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Grotta Grande (southern Italy). Disentangling the Neandertal and carnivore interaction in a short-term palimpsest at the last glacial onset (∼116-109 ka)

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ABSTRACT

The Mousterian of the Grotta Grande (Southern Italy) is here subject to new dating, which provide a surprisingly high-resolution on the stratigraphic sequence. Overall, the deposit in the Trench F appears framed in the MIS 5, into a brief chronological time span immediately after the Last Interglacial, between ∼116 ka and 109 ka.

Significant archaeological evidence has been found in this sector on the cave, consisting in two high-resolution archaeological records (layers 8 and 6) with evidence of anthropic organization of the space, involving possible constructed features, use of fire and, possibly, different activity areas. Here we focus on the layer 8, excavated for 10.5 m^2, which returned an intriguing entanglement of human and carnivore evidence.

An interdisciplinary approach based on the pivotal role of spatial taphonomy, as meeting point of zooarchaeology, lithic technology, lithic traceology and spatial archaeology, has been applied. Beyond the recognition of the two main components in the formation of the context (the human and carnivore agency), the results allow to recognize its very good preservation state. Moreover, the reciprocal interaction between Neandertal and spotted hyena has been hypothesized, reconstructing the meaning of their presence at the site. More specifically, a Neandertal camp would have been followed, immediately after its abandonment, by scavenging activities of the spotted hyena, profiteering of resources with food interest for its diet left in the site. This human/carnivore sequence contribute to shed new light on the taphonomy issues on Quaternary sites.

1. Introduction

Since the pioneering season of the *Processual Archaeology* the theme of the Human and Carnivore interaction during the Prehistory encountered a large interest in the scientific debate (e.g., Binford, 1978, 1981; Binford et al., 1988; Blumenschine, 1988; Brain, 1981; Bunn, 1982, 1983; Guadelli, 1989; Isaac, 1967, 1983; Kroll and Isaac, 1984; Potts et al., 1988). This is still a fundamental issue for the study of the Quaternary contexts (e.g., Coil et al., 2020; Daujeard et al., 2016, 2019a; Daschek and Mester, 2020; de La Rasilla et al., 2020; Discamps et al., 2019; Fernández-García et al., 2022; Hussain et al., 2022; Jimenez et al., 2021; Leslie, 2016; Mata-González et al., 2022; Micó et al., 2020;

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Orbach and Yeshurun, 2021; Pickering, 2002; Pizarro-Monzo et al., 2023; Rodríguez-Gómez et al., 2017; Sanchis et al., 2019; Sanz et al., 2016; Yravedra et al., 2022; Zilio et al., 2021). The centrality of this topic in the modern research is mainly linked to two important and complementary taphonomic issues: 1) the palimpsest nature of most of the prehistoric contexts (*see* Bailey, 2007) and 2) the damage/alteration of the anthropogenic assemblages due to the action of carnivores. Both these problems can produce a more or less significant misreading of a given context, hindering its correct interpretation (Sanchis et al., 2019; Yravedra, 2011).

The action of carnivores, in particular, can result to a number of different material output, mirroring both the large variety of possible involved actors (in turn increasing the magnitude of the palimpsest effect) and to the nature/duration of their presence at the site. Disentangling the components of a context, then, is both a complex task and an unavoidable premise.

The available actualistic literature and archaeological sample provide multiple data on the effect of carnivore action on the bone assemblage. From the one hand, the feeding behaviour can contribute both positively (e.g., the carnivores acting as “bone accumulators”) and negatively (modifications/destruction of the original set) to the composition of the bone assemblage (e.g., Arriaza et al., 2016, 2018; Arribas and Palmqvist, 1998; Binford, 1978, 1981, Binford et al., 1988; Boscato and Crezzini, 2005; Brain, 1981; Crezzini et al., 2016; de Lumley et al., 2004; de Ruiter and Berger, 2000; Domínguez-Rodrigo et al., 2022; Domínguez-Solera and Domínguez-Rodrigo, 2009; Eixea et al., 2020; Fourvel, 2012; Hill, 1989; Micó et al., 2020; Orbach and Yeshurun, 2021; Palomares et al., 2022; Sanchis et al., 2015; Sauqué et al., 2014, 2018; Sauqué and Sanchis, 2017; Stewart et al., 2021; Yravedra and Gómez-Castanedo, 2014; Yravedra Sainz de los Terreros et al., 2023). The scale by which these filters alter the composition of the original bone set varies consistently according to the nature of the carnivore, its feeding behaviour, the temporal relationship with the other actors in the site and the nature of the food. On the other hand, the action of carnivores is not limited to the role of bone accumulator/modifier. The original spatial arrangement of a site can also be significantly altered by carnivore behaviour, as the neotaphonomic and archaeological studies are highlighting more and more (Arilla et al., 2020; Arriaza et al., 2018; Binford, 1978, 1981; Binford et al., 1988; Blumenschine, 1988; Camarós et al., 2013; de Ruiter and Berger, 2000; Fourvel, 2012; Isaac, 1967; Krajcarz and Krajcarz, 2014; Marean and Bertino, 1994; Marean and Spencer, 1991). In addition to the disaggregation of preexisting meaningful patterns, the action of carnivore can produce new spatial patterns (e.g., indicative of the carnivore feeding) or false patterns (e.g., significant spatial correlations without a causation meaning), with possible problems of equifinality (Arilla et al., 2020; Arriaza et al., 2018; Domínguez-Rodrigo et al., 2007; Enloe, 2004; Krajcarz and Krajcarz, 2014; Lyman, 2004; Marean et al., 2004; Organista et al., 2023; Rogers, 2000).

Given these premises, an integrated taphonomic, spatial and processual perspective plays a key role in the analysis and deciphering of a bone assemblage. From the one hand, indeed, multiple processes can contribute to the formation of a bone assemblage (e.g., human activity, carnivore activity, gravitative/tractive phenomena, natural traps), leaving different spatial outcomes. From the other hand, the study of a mixed faunal assemblage has to establish not only who ate what, but also the order in which the identified agents have had access to the carcass (primary access *vs* scavenging), the eventual presence of components independent by a prey/predator/scavenger dynamic and their spatial/relational assessment.

This study of the layer 8 from Grotta Grande have been purposed to the taphonomic disentanglement of a Late Pleistocene context that records a case of human/carnivore interaction. The protocol used a three-step procedure, including.

1) Identification of all actors who have contributed to the site formation, isolating all the stigmata linkable to each actor;
2) Analysis of the spatial and taphonomic patterning of all behavioural stigmata, recognizing both the preservation degrees and correlations;
3) Reconstruction of the possible sequence of events occurred in the site.

2. Regional setting and the site of Grotta Grande

2.1. A brief overview of the Cave’s deposit

The cave site of Grotta Grande opens directly onto the Tyrrhenian Sea, along the southern coast of Cilento, in the locality called “Masseta”, not far from the village of Scario (S. Giovanni a Piro - Salerno, Campania, Southern Italy). The Cilento region is well known for the occurrence of several stratified prehistoric sites which preserve evidence of human occupation during the entire Palaeolithic time span (Aureli and Ronchitelli, 2018; Carmignani et al., 2021 and references therein) (see Fig. 2 in Carmignani et al., 2021).

Systematic excavations at Grotta Grande were carried out between 1979 and 2002 by the University of Siena in collaboration with the local Archaeological Office (SABAP per le province di Salerno e Avellino) and under the scientific direction of one of the authors (A. R.). The cave, 85 m long, develops along a fracture perpendicular to the coast and is divided into two rooms connected by a corridor (Fig. 1). The cave morphology and the sedimentological processes were conditioned by eustatic fluctuations occurring during the Late Middle Pleistocene and the Early Upper Pleistocene. The sea repeatedly entered the cavity, dismantling the original deposit, leaving only cemented plates in the wall or in the most protected areas of the cave. In these areas six test trenches were dug (indexed A-F) (Fig. 1b) and layers with Middle Palaeolithic materials were yielded, except for internal Trench E, that was devoid of any anthropogenic evidence.

The trenches which returned the most significant finds are.

- ***Trench A*** – This is the only one preserving sedimentological evidence prior to the Upper Pleistocene, represented by a marine conglomerate (unit A) followed by sterile continental red sandy and silty deposits (unit B) sealed at their top by a flowstone (unit C) dated to MIS 6 (Fig. 1b–d, 2). This date is confirmed in this paper by new U-series analyses (cf. chronological data). In this Trench, the following deposit sequence (unit D), consisting in concreted archaeological and hearth levels alternating with a red cemented breccia, are attributable to the Upper Pleistocene (Fig. 2). Faunal composition of large mammals is characterised by the predominance of ibex (*Capra ibex*), followed by the fallow deer (*Dama dama*). A morphometric analysis of teeth of the Savi vole (*Microtus* (*Terricola*) *savii*) point to the presence of a local population not contemporary to that found in Trench F (Ronchitelli et al., 1998, 2011).
- ***Trench F*** – This sequence, deposited after the Trench A speleothem crystallisation, is the main subject of this paper (Fig. 2). The major interest of Trench F is the occurrence of features attesting to the presence of living spaces including placing of fireplaces, faunal remains, lithics, one vertical constructed feature (Layer 7) and some possible stone-aligned structures (Figs. 2–3) (Boscato and Ronchitelli, 2004; Ronchitelli et al., 2011).

2.2. The trench F and the layer 8

The Trench F consists of a low tunnel (3 × 3m), a sort of small “cave within a cave” (Figs. 2 and 3a-c), eroded by the Tyrrhenian marine transgression posterior to the Trench A flowstone formation and anterior to the arrival of humans and sealed up to the ceiling by a roughly 1 m thick deposit (layers 1–14 in Fig. 2c). From below.

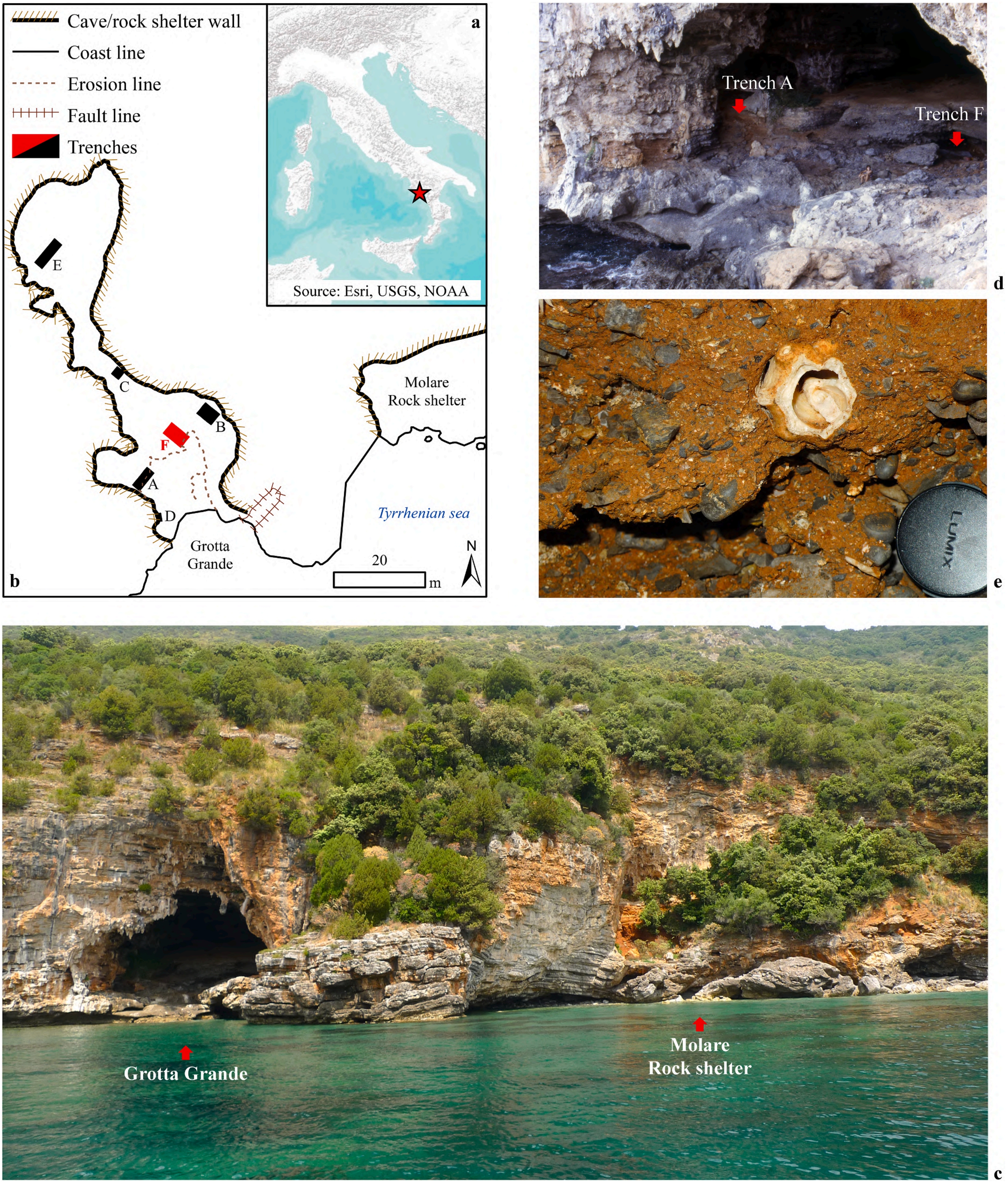

Fig. 1. Contextualization of the site with a) geographic localization of the cave; b) general planimetry including the cave and the nearby Molare Rock shelter, with the localization of the trenches; c) panoramic photo from the see showing the proximity between the Grotta Grande and the Molare Rock shelter; d) panoramic photo of the entrance of the cave, showing the localization of the Trenches A and F; e) close-up photo of a specimen of *Persististrombus latus* contained in the breccia (left at the site) (picture b of A. Ronchitelli; pictures c, f: F. Antonioli).

