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Evidence of raw material selection in Acheulean lithic tools of Notarchirico (MIS 15, Southern Italy)

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Abstract

A nondestructive technological, petrographic and granulometric analysis of 75 lithic artifacts excavated by M. Piperno in the 1980s in the Early Paleolithic site of Notarchirico (Venosa, Southern Italy) was carried out to check their compatibility with the lag deposit of layer B (MIS 15) and the hypothesis of lithological selection for knapping by hominins.

A total of 289 clasts selected via a virtual grid superimposed to orthophotographs of three areas documenting the palaeosurface of layer B (MIS15) were petrographically analyzed *in situ* to identify the petrofacies of the lag deposit from which the artifacts were collected.

The results obtained proved the lithic artifacts are compatible with clasts of layer B from a granulometric, petrographic and morphological point of view and that only some of the available lithotypes in layer B were used to knap artifacts. Although limestones, cherts, marls and sandstones were available in layer B, the latter are not present among lithic artifacts as lithotype. Moreover, the size and rock texture resulted to be stronger selection criteria than lithology. In fact, since the maximum length of stone tools are higher than those of layer B's clasts, this points to a supply area by hominins of lithic raw material larger than the investigated paleosurface. This study contributes to investigate the mode and criteria of selection of raw materials for knapping and shaping by hominins living in the South of Europe during the MIS 15 at 600 ka.

Keywords: Notarchirico, Venosa basin, lithic tools, petrography, petrofacies, granulometry

1. Introduction

The earliest Acheulean evidence (with Large Cutting Tools including bifaces) in Western Europe is late compared to Africa and the Levant, with rare manifestations suggesting at least a 700-year-old emergence in the Mediterranean Basin. Among the archaeological sequences preserved by volcano-sedimentary complexes associated to the eruptive activity of Monte Vulture, the site of Notarchirico (DMS geographical coordinates: 40° 58' 08.33" N 15° 53' 17.70" E), nearby Venosa (Basilicata) in southern Italy, provided large cutting tools (LCTs) in six of the eleven archaeological layers (Piperno 1999; Moncel et al. 2019, 2020).

Eramo et al. in (Moncel et al. 2020) identified most of the types of chert used for the studied artifacts of the archaeological layers F, G, H₂, I₁ and I₂ as of secondary origin and derived from the Flysch Rosso and Flysch di Faeto Fms.

The aim of this work is to better understand the existing relation between the lithic tools and the knappable lithic resources available *in situ* where hominins came on the site over the stratigraphic sequence of Notarchirico. For that, it is necessary to identify the lithotypes of the artifacts, as well as those of the geological pebbles and cobbles present in the fluvio-lacustrine and associated to the stone tools.

Previous researches (Dickinson and Rich 1972; Potter 1978; Ingersoll 1990; Díaz and Marensi 2020) proved that the presence of preserved palaeosurfaces over the sequence bearing gravel size clasts gave the opportunity to use them as proxy of the sediment sources in the basin, thus defining a petrofacies, to be compared with lithic industry.

In the Notarchirico site, the lag deposit of the layer B, located at the top of the sequence (around 610 ka), was taken as an example by the high density of pebbles and cobbles and its size (about 107 m²). It is a well representative layer to determine the petrofacies of the coarse sediments occurring in the Venosa Basin and

available to hominins. Moreover, testing the relationship between grain-size and lithology on geological and archaeological lithic materials found on the archaeosurface B allow to check the quality of the raw materials under the form of pebbles and cobbles and thus discuss the criteria of hominins for procurement and selection of raw materials.

1.1 The Notarchirico archaeological site

The archaeological site of Notarchirico is located in the Venosa Basin, within the Basilicata region (Italy). It was first discovered in 1979 and later underwent extensive excavations during the 1980s under the direction of Marcello Piperno. The stratigraphic profile reaches approximately 7 meters in thickness and includes eleven archaeological layers, five of which contain bifacial tools^{1,2}. A hominin femur fragment found in the uppermost layer (α) has been attributed to *Homo heidelbergensis*^{8,9}.

Chronological constraints based on $^{40}\text{Ar}/^{39}\text{Ar}$ dating of volcanic tephra place the archaeological sequence from layer α to layer F between roughly 610,000 and 675,000 years ago, corresponding to Marine Isotope Stages (MIS) 15 and 16^{10,11}. The faunal remains include key species such as *Palaeoloxodon antiquus*, *Dama cf. roberti*, *Cervus elaphus*, and *Bison schoetensacki*, and have been assigned to the Ponte Galeria and Isernia faunal units. Several archaeological layers reflect repeated human occupations, likely associated with butchering activities, as illustrated by the so-called “Elephant Butchery Area” at the top of the sequence (A–A1–B complex), although direct associations between artifacts and faunal remains remain undemonstrated¹². Since 2016, a 30-meter-long trench has been opened at the base of the previously excavated layer F, with excavation surfaces ranging from 8 to 26 m², depending on the stratigraphic context³. These investigations led to the identification of five new sedimentary units, each containing archaeological horizons: layers G, H, I1, I2, and J. These deposits are part of the upper section of the Piano Regio sedimentary formation in the Venosa Basin¹³.

Sedimentological features of the lower sequence bear strong similarities to those observed in the upper layers, which have already been dated to MIS 16 (Raynal et al. 1998; Lefèvre et al. 2010; Pereira et al. 2015). Layer F consists of cross-bedded sands with both volcanic and non-volcanic origins. Layer G is characterized by sandy sediments enriched with greenish-brown silts and clays, as well as encrusted pebbles, forming a thick lag deposit. In contrast, layer H comprises yellowish silty-sandy sediments, interpreted as altered distal pyroclastic flow deposits. Layer I1 is composed of coarse sands ranging from grey to greenish in color, along with gravel lenses and shallow pits. Layer I2 represents a dense lag deposit, with a cobble-rich pavement indicative of post-eruption sediment reorganization³.

Each of these deposits reflects relatively rapid accumulation events, often resulting from the infilling of paleo-channels or localized slope instability triggered by volcanic activity. Low-energy fluvial processes and short-term water saturation are inferred in many units, although the duration of waterlogging remains uncertain.

Recent chronometric analysis using both $^{40}\text{Ar}/^{39}\text{Ar}$ on single feldspar crystals and ESR dating on bleached quartz places the bottom of the stratigraphic sequence between 690.3 ± 5.8 ka and 695.2 ± 6.2 ka, aligning with the terminal phase of MIS 17. Newly identified faunal remains from these basal layers do not currently show conclusive signs of human activity (Moncel et al. 2020; Mecozzi et al. 2021). The revision of the fauna corpus of the whole sequence attributes the site to a longer chronological period, from the MIS 15 to the MIS 17 (Mecozzi et al., 2024).

