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Abstract

New excavations in the lower part of the sequence dated between 670 and 695 ka by $^{40}Ar/^{39}Ar$ and ESR-U-Th at Notarchirico revealed layers with lithic and bone remains attesting several phases of human occupations. Some of these occupations are located at the top of residual pebble/cobble lags along former water channels, while others are more disturbed. All the layers yield faunal and lithic remains. Here, we aim to discuss the interpretative limits of traces of hominin occupations in such Early Palaeolithic sites through a multidisciplinary approach focusing on depositional and post-depositional processes in sedimentary units applied on the micro/macro-mammal remains, artefacts (surfaces, micro-wear traces) and spatial distribution of the archaeological material. These data are then compared with those from M. Piperno's previous excavations in the upper part of the sequence (610-670 ka). As is often the case in open-air deposits and wetland environments, the majority of the bone surface modifications are related to natural abrasion caused by trampling and water flow.By contrast, the lithic material provides more relevant results both on taphonomic processes before and after the hominin occupations and function of the site. Despite the strong impact of post-depositional processes on archaeological material, evidence of hominin activities can nonetheless be inferred, shedding light on early hominin occupations of western Europe at the MIS 17/MIS 16 transition. The discussion takes penecontemporaneous open-air sites into consideration.

Key-words: Early Palaeolithic, Acheulean, Mediterranean Europe, taphonomy, fauna, lithics, spatial distribution, hominin occupation

1.Introduction

The earliest Western European human settlement is older than 1.2 Ma (i.e., Pirro Nord; Arzarello et al., 2012) and probably related to *Homo antecessor*, the earliest currently known hominin in Western Europe (1.2-0.8 Ma; Lunery, Pont-de Lavaud, Sima del Elefante, Barranco Leon, Funete Nueva 3, Vallparadis) (Toro-Moyano et al., 2013; Bermúdez-de-Castro et al. 2017). After the Early to Middle Pleistocene transition, *Homo heidelbergensis*, and possibly other hominins, are associated with significant behavioural changes, such as the onset of biface production and more complex core technologies (technological Mode 2, Acheulean) (Buck and Stringer, 2014). The Acheulean emerges at a very late stage in Western Europe compared to initial occurrences in Africa (1.75 Ma) and the Levant (Beyene et al., 2013; Díez Martin et al., 2015; Torre, McHenry and Njau, 2018). Rare manifestations indicate the emergence of such technologies earlier than 700 ka ago in the Mediterranean Basin (e.g., Barranc de la Boella, Spain; Vallverdù et al., 2014; Mosquera et al., 2015). Over the past decade, fieldwork has shown that elaborate biface production appeared suddenly around 700 ka ago in Western Europe, both in the Northwest and the South (Moncel et al., 2013; Ollé et al., 2013), although sites of this age are still rare. Despite these new discoveries, the knowledge on the timing and characteristics of the earliest Acheulean groups in Western Europe is still fragmentary. Various scenarios have been put forward to explain the onset of Acheulean diffusion in this area but they do not account for the late emergence: (1) a local origin stemming from previous traditions; (2) the dispersal of new populations or the diffusion of new ideas with new behaviours and adaptation to European environments.

In this general context, Notarchirico (Basilicata, southern Italy) is a key site for better understanding the age of the earliest Acheulean occupations and the behaviours of biface-producing hominins between 700 and 600 ka **(Fig. 1)**. Highlighting modes of early human occupations in Western Europe before the major Marine Isotopic Stage (MIS) 12 glacial event is limited by post-depositional processes and palimpsests at most sites, especially in the case of open-air sites (i.e. Pineda and Saladié, 2022). Like for most penecontemporaneous open-air sites in Europe, this case study applies a multidisciplinary approach to the depositional and post-depositional processes in the sedimentary units, and considers the taphonomy of lithic and micro/macro-mammal remains, availability and access to stone nodules for hominins and the spatial distribution of the archaeological material. New investigations into the poorly known base of the sedimentary sequence at Notarchirico since 2016 have provided new and crucial data on several phases of occupation dated between 670 and 695 ka. Some of these are related to beds of pebble formation remains along water channels (Moncel et al., 2020). Additional analyses were performed on the faunal and lithic remains which enlerge the corpus of the fieldwork (2016-2021). They have focused on the surfaces of the faunal remains and the lithic artefacts, especially on chert, and the spatial distribution of the whole archaeological material. In this paper, we investigate the question of human activities in open-air sites, identify the role of the post-depositional processes, decipher the types of human behaviours and activities at Notarchirico, and discuss the interpretative limits of traces of hominin occupations in such Early Palaeolithic sites.

2.The site of Notarchirico and the Venosa Basin

The Basilicata region in Italy is characterized by the preservation of long archaeological sequences in volcano-sedimentary complexes linked to the eruptive activity of the Vulture stratovolcano (Raynal et al., 1999; Lefèvre et al., 2010). Among these sites, Notarchirico (Venosa Basin), discovered in 1979, has yielded a 7-m-thick sequence of fluvial sediments including eleven archaeological levels, six of which contain bifaces (A1, B, D, E/E1, F and G) (Piperno, 1999) **(Fig. 2)**. A hominin femur fragment was also found in the upper part of the sequence (level α) (Belli et al., 1991). $^{40}Ar/^{39}Ar$ ages and ESR dates have revised the chronology of the sedimentary sequence excavated by Marcello Piperno and constrained the archaeological levels α to F between ca. 610 and 675 ka, i.e., coeval with the MIS 16 glacial stage (Pereira et al., 2015). The faunal assemblages from the upper levels A and α, described by Cassoli et al. (1999) were initially considered as representative of an intermediate faunal unit between Isernia (MIS 15, but initially dated at approximately 700 ka) and Fontana Ranuccio (MIS 13 - MIS 11) faunal units, but then usually referred to the former. In particular, two species reported by Cassoli et al. (1999) would suggest a younger age, *Bos primigenius* and *Dama clactoniana*. If there is a general consensus in placing the European dispersal of *Dama clactoniana* within the Fontana Ranuccio faunal unit (e.g., Sardella et al. 2006; Breda and Lister, 2013; Breda et al. 2015), uncertainty persists on the first occurrence of *Bos primigenius*. However, reliable cranial remains of *Bos primigenius* are indeed attested only since the Fontana Ranuccio faunal unit (Iannucci et al., 2021). In this scenario, the mammal assemblage from levels A and α needs to be revised.

A 30-m-long trench was opened on the side of Notarchirico hill, at the base of the previously studied sequence layer F. Excavations were conducted over a surface of 8 to 26 m², depending on the investigated stratigraphic unit (Moncel et al., 2020) **(Fig. 3, 4)**.

Since 2016, excavation campaigns focusing on the base of the sequence have identified five sedimentary units, including five archaeosurfaces (F, G, H, I and J). The studied deposits belong to the top of the Piano Regio sedimentary formation of the Venosa Basin. The basal units (units 8 to 6) are characterized by low-energy fluvial sedimentation and regular inputs of volcanic material. In the upper units (units 5 to 3), sedimentation progressively indicates somewhat higher energy currents and mainly volcano-derived sediments **(Fig. 5, Table 1)**. Under layer F (unit 3), already excavated by M. Piperno, the main new archaeological horizons are layers G (bottom of sub-unit 4.2), H (bottom of sub-unit 5.3), I1 (sub-unit 6.1), I2 (sub- unit 6.2) and J (sub-unit 7.4). The lithology and sediments at the bottom of the Notarchirico sequence are similar to the types of infillings in the upper part of the sequence, dated to MIS 16 (levels α to E) (Raynal et al., 1999; Lefèvre et al., 2010; Pereira et al., 2015). For layer F (unit 3), the deposit is composed of a cross-bedded volcano-derived and non-volcanic sands. Fluvial processes governed this sedimentation and volcaniclastics do not represent direct inputs. For layer G (sub-unit 4.2), data indicate a sandy sub-unit rich in brownish-greenish silts and clays with encrusted pebbles (see detailed sedimentological analyses in SOM, Moncel et al., 2020). Archaeological layer G is a thick lag deposit, with dark-grey volcano-derived sands covered by fluvial sands. Layer H is a yellowish unit similar to a degraded distal pyroclastic flow, included in sub-units 5.1, 5.2 and 5.3. They are silty-sandy deposits. Layer I1 is part of sub-unit 6.1, with coarse greyish to greenish sands and beds of more or less dense gravels, sometimes concentrated in lenses or metric shallow pits. Layer I2 is in sub-unit 6.2, a lag deposit with a dense accumulation of cobbles and pebbles ("pavement"). This lag deposit and the characteristics of the matrix could indicate dynamic re-equilibrium following a volcanic input.

The set of each deposit corresponds to a relatively short period of accumulation, often due to infilling of paleo-channels, sometimes with actions of low-energy currents, deposits of cobbles and gravels due to slope destabilization after arrival of tephras, before the hominin occupation and animal passages. The deposits were saturated with water without knowing the duration of this action. Detailed data on the lithostratigraphy and sediment analysis are available in the SOM of Moncel et al. (2020).

Four sedimentary units, some of which contain archaeological horizons, were dated by $^{40}Ar/^{39}Ar$ on single crystals and ESR on bleached quartz. The stratigraphic positions of these samples are shown in **fig. 2**. The bottom of the sequence is framed between 690.3 ± 5.8 ka and 695.2 ± 6.2 ka, which corresponds palaeoclimatically to the end of MIS 17.

3. Material and methods

3.1. Faunal assemblages

3.1.1. Large mammals

For 2016-2018, the majority of remains comes from levels F and I1, and amounts to 4,081 remains (NRT: Number of total remains), including 289 anatomically identified elements (NISPa: Number of anatomically identified specimen) that allow an inference of 24 minimum number of individuals (MNI) (**Tables 2 and 3**). Preliminary mammal faunal list was reported by Moncel et al. (2020), and the only remain of macaque was studied by Mecozzi et al. (2021a). The analysis has been enriched by the material of 2019-2021 where 138 remains are anatomically identified (total of 1068 remains) These fossils allow us to expand our knowledge on the mammal faunal assemblage of the lower levels of Notarchirico and to identify the presence of new taxa. For the taphonomic analysis of the paper, we focus on the data from 2016-2018.

The taphonomic methods and analysis are detailed in a previously published paper (Moncel et al., 2020). Here, we focus on some of the new results elucidating the taphonomic process involved in faunal accumulation and site formation.

Taphonomic analysis was conducted on all the large faunal remains. We registered the dimensions, degree and type of breakage, as well as bone surface modifications, for all the spatially identified and recorded specimens (plotted in 3 dimensions, X and Y on squares and depth). Non-spatially recorded fragments (faunal unidentified fragments less than 20 mm long, recorded by square and layer) were only used for fragmentation analysis, distinguishing green bone fractures from dry or recent ones. For recorded remains, we made the whole taphonomic analysis, including the bone surface reading. All the sediments are sieved by water for micro-mammals and micro-remains and the material included in the study. Bone surfaces were analysed and wand photographed in order tocharacterize the various surface alterations using two Dino-Lite Digital Microscopes (AD7013MZT and AM7915MZT, magnification 20-220x). We recorded the types and locations of relevant modifications on the outer surface, including those made by rodents, carnivores (tooth marks) or hominins (cut and percussion marks), as well as climatic and edaphic modifications (Behrensmeyer, 1978; Binford, 1981; Haynes, 1983; Blumenschine and Selvaggio, 1988; Villa and Mahieu, 1991; Lyman, 1994; Blumenschine et al., 1996; Fernández-Jalvo and Andrews, 2016). The latter include cracking, desquamation, polishing, concretion, root marking, chemical corrosion and oxide colouration. The illegible remains were not included in the percentages. We specifically distinguished trampling marks from butchering marks with reference to works by (Shipman and Rose, 1984; Behrensmeyer et al., 1986; Olsen and Shipman, 1988; Fiorillo, 1989; Blasco et al., 2008).

As the sediments were partly accumulated by hydraulic factors, we have focused on specific taphonomic alterations related to natural abrasion, such as random striations, lustre and polishing, and water exposition, including corrosion and concretions (Brugal, 1994; Aslan and Behrensmeyer, 1996; Fernandez-Jalvo, 2003). The Voorhies groups have been tested for the anatomically identified specimens, which are mostly complete or nearly so. Furthermore, they include all the taxa, with a majority of middle-sized and large-sized ungulate remains, and fewer proboscideans and hippos remains. We tested Voorhies groups to evaluate the effects of water transportation on the faunal assemblage (Voorhies, 1969). Voorhies groups classify the anatomical elements of mammals (> 10 kg) depending on their susceptibility to hydraulic transport. This method relies on the size and density of the elements. The relative representation of each group indicates whether an assemblage underwent fluvial transport, as well as the flow of the watercourse. Some studies have shown that the relative transportability of bones is similar regardless body size, from small to large mammals, including elephants (Todd and Frison, 1986). Commonly, the light and porous elements (vertebrae, phalanges, etc.) are transported farther than heavy and dense bones (limb bones or mandibles). According to experiments conducted by A. K. Behrensmeyer (Behrensmeyer, 1975), in addition to those of Voorhies, high-energy fluvial deposition environments, such as channel fills and lag deposits, tend to have high ratios of teeth-to-vertebrae, whereas low-energy environments, such as deltaic and lacustrine settings, tend to have low ratios. Abrasion and the fluvial transportability of bones are the main taphonomic alterations in fluvial depositional environments.

3.1.2. Small mammals

The material of the excavations of 2016-2021 is presented here. The small mammal material is represented by bone fragments collected by water screening using 1-mm-mesh sieves. The small mammal attributions were performed using a DinoLite AF series and Celestron HDM Pro microscopes. They were based on the best diagnostic elements: the mandible, maxilla, and isolated teeth for rodents and lagomorphs, and postcranial bones for Talpidae. The assemblage is composed of 53 Identified Specimens, 23 of which were identified at least to genus level (**Table 4**). Im contrast to the large mammals, we followed different methodologies in the taphonomic observations for the small mammals due to the different accumulation and post-depositional processes which affect this material (Andrews, 1990). Taphonomic observations followed Andrews (1990), Fernández-Jalvo et al. (2016), and Fernandez-Jalvo and Andrews (2016).

3.2. Lithic assemblages

3.2.1. Lithic material

The lithic component presented here is from 2016 and 2021 (**Table 5**). It was classified according to raw materials and technological categories: pebbles with percussion marks or broken pebbles, pebble tools, Large Cutting Tools (LCTs, i.e., bifaces, cleavers, unifacial tools, pick), cores, flakes, flake-tools and retouched nodules **(Fig. 6;** see details in **SOM Fig. S1 to S9)**. More than 1,000 lithic objects were found over the sequence associated with faunal material. The richest layers in term of quantity are F, G, I2 and I1 (**Table 5, see Tabel 12 for density/m²**).

Material in layer H is scant, consisting only of small flakes and flake-tools in chert. The surfaces and the cutting edges of all the material were observed to identify if crush marks or post-depositional alterations could have affected the artefacts. Double patina and evidence of recycling were also noted. These features were coupled with the spatial distribution of the material.

Cores are on nodular chert, flysch chert and radiolarite nodules of small sizes. They consist of small unifacial, unifacial discoid-type, multifacial, orthogonal and semi-rotating cores. There is a mixture of capabilities between complex (organization of the removals) and simple (some removals) technologies. The economy of the raw materials is limited perhaps due to the availability of stones *in situ*. There is also an adaptation to the local mineral resources. Cores are often broken, possibly during reduction processes or post-depositional processes among the pavement of pebbles **(Table S1)**. In all layers, cores (typically 20-50 mm long) produced low quantities of small 10-20 mm-long flakes, often thin and sometimes backed. Flake fragmentation is high, possibly during the flaking process or due to pressures among pebbles. Flakes, flake fragments and small nodules are retouched (between 5 and 20% of the corpus) on one (the longest) or several edges by marginal, abrupt or denticulate retouch **(Table S2)**. Some convergent tools are often made by abrupt retouch. Most of the flakes are very small (10-20 mm) and retouched nodules are longer and wider (20-40 mm). Retouch has been considered only when it is regular. Crushing traces were also recorded (by eye), for discussion on taphonomy or tool use. The question of the meaning and origin of the denticulate retouch was investigated (angles, regularity *v.s.* irregularity and crushed marks).

The analysis also includes limestone pebbles. Cores are rare andorthogonal, unifacial or partially bifacial, with few removals. The heavy-duty component is characterised by diversified and poorly-standardised artefacts. It includes unifacial round and thin pebble tools with limited shaping on flat and round pebbles, some of which are pointed. Some tools can be described as “rabots” with a limited and regular invasive retouch. We can also mention some broken pebbles with impact points and pebbles with isolated removals, remains of hammerstones. Sizes vary between 40 to 200 mm, most are between 60 and 80 mm and cutting edge angles are between 30 and 90°.

Regarding the LCTs, bifaces demonstrating overall volume management were observed in layer F, the layer with the most bifaces, confirming discoveries made by Marcello Piperno’s excavations (Piperno, 1999; Moncel et al., 2019). In this layer, four bifaces on limestone and large chert nodules were found among the ten Large Cutting Tools composed of partial bifacial tools. Bifacial shaping covers a large part of the periphery on cobbles or large limestone flakes and surface of the tool with one or several series of removals, with retouch sometimes regularizing cutting edges. These retouches were analysed in detail to discuss possible post-depositional effects. Two limestone bifaces and one on a large chert nodule discovered in layer G, associated with various pebble tools and cleavers, were also analysed.

3.2.2. Sampling and analytical methods for post-depositional processes on the available raw materials

The 76 chert artefacts selected from the findings of the 2016 (n = 33) and 2017 excavations (n = 43), partly characterised in Moncel et al. (2020), were investigated for additional post-depositional surface modifications. In order to identify the black patina observed on some of the lithic tools, four geological chert pebbles with the same patina and collected from the same layers were also investigated (NOTG9, NOTG11, NOTG20, NOTG22).

The pH in the investigated layers was measured in the field using 10 g of sediment (Ø < 63 µm), added to 10 g of distilled water. The water/sediment mixture was stirred in a polypropylene bottle every 10 minutes. After 30 minutes, the pH of the sediment slurry was determined with test stripes with four colour panels (ISOLAB, accuracy = ± 0.2). Mean values of three samples analysed per layer are reported in **Table 6**.

Mesoscopic observation was carried out with a Nikon SMZ800 stereomicroscope equipped with a CCD camera Nikon DS-Fi1c. Petrographic analysis on thin sections was conducted with a Carl Zeiss Axioskop 40 Pol polarizing microscope (POM). A scanning electron microscope (SEM) 50XVP LEO, operated at 15 kV and 500 pA probe current, was used to analyse the thin section of NOTG9. Elemental maps were collected with an energy dispersive spectrometer (EDS), consisting of a X-Max N (80 mm2) SDD detector and AZtec software (Oxford Instruments).

3.2.3. Surface analysis of the lithic material by micro-wear studies

Here we present the results of the analysis of the chipped stone tools found in layer F. We decided to concentrate in layer F (material of 2016-2021) since the lithic assemblage of this unit the best preserved of the excavated sequence. The surfaces of the lithic tools were macroscopically and microscopically observed to identify alteration processes. A first evaluation with the naked eye allowed for the categorization of the most evident alterations, such as fractures, surface brightness (gloss), colour patina, thermal stress and concretions. Inspection with a stereomicroscope, with magnifications up to 75x, distinguished: a) scars with typical irregular distribution, orientation and morphology as a result of mechanical stress; b) two degrees of gloss, light and developed. Finally, the observation of the microsurfaces at magnifications up to 200x with a metallographic microscope allowed us to distinguish further degrees of gloss evolution.

The observations were carried out with an Optical Light Microscope (OLM) equipment: stereomicroscope Nikon STZ (oculars 10x and objectives 0.5x and 1x, magnification range 0.75x-7.5x), metallographic microscope Nikon Eclipse (oculars 10x, objectives 10x, 20x, 50x). Digital camera AmScope and focus stacking software Helicon Focus.