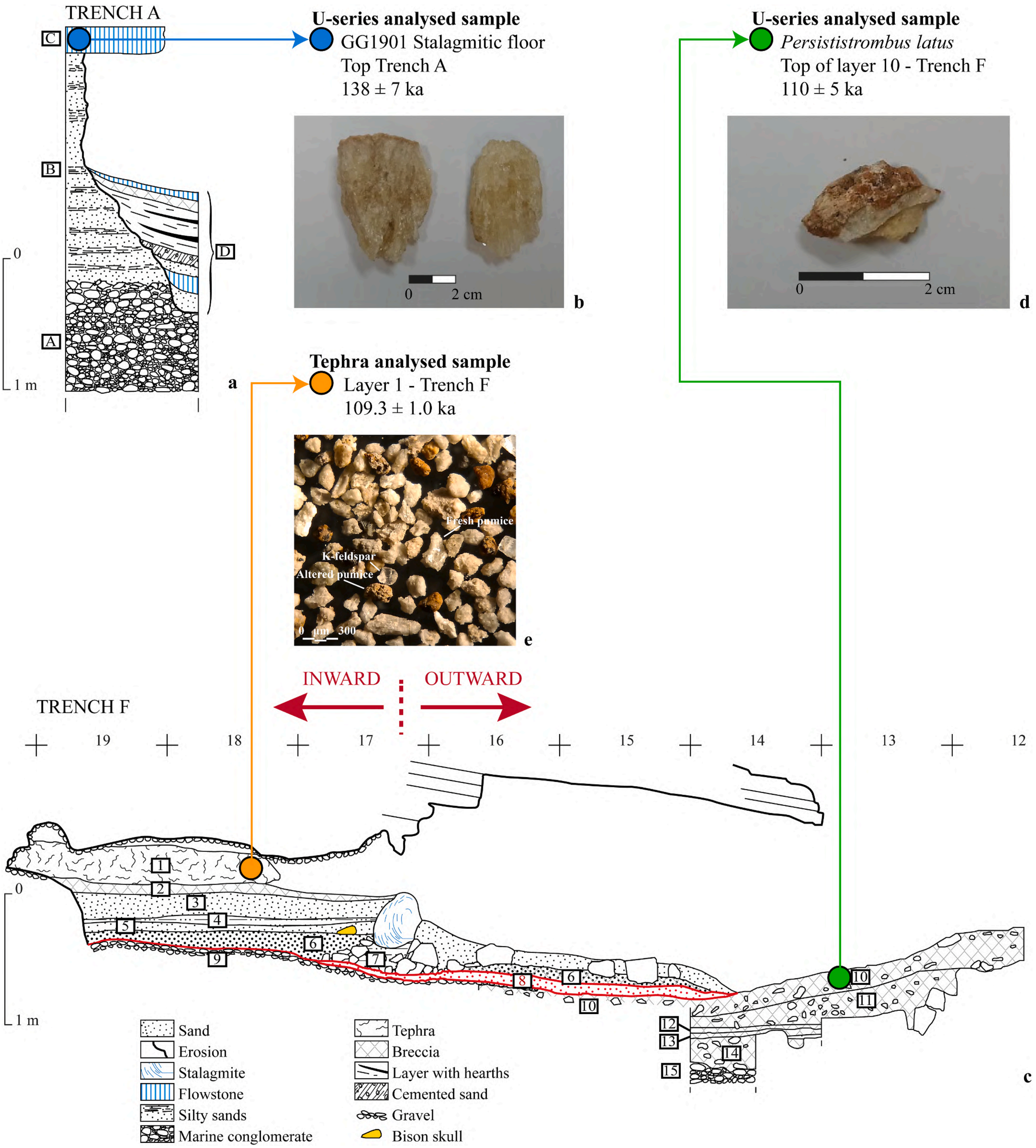

Fig. 2. a) Stratigraphic sketch of the Trench A (mapping: P. Gambassini; drawing: V. Spagnolo); b) sample GG1901, corresponding to a calcite fragment extracted from a speleothem capping the trench A sequence; c) stratigraphic profile of the Trench F along the section AA' (mapping: P. Boscato; drawing: V. Spagnolo), with characterization in red of the layer 8 (see the map in Fig. 3); d) sample GG1902, corresponding to a fragment of a shell (*Persististrombus latus*) found in a base layer of the Trench F sequence; e) microscope photo of the tephra sample.

- ***Layer 15*** – marine conglomerate (probably Euthyrrenian), unexcavated.
- ***Layers 14-10*** – continental red breccias containing, in secondary deposition, rare specimens of *Patella ferruginea* and *Persististrombus latus* (Fig.. 1e and 2d). These molluscs are considered, in Southern Italy, to be typical of the warm interglacial MIS 5e peak, although dates obtained from analysed samples are slightly more recent (cf. chronological data);
- ***Layer 9*** – gravels derived from disintegration of the Middle Pleistocene marine conglomerate stuck to the ceiling;

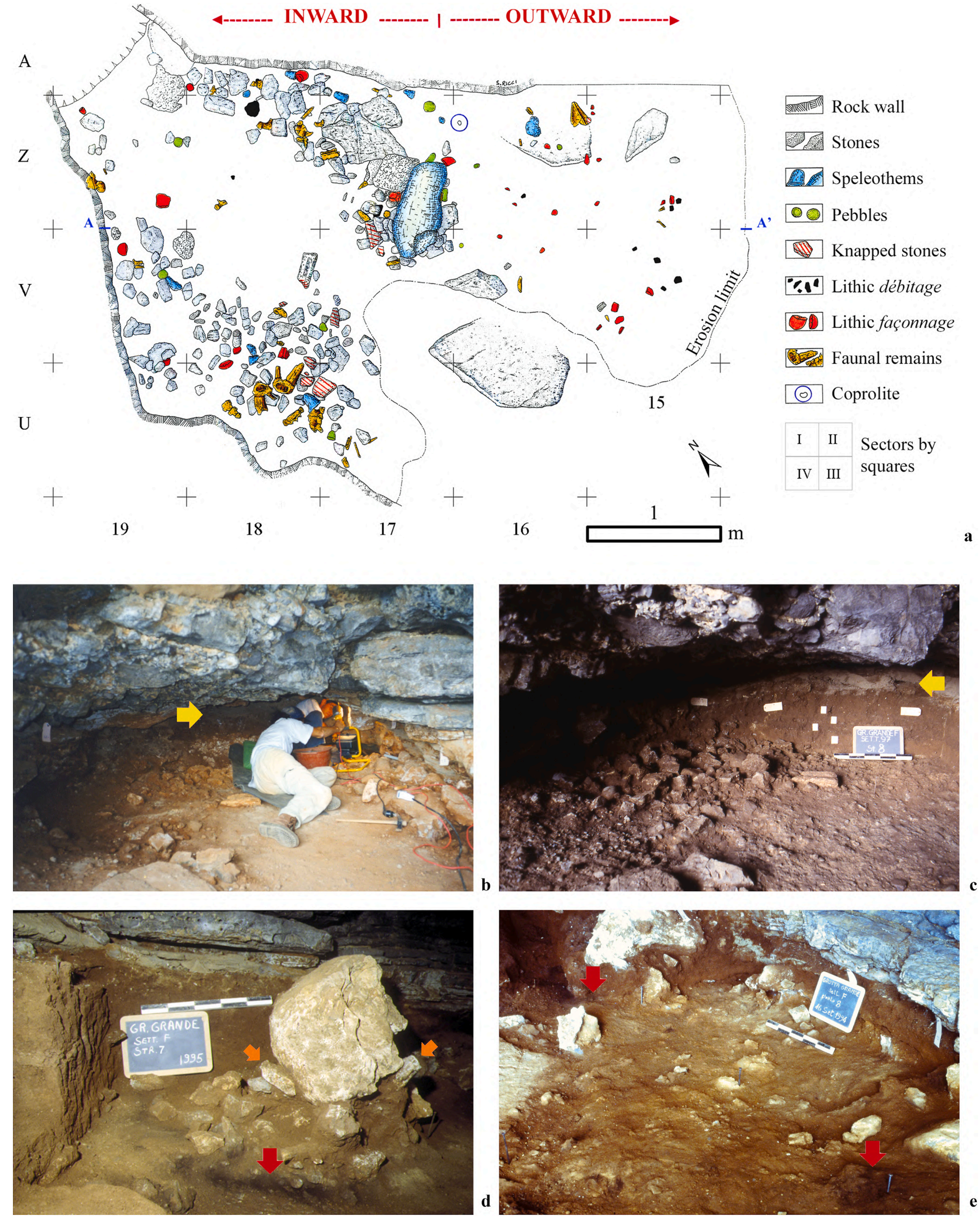

Fig. 3. a) General planimetry with different characterizations for stones, speleothem, pebbles and larger findings (mapping: P. Boscato; drawing: S. Ricci); b) photo of the Trench F during the excavation in the niche, the yellow arrow shows the position of the tephra layer; c) excavation of the layer 8 and stratigraphic baulk in the inner part of the niche (the yellow arrow shows the position of the tephra layer); d) detail photo showing the layers 7 and 8 (notable the evidence of the charcoal lens of the layer 8 below the vertical feature). The orange arrows show two of the stone wedging the sides of the large stalagmite. The red arrows show the position of the charcoal areas (picture b: A. Ronchitelli, pictures c–e: P. Boscato).

- ***Layer 8*** – archaeological layer (see the description below) (Fig. 3);
- ***Layer 7*** – vertical feature, formed by a mound of earth, stone and pebbles, supporting a large stalagmite in a secondary position, which was wedged on both sides by stones (Figs. 2c and 3a, d).
- ***Layer 6*** – archaeological layer made by red orange slightly hardened sand containing a horizontal living feature, unfortunately strongly damaged by erosion (Ronchitelli, 1998);
- ***Layers 5-3*** – sterile red sand and silt;
- ***Layer 2*** – red breccia with rare bones;
- ***Layer 1*** – tephra identified with the Maddaloni/X-6 marker, dated to 109.3 ± 1.0 ka and 109.1 ± 0.8 ka (Monaco et al., 2022) (cf. chronological data).

Both data from faunal (micro and macro) and pollen remains (Ronchitelli et al., 2011) from the whole sequence of Trench F testify to a temperate-warm wooded environment with Mediterranean affinities. The area surrounding the cave provided humans with a very diverse environment as it was characterised by steeply sloping hills, and by a coastal plain (presently under sea). These physiographic characteristics are well-represented in the faunal associations, suggesting a mild climate and the presence of a patchy landscape around the cave, characterized by forested environments and by more open areas. The rocky slopes, for instance, favoured the presence of the ibex (abundant even during interstadial periods). Faunal remains include eleven large mammal taxa (for the whole list of mammal taxa, see the Table S1 of this paper and refer to Ronchitelli et al., 2011), among which the hippo, the straight tusked elephant and the narrow-nosed rhino, and fourteen small mammal taxa, mainly rodents, with a significant amount of glirids (*Glis* and *Muscardinus*). Pollen from layer 8 indicate vegetation organised in different bands, mainly evergreen Mediterranean scrub and mixed woodland with conifers (*Pinus*, *Juniperus*), deciduous broad-leaved trees (*Quercus*) and Mediterranean trees (*Quercus ilex*). Plants of freshwater communities are absent. The decrease of glirids together with the increase of *Microtus* (*Terricola*) *savii* in the upper part of the sequence (layers 5-2), as well as the episodic spread of steppe vegetation in the pollen record, suggest that the environment evolved, over time, towards more open, colder and/or more arid landscapes (Ronchitelli et al., 2011). The chronological, archaeological and paleoenvironmental evidence is, therefore, in accordance with the attribution of the entire series to a relatively brief time span, which can be placed inside the MIS 5d climatic fluctuation.

The layer 8, in particular, is preserved for about 10.5 m^2. The characteristics of the "niche", where this layer is confined, conditioned its features, producing a dualism between an outer space (the atrium) and an inner chamber (the tunnel), approximatively with a similar extension. On the visual level, indeed, this is strongly accentuated both by the different heigh of the vault ceiling in these partitions (about 80 cm in the "tunnel" and 150–160 cm in the "atrium") and by a constructed Palaeolithic wall (layer 7), contemporaneous to the layer 8, acting as a diaphragm between the "tunnel" and the "atrium" (Figs. 2c and 3). Interestingly, these spatial constraints also conditioned the quantitative and qualitative structure of the findings from these parts. The inner space, indeed, is characterized by the presence of a ring of stones adjacent to the chamber natural walls (the inner area with stones), leaving a central free space (the spared inner area). No stones were in the outer part, where some charcoal and ash patches have been recorded (Fig. 3a, c-e). The archaeological material also changes according to these partitions, as noted in previous works (e.g., Ronchitelli et al., 2011). The presence of fireplaces was recorded on the top of the layer 8, by an about 4 cm thick layer of ash, overlapping an about 2–3 cm thick layer of charcoal sediment. This evidence was recorded mainly in the atrium (in the squares V15/II and Z15/III-IV, and, with a minor extent in V16/I-II and Z16/III-IV) and immediately under the structure of the layer 7 (in the squares V17/I-II and Z17/III-IV, mainly in the centroid between these squares) (Fig. 3c and d). Significantly, the presence of calcined stones was recorded in the charcoal/ash area in the squares V17/I-II and Z17/III-IV.

3. Material and methods

3.1. Chronological analyses

3.1.1. U-series dating ($^{230}Th/^{234}U$)

Two carbonate samples were analysed by uranium-series Q-ICP-MS. The first sample (GG1901) corresponds to the stalagmitic floor which seals the Trench A (Fig. 2a and b). It is well crystallized with acicular shaped crystals. The second sample (GG1902), a *Persististrombus latus* shell fragment sampled in the continental breccia at the bottom of Trench F sequence (level 10, Fig. 2c and d). This fragment was cut with a saw in order to observe a clean slice before sampling. After observation, regions of interest with the less amount of apparent contamination were selected and removed using a rotary tool fitted with a diamond disc. The samples were then slightly fragmented and cleaned several times in an ultrasonic bath with Milli-Q water.

For each analysed sample, a known quantity of $^{229}Th–^{233}U–^{236}U$ tracer was weighed and evaporated to dryness in a teflon beaker. Each sample was then weighed (over 500 mg) and dissolved in nitric acid (HNO_3). A few drops of H_2O_2 were added to remove the organic matter. An iron hydroxide precipitate was made to remove most of the carbonate matrix and thus pre-concentrate the uranium and thorium. The separation and purification of the uranium and thorium isotopes fractions were carried out on a single UTEVA-type ion exchange resin (Douville et al., 2010; Horwitz et al., 1992) conditioned and rinsed with hydrochloric and/or nitric acid at different molarities according to the different steps of the established protocol.

The different U and Th fractions were then dried and dissolved in a mixture of 2% HNO_3, prior to dilution for U and Th isotopic analyses by quadrupole mass spectrometry. Each chemistry includes an internal laboratory standard for control and a blank chemistry is performed and quantified.

Isotopic measurements were performed at Musée de l'Homme, Paris, on a Thermo iCAP-RQ ICP-Q-MS, coupled to a Teledyne CETAC Aridus 3 desolvator system and a Teledyne CETAC ASX-112FR autosampler. The interface was configured for high sensitivity (insert high sensitivity - skimmer cone) and the signals were tuned and optimized for ^{238}U and ^{235}U. Given the low uranium sample content, the Helium mode (CCTS) of the Qcell was used to optimize ion focusing and thus boost the signal sensitivity. All the samples are first rapidly measured (pre-screening) to determine each best dilution factors for the final measurements.

The signal intensities of the isotopes ^{229}Th, ^{230}Th and ^{232}Th, and ^{233}U, ^{234}U, ^{235}U, ^{236}U were all measured on an electron multiplier (SEM) in the pulse counting mode. The instrument background is measured prior to each sample or standard.

An analytical standard (without chemistry) of spiked uraninite (HU-1), in secular radioactive equilibrium, was analysed at the beginning, middle and at the end of the sequence for instrument deviation control. The corrected activity ratios obtained must match the true ratios.

For data treatment, the mass fractionation correction was determined using an exponential law (Russell et al., 1978), comparing the measured $^{233}U/^{236}U$ tracer ratio to its true value and then applied to each sample ratios. The $^{234}U/^{238}U$ ratio is obtained via the $^{234}U/^{235}U$ measurement according to the known natural $^{238}U/^{235}U$ ratio (Hiess et al., 2012). After processing the results, the measured atomic isotope ratios are converted into activity ratios.

The total blank chemistry values must be as low as possible, and the internal standard sample values must be correct to validate the ages.

Ages were calculated using half-lives of 75,584 years and 245,620 years for ^{230}Th and ^{234}U, respectively (Cheng et al., 2013). The age uncertainty ($k = 2$) was estimated taking into account all sources of analytical uncertainty.

Recently, a second fragment of the stalagmitic floor, GG1901* was analysed according the same protocol with some few improvements.

3.1.2. Tephrochronology

Trench F Layer 1, consisting of an up to 20 cm-thick whitish-yellowish volcanic ash layer (Figs. 2c and e, 3b-c), was sampled for major element geochemical fingerprinting and thus for potential correlation with a well-dated tephra layer. Major and minor oxide element compositions were determined on micro-pumice fragments and/or glass shards (grain size >125 μm), from tephra L1. The analyses were carried out at the Istituto di Geologia Ambientale e Geoingegneria of the Italian National Research Council (IGAG-CNR) (Rome, Italy) using a Cameca SX50 electron microprobe equipped with a five-wavelength dispersive spectrometer. Operating conditions were set to 15 kV accelerating voltage; 15 nA beam current; 10–15 μm beam diameter; 20 s per element counting time; Wollastonite (Si and Ca), corundum (Al), diopside (Mg), andradite (Fe), rutile (Ti), orthoclase (K), jadeite (Na), phlogopite (F), potassium chloride (Cl), barite (S), and metals (Mn) were used as standards. The Ti content was corrected for the overlap of Ti-Kα peaks. In order to evaluate the accuracy of the electron microprobe analyses, three international secondary standards (Kakanui augite and rhyolite RLS132 glasses from the United States Geological Survey) were measured prior of the analytic run.