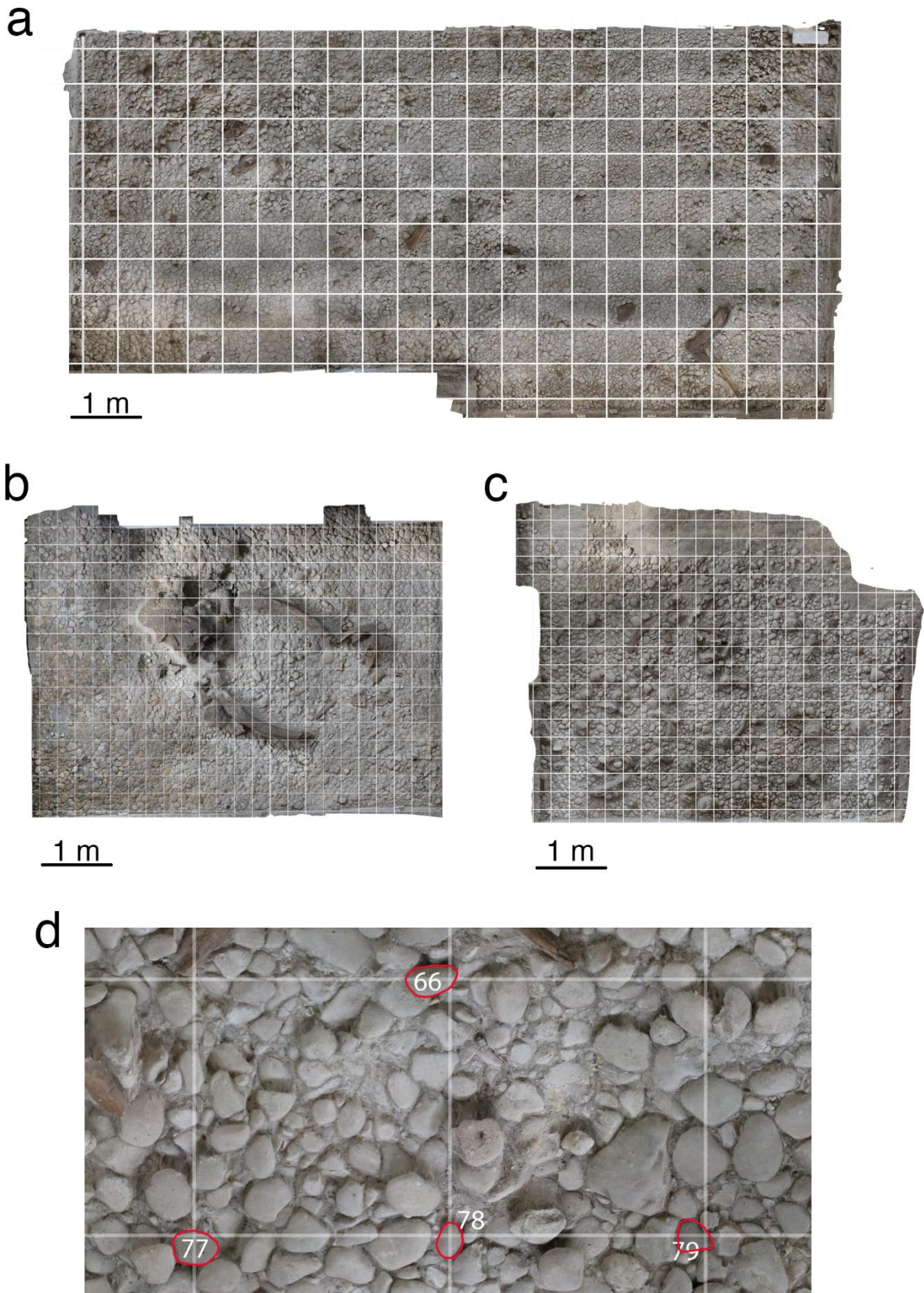


Figure 1 – Orthophoto of area 1 of layer B with an overlapping of 50 cm grid (a); orthophotos of areas 2 and 3 with an overlapping of 25 cm grid (b, c); a detail of the grid on the area 1 (d; in red, the outline of the selected clasts; the grid nodes without coarse clasts are not numbered). Images allowed by the agreement of the Italian Ministry of Culture and the Museo Parco Archeologico Melfi e Venosa.

1.2 Geological background

From a geological point of view, the area of Notarchirico (Venosa, PZ) is characterized by a complex geological framework shaped by sedimentary, volcanic, and tectonic processes over the last 10 million years dominated by the orogenesis of Southern Apennines (Bonadonna et al. 1998; Giannandrea et al. 2006; Patacca and Scandone 2007). The Venosa lacustrine-alluvial basin is a palaeovalley adjacent to Monte Vulture stratovolcano embedded in the sediments of the Bradanic Trough and mostly filled with epiclastic sediments contemporaneous with heterotopic volcanic products aged between 687 ± 8 ka and 141 ± 11 ka (Raynal et al. 1998; Buettner et al. 2006; Principe and Giannandrea 2008; Giannandrea 2009).

The Bradanic Trough is the NW-SE oriented foredeep basin placed between the Adriatic-verging thrust belts of the Southern Apennines and the Apulian Foreland (Casnedi 1988; Tropeano et al. 2002; Catalano et al. 2004; Patacca and Scandone 2007). The thickness and the depositional environments of the sedimentary successions depended on the inclination of the Apulian Foreland ramp and the proximity to the frontal part of the Apennines chain (Pieri et al. 1996). The inner successions include hemipelagites, turbidites and allochthonous Meso-Cenozoic thrust sheets which pass to outer successions of hemipelagites and coarse-grained shallow-marine and alluvial deposits toward the Apulian forland (Ciaranfi et al. 1979; Tropeano et al. 2002). Following basin filling, the Quaternary evolution of the Bradanic Trough is characterized by erosional regression in an uplifting basin there were a few terracing stages associated with discontinuous uplift and glacio-eustatic oscillations (Doglioni et al. 1996; Sabato et al. 2004; Azzillonna et al. 2023).

The volcanic edifice of Monte Vulture is set on alluvial paleogeography modeled on outer Apennine units and Plio-Pleistocene deposits of the Bradanic Trough (Giannandrea et al. 2006).

In this framework began the early Middle Pleistocene history of the Venosa basin, with a significant development stage between the middle and Late Pleistocene, mainly due to regional uplift and retrogressive erosion, which cut into the closing sediments of the Bradanic cycle (Monte San Marco Fm and Palazzo San Gervasio Synthem)(Colella et al. 2020). The Venosa basin is crossed by the Fiumara di Venosa stream originally drained to the Bradano River basin and captured by the Ofanto River drainage system starting from 500 ka (Giannandrea 2009). The stratigraphic succession was sedimented in about 150 ka, between two erosional phases and correlates with volcanic products emitted at Vulture of Foggianello, Barile and Melfi synthems (Giannandrea 2009; Pereira et al. 2015). Based on an analysis of the sedimentary facies, the Foggianello Synthem formed in a depositional system of gravelly braided plains, while the Barile Synthem originated in small lake basins connected by high sinuosity channels (Giannandrea 2009).

Raynal et al. (Raynal et al. 1998) identifies three lithostratigraphic units in the Venosa basin. The Fonte del Comune Fm is the oldest unit associated with the Foggianello Synthem. It is overlain by the Piano Regio Fm. and the Tufarelle Fm. constituted by volcanic and sedimentary clastic components deposited during the maximum volcanic activity of Monte Vulture (Barile Synthem).

The chronostratigraphy of these deposits has been investigated in detail since 1988, providing a tephrochronology framework for correlations with the lithostratigraphic units of the Venosa basin (Brocchini et al. 1994; Lefèvre et al. 1999, 2010; Giannandrea et al. 2006; Villa and Buettner 2009).

In the Notarchirico site, eleven archaeological layers were identified, six containing large cutting tools (A1, B, D, E/E1, F and G) (Piperno 1999; Moncel et al. 2023). The revised chronology frames the whole sequence between ca. 610 and 700 ka, corresponding to the MIS 17, 16 and 15 (Pereira et al. 2015; Voinchet et al. 2020; Moncel et al. 2023).

The lower part of the sequence (units 8 to 6) is characterized by low-energy fluvial sedimentation and regular inputs of volcanic material. In the intermediate units (units 5 to 3), fluvial sediments are mainly of volcanoclastic origin and point to progressively higher energy currents as depositional environments. The top of the sequence starts with unit 2, in particular with layers 2-1 to 2-5 made of several tephra layers identified as Notarchirico Tephra Complex (NTC) (Raynal et al. 1999). These layers correlate with the top of the Piano Regio Fm (Lefèvre et al. 2010). From layer 2-6 to 2-9 the sequence is made of layers with more or less fine texture rich in volcanic materials and passes to coarse sand in layer 2-10, with the archaosurface of layer B at its top (Moncel et al. 2023). As well in unit 1 the lower layers (1-1 to 1-3) are rich in fine volcanic clasts, while pebbles and cobbles became more present in the higher layers (1-4 to 1-6) (Raynal et al. 1998).

In this work, only the archaosurface of layer B was considered for the petrographic investigation, as a proxy of the detrital source of the pebbles and cobbles and as an expression of the conglomerate petrofacies (Díaz and Marensi 2020) available in the Venosa Basin.

