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# Petrographic and Size Analysis of Lithic Artifacts of Loreto (Early Middle Pleistocene, Basilicata, Italy) to Support Insight on the Site Lithic Industry and Human Behavior

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**Abstract:** The Lower Paleolithic site of Loreto (Venosa Basin, Basilicata, Southern Italy), discovered in 1929 and excavated from 1956 to 1961 and from 1974 to 1981, consists of three main archaeological layers showing evidence of human occupation. The bottom layer (Layer A) is the richest and best-preserved layer, and its lithic industry includes flakes, retouched flakes, cores, and pebble tools mainly made of chert and limestone. This study involves the petrographic and morphometric analysis of about 400 artifacts. A comparison with the geological clasts of Layer B of the archaeological site of Notarchirico (Venosa), as well as geological samples from the outer tectonic units of the Southern Apennines chain available in the SiLiBA lithotheque and analyzed with the same methodological approach, provided not only the identification of the lithotypes and their source formations but also allowed for insights into technological behavior and human–environment interaction.

**Keywords:** chert; limestone; Paleolithic; lithic industry; human behavior; raw material supply

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## 1. Introduction

Chert, thanks to its physical and mechanical properties, is the most used raw material by Prehistoric hominins for the production of tools with sharp edges useful for different purposes and functions (from cutting, to drilling, to scraping) [1]. This material, natural and widely available, in fact, shows characteristics in terms of hardness and sharpness that, combined with its homogeneous structure and conchoidal fracture, make it particularly suitable for knapping and obtaining predetermined artifacts [1,2]. Chert is the *file rouge* of all Prehistory since its use is attested from the Early Paleolithic to the Bronze Age, and the knapping techniques and methods [1] are varied and constantly evolving in relation to the *débitage* objectives of different human species and communities [3–22].

However, there are numerous examples of the use of different lithological materials, including limestone [23–25], quartz [26–40], quartzite [24,34,40–43], obsidian, and other volcanic rocks [14,34,37,43–47]. The use of these lithotypes, "other than chert", is the result of a combination of different factors related to resource availability, mobility, and *débitage* purposes, which are a reflection of the subsistence activities of different human groups.

The integrated approach between the petrography and archaeology fields, applied to prehistoric lithic artifacts, significantly contributes to provides data to answer questions relating to the provenance of raw materials that, combined with techno-typological

and techno-functional aspects, allow the reconstruction of supply strategies, knapping objectives, settlements, activities, interaction with the environment, and a network of relationships and exchanges of human communities [9,10,19,25,48–50].

An essential tool for achieving these objectives is the in-depth knowledge of the morphometric and petrographic characteristics of lithic artifacts and their comparison with the geological and lithological characteristics of primary outcrops and secondary polygenic deposits [22,51–56].

Early research carried out to identify chert sources dates back to the end of the nineteenth century and was essentially based on macroscopic description. It was only later that optical microscopy was introduced [57]. In the 1970s, the first studies highlighted the importance of lithic sourcing to retrace prehistoric connection networks [58,59]. These investigations aimed at recognizing and differentiating specific geological chert sources and successively comparing archaeological artifacts to their resources [58,60,61]. In the archaeological studies, a macroscopic approach is commonly employed to describe visible properties of artifacts and to compare them with geological samples. The identification of chert raw materials is a geological issue that was approached through either geochemistry or petrography (e.g., [51,52,58–60,62–64]).

The geological approach of Séronie-Vivien [62] showed that the morphology and textures of chert were connected to the sedimentary environment. Even if the petrological meaning is not the same, Dunham's classification for limestone texture [65] is quite widespread in chert petrography (e.g., [51,52,62]).

A pivot work was conducted by Luedtke [2], who proposed a standard description of visible properties in order to facilitate comparisons using formalized descriptions of geological, mineralogical, and petrological features.

Sieveking [58] and Luedtke [59,60] addressed the problem of trace element variation within geologic sources of chert. Hess [66] and Malyk-Selinova [67] highlighted the importance of petrographic and geochemical signatures to identifying the provenance of chert artifacts, using NAA, ICP-MS, or X-ray fluorescence (XRF) techniques and suggesting the use of statistical analysis to improve the interpretation of results. Bressy [51] proposed a macroscopic approach that combines empirical observations with nondestructive petrographic analyses of the bulk samples under a stereomicroscope (frequency, dimension, and nature of inorganic inclusions, oxides, organic matter, and micropaleontological contents). If the cortex and cortex/chert transitions are a peculiarity of chert in a primary source, the outer surface of sub-primary and secondary source chert, which preserves the traces of mechanical transport and exposure of weathering, is indicated as the 'neocortex'. Despite the limitations associated with the difficulty of objectifying empirical observations and the impossibility of determining highly patinated pieces, the speed of characterization, nondestructively, and the low cost of the methodology proposed by Bressy [51] constituted fundamental progress in chert investigations. In Italy, this method has been used by Bertola [68–71].

Fernandes and Raynal [52] analyzed the elements observable on the surfaces of prehistoric artifacts at different scales using a petroarchaeological method in order to identify the sources of raw materials and the locations of deposition of the analyzed objects. The examination of the micromorphology of different types of neocortex allowed them to recognize the features of each geological environment. Through a multidisciplinary approach, they aim to reconstruct 'silica evolutionary chains', produced by genetic and postgenetic phenomena, including all natural modifications occurring during the predepositional phase before prehistoric modifications, but also all those due to anthropic use and subsequent to the abandonment of the chert artifact.

In recent years [55], a nondestructive multiparametric protocol for chert investigations (NM-PCI) that combines the petrographic analysis of macroscopic and mesoscopic characteristics (structures, textures, and paleontological contents) and the acquisition of colorimetric and geochemical data by portable devices was introduced. Through the treatment of data obtained by a multivariate statistical approach, this methodology allows overcoming the partial information derived from individual analytical techniques to deepen the real complexity of the chert provenance issue.

The presented case study is dedicated to the lithic industry of the Paleolithic archaeological site of Loreto (Basilicata, Italy). Significant considerations were reinforced thanks to the comparison of artifacts of Loreto with clasts of Layer B of the near site of Notarchirico (Basilicata, Italy) and with geological samples of SiLiBA, a lithotheque of the University of Bari Aldo Moro (Italy).

It aims mainly to contribute to the current studies on knapping technologies, selection of raw materials, and exploitation of supply sites, in order to improve the knowledge of human behaviors of Paleolithic hominins and their interaction with the surrounding environment. Furthermore, the research intends to contribute to the definition of investigation protocols based on the comparison of petrographic and archaeological data.

### *1.1. The Paleolithic Site of Loreto*

The Loreto site (40°58′32.60″ N, 15°52′30.33″ E), located in the Venosa Basin (Basilicata, Italy) above a hill a few hundred meters from the Notarchirico paleolithic site (Figure 1a), is part of the Monte Vulture volcanic complex. The site was first identified in 1929 by Don Briscese, with initial investigations conducted in the 1930s by Rellini and d'Erasmo [72]. However, systematic excavations began only between 1956 and 1961 under the supervision of Chiappella, representing the Istituto Italiano di Paleontologia Umana [73,74] and continued by Barral and Simone of the Musée d'Anthropologie Préhistorique of Monaco [75–77] between 1974 and 1981.

In the stratigraphic sequence (Figure 1b), three archaeological horizons, interbedded by sterile, fluvio-lacustrine sediments rich in sand, silt, clay, and travertine, containing lithic tools in association with faunal remains, have been identified [74,77,78]. From the top to the bottom, these layers include (i) Layer C, approximately 3 m thick, composed of sandy silt with pebbles [74]; (ii) Layer B, 25 cm thick, consisting of green cemented sand rich in volcanic material; (iii) Layer A, 40–60 cm thick, composed of cemented sandy silt, which was the focus of excavations by Chiappella and by Barral and Simone, covering a surface of 20 $m^2$.

Lithic artifacts have been documented across all three archaeological layers, although comprehensive analysis has primarily focused on Layer A, which yielded the most abundant and best-preserved material [77,79]. The lithic assemblage from Layer A includes flakes, retouched flakes, cores, and pebble tools, mainly manufactured from chert and limestone.

Technological assessments have attributed these artifacts to the Lower Palaeolithic "Tayacian culture" (though this term is not used anymore) characterized by large flakes, open core reduction angles, and scalariform retouch techniques for the production of scrapers and pointed tools [74,77–79]. A total of 528 lithic samples were collected during the 1974–1981 excavations; however, the number of artifacts retrieved during the 1956–1961 campaigns, including those from Layers B and C, remains undocumented. The assemblage from Layer B appears technologically comparable to that of Layer A, even if less abundant. In contrast, artifacts from Layer C, which include Mousterian-type tools, may correspond to a Middle Palaeolithic context [74].

The faunal assemblage comprises remains of rhinoceroses, equids, bovids, cervids, hippopotamuses, canids, hyaenids, felids, and bears from Layer A, while elephants, equids, and bovids are reported from Layers B and C [74,75,77]. These faunal remains support an attribution to the early Middle Pleistocene [75,80,81].