3.2.4. Residues on a sample of artefacts

Artefacts were examined for the presence of residues with Dino-Lite digital microscopes with magnifications ranging from 20-485x. All observed residues were photographed using Dinocapture 2.0 software and their location was noted on a line drawing of each artefact. Residue identification was based on comparison with a large modern reference collection (over 1,000 experimental artefacts) and with published sources (see Hardy and Moncel, 2011; Hardy et al., 2013). Identifiable residues include wood, bark, plant fibres, starch grains, calcium oxalate crystals, plant tissue, resin, hair, feathers, fish scales, skin, and bone. Suites of related residues (e.g., hair fragments, collagen, bone or plant cells, starch grains, plant fibres) can confirm identification. Markers of the relative hardness of the used material and use-action included the identification of striations, edge rounding and micro-flake scars. All artefacts were unwashed prior to analysis.

3.3. Spatial analysis of the archaeological material

The spatial analysis has been performed on the whole material (2016-2021). The excavated surface varies for each layer, from 20 m² for layer I2, 18 m² for layer I1, 10 m² for layer H, 15 m² for layer G and 18 m² for layer F. Most of the material was plotted in a three dimensional coordinate system (X, Y, Z), associated with micro-flakes and micro-fragments of bones, and teeth, recovered during sieving (located by layer and square). All the determined faunal remains whatever the size and bone fragments longer than 20 mm were coordinated. For the lithic material, all the material, whatever the size was plotted. For the material, the orientation and slope (in degree according to the archaeological North between flat on the archaeological ground, 45° for a slope and 90° for straight position) have been noted and graphs for each square and level established. For the large quantity of the lithic artefacts measuring between 10 and 20 mm and not elongated (length = width), orientation and slope cannot be noted. The non-coordinated faunal and lithic material is recorded by square and layer. Attempts at refits were not successful for lithics, despite systematic sieving and recovering micro-flakes, possibly derived from retouching small chert nodules. For limestone, some flakes can be matched with pebble tools or cores but not refitted due to surface alteration.

For layers F and I2, the faunal and lithic material is associated with a more or less dense bed of pebbles of various sizes. For layer F, the bed of pebbles is thick, with no slope (inclination), with two sub-beds, while for layer I2, only one bed, "pavement", also with no slope, is partially preserved. For layers G and I1, pebbles are dispersed among sediments in a 50-cm-thick deposit. For layer H, there are no pebbles and the sparse material is dispersed over the whole deposit **(Table 1)**. Orientation of the material was noted when long enough. Most of the chert material is very small (less than 20 mm long).

We have applied the whole distribution of all remains for each layer during fieldwork in 2016-2021, in order to observe dispersion and possible clusters. We used a variety of methods and applications depending on the archaeological context (cf. Binford, 1978a, b, 1979, 1981, 1982; Isaac, 1983; Rigaud and Simek, 1991; Lhomme et al., 2000; Pois, 2000; Domínguez-Rodrigo et al., 2009, 2012; Böhner et al., 2015; Sánchez-Romero et al., 2016; Torre de la and Wehr, 2018; McPherron, 2018; Torre de la et al., 2018; Méndez-Quintas et al., 2019, 2022; Organista-Labrado et al., 2023). These maps were used to examine taphonomic features and the spatial organization of the archaeological material (cf. Bertran et al., 2012, 2017). All the spatial analyses were carried out with seaborn and sklearn Python 3 packages. We used kernel density analysis to visually identify distribution patterns of lithic objects and faunal remains for each of the five levels. Bandwidth was estimated by cross validation according to a log-likelihood maximisation criterion. We then performed a k-means cluster analysis to identify coherent clusters from the data. Each time, we used the silhouette method and a visual inspection of results to define the adequate number of clusters

The silhouette coefficient is used to validate the consistency of the computed clusters. For choosing how many clusters to retain, we had to balance three criteria, (1) a visual inspection of the results depending on the data to ensure their archaeological significance, (2) a criteria of minimization of the number of groups to be able to represent, characterize, and interpret the data in an intelligible way, and (3) the silhouette method that quantify how well the items have been classified regarding the number of groups retained.

4. Results. Taphonomic data on the archaeological assemblages from layers F to I2 at Notarchirico

4.1. Faunal assemblages

4.1. 1. Large mammals.

Among the identified fauna, cervids largely dominate the spectrum within levels H (91.7% of the NISP) and I1 (80.8%) (**Tables 7, 8**). Large-sized megacerines are abundant and found in the lower levels (I2-F), but the fragmentary preservation of the remains and the lack of antlers prevents a clear identification. Medium-size deer includes diagnostic elements of *Cervus elaphus*. In particular, the morphology of the M3 shows the anterior entoconid wing and the posterior metaconid wing more separated and the clear step between the 2nd and 3rd lobes is absent. Two specimens, a distal metatarsal from the level G and an upper molar from the level I1, are attributed to *Dama*-like deer, documenting for the first time the presence of fallow deer in the lower levels.

For cervids, anatomical representation is similar to that of level α, i.e., with abundance of limb extremities (phalanxes I and II, calcanei and astragals) (Tagliacozzo et al., 1999). The main difference is the higher proportion of cranial and trunk elements in relation to level α.

The straight-tusked elephant *Palaeoloxodon antiquus* prevails in levels F (45.7%), G (81%) and I2 (48.3%), but it was also found in all lower levels (**Tables 7, 8**). Elephants are represented by some cranial tusk and tooth fragments, trunk and girdle elements. For the appendicular skeleton, only an almost complete right humerus and some indeterminate bone shaft fragments were found.

Large bovinae cf. Bos/Bison fossils were found in all lower levels, excepted for level H (**Tables 7, 8**). Bovines are mainly represented by isolated teeth, the trunk, girdle and long bone shaft fragments. Two tarsals are the only short articular elements. Some fossils show a typical "bisontine" morphology (as for example the square and buccolingually wide occlusal surface of the upper teeth) are quite frequent in levels F (42.9%) and I2 (37.9%) (**Tables 7, 8**). Not all remains preserve useful trait for distinction, but several upper and lower molars possess a distinct swelling just above the cervix, a slightly developed para-, meso- and metastyles/metastylids, a U-shaped enamel in the central cavity and an angular profile of the re-entrant valley between hypoconid and hypoconulid in the M3. These features are clearly indicative of *Bison shoetensacki* (Sala, 1986; Sorbelli et al., 2021).

This faunal list is similar to that of the youngest levels α and A of Notarchirico (Cassoli et al., 1999; **Table 2**), even if mammal fossils recovered during ongoing excavations, unfortunately, are generally poorly preserved and scarcely diagnostic. Two species have been documented during the new excavations, not found in the upper levels (α and A): *Hippopotamus antiquus* in levels G and I1, and *Macaca* sp. in level G (Moncel et al., 2020; Mecozzi et al., 2021a).

The first is represented by four dental fragments, two from the level I1 and two from the level G. The macaque is only documented by a proximal fragment of a right ulna.

About the skeletal distribution of all species, the transportable indices (Voorhies groups and teeth-to-vertebrae ratio) indicate different type of information according the levels (see detailed tables on in Moncel et al., 2020). In unit F, data tend to support the hypothesis of a lag deposit, with a majority of remains of the less transportable groups (78% of the NISP), and a high teeth-to-vertebrae ratio (5,3). Conversely, in unit I1, the majority of the elements (71% of the NISP) belong to the first groups (mainly trunk and phalanges, i.e. the bearing bones), which are usually the first to be sorted by fluvial transport, and the teeth-to-vertebrate ratio is much lower (0,5). For this unit, data rather indicate deltaic or lacustrine settings. In any case, the two skeletal distributions support the hypothesis of fluvial sorting processes, with bone assemblages affected alternately by low and high energy flows (Domínguez-Rodrigo et al., 2018).

Fauna remains are heavily fragmented, mostly represented by isolated teeth and bone fragments, the majority of which are less than 50 mm. The low identification indexes (the number of anatomically identified remains out of the total number of remains) reflect the high degree of fragmentation of the assemblage. Very rare elements are complete or almost complete (13.8% of the NISPa). Among them, we count the complete elephant humerus from level H. This bone was lying lengthways in relation to the trench, and was lying flat in relation to the level. It is interesting to note that, like in level α, the largest remains are generally the most abraded and weathered, possibly due to longer burial time and prolonged surface exposure. This is the case for the elephant humerus, which presents high degrees of abrasion and weathering.

No anatomical connections were observed during the excavation. Dry and green bone fractures are the most recurrent type of fragmentation, respectively 58% and 45% in unit F and 44% and 32% in unit I1 (**Table 9**). Recent breakages are also very common, 90% in unit F and 66% in unit I1, and almost one third of the remains present indeterminate fractures in both units. In a few cases, small internal and cortical notches are associated with green bone fractures **(Fig. 7**).

As for bone surface modifications, although the bone destruction indexes (the number of isolated teeth out of the total number of anatomically identified remains) indicates a relatively good state of bone preservation (between 22% and 24% in units F, G and I1, and a range from 13% for I2 to 46% for H), about a third of bone surfaces are illegible as a result of post-depositional alteration (**Table 9**). Cracking, desquamation, concretion, chemical corrosion and abrasion have modified the assemblage. They may be mainly related to the effect of climatic and edaphic weathering, water exposition and transport and/or trampling. Some white and thin crusts, possibly calcite, cover a large proportion of bone surfaces (**Fig. 8**). As in the Alpha level, natural abrasion is the most common post-depositional alteration, reaching almots a third to half of the faunal remains, respectively in layers F and I1. Indeed, many random striations, glossy surfaces and smoothed edges were observed, highlighting the strong effects of abrasion on the bone assemblage (**Table 7**). No or very scarce elements have shown carnivore marks (n = 3 in level I1) and no clear cut or percussion marks could be identified within the faunal series from unit F to J. Thus, unlike in level Alpha, where some notches were identified as resulting from anthropic percussion, here we could not confidently establish the presence of anthropic marks. Indeed, some trampling and water abrasion experiments have shown the presence of fresh bone breakage and small notches, in addition with scratches and polish marks on the bone surfaces (Fiorillo, 1989; Fernández-Jalvo & Andrews, 2003; Blasco et al., 2008). Therefore, in the absence of cut marks in this studied series, and in the presence of abrasion striations and polishes, it does not seem prudent to attribute the presence of the notches to an anthropic origin. Violent post-depositional events, such as hydraulic transport or trampling, seem to us to be the most plausible and wise interpretation in such a context.

4.1.2. Small mammals

Arvicola mosbachensis is the best represented species (MNI=6; NISP=22) **(Table 4)**. In all the analysed specimens, the mimomyan enamel is well recognizable while no rooted or incipient rooted teeth are present. *Microtus* cf. *nivaloides* remains only consist of a broken m1 with closed T4-T5 and confluent T6-T7 related to a well-developed anterior cap. The tooth is unrooted. Two m1 with confluent T4-T5 were recognised in layers I1bc and I2b, allowing us to assign these molars to *Microtus* (*Terricola*) cf. *arvalidens*. One left M_1 attributed to *Microtus* (*Terricola*) *savii* (a species that appears in Southern Italy during the Late Pleistocene, see Petruso et al., (2011) for details) was found in Unit H2. It is possible that this specimen comes from reworked layers above this upper unit. Some molars and incisors, initially attributed to Lagomorpha indet., were found in Units G, H, I1, I1bc, and I1c. A reference collection is required for the definitive identification of these remains, but we can suggest that they might be assigned to *Lepus* sp. due to their morphologies and dimensions. A proximal portion of a relatively small radius was attributed to *Talpa* sp. This specimen comes from Unit I1 and, up to now, is the only Eulpotyphla representative of the new material collected at Notarchirico.

Considering the species present in layers I1, I1c, and I2b, the small mammal assemblage of Notarchirico is closely related to the previous published material (Sala, 1999), allowing us to attribute this locality to the beginning of the Early Toringian (*Arvicola-Microtus* zone, *Arvicola mosbachensis* subzone) (Sala and Masini, 2007).

Part of the analysed sample (16 remains) presents corrosion marks due to causes other than digestion (**Fig**. **8**). These marks are multiple and pointed and sometimes the enamel is corroded up to the dentine. The cause of this type of mark has not yet been identified but it could be tentatively related to post-depositional processes, such as sediment corrosion processes **(Table 10)**. Finally, corrosion due to plant roots was identified on three remains, while trampling traces were observed on a single specimen attributed to *M. (T.)* cf. *arvalidens*.

Among the analysed material, nine arvicolids bear light to heavy digestion marks **(Table 10)**, showing that at least some of the small mammals were accumulated by predators such as Strigiformes. Unfortunately, it is not possible to identify the predator category due to the scarcity of digested remains.

4.2. Lithic assemblages

4.2.1. Taphonomic data from raw materials (anthropic and natural)

Artefacts are mainly on nodules of various types of chert and limestone pebbles and cobbles, which are abundantly available along the palaeochannels. Most of the nodules are cubic or slightly rounded, 10 mm to 35 mm long, with some larger exceptions (70-90 mm). Three main lithotypes were identified: silicified calcarenites (flysch chert), nodular chert (carbonate platform/ramp) and radiolarite (basin). The partial presence of neocortex demonstrates the secondary origin of the raw materials (Synthem of Palazzo San Gervasio), associated with the Flysch Rosso and Flysch di Faeto Fms (Eramo et al., in Moncel et al., 2020).

A stereomicroscopic analysis of artefacts aimed to identify post-depositional surface modifications (**Table 6**) shows how weathering varies according to the lithotype and stratigraphic position. Surface encrustation due to micritic calcite cementing volcanic minerals and lithic fragments, as well as terrigenous grains, was observed on all samples. Chert desilication and consequent formation of white patina (Burroni et al., 2002; Fernandes et al., 2007; Caux et al., 2018) is slight and only affects small portions of the pieces. It was mainly attested in layers F (40%) and G (56%) , and was not observed on radiolarite.

The presence of black patina is more frequent in layers H2 (60%) and G (44%) and does not cover the whole surface of the artefacts (Moncel et al. 2020, **figure S15g, h**). Radiolarite does not show black patina. Under the stereomicroscope, it appears more or less dense on the surface, with a gloss ranging from dull to metallic. Black patina does not form a continuous and superimposed film, but rather infiltrates surface micropores. Surface measurements with ED-XRF on black patina did not detect an increase in Fe and Mn compared to the unaltered portions of samples (Moncel et al. 2020).

Black patina occurs on both archaeological and geological chert in the excavated area. Comparative analyses of four patinated chert pebbles showed analogous features already described for archaeological pieces. On a fresh fracture transverse to the surface, we observed that black patina can be present on an apparently unaltered or desilicated surface **(Fig. 9)**. On the thin section, NOTG9 appears zoned, with a brownish rim about 500 µm thick which becomes darker closer to the pebble surface (**Fig. 10**). In-depth SEM-EDS analysis of the thin section ruled out the presence of Fe and/or Mn oxides (**Fig. 10d**), pointing to an organic origin.

A faint glossy patina (Howard, 2002; Levi Sala, 1986) is present on artefact surfaces (see below), combined with ridge rounding. It seems to be correlated with white or black patina in percentage per layer but not on the same sample. In silicified calcarenites, relict coarse calcite grains were dissolved by a sediment water solution, leaving pits on the surface of artefacts and pebbles**.**

Table 3 reports the mean pH values measured in the excavated layers, ranging between 5.3 and 7 and progressively decreasing downwards.

4.2.2. Taphonomic data. A special focus on the lithic assemblage from layer F

A total of 133 chipped stone tools (127 chert items, four limestone items, one calcarenite item, one quartz item) from layer F were analysed and the results are summarised in **Table 11**.

In spite of the fact that weathered surfaces are by far the most numerous, a number of artefacts (17 items, 13%) bear well-preserved surfaces (**Fig. 11a**), suggesting some fast-sealing episodes of tools in the palimpsest.

The scarce presence of rolled artefacts (14 items, 10%) shows that the lithic assemblage of layer F is composed of relatively few items transported by high-energy water flow. Evidence of mechanical alterations is also limited (14 items, 10%), suggesting that trampling activities only marginally affected the artefacts.

The most common alteration observed in layer F is a diffuse brightness of the lithic surface (94 items, 70%) with different degrees of intensity **(Fig. 11bd)**.

This alteration is defined in literature as glossy patina (Rottländer, 1975, Fiers 2020; Levi Sala 1986a,b). Glossy patina develops as a result of the dissolution and reprecipitation of silica on the chert surfaces. This alteration is thus triggered by a chemical process but it can be combined with the mechanical process of abrasion due to the action of fine particles. This mechanical process, known as soil sheen, is characterised by the slight scratching of the microsurface, producing large bands of oriented polishes **(Fig. 11d)**.

In layer F, soil sheen is clearly visible on many artefacts, but it does not affect the whole assemblage. In addition, some artefacts show bright spots and deep randomly oriented striations pointing to strong localised abrasion due to the rubbing with other lithics or stones from the deposit (**Fig.11**).

The main alteration process observed in layer F is clearly the formation of gloss due to dissolution processes that affected the whole assemblage. This gloss presents different degrees of development, clearly distinguishable at high magnification (**Fig. 11**). In its more developed state, the process of dissolution caused the break-up of the microsurface, creating localised collapses and a typical cratered appearance (**Fig. 11**).

In layer F, 70% of the artefacts underwent varying degrees of dissolution. However, a consistent number of lithic items (28%) was only affected by the initial stages of this process, or not affected at all (14%), and it was thus possible to investigate use-related micro-wear. Moreover, on account of the low degree of mechanical stress due to trampling, no edge-damage (pseudo-retouch, fractures, etc...) masked use-related macro-wear.

4.2.3. Considerations on the cutting edges of the lithic material and retouches

Regarding the whole lithic material, in particular the chert, only 10% of the retouched material has been discarded for each layer due to irregular retouches and considered as unretouched. Few traces of mechanical alterations have been observed by microscopy on the material of layer F (see above). In layer G, due to disturbed material, and layers I1-I2, more than 50% of the lithic pieces present slight smooth edges without micro-scars. But the rest of material indicate fresh cutting edges both on the unretouched and retouched flakes without micro-scars, suggesting slow disturbances of these units, as for layer F (**Fig. 12, n°2ab, 3, 4**).

The retouch, when it exists, is regular on a part or the total of the edge, thin or invasive, both on a back or a sharp cutting edge. We note that retouch substantially modifies initial blank shape in many cases. Most of the flakes are very small (10-20 mm) and retouched nodules are longer and wider (20-40 mm). Retouched edge angles vary from 30-50° to 90°depending on retouch type. Retouch on nodules is often abrupt and denticulate with a regular angle close to 90°. On the frequent backed flakes (use of the core edges), retouch is always opposite the back suggesting both technological and functional reasons for the high frequency of this type of flakes. Flakes and quadrangular nodules (direct shaping process) in chert could be considered as a complementary tool kit in terms of size and possibly functional purposes.

A double patina can be observed with the retouch (**Fig. 12, n°1ab**) indicating humid conditions on abandoned material after the departures of hominins. Duration is, however, impossible to estimate. The double patina on a flake in layer F, a flake in layer I1, and a flake-tool and a core in layer I2 suggests a recycling of pieces. It has been considered as evidence of repeated occupations and possible recovery of discarded tools.

Regarding the denticulate retouches, the anthropic feature of this retouch has been often questioned (i.e. Valin et al., 2001; Dibble et al., 2006; Thiébaut, 2007; Theodoropulou, 2008; Picin et al., 2011; McPherron et al., 2014). For all the layers, the regularity of the denticulate retouch on the abrupt edges of small nodules or flakes (on one side or periphery) and the regular angles (80-90°) along the edges suggest intentional retouches and not pressure by post-depositional processes (see i.e. for instance Picin et al., 2011) (**Fig. 13**). When the retouch was irregular, the pieces were excluded from the sample out of caution.