2. Sampling and methods

2.1 Sampling strategy

2.1.1 Artifacts

The lithic artefacts considered in this research are 75 (tab. X): 64 stored in the archaeological museum of Venosa “M. Torelli”, and 11 preserved on the palaeosurface of layer B at the Notarchirico site.

All artefacts presenting clear traces of knapping activities were sampled and analysed using a classic techno-economic approach, featuring the reconstruction of the “chaîne opératoire” aimed at the understanding of hominins technical behaviours.

The hierarchy of flaking surfaces, removal organisation, type of striking platform and debitage angle, were considered on cores to evaluate the knapping strategies and techniques employed by the hominins (i.e. Tixier et al. 1980). Similar characteristics were also applied for flakes description, including, when present, the location, extension and angle of retouch. Furthermore, we applied a standard typological classification modified from Bordes (Bordes 2000), to facilitate the comparison with other lithic assemblages. For pebble tools and LCTs/bifaces component, the classification was made according to the organisation of the removals and volume management similar to other works (Moncel et al., 2021).

The analysed assemblage consists of 46 (62 %) pebble tools (unifacial tools, bifacial tools, chopper-like, “rabort”), 10 (14 %) LCTs (Large Cutting Tools) and bifaces, 6 (8 %) cores, 6 (8 %) flakes, 4 (5 %) retouched flakes and 2 (3 %) retouched nodules.

2.1.2 Geological samples

The investigated layer B is composed of 3 areas, whose excavated area reaches about 107 m² (B1: ca. 59 m²; B2: ca. 23 m²; B3: ca. 25 m²). The paleosurface is characterized by a significant density of embedded pebbles. To ensure representativeness, a systematic sampling method was adopted, as following explained. Firstly, the digital reconstruction of the palaeosurfaces based on photogrammetry was carried out. For this purpose, the photographic acquisition took place using a Canon EOS R100 camera equipped by Canon RF-S 18-45 mm F4.5 lens, without the use of flash or light supports but exploiting the natural and diffused light (without disturbing shadows) coming from windows of the covering building.

A set of 650 freehand photographs were collected, taking care to cover the entire surface and ensuring an overlap of about 50% between one frame and another both in the horizontal and vertical direction.

For the digital survey, the Agisoft Metashape 2.1.3 Professional Edition software was used and the following workflow was adopted: 1. the alignment of the photos was performed with high accuracy; 2. the model building was performed by choosing depth maps as source data, high quality and high face count; 3. for the orthomosaic building, the projection was planar and the projection plane was Top XY. After the orthomosaic was exported as tiff images and scaled using physical measurements acquired by an electronic device directly on site. This image was the basis for the sampling by superimposing a virtual grid with a mesh size of 50 cm, as large as the investigated surface, using Adobe Illustrator 2024 (figure 1). This step was chosen by previously evaluating the number of samples necessary for the research. The clasts intercepted by the grid nodes were selected and marked by an identification number. Conversely, the grid nodes not corresponding to clasts were skipped. The output of the virtual sampling was 175 samples for area B1, 65 samples for area B2 and 49 samples for area B3, for a total of 289 samples.

Aspect ratio, and circularity of clasts were estimated by digital image analysis (DIA) using 3 not overlapping and spaced photographs for each sub area to achieve the minimum conditions of representativeness (largest clast area/analyzed area ≤ 0.01).

The photographs obtained were processed with the Java based Fiji software (Schindelin et al. 2012) for the DIA. The pre-processing to facilitate segmentation considered: 1) Filter>Gaussian blur (5); 2) Image>Type>8-bit; 3) Plugins>FeatureJ>Feature Laplacian (3); 4) Math>Subtract (85); 5) Math>Divide (110); 6) Math>Multiply (100). Afterward, a global thresholding algorithm (Image>Adjust>Threshold>Default) was preferred. Some cleaning operations were necessary after the segmentation, to reduce noise (e.g. Remove outliers) and approximate the size and shape of the clasts (e.g. Erode, Dilate, Fill holes). Since the algorithms used for segmentation did not always return an accurate identification of clasts, a manual separation of the segmented clasts was operated. Between 111 and 115 clasts were selected for each sub area, imposing size \geq

32 mm and circularity between 0.5 and 1 as conditions in Analyze particles to minimize errors deriving from segmentation.

The Roundness (R) parameter proposed by Takashimizu and Iiyoshi (Takashimizu and Iiyoshi 2016) was calculated according to the equation:

$$R = C_I + (0.913 - C_{AR})$$

where circularity (C_I) and aspect ratio (AR_I) were determined with Fiji (ImageJ) software from clast images. R was preferred to the roundness determined with Fiji (ImageJ) software because it reveals a strong positive correlation ($r = 0.937$) with Krumbein's roundness (Krumbein 1941).

2.2 Sample preparation and methods

All the geological samples selected using the strategy described in the previous paragraph, although remaining fixed to the paleosurface, were cleaned with water by a brush to remove dust. Where necessary, further cleaning with a hydrochloric acid solution (diluted to 2%) was operated to eliminate the carbonate crust on small areas to observe the lithological features. The surface of the clasts was studied using a 40x magnifying lens equipped with LED light.

In the same way and for the same purposes, all the artifacts were after washed with water and cleaned by a brush and, if necessary, using a hydrochloric acid solution (diluted to 2%). In this last case, because of the possibility to move samples, they were photographed inside a lightbox (30x30 cm) with light from all directions by a Canon EOS R100 camera and Canon lens (RF-S 18-45mm F4.5), mounted on a support fixed to the base of the table. This procedure allowed us to obtain high-definition images, standardized and free of shadows and photographic artifacts. Following, each archaeological sample was placed in a container of water and observed at the microscopic scale using a Leica stereoscope (EZ4 W). Studying samples by water immersion allows to improve petrographic description without damaging the samples. Both for geological samples of the paleosurface and for artifacts, the maximum size was measured with a caliper to obtain the grain size distribution.

2.3 Petrography

Both for the artifacts and the geological samples, some significant petrographic parameters were considered to identify the lithotypes: lithology (limestone, chert, marl, sandstone), structure (homogeneous or laminated), texture (rudite, arenite and lutite), lithotype (mudstone, wackestone, packstone and rudstone (Dunham 1962) in case of limestone and silicified calcarenite and calcilitite in the case of chert). Moreover, for the artifacts, the presence of natural surface alteration was recorded in order to prove the secondary origin of raw material.

3. Results

3.1 Artifacts

3.1.1 Technology

3.1.1.1 Cores

Limestone cores (6; figure 2) were made from cobbles and were knapped using direct percussion with a hard hammer. The debitage was conducted on one or two knapping surfaces from natural and flat platforms (mean knapping angle of 83°) and taking advantage of the pebbles' natural shape. Reduction sequences were rather short (6 removals per core) and limited to the exploitation of suitable natural surfaces, including different knapping strategies such as centripetal, unipolar, bipolar and crossed removals. The presence of natural surface alteration is recurrent. The single core on chert is made on a nodule and is knapped on one knapping surface with two crossed removals from a natural platform.

3.1.1.2 Flakes

The few available flakes (6; figure 2) are obtained from limestone cobbles and are large-sized. Four of them are cortical, including two opening flakes, while the remaining two display orthogonal scars. It is possible that

some of these flakes could derive from shaping reduction sequences, though the data to confirm this are not sufficient. Platforms (natural, flat and dihedral) show a mean debitage angle of 87°.

3.1.1.3 Retouched flakes and retouched nodules

Three retouched flakes on limestone were documented (figure 2; figure 3 (nr. 4)). Two of them are cortical while the last one shows 4 unipolar removals. The retouch was applied on the ventral or dorsal face affecting a discrete portion of the margins, with a marginal extension, and creating angles of ~65°. Typologically there are two denticulates and one scraper.

The retouched flake on chert is from a pebble's opening flake and is a denticulate. The retouch is applied on the dorsal face with a semi-peripheral localization. The two retouched nodules both exhibit an abrupt retouch (79°) on one face to produce a denticulate with convergent edges and a scraper.