A recent taphonomic and taxonomic reassessment of the Layer A faunal remains [82] indicates a biased assemblage, likely due to the excavation methods employed during mid-20th-century excavations. This has resulted in a predominance of larger, anatomically and taxonomically identifiable specimens, with a lack of smaller remains limiting taphonomic interpretations. Preliminary analyses suggest a dominance of medium-sized (cervids) and large-sized ungulates (equids and bovids). Although scarce, evidence of human activity includes cut marks and bone breakage, suggesting primary access to carcasses by human groups. Carnivore modification is also present, albeit less frequently, implying independent and partial access by both agents during the assemblage's formation.

Paleoenvironmental data suggest an open landscape with lacustrine features and a mosaic of vegetation, paralleling conditions inferred at Notarchirico. Durante and Settepassi [83] analyzed terrestrial gastropods recovered from Loreto to reconstruct the paleoenvironment. According to their findings, Layer A corresponds to humid forested conditions, while Layers B and C indicate drier and warmer climates.

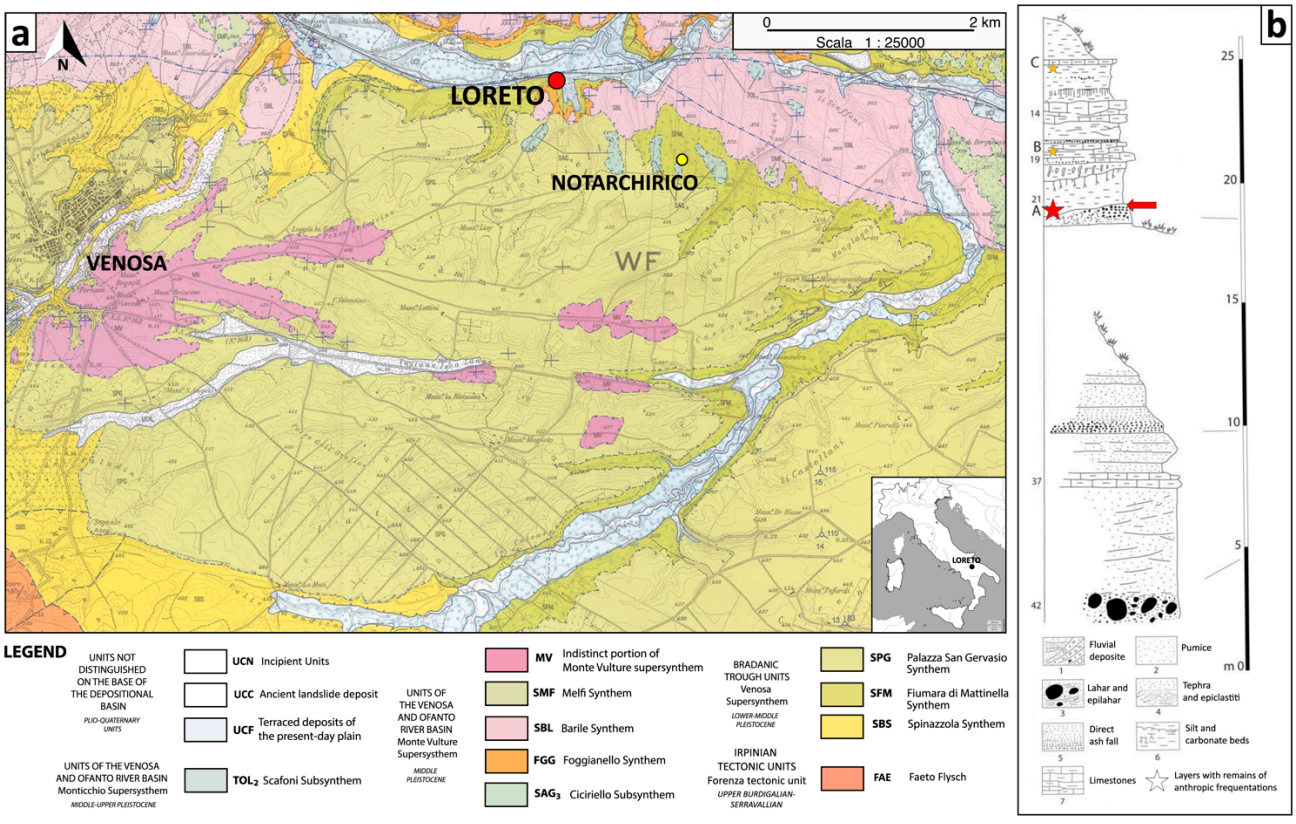



**Figure 1.** Geological map of the Venosa Basin ((**a**), modified after Giannandrea 2009 [84], and stratigraphy of the Loreto archaeological site (**b**).

### *1.2. Geological Background*

The archaeological site of Loreto belongs to the Venosa lacustrine-alluvial basin, which is located next to the Monte Vulture and embedded in the Bradanic Trough and has a complex geological structure dominated by the Southern Apennines orogenesis [85–87]. The foredeep basin of the Bradanic Trough is placed between the Apulian Foreland and the Adriatic-verging thrust belts of the Southern Apennines, and it is NW-SE oriented [88–91].

The depositional environments and thickness of the sedimentary sequences were influenced by the inclination of the Apulian Foreland ramp and the proximity to the frontal part of the Apennine chain [92]. The inner sequences include deep-marine deposits and turbidites [90,93], while the outer sequences feature shallow-marine and alluvial deposits. The Quaternary evolution of the Bradanic Trough was marked by erosional regression due to regional uplift, with terrace formation phases associated with glacio-eustatic oscillations [90,94,95].

The Venosa Basin is characterized by the presence of the Fiumara di Venosa stream [84] and developed during the regional uplift and regressive erosion that occurred between the middle and late Pleistocene [96]. The stratigraphic succession (formed in about 150 ka) is correlated to volcanic products emitted at Vulture of Synthems of Foggianello, Barile, and Melfi [78,84] and includes three lithostratigraphic units [97]: from the oldest to the newest, the Fonte del Comune Fm., associated with the Foggianello Synthem, the Piano Regio Fm., and the Tufarelle Fm., both associated with the Barile Synthems.

The Loreto site [74,77,98] shows a 30 m thick stratigraphic sequence in which 42 layers have been identified, based on the study of several records from the slope of Loreto Hill [77,78,99] (Figure 1b). This sequence has been compared to a drill core collected in 1988 [100,101] made on the top of the hill to a depth of 40 m. Three anthropic occupation layers (A, B, and C) have been identified [77,78] (Figure 1b). Paleomagnetic data made by Baissas [99] identified the Brunhes/Matuyama boundary in Layers 37–38 (e.g., 775–780 ka) while Gagnepain [102] identified a reverse polarity 5.5 m below Layer 37 of Baissas [99]. The reinterpretation of litho-stratigraphic succession allowed the identification of the Brunhes/Matuyama boundary at 31.20 m between the conglomerate of the Fonte del Comune Formation and the lahar deposits of basal member A of the Tufarelle Formation [78,100,101]. Baissas [99] also identified "Levantine" and "Jamaica" paleomagnetic excursions in Layers 9–8 and 4–2, around archaeological Layer C, but the most recent geomagnetic instability scale suggest that the excursions identified in Loreto could be associated with the excursions at Pringle Falls (ca. 210 ka) and Laguna del Sello (ca. 340 ka) or simply be re-magnetization of the sediments [103].

The basal stratigraphic unit of the basin fill is the conglomeratic deposits that belong to the Fonte del Comune Formation [101]. Above, there are highly heterometric conglomerate, coarse-grained sand, and scattered meter-size boulder deposits formed by lahar flows, of member A of the Tufarelle Fm. Epiclastites and gray scoria-fallout deposits outcrops higher in the hill slope. In member B of the Tufarelle Fm., the tephra layer in Layer 32 corresponds to fallout R1 [100,101]. Higher up, the deposit becomes less epiclastic and thick limestone banks, yellow silts, hydromorphous paleosols, and a cemented and encrusted emersion surface, characterize the palustrine environments of member C of the Tufarelle Fm. The epiclastites of member C may correlate with the Case Lopes subsynthem of the Mount Vulture volcano [101] and were estimated to date between ca. $484 \pm 8$ ka and $530 \pm 22$ ka [104,105]. Gray clayey carbonate banks with carbonate nodules and ferruginous pisolites and reworked tephras characterize the upper facies and correspond to member D of the Tufarelle Fm.

Archaeological Layer A with Lower Palaeolithic evidence belongs to member C of Tufarelle Fm. [78] and previous studies have attributed to early Middle Pleistocene the human presence at the site [75–100]. The latest absolute dating made at the Loreto site to date the Lower Paleolithic Layer A applied three different methods (ESR/U-series, ESR and $^{40}Ar/^{39}Ar$) and, in agreement with the geological and paleontological works [100–106], suggests an age between MIS 15 and 13 age for this layer [78].

