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1 The earliest evidence for mechanically delivered projectile weapons in Europe

2

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- 16

17 Microscopic analysis of backed lithic pieces from the Uluzzian technocomplex (45–40

18 thousand yr ago) at Grotta del Cavallo (southern Italy) reveals their use as mechanically

19 delivered projectile weapons, attributed to anatomically modern humans. Use-wear and

20 residue analyses indicate that the lithics were hunting armatures hafted with complex

21 adhesives, while experimental and ethnographic comparisons support their use as projectiles.

22 The use of projectiles conferred ahunting strategy with a higher impact energy and a

23 potential subsistence advantage over other populations and species.

24

The Uluzzian was traditionally recognized as one of the Middle to Upper Palaeolithic transitional 25 cultures in southern Europe (that is, Italy and Greece), but has been recently redefined as an Early 26 Upper Palaeolithic culture1. Grotta del Cavallo (Fig. 1), excavated by A. Palma di Cesnola and P. 27 Gambassini between 1963 and 1986, is a pivotal site for the Uluzzian because its stratigraphic 28 sequence includes three main Uluzzian layers, EIII (archaic Uluzzian), EII-I (evolved Uluzzian) and 29 D (final Uluzzian)¹ (Supplementary Fig. 1), sandwiched by the tephra Y-6 at 45.5 ± 1.0 thousand 30 years ago (ka)² and Y-5 (Campanian Ignimbrite) at 39.85 ± 0.14 ka (refs.^{2,3}). The Uluzzian 31 technocomplex exhibits features that are typically associated with modern human assemblages 32 (Supplementary Information 2) and characterized by the presence of ornaments, bone implements⁴, 33 colouring substances⁵ and crescent-shaped backed pieces made on small blades or bladelets¹. These 34 crescent shaped backed pieces (also referred to as lunates or segments) are a hallmark^{1,6} of the 35 Uluzzian and exhibit no techno-morphological link to the Mousterian or Initial Upper Palaeolithic 36 assemblages in Europe before the Uluzzian. Similar backed pieces on bladelets have been observed 37

in East Africa, although there is no archaeological evidence indicating a route from East Africa into
 Europe⁵. To better understand the differences between the Uluzzian and earlier lithic traditions, as

Europe⁵. To better understand the differences between the Uluzzian and earlier lithic traditions,
well as the importance of the emergence of this new technocomplex in Europe, it is crucial to

41 identify the function of the backed pieces.

42 The excavations of Grotta del Cavallo unearthed numerous backed pieces⁶, and we undertook a

43 systematic use-wear analysis of a total of 146 of them from the three Uluzzian layers. This analysis

44 indicates that the major function of the Uluzzian backed pieces was hunting (Supplementary Table

