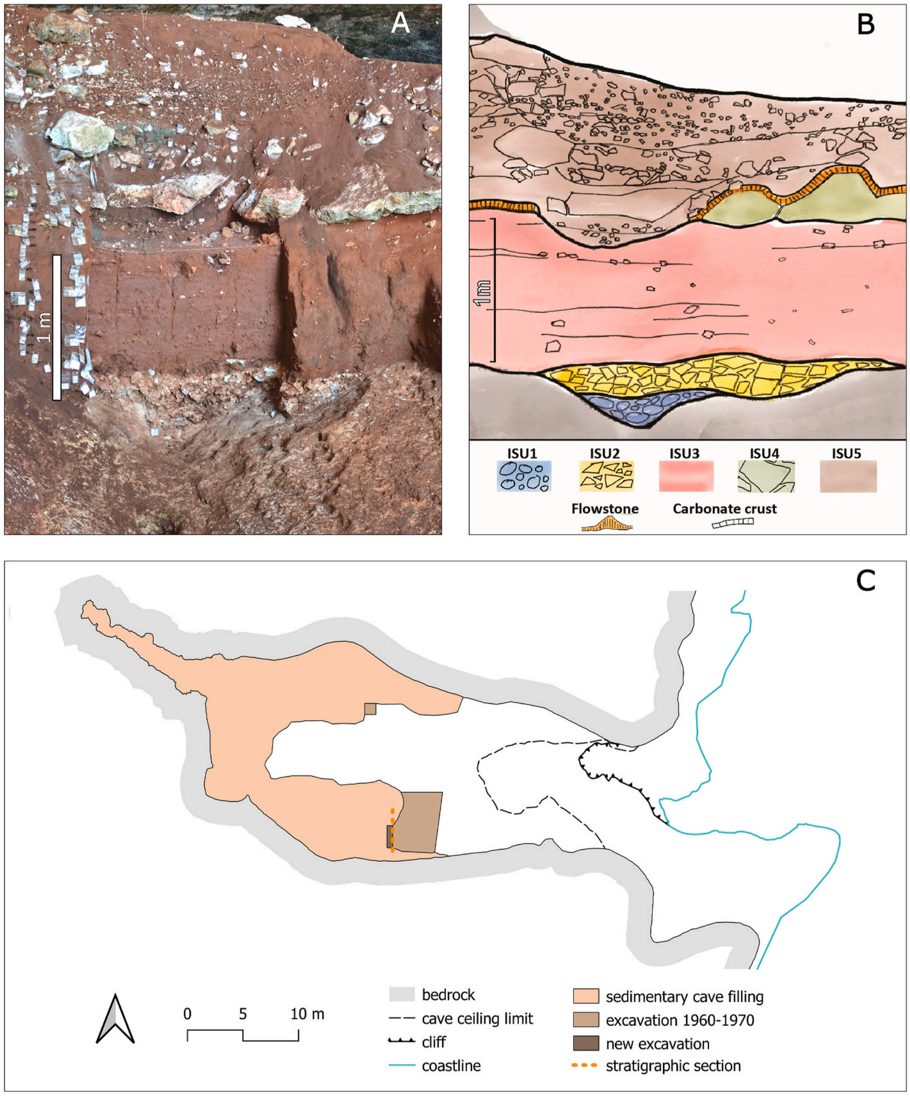

Fig. 2. Stratigraphic sequence in the south section, during the 2018 fieldwork (A) and line drawing of the same section (B) (modified from Pieruccini et al., 2022). C) Planimetry of the cave with the indication of the ongoing ISU3 excavated area and the Cardini excavations (1960s–1970s) (Photo: L. Forti; artwork: P. Pieruccini; map: G. Lembo).

leached soils, indicate landscape instability following a warm and humid climatic phase (Pieruccini et al., 2022). The presence of olive trees within the pollen spectra further supports this interpretation (Ermolli et al., 2022).

By the late 1960s, the chronology of this stratigraphic unit was constrained to span from 69 ka (speleothem H; no associated error with this date) and 40 ± 3.2 ka (speleothem F) using the Th^{230}/U^{234} method (Fornaca-Rinaldi and Radmilli, 1968). Currently, according to new U/Th ages of the underlying ISU2 and overlying ISU4, the chronology of ISU3 is broadly comprised between 218.8 ± 34 ka and 112.5 ± 1 ka. However, due to the "colluvial" nature of the sediments inherited by the possible erosion of Interglacial leached soils, IUS3 can be correlated to the early phases of climate deterioration that followed the Last Interglacial (Pieruccini et al., 2022).

The faunal assemblage recovered from ISU3 is composed of mammals, birds, reptiles, amphibians and fishes (Blanc, 1920, 1928; Mecozzi et al., 2024). The mammal assemblage includes taxa adapted to different environments. The predominant presence of fallow deer *Dama dama*, suggests a forest-dominated environment, supported by other ungulates like roe deer, red deer, and wild boar. The rhinoceros *Stephanorhinus hemitoechus* and horse *Equus ferus* indicate open spaces (Mecozzi et al., 2024). The occurrence of freshwater bodies is the testified by remains of the European otter *Lutra lutra* (Mecozzi et al., 2022) and hippopotamus (Mecozzi et al., 2024). The occurrence of a slender wolf *Canis lupus* is testified by some cranio-dental remains (Blanc, 1920; Sardella et al., 2014).

The lithic industry of ISU3, which amounts to more than 1000 elements in local limestone, was mainly recovered in the lower part of the stratigraphic unit (Piperno, 1974).

In the early 1970s, Piperno (1974) performed the first systematic typological study of the lithic industry of ISU3. Piperno attributed the industry to the Charentian Mousterian of Quina type (Bordes, 2002; Bordes and Bourgon, 1951), due to the high frequency of sidescrapers, mainly transverse with scaled and deep retouch, and the absence of Levallois products.

In the second decade of the 2000s, Spinapolice (2018a) revised the ISU3 industry in a techno-economic perspective, introducing some discrepancies with previous studies: a significantly higher number of cores with a prevalence of Levallois debitage over other methods; a lower number of tools compared to those identified by Piperno; a predominance of denticulates and notches within the toolkit (Table 1). Moreover, Spinapolice (2018b) reported the presence, although very limited,

Table 1
Composition of ISU3 lithic assemblage. Comparison between this work, and those of Piperno (1974) and Spinapolice (2018a). The lithic objects found during the 2018 excavation campaign are in parentheses (and included in the number of pieces indicated before the parentheses).

ISU3	Piperno		Spinapolice		This work	
Categories	n.	%	n.	%	n.	%
Cores	32	*2.8*	130	*12.8*	38 (4)	*6.2*
Flakes	937	*82.9*	720	*71.0*	479 (13)	*77.9*
Retouched tools	162	*14.3*	94	*9.3*	19 (1)	*3.1*
Material with percussion marks	–	–	10	*1.0*	6	*0.9*
Debris	–	–	60	*5.9*	73 (5)	*11.9*
Tot. artefacts	**1131**	***100***	**1014**	***100***	**615 (23)**	***100***
Cobbles	–	–	–	–	32 (2)	*6.8*
Pebbles	–	–	–	–	14 (2)	*2.9*
Angular elements	–	–	–	–	430 (2)	*90.3*
Tot. unmodified material	**-**	**-**	**-**	**-**	**476 (6)**	***100***
Tot. analysed material	**1131**	***100***	**1014**	***100***	**1091 (29)**	***100***

of non-local raw materials (twelve retouched tools in flint, jasper, and quartzite).

5. Materials and methods

Here we report our revision of the lithic assemblage from the ISU3 ($n = 1091$; Table 1). This includes both the historical collections (Cardini excavations, previously studied by Piperno and revised by Spinapolice) and few lithic items ($n = 29$; Table 1) recovered in 2018 from the lowermost part of the unit, within the same cave area investigated by Cardini in the 1960s, in the southern sector (Fig. 2).

Considering the extremely limited number of lithics recovered in ISU1 and ISU2 ($n = 8$), which precludes any reconstruction of technical behaviours, these units are not considered in this work.

The historical collections are stored at the *Soprintendenza Nazionale per il Patrimonio Culturale Subacqueo in Taranto* (Apulia), and at the *Istituto di Paleontologia Umana* (ISIPU) located in Anagni (Latium). The material from recent excavations is stored in the laboratory Palaeofactory at *Sapienza Università di Roma*.

The historical material analysed corresponds to the entirety of the currently available material in the storages, but not to the entirety of the pieces studied by Piperno (68 pieces are missing).

All the pieces are labelled with the site acronym (GR), the discovery date (1963, 1964, or 1970; sometimes even the day and month are indicated), the stratigraphic unit (i.e., level G or *Bolo*, followed by an Arabic or Roman numeral, 1 or I, 2 or II, 3 or III), and the artificial layer (if present).

Since lithic objects do not have an identifying number, it is impossible a detailed comparison between the artefact attributions of this work and those of Piperno and Spinapolice's works. Only in a few cases a specific comparison was possible thanks to the diacritic schemes and photos published by Piperno (1974) and Spinapolice (2018a).