## 2. Materials

### 2.1. Artifacts

The considered group of the Loreto collection includes 415 lithic artifacts from Layer A, stored in the Museo Archeologico "M. Torelli" in Venosa, supervised by the Musei Parchi Archeologici Melfi e Venosa. The original number of artifacts included another 145 pebble tools cited by Crovetto [79], now lost. The impossibility of analyzing all the pebble tools undoubtedly represents a limitation. As pointed out in the review of the faunal remains [82], there is a concrete possibility that the lithic assemblage is biased. The absence of transport traces allows us to exclude a selection due to secondary agents [82]. The almost absence of <20 mm flakes and the high frequency of complete pieces and large-sized flakes are probably attributed to the excavation methods, and, consequently, the analyzed assemblage may not entirely represent the original lithic assemblage [107]. Despite these constraints, the lithic assemblage was nevertheless analyzed with a techno-economic approach [1,108,109] to reconstruct, as far as possible, the *chaîne opératoire* and the production objectives [107]. Figure 2 shows a selection of lithic artifacts from Layer A of Loreto.

The analyzed assemblage is dominated by flakes (312 samples, 75% of total) followed by a smaller number of retouched tools (77 samples, 18% of total), among which retouched flakes prevail, while cores (9 samples, 2% of total), pebble tools (6 samples, 1% of total) and debris (10 samples, 2% of total) are rarer.

The main goal in the analyzed lithic industry of Layer A is the production of flakes, some of which are retouched. Direct percussion is the predominant technique across all raw materials. Nonetheless, limited evidence suggests the occasional use of bipolar-on-anvil methods, possibly employed to fracture large limestone blocks, maximize small chert cores, or knapping rounded and oval-shaped pebbles.

The production of chert flakes is performed through various knapping strategies, most notably characterized by a single or dual-surface debitage approach (SSDA), employing unipolar removals from natural or cortical platforms and taking advantage of the original morphology of the raw material.

Frequent alternation between striking platforms and knapping surfaces results in a high incidence of flat butts on flakes, although natural and cortical platforms appear in similar proportions.

The flakes produced are generally medium to large in size and exhibit regular profiles and thickness, which reflects the technical capacity of hominins to extract products with specific features from larger blocks. Backed flakes are relatively common, often featuring a non-cutting edge opposite the active cutting edge. While no unequivocal discoid flakes are recorded, several cores either correspond to or resemble discoid reduction schemes, including two with centripetal flake removals. These cores exhibit competent management of convexities and volumes, with peripheral striking platforms and debitage angles around 70°. Evidence also suggests that flakes were occasionally reused as cores. Some cores are retouched, reflecting the operational flexibility of the reduction strategies.

Limestone flake production follows similar patterns, generally obtained by unipolar removals and short reduction sequences on one or two surfaces. Given the frequent use of pebbles as raw material, the creation of a striking platform, via either split fractures or simple removals, was often a preliminary step. It is plausible that some limestone flakes originated as by-products of pebble-tool production (*façonnage* flakes).

The pebble tool is a minor component of the analyzed assemblage (only 6 samples) and includes unifacial and bifacial tools lacking standardization in terms of removal orientation or edge morphology. However, the original number of pebble tools mentioned by Crovetto [79] was 145, and these pieces were not found.

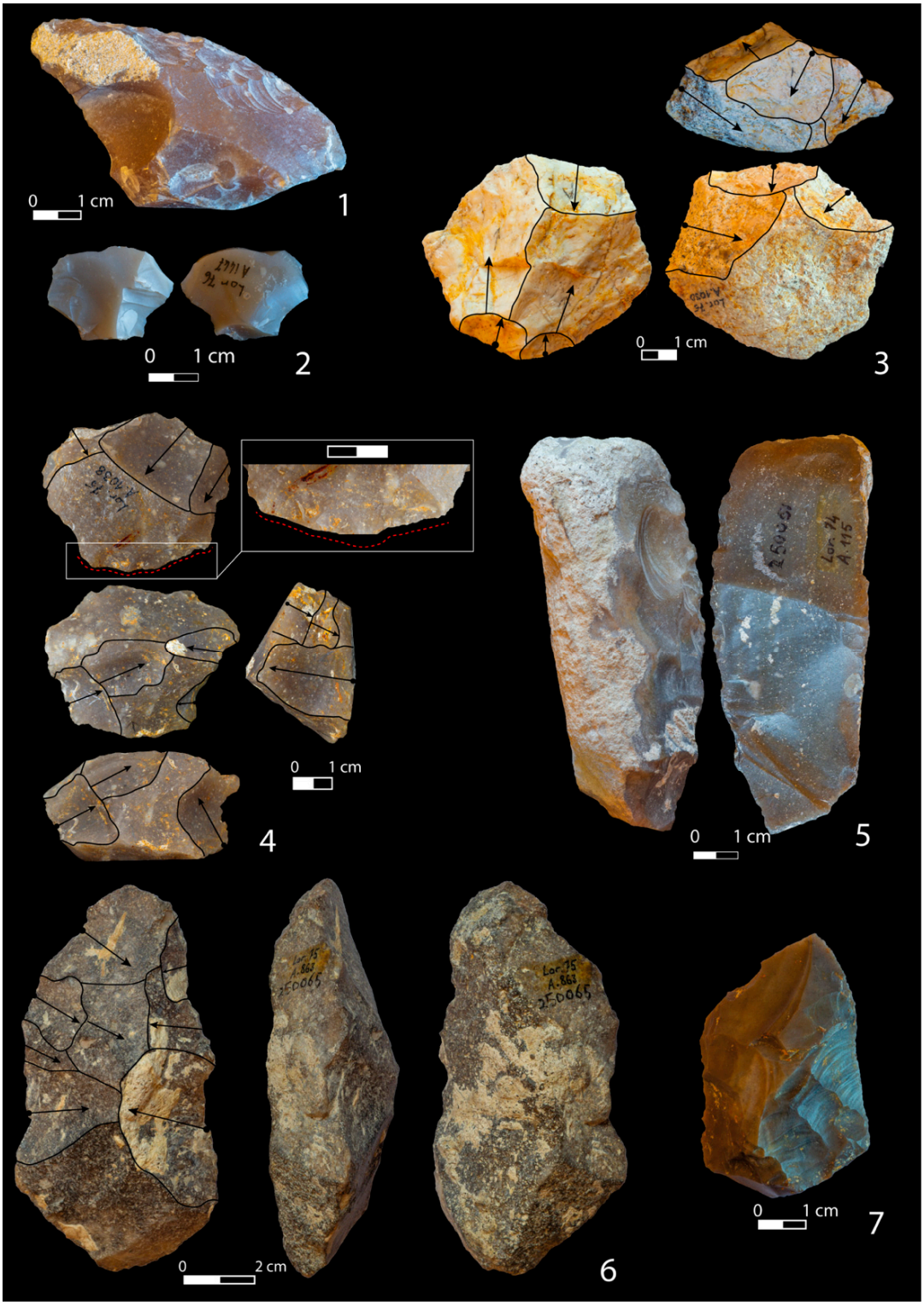



**Figure 2.** Selection of lithic artifacts from Layer A of Loreto. 1. Retouched flake on chert; 2. small-sized flake on chert; 3. centripetal core on limestone; 4. retouched core on chert with discoid conception; 5. large-sized flake on chert with cortical back; 6. unifacial tool on large-sized flake; 7. retouched flake on chert. Images used with the agreement of the Italian Ministry of Culture and the Museo Parco Archeologico Melfi e Venosa.

Retouched flakes represent a significant portion of the assemblage. No specific recurrence is observed in the selection of flakes for retouching, except the clear preference for chert and the choice oriented toward products large in size. Retouch is predominantly

direct, marginal, and applied to various parts of the flake edges. Some artifacts exhibit multiple phases of modification, indicating that retouching could significantly alter the original morphology of the flake. Thin, scalariform retouches, potentially indicative of soft hammer use and edge rejuvenation, are also present. However, additional data are required to confirm these interpretations.

### *2.2. Geological Samples from Layer B of Notarchirico*

In order to obtain information on the provenance of the raw materials used at the Loreto site, a group of 289 clasts in their original position on Layer B (Figure 3) of the nearby archaeological site of Notarchirico (approximately 200 m away), currently the focus of a specific study in publication [110], was considered as geological proxy of the geolithological variability, and then of the availability of raw material, of the fluvio-lacustrine basin of Venosa. Most details about the sampling strategy will be reported in the Methods section. According to that study [110], Layer B of the Notarchirico site could be considered as a representation of the Venosa fluvio-lacustrine basin, and it serves as a good indicator of local petrofacies, as it shows a very low anthropization degree, the clasts are in situ, and the surface is highly dense.