3.2. Zooarchaeological analysis

The whole large mammal sample from layer 8 of Trench F was reanalysed in this paper. Faunal remains have been identified using the osteological reference collection of the Zooarchaeology Lab at the Department of Physical Sciences, Earth and Environment of the University of Siena. The composition of the assemblage and the body part representation is expressed through the NR (Number of Remains), NISP (Number of Identified Specimens), MNE (Minimum Number of Elements), and MNI (Minimum Number of Individuals). MNE and MNI were counted considering anatomical overlap of specimens, side, size, and ontogeny. Bone surface modifications were identified following Blumenschine et al. (1996), Binford (1981) and Domínguez-Rodrigo et al. (2009). An Hirox KH-7700 digital microscope with an MX-5040RZ body, and an AD-5040HIS Adapter was used for the 2D measurement of pits (length and breadth) and tooth scores (breadth), following Domínguez-Rodrigo and Piqueras (2003). The presence of impact notches was registered, and they were measured following Capaldo and Blumenshine (1994). Freshness of bone tissues at the moment of breakage (green vs dry-bone fractures) was evaluated by means of FFI (Fracture Freshness Index; Outram, 2002). The presence or absence of burnt bones was preliminarily identified considering colour and surface's texture (Shipman et al., 1984). Exfoliation of bone surfaces was registered only in terms of presence/absence. Taxonomically unidentified specimens from layer 8 were divided according to size, bone tissue and body size of individuals the specimens derived from. Bone tissue categories are "diaphysis", "epiphysis", "compact bone", "spongy bone" and "flat bone". Size of specimens was evaluated using size classes "1–3 cm", "3–6 cm", "6–10 cm" and ">10 cm". Body size of individuals was categorised according to Brain (1981). When it was clear, that specimens belong to ungulates, we referred to "large ungulate", "medium ungulate", "and small ungulate", corresponding respectively to Brain's size 4 (300–1000 Kg), 3 (70–300 kg), and 2(18–100 kg).

3.3. Lithic technology

The lithic set from the level 8 of Grotta Grande was studied with a technological approach, aimed to reconstruct the lithic reduction sequences present in the site (e.g., Boëda, 2013; Geneste, 2010; Inizan et al., 1995; Pelegrin et al., 1988). Each item was individually studied, recording its technological and taphonomic data in an Access® database. The technological data include the blank exploited (pebble, block, indeterminate), the lithotype (chert, radiolarite, siliceous limestone, limestone, quartzarenite, quartz), the granulometry (fine, coarse), the size-class (DC 1: 1–50 mm^2; DC 2: 50–100 mm^2; DC 3: 100–150; mm^2; DC 4: 150–200 mm^2; DC 5: >200 mm^2), the *chaînes opératoire* (*façonnage*; *débitage*), the technological class (pebble, core, flake, debris, *façonnage* product), and other technological parameters. The taphonomic data include the post-depositional alterations (chemical, mechanical or thermal) present on the artifact.

Based on the concepts described in Spagnolo et al. (2019), some specific parameters of the database were used for the statistical and spatial analyses performed in this work. These include only the significant information to infer the preservation state of the context and the human spatial behaviour. In particular, the distribution of items by size classes has been taken into account to evaluate the completeness of the lithic assemblage and to recognize eventual tractive phenomena and scuffing/trampling effect (e.g., Bertran et al., 2012; Stevenson, 1991). The technological macro-categories used for the spatial analysis of the lithic assemblage include: production waste (debris and management flakes), objective flakes (without use-wear evidence on the edges), tools (retouched items and flakes with macro-/micro-traces on the edges), cores and pebbles. In turn, the category of tools has been created distinguishing the products by reduction sequence: from *débitage* or from *façonnage* (i.e., heavy-duty tools).

3.4. Use-wear analysis

A preliminary test aimed at evaluating the presence and the preservation of use-wear traces was conducted on a sample (n = 26) of lithic artefacts from Grotta Grande. All the lithic implements were analysed using both the Low-Power (Odell and Odell-Vereecken, 1980; Odell, 1981) and the High-Power Approaches (Keeley, 1980; Van Gijn, 1990) by means of a 3D digital Hirox KH 7700 microscope. The LPA was performed with an MX-G 5040Z body and an AD-5040Lows lens (20x-80× magnifications), while the HPA using an MXG-10C body and OL 140 II lens (140x-560× magnifications), a polarizing filter and an AD-10S Directional Lighting Adapter.

3.5. Statistical and geostatistical analyses

The analytic protocol here applied has been developed and adopted in previous studies (e.g., Spagnolo and Garcea, 2023; Spagnolo et al., 2016, 2019, 2020a, 2020b, 2020c). This methodology is grounded in the systemic and processual description of the activities (also in terms of spatial outcome) by the behavioural chain method (Binford, 1987; Leroi-Gourhan, 1964–1965; Newell, 1987; Schiffer, 1972, 1975a, 1975b). This allows the preliminary selection of spatially-relevant information in the archaeological record, to explore the general and deep structures of data, inferring clues about the preservation of the context, the presence and interrelation of different behavioural components (e.g., human vs carnivore activities) and, if possible, their diachrony.

Purposely selected data from the lithic set for the statistical and spatial analysis include the dimensional classes and the technological macro-classes. Among the zooarchaeological data, the size classes, the taxonomic/anatomic data and the taphonomic observation related both to human action and to natural agents have been included.

The statistical and geostatistical exploration of data followed a three-step workflow using ArcGIS® 10.8 and Past 4.12. Firstly, the preliminary estimation of the spatial patterns of findings was performed for each category individually taken, combining the Multi-Distance Spatial Cluster Analysis (Ripley's K Function), the Spatial Autocorrelation (Global Moran's I) and the High/Low Clustering (Getis-Ord General G) approaches. In this manner, the statistical relevance of the random/cluster patterning has been also evaluated. Secondly, the Hot Spot Analysis (Getis-Ord Gi*) and the plot maps (also implemented with different symbology for different qualitative data) were made to highlight the spatial patterning of taphonomic and behavioural information. Finally, a deeper analysis was also conducted, through a Ward's Cluster Analysis, in this case aimed to evaluate both the robustness of the classification itself (e.g., cophenetic correlation) and the eventual spatial coherence of the retrieved clusters (in turn further clue of a well-preserved spatial context). The cluster analysis was performed on the base of the percentage distribution of some selected behavioural categories of findings for each sufficiently integer 50x50 excavation sectors. These categories are extrapolated both from faunal remains (specimens <6 cm, specimens >6 cm, large ungulate calvaria/bear skull, unburnt remains, charred/calcined remains, cortical bones, spongy bones, butchered bones) and lithic finds (tools from debitage, tools from façonnage). The more or less combined use of these techniques becomes more and more common practice in the analysis of Palaeolithic contexts (e.g., Birkenfeld et al., 2015; Coil et al., 2020; Crezzini et al., 2016; de la Torre et al., 2021; Discamps et al., 2019; Domínguez-Rodrigo and Cobo-Sánchez, 2017; Eixea et al., 2020; Gabucio et al., 2023; García-Moreno et al., 2016; Giusti et al., 2016, 2018; Marciani et al., 2020; Marín et al., 2019; Moncel et al., 2023; Moreau et al., 2021; Panera et al., 2019; Peters and van Kolfschoten, 2020; Rabuñal et al., 2023; Sánchez-Romero et al., 2020, 2022, 2023; Spagnolo et al., 2019, 2020a, 2020b, 2020c; Walker et al., 2022; Zilio et al., 2021).

4. Results

4.1. Chronology of the deposit

The U-series results of the Q-ICP-MS analyses are displayed in Table 1.

For GG1901, U content varies from a factor 2 suggesting a kind of heterogeneity of the speleothem which could correspond to different calcitic growth steps, as the first analysis (GG1901) corresponds to the top of the stalagmitic floor and the second (GG1901*) to a larger mixed powder taken from the entire thickness of the speleothem. Isotopic ratios are close taking into account the error range. The age ranges between 131 and 156 ka suggesting a contemporaneity with MIS 6 or the beginning of MIS 5.

The GG1902 mollusc shell sample exhibits a rather high uranium content with a possible posterior uranium uptake meaning an opening of the system versus uranium. The obtained age of 110 ka should be considered as a minimum age.

For both samples, the ^{230}Th/^{232}Th ratio is high indicating that the samples are clean and that no exogen ^{232}Th has polluted the samples. Hence, no correction of the age is necessary here.

Full analytical data for major element composition of the glass from Layer 1 (L1) are provided in Table 2. Glass shards from L1 tephra are quite homogenous and mainly trachytic in composition, with a mean silica and alkali sum content of 62.09 ± 0.84 wt% and 13.33 ± 0.38 wt %, respectively. This is a common composition of the pyroclastic products from the Neapolitan volcanoes, particularly from the Campi Flegrei and Ischia (e.g., Branca et al., 2023). However, due to the relatively high CaO/FeO ratio, comprises between 0.5 and 0.7, and Cl content (0.35–1.10 wt%), the tephra L1 can be ascribed to the Campi Flegrei (Giaccio et al., 2017).

4.2. Taxonomy and taphonomy of faunal remains

A total amount of 740 specimens (NR) was analysed (Table S2). As some elements were fragmented *ab antiquo*, and then scattered throughout the excavated area, the NR and NISP can differ for some taxa. As an example, two fragments of a bear skull, found in two different squares refit. Thus, considering interdependency in counting NISP, the bear is represented by a NR of two and a NISP of one. The specimens have been considered as separate units in conducting spatial analysis. Faunal composition is in agreement with previous identifications (Ronchitelli et al., 2011) which were published just at a taxonomic level. The macrofaunal assemblage from Layer 8 is dominated by the fallow deer (*Dama dama*). Other cervids as *Capreolus capreolus* and *Cervus elaphus* are represented with lower percentages. The ibex (*Capra ibex*) is the second most represented taxon. Five remains related to hippo (*Hippopotamus amphibius*) and one related to the brown bear (*Ursus arctos*) were also identified (Table S2; Fig. 4, S1-S3). In addition to bone remains, a coprolite was retrieved from layer 8 (Fig. 5i). Its shape is globular, with a diameter of 3.5 cm and resembles that of a spotted hyaena (*Crocuta crocuta*) scat (Diedrich, 2012).

Despite the small size of NISP sample, distribution of body parts evidences a dominant presence of cranial elements and long bones, while carpal and tarsal bones are absent. The acropodium is also poorly represented. Hippo is represented by a proximal femur, a fragmented canine, a sacral vertebra and by a series of cervical vertebrae belonging to the same individual (Tables 3 and 4). The most represented anatomic portion in red deer, fallow deer, ibex, and brown bear is the skull. If MNI is calculated only considering post-cranial elements, values drop from 4 to 2 in the case of fallow deer, from 3 to 1 in the case of ibex and red deer, and to zero in the case of brown bear. The high number of potential individuals represented by head elements is due, in the case of ungulates, to the presence of calvaria. They all belong to male individuals, and all fallow and red deer specimens bear antlers. Three fallow deer and two ibex specimens show a large portion of the frontal bone (left and right side) with cornual processes or horncores. The latter, as well as the antlers, are not well preserved. One fallow deer and four red deer specimens consist in half of the frontal bone (right or left) with the cornual process and the antler's base. Finally, the third ibex skull is represented by a basal fragment of a horncore. The brown bear is represented by two maxillary fragments that refit (Fig. 4, S1-S3).

The fragmentation of the bone sample is high. The most common size-classes are 1–3 cm (n = 502; 67.8%) and 3–6 cm (n = 172; 23.2%). However, remains in the size-class 6–10 cm (n = 39; 5.3%) and larger than 10 cm (n = 27; 3.7%) are also present. The mean FFI value of the sample (n = 30) is 1.06, suggesting a fresh-bone breakage (Outram, 2002) as the main phenomenon for explaining the fragmentation of specimens (FFI 0 = 13; FFI 1 = 6; FFI 2 = 8; FFI 3 = 2; FFI 4 = 1; FFI 5 = 0; FFI 6 = 0). Among girdles, stylopodium and zeugopodium, complete or almost complete specimens are represented by only two scapulae (one fallow deer and one ibex). Only one cylinder was found among diaphyseal fragments. It is a cut-marked fallow deer metatarsal showing green-bone fractures at the extremities. No gnawing marks are present on this specimen. The analysis of bone surface modifications was prevented by calcite crusts on the 23% of specimens. As for the remaining sample, only 25 specimens are characterised by the presence of exfoliation (flaking) on the surface. A high number of specimens are burnt (n = 261). They count for the 35% of the total sample. Most of them are charred (combustion level 2 = 179; 68.6%) or heated (combustion level 1 = 75; 28.7%), while the calcined fragments are rare (combustion level

Table 1
U and Th content, isotopic ratios and age of the Grotta Grande carbonate samples (stalagmitic floor GG1901 and *Persististrombus* shell fragment GG1902). Uncertainties are given with 95% of confidence (k = 2).

sample	nature	m (g)	^{238}U (ppb)	^{232}Th (ppb)	^{234}U/^{238}U	^{230}Th/^{234}U	^{230}Th/^{238}U	^{230}Th/^{232}Th	Age (ka)
GG1901	speleothem	0.8218	187.208 ±3.871	0.570 ±0.012	1.091 ±0.023	0.729 ±0.015	0.795 ±0.016	797.431 ±8.351	138 ±7
GG1901*	speleothem	0.1557	403.898 ±4.515	1.044 ±0.013	1.060 ±0.012	0.759 ±0.009	0.804 ±0.009	950.757 ±5.416	152 ±4
GG1902	mollusc shell	0.5427	4669.263 ±114.534	2.862 ±0.059	1.054 ±0.024	0.639 ±0.014	0.674 ±0.015	3358.441 ±35.285	110 ±5

Table 2
Individual and mean major element compositions of the glass from the tephra Layer 1.