The study of the lithic industries was performed adopting a techno-economic approach based on the *chaîne opératoire* concept (e.g., Boëda et al., 1990; Inizan et al., 1999; Leroi-Gourhan, 1964; Perlès, 1991). The unworked material has been studied considering the set of discriminative attributes established for distinguish geofacts from artefacts (Table 2).

Each analysed lithic object (knapped and unmodified) was lithologically characterised to infer the raw material composition and the provisioning and exploitation patterns as a potential source of archaeological assemblage variability. To ascertain the type of limestone, we conducted a macroscopic classification based on texture, limestone variety, shape, roundness, and colour.

Table 2
Discriminative lithic attributes considered in this work to distinguish geofacts from artefacts.

Attribute	Artefacts	Geofacts	References[s]
Identifiable knapped dorsal and ventral surface	Present	Absent	Bradbury (2001)
Bulb/negative bulb of percussion	Present	Absent	Patterson (1983); Peacock (1991)
Bulb scars	Present	Absent	Patterson (1983); Peacock (1991)
Impact point/negative of impact point	Present	Absent	Gillespie et al. (2004); Patterson (1983)
Ripples and hackles	Present	Absent	Peacock (1991)
Striking platform	Present	Absent	Patterson (1983); Peacock (1991)
Striking platform angles	≤90°	>90°	Barnes (1939); Gillespie et al. (2004); Patterson (1983); Peacock (1991)
Differential weathering of flake scars[a]	Absent	Present	Gillespie et al. (2004); Patterson (1983); Peacock (1991)

[a] After excluding the artefact reuse.

Unworked objects were classified in terms of natural shape and size to appraise the range of available shapes and dimensions, which could play a role in the choice of a specific production activity or flaking method.

Core classification, particularly informative in the assessment of knapping methods and techniques, was performed using 1) the identification of the number and type of flaking surfaces (unifacial, bifacial, multifacial, peripheral exploitations), 2) the direction of flaking (unidirectional, bidirectional, centripetal/tangential, multidirectional exploitations), 3) the presence or absence of a distinct rectified or prepared striking platform, 4) the value of the angle between the striking platform and the flaking surface, and 5) the core volume management.

The analysis of flakes encompassed key characteristics used to distinguish different methods and techniques, such as dorsal scar patterns, butt, bulb attributes, flaking angle, as well as the assessment of the stage of lithic reduction, including cortex and platform attributes. We examined how the flake edges were intentionally modified to create a tool, considering aspects like their delineation, extension, angle, localisation, morphology, and distribution (Bordes, 1961; Inizan et al., 1999), also exploring any potential relationships between the flaking method, size, and shape of the blank.

6. Results

6.1. Characteristics of raw materials

Based on their macroscopic features, the limestones of Grotta Romanelli have been grouped into two main categories. The first one is characterised by limestone with a grainstone to wackestone texture, with colours ranging from light grey to pinkish white (Upper Cretaceous Altamura Limestone Unit, Ciolo Limestone Member). The second category of limestone has a packstone to grainstone texture, with colours ranging from white to very pale brown (Upper Oligocene Castro Limestone Unit).

Many lithic objects exhibit an irregular shape with angular to sub-angular edges and a high degree of alteration. Few of them display a shape with rounded to sub-rounded edges. Based on these features, we consider that the raw materials are directly sourced from secondary deposits found both within the cave and outside, dated to the Middle Pleistocene (Pieruccini et al., 2022).

We infer that lithic objects exhibiting a notably high roundness originate from gravel deposits situated both externally, above the cave entrance (referred to as OSU1), and within the cave in ISU1.

Conversely, pieces displaying a polyhedral form and sharp edges are probably sourced from collapsed blocks of the internal cave walls and ceiling or from deposits on the external slope, associated with OSU2 (outside the cave) and ISU2 (inside the cave).

ISU1 and ISU2 contain mainly Upper Cretaceous Altamura Limestone Unit (Ciolo Limestone Member) clasts OSU1 and OSU2 contain both Upper Cretaceous Altamura Limestone Unit (Ciolo Limestone Member) and Upper Oligocene Castro Limestone clasts (Fig. 3). Therefore, the lithic objects coming from the lowest stratigraphic units of Grotta Romanelli (ISU1-3) were obtained from locally available limestone, specifically belonging to the following formations: 1) Upper Cretaceous Altamura Limestone Unit (Ciolo Limestone Member), corresponding to the Melissano Formation, referred as "type 1″ in Spinapolice (2018a); 2) Upper Oligocene Castro Limestone Unit referred as "type 2″ in Spinapolice (2018a). In our collection, non-local raw material (referred as "type 3" in Spinapolice, 2018a) was not detect.

6.2. Unmodified material

The ISU3 lithic assemblage is composed for 44% of unmodified material (Table 1), primarily made up of angular elements (n = 430; 90% of the unworked material), cobbles, and pebbles (n = 46). Angular items are characterized by an irregular shape and a great dimensional variability, varying between 15 and 190 mm in length, 9 and 145 mm in width, 2 and 100 mm in thickness (Figs. 4 and 5a). These angular specimens, that still abounds today in front of the entrance to the cave, plausibly come from the detachments of the cave walls and ceiling.

Whole and naturally broken cobbles (n = 32) and pebbles (n = 14) are present in the lithic assemblage (9.7% of the unworked material). Among the cobbles (23 whole and nine broken) the dimensions between 70 and 90 mm in length, 50 and 70 mm in width, 35 and 50 mm in thickness prevail. Only one piece has bigger dimensions (136 x 132 × 115 mm; subcircular plano-convex) (Fig. 5b). The ovoid and sub-circular shapes with plano-convex and biconvex section prevail. No dimensional difference was found between the various morphologies identified.

Among the pebbles (11 whole and three broken), most are ovoid and sub-circular with a biconvex section., Their dimensions predominantly range from 52 to 60 mm in length, 40 to 55 mm in width, and 28 to 43 mm in thickness (Fig. 5c).

6.3. Worked material

A single production is documented in the ISU3, i.e., the debitage of small medium sized flakes of limestone. The worked assemblage is mostly composed of flakes (n = 479; 77.9% of the artefacts), whereas cores (n = 38; 6.2%) and retouched tools are few (n = 19; 3.1%) (Table 1). Six pebbles with percussion marks and a single sub-spheroid were recovered. Debris are relatively numerous (11.9%).

6.3.1. Material with percussion marks

Six pebbles bear evidence of percussion (Fig. 6a–d), with battering marks concentrated on one active/working zone, generally corresponding to the most protruding and convex part located at the extremity of the pebble long axis. The pebbles are sub-circular and ovoid, with a bi-convex section (only in a case, plano-convex). These artefacts are small in dimensions (Table 3). A sub-spheroid with fractured angles was identified (Fig. 6e). This artefact is almost completely covered with multidirectional and irregular negative scars, creating wide angles - exceeding 90°- unsuitable for flake production. These features, together with the presence of battering marks, micro-fractures, and impact points originating from the central part of the negative scars, would suggest that this stone tool was obtained by repetitive percussive action which could be related to both knapping and other activities.

6.3.2. Cores

Seven broken cores and 31 whole cores are present in the lithic assemblage. The whole cores were exploited trough different debitage methods, from simple debitage to organized exploitations.

The simple debitage involves most of the whole cores (named, "simple cores") (n = 12; 39%), displaying from one, in most cases, to three flake scars with a random distribution on the core, as if the pieces had been discarded after having been tested (Fig. 7a and b). Consequently, simple debitage does not significantly alter the initial morphometry of the blanks, which are small to medium-sized cobbles/pebbles, except for two cores obtained from angular elements. The cobble/pebble blank morphology is usually ovoid with plano-convex section, and the few flakes were extracted from the flat surface used as striking platform. The shapes and dimensions of the initial blank (Table 4) are representative of the frequencies observed in the

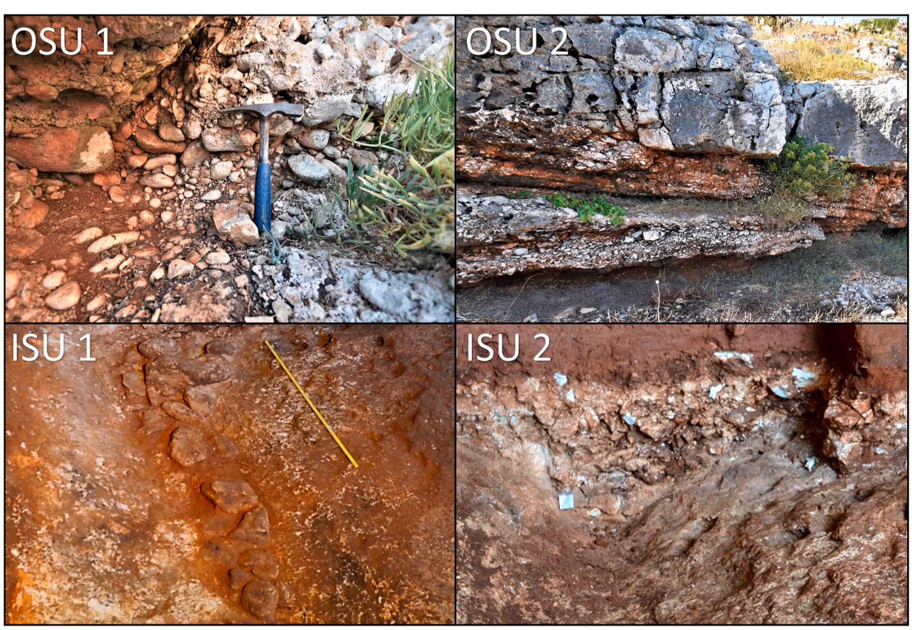

Fig. 3. Field picture of the pebbles in the marine deposits of OSU1 and debris-slope deposit of OSU2 above the Grotta Romanelli entrance. Detail of the marine pebbles of ISU1 and angular clasts of ISU2 in the southern sector within the cave (Photo: L. Forti).