3.1.1.4 Pebble Tools

Pebble tools on chert (7; figure 2) consists of six unifacial tools and one bifacial tool realised on flat (5) or thick (2) pebbles. The removals are located on the margins of the supports being either on one side or on the semi-periphery. As a consequence, the cortical patches are significant. The range of tools produced is diversified, including denticulate-like, convex, and pointed-shaped.

Pebble tools on limestone (figure 2) features unifacial (26; figure 3 (nr. 2, nr. 3)) and bifacial (7; figure 3 (nr. 1)) tools, chopper-like (1) and rabot-like (1). Flat and thick pebbles represent the privileged supports, followed by plano-convex ones. Similarly to chert tools, removals mostly affect the pebbles' margins – with an abrupt extension – with few cases attesting to a more invasive edge modification. The associated angles range between 60° and 85°. The removals' location is equally on the longest or shortest margin or on the semi-periphery of the pieces taking advantage of the pebbles' thinnest portions. The edges' morphology is dominated by denticulates and pointed shapes, followed by convex and rectilinear ones. The shaping mode for bifacial tools included two strategies: a series of alternated removals from the two faces, or the exploitation of each face separately.

Four pebble tools on marl were also attested. They are similar to limestone and chert tools, being realised on flat, thick or plano-convex pebbles. The shaping aimed at the production of denticulate-like, convex, rectilinear or pointed morphologies through abrupt removals on the margins of the tools.

3.1.1.5 LCTs and Bifaces

The ten Large Cutting Tools analysed are realised on chert (4), limestone (5) and marl (1) from flat and plano-convex pebbles (figure 2). Six of them exhibit a shaping on two faces through alternated removals while the remaining four are shaped only on one face. The presence of the bifacial symmetry is attested on six artefacts, while only one is characterized by a bilateral symmetry as well. Generally, the shaping does not often involve the entire perimeter of the artefacts being also located on their semi-periphery, on one side or on a small portion of it. The mean number of removals per tool is five being equally marginal, abrupt or invasive and featuring a wide range of angles (60° - 88°). For the LCTs shaped on two faces, there is always one face showing more removals than the other. The global shape of the tools is diversified (oval, pointed, rectangular, etc.) but they are all characterized by a cortical base and a rounded or pointed tip prepared through few removals.



Figure 2 – Boxplot with length, width and thickness of the archaeological sample analyzed divided into technological categories and raw materials.

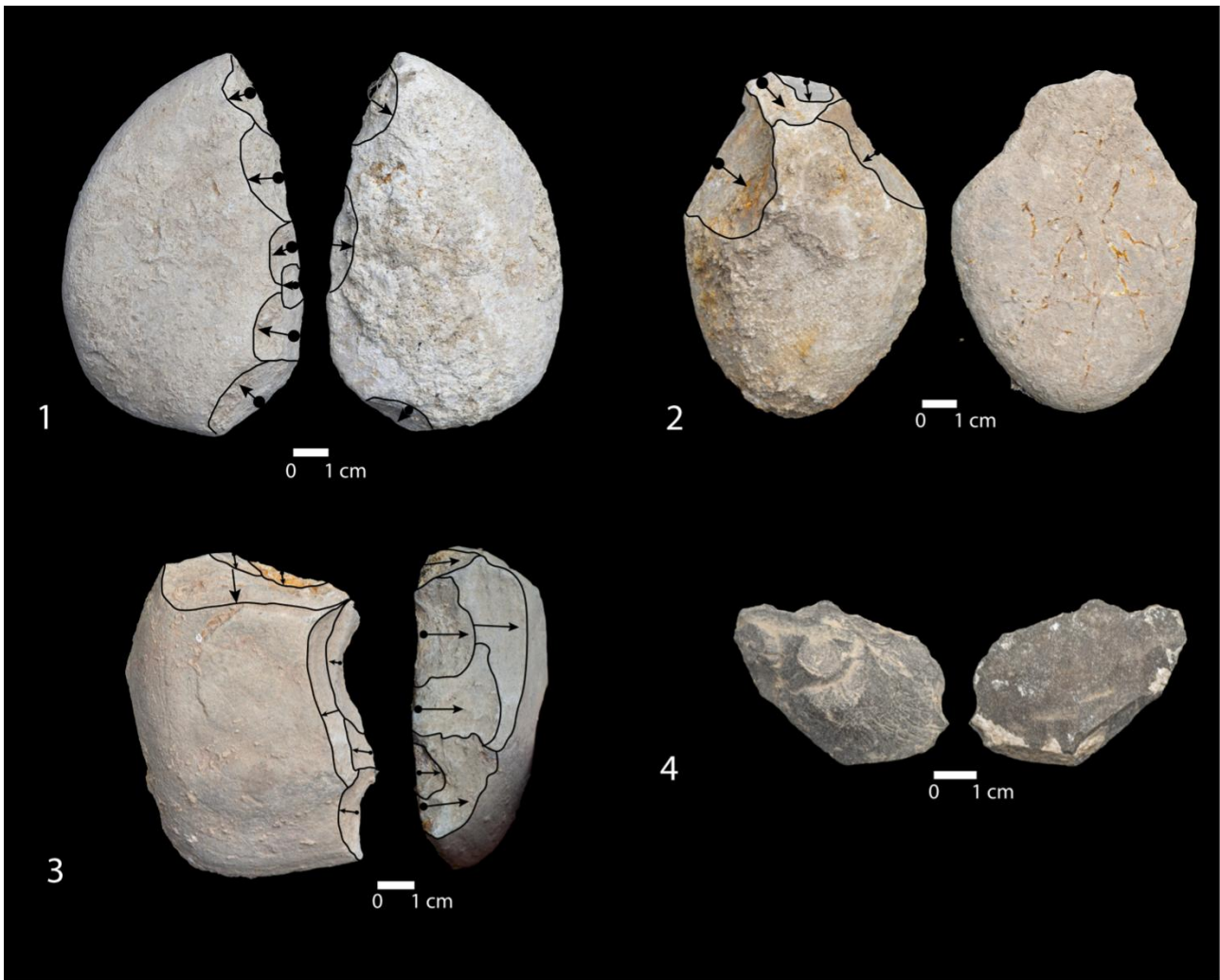


Figure 3 – Lithic artefacts on limestone from layer B: 1 – Bifacial tool; 2, 3 – Unifacial tool; 4 – Retouched flake. Images allowed by the agreement of the Italian Ministry of Culture and the Museo Parco Archeologico Melfi e Venosa.

3.1.1 Granulometric analysis

In general, the recorded maximum sizes for archaeological samples ranged from 42 to 203 mm with a mean of 121 mm and a median of 123 mm. The granulometric distribution, also considering lithology, was reported in figure 4. In detail, 3 samples (4 %) belonged to very coarse pebble class (32-64 mm), 41 samples (56 %) belonged to small cobble class (64-128 mm) and 30 samples (40 %) belonged to large cobble class (128-256 mm) (Table 1).

The grain size data shows a quasi-normal and symmetrical distribution, with platykurtic character.

Considering each type of artifacts (Figure 2), it was observed that the grain size ranged between 61 and 126 mm with a mean of 125 and a median of 126 in the group of tools, between 42 and 58 mm with a mean and a median of 50 mm in nodules, between 66 and 156 mm with a mean of 119 mm and a median of 128 mm in the flakes group and between 74 and 153 mm, with a mean of 115 mm and a median of 117 mm for cores group.