N.	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P2O5	F	Cl	SO3	Total	K_2O/Na_2O	CaO/FeO	$K_2O + Na_2O$
1	61,83	0,41	18,56	2,97	0,16	0,48	1,82	5,52	8,12	0,13	0,39	0,61	0,08	97,08	1,47	0,61	13,64
2	62,09	0,45	18,21	3,33	0,37	0,30	1,74	6,72	6,74	0,06	0,39	1,09	0,03	97,61	1,00	0,52	13,45
3	62,80	0,50	18,07	3,21	0,37	0,31	1,67	6,71	6,30	0,05	0,42	1,06	0,08	96,66	0,94	0,52	13,01
4	59,92	0,46	18,73	3,68	0,15	0,91	2,48	4,33	9,12	0,23	0,14	0,35	0,04	98,29	2,11	0,67	13,45
5	60,61	0,44	18,68	3,47	0,15	0,79	1,83	5,13	8,72	0,19	0,28	0,34	0,03	98,97	1,70	0,53	13,84
6	60,98	0,51	18,49	3,39	0,19	0,71	2,27	4,44	8,86	0,16	0,15	0,37	0,00	96,07	1,99	0,67	13,31
7	63,37	0,46	18,35	2,79	0,12	0,56	1,83	4,88	7,52	0,11	0,18	0,53	0,10	94,90	1,54	0,66	12,40
8	62,75	0,43	18,16	3,11	0,30	0,27	1,69	6,84	6,43	0,01	0,60	0,95	0,06	97,01	0,94	0,54	13,27
9	62,76	0,44	18,11	3,22	0,28	0,30	1,78	6,40	6,71	0,00	0,66	1,04	0,05	96,76	1,05	0,55	13,12
10	61,13	0,46	18,57	3,50	0,14	0,73	2,21	4,84	8,26	0,16	0,30	0,45	0,06	98,60	1,71	0,63	13,10
11	63,08	0,47	18,05	3,32	0,38	0,30	1,78	6,08	6,52	0,04	0,64	1,01	0,04	95,57	1,07	0,54	12,59
12	62,34	0,38	18,50	2,78	0,26	0,46	1,85	5,39	7,92	0,12	0,25	0,63	0,00	97,30	1,47	0,66	13,31
13	61,94	0,50	18,23	3,39	0,32	0,30	1,72	7,07	6,48	0,05	0,71	0,89	0,04	99,14	0,92	0,51	13,55
14	62,14	0,53	17,93	3,30	0,26	0,27	1,61	7,25	6,64	0,07	0,85	0,85	0,03	99,80	0,92	0,49	13,88
15	62,19	0,42	19,09	2,64	0,25	0,30	1,68	6,94	6,46	0,03	0,29	0,98	0,02	97,32	0,93	0,64	13,40
16	62,46	0,47	18,02	2,97	0,40	0,30	1,69	6,79	6,86	0,02	0,50	1,04	0,06	100,26	1,01	0,57	13,65
17	62,85	0,52	17,95	3,17	0,41	0,28	1,67	6,69	6,37	0,08	0,48	1,06	0,06	96,51	0,95	0,53	13,06
18	62,12	0,47	18,25	3,24	0,30	0,35	1,73	7,17	6,32	0,04	0,61	0,99	0,01	98,18	0,88	0,54	13,50
19	62,56	0,45	18,02	3,09	0,32	0,33	1,69	7,14	6,34	0,07	0,63	1,04	0,05	99,11	0,89	0,55	13,48
20	61,85	0,48	18,25	3,22	0,34	0,31	1,68	7,29	6,57	0,00	0,51	1,02	0,03	97,67	0,90	0,52	13,86
21	62,10	0,40	18,43	3,07	0,20	0,59	2,02	4,81	8,29	0,09	0,36	0,49	0,01	95,20	1,73	0,66	13,10
Mean	**62,09**	**0,46**	**18,32**	**3,18**	**0,27**	**0,44**	**1,83**	**6,11**	**7,22**	**0,08**	**0,44**	**0,80**	**0,04**	**97.52**	**1,24**	**0,58**	**13,33**
sd	*0,84*	*0,04*	*0,30*	*0,25*	*0,09*	*0,20*	*0,23*	*1,03*	*0,97*	*0,06*	*0,20*	*0,28*	*0,03*	*1.47*	*0,41*	*0,06*	*0,38*

Table 3
NISP by skeletal elements and species: *B/B* = *Bos/Bison*; *Ci* = *Capra ibex*; Cap = *Caprinae*; *Cc* = *Capreolus capreolus*; *Dd* = *Dama dama*; *Ce* = *Cervus elaphus*; Cer = *Cervidae*; *Ha* = *Hippopotamus amphibius*; *Ua* = *Ursus arctos*.

NISP	B/B	Ci	Cap	Cc	Dd	Ce	*Cer*	Ha	Ua	TOT
Antler							2			**2**
Skull		3			9	4	1		1	**18**
Mandible		3			2					**5**
Teeth		2			3	2	1	1		**9**
Vertebra								3		**3**
Rib					1					**1**
Scapula		1			1					**2**
Humerus	1				2	1				**4**
Radius				1	3	1				**5**
Radius-Ulna					1					**1**
Metacarpal					1					**1**
Innominate					1					**1**
Femur					2			1		**3**
Tibia					2	1				**3**
Metatarsal		1			1					**2**
Phalanx		3	1		2					**6**
TOT	**1**	**13**	**1**	**1**	**31**	**9**	**4**	**5**	**1**	**66**

3 = 7; 2.7%) (Fig. 5a and e).

Cut marks were recorded on 31 remains (4.3 % of the sample, isolated teeth excluded). Notches are rare (n = 5) and all but one (incomplete) were measured following Capaldo and Blumenshine (1994) (Tables 5 and 6). Considering ratio between breadth and depth of the notch and of the flaking surface, these modifications can be classified as anthropogenic rather than as produced by carnivores (following Fig. 5 in De Juana and Domínguez-Rodrigo, 2011). In addition, one notch is

Table 4
MNE by skeletal elements and species: *B/B* = *Bos/Bison*; *Ci* = *Capra ibex*; *Cc* = *Capreolus capreolus*; *Dd* = *Dama dama*; *Ce* = *Cervus elaphus*; *Ha* = *Hippopotamus amphibius*; *Ua* = *Ursus arctos*.

MNE	B/B	Ci	Cc	Dd	Ce	Ha	Ua	TOT
Skull		3		4	3	1	1	**12**
Mandible		2		2				**4**
Vertebra						3		**3**
Rib				1				**1**
Scapula		1		1				**2**
Humerus	1			2	1			**4**
Radius			1	1	1			**3**
Radius-Ulna				1				**1**
Metacarpal				1				**1**
Innominate				1				**1**
Femur				2		1		**3**
Tibia				1	1			**2**
Metatarsal		1		1				**2**
Phalanx		2		2				**4**
TOT	**1**	**9**	**1**	**20**	**6**	**5**	**1**	**43**

Table 5
Measures of four notches found on four specimens, following Capaldo and Blumenshine (1994).

	Notches		Flake scar		Notch	Scar
	Breadth	Depth	Breadth	Depth	B/D	B/D
Unidentified mammal size 3 diaphysis	6.4	1.7	10.8	2.6	3.8	4.2
Unidentified mammal size 2 diaphysis	13.4	3.2	21	4.3	4.2	4.9
Unidentified mammal size 3 diaphysis	15.6	3	22	4.6	5.2	4.8
Red deer humerus	13.6	4.6	10	1.6	3.0	6.3

Table 6
Distribution of human and carnivore activity evidence by species and anatomic district. Percentages are related to the number of specimens per each taxonomic category (NISP for identified sample and NR for unidentified one).

Species	Element	Cut Marks	Notch + Cut marks	Notch	Cone	Digestion	Scores + pits
Bos/Bison	Humerus	1 (100%)					
Capra ibex	Scapula	1 (9%)					
	Phalanx	2 (18%)					
Capreolus capreolus	Radius	1 (100%)					
Cervus elaphus	Humerus		1 (14%)				
Dama dama	Skull	1 (3.6%)					
	Humerus						1 (3.6%)
	Radius						1 (3.6%)
	Metacarpal			1 (3.6%)			
	Innominate	1 (3.6%)					
	Femur	2 (6.4%)					
	Metatarsal	1 (3.6%)					
	Phalanx					1 (3.6%)	
Ursus arctos	Skull	1 (100%)					
Mammal size 3	Diaphysis	6 (4.4%)		2 (1.5%)	2 (1.5%)		1 (0.7%)
	Vertebra	2 (1.5%)					
	Rib						1 (0.7%)
Mammal size 2	Vertebra	1 (2.6%)					
	Rib	1 (2.6%)					
	Phalanx					1 (2.6%)	
	Diaphysis	3 (7.9%)		1 (2.6%)			1 (2.6%)
Unidentified	Compactbone	5 (1%)			1 (0.2%)		1 (0.2%)
	Diaphysis	1 (0.2%)					1 (0.2%)
TOT		30 (4.1%)	1 (0.1%)	4 (0.5%)	3 (0.4%)	2 (0.3%)	7 (1%)

associated with cut marks, whilst the other four are not associated with any other type of bone surface modification. Cut marks are present on all taxa but the hippo, and are often located on meat bearing portions, such as scapula, humerus and femur, suggesting a primary access to carcasses by humans (Fig. 5a and b). In addition, some marks on the ventral side of a small ungulate rib may testify evisceration. Small striations on a bear maxillary fragment and on a fallow deer skull indicate skinning (Table 6; Fig. 4).

Regarding carnivorous action, few remains (n = 9, 1.2% of the postcranial sample) bear signs of chewing and digestion (Fig. 5e–h). Gnawing evidence is mainly located on diaphyseal or on cortical bone fragments and these marks were never found on epiphyses (Table 4). Size of pits (breadth and length), as well as the less diagnostic breadth of scores are compatible with the action of a wide range of carnivores, among which also the *Crocuta crocuta* (Table S3). Two phalanges (one belongs to the fallow deer and one referable to a small ungulate) are digested (Fig. 5g and h). This behaviour is compatible with spotted hyaena, but also with other carnivores, such as canids.

All post-cranial-based individuals but the hippo are potentially cut-marked, whilst the Minimum Number of Individuals gnawed by carnivores is represented by one fallow deer (Table 7) and possibly by a medium ungulate. Among taxonomically identified remains, epiphyses are only represented by seven specimens: two proximal first phalanges, one distal first phalanx, two distal radii and two distal tibiae; none of them bear toothmarks, whilst one phalanx is cut-marked, and four (the phalanx, two radii and one tibia) were heated.

The unidentified sample (674 remains) mainly consists in compact bone fragments (75%, diaphysis included). Spongy fragments count for the 17% of the sample and are mostly grouped in the 1–3 cm size class. Axial and head remains are scarce (Table 8).

4.3. Technological data from lithic assemblage

The lithics from this level is represented by a very small sample (102 items). Significantly, the distribution by dimensional classes highlights a dominant presence of large pieces to the detriment of the element smaller than 100 mm^2 (DC 1 = 4; DC 2 = 9; DC 3 = 4; DC 4 = 15; DC 5 = 70).

From a technological point of view, the study is currently undergoing for a specifically dedicated work. However, some preliminary data can be returned. In general, two main technical components are recognizable in the lithic sample: the production of flakes (*débitage*) and the shaping of heavy-duty tools (*façonnage*) (Table 9; Fig. S4). As far as the *débitage* is concerned, a main *chaîne opératoire* of additional type is recognizable. It is characterized by the exploitation of a sub-volume of the core, starting from pebbles or blocks. The cores have a main striking platform orthogonal to the débitage surface and an opposite second striking platform to control the distal convexities. Possible lateral striking platforms, for a better control of the lateral convexities, can also be present. The main technique is direct percussion with hard hammerstone, however, rare stigmata of bipolar percussion on anvil are documented. The objective flakes are mostly small-sized (about 20–40 mm length), backed and elongated, usually with cortical backs opposite to the unmodified cutting edge (with angles of 25°–30°). The cutting edges of some flakes are modified by retouch, purposing rectilinear or zig-zag delineations. Beside the additional reduction sequence, some sporadic elements indicate the presence of a Levallois-like reduction sequence (as an ended radiolarite core). Despite the smallness of the sample, the same *chaîne opératoires* are clearly advised in the near site of Molare Rock shelter (Aureli and Ronchitelli, 2018; Spagnolo et al., 2020b). Concerning the *façonnage*, its relevant proportion on the total of lithics is significant. The techno-functional characteristics of this sample (under study) allow the identification of an important variety of tools, including different kind of "*rostra*", and rectilinear and concave cutting edge. These tools take advantage of the mass of large limestone pebbles used in their shaping. This physical characteristic was selectively chosen during the acquisition of the pebbles, aimed to the functional objective. Overall, the technical and physical features of the *façonnage* component suggest its use in thrown percussion, for activities aimed to the crushing or very incisive cutting.

4.4. Traceological data

At the microscopic observation, the lithic surface appears well preserved and unaffected by intense post-depositional alterations. Use related traces, such as edge rounding, edge scarring and polishing, were identified on n = 8 items. These traces can be attributed to processing carcasses (n = 4) as well as to cutting soft tissues (n = 2) and hard materials (n = 2).

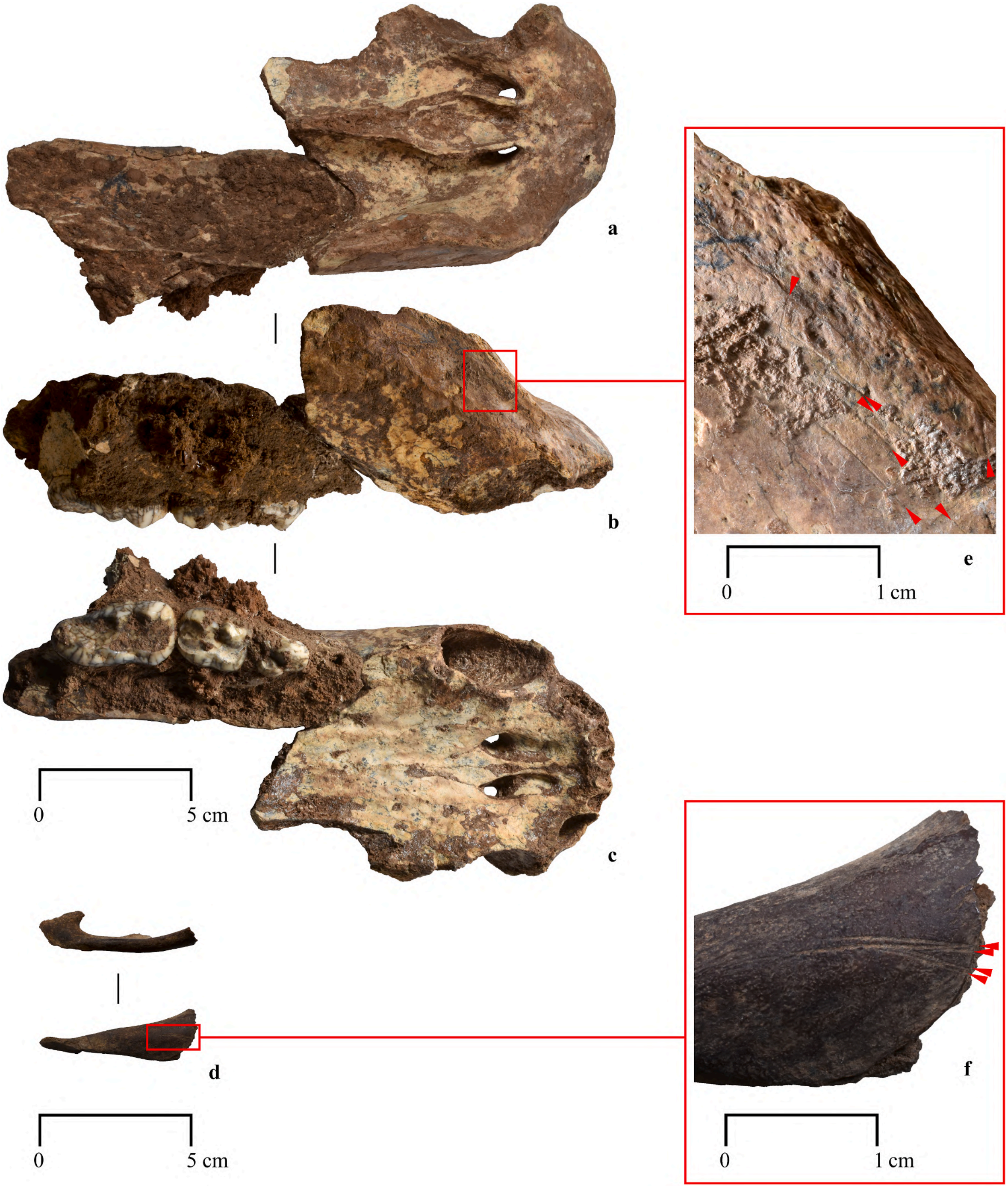

Fig. 4. Photos of the *Ursus arctos* skull (specimens IDs 53 and 92) recovered in the niche (showing the connexion between the two fragments): a) upper view; b) right view; lower view; e) magnification of the premaxillary bone with the main cutmarks. Photos of the *Dama dama* maxillary bone (specimen ID 63): d) upper and left views; f) magnification bone with the cutmarks (pictures of V. Spagnolo).