1). Only seven pieces were used for functions other than hunting (cutting and scraping). Out of the 45 146 backed pieces, 26 show 55 diagnostic impact fractures (DIFs), which form only when stone tips 46 hit an animal target (Fig. 2). Among them, 9 backed pieces (34.6%) bear DIFs only at a single 47 location, while 17 (65.4%) yield multiple DIF types (Supplementary Table 2 and Supplementary 48 Fig. 2). As several projectile trials resulted in no fractures or only non-diagnostic ones^{7,8}, the 49 number of DIFs indicates the minimum number of specimens used as hunting weapons. Six pieces 50 51 showed microscopic linear impact traces (MLITs) as well (Fig. 2a,f), proving that they were securely used as hunting armatures. Most of the Uluzzian backed pieces showed residues on the 52 back, suggesting that this portion was covered by a type of adhesive (Supplementary Fig. 3). We 53 therefore performed Fourier transform infrared (FTIR) spectromicroscopy on these pieces to 54 55 characterize the chemical nature of the residues and identified them as a mixture of both organic and inorganic components, mainly ochre, a plant/tree gum and beeswax. The main absorption bands 56 attributed to the organic fraction are highlighted by the grey shaded areas in Fig. 20 (see Methods 57 for more details). In addition, FTIR spectroscopy analyses of several red deposit and soil samples 58 59 recovered from Grotta del Cavallo enabled us to rule out the presence of organic contaminants from the burial environment and to confirm the presence of ochre as a mixture of 60 silicate and iron oxides by correlative scanning electron microscopy/energy dispersive X-ray 61 (SEM/EDX) measurements (see Supplementary Figs. 4 and 5). Together, the results allowed us to 62 postulate that the three adhesive components had been intentionally mixed, as known in the middle 63 Upper Palaeolithic context⁹. To reconstruct the hafting modes of Uluzzian backed pieces, the 64 frequency of the DIF types (Supplementary Fig. 2) was compared with those obtained by projectile 65 experiments with backed piece replicas^{10,11}. The projectile experiments indicated that hafting as 66 barbs resulted less often in multiple DIFs, compared with when the pieces were hafted as tips. 67 68 Among the multiple DIF types, the type a2m (flute-like, burin-like or transverse fractures from bidirectional 69 ends) was dominant in the Cavallo backed pieces (Fig. 2b-f) and occurred only in experiments with 70 tip hafting (straight/obliquehafting). We do not rule out the possibility that some Uluzzian backed 71 pieces were hafted as barbs because of the relatively high frequency of type a2 (burin-like fracture 72 from steep angle) (Fig. 2a), which occurred in barb hafting as well. However, the frequency of the 73 DIF types suggests that several Uluzzian backed pieces were attached on the tip of a wooden shaft. 74 Uluzzian backed pieces are notably small: complete or almost complete backed pieces with DIFs 75 measured an average of 27.1 mm in length, 10.5 mm in width and 4.6 mm in thickness 76 77 (Supplementary Fig. 6a). The tip cross-sectional area (TCSA) and tip cross-sectional perimeter (TCSP) of Cavallo backed pieces with DIFs were compared with those of ethnographic North 78 American dart tips and arrowheads^{12,13}. The box plots of the TCSA and TCSP of the Uluzzian 79 backed pieces with DIFs fell within the range of those of North American ethnographic arrowheads, 80 but were concentrated on a smaller range (Supplementary Fig. 6b,c). The Uluzzian backed pieces 81 are significantly smaller than the ethnographic dart tips in terms of TCSA and TCSP (TCSA: t =82 -9.414, P < 0.05; TCSP: t = -13.650, P < 0.05), and even smaller than the ethnographic arrowheads 83 (TCSA: t = -2.773, P < 0.05; TCSP: t = -5.709, P < 0.05). The extremely small dimensions of the 84 Uluzzian backed pieces suggest that they are suitable for neither thrusting nor throwing spear tips 85 (Supplementary Fig. 7a,b). Despite the small size, the DIFs found on Cavallo backed pieces are 86 relatively large: the largest DIF measures 24.7 mm in length, and 9 DIFs are larger than 10 mm. 87 Several pieces show a significant eduction in the body due to impact damage (Fig. 2b,d,e). Even if 88 specimens retain almost their original length, they often bear elongated DIFs along the side or on 89