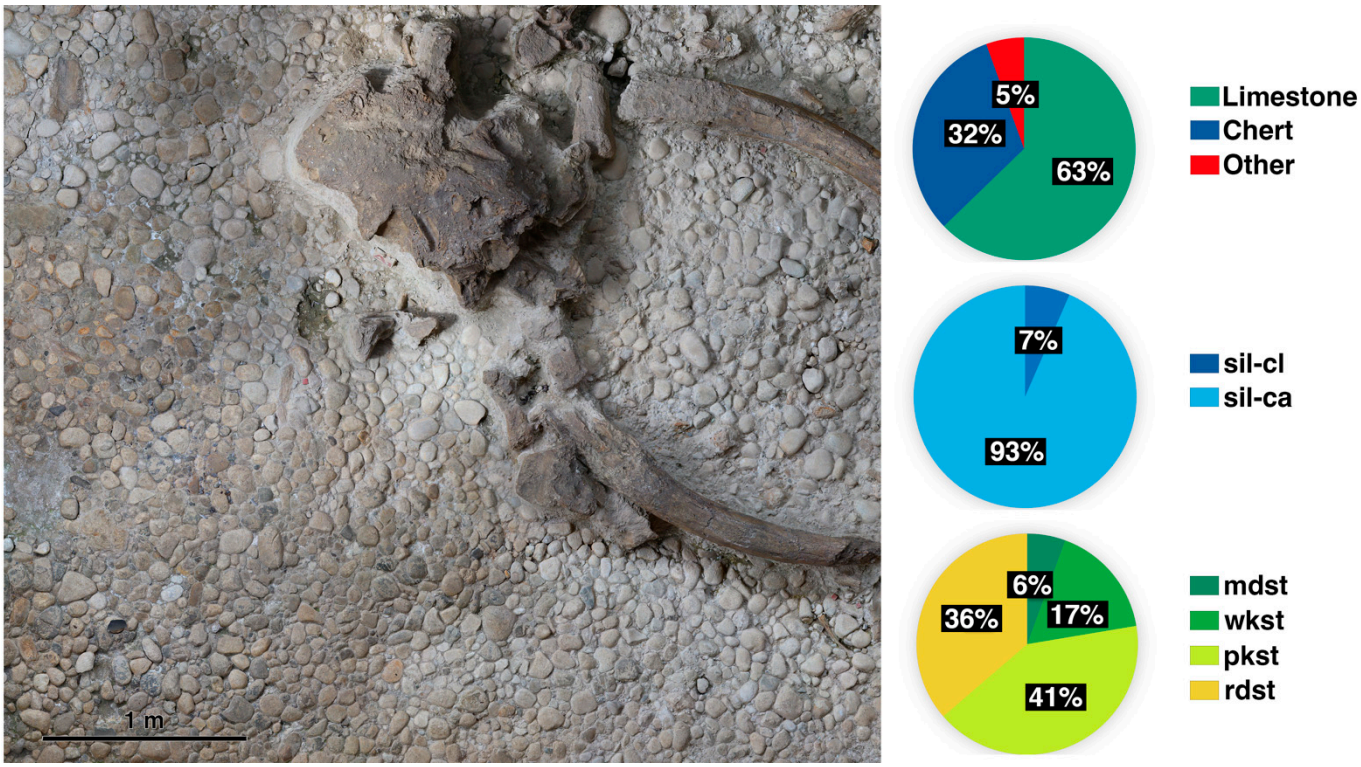



**Figure 3.** Notarchirico Layer B detail, lithologies, and textural features of chert and limestone sample clast. Image of Notarchirico Layer B used with the agreement of the Italian Ministry of Culture and the Museo Parco Archeologico Melfi e Venosa. Abbreviations: sil-cl = silicified calcilutite; sil-ca = silicified calcarenite; mdst = mudstone; wkst = wackestone; pkst = packstone; rdst = rudstone.

The results about the identification of lithological and textural features of clasts on Layer B in the Notarchirico site suggested the presence of different lithotypes (Figure 3). In fact, this study revealed that the surface included 182 limestone (63%), 92 cherts (32%), and 16 samples of other lithologies (5%), which will be excluded from the comparison with the Loreto artifacts. Specifically, limestone included 10 mudstone (6% of limestone), 30 wackestone (17% of limestone), 74 packstone (41% of limestone), and 65 rudstone (36% of

limestone), whereas cherts included 6 silicified calcilutites (7% of chert) and 86 silicified calcarenites (93% of chert) [110].

Pebbles of Layer B of Notarchirico taken into account showed a maximum size variable between 12 and 210 mm. Considering the granulometric distribution, 2 samples (<1%) belonged to the medium pebble class, 26 samples (9%) to the coarse pebble class, 79 samples (27%) to the very coarse pebble class, 162 samples (56%) to the small cobble class, and 20 samples (7%) to the large cobble class.

### 2.3. SiLiBA Lithoheque Samples

A further comparison with geological samples collected in the neighborhood of the site, housed in the SiLiBa lithotheque [111] of the Department of Earth and Geoenvironmental Sciences of the University of Bari Aldo Moro (Italy), was considered. It represents a reference collection for provenance studies of the archaeological samples. It consists of about 1500 pieces, both primary and secondary geological sources, belonging to formations of Cretaceous to Quaternary age collected across Italy, Croatia, Serbia, and Switzerland. The database of SiLiBA includes geographical coordinates, macro- and microphotographs, colorimetric coordinates (CIEL*a*b* space), chemical, petrographic, micropaleontological, and morphological data, obtained by a non-destructive multiparametric investigation protocol [55].

For the present study, artifacts of Loreto were compared with geological samples of radiolarite and silicified calcilutite and calcarenite from four chert-bearing formations of Irpinian and Lagonegrese-Molisano Basins, which surely contributed to the secondary deposits of the Venosa Basin, used by the human groups of the Loreto Layer A for the production of the lithic industry: Flysch di Faeto Fm. from Forenza (FRZ), Flysch Rosso Fm. from Tolve (TLV), Flysch di Galestrino Fm. from Bivio di Tricarico (BDT), and Scisti Silicei Fm. from San Fele (SFL) e Sasso di Castalda (SDC).

Flysch di Faeto Fm. (FAE) (Burdigalian-Serravallian) [112] is an Irpinian Basin formation consisting predominantly of marly limestones and light gray calcilutites to Orbulina spp and turbiditic bioclastic calcarenites in centimeter to decimeter layers, with centimeter intercalations of clays, marly clays, and gray-green siltstones and sometimes fine gray turbiditic arkosic sandstones (FAE). This succession appears to be intercalated with a lithofacies characterized by whitish-gray marly clays and silt with intercalations of centimetric marly-arenaceous and calcilutite layers (FAEa). Chert nodules were sampled in primary outcrops of this formation in the area between Venosa and Forenza (FRZ). The chert is gray silicified calcarenites characterized by a predominantly microspotted and spotted structure, sometimes laminated with well-sorting of grains, a well-represented terrigenous component, and abundant bioclastic features (mainly indeterminate). Siliceous sponge spicules and planktonic foraminifera (especially globigerines) are well-represented. Less frequent benthic foraminifera (especially nummulites), radiolarians, sponges, echinids, and bivalve fragments.

The Flysch Rosso Fm. (FYR) [113] is a formation of the Lagonegrese-Molisano Basin composed of calcareous clastic and pelagic slope to basin successions, with turbiditic episodes, attributable to the Lower Cretaceous p.p.-Miocene p.p. interval (Valanginian-Aquitanian). The Flysch Rosso Fm. can be succinctly described as a succession consisting in the lower part of argillites and radiolarites with thin intercalations of bituminous levels (black shales) ("membro diasprigno"—FYR1), which is followed by alternating clays, marls. and red calcilutites (calcareous member—FYR2) with intercalations of decametric lenticular levels of calcarenites and calcirudites to carbonate platform elements (*Nummulite* neritic limestones, *Orbitolites*, rudiste fragments, sponges, etc.) (calcareous-clastic lithofacies—FYR2a) and sometimes deposits related to synsedimentary landslides [114]. A level of

gray-green pelites with thin volcano-clastic intercalations (pelitic lithofacies—FYR2b) closes the succession. The chert slabs and nodules of Flysch Rosso Fm. of SiLiBA lithotheque were samples south of Tolve (TLV), but this formation also outcrops in several places in the geological map of Rionero in Vulture (https://www.isprambiente.gov.it/Media/carg/452_RIONERO_IN_VULTURE/Foglio.html, accessed on 6 May 2025).

The chert sampled in the calcareous member is polychrome silicified calcarenite (rarely calcilutites) characterized mainly by a spotted-microspotted and banded-laminated structure. The grains are well sorted with an abundant terrigenous component, while, regarding microfossils, radiolarians and spicules are attested. In the membro diasprigno (FYR-1), red radiolarites were sampled, characterized by a spotted-microspotted structure and abundant radiolarians, poorly sorted.

Flysch Rosso Fm. bears directly on the Flysch di Galestrino Fm. (FYG) [113,115,116]. This formation, of a deep marine environment, attributable to the Upper Jurassic-Lower Cretaceous, consists of alternating, thin layers, varying in thickness from a few centimeters to a few decimeters, of locally silicified gray and yellowish calcilutites and calcisiltites, calcareous and siliceous marls with radiolarians and siliceous sponge spicules, conchoid-fractured, laminated siliceous argillites with prismatic fracture that are black, gray and greenish, and rare calcarenites. Calcarenites and calcilutites often show parallel, convolute laminations and are turbiditic. This formation has been sampled near the Bivio di Tricarico (BDT) but also outcrops extensively in the Melfi area (https://www.isprambiente.gov.it/Media/carg/451_MELFI/Foglio.html, accessed on 6 May 2025). The gray-green silicified calcilutites frequently show latent "ruin marble"-type fissure planes, often recemented by the deposition of calcite crystals. The structure is homogeneous or microspotted with areas characterized by laminations, where more or less sorted radiolarians are visible.