4.5. Statistical results and spatial pattens

The Ripley's K Function returned clustered patterns for almost all investigated categories of findings. Only some poorly represented categories (as the axial and foot skeletal parts, the pebbles and the heavy-duty tools) entirely fall into the confidence envelope, with random patterns. Statistically significant clustering values tend to occur within relatively short distance ranges, typically less than 0.5 m (in any case within 0.8 m) (Figs. S5–S7). Interestingly, a decrement of clustering rate is clearly evident incrementing the dimensional classes of faunal remains (Figs. S5a–d). Remains with a low combustion level appear relatively more clustered than the charred/calcined ones (Figs. S5g–h).

Both the Spatial Autocorrelation (Global Moran's I) and Getis-Ord General tests were performed on the categories with clustered patterns according to the Ripley's K Function (with the addition of the heavy-duty tools, given their behavioural importance). The results of Global Moran's I suggest significant clustered patterns (p-values ≤ 0.05) for all categories of findings, with exception of head skeletal parts (including the large skull elements), lithic cores and heavy-duty tools, whose patterns do not appear significantly different than the random. With z-scores higher than 2.58, the likelihood of clustered patterns is higher than 99% for almost all remaining categories. Given the z-score of faunal

Fig. 5. Photos of representative taphonomic evidence. a) ID 61 (phalanx of *Capra ibex* with cutmarks and evidence of fire exposition); b) ID 28 (femur of *Dama dama* with cutmarks); c) ID 14 (diaphysis of middle ungulate with chopping mark); d) ID 40 (cortical bone, cone); e) ID 25 (radius of *Dama dama* exhibiting evidence of both fire exposition and toothmarks); f) ID 15 (rib of middle ungulate with toothmarks); g) ID 42 (digested phalanx of *Dama dama*); h) ID 43 (digested phalanx of small ungulate); i) coprolite pellets (pictures: V. Spagnolo).

Table 7
Distribution of human and carnivore activity evidence on the MNI of identified taxa.

Taxon	MNI Total	MNI skull	MNI post-cranial	MNI cutmarked	MNI Gnawed
Bos/Bison	1	0	1	1	0
Capra ibex	3	3	1	1	0
Capreolus capreolus	1	0	1	1	0
Cervus elaphus	3	3	1	1	0
Dama dama	4	4	2	2	1
Hippopotamus amphibius	1	0	1	0	0
Ursus arctos	1	1	0	1	0

remains with concretions (1.80484927902), the likelihood that the clustered patterns could be the result of random chance is less than 10% (Table 10a). These results are substantially confirmed by Getis-Ord General G, which detects as random the patterns of large skull elements, lithic cores and heavy-duty tools. Given the z-scores, the likelihood that observed high-clustered pattern could be the result of random chance are less than 1% for all analysed categories of findings, with exception of head skeletal parts (less than 10%), and notches-cones (less than 5%) (Table 10b).

The hot spot maps highlight the importance of the outer part of excavated area for almost all investigated categories (Figs. S8–S10). Only the concreted faunal remains, the large skull remains and the heavy-duty tools appear spatially related to the inner part and, in particular, to the stone alignments (Fig. S8b, S10d-e). Despite the relatively low resolution of these maps, small spatial differences are detectable among the main categories, based on the hot spot dimensions of clusters (usually 1–1.5 m wide), the involved squares (behind a relative overlapping rate some specificities are recognizable) and the kind of pattern (unimodal or bimodal) (Figs. S8–S10).

More details arise from the analysis of the plot maps. The faunal remains show different patterns in the inner and in the outer part of excavated area respectively. The outer part is characterized by a denser zone (Z15/III-IV, V15/I-II) with elements from 1 up to 10 cm large, bordered by a kind of “halo” with a lower density of findings. In the inner part of excavated area, the remains exhibit a kind of peripheral pattern (overlapped to the “ring” of the stones), leaving a null/low-density core in the central area spared by stones. Remarkably, this general pattern seems to be perfectly resumed by remains of 6–10 cm. Other interesting observations concern the largest elements, mainly located into the inner part of excavated area, in correspondence of the stones (Fig. 6).

Regarding the anatomical categories, the few elements related to the axial and the foot skeleton are sparsely and randomly distributed. At the contrary, both head and leg elements (zygopodium and stylopodium) are clustered (Fig. 7a–d). In particular, the number of head elements in the inner and outer part of excavated area is approximately similar, nevertheless, the inner part is dominated by skulls and mandibles (note the exclusively inner location of the ungulate large calvaria with horn-core/antler and the bear skull elements), the outer part is dominated by isolated teeth and small fragments of skull (Fig. 7a). The leg elements are highly clustered in the outer part of excavated area, without evidence of spatial co-varying by hind/fore or proximal/distal elements (Fig. 7c).

Among the cervidae, *Cervus elaphus* and *Dama dama* are the most represented. The head elements of red deer are almost exclusively in the inner part of excavated area, the legs in the outer part. The fallow deer is mainly clustered in the outer part (Fig. 7e). The remains of caprinae (mainly represented by *Capra ibex*) are primarily represented by head elements, located in the inner part (Fig. 7f).

The pattern of small ungulates seems to be strongly influenced by the spatial dichotomy of the niche: the outer area exhibits a cluster of appendicular elements with some small fragments of skull/isolated

Table 8
Distribution of skeletal elements by size classes of remains and mammals.

Size	1–3 cm			3–6 cm				6–10 cm				>10 cm			TOT
Skeletal elements	Mammal size 2	Mammal size 3	Unidentified	Mammal size 2	Mammalsize3	Mammalsize4	Unidentified	Mammalsize2	Mammalsize3	Mammalsize4	Unidentified	Mammalsize2	Mammalsize3	Mammalsize4	
Skull			2	1			5				1				**9**
Mandible											1				**1**
Teeth			4				1								**5**
Cervical vertebra				1	1										**2**
Lumbar vertebra					2				1						**3**
Thoracic vertebra				1											**1**
Vertebra	1		4	1	2			1							**9**
Rib	2			1	1			1	2			1	1		**9**
Humerus (diaphysis)				1											**1**
Diaphysis	3	23	4	17	65		9	2	13				4		**140**
Phalanx	1														**1**
Epiphysis	1		3		1	1				1					**7**
Compact bone		11	318		4		30	1	1		2			1	**368**
Flat bone			3	1	1										**5**
Spongy bone			101				9								**110**
Indet.			1		1		1								**3**
TOT	**8**	**34**	**440**	**24**	**78**	**1**	**55**	**5**	**17**	**1**	**4**	**1**	**5**	**1**	**674**

Table 9
Distribution of lithic implements by technological macro-categories and lithotype.

	Chert	Radiolarite	Siliceous limestone	Quartz	Quartzarenite	Limestone	Tot
Façonnage							
Heavy-duty tool						11	**11**
Débitage							
Core	2	1			1	3	**7**
Production waste	9	3	1		3	18	**34**
Objective flakes (no use-wear)	2	1				3	**6**
Tool?	4				2	1	**7**
Tool	7	6			1		**14**
Other							
Natural item?				1		18	**19**
Pebble (hammer stone?)						4	**4**
Tot	**24**	**11**	**1**	**1**	**7**	**58**	**102**

Table 10
Results of the a) Spatial Autocorrelation (Global Moran's I) and b) Getis-Ord General test.

Global Moran's I Summary (a)	Moran's Index	Expected Index	Variance	z-score	p-value
Head	0.004755	−0.018182	0.004959	0.325712	0.744642
Leg	0.576802	−0.018182	0.004537	8.833673	0
Large skulls	−0.044675	−0.018182	0.00361	−0.440937	0.659259
No burnt	0.529134	−0.018182	0.004612	8.059016	0
Low combustion	0.233229	−0.018182	0.003427	4.294915	0.000017
High combustion	0.263308	−0.018182	0.004718	4.097907	0.000042
Cortical bone	0.571851	−0.018182	0.004555	8.742434	0
Spongy bone	0.267901	−0.018182	0.004791	4.132914	0.000036
Cutmarks	0.497198	−0.018182	0.004909	7.355577	0
Notches-cones	0.134961	−0.018182	0.003479	2.59626	0.009424
Cores	−0.077526	−0.018182	0.003217	−1.046278	0.295433
Production waste	0.152521	−0.018182	0.003893	2.735984	0.006219
Debitage tools	0.269989	−0.018182	0.004363	4.362722	0.000013
Faconnage tools	−0.007537	−0.018182	0.004686	0.155505	0.876423
Carnivore	0.27734	−0.018182	0.004275	4.519906	0.000006
Exfoliation	0.236871	−0.018182	0.004161	3.954123	0.000077
Concretion	0.103839	−0.018182	0.004571	1.804849	0.071098
General G Summary (b)	**Observed General G**	**Expected General G**	**Variance**	**z-score**	**p-value**
Head	0.156686	0.108442	0.000613	1.949196	0.051272
Leg	0.396324	0.108442	0.001156	8.466178	0
Large skulls	0.155556	0.108442	0.014083	0.397015	0.691357
No burnt	0.296434	0.108442	0.000532	8.152507	0
Low combustion	0.451654	0.108442	0.005614	4.580584	0.000005
High combustion	0.251456	0.108442	0.001278	4.001122	0.000063
Cortical bone	0.332627	0.108442	0.000709	8.418563	0
Spongy bone	0.217343	0.108442	0.000558	4.610138	0.000004
Cutmarks	0.374429	0.108442	0.00138	7.159953	0
Notches-cones	0.375	0.108442	0.012712	2.364226	0.018068
Cores	0	0.108442	0.020679	−0.754112	0.450782
Production waste	0.264402	0.108442	0.001857	3.619274	0.000295
Debitage tools	0.450495	0.108442	0.005497	4.613579	0.000004
Faconnage tools	0.150943	0.108442	0.00294	0.783816	0.433148
Carnivore	0.5	0.108442	0.007381	4.557601	0.000005
Exfoliation	0.354839	0.108442	0.003448	4.195946	0.000027
Concretion	0.189189	0.108442	0.000474	3.710113	0.000207

teeth; in the inner area the remains (with a significant component of large head elements and some axial and foot elements) are located along the borders with the stones. The middle ungulates follow a similar spatial structure, with the baulk of remains (mainly leg elements) clustered in the outer part of the excavated area and some remains scattered in the peripheral area of the inner part. The agglomeration of large skull fragments of red deer in the NE sector of the inner part is significant. Finally, the remain pertaining to large ungulated and to the *Ursus arctos* are exclusively placed into the inner part of the excavated area. Interestingly, the presence of a hippo canine in the NE sector of the inner part (close to the red deer skull clusters) appear also significant (Fig. S11).

Other details become from the taphonomic data. The unburnt faunal remains do not significantly differ from the general pattern of faunal remains (also taking into account the dimensional classes of findings). The pattern of burnt faunal remains is strongly characterized (also taking into account the combustion levels). Indeed, the elements with a low combustion level are mainly clustered in the squares V15/I and Z15/III, while, the remains with a higher combustion level (e.g., charred and calcined), are present into two separated clusters, respectively, in V17/II – Z17/III-IV (under the vertical feature of layer 7) and in V15/II – Z15/III-IV (in the outer area) (Fig. 8a–d). Significantly, these latter clusters overlap to the charcoal patches identified during the excavation (Fig. 3d and e). Cortical and spongy bones share evidence of exposition to the fire, with similar proportions (about 60% unburnt, about 10% heated and about 30% charred/calcined). Nevertheless, the dichotomy between these bone categories is well-expressed by their spatial arrangement. The cortical bones are concentrated mostly in the outer part of the study area, with a minor presence in the inner part (in correspondence of the stones), closely resembling the general distribution of faunal remains. The pattern of the spongy bones, instead, has strong

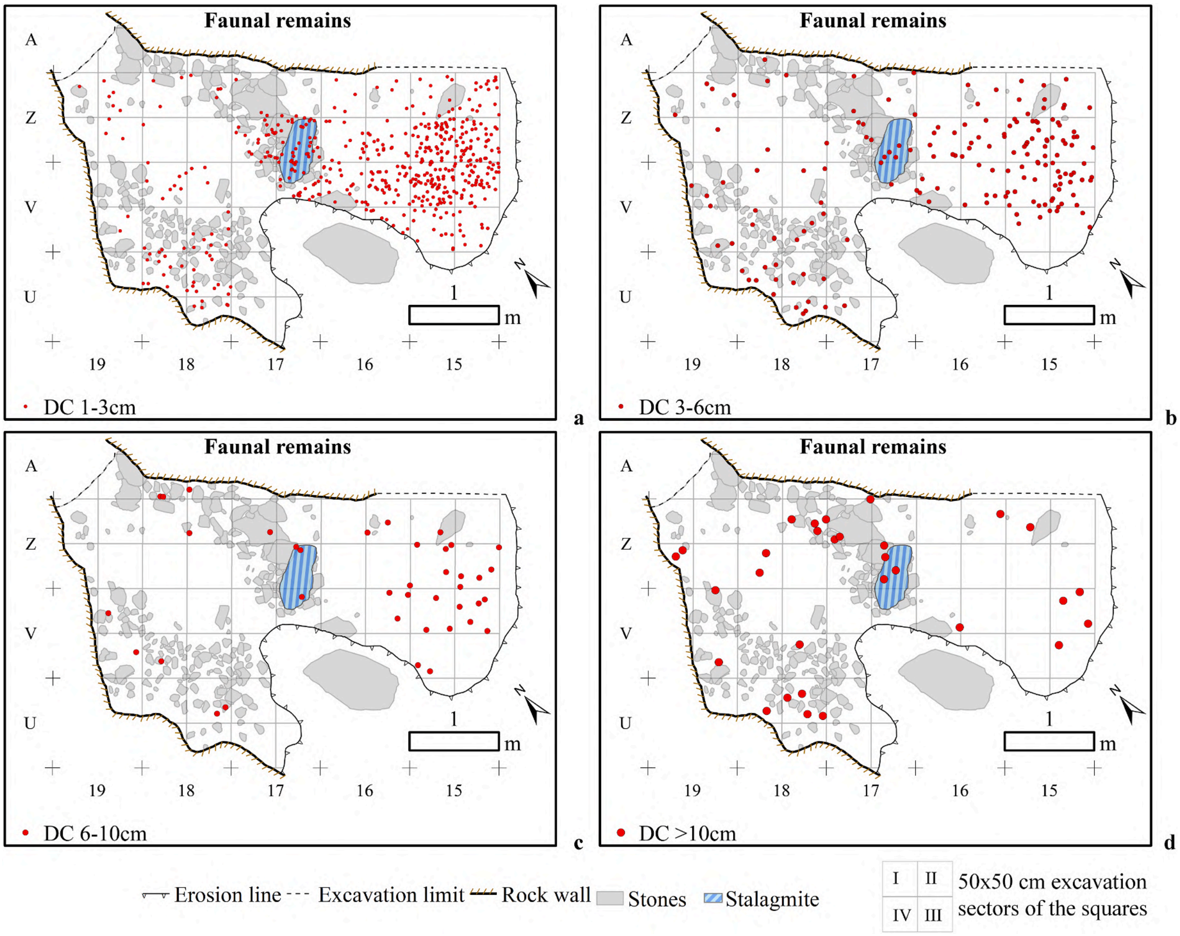

Fig. 6. Plot maps of a) faunal remains (1–3 cm); b) faunal remains (3–6 cm); c) faunal remains (6–10 cm); d) faunal remains (>10 cm). Here and in the following maps, the position of the 50 × 50 cm sectors of each square is reported in the legend.

affinities with the one of charred/calcined bones, with two spatially well-defined concentrations, in V16/I – Z17/III-IV and in V15/II – Z15/III-IV respectively (Fig. 8e and f). Faunal remains with butchering traces (cutmarks, notches and cones) are mostly clustered in a very small area, between the squares V15-Z15 (Fig. 9a and b). On the same area stay the remains with evidence of exfoliation and the gnawed bones (Fig. 9d and e). Nevertheless, the spatial visibility of these patterns could be partially biased (in particular in the inner part) by the presence of concretion covering some bones (Fig. 9c).