Fig. 4. Angular items without evidence of anthropic modification (Photo: G. Lembo).

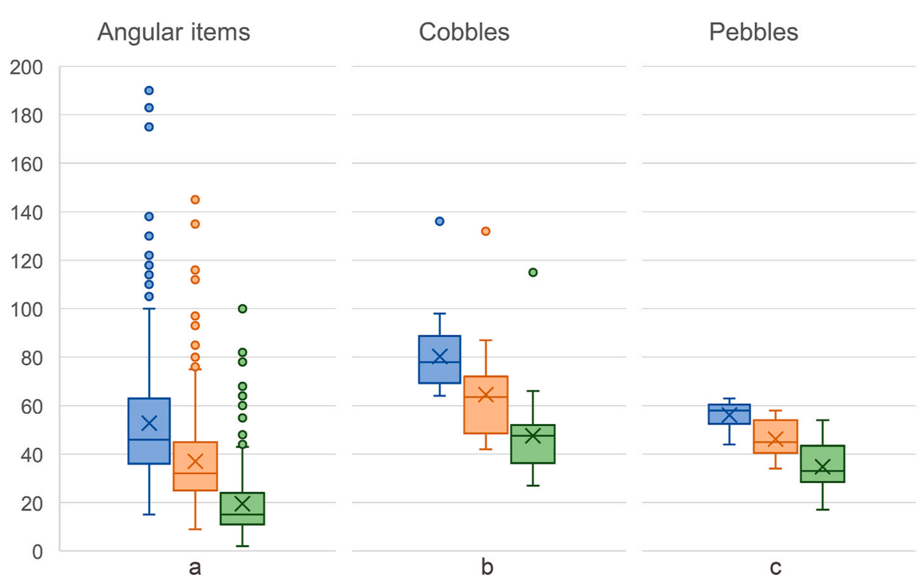

Fig. 5. Boxplots of unmodified material dimensions: length (in blue), width (in orange), and thickness (in green). a) Distribution (mm) of angular items. b) Distribution (mm) of the cobbles with a length between 64- and 99-mm. c) Distribution (mm) of the pebbles with a length less than 63 mm. The box represents the interquartile range, and the whiskers the range of the data. The horizontal line inside the box represents the median, the cross represents the mean. Individual data points lying beyond the whiskers are considered outliers and are plotted individually.

unmodified sample. An *entame* flake refits with a simple core obtained from a plano-convex pebble (Fig. 8b).

The remaining cores (n = 19; 61% of the whole cores) have been exploited following two flaking methods, unifacial unidirectional and multifacial multidirectional.

1. Unifacial unidirectional cores (n = 10; Fig. 7c–e, Fig. 8a). In this category we include both cores with a single flaking surface (n = 6)

Fig. 6. Pebbles with probably percussive marks (a, b, c, d). A sub-spheroid with fractured angles (e). Magnification at 2× of some parts (Photo: G. Lembo).

Table 3
Comparison between the dimensions (mm) of pebbles with percussion marks and unmodified pebbles/cobbles (p/c). S.D. (= Standard deviation).

	Length		Width		Thickness	
	p/c with percussion marks	unmodified p/c	p/c with percussion marks	unmodified p/c	p/c with percussion marks	unmodified p/c
Mean	60.7	71.9	52	57.8	42.2	42.3
Max	63	136	58	132	54	115
Min	58	44	47	34	29	17
S.D.	2.6	18.2	4.6	18.9	9	17.4

and a single series of unidirectional removals (from four to 12) and cores with two flaking surfaces ($n = 4$), independently exploited through four-six unidirectional removals. These surfaces are generally adjacent: one debitage surface (with two-three negative scars) is subsequently used as a striking platform to produce another series of flakes (two flakes). Only one core shows a semi-peripheral unidirectional exploitation, with 12 unidirectional scars detached from a continuous semi-peripheral striking platform corresponding to the natural flat surface of a plano-convex cobble (Fig. 7d). Except for a single angular block, core blanks are plano-convex pebbles/cobbles, and the flat natural surface usually serves as striking platform. Only in two instances the striking platform was rectified by a removal (Fig. 7c). The use of bipolar-on-anvil percussion technique is documented in four cores for flake removals on the debitage surface (Fig. 7c) and for split a pebble used as core blank (Fig. 8a). These cores were commonly abandoned due to the exhaustion of suitable convexities and angles, rather than the depletion of raw material. Two refitting groups (two flakes that refit with a core having two flaked surfaces) were identified within this set (Fig. 8a). The corresponding flakes are of small to medium size, sub quadrangular, with variable morphologies and natural or plain butts, along with some residue of cortex on the dorsal surface. The negative flake scars on the dorsal face are unidirectional with the same direction of the flaking axis.

2. Multifacial multidirectional cores ($n = 9$). From six to 12 multidirectional removals were detached without a clear organization of the reduction process (Fig. 7f). In three instances, an orthogonal pattern organization is recognizable on the negative scars of the detached flakes. The initial blank is usually an angular block, while in a few cases, a pebble/cobble is used ($n = 3$). In only one instance, the original blank could not be identified, due to the intensive exploitation of the core. The dimensions of these cores are bigger than the other cores (Table 4). At the same time, these cores show a more intensive exploitation. Therefore, their dimensions depend on the greater size of the original blank. The corresponding flakes, various in shape, display multidirectional and orthogonal negative scars on the dorsal surface and plain or dihedral butts.

6.3.3. Flakes

Broken flakes are very frequent ($n = 301$; 63% of the flakes) and outnumber whole flakes ($n = 178$). Most flakes fall within the small to medium size range: there are no flakes shorter than 1 cm, and there are only 14 flakes measuring ≤2 cm; at the same time, the assemblage includes only one large flake (>10 cm) (Fig. 9).

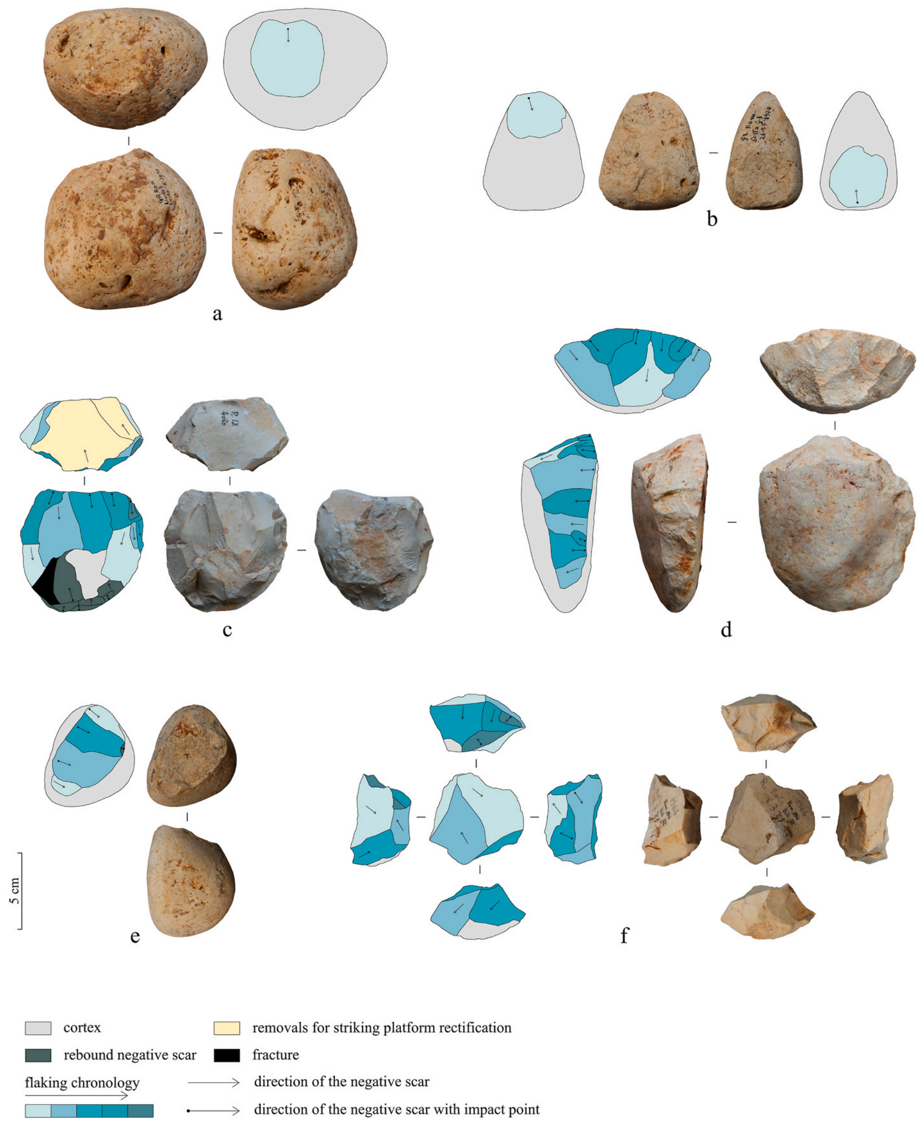

Fig. 7. Simple cores (a, b). Unifacial unidirectional cores (c–e), with a rectified striking platform (c) and a semi-peripheral unidirectional exploitation (d). Multifacial multidirectional core (f). (c) shows technical aspects of bipolar-on-anvil technique (Photo and drawings: G. Lembo).