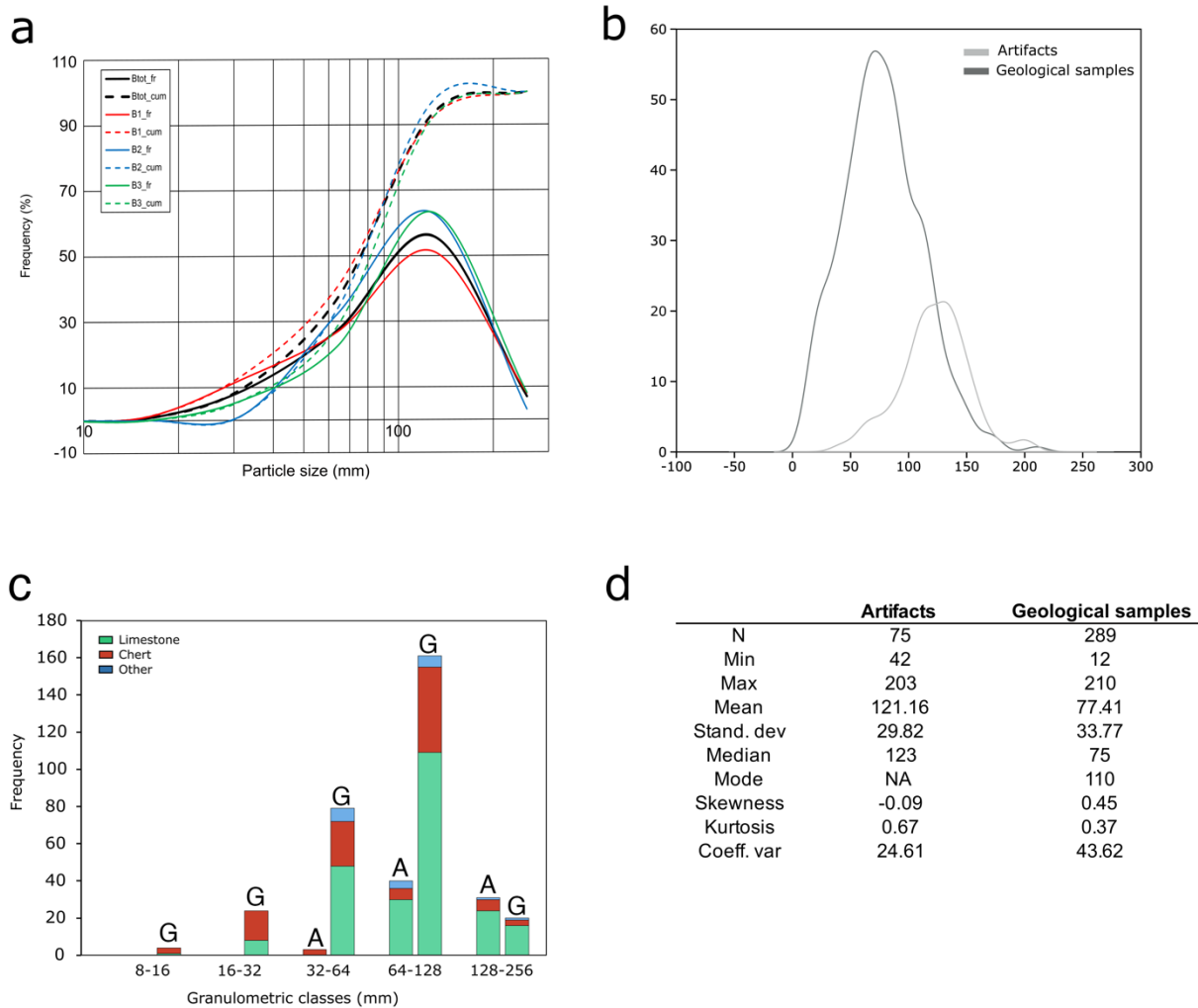


Figure 4 – Frequency and cumulative frequency distribution in the geological samples (a), Kernel curves for geological samples and artifacts (b), frequency histogram of lithologies relative to each size class for geological (G) and archaeological (A) samples (c) and summary statistic (d).

3.1.2 Lithological variability

The identification of the lithologies and textural features of archaeological artifacts observed by a stereomicroscope had highlighted some correspondence with the samples of the paleosurface. In particular, 54 limestone (72 %), 16 cherts (21 %) and 5 marls (7 %) were recognized. Among the limestones, 4 lithotypes were identified: 28 packstone (52 % of limestone and 37 % of total), 18 wackestone (33 % of limestone and 24 % of total), 3 rudstone (6 % of limestone and 4 % of total) and 4 mudstone (7 % of limestone and 5 % of total). Instead, in the chert group, 11 silicified calcarenites (69 % of chert and 15 % of total) and 4 silicified calcilitutes (25 % of chert and 5 % of total) were identified. Only one sample was not identifiable for the patina that completely covered it. In Figure 5, were reported a photo at the macroscale and a microphotograph under the stereomicroscope of each recognized lithology.

All studied archaeological samples still showed the natural surface alteration of the nodule formed before human modification.

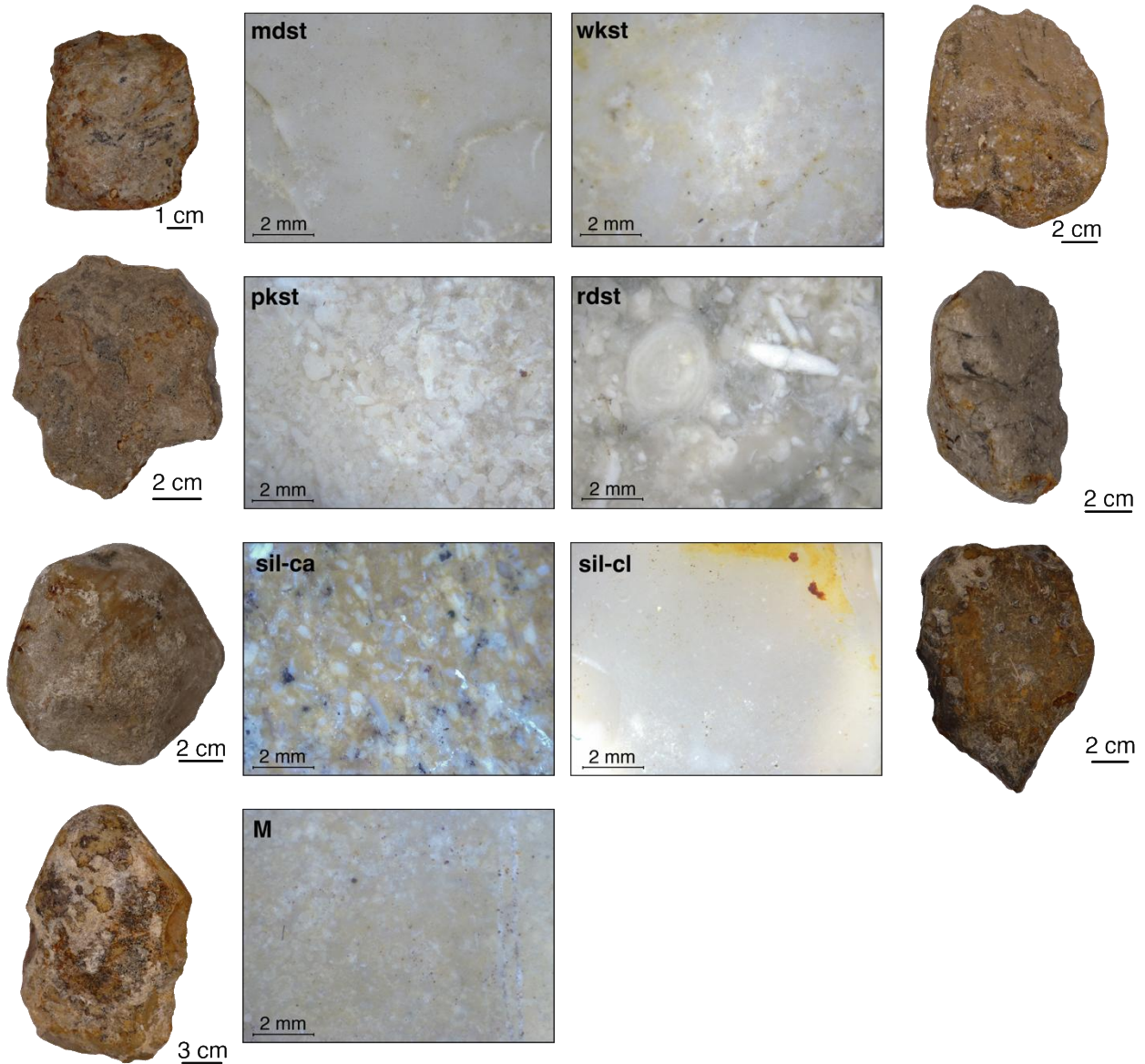


Figure 5 – Macrophotos and relative photomicrographs (10x magnification) of a selection of the lithic artifacts found on the layer B. Abbreviation key: wkst = wackestone; pkst = packstone; rdst = rudstone; sil-ca = silicified calcarenite; sil-cl = silicified calcilutite; m = marl. Images allowed by the agreement of the Italian Ministry of Culture and the Museo Parco Archeologico Melfi e Venosa.