For the limestone material, a frequent chemical and superficial alteration can affect the surface and erase a bit of the removal edges (above all for layer G), but does not prevent the technological analyses and the observation of the cutting edges and the macro-traces. For the few limestone flakes, the retouch is rare and limited, but regular in shape and size. For the LCTs (limestone and siliceous stones), micro-traces and macro-traces are observed on some parts of the cutting edges. Only the regular retouches were considered as final retouch to rectify the edges. They are justified both by the technological analysis of the tools and their location. Few crushing traces are observed on the cutting edges that are fresh for chert. Traces of recycling were only observed on a triface/biface on a calcarenite pebble with centripetal smooth removals on one flat face (lower face).

4.2.3. Residues

Eighteen of the 50 stone artefacts examined in layers H, I1 and I2 showed possible use-related residues. Residues, including feather barbules, plant, and wood co-occur with wear patterns suggesting they are related to use (Moncel et al., 2020). In the current context, the preservation of use-related residues suggests that some stone artefacts are in primary context and were buried fairly rapidly after being discarded. Longer exposure on the surface or movement by water greatly decreases the likelihood that residues will survive. Thus, while the evidence from the surface analysis shows patination and rolling on some pieces, the residue preservation suggests that others were undisturbed.

4.3. Spatial patterning of the archaeological material

Layer F is a dense bed of pebbles with at least two sub-levels. The material, natural or retouched, does not show specific orientation (**SOM Fig. S15, S16**). The dense distribution of the archaeological material (density of pebble tools among the pebbles) is possibly a consequence of palimpsests and successive occupations (**Fig. 14, 15, Table 12**). The faunal remains are mainly concentrated in the western part of the excavated area, in a thicker and less eroded deposit, except for elephant tusks dispersed in the eastern part. Bones are located on the “pavement” or between pebbles with no specific orientation. We observed two sub-levels of pebbles during the excavations with a horizontal distribution of fauna and lithics (see Fig. S10, S11). The results of the silhouette method for the K-means clustering analysis of the faunal material suggest an optimal number of 3 clusters. The densest one plots in the western part of the excavation area is comprised of faunal remains. The lithic material is distributed among two main clusters, more concentrated in the middle part of the excavated area where all artefact categories are found. LCTs are dispersed in the west and middle part of the site **(Fig. 14, 15, SOM S10, S11)**.

In **layer G**, pebbles are dispersed among a coarse-grained deposit, the remains of a pebble pavement. The layer was excavated over a depth of more than 50 cm but the material is mainly concentrated over a thickness of 30 cm in the middle part of the unit, corresponding to sub-unit G1. Post-depositional disturbance thus appears to be limited in thickness. Graphs indicate that the disturbance affected the vertical more than the horizontal distribution of the material (**SOM Fig. S15**). This disturbance is characterized by bones in vertical positions **(Fig. 16, 17, S12)**. The spatial distribution of artefacts covers a larger surface than for faunal remains. The latter show no specific distribution in terms of species or size of remains. The results of the silhouette method for the K-means clustering analysis of the faunal material suggest an optimal number of two main clusters and some secondary clusters, while lithics are concentrated in at least three clusters and are more vertically dispersed than bones. This could be due to the small overall size of the lithic material allowing movement down into the deposit (cores, flakes, retouched nodules less than 2 cm long). However, the largest tools, pebble tools and Large Cutting Tools are as dispersed as the small pieces, with no specific distribution pattern. Inverse grading or random vertical distribution of the lithic material could explain this distribution by the coarse aspect of the sediment. All the main categories of pieces are concentrated in the main clusters, suggesting that the disturbance observed in the field did not affect clusters in terms of the size of objects but rather resulted in a general mixture **(Fig. 16, 17)**. The same applies to bones, which are not grouped by size or animal size in the squares.

Layer H is the poorest layer in term of the quantity of material, and was excavated over a reduced surface. However, the density by m² is higher than for layer I2 (7.3 and 4.3). It is characterised by the discovery of a complete elephant long bone (humerus). The lithic material was lying flat, dispersed around the elephant humerus (sub-level H2). The results of the silhouette method for the K-means clustering analysis of the faunal material suggest an optimal number of two clusters of faunal and lithic remains, distributed in two sub-levels, corresponding to the sedimentological sub-units. Due to the dispersion of the rare material, it is difficult to clearly relate the lithic material to the faunal material. The Elephant humerus does not show any traces of human activity. The residues observed on a sample of artefacts indicate only plant and wood uses. No cluster related to animal size was observed. The material from layer H is thus probably highly disturbed in terms of spatial distribution and patterning by fluvial and post-depositional processes but the hypothesis of sporadic hominin visits to the site, leaving only flakes and flake-tools, cannot be ruled out. No cores have been discovered so far **(Fig. 18, 19)**.

Layer I1 is a 30-cm-thick bed composed mainly of yellow sands and some small and large dispersed pebbles. There is also a thin lens of small pebbles with archaeological material (I1a). The layer was excavated in the trench and over a larger surface partly covering layer I2. The results of the silhouette method for the K-means clustering analysis of the faunal material suggest an optimal number of three clusters of faunal remains, including one of considerable size. These were recorded with a huge concentration in the thickest part of the deposit on the North. The layer is less preserved in the southern part due to the erosion of the deposit on the hill slope. The material is not vertically oriented but rather shows diverse orientations and does not show dipping towards the South (**SOM Fig. S15**). Species, bone size and anatomical categories are dispersed homogeneously throughout the layer. Regardless of category, the lithic material shows the same distribution as faunal remains, with similar clusters. The largest artefacts are no longer located at the bottom of the deposit **(Fig. 20, 21, S13)**. The vertical distribution clearly shows the dispersion of the material in the deposit with a higher density at the bottom, at the limit of underlying layer I2. This may possibly indicate palimpsests with a denser occupation at the beginning of the deposit, a recovery of material by hominins (see double patina on some pieces) and perhaps by the mixture of some material coming from layer I2 by post-depositional processes.

Layer I2 is a partially preserved bed of pebbles with a disparate density of material on the excavated surface. The results of the silhouette method for the K-means clustering analysis of the faunal material suggest an optimal number of four clusters for fauna remains and two clusters for lithics. Visual inspection of the K-means cluster analysis suggests a random distribution of the different lithic categories. Indeed, being simple distribution maps, one could see a different pattern in the same map, e.g., chert flakes plotting more North and higher in elevation with respect to chert cores. Indeed, the largest pieces are dispersed on or among the "pavement" of whole pebbles. Bones and teeth do not show any specific orientation and species size is not related to any specific distribution, except perhaps for a concentration of very large-sized remains in some squares. The material is concentrated on some squares. The horizontal distribution of the lithic material is similar to that of faunal distribution, possibly due to the partial preservation of the bed of pebbles **(Fig. 22, 23, S14)**.

5. Discussion. Contribution of Notarchirico to the analysis of Middle Pleistocene human occupations in Western Europe

The various facies of the stratigraphic units at Notarchirico correspond mainly to palaeochannel infillings intersected in places by the action of low-energy currents. The fine components of these deposits derive from the alteration of volcanic fallout. The layers incorporating cobbles and gravels correspond to slope destabilization processes, which intervened after the arrival of masses of tephra and the release of lateral contributions from older conglomeratic deposits. The fine components of these deposits almost exclusively derive from the alteration of the volcanic material (Raynal et al., 1999; Moncel et al., 2020). The faunal and lithic remains are dispersed on pebble-cobble “pavements”, while others are part of sandy-silty deposits with dispersed pebbles indicating diverse degrees of preservation of the archaeological material and different post-depositional processes (layers F and I2 *v.s.* layers G and I1). This also indicates either successive phases of deposits/occupations or deep disturbances.

Regarding the faunal remains, if we refer to the M. Piperno’excavations, the animal bone remains from level α of Notarchirico, a palaeosurface with abundant faunal remains and artefacts extending over about 62 m², underwent previous taphonomic analysis (Tagliacozzo et al., 1999). On account of the difference in the size and number of bone remains between level α, the upper level in the Notarchirico sequence, and the lower levels considered in this paper, the two areas are not directly comparable. Level α contained 2,406 bone remains, 645 of which were specifically determined, including mainly *Dama* (53%), followed by Elephantidae (25%) (*Elephas antiquus* [=*Palaeoloxodon antiquus*] in Piperno and Tagliacozzo, 2001), *Bos*/*Bison* (11%) and a few remains of *Cervus*, *Lepus, Emys* (see Table 1 in Tagliacozzo et al., 1999; Cassoli et al., 1999). The analysis of level α considered the distribution of skeletal elements, bone clustering and orientation, surface modifications and fracturing. About half of the bone surfaces show different degrees of abrasion due to water action from slight to strong stages. The detailed observation of palaeosurface α suggested multiple origins for the deposited bone remains. They were transported to the studied area by water flow and bank erosion, which caused a second deposition of external elements. However, they might also have derived from the carcasses of animals that died naturally or were chased by carnivorans or humans near the water stream. Concerning the interpretation of the faunal accumulation context and the significance of hominin or carnivoran activities at Notarchirico, the two taphonomic analyses carried on the formerly and newly excavated remains indicate that natural processes appear to have been the main agents behind the formation and modification of the bone bed. Indeed, for now, apart from some notches interpreted as being of anthropogenic origin (Tagliacozzo et al., 1999), no evidence of human activities has been found on the faunal material, in spite of the co-occurrence of stone artefacts and faunal remains (Belli et al., 1991; Moncel et al., 2019). Nevertheless, we must remain cautious in our interpretations. In this lacustrine context, bone surfaces are highly damaged, with a low degree of legibility, which may have led to the disappearance of any anthropogenic or carnivoran surface modifications. Natural abrasion (polish and striations) and encrustations are the main natural alterations. However, like the state and type of fragmentation, they provide information on the post-depositional processes that contributed at least to the final part of the formation of the bone bed.

In conclusion, our data confirm previous observations for level α, i.e., the bone assemblage in the outside trench does not result from a single accumulation agent. It represents a mixture of multiple deposits of animal carcasses, most of which may have died naturally in the surroundings of this channel/lacustrine context, and then have been secondarily transported, sorted and modified by fluvial transport and trampling. As far as the role of water is concerned, skeletal distribution does not a priori point to a lag deposit but rather to a shore deposit or a low-energy deltaic or lacustrine environment, possibly with some more violent hydraulic transport episodes. Thus, abrasion seems to be mainly due to trampling rather than to hydraulic transport, although both factors may have been involved in bone assemblage modifications. Similar environmental conditions may have occurred during the depositional events of level α and layers E to J in the outside trench

Finally, we do not have yet evidence to support any human or carnivore contribution to the bone assemblage. There is an (almost total) absence of direct (cut marks, or anthropic breakage). However, use-wear analysis documented the processing of soft material that could be related to soft animal tissues as well as soft plant tissues, indicates a variety of activities for layer F. It could be indicative that the hominins who occupied these spaces did so to exploit resources of non-animal origin, such as plants (demonstrated through the residues documented on stone tools on layers H, I1 and I2), water or raw materials, which hominin would have used for the stone tools production (Leakey, 1971; Egeland, 2008; 2014; Gaudzinsky, 2005; Yravedra et al., 2016; Pineda et al., 2017b; Pineda and Saladié, 2022). However, we cannot exclude the possibility that some animals were collected and/or consumed in situ by the two types of agents.

Optical and scanning electron microscopy of the lithic component provided useful data for understanding the taphonomic aspects of chert tools. Observations focused on encrustation, and white, black and glossy patina (**Table 4**). The neutral to moderately acidic sediment of the investigated layer hindered silica dissolution (Thiry et al., 2014), whereas it favoured carbonate dissolution and precipitation, as demonstrated by micrite, which partly cemented the layers, in surface encrustations of geological and archaeological chert (**Fig. 6**). However, analysed cherts from the upper layers show more frequent combinations of desilication and black organic patina. This can probably be explained by the increasing effect of organic-rich aqueous solutions at circum-neutral pH on silica solubility (Bennet, 1991; Glaubermann and Thorson, 2012; Thiry et al., 2014), in anaerobic environments (soil, swamps, wetlands, etc.). The limited presence of soil sheen and ridge rounding points to limited movements of the analysed pieces in the sediment. No clear effects of lithology on surface alteration were observed, although radiolarite seems more stable than nodular chert and silicified calcarenite. The analysis of the surface of the 133 chert flakes and retouched flakes from layer F did not reveal white patina. White patina was only observed on calcarenite. The main alteration process observed on artefacts made by hominins in layer F is clearly the formation of glossy patina due to processes of dissolution acting on the whole assemblage, but to different degrees.

How does Notarchirico contribute to our understanding of early human occupations in Western Europe? At many early sites are open-air sites like Notarchirico, the role of human as opposed to carnivoran activities is sometimes difficult to demonstrate (Pineda and Saladié, 2022). The combined presence of hominins and carnivorans is commonly documented in many early assemblages, indicating competing access to herbivore carcasses. Resource availability, adaptation to various environments and types of habitat selection by hominins are some of the main topics related to early human occupations in Western Europe. Habitats with recurrent occupations (open-air sites or karstic refuges) or sporadic sites for carcass acquisition (butchery and meat sharing) are the two main known cases, most of which are located near water areas (i.e., Shea, 1999; Mosquera et al., 2018; Saladié et al., 2019; Yravedra et al., 2021). The reasons underlying hominin choice of sites are often related to the quantity of available carcasses (Pineda et al., 2015), as observed in East African assemblages (i.e., Egeland and Domínguez-Rodrigo, 2008; Domínguez-Rodrigo et al., 2014, 2015; Yravedra et al., 2017; Panera et al., 2019). They can also be related to the availability of raw materials and water resources (Egeland, 2008, 2014; Baena and Navas, 2019).

In open-air Acheulean contexts, some sites provide more data on hominin activities than others, mostly related to the preservation status of bones. This is the case for the Acheulean site of Barranc de la Boella (Spain), with a rich faunal and lithic archaeological record from the late Early Pleistocene. To date, fieldwork has been carried out in three different localities, with the same stratigraphic position: Pit 1 (P1), la Mina (LM), and el Forn (EF). Fossils recovered up until now are almost exclusively from Unit II, dated to 960-781 Ka (Vallverdú et al., 2014). The P1 faunal sample is almost entirely composed of mammoth remains, associated with a lithic sample of more than 100 pieces, including a pick used to prove the early arrival of Acheulean technology in Europe. The site has been interpreted as a butchering site (Vallverdú et al., 2014; Mosquera et al., 2015, 2016). The other two sites, LM and EF, show technological similarities (Mosquera et al., 2016), but with more diversified faunal assemblages (Pineda et al., 2015; 2017b). Bone surface preservation is poor at the three sites, caused by lixiviation, weathering or abrasion (Pineda et al., 2014; Mosquera et al., 2015; Pineda et al., 2017b; 2019). The result of these processes is the almost total absence of anthropogenic modifications on faunal remains, which could be caused by ravaging activities of those hominins not related with faunal exploitation (Pineda and Saladié, 2022).

Chronologicaly and geographically speaking, Isernia La Pineta (Italy) is close to Notarchirico (590 ka; Pereira, 2017). The archaeological formation, with thick and dense layers of bones associated with artefacts composed of pebble tools, debitage products and cores is similar as well. The lithic assemblage is characterized by generally complete reduction sequences, mostly expeditious, and good surface preservation. The raw materials (small chert plates and limestone pebbles) are essentially local. Reduction sequences are aimed at producing sharp edges on non-standardized blanks, with some more complex reduction sequences (usually centripetal-discoid debitage on the best quality cherts). Retouched blanks are not very frequent but well diversified. Shaping is attested on some rare chert elements with converging edges-points (Gallotti and Peretto, 2015; Arnaud et al., 2017). The analysis of archaeosurfaces 3a and 3 colluvio, in sands and thin layers of gravels deposited by ephemeral rivers, demonstrated a strong anthropogenic influence in the formation of the deposit, mainly by the study of bone portion representation. The climate during occupations was arid and cool. The intensive and systematic exploitation of herbivore carcasses by hominins and the intervention of carnivorans are well documented. Both agents acted independently. The site is characterized by a low number of cut marks, probably as a result of post-depositional alterations (weathering, hydric abrasion, lixiviation), but bone breakage on fresh bones is well documented (Hohenstein et al., 2009; Pineda et al., 2020), as are large traces of alteration in the central part of the site (Channarayapatna et al., 2018). The faunal composition is similar to that of Notarchirico, differing mainly in the abundant presence of *Stephanorhinus hundsheimensis* and *Ursus deningeri*, and that of some rarer species (e.g., roe deer, lion, and leopard) (Accorsi et al., 1996; Sala, 1996; Thun Hohenstein et al., 2009; Peretto et al., 2015).

If we enlarge the comparison to younger sites, the site of Atella (Italy) is close to the Notarchirico basin, in a similar volcanic context, and dated to MIS 15 (Abruzzese et al., 2015)., It yielded layers with archaeological material (cores, tools, flakes and debris, with a few LCTs) related to lakeshore landslides. Most of the faunal remains are attributed to *Palaeoloxodon antiquus* and very altered as a result of permanent immersion in water.

The site of Ficoncella (Aureli et al., 2015) also yielded evidence of a short occupation with a few artefacts in an alluvial setting around a *Palaeoloxodon antiquus* carcass, dated to MIS 13. The sediments are sandy and silty deposits with volcaniclastic components. The carcass was probably trapped in floodplain sediments and buried very quickly, as it presents little damage.

Finally, the younger site of Castel di Guido, dated to MIS 11, is a similar open-air site in the Latium region, with elephant remains and associated artefacts (Santucci et al., 2016; Villa et al., 2021) as the Iberian sites (Panera et al., 2014; Yravedra et al., 2010, 2017ab, 2019). Fragments of elephant bones were used for shaping bifaces, bifacial tools and diverse bone tools, as opposed to Notarchirico where large limestone pebbles/cobbles and small chert nodules were available *in situ*. The preservation of these pyroclastic deposits, or fluvial and palustrine phases, depending on the site, is much better than for Notarchirico.

At Notarchirico, during MIS 17 and 16, hominins came back to the site regularly (there are more than ten phases of occupation), although it is impossible to estimate the number and rhythm of occupations. During an interglacial and a glacial event, for almost 100 ka, hominins came back occupying lakeshores or water channels on the same spot. No carnivoran remains have been found so far, unlike at other sites such as Barranc de la Boella or Isernia La Pineta (Pineda et al., 2017a, b; 2020), although their role as modification agents is attested through some tooth marks identified in level I1. The absence of remains is, not conclusive, considering the low density at which most carnivoran species are documented at Isernia La Pineta and others non-anthropic early Middle Pleistocene sites of the Italian Peninsula (i.e., Mecozzi et al., 2021b; Strani et al., 2022). The lithic component and micro-wear traces indicate domestic activities, in addition to possible meat procurement and we can consider Notarchirico as a favourable "foraging site" in an auspicious, attractive and rich environment. Raw materials are available *in situ* and hominins took advantage of them, leading to regular occupations exploiting multiple resources (meat, plants and wood).

The spatial distribution of the material at Notarchirico shows various densities of material (**Table 11**) and clusters of faunal and lithic remains, sometimes combined, but the taphonomic analysis of bones (lack of unquestionable anthropic marks) does not confirm the relationships between the lithic component and faunal remains. Spots of activities, debitage, shaping or for management of carcasses, are not recorded or are erased, perhaps by the recurrence of occupations or dispersion of activities without clear organization, and with possible post-depositional processes that could have affected the distribution of the material. It is different from sites such as Boxgrove (Britain, MIS 13) with localities related to possibly hunting activities (Leroyer, 2016) or Cagny-l'Epinette (France, MIS 9) with clusters of fauna remains, possible evidence of areas of activities (Peudon, 2021). Bones are highly fragmented and teeth were dispersed, as the hominin remain in layer α at the top of the sequence (Piperno, 1999). Some layers yielded bifaces while others only contained pebble tools, some of which are pointed. These LCTs are dispersed on the surface with no clear association with faunal remains or other categories of artefacts. Evidence of knapping or shaping areas is impossible to demonstrate as at Boxgrove (Pope, 2002). The “Aera de Elefante” in levels A1-B at the top of the Notarchirico sequence is the only level with less fragmented faunal remains, namely an elephant skull surrounded by LCTs and smaller artefacts (Piperno, 1999), like in Pit 1, in Barranc de la Boella (Mosquera et al., 2016). In level α, excavated over a large surface, LCTs, including various pebble tools, seem to be concentrated in clusters, but they are also dispersed among highly fragmented bones and the chert assemblage (Piperno (dir., 1999). The Caune de l’Arago (France) illustrates a possible functional link between bifaces (LCTs) and remains of megafauna (i.e., elephant) during cold events (for instance MIS 14), suggesting that these tools could have been effective for working large herbivore carcasses (Moigne et al., 2006; Barsky and Lumley de, 2010; Barkai, 2016). Small tools have been also suggested to be effective in processing megafauna (Venditti et al., 2019; Tourloukis et al. 2018; Guibert-Cardin et al. 2022). However, use-wear analyses at penecontemporaneous sites indicate that LCTs were used for diverse domestic activities (Hardy et al., 2018). The palimpsests and poor preservation of the faunal material at Notarchirico make it difficult to evaluate hypotheses in this domain.