Table 4
Table showing dimensions (mm) of the whole cores grouped by flaking method. S.D. (= Standard deviation).

Whole cores	n.	%	Length	Max	Min	S.D.	Width	Max	Min	S.D.	Thickness		Min	S.D.
			Mean				**Mean**				**Mean**	Max		
Simple cores	12	*39*	**71**	99	53	14	**61**	93	35	18	**45**	74	15	18
Unifacial unidirectional cores	10	*32*	**85**	121	59	21	**74**	104	59	17	**56**	77	34	14
Multifacial multidirectional cores	9	*29*	**100**	200	60	45	**77**	135	38	31	**66**	120	31	28
Total	31	*100*												

Most flakes exhibit one to five negative scars on the dorsal face. When determinable, the flake blank is usually a cobble/pebble; only in a few specimens it is an angular block. The Minimum Number of Flakes (MNF), calculated as the total number of complete and proximal flakes (Barrett 2014), amounts to 261. The flake/core ratio is 7 flakes *per* core, which approximately match the average number of negative scars on the cores (average 5.5). This is an index that should be interpreted cautiously since it doesn't consider the degree of exploitation of the cores, as well as the size and shape of the initial blank. Nonetheless, it seems to align with the identified methods, which rarely involve intensive core exploitation.

Five conjoinings of two/three fragments of flakes and a refitting of three broken flakes were identified in the set. However, due to their incompleteness, it was not possible to determine the flaking method.

Flakes with fully cortical dorsal surface ($n = 36$) are well represented among the whole flakes (Fig. 10) and were flaked almost exclusively from pebbles/small cobbles. Most of them ($n = 19$) are *entame* flakes (Fig. 11a and b). They have a sub-circular morphology, mainly natural butts, or plain butts in few cases. Their dimensions rarely exceed 60 mm in length and width. Overall, the average dimensions of the *entame* flakes (length 44 mm, width 43 mm, thickness 14 mm) fit with those of the cobbles/pebbles recovered. The aspect ratio is nearly 1:1, indicating

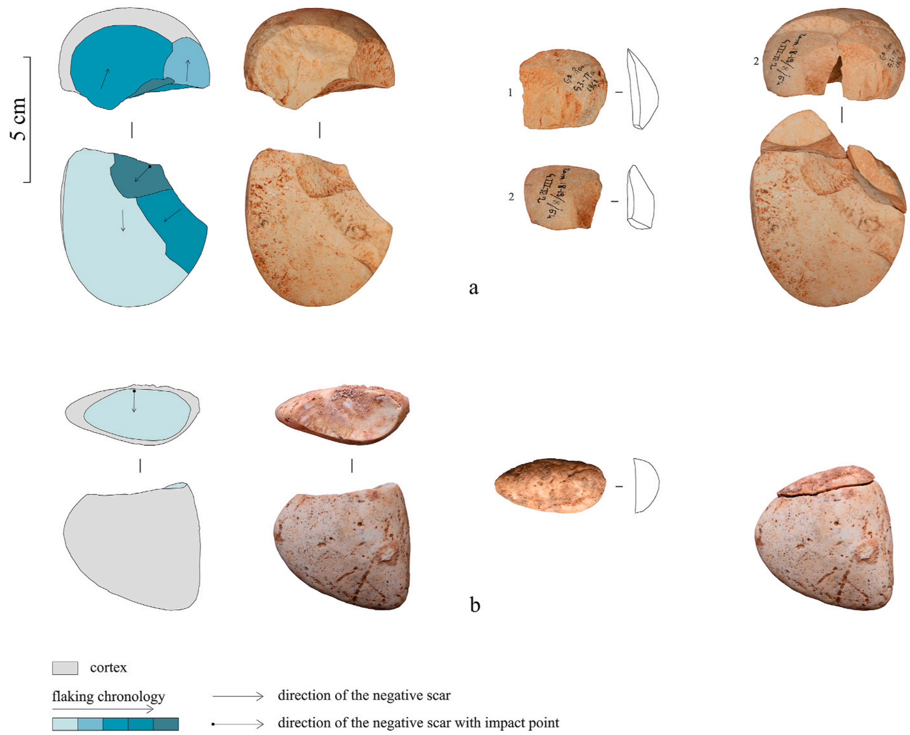

Fig. 8. (a) Unifacial unidirectional core with two refitting flakes (1, 2): pebble split by bipolar-on-anvil technique along the longitudinal axis. From the split-platform thus created, two partially cortical flakes were detached (1, 2), which refit with the core (on the right). The negative of one of these flakes is then used as a percussion platform for the extraction of two small flakes (on the left). (b) Simple core with *entame* refitting flake (Photo and drawings: G. Lembo).

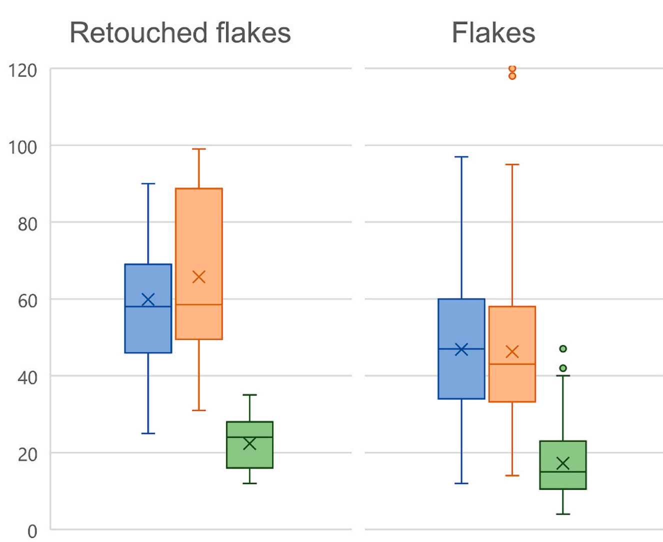

Fig. 9. Boxplot showing dimensions (length in blue, width in orange, thickness in grey) of the unretouched flakes (right) and retouched flakes (left). The box represents the interquartile range, and the whiskers show the entire data range. The median is indicated by the horizontal line within the box, and the mean is denoted by a cross. Any individual data points beyond the whiskers are considered outliers and are plotted individually.

an almost equal length-to-width ratio. The average flaking angle is around 91°. The predominant technique adopted is the direct percussion, but four flakes exhibit two opposite impact points on the ventral surface, typical of the bipolar-on-anvil percussion.

Unidirectional flakes (n = 34; Fig. 11c–e) exhibit one to five unidirectional negative scars on the dorsal face, with the same flaking direction of the flake. Among these, 26 flakes display cortical residual areas from pebble/cobbles. The morphologies vary, with sub-rectangular being the most common, followed by sub-quadrangular and ovoid. Two flakes were likely produced by bipolar axial percussion on anvil. Butts are usually plain (n = 19), cortical (n = 12), and dihedral (n = 3). Five flakes have lateral and distal cortical backs and three flakes have backed lateral and distal edges. Although the average size agrees with that of the cortical flakes, the dimensions are more variable, and the products are slightly more elongated (Fig. 10). The main characteristics of these flakes are consistent with the methods identified: single or two flaked surfaces exploited through unidirectional detachments and/or the first phases of the multifacial multidirectional cores. The average flaking angle is wider, around 96°.

Flakes with orthogonal negative scar pattern (n = 44; Fig. 11f and g) are the most abundant in the assemblage. These flakes display one to 10 orthogonal negative scars on the dorsal face. Sub-rectangular morphologies prevail over sub-circular and sub-quadrangular ones. Twenty-six flakes exhibit residual cobble/pebble cortex on the dorsal face, which often cover more than 50% of its surface. Two flakes were obtained through bipolar-on-anvil technique, specifically through split fracture of a pebble. Butts are mainly plain (n = 22) and cortical (n = 13), whereas dihedral and faceted butts are occasional. Backed lateral edges are relatively frequent (n = 14), while hinged and plunging flakes are very rare.

Flakes with multidirectional irregular negative scar pattern (n = 27; Fig. 11h–l) exhibit two to nine removals. Sub-rectangular morphologies prevail over the sub-triangular and sub-quadrangular. In most cases (n = 14), flakes preserve a minimal cortical portion (<25%) on the dorsal face. The cortex could belong to both a pebble/cobble or and an angular element. Butts are mainly plain (n = 15), followed by cortical (n = 8), and only occasionally dihedral. Five flakes have backed lateral and distal edges. The flakes within this group have the largest dimensions (average length 54 mm, width 47 mm, thickness 21 mm) and the highest flaking angle (average angle 104°). Flakes with orthogonal and multidirectional negative scars might be associated with multifacial multidirectional cores.