3.2 Geological samples

3.2.1 Granulometric analysis

In general, the sizes of geologic samples on the paleosurface of the layer B range from 12 to 210 mm, with a mean of 77 mm and a median of 70 mm (Table 2). The granulometric distribution was as follow: 2 samples (< 1 %) belonged to medium pebble class, 26 samples (9 %) to coarse pebble class, 79 samples (27 %) to very coarse pebble class, 162 samples (56 %) to small cobble class and 20 samples (7 %) to large cobble class. The lithological variability mirrors that of artifacts (Figure 4c).

The cumulative probability curve of the grain size data (Figure 4a) deviates from normal distribution and shows strong positively skewed and very platykurtic character. The grain size distribution of clasts in areas B2 and B3 is more similar and well sorted than in area B1.

Texture is clast-supported throughout the exposed surface. The roundness (R) of clasts is comprised between 0.51 and 0.87 and the aspect ratio (AR_1) varies between 1.01 and 2.98 (Table 3).

3.2.2 Lithological variability

Observation of the selected clasts on the paleosurfaces allowed to identify the lithologies and the structure and texture characteristics of the source rock (Figure 7; Table 2).

The conglomerate clasts were assigned to nine lithological classes. They are composed of 182 limestone (63 %), 92 cherts (32 %), 12 sandstones (4 %) and 2 marls (1 %). A clast of crystalline quartz was also identified. The limestone group is composed of 74 packstone (41 % of limestones and 26 % of total), 65 rudstone (36 % of limestone and 22 % of total), 30 wackestone (16 % of limestone and 10 % of total) and 10 mudstone (5 % of limestone and 3 % of total).

As regards chert, it was observed that 86 samples (93 % of cherts and 30 % of total) are silicified calcarenites and 6 samples (7 % of chert and 2 % of total) are silicified calcilutites.

Only in area B1 were identified 11 clasts made of chert associated to the hosting limestone (packstone).

According to the classification scheme proposed by Scasso and Limarino (Scasso and Limarino 1997), layer B is a lithic orthoconglomerate (figure 8). In the ternary diagram for clast supported conglomerates, the C vertex includes the more stable species like mono- and polycrystalline quartz (chert, quartzarenite and quartzite); the crystalline basement and/or high-grade metamorphic clasts are counted in G vertex; and the less stable lithic clasts (sedimentary, low and medium grade metamorphic, volcanic) contribute the L vertex's percentages.

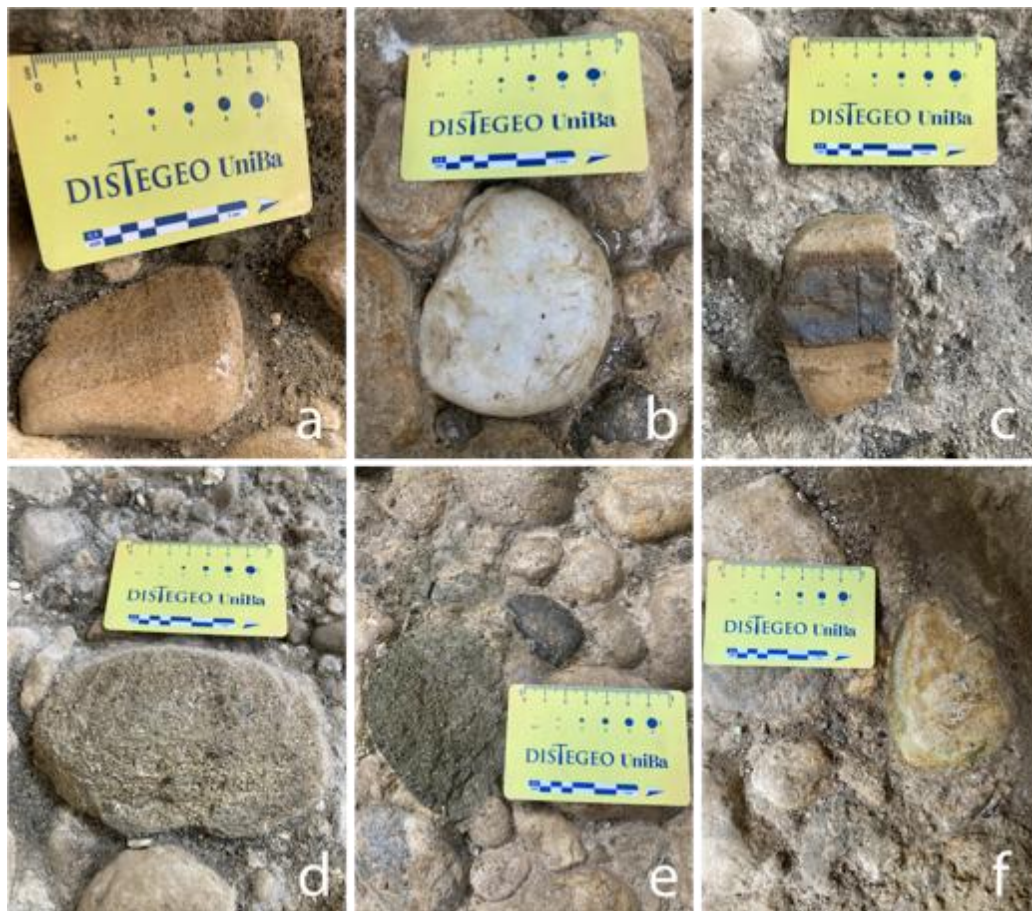


Figure 6 – Examples of lithotypes identified in layer B: a) stratified packstone; b) crystalline quartz; c) laminated silicified calcarenite (chert) in packstone; d) lithic arenite; e) arkose; f) marl. Images allowed by the agreement of the Italian Ministry of Culture and the Museo Parco Archeologico Melfi e Venosa.

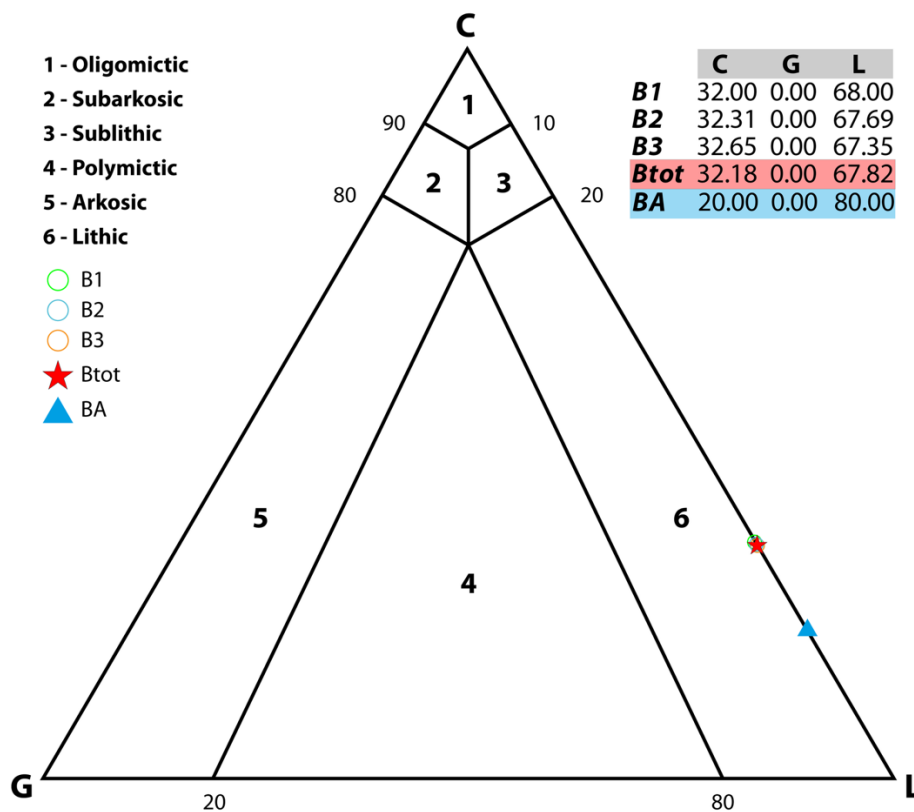


Figure 7 – Classification of conglomerates after Scasso and Limarino (Scasso and Limarino 1997) of the three investigated areas of layer B and of the lithic assemblage (BA). See text for details.