The lithic tools are strongly characterized on the spatial perspective, with the *façonnage* component in the inner part of the study-area (in correspondence with the stones) and the *débitage* component in the outer part, in two small clusters (Fig. 9f). The cluster in the squares V15/II – Z15/III-IV is characterized by a significant presence of retouched items (with a concentration of retouched tools in the NE half of the area and a concentration of flakes with traces in the SW half of this area). The cluster in square Z16/III-IV exhibits a prevalent presence of flakes with traces on the retouched tools (Fig.. 9f and 10a). The results of traceological analysis are not sufficient to make spatially valid generalizations, nevertheless, a relative mixing of different activities seems to be mirrored by available data (Fig. 10b). Among the *débitage* products and cores, the production waste is clustered into two areas, respectively focused around the squares Z16/IV and V15/I. The cores seem to gravitate around the waste clusters (but not overlapping them) (Fig. 10a).

The Ward's cluster analysis returned significant results. The goodness of the dendrogram is confirmed by the high cophenetic correlation (0.8536). The most suitable threshold to cut the dendrogram (best balancing the number of clusters and their quantitative/qualitative differences) appears to be the distance level 30, which returns 6 clusters (Fig. 11a). These clusters display a significant spatial contiguity further reinforcing the overall quality of the analysis (Fig. 11b).

5. Discussion

5.1. Chronology and climatostratigraphic setting

The results from U-series dating of the stalagmite sealing the first marine-terrestrial sedimentary cycle of infilling at 152 ± 4 ka and 138 ± 7 ka (samples GG1901* and GG1901 respectively, Fig. 2a and b), provide a terminus *post quem* for the second infilling cycle, i.e., the unit D in the Trench A and the succession exposed in Trench F. The U-series dating of the fragment of *Persististrombus latus* (sample GG1902) from the Trench F Layer 10 (Fig. 2c and d), yielding an age of 110 ± 5 ka, is instead a direct age constraint for the deposits laying immediately below Layer 10, from which the shell of *Persististrombus latus* derived. These new chronometric indications are in in good agreement with the previous finding of marine gastropods belonging to the typical warm faunal assemblage of the Mediterranean "Tyrrhenian", the regional synonym of Last Interglacial (LIG), in the Layers 14-10 (Ronchitelli et al., 2011), thus allowing the second marine cycle to be reliably ascribed to the LIG (~129-116 ka, e.g., Muhs et al., 2015), roughly matching the MIS 5e (Govin et al., 2015). Therefore, the lower chronological boundary of the terrestrial deposits in Trench F should be younger than the end of the LIG sea level highstand, i.e., younger than ~116 ka.

The upper chronological boundary can be instead constrained by the

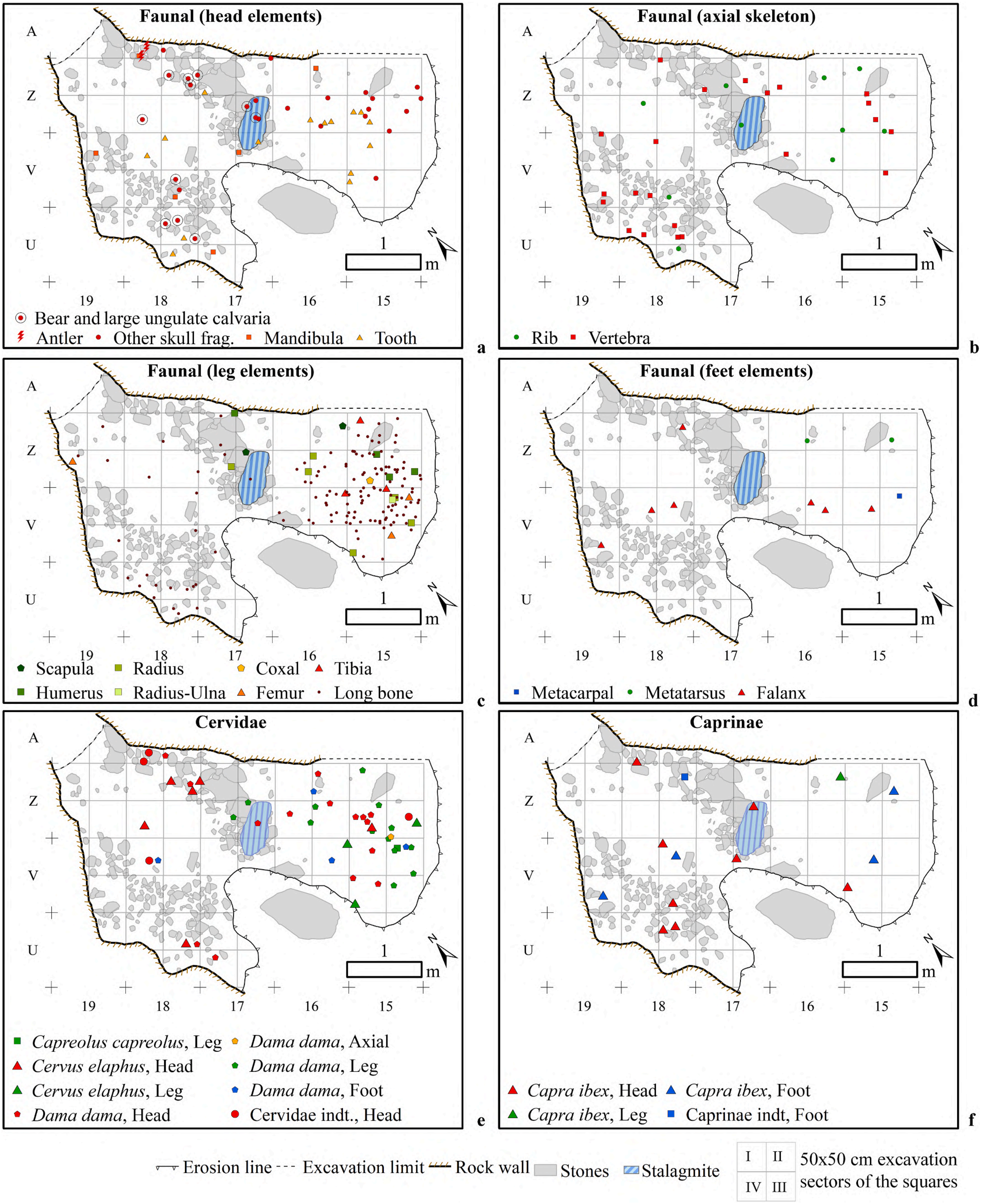

Fig. 7. Plot maps of a) faunal remains (head elements); b) faunal remains (axial skeleton elements); c) faunal remains (fore/hind leg elements); d) faunal remains (feet elements); e) faunal remains (cervidae); f) faunal remains (caprinae).

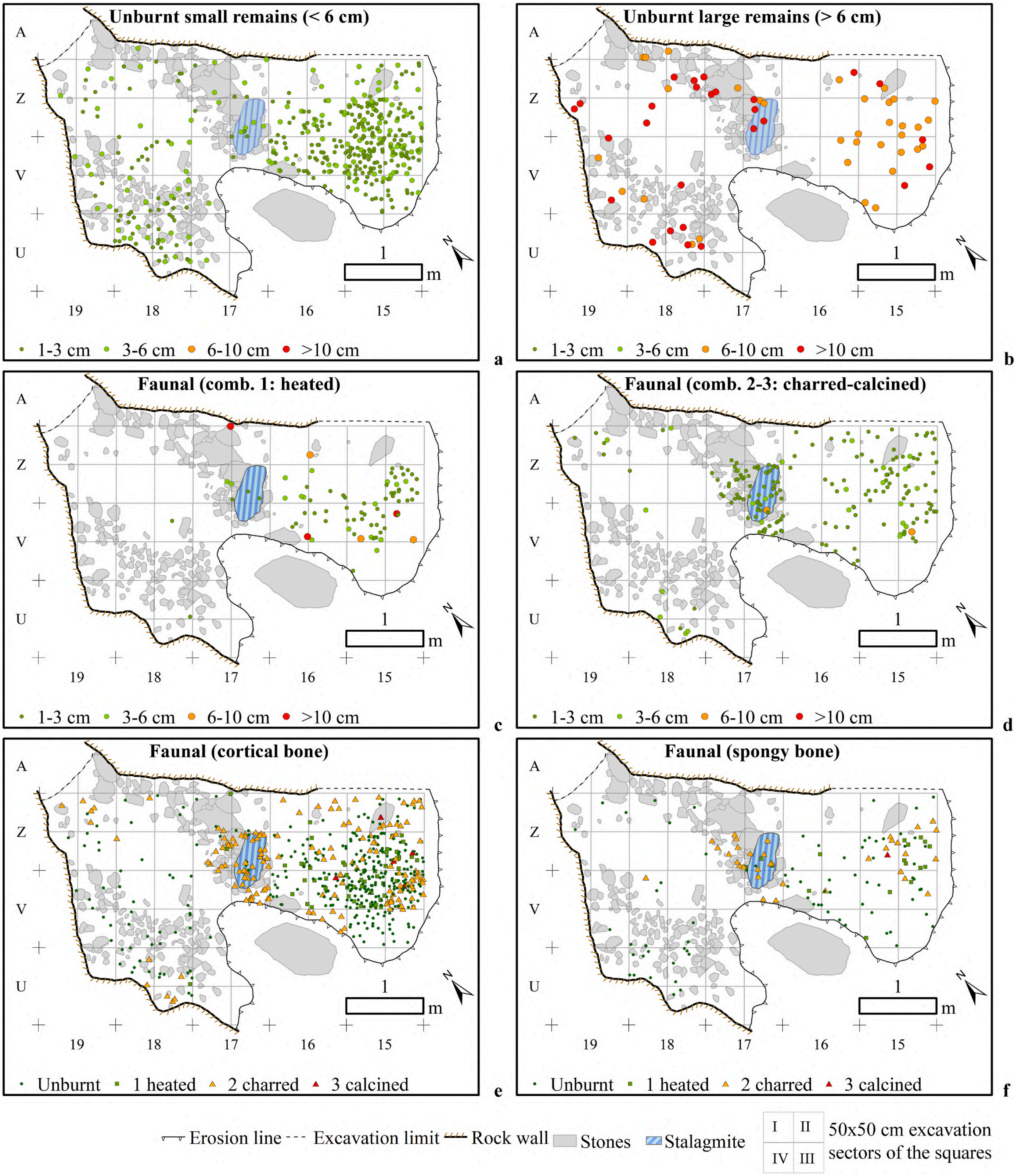

Fig. 8. Plot maps of a) faunal remains (unburnt small); b) faunal remains (unburnt large); c) faunal remains (low combustion level); d) faunal remains (high combustion level); e) faunal remains (cortical bones); f) faunal remains (spongy bones).

Layer 1 (L1) tephra capping the Trench F succession (Fig. 2c). With this regard, it is worth noting that the overall stratigraphic and chronological setting of L1 tephra replicates that of the ash layer Inf-1, found at Infreschi Cave, not far from Grotta Grande di Scario (Bini et al., 2020). Indeed, like L1, Inf-1 seals a terrestrial succession containing Mousterian lithic industry laying on beach deposits attributed, on the basis of a robust U/Th chronology, to the LIG sea level highstand (Bini et al., 2020). Inf-1 was correlated to the widespread Mediterranean marine

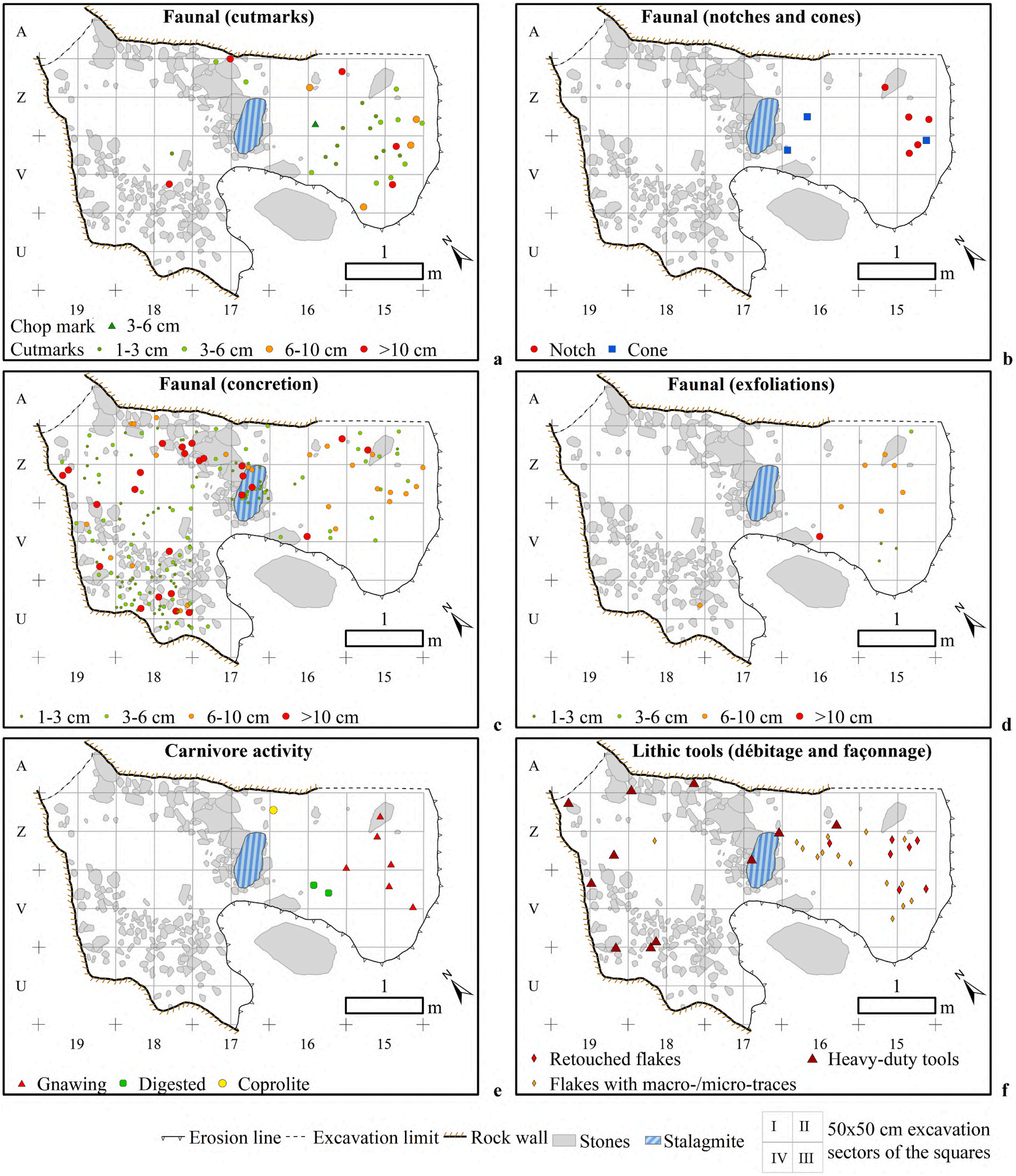

Fig. 9. Plot maps of a) faunal remains (cut-marks); b) faunal remains (notches/cones); c) faunal remains (concretion); d) faunal remains (exfoliation); e) faunal remains (predator activity); f) lithic heavy-duty tools (*façonnage*) and tools (*débitage*).