Finally, a significant number of flakes with tangential/centripetal

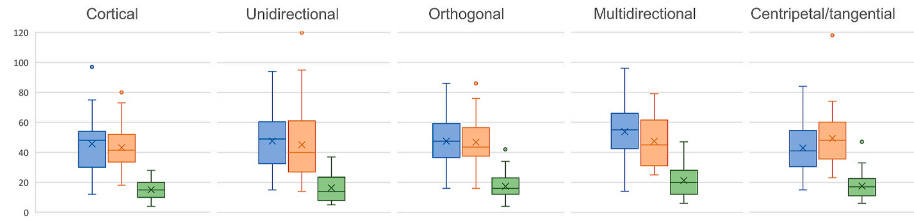

Fig. 10. Boxplot showing dimensions (mm) (length in blue, width in orange, thickness in grey) of the whole flakes grouped by the presence of cortex and negative scars pattern on the dorsal face of the flakes. The box represents the interquartile range, and the whiskers show the entire data range. The median is indicated by the horizontal line within the box, and the mean is denoted by a cross. Any individual data points beyond the whiskers are considered outliers and are plotted individually.

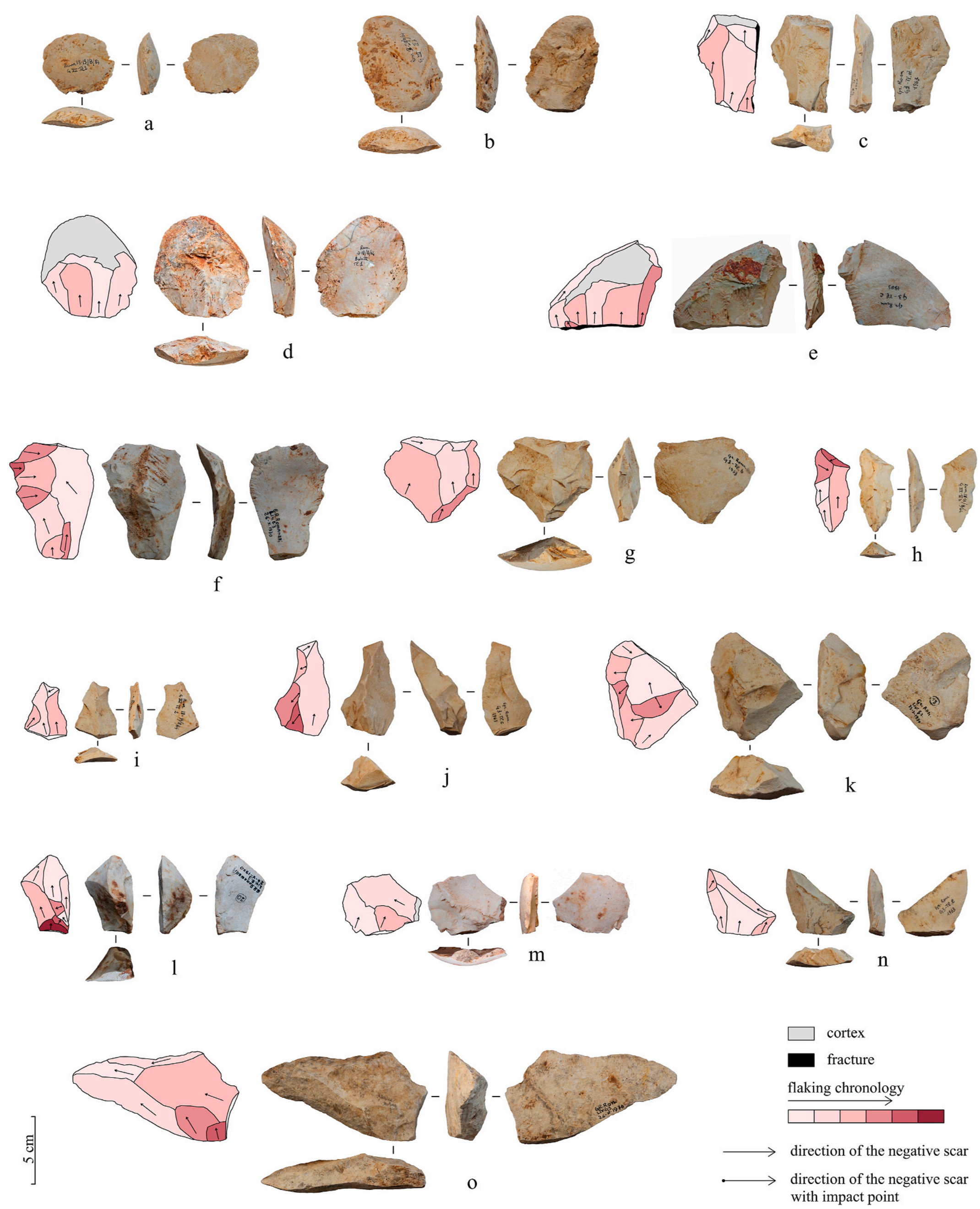

Fig. 11. *Entame* flakes (a, b). Flakes with unidirectional negative scar system on the dorsal face (c–e). Flakes with orthogonal negative scar system (f, g). Flakes with multidirectional negative scar system (h–l); (g) and (k) are core edge flakes. Flakes with tangential/centripetal scar system (m–o); (n) and (o) are pseudo-Levallois points (Photo and drawings: G. Lembo).

negative scar pattern ($n = 37$; Fig. 11m–o) have been identified within the assemblage. These flakes, which display three to seven scars on the dorsal face, are generally wider than longer (average dimensions: 43x49x18 mm) (Fig. 9). Subcircular and subtriangular morphologies prevail. Butts are usually plain ($n = 24$), followed by dihedral ($n = 5$), natural ($n = 5$), and faceted only in a case. The cortex is absent in most cases or present in a proportion lower than 25%. Therefore, only in few cases it is possible to recognize the original blank, that is a pebble/cobble. The average flaking angle is 100°. Pseudo-Levallois points, characterized by a deviation of the flaking axis from the morphological axis are relatively numerous in this group ($n = 11$; Fig. 11n and o), as well as flakes with distal and lateral back ($n = 12$). Additionally, two core-edge flakes were recovered, resulting from a change in core orientation. However, cores with a centripetal-based exploitation have not been identified in the assemblage.

6.3.4. Tools

Few pieces bear evidence of retouch ($n = 19$). They are sidescrapers produced by retouching flakes (12 whole flakes and four broken flakes), and only in a case a cortical natural blank (Fig. 12g). The sidescrapers are predominantly lateral ($n = 7$; mostly straight but also convex; Fig. 12i) and transverse ($n = 6$; convex, only in one case straight;