the surface. The lengths of several elongated DIFs (flute- and burin-like fractures) exceed 20% of 90 theentire length of the backed pieces, and four DIFs have a length greater than half the entire length 91 of the specimens (Supplementary Table 3). The relatively large dimensions of DIFs suggest that 92 thebacked pieces were delivered at high impact velocities. As several Uluzzian backed pieces were 93 hafted on the tip of a wooden shaft, the small dimensions of the backed pieces must reflect the small 94 diameter of the shaft. If a thinner shaft is used, the total size of the hunting weapon is smaller. 95 Therefore, large DIFs, as well as multiple DIF types, occur only when the impact velocity is as high 96 as is found for mechanical delivery, such as by a spearthrower or bow⁸. Although the TCSA and 97 TCSP values indicate that the projectile capability of the Uluzzian backed pieces is closer to that of 98 the North American arrowheads than to that of dart tips, we do not have sufficient information to 99 100 discriminate between them. Nonetheless, because of the assumed velocity based on the DIF pattern, it is more plausible that the Uluzzian backed pieces were projected 101 using either a spearthrower or a bow. A higher impact energy, however, requires more stable 102 hafting, since otherwise, stone tips can easily be displaced. A complex mixture, characterized by the 103 104 addition of beeswax and ochre, increases the mechanical properties of the adhesive, making it less brittle14. The use of the complex adhesive demonstrated by FTIR spectroscopy in this study 105 suggests that hunters at Grotta del Cavallo used advanced hafting technology for projectiles with a 106 higher impact velocity. While the mechanical projectile system enables a higher impact velocity and 107 long-range shooting, fletching to the base of the shaft is necessary to propel armatures in a straight 108 trajectory. The discovery of cut marks due to the removal of feathers from bird remainsat the 109 Uluzzian site of Castelcivita (southern Italy) (Supplementary Information 3) indicates that the 110 fletching technology was also practiced by the Uluzzian people. The multiple findings, such as use-111 wear patterns, significant smallness of the Uluzzian backed pieces and complex adhesives, for 112 113 Grotta del Cavallo samples dated between 45 ka and 40 ka constitute the earliest evidence for the use of mechanically delivered projectile weapons in Europe, which is more than 20,000 years 114 earlier than previously thought. In Europe, the earliest direct evidence for spearthrowers was found 115 from a Solutrean layer at Combe Saunière, France, dated between ~23 ka and ~20 ka (ref. ¹⁵), and 116 for bows and arrows preserved in peat bogs at an Ahrensburgian site of Stellmoor, Germany, at 117 12.9–11.7 ka (ref. ¹⁶). Taking into account that most of the ethnographic spearthrowers are made of 118 perishable materials, such as wood¹⁷, it is no wonder that we have only much younger 119 archaeological remains of spearthrowers and bows and arrows. Neanderthals used wooden spears¹⁸ 120 and might also have used stone-tipped ones¹⁹. Their possible stone spear tips, including Levallois 121 and Mousterian points, are overall much larger than the Upper Palaeolithic points²⁰. Although 122 micropoints recovered from layer E (Neronian) of Grotte Madrin, France, that might be ~5,000 123 years older than the Uluzzian appearance in Europe are significantly small^{21,22}, a systematic use-124 wear analysis is required to detect their function. Based on the current state of studies on 125 Neanderthal hunting²³, their spears were basically hand delivered (thrusting or throwing), but not 126 mechanically projected. Conversely, evidence from Africa suggests that modern humans innovated 127 mechanically delivered projectile weapons before they expanded out of Africa^{20,24}. 128 Although the association between the Uluzzian technocomplex and modern humans has been 129 challenged²⁵, the information currently available from Grotta del Cavallo links the Uluzzian to 130 modern humans. In particular, the two deciduous teeth retrieved from the Uluzzian layers of Grotta 131 del Cavallo were attributed to modern humans²⁶, and their association with the Uluzzian materials 132 has been recently confirmed by excavation field notes¹ (Supplementary Information 1) and the 133 stratigraphic sequence². If further studies confirm the attribution of the Uluzzian to modern humans, 134

135 we suggest that modern humans equipped themselves with new projectile technology when they

- 136 migrated into Europe at around 45 ka. Zooarchaeological data on faunal remains from Grotta del
- 137 Cavallo indicate more intensive exploitation of young horses at the Uluzzian levels than that seen at

the late Mousterian (Supplementary Information 4). Considering the fact that young

- horses are protected by stallions²⁷, the intensive hunting of young horses may reflect skilled long-
- 140 range hunting in the Uluzzian. As mechanically delivered armatures allow more accurate hunting 28
- 141 while keeping a greater distance from potentially dangerous prey than hand-delivered hunting (but
- see ref. ²⁹), this new projectile technology could have offered modern humans an advantage in
 subsistence strategies.
- 143 144