The Scisti Silicei Fm. (STS) is a unit of the Lagonegrese-Molisano Basin [113] chronologically framed between the Upper Triassic and Jurassic. This deep-sea formation, a junction between continental escarpments and abyssal plains with fine turbiditic contribution [117], consists of cherty clays and radiolarites, with intercalations of calcarenites and calcirudites, often silicified. Based on the quantity and frequency of resedimented carbonate material exported from adjacent platforms, four facies have been distinguished within this formation [113]. The Scisti Silicei Fm. were sampled in the Sasso di Castalda (SDC) and San Fele (SFL) formation-type sections (Marsico Nuovo e Melfi geological maps) (https://www.isprambiente.gov.it/Media/carg/451_MELFI/Foglio.html, accessed on 6 May 2025; https://www.isprambiente.gov.it/Media/carg/489_MARSICO_NUOVO/Foglio.html, accessed on 6 May 2025) where they outcrop below the Flysch di Galestrino Fm. The silicified calcilutites show a coloration ranging from red to gray to green, the structure is predominantly shaded or laminated, the grains are very fine and well sorted, and among the microfossils, only radiolarians (generally shaded phantoms) can be recognized.

## 3. Methods

The artifacts of Loreto were washed with tap water and cleaned, if necessary, by a soft brush and a hydrochloric acid solution (diluted to 2%) to dissolve the carbonate crust and to better observe the surface of the sample and identify their features. Firstly, a photographic documentation was collected with a Canon EOS R100 camera equipped with a Canon lens (RF-S 18–45 mm F4.5) and using an LED light in a lightbox. The lightbox ensured high-definition photos without photographic artifacts and shadows. Afterward, a documentation at the microscale of samples was obtained by means of a Leica EZ4 W stereoscope. In this case, samples were photographed in water to enhance the observation of sample features, in particular the structure and texture of the rock. For all samples, the maximum size was recorded using a digital caliper. Residues of natural surface alteration

on artifacts formed before knapping by hominins were recorded considering the following semi-quantitative scale: absent, <50%, >50%.

The size analysis and the petrographic results were compared with those of Layer B of the Notarchirico site. Although the sampling methodology for this site is the subject of a specific study currently under publication [110], it is necessary to briefly outline the steps that were followed. Since the samples could not be physically moved and the surface was quite extensive (approximately 107 $m^2$), a systematic virtual sampling approach was adopted. Firstly, a 3D survey of the level surface was obtained from a collection of more than 600 photographs, using the Agisoft Metashape 2.1.1 software based on the photogrammetric technique. From the digital model, an orthophoto was extracted, and on that a virtual grid (with a spacing of 25 or 50 cm) was overlapped. Samples intercepted by the nodes of the virtual grid were considered, and significant petrographic parameters (lithology, structure, texture, lithotype) were determined using a 40x magnifying lens. The maximum size of all the samples was also measured by a caliper.

## 4. Results

### *4.1. Petrography*

Only 397 out of 415 artifacts underwent petrographic characterization, as 18 of these were completely covered by black patina that hid the surface. A complete report of petrographic data was included in Table S1 in the Supplementary Materials section.

Considering the residues of natural surface on artifacts, 55% of these samples exhibited traces of natural alteration; however, only 16% were characterized by the presence of residual cortex covering more than 50% of the surface.

Results of the microscopy observation revealed that the assemblage was composed of chert (326 samples, 82% of total), limestone (70 samples, 18% of total), and sandstone (1 sample). In particular, they were grouped on the basis of different textures and lithotypes (Figure 4) as follows: for chert, 105 silicified calcilutites (32% of cherts and 26% of total), 214 silicified calcarenites (66% of cherts and 54% of total), 6 silicified calcirudites (2% of cherts and 2% of total), and 1 sample of radiolarite were identified; for limestone, 14 mudstone (20% of limestone and 4% of total), 30 wackestone (43% of limestone and 8% of total), 25 packstone (36% of limestone and 6% of total), and 1 rudstone were recognized. Analyzing the frequency of lithologies within the techno-categories (Figure S1, in Supplementary Materials) of the analyzed knapped artifacts of Loreto Layer A, we can observe that chert is clearly prevalent within almost all the categories and in particular among the retouched artifacts, where it represents almost the entire set (72/74). On the other hand, limestones are marginal within almost all the techno-categories, except for the heavy-duty tools (3/5) and the flakes, among which they are represented with non-negligible percentages (20.7%).

Analyzing the frequency of the different petrographic groups within the same techno-categories (Figure S2, in Supplementary Materials), we can observe that, among the cherts, the silicified calcarenites (sil-ca) prevail in almost all cases, with the exception of the debris. The ratio between calcarenites and silicified calcilutites (sil-cl) in fact generally ranges between 2.08 (for the flakes), 2.23 (for the retouched artifacts), and 2.5 (among the cores). Among the limestones, however, packstone (pkst) and wackestone (wkst) are substantially equivalent, with a slight prevalence among the latter, which are sporadically represented also among the cores (1) and the retouched artifacts (2).

The only possible hammer is instead a chert pebble (a silicified calcarenite). The frequency of the lithology and petrographic group is reported in the plots in Figure 5.

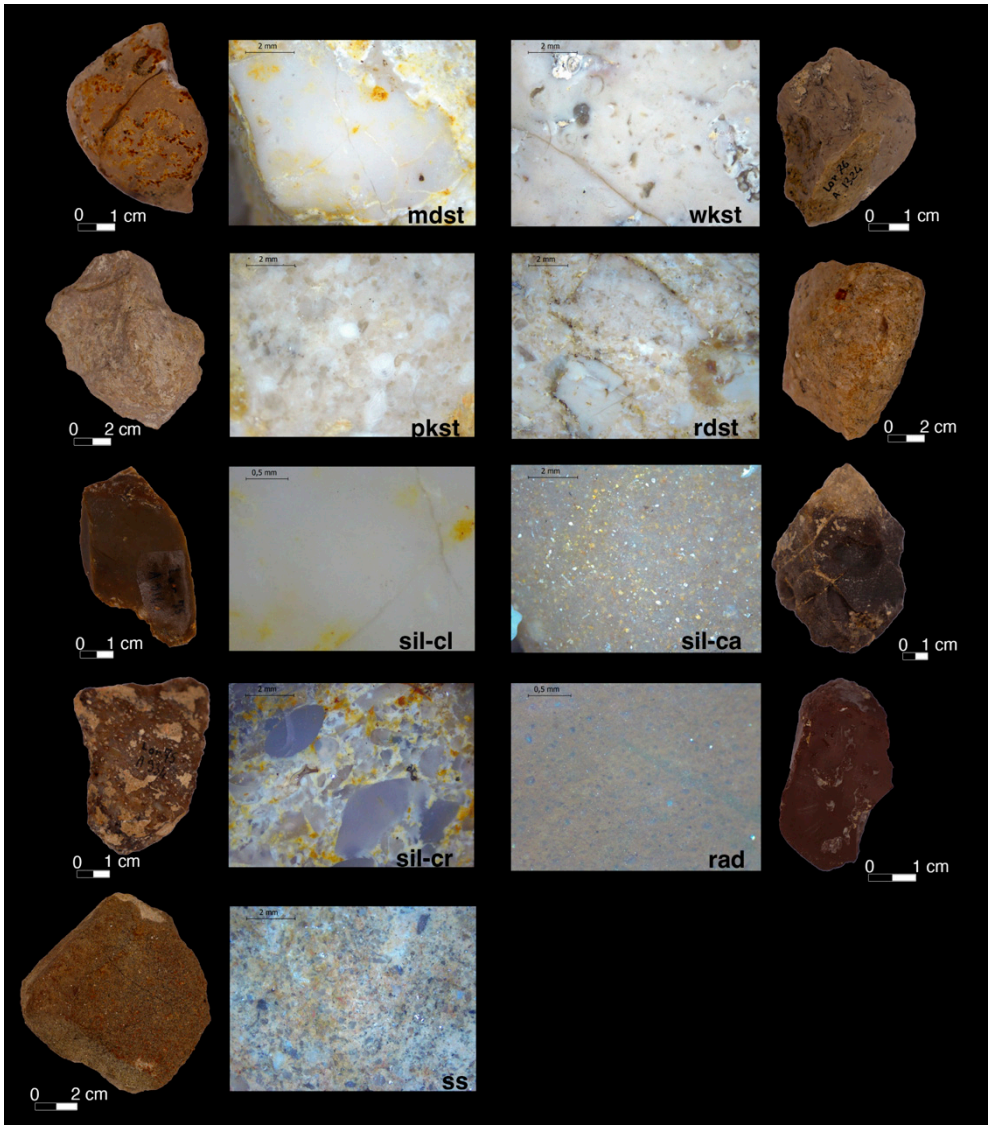



**Figure 4.** Macrophotographs and relative photomicrographs (10x magnification) of representative samples for each petrographic group of Loreto Layer A artifacts. Images used with the agreement of the Italian Ministry of Culture and the Museo Parco Archeologico Melfi e Venosa. Abbreviations: mdst = mudstone; wkst = wackestone; pkst = packstone; rdst = rudstone; sil-cl = silicified calcilutite; sil-ca = silicified calcarenite; sil-cr = silicified carcirudite; rad = radiolarite; ss = sandstone.