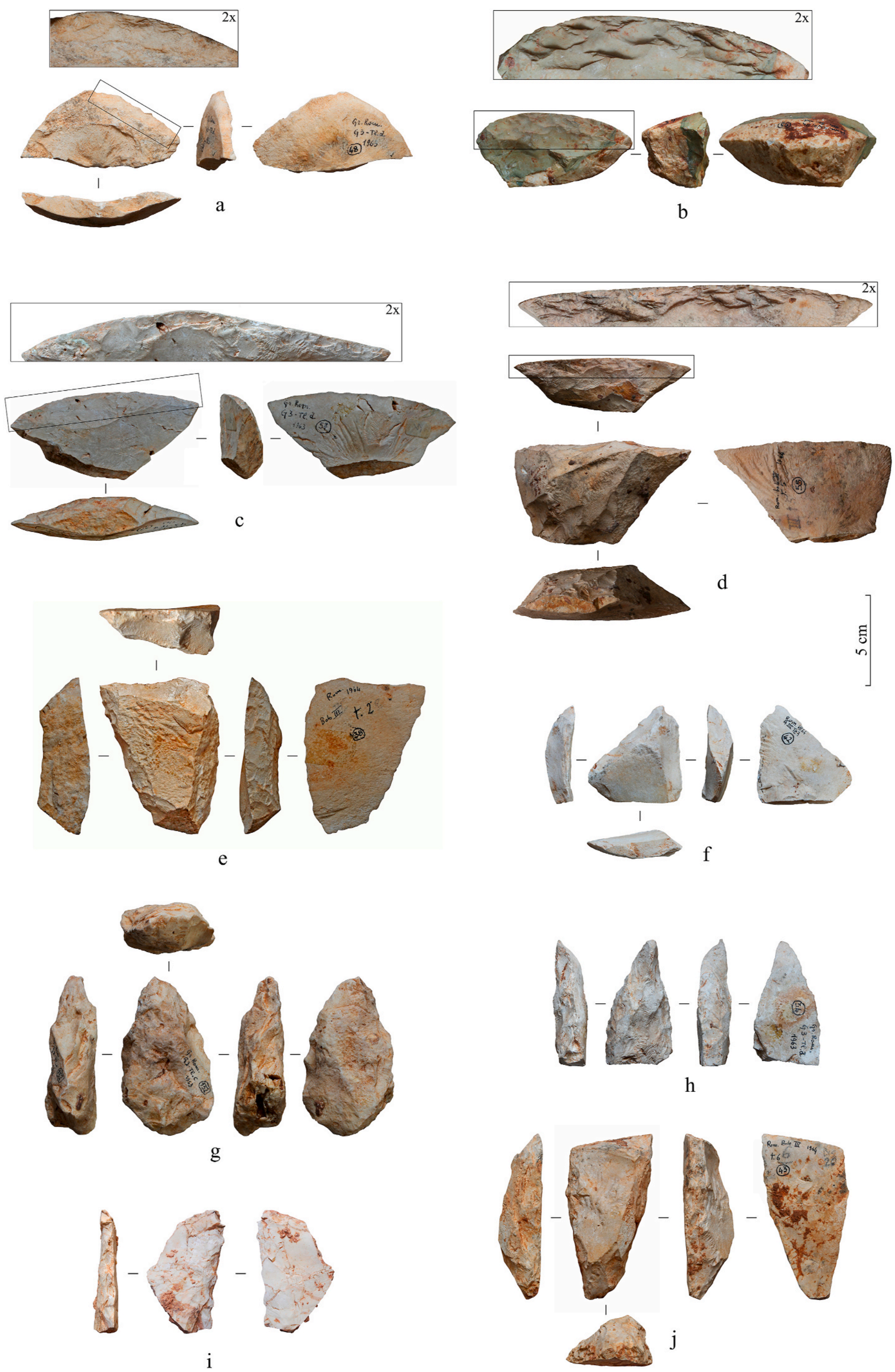

Fig. 12. Tools. Transverse (a–d), convex (a–c) and straight (d) sidescrapers. *Déjeté* sidescrapers (e, f), with a deviation of the morphological axis from the flaking axis. Convergent sidescrapers (g, h), one of which obtained from a natural blank (g). Straight-lateral sidescraper (i). Double straight-convex sidescraper (j) (Photo: G. Lembo).

Fig. 12a–d). Additionally, some are convergent ($n = 3$; Fig. 12g and h), and *déjété*, with a deviation of the morphological axis from the flaking axis ($n = 3$; Fig. 12e and f). Finally, there is a double straight-convex sidescraper (Fig. 12j).

The retouch is scaled (tendentially stepped in some cases), semi-abrupt, direct (inverse only in one specimen; Fig. 12b), and short.

The dimensions of retouched flakes (average dimensions: 60x66x22 mm) are higher than those of unretouched flakes (average dimensions: 47x46x17 mm) (Fig. 9). This could indicate a selection based on flake dimensions. Moreover, the retouched flakes are wider than long due to the presence of transverse and *déjeté* scrapers.

Retouching applied to both flakes from *plein débitage* and flakes from the initial stages of flaking (six are cortical flakes from angular blocks). It's not recognizable a selection of flakes resulting from a specific flaking method. A sidescraper was obtained on a pseudo-Levallois point in only one instance (Fig. 12f). When identifiable, negative scars are predominantly unidirectional and tangential, with a lesser occurrence of multi-directional and orthogonal, ranging from three to 11 scars in number.

7. Discussion

7.1. Technical behaviours at Grotta Romanelli ISU3

The revision of the lithic collection recovered in the 1960s and 1970s from ISU3, combined with the analysis of artefacts from recent excavations, provides new insights into the technological strategies adopted by hominins at the end of the Middle Palaeolithic in this area of the southern Italy. It provides a different interpretation compared to what has been suggested in previous studies (Piperno, 1974; Spinapolice, 2018a, 2018b).

Our analysis confirms that the raw materials used are strictly local, collected in secondary deposits, both inside the cave and in its immediate exterior. No exotic materials were found. The lithic industry of ISU3 was obtained from two local limestone formations: the Upper Cretaceous Altamura Formation (Ciolo limestone member, corresponding to the Melissano Formation, "type 1″ in Spinapolice, 2018a), and the Upper Oligocene Castro Limestone (lower Chattian, "type 2″ in Spinapolice, 2018a).

The ISU3 lithic assemblage is composed of a significant proportion of unmodified natural material, composed of pebbles and cobbles and a great number of angular elements with highly variable size and morphology. These elements exhibit fractured surfaces and numerous natural detachments that may resemble anthropogenic ones. This unworked material is the result of the cave's roof and wall collapsing and is still abundant in front of the current cave entrance. This natural material has never been reported in previous studies.

The production of small-medium sized undifferentiated flakes is the main activity documented by the worked assemblage. Retouch is feebly represented. Piperno (1974) mentioned a single handaxe, now interpreted as a convergent sidescraper (Fig. 12g).

Flakes and cores are mostly on pebbles/cobbles, and only rarely on blocks and/or angular fragments, as has been suggested so far (Piperno, 1974; Spinapolice, 2018a). The initial stages of flaking are well represented: numerous fully corticated and *entame* flakes were recovered in the assemblage. Freehand direct percussion with hard hammer is the main technique. However, the bipolar-on-anvil technique is indeed documented, as already suggested by Spinapolice (2018a).

If the number of the cores is approximately in accordance with what reported by Piperno ($n = 30$), it significantly diverges from the number of cores reported by Spinapolice ($n = 130$).

Additionally, the most notable difference with Spinapolice's work is the absence of the Levallois concept. Following Spinapolice (2018a, 2018b), the Levallois method, mainly recurrent centripetal and unidirectional, is the most represented (48%), identified thanks to cores ($n = 17$), flakes, and points.

In our work, no clear evidence indicating a prepared core technology has been identified: none of the cores analysed exhibits the intersection of two asymmetrical hierarchically organized surfaces with lateral and distal convexities. Very few flakes could typologically resemble Levallois products, but the analysis of their key characteristics (butt, flaking angles, back, scars organization on the dorsal face) would seem to lean towards a discoid concept or a not-well defined peripheral centripetal exploitation.

The knapping sequences do not appear to be very long, as previously suggested (Spinapolice, 2018a). This is confirmed by the identified flaking methods, most of which does not involve intensive core exploitation, and by the limited number of scars on the recovered cores. Furthermore, core abandonment mostly coincides with the exhaustion of available angles and convexities, rather than the depletion of raw material.

Our re-analysis notably reduces the number of retouched tools ($n = 164$ for Piperno; $n = 94$ for Spinapolice; $n = 19$ in our study) and their variability recognized in previous studies. Probably what has been interpreted as retouching in previous studies corresponds to pseudo-retouching, to naturally modified edges. For Piperno (1974) sidescrapers are predominant (50%), followed by a great number of notches and denticulates (30%); for Spinapolice (2018a, 2018b) sidescrapers represent only 14% of the tool assemblage; meanwhile retouched flakes without a precise typological standardization (35%), and notches and denticulates (33%), often retouched on Levallois blanks, prevail. Our revision reveals that flake retouch is only occasional and does not seem to have been the primary objective of the knapping activities. Moreover, all the identified tools are sidescrapers, obtained by scaled, direct, semi-abrupt, and short retouching.

In conclusion, the interpretation of the ISU3 lithic assemblage here provided diverges both from that of Piperno and Spinapolice.

Despite the differences with the Piperno's analysis, we agree that numerous elements of the lithic industry (few retouched tools and, among these, the absence of points; exploitation of exclusively local raw material; absence of predetermined debitage methods) point to an expedient lithic technology mainly focused on the production of undifferentiated flakes on local limestone.

7.2. Grotta Romanelli ISU3 in the Salento regional context

Here we explore the principal technological patterns of key pene-contemporaneous sites in the Salento region: Grotta Romanelli and Grotta dei Giganti, within the Capo di Santa Maria di Leuca; Grotta del Cavallo, Grotta Mario Bernardini, Grotta Uluzzo C, Grotta Torre dell'Alto, and Grotta di Serra Cicora A, located within the Natural Regional Park of Porto Selvaggio e Palude del Capitano (Table 5; Fig. 13).

7.2.1. Grotta del Cavallo (Nardò, Lecce; 15 m asl)

Excavations at Grotta del Cavallo began in the 1960s by Palma di Cesnola (1964, 1966) and are currently led by L. Sarti (Sarti and Martini, 2020). The Mousterian series (from bottom to top, levels N-F) comprises two major complexes separated by a deep hiatus (*tephra* level G) (Sarti, 2020): late Mousterian (level F), attributed to MIS 3 (Fabbri et al., 2016; Zanchetta et al., 2018); early Mousterian (levels N-H), whose beginning was attributed to MIS 7, based on the faunal association (Berto, 2020; Sala and Berto, 2020; Sarti, 2020; Sarti and Martini, 2020). However, this attribution in not in agreement with the U/Th dating results, which indicate MIS 5e (Zanchetta et al., 2020) (Table 5).

Most of the exploited lithic resources, including limestone and silicified limestone, were collected near the site. Furthermore, non-local raw materials, such as flint and radiolarite, were identified in all the archaeological levels, and considered to have been collected in an area near Taranto, approximately 100 km away from the cave (Romagnoli, 2020a).

The main significant technological innovations along the stratigraphic sequence are the appearance of Levallois and laminar methods in I level (MIS 5?) (Martini et al., 2020a) and the appearance of

Table 5
Main Mousterian sites in Salento cited in the text.