tephra marker X-6 (Bini et al., 2020), which has been also found, with a similar archaeo- and litho-stratigraphic position, in another important Italian Palaeolithic site of the Cavallo Cave (Layer G), in Apulia (Zanchetta et al., 2018). The marine X-6 marker, and its equivalent layer in terrestrial records, was in turn recently attributed to the Maddaloni eruption, from a poorly know activity of the Campi Flegrei preceding the large Campanian Ignimbrite eruption, dated by $^{40}Ar/^{39}Ar$ method to 109.3 ± 1.0 ka (Monaco et al., 2022). As matter of fact, the composition

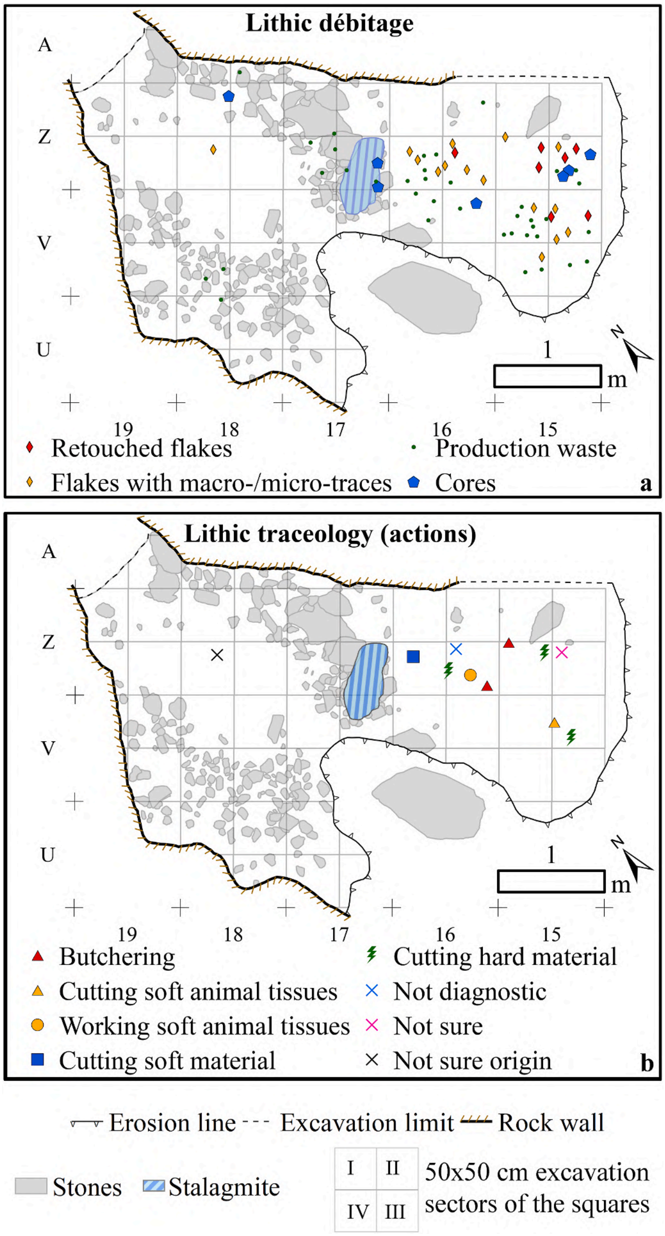

Fig. 10. Plot map of a) lithic debitage; b) results from traceological analysis.

of the glass from the L1 tephra matches very well those of the glass from the layer Inf-1 from Infreschi Cave and Layer G from Cavallo Cave, as well as with that of the glass from Maddaloni pumice fallout deposit and its marine and terrestrial equivalents (Fig. 12).

Overall, such a strong coherence of stratigraphic, chronological and geochemical data, allow to reliably correlate L1 tephra to the Maddaloni/X-6 tephra. In addition to provide a robust and precise chronological constraint at 109.3 ± 1.0 ka, due to its occurrence high-resolution Mediterranean MIS 5 paleoclimatic records, Maddaloni/X-6 tephra also allows the climatostratigraphic context of the successions containing it to be detailed defined, as it represents an excellent marker of the onset of the Greenland stadial 25 (GS-25), equivalent to the North Atlantic cold event C24 (Regattieri et al., 2015; Monaco et al., 2022).

Summarising, the succession of the terrestrial deposits exposed in Trench F, and thus of the human-carnivore occupation in Layer 8, can be reliably constrained between the end of the LIG sea level highstand and deposition of the Maddaloni/X-6 tephra; that is, between ~116 ka and 109.3 ± 1.0 ka, so in a very narrow interval of ~7 kyr, at most, roughly corresponding to the Greenland Interstadial 25 (Fig. 13) (Rasmussen et al., 2014).

5.2. Taphonomy of the context

Multiple evidence account for a good preservation of this context. The state of lithic edges (some of them with well-preserved use wear traces) and the state of the bone surface (some of them with preserved cut-marks) allow to rule out the action of abrasive phenomena, that would have obliterated such traces and smoothed the edges. Tractive phenomena are ruled out by the size sorting of faunal remains (with a high percentage of items smaller than 3 cm), the absence of size-related linear gradients and the dominance of clustered/highly-clustered patterns. The low degree of inverse correlation between the size of faunal remains and the clustering rate suggests a low (or in any case negligible) incidence of other displacement factors (e.g., scuffing, trampling) (e.g., Arriaza et al., 2018; Domínguez-Rodrigo et al., 2014; Eren et al., 2010; Frostick and Reid, 1983; Krajcarz and Krajcarz, 2014; Lenoble et al., 2008; Olsen and Shipman, 1988; Stevenson, 1991). In this regard, the spatial correspondence between the highest concentration of charred/calcined remains and the ashy-charcoal areas identified during the excavation is certainly noteworthy. Overall, this evidence and the very low proportion of exfoliated remains suggest a relatively rapid burial of the context (e.g., Behrensmeyer, 1978; Camarós et al., 2013; Domínguez-Rodrigo et al., 2022; Yravedra and Uzquiano, 2013), well-preserving the functional relations between the behavioural correlates of the material culture. Patterned activities, indeed, tend to produce patterned spatial outcomes (Binford, 1983; Newell, 1987; Schiffer, 1972, 1975a). Starting from this observation, a clustered distribution of homogeneous features (representing a kind of patterned distribution) is expected to better reflect the original spatial structure of the systemic context (*sensu* Schiffer, 1972). On the contrary, a scattered pattern could indicate a more intense entropy. As a corollary, a scattered/dispersed distribution of items may be the outcome of a longer (and/or more intense) exposition of the materials to entropic agents than a clustered distribution, conceivably buried sooner (e.g., Marean and Spencer, 1991; Marean and Bertino, 1994; Schick, 1986; Spagnolo et al., 2016; Stevenson, 1991). Moreover, both the presence of some groups of findings spatially differentiated by category and the spatial coherence of the clusters identified with the Ward's Method further strengthen the hypothesis of a well-preserved context. Apparently in contrast to this picture, the smallest size classes of lithics are strongly under-represented compared to the typical débitage composition (e.g., Bertran et al., 2012 and references therein). Since all the sediment from the excavation have been sieved with 1 mm wide mesh sieves and accurately screened, the micro-debris must be considered actually absent from the original set of the preserved and excavated area. Given the robustness of previous evidence, this particular size sorting of lithics could be linked to the functional meaning of the sampled area, rather than to a problem of preservation state of the context. In other terms, this evidence suggests a different location of the *de-facto refuses* related to lithic knapping activity (then performed in other areas than the excavated one).

As a whole, this evidence allows to infer a null/low-energy depositional environment, which has not undergone substantial displacements of findings and other post-depositional alterations. This is a good premise to detect a direct/isomorphic correspondence between the archaeological context and the living derived one (see Spagnolo et al., 2019 and references therein).

5.3. Reconstruction of the homo-carnivore relation

The context studied exhibits one clear evidence of Homo-carnivore interaction: the skinning marks found on the bear skull testify fur acquisition and possibly a prime access to the carcass of this large carnivore (e.g., Auguste, 1995, 2003; Brasser, 2020; Bratlund, 1999;

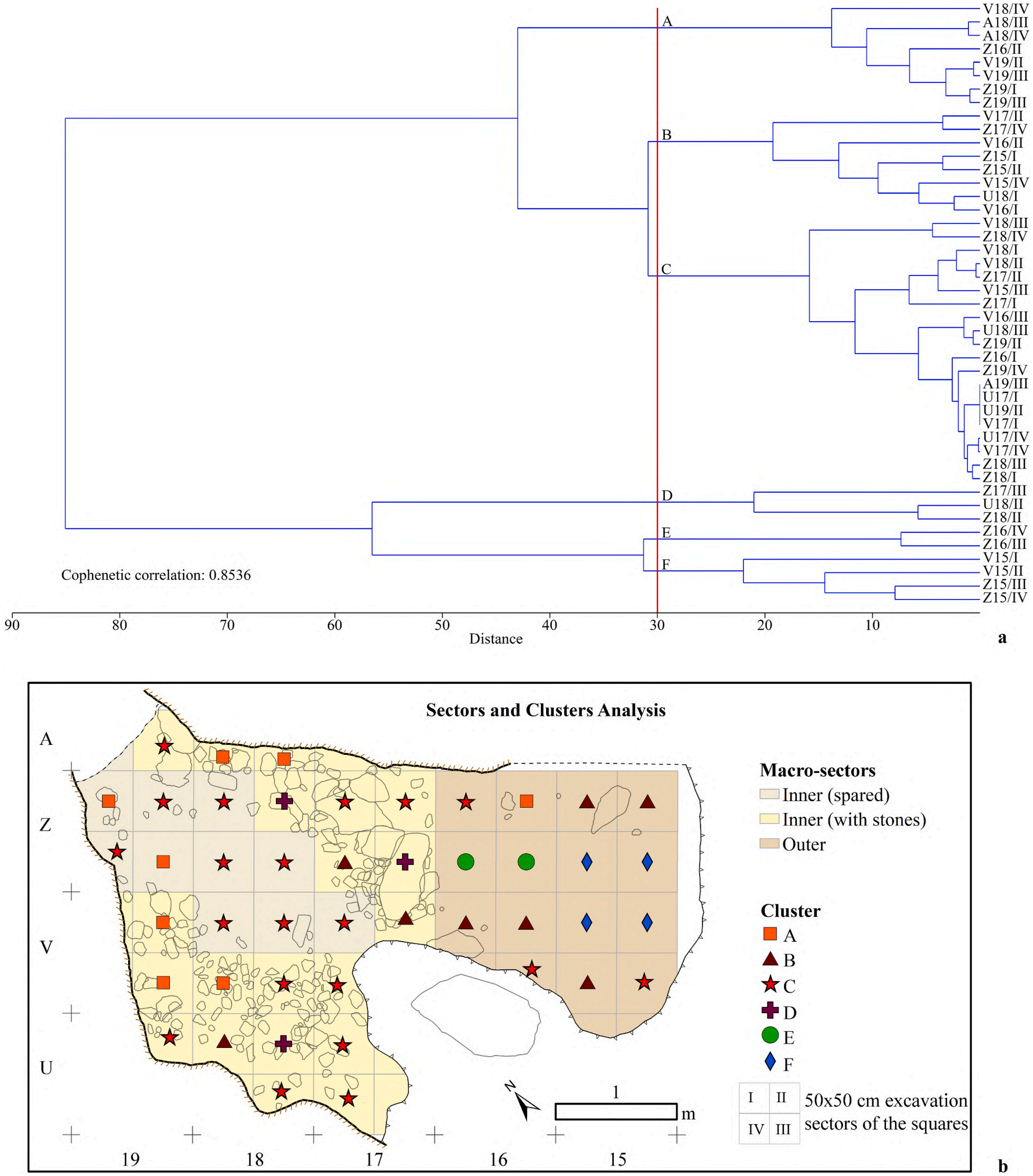

Fig. 11. Ward's Cluster Analysis. a) dendrogram returned with the identified clusters; b) plotting on the map of the groups detected from the dendrogram.

Münzel and Conard, 2004; Parfitt, 1999; Romandini et al., 2018; Thun Hohenstein et al., 2005; Verheijen et al., 2023; Wojtal et al., 2015). Whether this taxon was hunted by humans or not, is beyond the possibilities of our analyses. Establishing the nature of the relation between the Humans and the carnivore responsible for the chewing marks and digested bones is more complicated. This evidence, indeed, could be related both to some totally independent episodes or to a kind of commensalism.

Although among the bones the traces of carnivorous activity are less represented than those of anthropogenic origin, the gnawed/digested bones cannot be ignored. A plausible agent linkable to this evidence could be the spotted hyena, as suggested by the presence of a coprolite

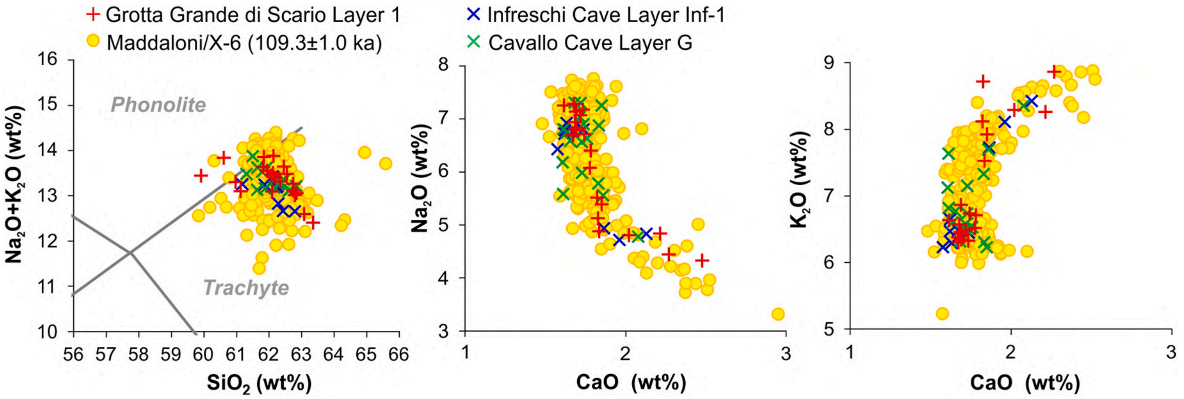

Fig. 12. Selected bi-plots showing the composition of the glass from the Layer 1 of Grotta Grande di Scario compared with those of layer Inf-1 and layer G from the Middle Palaeolithic levels of Infreschi Cave and Cavallo Cave sites. as well as with those of Maddaloni/X-6 tephra. Data source: Grotta Grande Layer 1: this study; Infreschi Inf-1, Bini et al. (2020); Cavallo Cave Layer G: Zanchetta et al. (2018); Maddaloni/X-6; Monaco et al. (2022 and reference therein).

macromorphologically referable to the faecal remains of *Crocuta crocuta*, nevertheless, other middle/large carnivores may have equally contributed to these traces. The spotted hyena (but also other carnivores) is a typical bone accumulator (e.g., Cruz-Uribe, 1991; Fourvel, 2012; Klein, 1975, 1982; Kruuk, 1972; Palomares et al., 2022 and references therein; Pickering, 2002; Richardson, 1980). Nevertheless, on the one hand, this does not necessarily imply a mixed genesis (anthropogenic and carnivore) for the input of faunal remains in the layer 8. The dynamics of the bone accumulation, indeed, depend on the nature of the carnivore presence in this context (denning vs scavenging/feeding), the length of frequentation and its diachrony in relation to the human occupation. On the other hand, a high-resolution sequence of discrete events is a very complex task. The presence of a fallow deer fragment of radius exhibiting both a low combustion level and gnawing traces, for instance, is emblematic. This evidence can be interpreted by two opposite perspectives: 1) accidental burning of a remain from a previous carnivore meal, 2) carnivore profiteering of the last meal remains left by Neandertals in the abandoned camp.