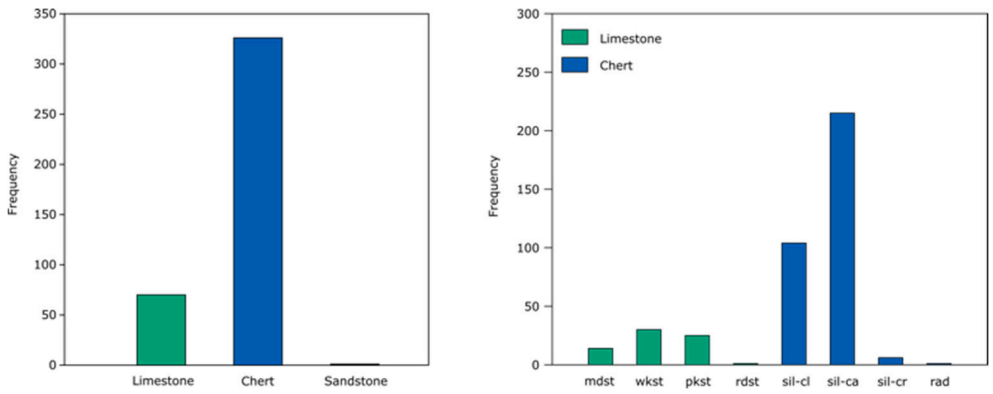



**Figure 5.** Frequency of lithology and petrographic group for Loreto Layer A artifacts, distinguished by limestone and chert.

### *4.2. Size Analysis*

Generally, the recorded maximum size of artifacts ranged between 20 and 140 mm, with a mean of 48.3 mm and a median of 46 mm. The artifact's size analysis revealed that almost all the samples are dimensionally classifiable as coarse pebbles [118], very coarse pebbles, and small cobbles, whereas the class of medium pebbles (8–16 mm) was not represented and the class of large cobble (128–256 mm) included only one sample; more precisely, 59 samples (15%) were coarse pebbles (16–32 mm), 285 (72%) were very coarse pebbles (32–64 mm), and 51 (13%) were small cobbles (64–128 mm). In Figure 6, plots of the general size distribution (Figure 6a) and the size distribution in chert (Figure 6b) and limestone (Figure 6c) groups were reported. A complete report of size data is included in Table S1 in the Supplementary Materials section.

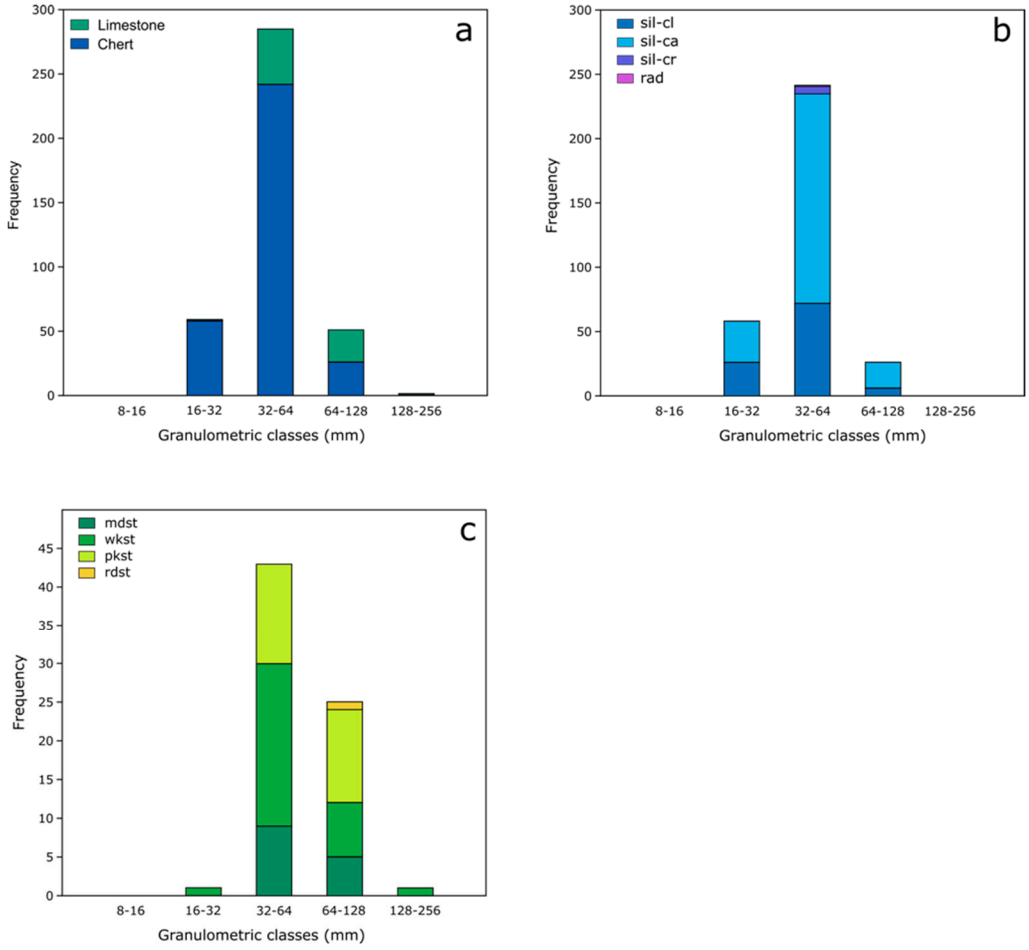



**Figure 6.** General size distribution (**a**) and the size distribution in chert (**b**) and limestone (**c**) artifacts of Loreto Layer A.

## 5. Discussion

Analyzing the size of the knapped artifacts of the Loreto Layer A industry in relation to the techno-categories and lithologies, some observations can be made (Figure S3, in Supplementary Materials). As regards the chert pieces, the core size is generally small due to the intense exploitation. Size distribution curves of flakes and retouched artifacts largely overlap, and both show a certain variability regarding the maximum values. The limestone artifacts present larger dimensions (maximum and minimum sizes) in each category, with the partial exception of the retouched artifacts. The possible chert hammer has a maximum length of 53 mm.

The petrographic analysis of the lithic industry provided useful data to identify the depositional environments of the sedimentary rocks knapped by hominins in Loreto. Firstly, data on residues of natural surface on artifacts revealed the secondary origin of raw material. The presence of carbonates of different textures, most of them silicified during diagenesis, pointed to marine carbonate environments. Lithology and bioclast content revealed facies tracts of carbonate slope characterized by turbiditic and slump deposits [119], except for the radiolarite samples, which can be associated with a basin environment below CCD. Such interpretation is consistent with the lithofacies of the outer units of the Southern Apennines related to the formations of Lagonegrese-Molisano and Irpinian Basins [114]. The correlation with the samples of the SiLiBA lithotheque showed that the lithotypes of Loreto's artifacts were compatible with the Flysch di Faeto Fm., Flysch Rosso Fm., Flysch di Galestrino Fm., and Scisti Silicei Fm. lithofacies (Figure 7). Among chert artifacts (Table S1, Supplementary Materials), the varieties compatible with the Flysch di Faeto Fm. (FAE) cherts clearly prevail (295 pieces, 90.5%). This is consistent with the fact that this formation is the most external of the Apennine units and that it outcrops widely to the West and North of the Venosa area. These characteristics have most likely led to a greater presence of cherts from this formation among the secondary deposits of the Venosa Basin supplied by the human groups of Loreto Layer A. They are followed, with much lower percentages, by the cherts of the Flysch Rosso Fm. (19 pieces, 5.8%) while the cherts of the other formations are instead represented sporadically. A partial correlation with the lithotypes occurring in Layer B of Notarchirico was attested, where no clasts of Scisti Silicei Fm. were identified [110]. Silicified calcilutites of this formation were not attested among the clasts of Notarchirico's Layer B, and this would seem to suggest their absence (or rarity) among the lithotypes of polygenic secondary deposits in the local fluvio-lacustrine basin. The Scisti Silicei Fm., in fact, is one of the innermost formations of the Lagonegrese-Molisano Basin, and, although it is scarcely outcropping in the Ofanto palaeobasin [86], it can be assumed that chert pebbles and cobbles from this formation were eroded and transported eastward to the Venosa area and reworked in the fluvio-lacustrine deposits of the Venosa Basin [84].

Comparing the stratigraphic successions of Loreto and Notarchirico, some points can be discussed. Contrary to what was observed in Notarchirico, the archaeological layers of Loreto were prevalently associated with pyroclastic and lacustrine deposits, almost devoid of coarse clasts exploitable for knapping [103]. If the lithic artifacts found on the palaeosurface of Layer B in Notarchirico were compatible with the petrofacies and grain size expressed by the clasts of the same layer [110], the lithic assemblage of Layer A in Loreto was necessarily produced by secondary clasts collected outside of the site.

Further, the lithic industry at Loreto generally consisted primarily of chert (82%) and, to a lesser extent, of limestone (18%). As already mentioned, the lithic assemblage analyzed could be affected by biases connected to the excavation methods, and, therefore, for the reconstruction of the raw material supply strategies of Loreto Layer A hominins, a certain caution is necessary, and the identification of convergent elements to support each hypothesis.