Site	Level	Absolute dating	Lithic technology	Other technology	Raw material	Human remains
Grotta del Cavallo (Nardò, Lecce)	F	45.5 ± 1.0 ka (Zanchetta et al., 2018) 45.600–42.900 cal BP (Fabbri et al., 2016)	Laminar and Levallois (only in early phases), Discoid (Carmignani, 2010; Carmignani et al., 2020)	No	Local and non-local (Romagnoli, 2020a)	1 deciduous tooth (Fabbri et al., 2016)
	G	108.7 ± 0.9 ka (Zanchetta et al., 2018)	Sterile	No		No
	H	No	Levallois, Discoid (Ricci and Sarti, 2020)	No		No
	I	No	Laminar, Levallois, Discoid, unipolar, SSDA (Martini et al., 2020a)	No		1 deciduous tooth (Palma di Cesnola and Messeri, 1967)
	L	No	Discoid, unipolar, SSDA (Martini et al., 2020b)	Shell technology (Romagnoli, 2020b)		No
	M	No	Discoid, unipolar, SSDA (Martini et al., 2020c)	No		2 deciduous teeth (Fabbri and Vincenti, 2020)
	N	116 ± 0.7 ka, 117 ± 0.7 ka (Zanchetta et al., 2020)	Discoid, unipolar (Ricci, 2020)	No		No
Grotta Torre dell'Alto (Nardò, Lecce)	E	No	Non Levallois (Borzatti von Löwenstern, 1966; Borzatti von Löwenstern and Magaldi, 1967) Unipolar, Levallois, laminar (Ranaldo et al., 2022)	No	Local (Borzatti von Löwenstern, 1966; Borzatti von Löwenstern and Magaldi, 1967) Local and non-local (Ranaldo et al., 2022)	No
	D	No	Non Levallois (Borzatti von Löwenstern, 1966; Borzatti von Löwenstern and Magaldi, 1967) Levallois, non Levallois (Spinapolice, 2018a, 2018b) Unipolar, Discoid, Levallois, laminar (Ranaldo et al., 2022).	No	Local (Borzatti von Löwenstern, 1966; Borzatti von Löwenstern and Magaldi, 1967) Local and non-local (Ranaldo et al., 2022; Spinapolice, 2018a, 2018b)	No
Grotta Uluzzo C (Nardò, Lecce)	F-G	46 ± 4.0 ka, level G (Spinapolice et al., 2022)	Rare Levallois (Borzatti von Löwenstern, 1964, 1965, 1966; Borzatti von Löwenstern and Magaldi, 1969) Predominance of Levallois (Spinapolice, 2018a, 2018b)	No	Local (Borzatti von Löwenstern, 1964, 1965, 1966; Borzatti von Löwenstern and Magaldi, 1969) Local and non-local (Spinapolice, 2018a, 2018b)	No
Grotta Serra Cicora A (Nardò, Lecce)	B-F	No	Rare Levallois (Campetti, 1986)	Rare shell technology (Campetti, 1986)	Local (Campetti, 1986)	No
Grotta Mario Bernardini (Nardò, Lecce)	A^{V}-A^{IX}	No	Non Levallois (Borzatti von Löwenstern, 1970) Discoid, Kombewa, SSDA (Carmignani and Romagnoli, 2017)	Shell technology (A^{VIII}) (Borzatti von Löwenstern, 1971; Douka and Spinapolice, 2012)	Local and non-local (Carmignani and Romagnoli, 2017)	No
	B	No	Levallois (Borzatti von Löwenstern, 1971) Levallois and laminar (Carmignani and Romagnoli, 2017)	Shell technology (Borzatti von Löwenstern, 1971; Douka and Spinapolice, 2012)	Local and non-local (Carmignani and Romagnoli, 2017; Spinapolice, 2018a, 2018b)	No
	D	No	Levallois (Borzatti von Löwenstern, 1971). Discoid, Kombewa, SSDA (Carmignani and Romagnoli, 2017)	Shell technology (Borzatti von Löwenstern, 1971; Douka and Spinapolice, 2012)	Local and non-local (Carmignani and Romagnoli, 2017)	No
Grotta dei Giganti (Santa Maria di Leuca, Lecce)	3f-c, 3a	No	Predominance of Levallois (Spinapolice, 2018a, 2018b)	Shell technology (Douka and Spinapolice, 2012)	Local and non-local (Spinapolice, 2018a, 2018b)	No

shell-retouched tools (on *Callista chione*) in L level (MIS 6?) (Romagnoli, 2020b). Moreover, four Neanderthal deciduous teeth were unearthed from different Mousterian levels (Fabbri et al., 2016; Fabbri and Vincenti, 2020; Palma di Cesnola and Messeri, 1967) (Table 5).

7.2.2. *Grotta Torre dell'Alto (Nardò, Lecce; 35 m asl)*

Grotta Torre dell'Alto was excavated by Borzatti von Löwenstern between 1961 and 1967. Despite the absence of absolute dating, the lower levels of the site (E, D) are traditionally considered the oldest in the region (Ranaldo et al., 2022; Spinapolice, 2018b), based on the typological and technical characteristics of the lithic industry (Palma di Cesnola, 1982) and on the absence of the MIS 5e high stand (Spinapolice, 2018a, 2018b).

The abundant lithic assemblages of the Mousterian levels, lacking Levallois method, are composed by short and thick flakes with plain butts, few non prepared cores and many retouched tools, especially bifacial points, and sidescrapers (also on small marine pebbles). They also include carinated tools and tools with a dihedral ventral face, the so-called "*Quinson* tools" (Borzatti von Löwenstern, 1966; Borzatti von Löwenstern and Magaldi, 1967).

Fig. 13. Main Mousterian sites in Salento cited in the text. 1: Grotta del Cavallo; 2: Grotta Torre dell'Alto; 3: Grotta Uluzzo C; 4: Grotta Serra Cicora A; 5: Grotta Mario Bernardini; 6: Grotta dei Giganti; 7: Grotta Romanelli (Physical map modified from Wikipedia).

Recent revisions of the earliest lithic industry, although limited to a very small sample (level D, Spinapolice, 2018a; levels E and D, Ranaldo et al., 2022), highlight aspects that differ from the interpretation provided by Borzatti von Löwerstern: a significant presence of the Levallois method in level D (Ranaldo et al., 2022; Spinapolice, 2012, 2018a, 2018b) and E (Ranaldo et al., 2022), as well as the occurrence, although minimal, of the laminar method in both levels (Ranaldo et al., 2022). Furthermore, despite the extensive exploitation of local siliceous limestone and limestone, both authors have observed the utilization of non-local raw materials.

7.2.3. *Uluzzo C (Nardò, Lecce; 15 m asl)*

Considered to be more recent of Grotta Torre dell'Alto is the lithic industry of Grotta Uluzzo C. The site was investigated from 1964 to 1968 by Borzatti von Löwerstern (Borzatti von Löwenstern, 1964, 1965, 1966; Borzatti von Löwenstern and Magaldi, 1969) and resumed in 2015 by Spinapolice (Spinapolice et al., 2022).

The site yielded a Charentian Mousterian lithic industry of Quina type in the lowest levels F-G, which lay over MIS5e beach deposits. The only available dating for the Mousterian levels is the Optically Stimulated Luminescence (OSL) date for level G, which is 46 $\pm$ 4.0 ka and is interpreted as the minimum age for Neanderthal occupation (Spinapolice et al., 2022). The Mousterian lithic assemblage on flint, limestone, and siliceous limestone, is characterised by rare Levallois products, and numerous transverse sidescrapers with the typical stepped retouch (Borzatti von Löwenstern, 1964, 1965, 1966; Borzatti von Löwenstern and Magaldi, 1969). The occasional presence of the Levallois method was re-evaluated in more recent years by Spinapolice (2018a), who considers it to be predominant, regardless of the raw material used.

7.2.4. *Grotta Serra Cicora A (Nardò, Lecce; 37 m asl)*

Near Grotta Mario Bernardini is located Grotta di Serra Cicora A, discovered by Borzatti von Löwerstern in 1978 (Campetti, 1986; Spennato, 1981). The lithic industry of the Mousterian levels (B-F) is mostly composed by flakes, a significative number of tools, and few cores. It was mostly made on limestone, and only on the lesser extent, on siliceous limestone and flint. The predominance of scrapers (also transverse) with a Quina-type retouch, together with the paucity of Levallois elements, point to an attribution to a Charentian Mousterian of Quina type (Campetti, 1986). A retouched tool on *Callista chione* shell was identified.

7.2.5. *Grotta Mario Bernardini (Nardò, Lecce; 35 m asl)*

Plausibly more recent are also the lithic industries recovered in the lowest levels (A^{V}- A^{IX}, B, D) of Grotta Mario Bernardini, investigated between 1964 and 1970 by Borzatti von Löwerstern (Borzatti von Löwenstern, 1970, 1971).

The Mousterian industry starts from the lowermost part of level A (A^{V}- A^{IX}) downward to level D (level C is sterile). The lithic assemblage is not very abundant, and the toolkit mostly consists of sidescrapers with stepped retouch, followed by points and denticulates. Based on the presence of the Levallois method identified from the level B downward, Borzatti von Löwenstern (1971) proposed an attribution to the final phase of the Mousterian.