4. Discussion

Results allow to investigate two research facets. The first one concerns the origin of the raw materials and the selection strategy applied by the hominins. They contribute to the technological analysis of the lithic industry of Notarchirico and provide a broader knowledge about the hominins' behavior in Western Europe during the MIS 15. The second one is methodological and interests the validity and reproducibility of the sampling and analytical method adopted and its effectiveness as a tool to evaluate lithological variability and petrofacies expressed by the geological deposits.

Regarding the raw materials, the results obtained suggest some significant considerations. The lag of layer B can be classified as a lithic orthoconglomerate (Scasso and Limarino 1997). The predominant presence of limestones and chert formed in carbonate slope environments is consistent with the outer Apennine units (Faeto Flysch and Flysch Rosso Fms) and confirms a short-distance transport for these clasts. If the petrofacies points to the proximal provenance of the clasts, their roundness ranging from 0.51 to 0.87 (rounded to well-rounded after Power (Powers 1953)) suggest that they had formed before than the sedimentary cycle of Venosa Basin, and thus were eroded from regressive deposits of the Bradanic cycle (Sabato et al. 2004; Giannandrea 2009; Giannandrea et al. 2014). This is also demonstrated by the absence of coarse clasts of Mt. Vulture's lavas among the clasts of layer B. In terms of lithological variability, all the petrographic types identified on the artifacts were recognized among the geological samples, suggesting a local supply of raw material by hominins. The natural modification of the surface, shape and texture of the clasts, occurred before the anthropic transformation, and still visible on the artifacts, is consistent with what is observed on the clasts on the layer B. However, comparable ratios of limestones, cherts and other less represented lithotypes in both geological and archaeological samples demonstrate that hominins had low preference in specific lithologies when selecting raw materials for knapping.

The stone tools mainly belong to the larger granulometric classes (small cobble and large cobble), whereas the geological samples showed a more variable distribution, with a concentration in the intermediate classes (very

coarse pebble and small cobble). In addition, as well evident in the Kernel density curves (figure 4c) and in the summary statistic (figure 4d), mean, median and mode show higher values for the stone tools population than for the geological clasts. In Figure 8, it can be observed that the median of the maximum size of the tools is always higher than that of clasts of the same lithology. Such trend could represent a first indicator of selection of raw materials (forms and types) which should suggest intentional choices by hominins to select larger pebbles/cobbles available *in situ* (layer B). Further evidence of selection is the similar median values (130-150 mm) shared by the stone tools of different lithology compared to the different values of maximum size of the geological samples of the layer B.

However, some of the tools made by silicified calcilutite and wackestone are bigger than the geological cobbles of the same lithology sampled from the layer B. Moreover, it must be considered that the maximum size of the pebbles/cobbles before knapping was necessarily larger than that of the artifacts made from them. These evidence points to two possible reasons: 1) local cobbles were used but the maximum size of the clasts analyzed was underestimated because of sampling strategy; 2) nonlocal cobbles of the same type existing in the Venosa area were used, to date not accessible. Although the frequency of silicified calcilutite on the layer B is low (B1 = 1; B2 = 3; B3 = 2; \bar{x} = 2; s = 1), the standard error that refers to the whole sample population (n = 289) is 0.058, with a relative standard error of 3%, is quite precise for the aims of this research.

Therefore, the second hypothesis seems more likely, suggesting that some of the tools were made from clasts not necessarily selected among the investigated area but in the surroundings of the site and the same fluviolacustrine environment. There is evidence on pene-contemporaneous sites that settlements could cover a large area. Lithic material moved on the excavated area of more than 100 m² on the French site of la Noira (700 ka) (Despriée et al., 2017; Moncel et al., 2020). Additionally, the occurrence of tools made of silicified calcilutite, but of larger size than the clasts of the same lithology available on layer B, points to a deliberate selection elsewhere.

Other than lithology and size of the raw material, rock texture and fracturation play a significant technological role in artifact production, because they may affect the fracture propagation and the quality of fracture (Tixier et al. 1980). As it can be observed on figure 9, among limestones, frequency of mudstone, wackestone and packstone is rather comparable between artifacts and geological samples, whereas the frequency of rudstone in the archeological samples was significantly lower than its large availability in the layer B. This demonstrates a clear preference for lithotypes with finer texture among those more represented (i.e. wackestone, packstone). The same behavior applies for chert lithotypes, where silicified calcilutite is more frequent among artifacts than geological clasts. It can be assumed that the preference for fine-textured lithotypes was determined by empirical tests done on rocks of different textures, quite easily identifiable by naked eye on the surface of clasts.

In the end, the hominins of Notarchirico locally collected limestone and chert for the production of small-sized flakes as well as pebble tools, LCTs and bifaces. Beyond this local procurement, a further selection based on the raw material texture and size was seemingly performed, reflecting a careful, yet straight-forward, economy of the lithic resources and specific production goals. The analysis of layer B highlights how open-air sites such as Notarchirico might function as passage areas, where hominins moved across wider areas while carrying, using, and abandoning lithic objects.

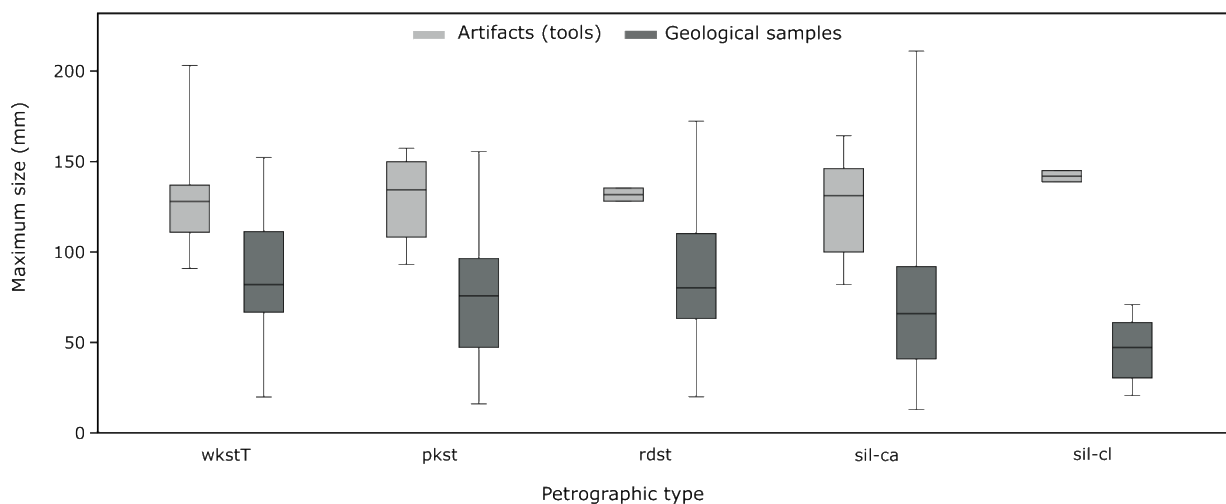


Figure 8 – Boxplot of the maximum size of the artifacts and the clasts according to the different lithotypes (wkst: wackestone; pkst: packstone; rdst: rudstone; sil-ca: silicified calcarenite; sil-cl: silicified calcilutite).