The almost total absence of artifacts with dimensions smaller than 20 mm, in contrast with the high degree of cores exploitation [107], should not represent a major limitation for the determination and frequency of the lithotypes represented in Loreto Layer A lithic industry. It is, in fact, likely that the lithologies of these pieces, mostly secondary products linked to the phases of full exploitation and residual knapping, roughly reflected the varieties and frequencies witnessed in the analyzed lithic assemblage. It is important to note that 145 pebble tools originally present in the assemblage were lost, and their exclusion from the present data analysis clearly affects the proportional distribution. How-

ever, even assuming hypothetically that all the missing samples were made of limestone, chert would still remain predominant (60%) compared to limestone (40%). As discussed in Fioretti et al. [110], since the Layer B of Notarchirico was an undisturbed coarse lag deposed in a fluvio-lacustrine environment, it can be considered a representative sediment to determine the source area (petrofacies) for the Venosa Basin. Given this, the strong difference between the chert/limestone ratio determined in Layer B of Notarchirico (0.5) and the lithic assemblage of Layer A in Loreto (4.7) is a further argument to demonstrate a clear preference for chert lithotypes and thus a deliberate selection oriented by lithology.

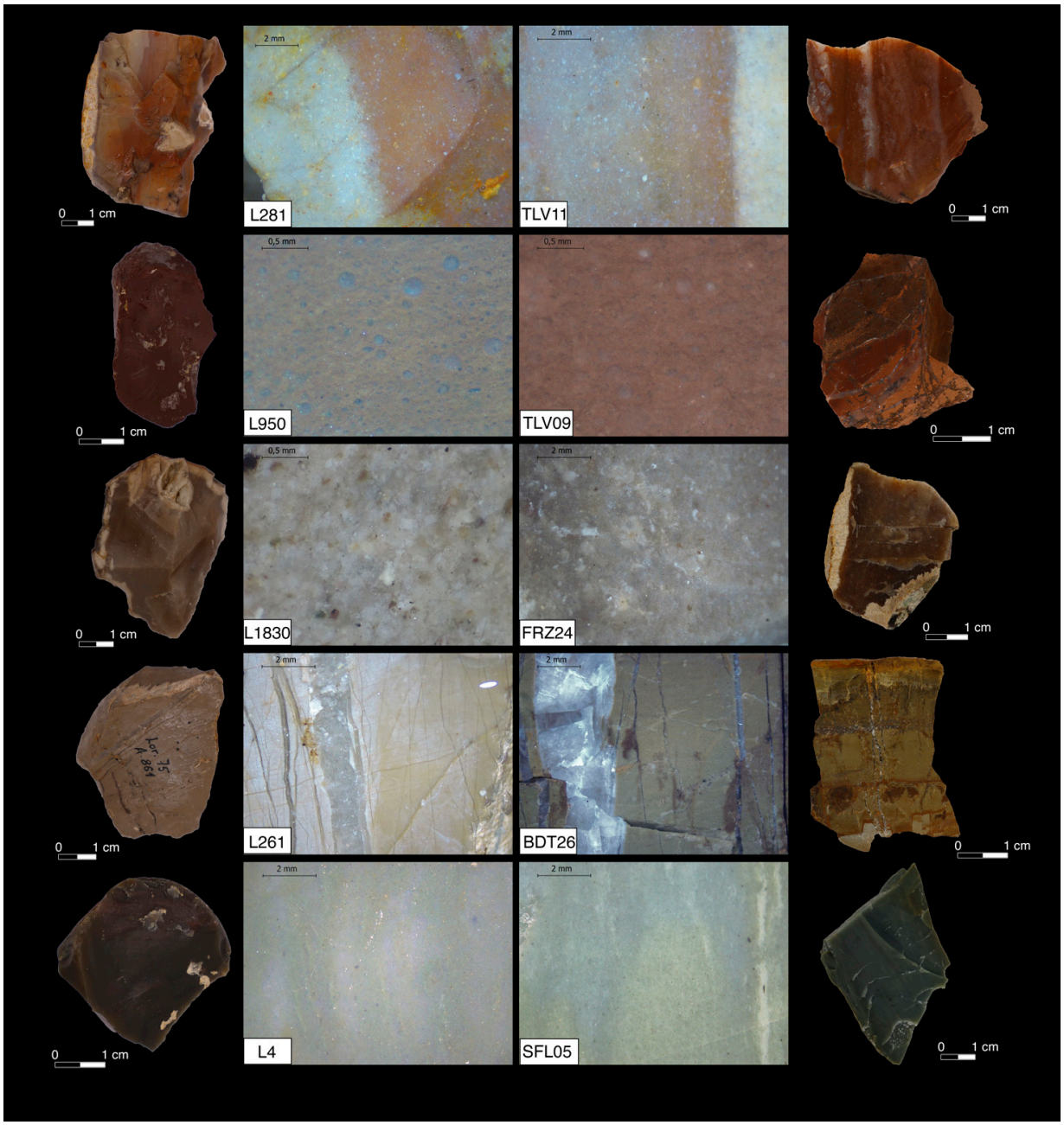



**Figure 7.** Macrophotographs and relative photomicrographs of Loreto Layer A chert artifacts (on the left) and geological comparison samples from the SiLiBA lithotheque. Silicified calcarenites (L281, TLV11) and radiolarites from Flysch Rosso Fm. (L950, TLV09); silicified calcarenites from Flysch di Faeto Fm. (L1830, FRZ24); silicified calcilutites from Flysch di Galestrino Fm. (L261, BDT26) and Scisti Silicei Fm. (L4, SFL05). Images used with the agreement of the Italian Ministry of Culture and the Museo Parco Archeologico Melfi e Venosa.

The lithic industry was undoubtedly a fundamental part of the Early Pleistocene hominins' toolkit linked with foraging activities. With the increased range of human groups during this period, it is unlikely that raw materials would always be available. It is therefore necessary to have ready-to-use tools. It follows that toolmaking must be disconnected from the immediate necessity of a foraging opportunity [120]. Tools must therefore be produced in advance of need, and this consequently also involves the temporal anticipation of the procurement of the resources needed to manufacture them [120–122]. Early Pleistocene hominins were living in a complex world, with shifting ecological zones with many threats, and opportunities. If an individual's home range did not contain readily available raw materials, then they needed to make a strategic decision to look for raw materials. If a specific residence area did not contain easily available raw materials, then they had to make a strategic decision to procure them during their movements along the territory [120]. Early hominins probably could build a home range around shelter and water, and forage for food and resources within this area. But when tools increase in gain their importance, these become an element for the definition of local range, and this makes it necessary to plan the supply of lithic resources in advance [120]. The picture that emerges from Notarchirico Layer B and from Loreto lithic industries seems to reflect precisely the two strategies described. On the one hand, Notarchirico Layer B [17,18], a site where human groups have procured raw materials and produced tools in the same place where they carried out subsistence activities and the frequency and variety of lithologies within the artifacts reflects the frequency and variety of the lithologies of the outcrop [110]; on the other hand, the Loreto human groups have introduced a lithic toolkit produced largely elsewhere, with specific raw materials supply mainly oriented toward cherts from outcrops outside the site. In this framework, tools become signals of cognitive abilities, human mobility on the territory, subsistence strategies, and economic and cultural choices.

The analysis of the frequencies of the petrographic groups (Figure 8) also seems to provide further elements that converge in indicating for the Loreto Layer A industry a supply oriented towards the choice of lithotypes with specific characteristics.

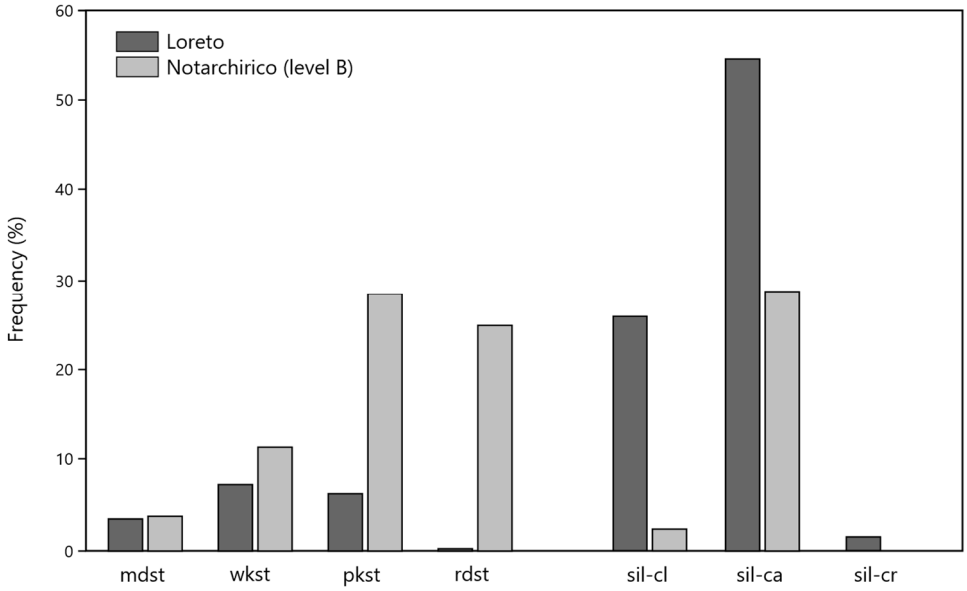



**Figure 8.** Petrographic group frequency for Loreto Layer A artifacts and Notarchirico Layer B clasts.

In fact, among cherts, if in the geological samples of the Notarchirico Layer B the ratio between silicified calcarenites and calcilutites is equal to 13.3, in Loreto Layer A this, although always in favor of the calcarenites, collapses to 2.04 (2.1 also considering the

calcirudites), denoting a supply clearly more oriented towards the choice of fine-textured siliceous lithotypes.