The absence of a differential preservation of remains attributable, respectively, to human and carnivore activity, together with the overall data about the context preservation, suggest a relative temporal closeness of the human and carnivore frequentations of the site during the formation of the layer 8. This reading is reinforced by spatial clustered patterns of both human and carnivore components, implying not only a possible good correspondence to their related living contexts of derivation, but also a relatively scarce human-carnivore interference. Put another way, the last occupant would have scarcely affected the general patterns left by first one.

The percentage of carnivore activity appears coherent to a small contribution of carnivore in the formation of the faunal assemblage (a brief visit contextual to feeding behaviour), or to the typical frequencies produced when it, attracted by the smells and remains left by humans, rapidly scavenges these remains (e.g., Arilla et al., 2020; Bartram et al., 1991; Bartram and Marean, 1999; Gabucio et al., 2012; Navazo Ruiz et al., 2021; Rosell et al., 2012; Villa et al., 2004; Yravedra, 2011). An alternative hypothesis of a carnivore den is not supported by taphonomic evidence, given the absence of carnivore decidual teeth or cub's bones and because a den would have led to a larger abundance of coprolites (see Villa et al., 2010 and reference therein). The presence of the carnivore is then related more to scavenging/feeding activity than to a denning. More in detail, the action of carnivore was recorded only on few ungulate bones ($n = 9$; Table 4), possibly belonging to one carcass. This smallness of the carnivore-related evidence together with the clear spatial separation of chewed bones, digested ones, and coprolite (despite the dimension of the sample) could suggest a sort of sequence of separated and concatenated events related to the feeding behaviour and compatible with a short stay at the cave by carnivore.

The reconstruction of the timing and behavioural meaning of the carnivore presence in the cave is more challenging, as both an anteriority and a posteriority of its brief visit compared to the human occupation seem equally plausible. The apparently good preservation of the carnivore spatial pattern and its temporal closeness to hunter-gatherer settlement are a possible key for the interpretation. If the carnivore preceded humans, then the original deposition of a thin level of sterile sediment (not recognizable during excavation) covering the remains left by the carnivore (and preserving its spatial patterns) has to be assumed. The multiple human activities performed into the camp (witnessed in the archaeological record) would probably have dispersed and/or erased these traces (e.g., Spagnolo et al., 2020a). Indeed, the overlapping of clustered carnivore-related evidence in the area with the most intense (and varied) evidence of anthropic activity is not a secondary factor. If the carnivore succeeded the humans, its presence has to be framed immediately after their abandonment of the site (as the both heated and gnawed bone would suggest). In this second hypothesis, the carnivore would have acted as scavenger (testing the resources left by humans in the camp), nevertheless the possibility that it also brought and consumed part of a carcass into the site cannot be ruled out *a priori* (although it appears less likely in this specific scavenging context). Under this reading, the spatial overlapping between the gnawed bones and the area with the highest density of faunal remains (most of them with traces of human exploitation) would be perfectly coherent with the scavenging behaviour of the carnivore. Nevertheless, based on the actualistic observations, the carnivores tend to be not interested in fragments of compact bones (as the diaphysis previously broken by humans to access to the marrow) and burnt elements, unless these still bear traces of food. This behavioural model may not be in contrast to the taphonomic evidence (e.g., presence of signs of teeth and alteration of digestion mainly on long bones) if one considers the possible bone assemblage left by the human activities on which the scavenging activity of the carnivore (the spotted hyena?) took place. The analysis of ungulate skeletal frequencies from level 8 shows a relative scarcity of spongy bones and epiphysis compared to diaphyseal fragments. This bone sample composition has been observed and analysed in several Upper Pleistocene Mousterian sites of the Southern Italy and, in addition, it characterizes some European Middle Palaeolithic deposits (e.g., Daujeard et al., 2019b; Livraghi et al., 2021; Marín et al., 2017; Navazo Ruiz et al., 2021; Terlato et al., 2019, 2021). In Apulia, southern Italy, the lack or scarcity of spongy elements in Mousterian assemblages, together with the evidence of green-bone breakage, was interpreted as an intense exploitation of bone marrow and grease by Neandertals (Boscato and Crezzini, 2006, 2012; Boschin et al., 2021; Crezzini et al., 2023). Hypothesizing this secondary access to the bone assemblage left by human occupation, the carnivore might have found a scarcity or a lack of spongy bones and epiphyseal parts (the most interesting skeletal parts

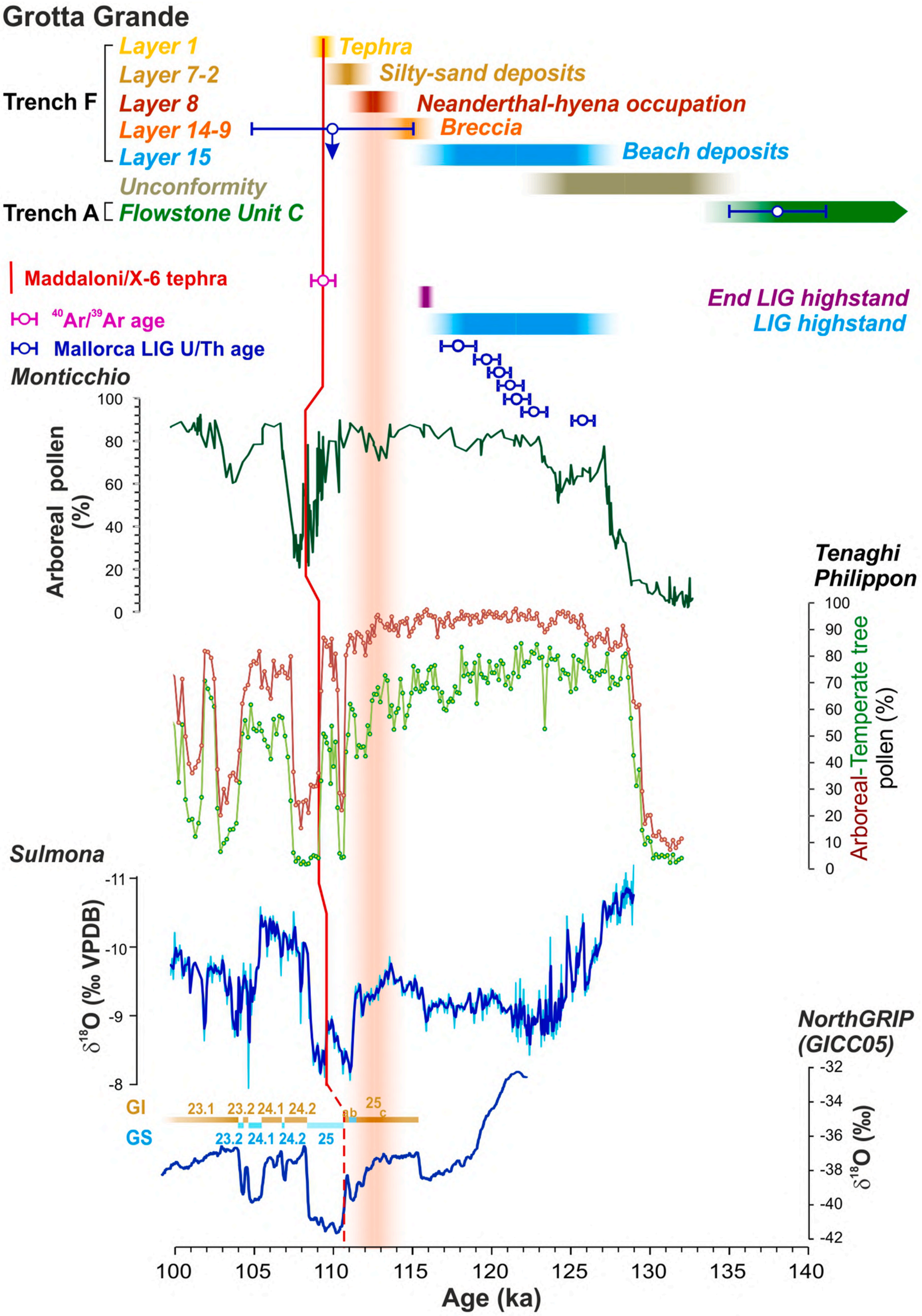

Fig. 13. Chronological and paleoenvironemental framework of Grotta Grande sedimentary infilling compared with selected high-resolution Mediterranean records containing the Maddaloni/X-6 tephra marker and with Greenland isotope record (Rasmussen et al., 2014). The arrow of the U/Th dating of the breccias (sample GG1901) indicates that it also refers to the beach deposit of the underlying Layer 15 from which the dated shell of *Persistrombus latus* derived (Fig. 2). Data source: U/Th-based chronology of the Last Interglacial Sea level high-stand from Mallorca Island: Muhs et al. (2015), Tenaghi Philippon pollen record: Milner et al. (2016); Monticchio pollen record: Brauer et al. (2007); Sulmona isotope record: Regattieri et al. (2015).

for the carnivores thanks to their fat content) due to the destruction or the intense fragmentation of these parts carried out by Neandertal to recover as much fat as possible. So, the carnivore could have gnawed the fragments of compact bones still present, digesting partially some elements during a short stay at the cave. If the lack of spongy tissues at the site was caused by carnivores, the signal of gnawing activities would have been more randomly distributed over the excavated area.

In summary, a brief carnivore visits hypothesis related to scavenging/feeding behaviour seems to be the one that best fits the archaeological evidence. An alternative scenario, in this context, appears less convincing. For instance, the evidence does not completely fit with the dismantling of a carnivore den and disposal of remains in a heap. This hypothesis, indeed, conflicts both with the patterning of the carnivore-related evidence (exhibiting a possible spatially-differentiated structure based on different steps of its feeding) and, in particular, of the human-related one. More specifically, the presence of a relative differential allocation of some clusters of homogeneous categories of findings (sometimes partially or totally "segregated") is not compatible with solely a waste disposal activity. In this case, indeed, one would have expected a more chaotic scene (e.g., Bartram et al., 1991; Binford, 1983, 1987; Schiffer, 1972; Spagnolo et al., 2019; Stevenson, 1991).

Overall, this evidence constitutes a good premise to develop a more in-dept study aimed to detect the functional organization of the Neandertal site. Further studies will contribute to open a window on the behavioural network behind the Neandertal homing, shedding new light on a particular (and still poorly studied) aspect of their settlement strategies: the construction of structures (see layer 7) delimiting different functional spaces (see Ronchitelli et al., 2011; Spagnolo et al., 2020b).

6. Conclusions

The spatial taphonomy plays a key role thanks to the rich scientific inheritance deriving from the spatial archaeology, its fertile permeation with other discipline and the fruitful progress of the epistemological debate from the season of the *Processual Archaeology* (see Spagnolo et al., 2020c and references therein). In the last decades, the rapid development of the GIS allowed an impressive advance of the practical applications.

This research was aimed at shedding new light on the relation between Neandertals and carnivores in the sample-context of the layer 8 from Grotta Grande, southern Italy. This layer has been dug into a peculiar context, as it extended into a niche forming a sort of small "cave within a cave".

The chronological constraints are given, respectively, by the beach deposits attributed to Last Interglacial (LIG) sea level high-stand (~129-116 ka) – which is here supported by a U/Th dating of a fragment of *Persististrombus latus* from the layer below the proposed case-study – and the identification of the tephra sealing the stratigraphic succession as the widespread Mediterranean X-6 layer, derived from the Maddaloni eruption, from Campi Flegrei, dated to ~109 ka. The new chronological data allowed to precisely constrain the stratigraphic sequence containing this layer within a narrow time window, shorter than 7 kyr, between the end of the LIG sea level highstand (~116 ka) and the Maddaloni eruption (~109 ka).

The study of this short-term MIS 5 context was addressed throughout an integrated methodological approach, which combined a zooarchaeology, lithic technology, use wear and spatial analyses. Multiple geostatistical approaches contributed to significantly strength the taphonomic analysis, allowing reaching ground-breaking results.

Firstly, a good preservation state of the context has been highlighted by different parameters. The recognition of a relatively good correspondence between the systemic context and the archaeological context (*sensu* Schiffer, 1972) constitutes a perfect premise for further studies, opening the way both for a high-resolution reconstruction of the Neandertal-carnivore interaction (that is the core of this paper) and for a deeper reconstruction of the meaning of the complex evidence related to the Neandertal behaviour (that will be the issue of a further work).

The taphonomic analysis of faunal remains allowed to characterize and quantify evidence related both to the human and carnivore activities. Nevertheless, the lonely evidence of a mixed assemblage can introduce some reading problems of the anthropic behaviour, due to the overlapping of multiple issues (palimpsest effect, positive/negative contribution of carnivore on the bone assemblage, dismantling of previous spatial patterns and/or spatial equifinality). The nature of some carnivores as bone accumulators and entropic agent, indeed, can contribute to falsify the original arrangement, the correlations between different evidence and their consequent interpretation.

The layer 8 is a high-temporal resolution context, consisting of a short-term palimpsest with intriguing evidence of both Neandertal and a large carnivore. The analysis of spatial patterns allowed to reconstruct the formational process of the context and to make a high-resolution hypothesis about the Neandertal and large carnivore relation.

The evidence of Neandertal behaviour includes the remains of different activities, as the lithic knapping, the involvement of both *façonnage* and *débitage* tools in different economic activities, different steps of prey butchery, the use of fire, the structuring of the space (with possibly different functional areas and with a constructed feature). The evidence of large carnivore activity includes gnawed and digested bones and a coprolite. Interestingly some skulls have been found into the confined space of the niche. These skulls mainly exhibit a same reduction pattern, resembling the ones from the near and relatively coeval site of Molare Rock shelter (Spagnolo et al., 2020b and references therein).

The best fitting scenario to the archaeological evidence suggests that a brief visit of a large carnivore took place into the site before the Neandertal occupation or immediately after the camp abandonment. In the first case, the carnivore plays the role of bone accumulator but with a small contribution in the formation of the faunal assemblage (as result of the feeding behaviour). In the second case, the carnivore, attracted by the bone left in the camp by humans, would have acted as a scavenger on these remains).

These results have a double significance. From the one hand, the integrated approach to the taphonomy of context powered by spatial archaeology can significantly contribute to enhance the scientific potentiality of the research. From the other hand, these results encourage to go beyond the threshold of current studies, characterizing both the nature and the weight of human and carnivore components in the "mixed" context. This result can open new opportunity to understand the commensalism phenomena in Pleistocene contexts (with the related dynamics), advancing the analytic protocols for the high-resolution studies.

Author contribution

Vincenzo Spagnolo: conceptualization, introduction, lithic technology, spatial analyses, and discussion; Jacopo Crezzini, Paolo Boscato and Francesco Boschin: taxonomical and taphonomic study of the faunal assemblage; Daniele Aureli: lithic technology; Simona Arrighi: traceological analysis of lithic implements; Jean-Jacques Bahain, Olivier Tombret, Lisa Garbé and Christophe Falguères: ^{230}Th/^{234}U dates on carbonate samples; Biagio Giaccio: analysis of the tephra; Isak Eckberg: constructing of the geodatabase and data insert from faunal and lithic studies; Annamaria Ronchitelli: research coordinator, regional settings, stratigraphy of the site and archaeological reports of excavations. Interpretations and conclusions are the result of the conjunct efforts of all the authors. All the authors collaborated in the editing of this paper.

Declaration of competing interest

It is important to underline that 1) all authors have made substantial contributions to the paper we are submitting, and 2) each of the authors has read and agrees with the content of the manuscript.

This original work has not been published in other Journals and it is not under consideration for publication elsewhere.

We hereby declare that there isn't any relationship that could give rise to conflicts of interest.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quascirev.2024.108628.

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