145 Methods

Functional analysis. A use-wear analysis was undertaken via a low-power approach^{30–33} and a 146 high-power approach³⁴⁻³⁷. Out of the 146 backed pieces, 34 pieces were recovered from layer EIII, 147 60 pieces from layer EII-I, 30 pieces from spit E-D and 22 pieces from layer D. Traces were 148 149 observed using a Hirox KH7700 digital microscope at magnifications ranging from ×20 to ×50 for macrotraces and from ×140 to ×480 for microwear traces. DIFs were analysed using projectile 150 experiments with backed pieces^{7,8,38,39}. The DIFs observed on archaeological materials were 151 recorded using the microscope mode of the Olympus TG-4 digital camera. Besides DIFs, 11 backed 152 pieces exhibited possible impact fractures, but we cannot rule out the possibility that they formed 153 accidentally due to knapping, retouching or post-depositional processes^{7,39-41}. For instance, pseudo-154 impact fractures, including tiny flute- and burin-like fractures smaller than 5 mm, can occur 155 throughout production and post-depositional processes. We therefore did not define these fractures 156 as DIFs. The use of the bipolar technique on an anvil in retouching the Uluzzian backed pieces may 157 158 create specific pseudo-impact fractures. We therefore conducted an experiment on the production of Uluzzian backed pieces to avoid the risk of misidentifying bipolar pseudo-impact scars as DIFs. 159 After the careful observation of experimental backed pieces, we confirmed that although bipolar 160 retouching sometimes produces mimic DIFs, we can distinguish these from real DIFs using the 161 presence of a negative bulb of percussion and the position of the fracture initiation (Supplementary 162 Fig. 8).MLITs are microscopically observable impact scars on lithic surfaces^{7,8,42,43}. They comprise 163 clusters of linear polishes running parallel to one another, exhibiting long shining stripes. Although 164 little is known about the process of MLIT formation, they probably formed through contact with 165 fragments detached from stone tips or the bones of animal targets. Similar linear polishes can occur 166 through knapping by a hammer (Supplementary Fig. 8f) and contact with other stone artefacts 167 during transport or storage³⁷. However, it is possible to distinguish MLITs from the other linear 168 polishes on the basis of attributes characterized by long, stripe-like linear polishes running in a 169 specific direction with other linear polishes. The MLITs were recorded using a Hirox microscope at 170 magnifications between $\times 140$ and $\times 480$. 171

Residue analysis. FTIR analyses were performed at the Chemical and Life Sciences branch of the
 SISSI beamline at Elettra Sincrotrone, Trieste⁴⁴. Ten backed pieces were analysed by FTIR

spectromicroscopy (100a from layer D; 106 from spit E-D; 75, 1, 34, 64, 45 and 52 from layer EII-

175 I; and 21 and 23 from layer EIII). A few grains of the adherent residues were gently scraped from

each backed piece using the tip of a needle under a stereomicroscope. Collected grains from each

- sample were pressed in a diamond compression cell (Diamond EX press by S.T. Japan, clear
- aperture 2 mm) to flatten them to a thickness suitable for FTIR transmission measurements. Owing

to the heterogeneous nature of the samples, 10-15 spectra for each were acquired in transmission