In the same way as most of the upper levels of the sequence, the newly excavated layers F to I2 at Notarchirico illustrate evidence of palimpsests, records of several events, and not living floors. Burial times would have affected the distribution of material more significantly in layer G than in layers I2 and F, with preserved “pavements”. The rarity of crushing marks on the cutting edges of the small flakes, but also on LCTs, could be possibly explained by their protection and thus preservation between and among pebbles, as we observed during the excavations. Double patina and evidence of recycling indicate that the artefacts remained an indeterminate time abandoned on the floor, available for successive occupations and possibly mixed by the palimpsests. Anthropic artefacts could have accumulated independently of carcasses, although the meat residues observed on some pieces also suggest on-site butchery processes. Hominins could have returned to the site regularly to retrieve various local resources, as suggested by the recycled pick in layer G. Few data so far can be used to assess early hominin land-use patterns, and in particular mobility. The strontium isotope study of the child’s tooth demonstrates the limited mobility of the Isernia La Pineta human group, relying mainly on local resources, like at Notarchirico. Data relating to isotopes at the time of gestation are the same as those relating to the place where the child died, revealing that the mother did not move, or returned regularly to the same place for about seven years (Lugli et al., 2017). The density of lithic material at Notarchirico, as at Isernia La Pineta, does not yield any evidence of the intensity and duration of each hominin visit. Moreover, the excavated area is limited. Hominins left flakes, cores, pebble tools and bifaces after their departure and the pick found in layer G indicates the recycling of an earlier tool (smooth removals on one face), suggesting the re-use of pieces abandoned on the ground in previous occupations (i.e. Titton et al., 2021). There are also some traces of recycling chert pieces. This suggests that at least some tools remained exposed for some time before burial. This hypothesis also explains the poor preservation of bones, the patina on some chert and weathering of limestone pieces. However, the low degree of mechanical stress due to trampling prevented edge-damage formation (pseudo-retouch, fractures, etc. ….), and enabled us to document macro-wear due to use. The presence of lithics with pre- and post-depositional black patina points to wetland conditions at the time of flaking, which also continued after abandonment.

Conclusion

New fieldwork at Notarchirico yielded five archaeosurfaces dated to more than 668 ± 6 ka. The $^{40}Ar/^{39}Ar$ ages point to the rapid deposition of the fluvial sedimentary complex during the period encompassing the end of interglacial MIS 17 to glacial MIS 16. The youngest eruptions identified in these levels correspond chronologically to the Toppo San Paolo sub-synthem of the Vulture stratovolcano (Barile synthem) dated in the literature to 679.6 ± 19 ka (Piano Regio Formation in the Venosa Basin), or to the Spinoritola sub-synthem (Foggianello synthem), dated to 693.8 ± 19 ka (Fonte del Comune Formation in the Venosa Basin).

Hominins probably lived nearby and took advantage of these palaeochannels to avail of local small chert nodules and limestone cobbles. Hominins possibly came to exploit large mammal carcasses but there is no clear evidence of this so far on the faunal remains whose bone surfaces are very badly preserved. Use-wear on small flakes and nodules indicates mixed actions. Residues attest to plant processing. Bifaces and bifacial tools present macro-traces on the edges resulting from working undetermined hard materials. Evidence of varied activities probably attests to diversified behaviour and spatial exploitation. Some evidence of recycling lithic materials is observed, suggesting recurrent hominin presence on the site. The gathering of small chert nodules and the production of very small flakes indicate adaptation to local raw materials or cultural traditions aiming to intentionally produce small end-products.

The multidisciplinary approach to the material did not reveal any spatial organization of the occupations or differentiate occupation events. Taphonomic analyses indicate post-depositional processes on palimpsests erasing the features of each passage. Each archaeological layer might be one phase of multiple hominin halts at the site, which thwarts our understanding of habitat organization. LCTs are not specifically located near faunal remains, and small flakes and retouched nodules are dispersed. This distribution is due to episodes of post-depositional disturbances affecting the surfaces of the archaeological material and their location before burial. The density of the material is more similar to that of Isernia La Pineta than to sites with a once-off event with a single elephant carcass. This attests to regular visits to Notarchirico over time by hominins, perhaps to avail of water, raw material resources and potential herbivore carcasses. These hominins left tools, including bifaces made on locally available stones. Due to the limited size of the excavated areas and the distribution of the material, we cannot consider the *in situ* mobility of pieces with workshop areas, as was possible at la Noira excavated over 100 m². Large slices of information are thus missing, and our understanding of how hominins organised habitats, the duration and frequency of their visits throughout the year is truncated. It was not possible to clearly estimate occupation seasons.

Bifaces were found lower in layer G, dated between 675 and 695 ka, providing the earliest bifaces in Italy and pushing back the age of the emergence of the Acheulean between MIS 17 and 16 in Italy. Repeated human occupations occurred in both glacial and interglacial climatic conditions. The technological shift between layers G and I is not reflected by core technology, which is similar to core-and-flake assemblages (Mode 1) and some other early records, Acheulean or not (TD6 Atapuerca in Spain, prior to 770 ka, Isernia La Pineta (590 ka), Moulin-Quignon at 650 ka in the North of France or la Noira at 700 ka in the centre of France), unlike other penecontemporaneous and younger sites (Ollé et al., 2013; Antoine et al., 2019; Moncel et al., 2013, 2020; Rineau et al., 2022). It is lso not due to the raw material availability as pebbles are present in high quantity. The lack of large pebbles-cobbles in some layers in the upper part of the sequence (for instance layers E/E1) does not explain the lack of bifaces

(Santagata et al., 2020). The core technology of the whole sequence at Notarchirico, from layer F to level α (excavations of M. Piperno), is similar to the technology applied in layers G and I at the bottom of the sequence. Core technology was thus unchanged for at least 80 ka (Santagata et al., 2020; Moncel et al., 2019, 2020). Layers A, A1, B, D, F and G in the upper part of the sequence yielded some bifaces (Moncel et al., 2019). The bifaces found in the lowest level (layer G) are similar to those found in the upper layers of the sequence. Taphonomic data from faunal and lithic remains and the spatial distribution of the material do not enable us to identify settlement and behavioural patterns. They attest to similar post-depositional processes over time, probably due to the location of the site near water channels, which affected the abandoned material.

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-Availability of data and material: The material si stored at the Museum of Venosa (Basilicata, Italy) and available by permission of the superintendancy of Basilicata.

-Authors'contributions

MHM, CL, GE, GF, CD, AC, CB, BH, AP, VR, MC, BS, MA, BM, AI, RS wrote the manuscript
MHM, CL, GE CB, AP, VR prepare the figures
MHM, AP, MC, BM, AI made the fieldworks
CD, AC, CB, AP, BM, IA, BS, RS worked on the faunal material
GE, GF worked on the raw materials
CL made the micro-wear analyses
MHM, MC, MA worked on the lithic assemblages
VR made the spatial distribution maps
All authors reviewed the manuscript

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Captions figures

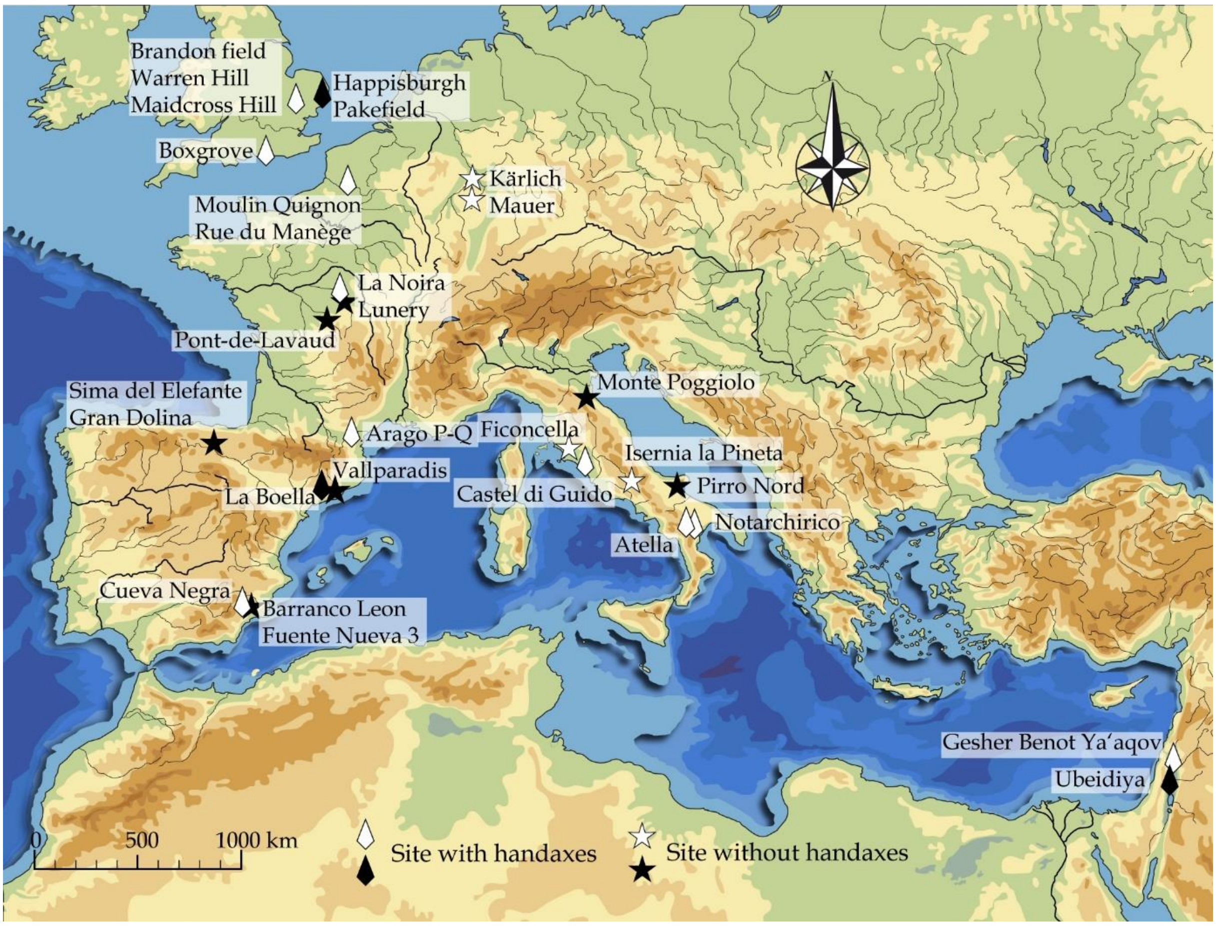

Figure 1. Map of some penecontemporaneous sites with Notarchirico (from Moncel et al., 2021). Star: without handaxe. Diamond: with handaxes. In black, Eraly Middle Paleolithic sites older than Notarchirico. In white, Middle Paleolithic sites pene-contemporaneous and younger than Notarchirico.

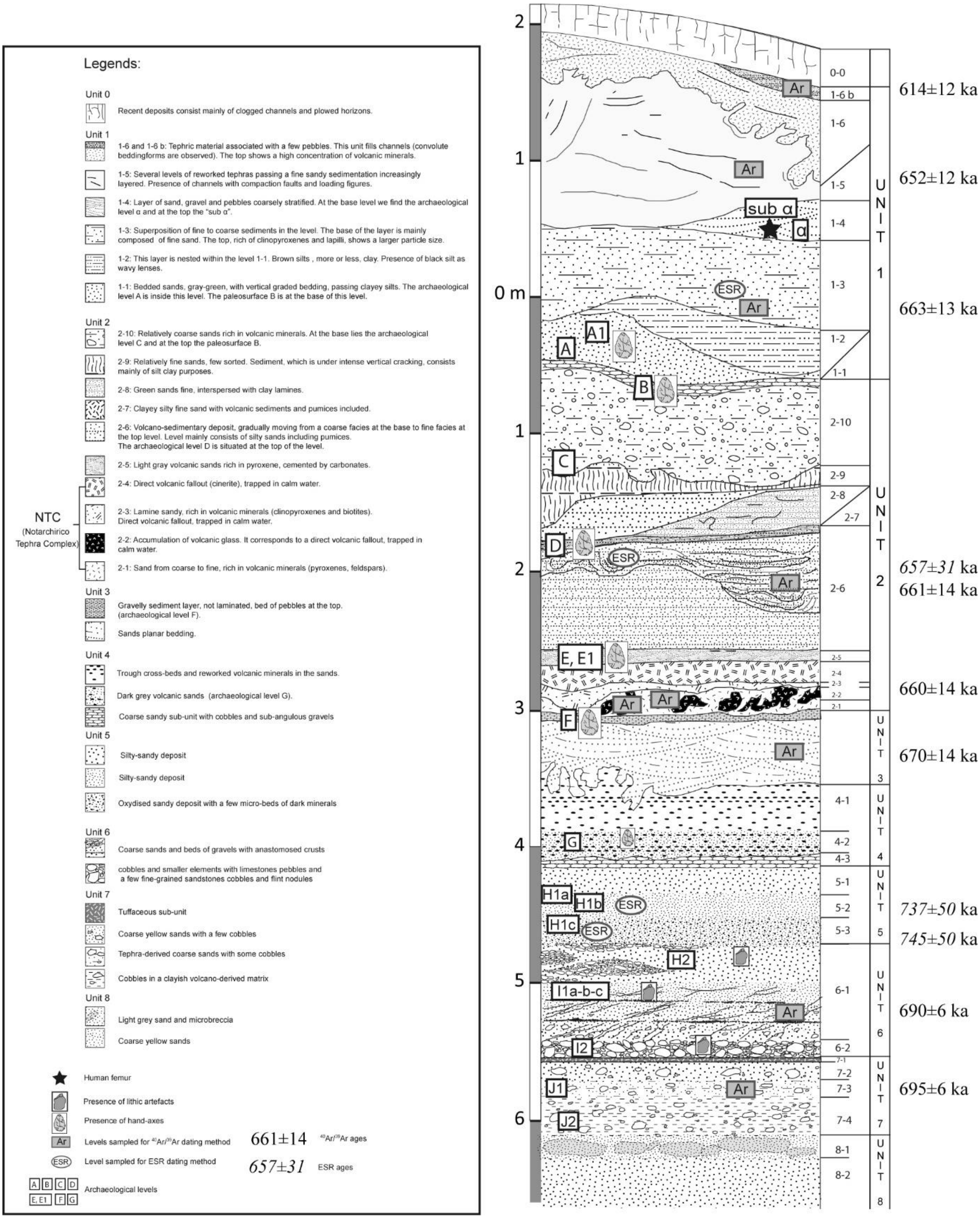

Figure 2. Stratigraphic log of the Notarchirico sequence with ages and archaeological units.

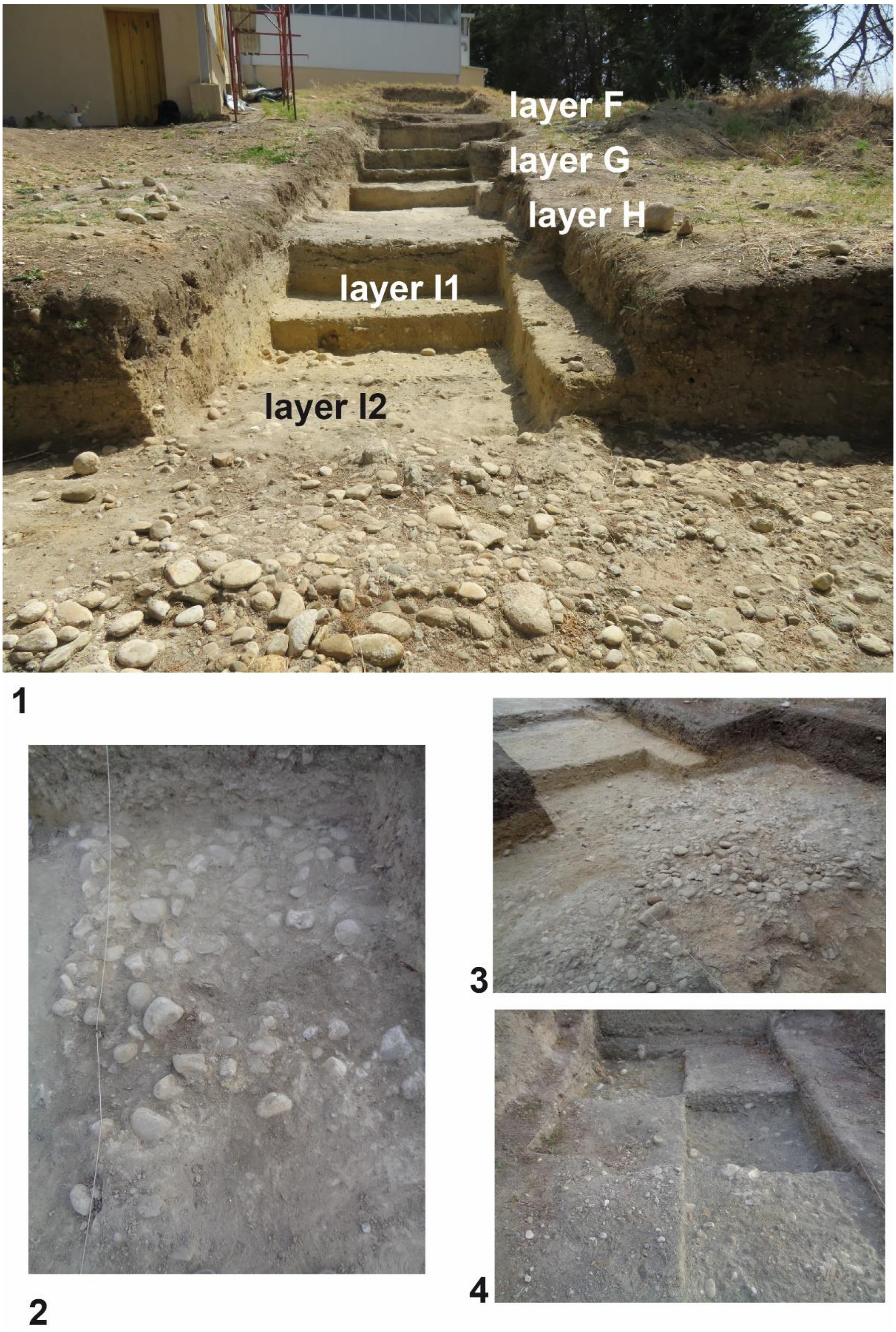

Figure 3. View of the archaeological layers of the new excavations at Notarchirico

1. General view of the trench with the layers
2. Bed of pebbles in layer F during excavations
3. Bed of pebbles in layer I2
4. Layer G