In the Mousterian levels, especially in the lowest level D, industry on *Callista chione* shells was also recovered (Borzatti von Löwenstern, 1971; Douka and Spinapolice, 2012). Alongside the predominant use of local raw materials (limestone, siliceous limestone), the occasional exploitation of non-local raw materials, such as quartzite, flint, and jasper, was also reported (Carmignani and Romagnoli, 2017; Spinapolice, 2018a, 2018b).

If Spinapolice's reassessment of the lithic industry (Spinapolice, 2018a) is constrained by the limited sample size (covering only a small portion of layer B), the revision conducted by Carmignani and Romagnoli (2017) is almost complete, except for retouched items from layer D. According to Carmignani and Romagnoli (2017), the Mousterian lithic industry shows a transition from a Discoid production system (level D) to the coexistence of Levallois and laminar volumetric conception (level B). A third final phase (level A^{IX-VI}) would document the replacement of these two systems in favour of a Discoid system. A similar technical succession is documented in the final Mousterian sequence of the nearby Grotta del Cavallo.

7.2.6. *Grotta dei Giganti (Santa Maria di Leuca, Lecce)*

On the tip of the Salento peninsula is located Grotta dei Giganti, a semi-submerged limestone cavity discovered in 1936 by G.A. Blanc. The cave was further investigated by A.C. Blanc and L. Cardini in 1958 (Blanc, 1961, 1962) and by L. Cardini and M. Piperno in 1974.

The Mousterian deposit, which rests on a marine conglomerate (3g) attributed to the Last Interglacial, has been divided into two main horizons (levels from 3f to 3c and 3a), separated from each other by a stalagmitic crust (3b).

The lithic assemblage, relatively poor, exhibited Mousterian and "micro-Mousterian" characteristics. It was obtained mostly on limestone and flint (Blanc, 1959) and, although rarely, also on shells (Blanc, 1959; Douka and Spinapolice, 2012). Limestone and shells are local, while flint and very rare pieces in quartzite and jasper are exotic, probably derived from secondary sources about 150 km to the north (Spinapolice, 2009, 2012, 2018b).

The lithic industry consists of few non prepared cores, many Levallois flakes, and a great number of flake tools. The Levallois method is prevalent and exploits all types of raw materials. The toolkit primarily includes *limaces* and proto-*limaces*, sidescrapers (including transverse sidescrapers with Quina retouch), and very small convergent sidescrapers, resembling short and thick points (less than 2 cm). Most of retouched tools are obtained from non-local raw material, exhibit more intensively retouch, and a high degree of curation. Spinapolice suggested that the high technical investment documented by these tools indicates their intended use for mobility (Spinapolice, 2009, 2012, 2018a, 2018b).

Few Mousterian sites in Salento have reliable radiometric dating (Table 5), which limits direct comparisons between the sites.

Early typological analyses of the main Mousterian lithic assemblages suggested that the Levallois method was absent in the oldest levels (Palma di Cesnola, 2001). However, more recent studies have shown that the Levallois method is present. It accounts for 48%–75% of the reduction methods identified at Grotta Romanelli, Grotta Torre del-l'Alto, Grotta Uluzzo C, Grotta Mario Bernardini, and Grotta dei Giganti. This method was mainly applied to local materials like limestone and siliceous limestone (Spinapolice, 2012, 2018a, 2018b).

All these sites also share a common trait: the presence, albeit in small quantities, of non-local raw materials such as flint, jasper, and quartzite, which likely came from sources no less than 100–150 km away (Romagnoli, 2020a; Spinapolice, 2012, 2018a, 2018b).

While the economy of raw materials in debitage methods doesn't show much variation, there are notable differences in tool production. Tools made from local raw material "are generally poorly reduced and frequently expedient" (Spinapolice, 2018b, p. 105). In contrast, tools made from imported materials show clear signs of curation and maintenance: these higher-quality tools were more extensively retouched, showing evidence of reuse. The significant investment in these materials indicates that these tools were designed to be portable and maintained for long-term use (Spinapolice, 2018b).

Spinapolice (2012) identified the closest potential outcrop of flint, quartzite, and jasper in the Bradano River basin (Basilicata region), 100–150 km north of southern Salento. However, no systematic survey of this area has been conducted. Based on this evidence, Spinapolice hypothesizes that the Mousterian sites in Salento formed part of a territorial system, with residential sites on the Ionian side, closer to non-local raw material sources (such as Uluzzo C, Grotta Mario Bernardini, and Grotta del Cavallo), and logistical sites on the Adriatic side, like Grotta Romanelli (Spinapolice, 2012, 2018b).

In summary, the use of predetermined technology and non-local raw materials is a feature shared by all the considered sites. This indicates that Neanderthals in this region exhibited behaviour and mobility comparable to that of modern humans (Spinapolice, 2012, 2018b).

However, our re-analysis of the Mousterian lithic industry at Grotta Romanelli contradicts this model. It suggests the absence of prepared core technology and the exclusive use of local raw materials. These findings imply a distinctive positioning of Grotta Romanelli's lithic technology within the currently known framework.

8. Conclusions

Comparing the Middle Palaeolithic lithic industry of Grotta Romanelli with other penecontemporaneous Mousterian sites in Salento is challenging. This is primarily due to the lack of absolute chronological data and the different methodological approaches used in the analysis of lithic industries. Additionally, most of these sites were discovered and excavated decades ago, and not all have been systematically reassessed, making precise comparisons difficult.

Therefore, at the current state of the research, assessing Grotta Romanelli's role within the context of the Salento Mousterian is complex. Despite these limitations, distinct features of Grotta Romanelli's lithic industry stand out when compared to coeval sites, contradicting recent revisions.

Our results indicate the absence of prepared core technology and the exclusive use of locally available raw materials. This lithic technology is primarily focused on producing unmodified flakes from a small number of cores using low-structured methods. Retouched tools, such as various types of sidescrapers, are very rare.

This raises critical questions: how does Grotta Romanelli's oldest lithic industry fit within the framework of nearby and presumed contemporaneous Salento Mousterian sites? How can we explain the absence of prepared core technology and the strictly local raw material procurement, elements not shared with the other Mousterian sites in Salento?

Several possible explanations could be considered. One scenario suggests that Grotta Romanelli might have been used only temporarily, a hypothesis already put forward by previous studies. The ISU3 lithic assemblage, with its expediency and its limited range of tools, could indicate a brief and sporadic occupation, further supported by the absence of structured hearths (Piperno, 1974; Spinapolice, 2018a, 2018b). Another possibility is that the variability seen in Grotta Romanelli's industry reflects the broader diversity of the Italian Mousterian. This period is often viewed as a multi-linear process, resulting in a mosaic-like landscape where each Mousterian complex followed a specific evolutionary pattern (Palma di Cesnola, 2001).

It is also worth noting that ISU3 was not fully excavated in earlier investigations, and exploration of this level is still ongoing in other areas of the cave.

This study is focused solely on the Mousterian lithic industry. A more comprehensive understanding will only be possible when this revision is integrated with other analyses, such as paleoenvironmental, paleontological, and archaeozoological studies. Future excavations and forthcoming analyses will undoubtedly provide deeper insights into the origins, characteristics, and development of techno-economic systems during the Middle Palaeolithic in the southernmost part of the Italian Peninsula. These results will help address the complex issues surrounding Grotta Romanelli and its place within the regional framework.

CRediT authorship contribution statement

Brunella Muttillo: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rosalia Gallotti:** Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis. **Luca Forti:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation. **Giuseppe Lembo:** Writing – review & editing, Visualization, Methodology, Formal analysis, Data curation. **Ilaria Mazzini:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation. **Pierluigi Pieruccini:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation. **Raffaele Sardella:** Writing – review & editing, Supervision, Funding acquisition.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to express our gratitude to the *Soprintendenza Archeologia, Belle Arti e Paesaggio per le province di Brindisi e Lecce* for granting permission for the research and field activities (2015–2023, resp. Raffaele Sardella). Additionally, our thanks extend to the *Soprintendenza Nazionale per il Patrimonio Culturale Subacqueo in Taranto* (Laura Masiello) for granting permission to study the historical collections.

We also thank the Castro municipality, *Capitanerie di Porto di Castro e di Otranto, Parco Naturale Regionale Costa Otranto S.M. di Leuca-Bosco di Tricase*, Ninì Ciccarese and Toto De Santis, Michele Rizzo and the Red Coral team, Don Piero Frisullo and Genesareth for their logistical support.

We also wish to thank all members of the Romanelli team and many students for helping during 2015–2023 fieldwork activities.

This work was funded by *Sapienza Università di Roma* with *Finanziamento Ricerche di Ateneo* 2015, *Grandi Scavi* 2016 (Grant no: SA116154CD9592F3); *Grandi Scavi* 2017 (Grant no: SA11715C81468801); *Grandi Scavi* 2018 (Grant no: SA1181642D3B3C58); *Grandi Scavi* 2019 (Grant no: SA11916B513E7C4B); *Grandi Scavi* 2020 (Grant no: SA120172B2C05E68); *Grandi Scavi* 2021 (Grant no: SA12117A87BC3F0A); *Grandi Scavi* 2022 (Grant no: SA1221816893E2AB); *Grandi Scavi* 2023 (Grant no. SA1231888AE771CD).

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