Even among limestones, a similar phenomenon could be visible, where the geological samples of Notarchirico Layer B rudstones and packstones (77%) clearly prevail over the finer textured lithotypes. In Loreto Layer A, wackestones and mudstones (62.9%) are the majority instead. In this case, however, the absence of 145 pebble tools advises a certain caution before drawing clear-cut conclusions.

The technological and petrographical analysis of the Loreto's artifacts revealed that their maximum size ranges between 20 mm and 140 mm, with a median of 46, and evidence of natural surface alteration linked with secondary deposits. These features point to fluvial clasts as raw materials, with similar granulometric characteristics observed in Layer B at Notarchirico. The size range of Loreto's chert artifacts falls within the size range of the chert clasts in Layer B (ranging between 12 and 210 mm, with a median of 75 mm). Although the gravel-sized layers of Notarchirico (MIS 16 and 15) were not accessible for the hominins at the age of Layer A in Loreto (MIS 14 and 13), the gravelly layers of Notarchirico still represent a proxy for the petrofacies and the granulometry of coarse clasts available in the area, excluding the volcanic products of Monte Vulture.

Lithotypes (Figure 8) and sizes of the lithic assemblages of Loreto (layer A) and Notarchirico (Layer B) showed two distinct strategies of raw material exploitation. This was particularly evident when comparing the lithic assemblages with the clasts of Layer B of Notarchirico, where sizes ranged from 12 to 210 mm, with a mean of 77 mm and a median of 75 mm [110]. While the clasts from Layer B have a size range of 42–203 mm (median = 123 mm) and a chert/limestone ratio of 0.4, which closely reflects the sizes and lithological characteristics of the local gravels (chert/limestone ratio = 0.5), the assemblage from Loreto differs significantly, particularly in terms of lithology (chert/limestone ratio = 4.7). The medium size of the chert clasts in gravels was smaller than that of limestones and sandstones [107], and this probably constituted a limiting factor in the size of artifacts. Additionally, the smaller size of artifacts of Loreto than those of geological clasts of Notarchirico's Level B could be related to a more intensive exploitation of chert, as proved by the small size of cores and by reuse and recycling practices evidenced by the techno-economic analysis of lithic industry [107]. On over 45% of the analyzed artifacts (180/397), cortical residues (natural surface alterations) are absent, while the pieces with cortical residues extending beyond 50% of the surface, connected to the first stages of knapping, are only about 16% of the total (63/397). This aspect suggests the introduction of raw materials from areas more or less distant from the Loreto site, possibly already partially exploited elsewhere. All data further confirmed a deliberate selection of raw materials with higher silica content and finer texture, which were more suitable for knapping and less frequent in the Venosa Basin. A selective raw materials supply for the Loreto Layer A industry is not surprising since the framing of human frequentation of the site at the Early Middle Pleistocene places it in relation with a phase of great behavioral changes [123].

Among the changes that have occurred in this period in the lithic industries, in fact, there is a better economy of lithic raw materials, bifaces and large cutting tools, increased production of retouched tools, a higher level of skill in the manufacture of tools (e.g., possible use of soft hammer) and more complex reduction sequences (e.g., discoid method) [124,125]. Except for bifacials, all these elements are attested in the Loreto Layer A industry.

Looking at the comparisons, other coeval contexts, similarly to the Loreto Layer A industry, show a more selective raw material supply, implying an increased importance of the toolkit, a project, the anticipation of needs, and/or a greater investment of time and energy. At Caune de l'Arago the transport of exotic raw materials is associated with specific

tool production and reduction sequences [126]. The intense retouched artifacts reduction has been interpreted as the result of the optimization of resources and correlated to a high mobility over the territory linked with the subsistence activities.

Another possible comparison, although more recent, is Karain Cave [127]: in that site, human groups used a variety of sources for lithic raw material procurement, and the Burhan River, located approximately 10 km away from the site, served as the main source. In the case of Karain Cave, this preference could be explained by more favorable conditions than those found at closer sources, such as accessibility and abundance of raw materials.

Regarding this element, the work of Brumm and McLaren [128] revealed that the prolonged use and multiple lives of scrapers at High Lodge are the result of various phases of retouch aimed at rejuvenating the margins, recycling old tools, and changing their function/use. These traits are powerful indicators of hominins' land-use and resource management, and among the fossil markers of the Middle Paleolithic [129].

Even in Loreto Layer A, industry shows the same elements. The high frequency of cherts and the greater presence of fine-grained lithologies denote a specific supply aimed at anticipating equally specific needs. This can be related to the need to produce a high number of retouched tools, often characterized by an accurate scalariform retouching. The life of these artifacts was prolonged through continuous rejuvenation of the retouches and recycling in order to use/reuse them in the context of a mobility connected to subsistence activities.

## 6. Conclusions

The analysis of the lithic assemblages of Loreto (Layer A) reveals significant behavioral, technological, and environmental aspects, suggesting significant adaptive strategies employed by Early Pleistocene hominins in the Venosa Basin.

Firstly, although the lithotypes used in Loreto's Layer A assemblage are petrographically compatible with those of the Ofanto palaeobasin, the stratigraphic succession directly below Layer A lacks gravel-sized clasts, indicating that these raw materials were not collected in the Loreto site area. This suggests exploitation of more distant deposits, likely dating to after the closing of the Bradanic cycle. The maximum size of the chert artifacts, ranging up to 140 mm, falls within the size range of the chert clasts found in the gravel beds of the Venosa Basin, and it is therefore in this area that the lithic supply of the Loreto human groups can be assumed to have been made.

Moreover, during MIS 13, the extensive deposition of pyroclastic materials from Monte Vulture would have obscured much of the surrounding landscape. Fluvial valleys, through their erosive action, likely exposed underlying gravelly strata, making them the most probable zones for raw material acquisition. The predominance of chert (82%) and finer-textured lithologies within the Loreto assemblage clearly indicates a deliberate raw material selection favoring high-silica rocks with higher knapping qualities, in contrast with the geological variability of Notarchirico, considered a reliable proxy of chert availability in the Venosa Basin.

Additional consideration about techno-economic strategies can be advanced. The Loreto site reflects a system in which raw materials, particularly selected cherts, were procured off-site and introduced as partially exploited cores, selected blanks, and retouched artifacts. This implies an anticipatory dimension in the *chaîne opératoire*, likely aimed at producing curated, retouched tools whose utility was prolonged through rejuvenation and recycling. The near absence of artifacts from initial knapping phases, along with the high incidence of reused cores and rejuvenated tools, should support this inference.

The technological choices at Loreto, including the emphasis on retouched tools, align with broader behavioral innovations associated with the Early Middle Pleistocene. These

include the emergence of more standardized reduction sequences, increased tool economy, and more complex land-use strategies. In particular, the supply of raw materials, the organization of operational chains, and the widespread practices of recycling and reuse point to significant mobility, which is strategic and conditioned by environmental constraints, and linked with subsistence activities.

In this context, the lithic industry of Loreto Layer A should be interpreted not merely as a byproduct of functional needs but as an expression of a cognitive and adaptive shift. Tools become indicators of planning, foresight, and spatial organization, testifying to a broader behavioral evolution. The selective raw material procurement, emphasis on tool curation, and evidence of technological investment suggest that the groups frequenting Loreto operated within a cultural framework shaped by long-term planning and complex interaction with the landscape.

Thus, the Loreto Layer A assemblage offers a powerful case study of behavioral flexibility at a critical evolutionary juncture. All available data converge to confirm that the human presence at the site occurred during a phase of significant behavioral innovations when hominins began to more deliberately manage resources, organize mobility, and shape their technological responses in increasingly strategic ways.

**Supplementary Materials:** The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/heritage8060228/s1, Figure S1: Frequency of lithology for Loreto Layer A knapped artifacts (396 pieces) distinguished by technological category; Figure S2: Frequency of petrographic groups for Loreto Layer A knapped artifacts (396 pieces) distinguished by technological category; Figure S3: Size of Loreto Layer A knapped artifacts (396 pieces) related to the technocategories and lithologies; Table S1:Petrographic features of the analyzed clasts of the level B.

**Author Contributions:** Conceptualization, G.E. and G.F.; methodology, G.E. and G.F.; formal analysis, G.F.; investigation, G.F.; data curation, G.F.; writing—original draft preparation, G.E., G.F., J.C. and M.C.; writing—review and editing, G.E., G.F. and J.C.; visualization, G.F., J.C. and M.C.; supervision, G.E.; project administration, M.-H.M.; funding acquisition, M.-H.M. All authors have read and agreed to the published version of the manuscript.

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**Data Availability Statement:** Data are contained within the article and Supplementary Materials.

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