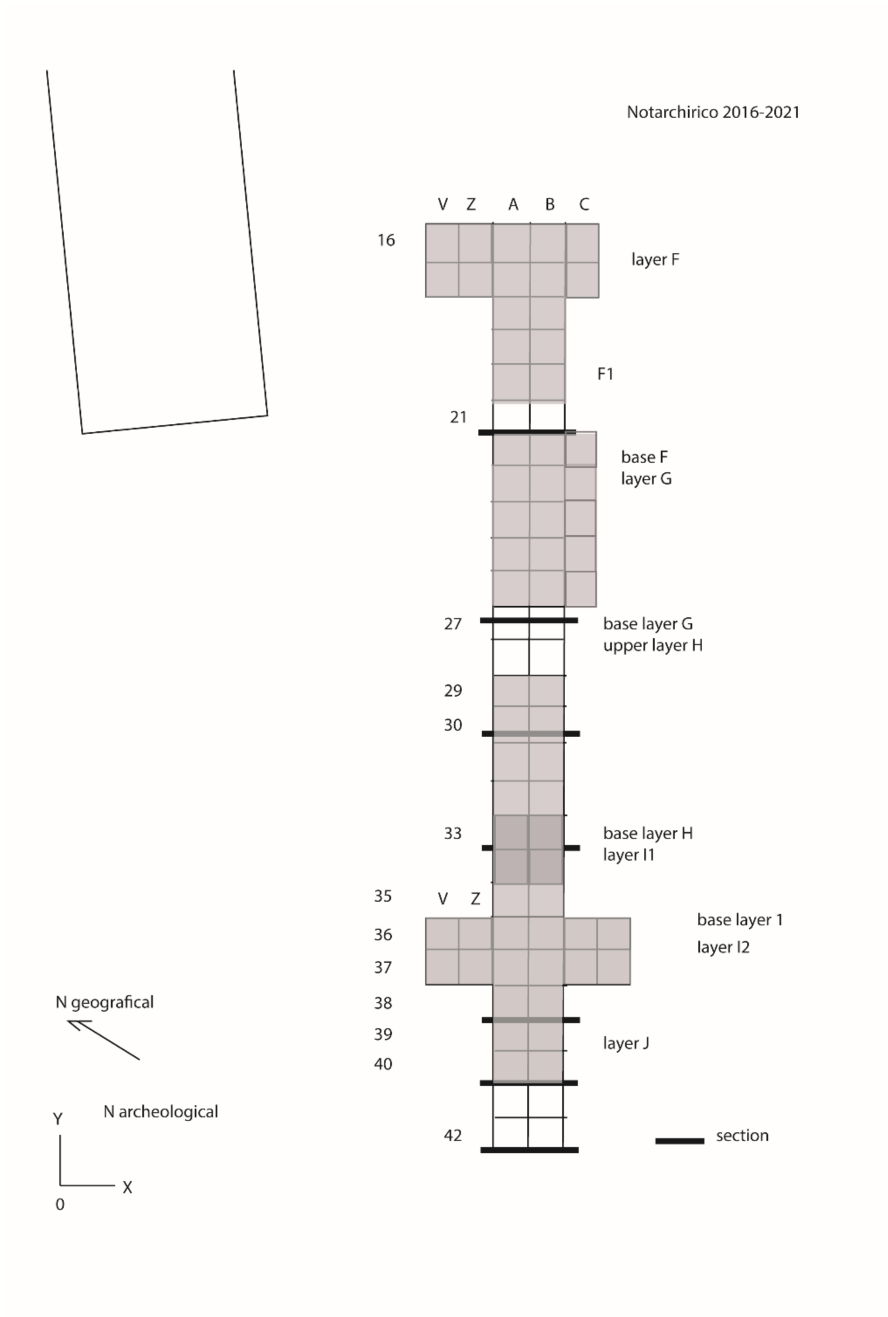

Figure 4. View of the excavated areas in the trench (2016-2021 fieldwork).

(Aerial photo by UAV, D'Andrea in Moncel et al., 2020)

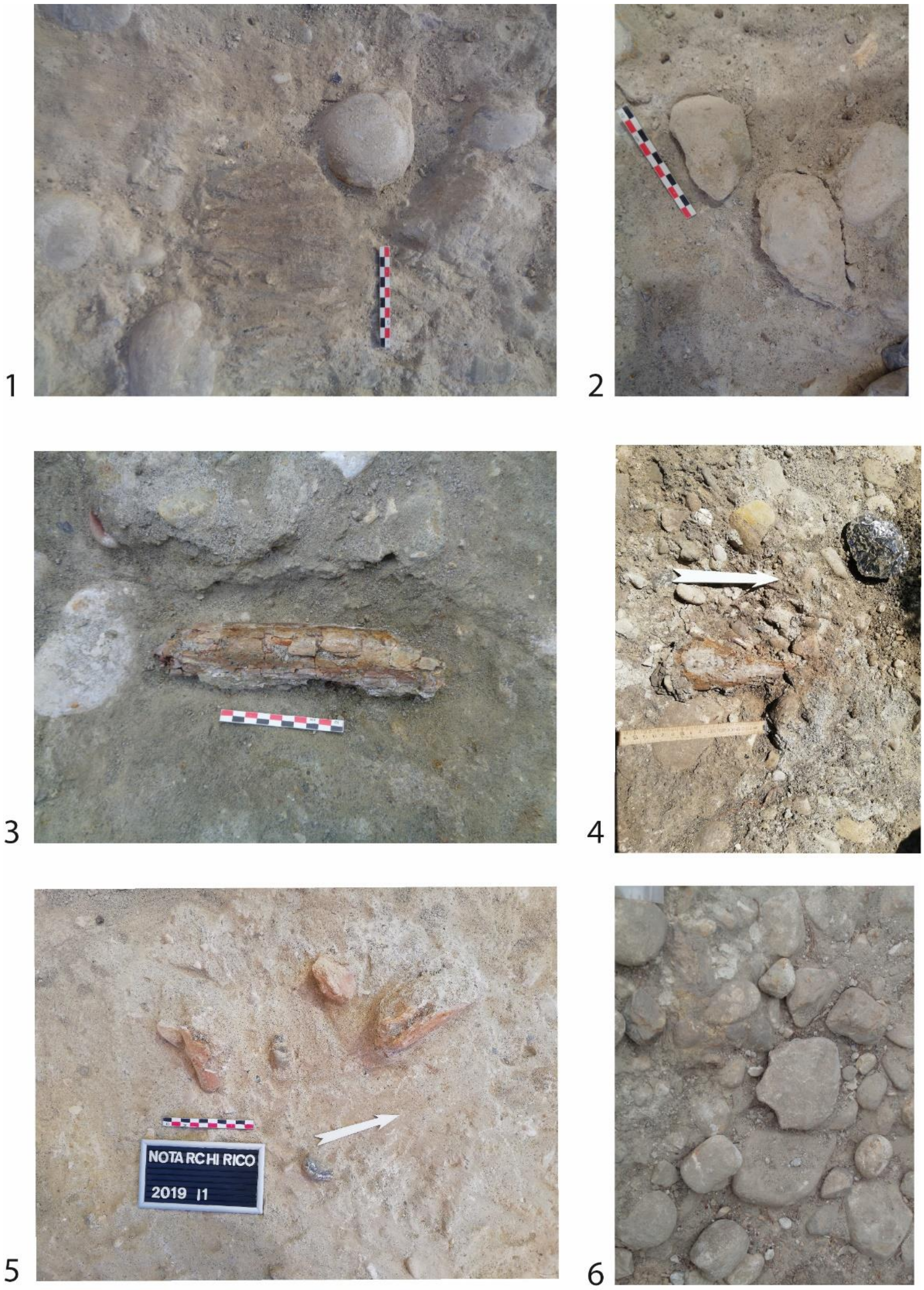

Figure 5. Material *in situ* at Notarchirico and view of the poorly preserved faunal remains

1. Elephant tooth and pebbles in layer F
2. Bifaces in limestone in situ in layer F
3. Fragmented long bone in layer G
4. Fragmented bone in layer I2
5. Fragmented bone in layer I1
6. Pebbles and a pebble tool in layer I2

(Photos M-H. Moncel)

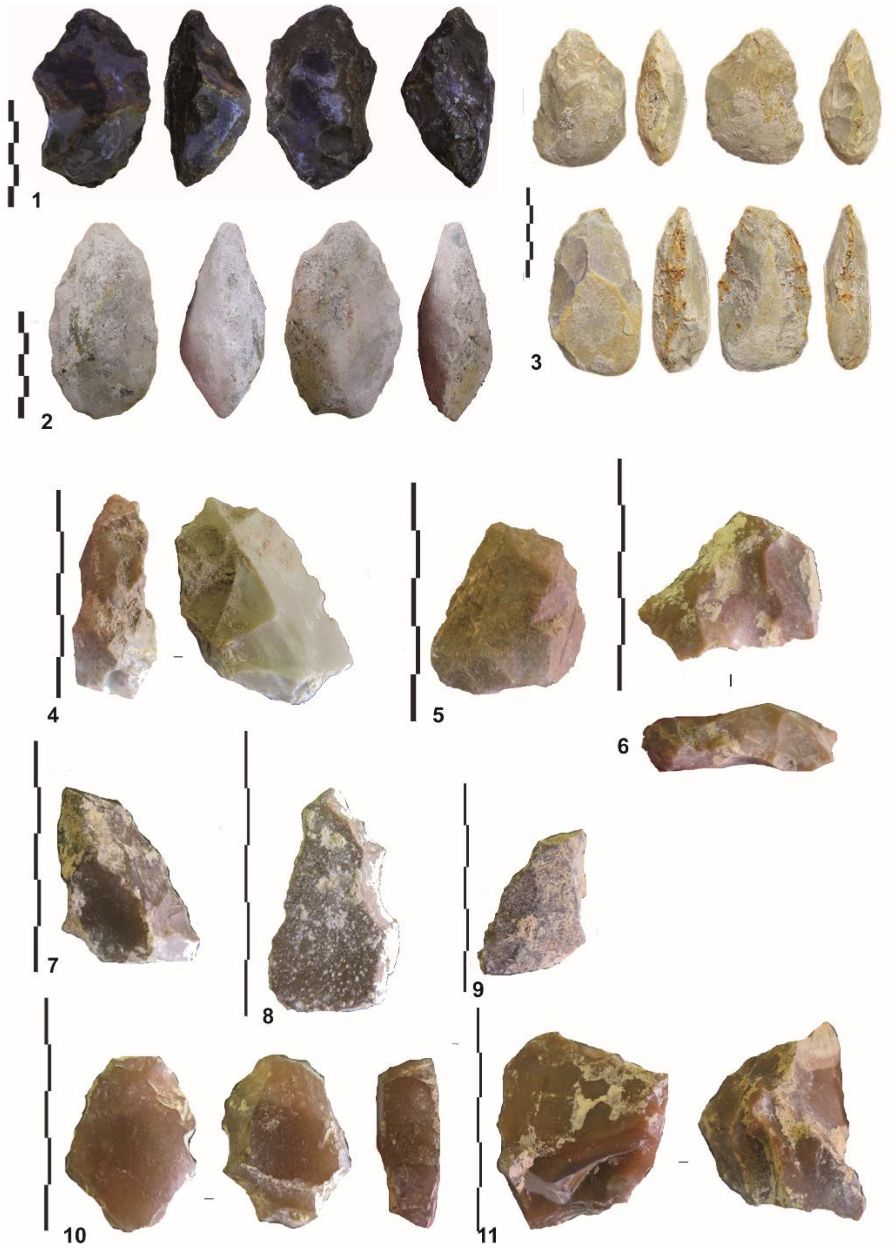

Figure 6. Lithic assemblages from the new excavations of Notarchirico

1. Bifacial tool on chert nodule, layer F
2. Limestone biface, layer G
3. Limestone bifaces, layer F
4. Backed flake in chert with marginal retouch, layer G
5. Backed flake in chert with abrupt and denticulated retouch, layer G
6. Chert flake, layer G
7. Triangular flake in chert, layer G
8. Elongated flake in chert with abrupt and denticulated retouch, layer G
9. Triangular flake in chert, layer H
10. Chert flake with semi-peripheral abrupt retouch, layer I1
11. Chert core with multiple faces and unprepared platform, layer I1

(Photos M-H. Moncel)

Figure 7. Different bones recovered at levels G (a and b) and H (c) showing the bad state of preservation of bone surfaces (Photos A. Pineda).

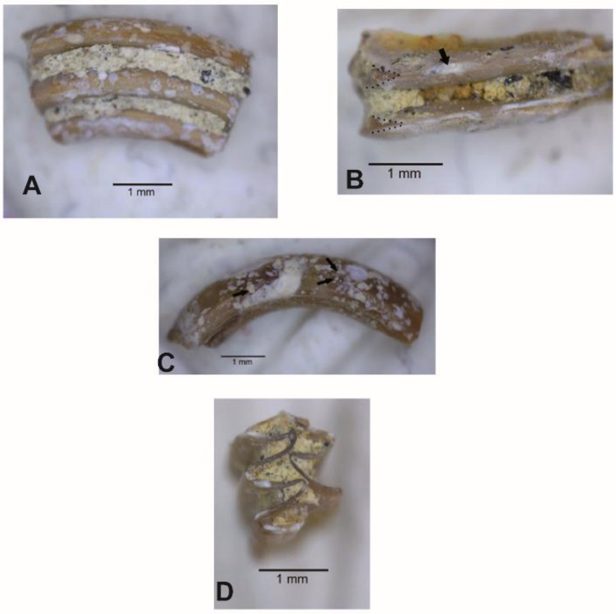

Figure 8. Examples of traces observed in the Notarchirico small mammal assemblage. A: *Arvicola mosbachensis* M3 with pointed corrosion marks; B: Molar of *Arvicola mosbachensis*, digestion marks are shown by the dotted line. Arrow: corrosion mark; C: Upper incisor with corrosion marks; D: *Arvicola mosbachensis* m1 with corrosion marks on the occlusal surface enamel; E: *Arvicola mosbachensis* upper molar with light digestion marks (arrows).

(Photos C. Berto)

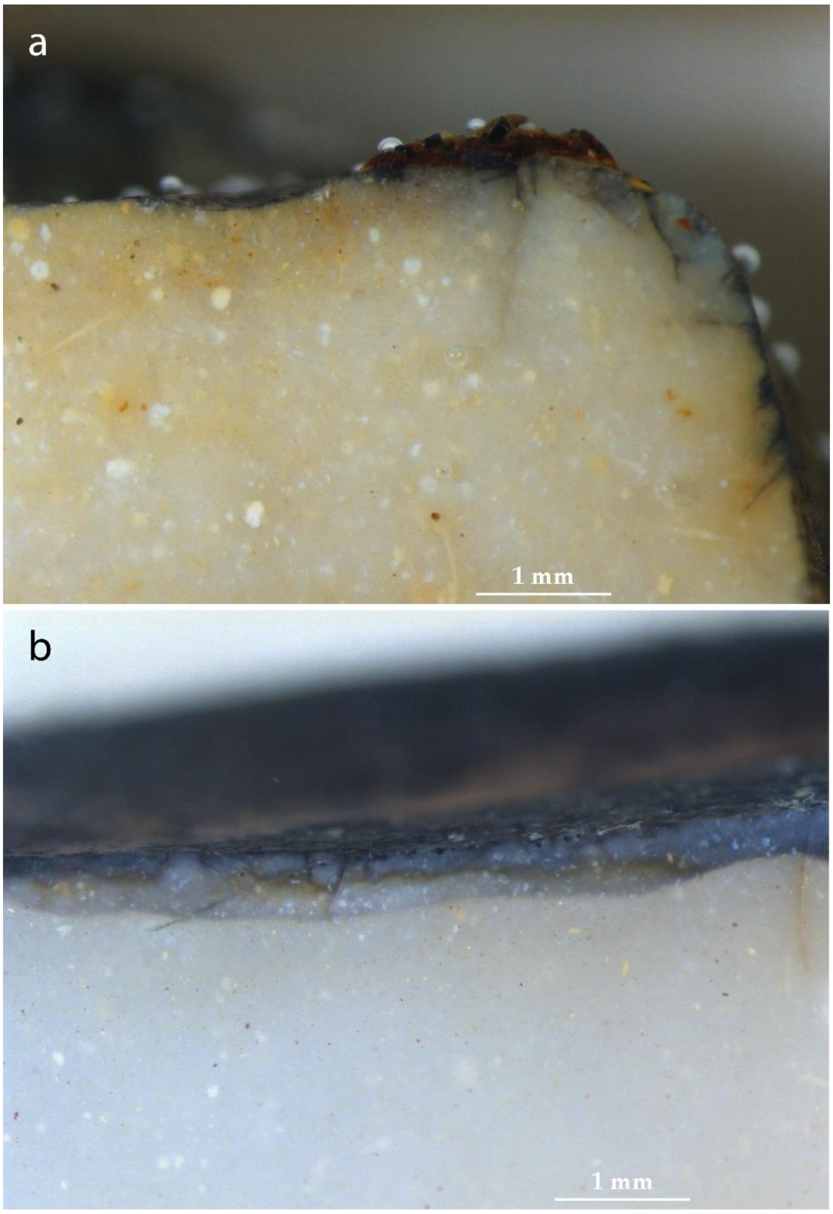

Figure 9. Surface alteration of chert pebbles NOTG22 (a) and NOTG20 (b).

(Photos G. Eramo)

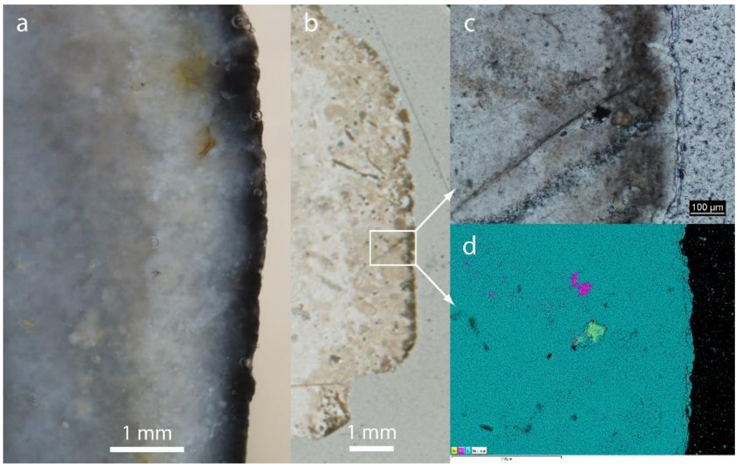

Figure 10. Multiscale analysis of surface alteration of a geological chert pebble (NOTG9) from layer G. a) Stereomicroscope view (10x) of the altered rim. Organic matter diffused in the white patina; b) digital scan of a thin section and framed area observed under the POM (c) and SEM-EDS (d).