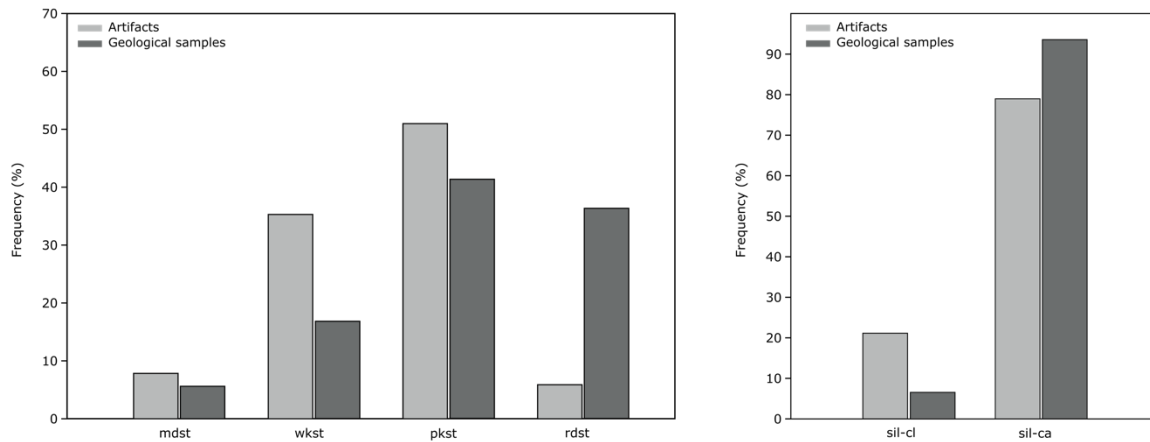


Figure 9 – Frequency of the limestone (a) and chert (b) lithotypes among the artifacts and the geological clasts for layer B

Some evaluation of the methodological approach adopted in this research can be done. The use of systematic sampling of geological clasts from the three areas of layer B proved to be effective in providing a representative sample, as shown by the very similar petrofacies classification in figure 11. The frequency of the lithologies (limestone, chert and other, Figure 10a) is comparable for the entire group of geological samples of layer B but above all it is coherent because observing their distribution on the three sub-areas (B1, B2 and B3). In the same way, the granulometric distribution shows overlapping boxplots, with comparable statistic values (figure 10b).

Moreover, the number of clasts obtained using a sampling grid of 50 cm results largely sufficient. As a matter of fact, if the percentage of the less frequent lithotype (mudstone = 4%), an absolute error of 4% (relative error = 1%) and a confidence interval of 98% ($t = 2.26$), the number of clasts necessary is 123 (Banning 2020).

$$n = \frac{t^2 p(1-p)}{d^2} = \frac{5.1076 \cdot 0.04 \cdot 0.96}{0.0016} = 122.58$$

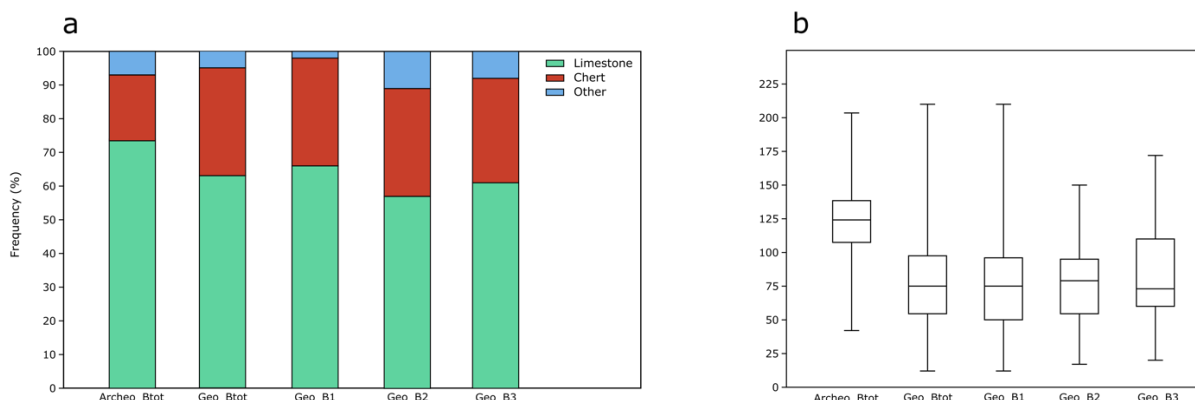


Figure 10 – Percentage of lithotypes as occurring in the lithic assemblage and on the layer B (a) and the boxplot of the samples' maximum size (b).

As concerns the granulometric analysis, a few considerations can be made about how clasts are measured. Although photos are calibrated with scale bars, direct measurement on site is preferable, especially for smaller pebbles. Image analysis on single orthogonal photos results very effective to extract morphometric indexes.

The use of a not destructive approach in petrographic and granulometric analyses was then effective in distinguish not only between limestone, chert and marl, but also specific lithotypes belonging to those rock subfamilies and relative source formations, without moving clasts from the paleosurface.

5. Conclusions

The extensive presence of coarse clasts in the layer B of the stratigraphic succession of Notarchirico represented a valuable opportunity to verify the archaeological hypothesis of deliberate selection of lithic raw materials by Lower Paleolithic hominins. The petrofacies of the layer B shows the source area of the coarse clasts ascribable to the Ofanto paleobasin (Giannandrea et al. 2014), where the formations of Lagonegrese-Molisano and Irpinian basins of outer units of the Southern Apennines (Patacca and Scandone 2007) were eroded and transported eastward to the Venosa area and reworked in the fluivo-lacustrine deposits of the Venosa Basin (Giannandrea et al. 2006). This constitutes a reference point of the naturally available lithic raw materials of secondary origin in the area. The comparison between the lithological variety of the lithic artifacts and that of the psephitic sediments of the layer B was carried out considering four main parameters: lithology, rock texture, clast size and post genetic surface alteration. According to these parameters, the stone artifacts are compatible with clasts of layer B from a granulometric, petrographic and morphological (post genetic surface alteration and size) point of view. In particular, the selection of stone nodules is demonstrated by: i) the very similar maximum length of the LCTs; ii) only some of the available lithotypes in layer B were used to knap artifacts; iii) central values of maximum length of stone tools are higher than those of layer B's clasts; iv) texture (fine vs. coarse) as a selection criterion was stronger than lithology (chert vs. limestone). This evidence also suggests that the area of lithic raw material supply was probably larger than the investigated paleosurface.

Recent results obtained on the lithic industry of layer A of Loreto (Eramo et al. 2025) allows to recognize clear differences in raw material exploitation, since the rare presence of psephitic clasts in the stratigraphic succession below the layer A of Loreto points to non-local exploitation of secondary deposits. The extensive coverage of pyroclastic deposits in the Monte Vulture area during MIS 13, probably drew the hominins toward the fluvial valleys where gravelly layers were more visible and accessible. Moreover, even though the lithotypes identified among the lithic industries of layer B in Notarchirico (MIS15) and of layer A in Loreto (MIS13) are compatible with the petrofacies of the Ofanto palaeobasin, in this latter case a clear preference for chert and finer rock textures was observed.

Finally, the results of this study show that the analysis of local psephitic sediments to define the petrofacies which characterizes the paleoenvironment of the archaeological context represents a powerful and sustainable way to understand the technological choices of hominins. Extending to more sites, few detailed analyses such this one have been made for Lower Paleolithic sites in Western Europe. As for most of sites, the raw materials at the Italian site of Isernia-la-Pineta (590 ka) or Atella (MIS 15-13) were probably collected in the vicinities of the site (Rocca et al., 2023). The only exception seems the site of the Caune de l'Arago in France (MIS 14, levels P-Q). Except a large collecting of local stones, a gathering of some specific and good quality stones in a perimeter of 30 km around the cave is attested (Gregoire et al., 2007; Capillari et al., 2021).

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Authorship

Author Contributions: Conceptualization, G.E. and G.F.; methodology, G.E. and G.F.; investigation, G.E., G.F. and M.C.; resources, G.E. and M.H.M.; writing—original draft preparation, G.E., G.F. and M.C.; writing—review and editing, G.E. and M.H.M.; visualization, G.E., M.C. and G.F.; funding acquisition, M.H.M. All authors have read and agreed to the published version of the manuscript.

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