(Photos G. Eramo)

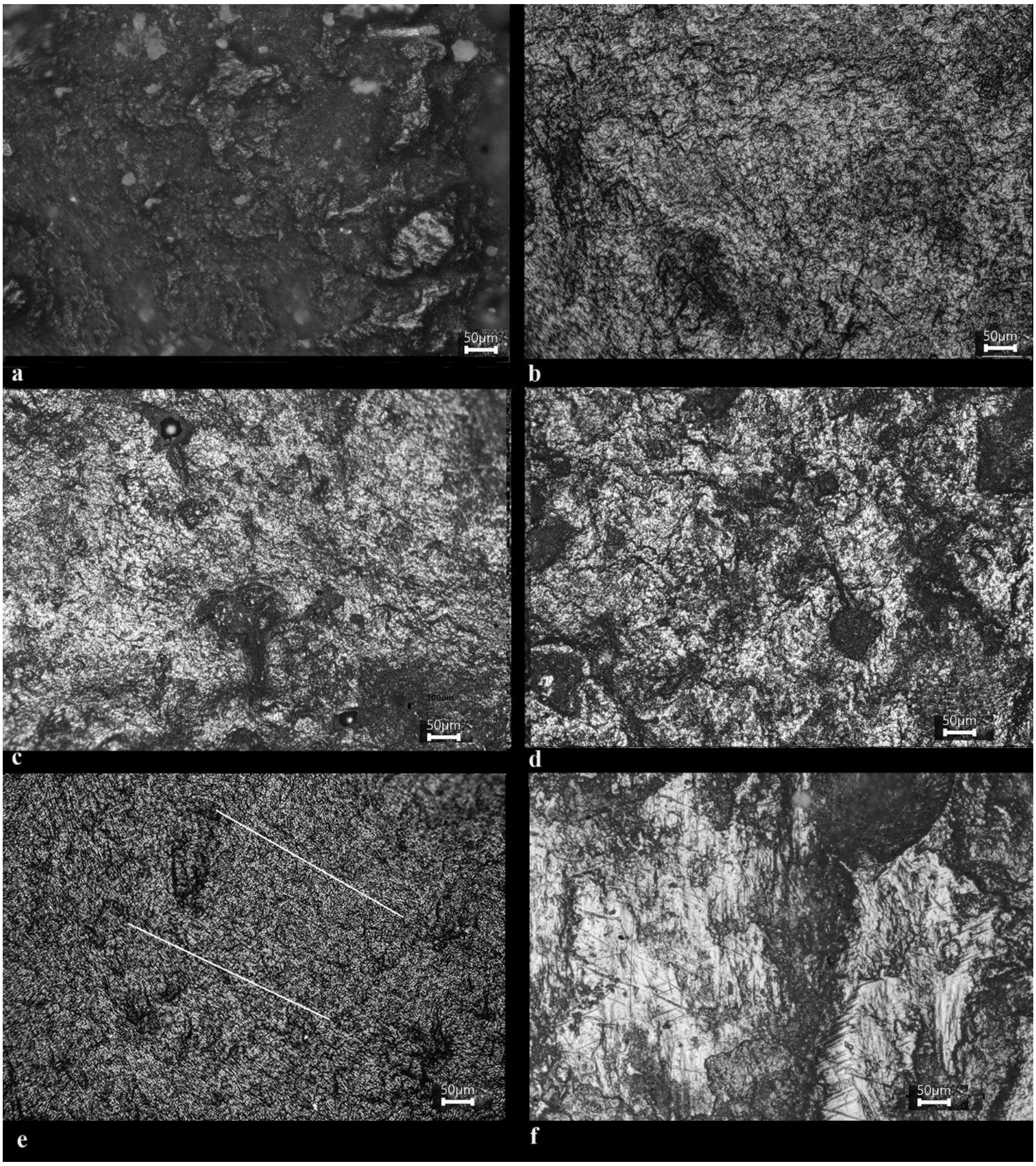

Figure 11. Level F, a) A17 n°30, preserved chert surface with polish resulting from use (right on the picture); b) B19 n°9, chert surface with glossy alteration; c); V16 n°17 chert surface with glossy alteration; d) V17 n°59 chert surface with strong glossy alteration; e) B17 n° 12 chert surface with oriented gloss suggesting abrasion (soil sheen); f) V17 n° 4 chert surface with bright spots and scratches suggesting strong localised abrasion.

(Photos C. Lemorini)

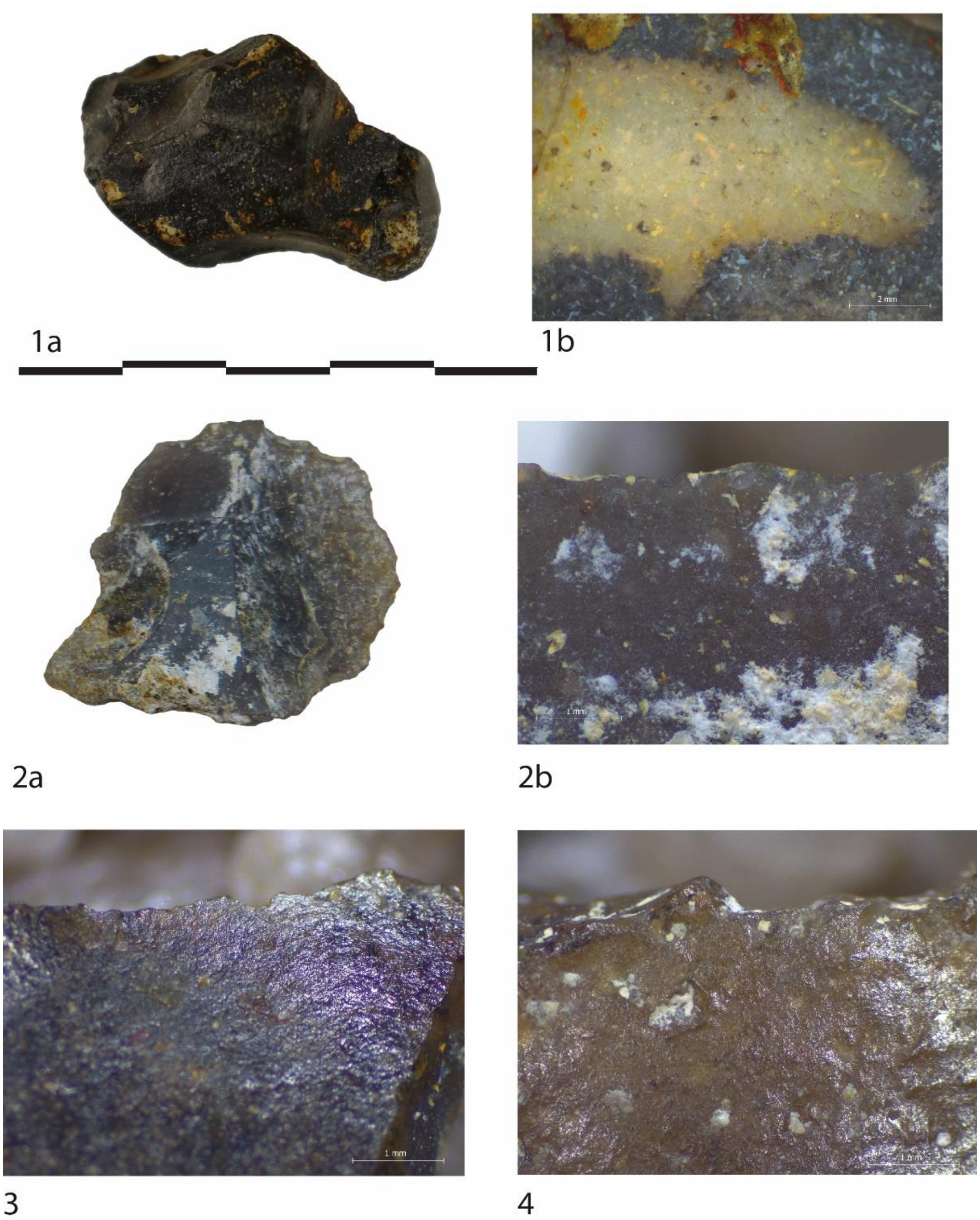

Figure 12. Macro- and micro-photos of lithic material of layers F, I1 and G.

1a. Retouched nodule with a double patina due to the retouch (micro-photo 1b) (A17 layer F n°30)

2a. Flake in silicified calcarenite (B33 layer I1 n°193) with micro-photo of the fresh cutting edge (2a)

3. Micro-photos of the slightly smooth cutting edges of flakes (C22 layer G, NC7, NC8)

(Photos 1a, 1b, 2b, 3, 4 G. Eramo, 2a M-H. Moncel)

Figure 13. Photo of a denticulate on chert, layer G. The series of notches are large and invasive, due to a regular and intentional retouch (Photo M. Carpentieri).

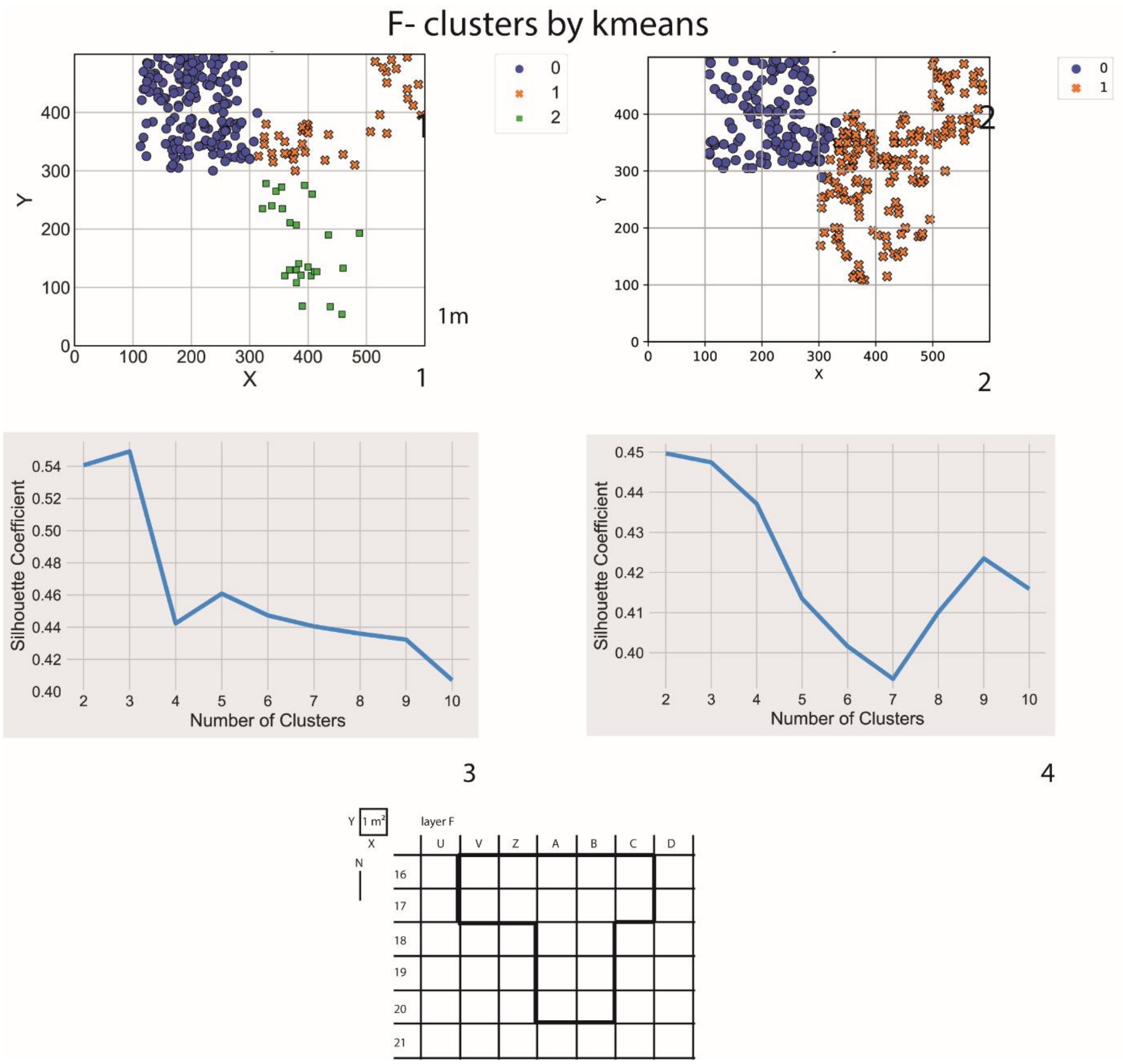

Figure 14. Spatial distribution of the faunal and lithic remains of layer F of Notarchirico

1. Clusters by kmeans of faunal remains
2. Clusters by kmeans of lithic remains
3. Number of clusters of faunal remains
4. Number of clusters of lithic remains

Outline of the excavated squares with dotted lines (sections by X-letters and Y-numbers) and names of the squares indicated on the excavated map

(Maps V. Rineau)

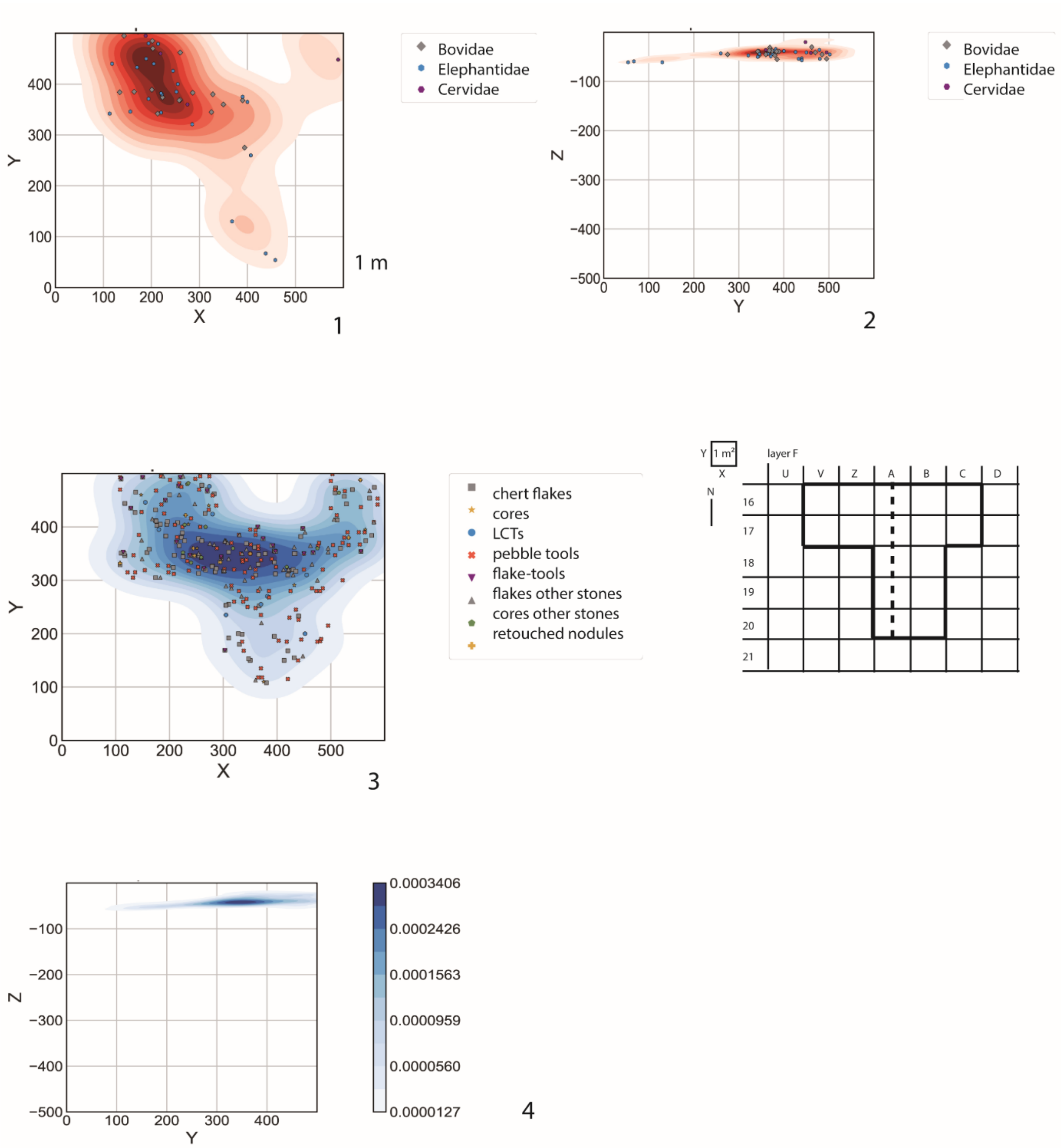

Figure 15. Spatial distribution of the faunal and lithic remains of layer F of Notarchirico

1. Horizontal distribution of faunal remains and species
2. Vertical distribution (by Y) of faunal remains
3. Horizontal distribution of lithic remains and categories of artefacts
4. Vertical distribution (by Y) of lithic remains

(Maps V. Rineau)

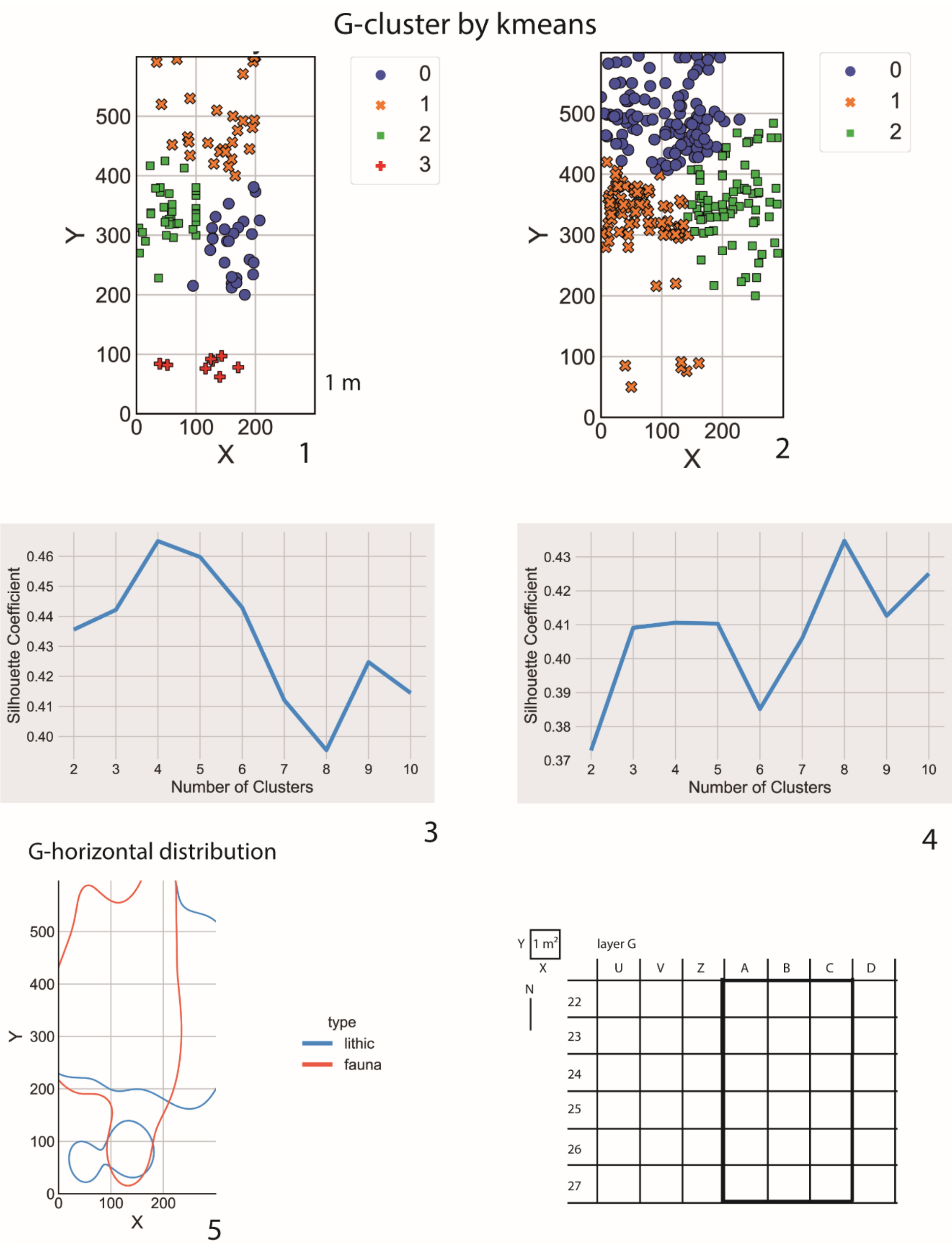

Figure 16. Spatial distribution of the faunal and lithic remains of layer G of Notarchirico

1. Clusters by kmeans of faunal remains
2. Clusters by kmeans of lithic remains
3. Number of clusters of lithic remains
4. Number of clusters of faunal remains
5. Horizontal distribution of faunal and lithic remains
   (Maps V. Rineau)

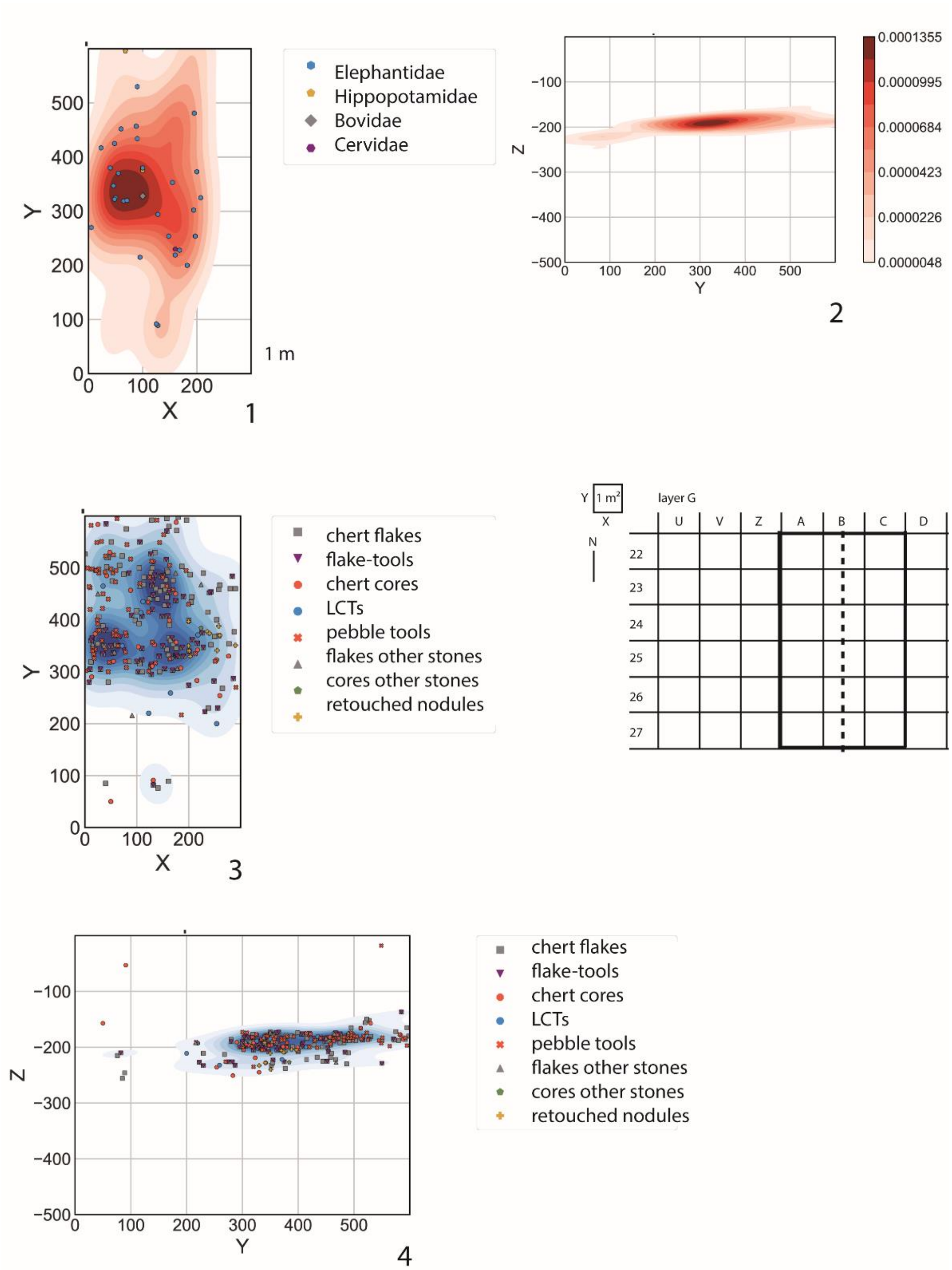

Figure 17. Spatial distribution of the faunal and lithic remains of layer G of Notarchirico

1. Horizontal distribution of faunal remains and species
2. Vertical distribution (by Y) of faunal remains
3. Horizontal distribution of lithic remains and categories of artefacts
4. Vertical distribution (by Y) of lithic remains
   (Maps V. Rineau)

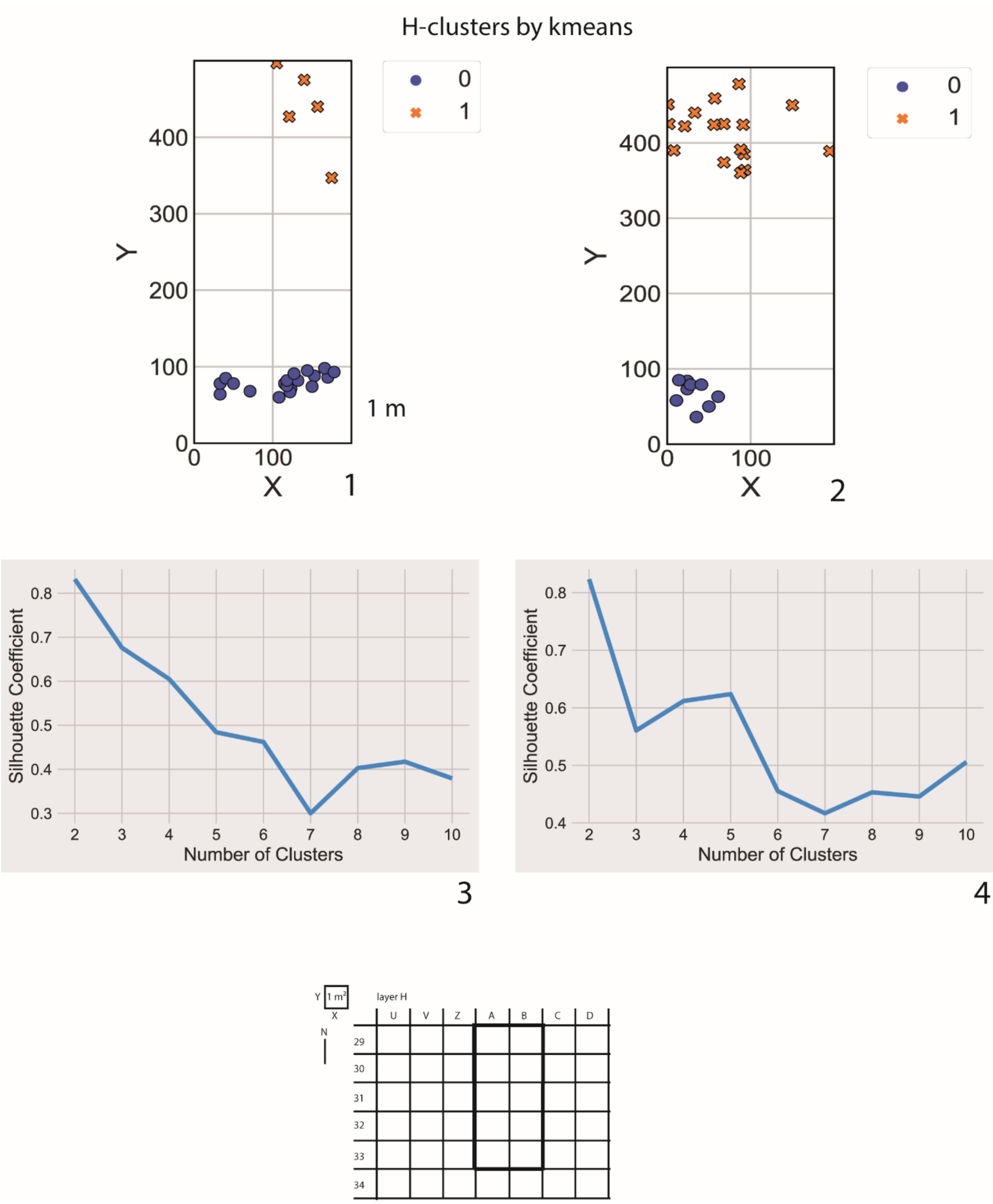

Figure 18. Spatial distribution of the faunal and lithic remains of layer H of Notarchirico

1. Clusters by kmeans of faunal remains
2. Clusters by kmeans of lithic remains
3. Number of clusters of faunal remains
4. Number of clusters of lithic remains

(Maps V. Rineau)

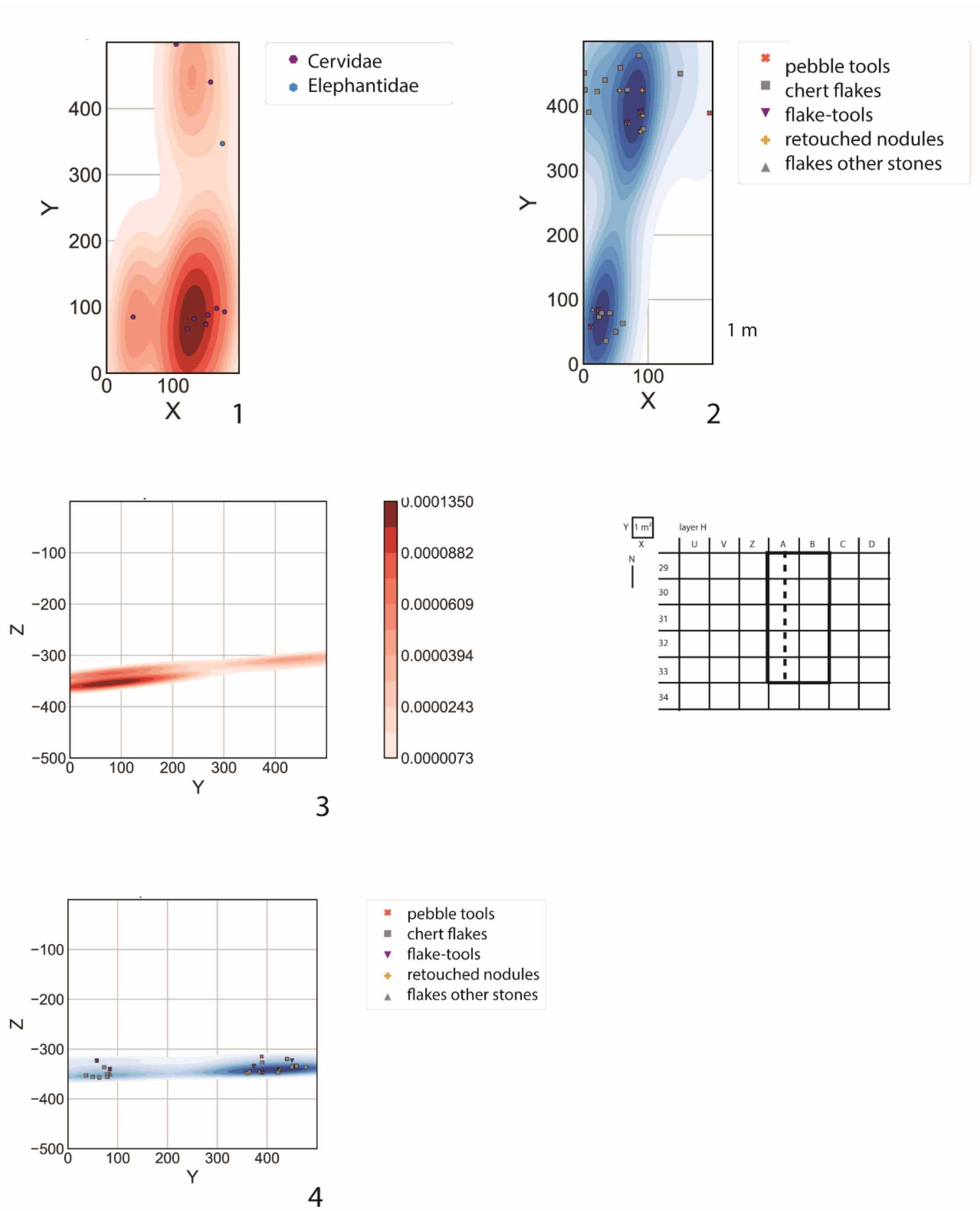

Figure 19. Spatial distribution of the faunal and lithic remains of layer H of Notarchirico

1. Horizontal distribution of faunal remains and species
2. Horizontal distribution of lithic remains and categories of artefacts
3. Vertical distribution (by Y) of faunal remains
4. Vertical distribution (by Y) of lithic remains

(Maps V. Rineau)

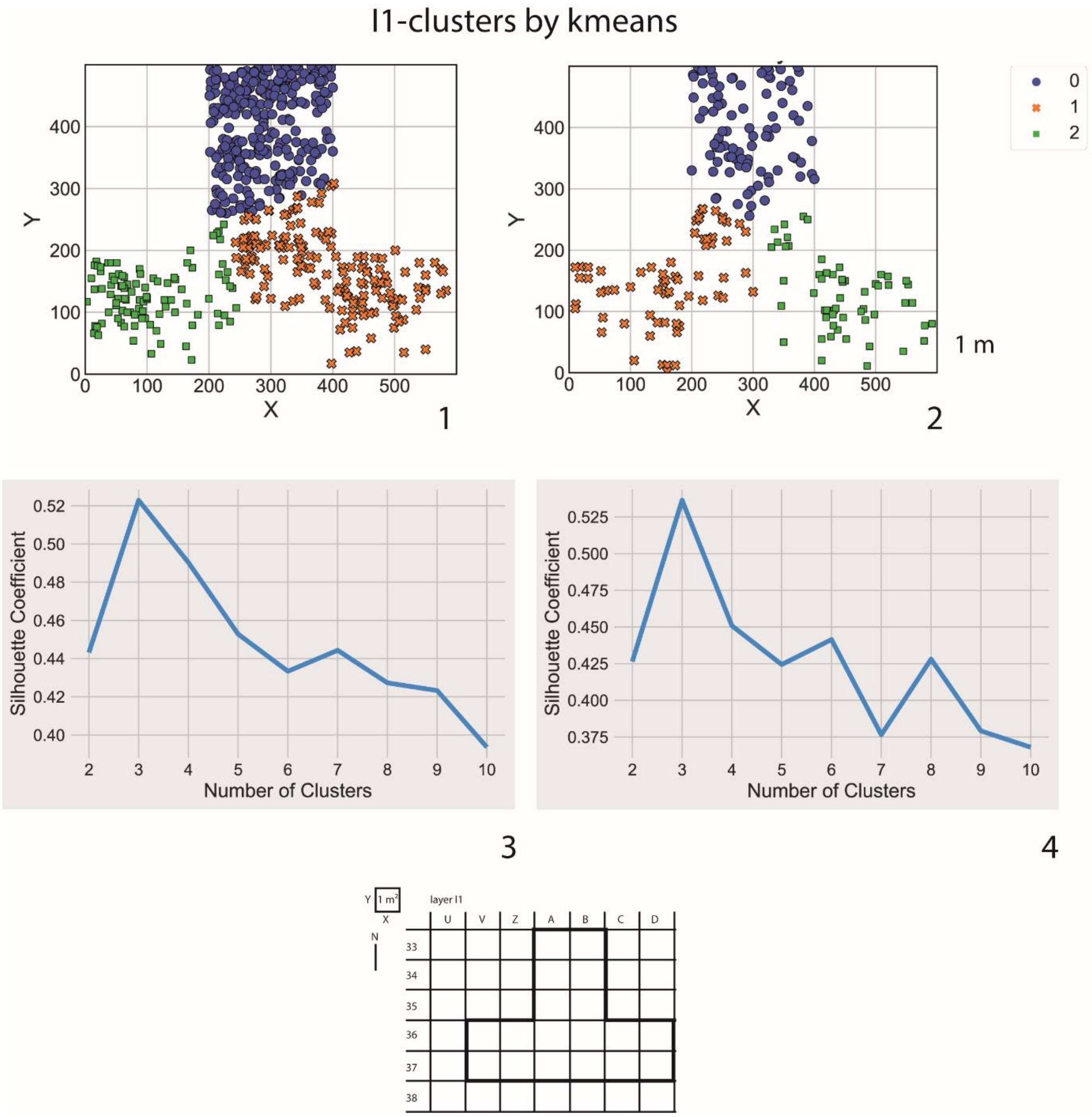

Figure 20. Spatial distribution of the faunal and lithic remains of layer I1 of Notarchirico

1. Clusters by kmeans of faunal remains
2. Clusters by kmeans of lithic remains
3. Number of clusters of faunal remains
4. Number of clusters of lithic remains

(Maps V. Rineau)

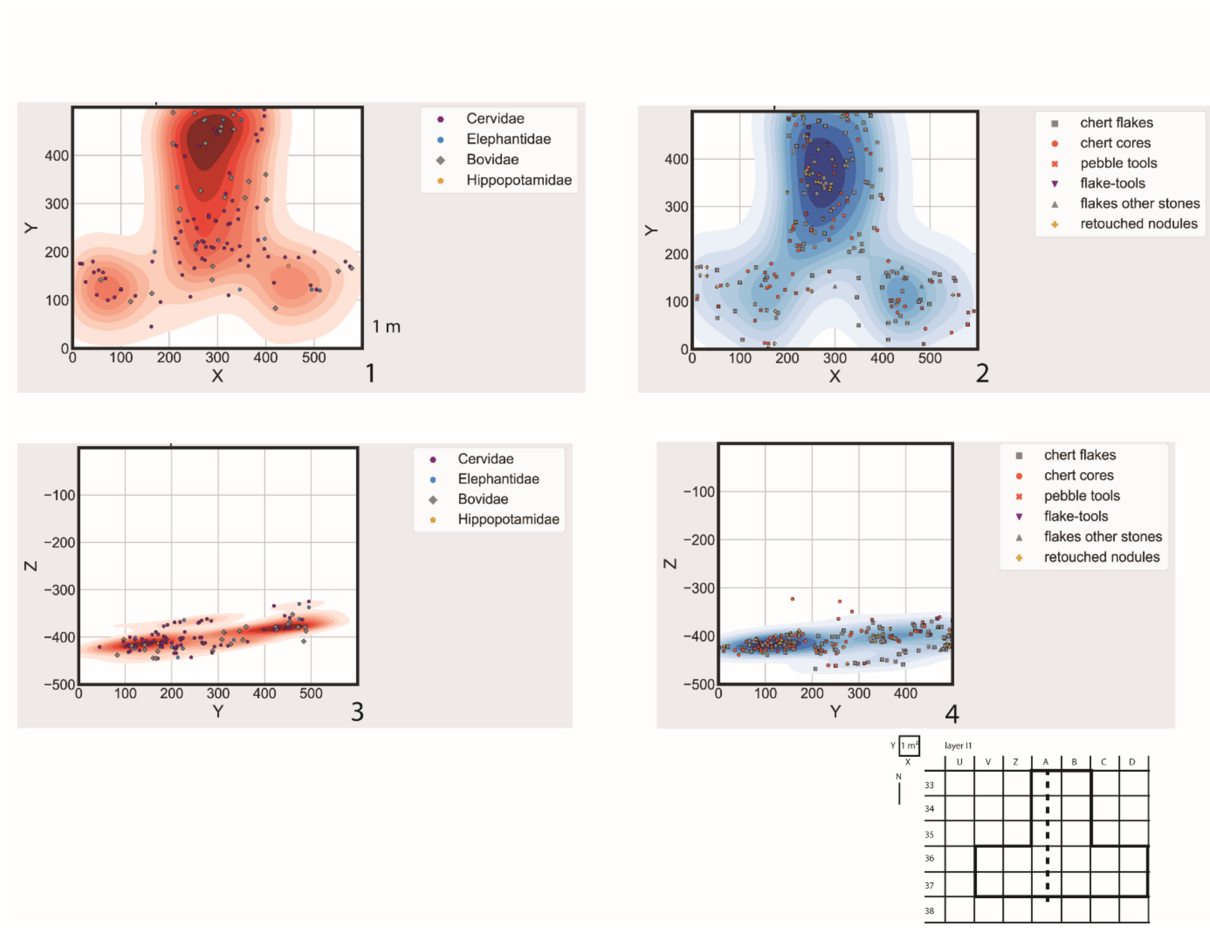

Figure 21. Spatial distribution of the faunal and lithic remains of layer I1 of Notarchirico

1. Horizontal distribution of faunal remains and species
2. Horizontal distribution of lithic remains and categories of artefacts
3. Vertical distribution (by Y) of faunal remains
4. Vertical distribution (by Y) of lithic remains

(Maps V. Rineau)

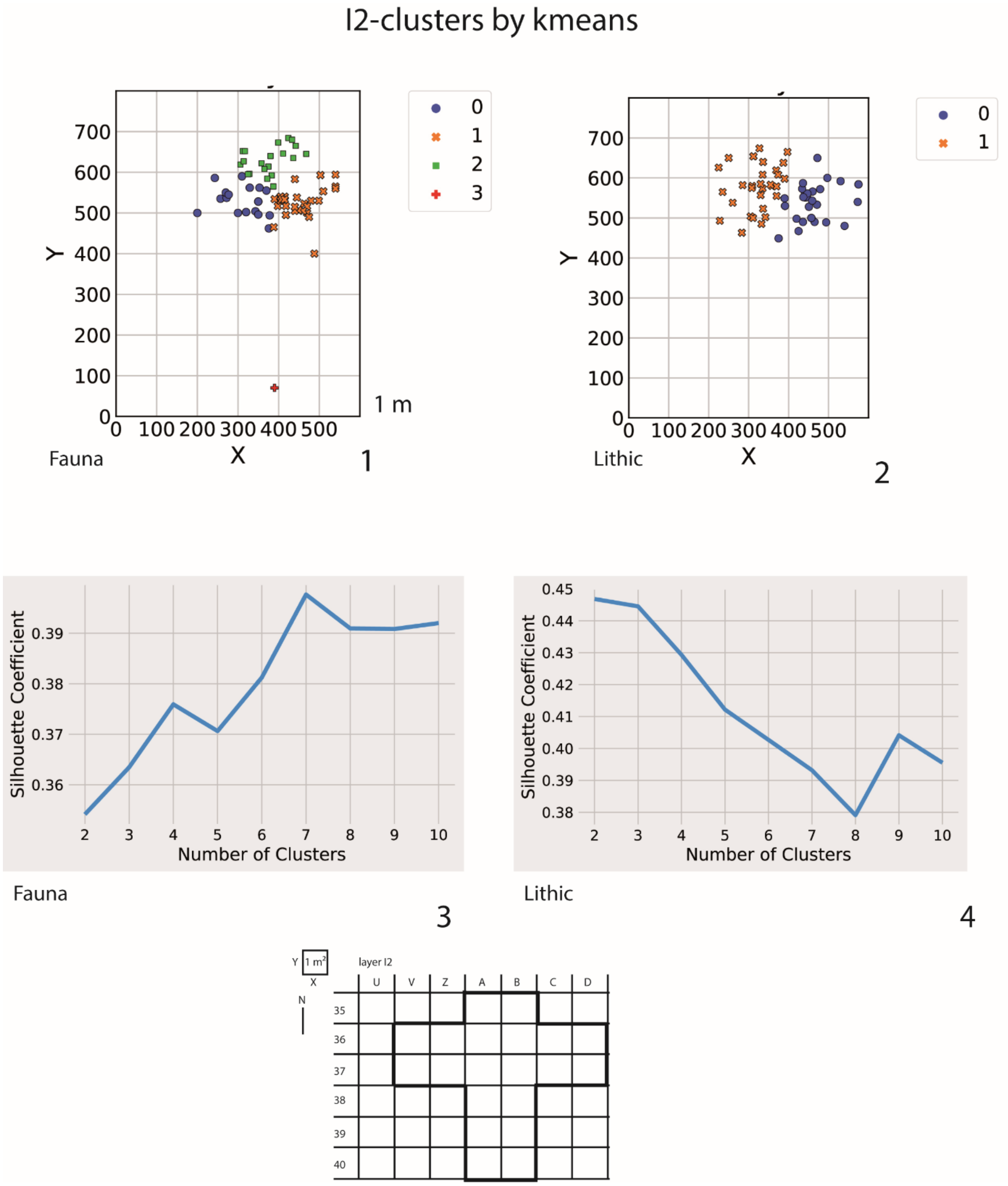

Figure 22. Spatial distribution of the faunal and lithic remains of layer I2 of Notarchirico

1. Clusters by kmeans of faunal remains
2. Clusters by kmeans of lithic remains
3. Number of clusters of faunal remains
4. Number of clusters of lithic remains

(Maps V. Rineau)

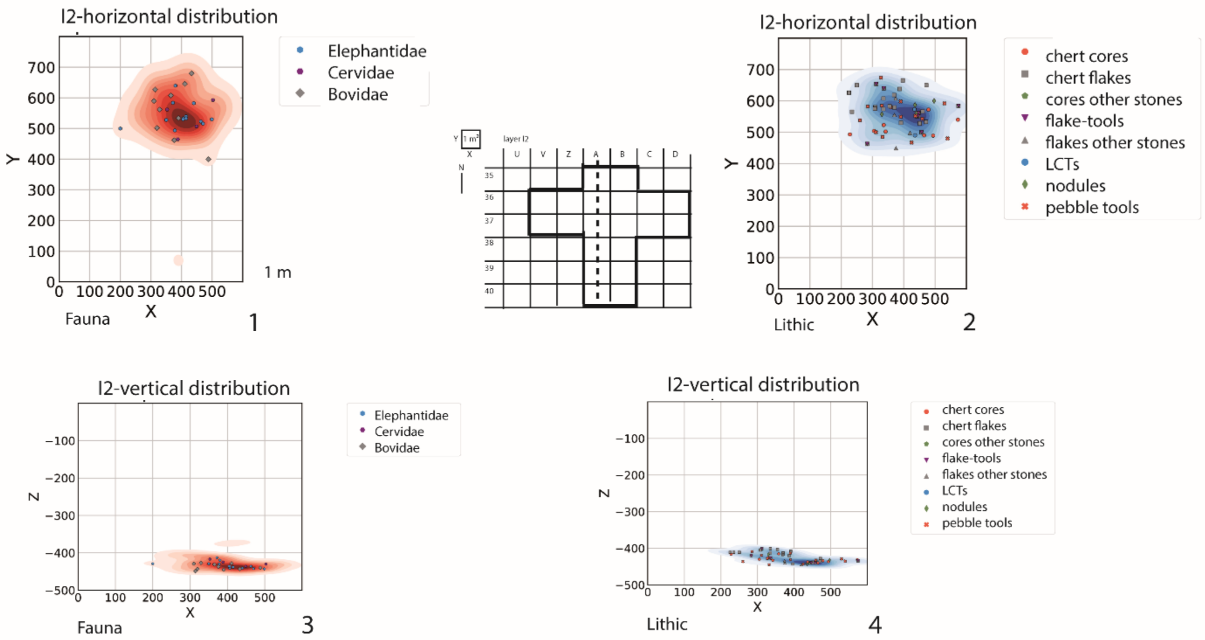

Figure 23. Spatial distribution of the faunal and lithic remains of layer I2 of Notarchirico

1. Horizontal distribution of faunal remains and species
2. Horizontal distribution of lithic remains and categories of artefacts
3. Vertical distribution (by Y) of faunal remains
4. Vertical distribution (by Y) of lithic remains

(Maps V. Rineau)

Table 1 Synthesis of the stratigraphic sequence (modified from Moncel et al., 2020)

Grey: archeological layer. Italic: sterile lithostratigraphic units, at the bottom or between the archeological layers. Bold: archaeological layers

Lithostratigraphic Unit	Archeo layer	Sub-unit	Characteristics
3	F	F	Bed of cobbles-pebbles Cross-bedded volcano-derived and non-volcanic sands 20 cm **Archaeological layer**
3		*F1*	*Black volcanic sands 20 cm*
4.1			Brown with small gravel 1m
4.2	G	G1	Dark-grey volcanic sands 30 cm **Archaeological layer**
4.3			*Coarse sandy sub-unit with cobbles and sub-angulous gravels 30 cm*
5.1	H	H1a	Silty-sandy deposit 10 cm **Dispersed archeological material**
5.2		H1b	Silty-sandy deposit 10 cm **Dispersed archeological material**
5.3		H1c	Silty-sandy deposit. Sandier and oxidized with a few micro-beds of dark minerals 30 cm **Dispersed archeological material**
6.1	I1	I1a-b-c	Local lenses of small pebbles 15-30 cm Coarse sands and beds of more or less dense gravels with pluri-millimetric anastomosed crusts 40-45 cm **Dispersed archeological material**
6.2	I2	I2	Dense accumulation of cobbles and smaller elements with limestones pebbles and a few fine-grained sandstone cobbles and flint nodules 10-15 cm **Archaeological layer**
7.1			*Tuffaceous sub-unit 3 cm*
7.2			*Coarse yellow sands with a few cobbles 15 cm*
7.3		J1	Tephra-derived coarse sands with some cobbles 10 cm **Rare artefacts non in situ.**

7.4	J	J2	*Cobbles in a clayish volcano-derived matrix 30 cm*
8.1			*Light-grey sand and micro-breccia*
8.2			*Coarse yellow sands*

Table 2 Large mammal taxa identified from Notartchirico. * Identifications reported in Piperno & Tagliacozzo (2001)

Layer	I2	I1	H	G	F	A	α
Reference Species	This work	This work	This work	This work	This work	Cassoli et al. (1999)	Cassoli et al. (1999)
Palaeoloxodon antiquus (=*Elephas antiquus*)	●	●	●	●	●	●*	●*
Hippopotamus antiquus		●		●			
Bovinae indet.	●	●			●	●	●
Bovinae cfr. *Bos primigenius*						●	●
Bos primigenius						●	●
Bison sp.						●	●
Bison schoetensacki	●	●		●	●		
Sus scrofa						●	
Cervidae	●	●	●	●	●	●	●
Cervus elaphus ssp.		●	●		●	●	
Cervus cfr. *elaphus*						●	●
Dama clactoniana						●	●
Dama cfr. *clactoniana*						●	●
Dama-like deer		●		●		●	●
Megacerine indet	●	●	●	●	●		
Megaceroides sp. (=*Praemegaceros* sp.)						●	
Macaca sp.				●			
Lepus cfr. *europaeus*						●	

Table 3 Number of Remains (NR), Number of Identified Specimen (NISP), Minimum Number of Individuals (MNI) and preservation indexes of Notarchirico large mammals (complete elements concern bones and teeth).

Notarchirico (2016-2018)	**E/F**	**F**	**G**	**H**	**I1**	**I2**	**J**	**Total**
NRT	204	1218	569	236	1681	167	6	**4081**
NR isolated teeth		11	6	6	37	4		**64**
NISP (rank of family)		35	21	12	99	29		**196**
NISPa		49	25	13	170	32		**289**
MNI		5	4	4	7	4		**24**
Identification index	0,0%	4,0%	4,4%	5,5%	10,1%	19,2%	0,0%	**7,1%**
Bone destruction index		22,4%	24,0%	46,2%	21,8%	12,5%		**22,1%**
NR recorded		147	61	25	294	61	1	**589**
Complete elements		9	2	3	22	4		**40**
Completeness		18,4%	8,0%	23,1%	12,9%	12,5%		**13,8%**

Table 4 NISP of the Notarchirico small mammal assemblages (campaigns 2016-2021)

	G	H	H2	I1	I1bc	I1c	I2a	I2b	J
Talpa sp.				1					
Arvicola mosbachensis				18	3	1			
Microtus cf. *nivaloides*				1					
Microtus (*T.*) cf. *arvalidens*					1			1	
M. (T.) *savii**			1						
NISP (Genus/species level)			1	20	4	1		1	
Arvicolinae indet.		1		5	1				
Rodentia indet.				2		1	1		1
Lagomorpha indet.	2	1		9	1	1			
Total NISP	2	2	1	36	6	3	1	1	1

*: reworked

Table 5 Lithic components of the layers F to J at Notarchirico (campaigns 2016-2021).

Archaeological layers	Flakes in chert, radiolarite	Cores in chert, radiolarite	LCTs: Unifacial Bifacial LCTs Cleavers Bifaces	Flakes in limestone and others	Cores in limestone	Retouched nodules in chert, radiolarite	Pebble-tools (unifacial, bifacial) Pebbles with isolated removals	Pointed pebble-tools (unifacial, bifacial)	Total
E-F	67 (10 flake-tools)	1		4		1	1		74
F	195 (31 flake-tools)	13	10 (3 bifaces)	50	11	12	104	16	411
G	223 (67 flake-tools)	35	9 (2 bifaces)	9	2	77	71	7	424
H	63 (16 flake-tools)			1		8	1		73
I1	255 (47 flake-tools)	41		10		39	32	9	386
I2	51 (16 flake-tools)	11	2	4	1	5	12	1	87
J	5 (4 flake-tools)	1		1			1		8

Table 6 Synthetic petrographic data of the lithic industries from the layers F to I. Numbers in parenthesis indicate the frequency of the lithotype in the layer and the numbers in the "0" (absence) and "1" (presence) columns is the frequency of the type of patina in a given lithotype, followed by their percentage (%) per layer.

			patina								
			glossy			white			black		
Layer	**pH**	**lithology**	**0**	**1**	**%**	**0**	**1**	**%**	**0**	**1**	**%**
F	7	silicified calcarenite (16)	4	12	65	9	7	40	8	6	30
		nodular chert (4)	3	1		3	1		4	0	
G	6	silicified calcarenite (9)	0	9	81	2	7	56	4	5	44
		nodular chert (3)	0	3		1	2		1	2	
		radiolarite (4)	3	1		4	0		4	0	
H2	5,5	silicified calcarenite (4)	1	3	80	4	0	0	2	2	60
		nodular chert (1)	0	1		1	0		0	1	
I1	5,5	silicified calcarenite (13)	5	8	59	11	2	9	12	1	23
		nodular chert (9)	4	5		9	0		5	4	
I2	5,3	silicified calcarenite (8)	5	3	46	5	3	23	5	3	23
		nodular chert (3)	1	2		3	0		3	0	
		radiolarite (2)	1	1		2	0		2	0	

Table 7 Large mammals faunal spectrum and indeterminate remains (NISP and %NISP).

Notarchirico (2016-2018)	E/F	F	F	G	G	H	H	I1	I1	I2	I2	J	Total	%
Palaeoloxodon antiquus		16	45,7%	17	81,0%	1	8,3%	8	8,1%	14	48,3%		56	28,6%
Hippopotamus antiquus			0,0%	2	9,5%		0,0%	2	2,0%		0,0%		4	2,0%
Cervus elaphus ssp.		1	2,9%		0,0%	4	33,3%	21	21,2%	2	6,9%		28	14,3%
Megacerinae indet.			0,0%		0,0%	3	25,0%	16	16,2%	1	3,4%		20	10,2%
Medium-sized cervids		2	5,7%		0,0%	2	16,7%	20	20,2%	1	3,4%		25	12,8%
Large-sized cervids		1	2,9%		0,0%	2	16,7%	23	23,2%		0,0%		26	13,3%
Total cervids		4	11,4%	0	0,0%	11	91,7%	80	80,8%	4	13,8%	0	99	50,5%
Bison schoetensacki		3	8,6%	1	4,8%		0,0%	1	1,0%	3	10,3%		8	4,1%
Bovinae indet.		12	34,3%		0,0%		0,0%	8	8,1%	8	27,6%		28	14,3%
Total bovines		15	42,9%	1	4,8%	0	0,0%	9	9,1%	11	37,9%		36	18,4%
Macaca sp.			0,0%	1	4,8%		0,0%		0,0%		0,0%		1	0,5%
Total NISP	0	35	100%	21	100%	12	100%	99	100%	29	100%	0	196	100%
Small-sized ungulates			0,0%		0,0%	2	0,8%	12	0,7%		0,0%		14	0,3%
Middle-sized ungulates		43	3,5%	15	2,6%	11	4,7%	135	8,0%	8	4,8%	1	213	5,2%
(Very) large-sized ungulates		66	5,4%	19	3,3%	2	0,8%	55	3,3%	19	11,4%		161	3,9%
Indeterminate	204	1074	88,2%	514	90,3%	209	88,6%	1380	82,1%	111	66,5%	5	3497	85,7%
Total Indet.	204	1183	97,1%	548	96,3%	224	94,9%	1582	94,1%	138	82,6%	6	3885	95,2%
NRT	204	1218	100,0%	569	100,0%	236	100,0%	1681	100,0%	167	100,0%	6	4081	100,0%

Table 8 Age categories and Minimum Number of Individuals (MNI) (Ad IND: individuals of undetermined age; YA: Young or Sub-Adults; JUV: Juveniles; MA: Prime-aged adults; OA: Old Adults)

Notarchirico (2016-2018)	**F**	**G**	**H**	**I1**	**I2**	**Total MNI**
Palaeoloxodon antiquus	1 Ad IND	1 Ad IND	1 IND	1 Ad IND	1 IND	**5**
Hippopotamus antiquus		1 Ad IND		1 YA		**2**
Cervus elaphus ssp.	1 MA		1 IND	1 JUV, 1 YA	1 IND	**5**
Megacerinae indet.			1 YA	1 JUV	1 IND	**3**
Large-sized cervids	1 IND		1 JUV	1 OA		**3**
Bovinae indet.	1 MA, 1 OA	1 MA		1 OA	1 YA	**5**
Macaca sp.		1 Ad IND				**1**
Total MNI	**5**	**4**	**4**	**7**	**4**	**24**

Table 9 Climatic, edaphic and biotic surface alteration (stages 1 to 3) and bone fragmentation indices (Number of total recorded elements: NR=154 for the level F and NR=311 for the level I1; Number of total bone elements: NR=1196 and NR=1643; Number of long bone elements: NR=67 and NR=94; Number of recorded bone elements: NR=131 and NR=28; and Number of legible recorded bone elements: NR=84 and NR=216).

Units	F						I1					
stages	1	2	3	n total	NR total	%	1	2	3	n total	NR total	%
cracking	46	25	18	89	154	57,8%	106	47	32	185	311	59,5%
desquamation	15	15	11	41	154	26,6%	70	64	14	148	311	47,6%
smooth edges	18	18	3	39	154	25,3%	40	40	11	91	311	29,3%
lustrous				2	154	1,3%				20	311	6,4%
abrasion (striations)				70	154	45,5%				85	311	27,3%
concretion/calcite	68	41	16	125	154	81,2%	106	68	23	197	311	63,3%
white crusts				125	154	81,2%				179	311	57,6%
chemical corrosion	61	28	2	91	154	59,1%	121	75	8	204	311	65,6%
root marking	45	34	9	88	154	57,1%	71	67	21	159	311	51,1%
oxides (black coloration)	77	12	1	90	154	58,4%	96	11		107	311	34,4%
illegible remains				59	154	38,3%				71	311	22,8%
bone completeness				2	1196	0,2%				22	1643	1,3%
green bone fracture (long bones)				48	67	71,6%				62	94	66,0%

green bone fracture (all bones)	59	131	45,0%		90	281	32,0%
notches (cortical and internal)	16	131	12,2%		17	281	6,0%
dry bone fracture	76	131	58,0%		123	281	43,8%
recent fracture	118	131	90,1%		185	281	65,8%
indeterminate fracture	41	131	31,3%		85	281	30,2%
carnivore marks	0	84	0,0%		3	216	1,4%

Table 10 Taphonomical observations on the small mammal assemblages.

Abbreviations: L: Light; M: Medium; H: Heavy (Fernández-Jalvo et al.,2016); Y: Yes; Ibs: Observations.

	Arvicolinae digestion					Concretion		Corrosion		
Layers	L	M	H	absent	Total	Y	Obs	Other	Plant	Obs
G							2			2
H				1	1		2			2
H2				1	1		1			1
I1	4	1	1	17	23	2	36	10	2	36
I1bc	3			2	5	1	6	3		6
I1c				1	1		3	1		3
I2a							1	1		1
I2b	1				1		1		1	1
J							1	1		1

Table 11 Level F Surface Alteration of the Chipped Stone Tools (campaigns 2016-2021)

Surface Alteration	number of Artefacts	%
Preserved	17	13%
Glossy Light	37	28%
Glossy Developped	48	36%
Mechanical Alteration	5	4%
Glossy + Mech.Alt.	9	6%
Rolled	14	10%
Thermal Stress	1	1%
Patina colour	1	1%
Concretion	1	1%
Total	133	100%

Table 12 Density by m² of the archaeological material for the bottom of the sequence (campaigns 2016-2021)

layer	Faunal remains > 20 mm	Lithic remains	Natural nodules
F	78.9/m²	21.6/m²	10/m²
G	63.6/m²	38.5/m²	20.6/m²
H	30/m²	7.3/m²	6/m²
I1	100/m²	21.4/m²	30/m²
I2	12.5/m²	4.3/m²	3.9/m²