mode on half compression cell with a Vis-IR Bruker Hyperion 3000 microscope coupled with the 180 Vertex 70v interferometer in the MidIR range (MCT-A detector, 4,000–750 cm-1). For each 181 spectrum, 512 scans were averaged at 4 cm-1 spectral resolution, setting the lateral resolution at 50 182 \times 50 µm2 to select the most diagnostic sample regions according to the observable differences in 183 colour. Spectra of red deposits from layers E and D and soil samples from several stratigraphic units 184 185 belonging to Grotta del Cavallo (see Supplementary Fig. 1) were also measured by FTIR spectroscopy in the sample compartment of the Vertex 70v interferometer, in the closed diamond 186 compression cell, using a 5 multiplication focusing unit (A524/Q, Bruker Optics) and the Bruker 187 wide range components (that is, beamsplitter and DTGS detector) for covering FIR (far-infrared) 188 and MIR (mid-infrared) spectral regions in a single scan. Each spectrum was collected averaging 189 256 scans at 4 cm-1. Extending the spectral range from 4,000 to 150 cm-1 allows better 190 highlighting of the presence of metal-organic spectral features. To identify a specific material 191 adhered on lithics, all of the acquired FTIR spectra were compared with those reported in the 192 literature and IR spectral libraries (Kimmel Center for Archaeological Science Infrared Standards 193 Library and IRUG Spectral Database). In addition, samples 1 and 106 were peeled off with carbon 194 conductive adhesive tape from the culet of the diamond after FTIR spectromicroscopy analysis and 195 SEM/EDX measurements were performed. Two red deposits (one from layer D and one from layer 196 EII-I) and a sample of soil from layer DII were also characterized from a mineralogical perspective. 197 198 All measurements were performed using a Zeiss Supra 40 field emission gun, an SEM equipped with a Gemini column and an in-lens secondary electron detector operated at 10 kV. EDX analyses 199 were performed using a LN2-free X-Act Silicon Drift Detector (Oxford X-ray detection system, 200 Aztec EDS). SEM/EDX measurements were performed at the IOM-CNR laboratories. Among the 201 10 backed pieces analysed by FTIR spectromicroscopy, only 6 (1, 34, 64, 106, 100a and 75) 202 203 showed clear infrared features indicative of an organic fraction (see Fig. 20). The organic fraction was verified by strong absorption peaks in the range 3,000–2,800 cm-1, which were assigned to 204 methyl and methylene asymmetric and symmetric stretching modes at ~2,956 and ~2,872 cm-1, 205 and ~2,930 and ~2,860 cm-1, respectively⁴⁵. At ~1,460 and ~1,378 cm-1, the bending modes of 206 the same moieties can be observed. The aforementioned stretching and bending modes are 207 characteristic of compounds containing long aliphatic chains. In addition, carbonyl (C = O) bands 208 can be detected at around 1,740 cm-1 for all the selected six samples, and an extra shoulder centred 209 at about 1,715 cm-1 can be seen for samples 34, 64, 75 and 100a. Typically, carbonyl stretching 210 modes of esters and carboxylic acids fall in this spectral region⁴⁶. Samples 75, 106 and 100a (Fig. 211 20) are characterized by two broad bands in the 1,650–1,550 cm-1 and 1,450–1,350 cm-1 spectral 212 regions. The two aforementioned contributions may derive from asymmetric and symmetric 213 stretching of carboxyl groups usually identified as diagnostic of gum (see the next paragraph for 214 more details)⁴⁷. These contributions are less intense for samples 1, 34 and 64 (Fig. 20), allowing the 215 peak centred at about 1,630 cm-1 to arise. All the aforementioned spectral ranges are indicated by 216 the grey shaded areas in Fig. 20. The collected data led to postulations that the organic fraction is a 217 mixture of two main components: tree or plant gum and beeswax. In particular, the broad peaks in 218 the 1,650–1,550 and 1,450–1,350 cm–1 spectral regions can be associated with carboxylate 219 fractions from plant or tree gum, a natural biopolymer composed mostly of diverse polysaccharides 220 and, to a much lesser extent, glycoproteins^{45,48}. This hypothesis was proven by the spectral 221 comparison of samples 75, 106 and 100a with the reference spectrum of tree gum (Fig. 20) and 222 several other spectra found in the IR databases (see, for example, spectra IDs ICB00011, ICB00012, 223 ICB00013 and ICB00038 in the IRUG database). Pure and fresh gum spectra are characterized by 224

narrower bands in the aforementioned spectral regions. Nevertheless, it is well known that the peak 225 position of both the asymmetric and symmetric modes of carboxyl groups are strongly dependent on 226 the coordinated cations⁴⁴; therefore, band broadening in our samples reflects the complex 227 mineralcomposition of the soil (see the SEM/EDX analysis and Supplementary Fig. 4 for more 228 details). Reference gum spectra show broad unresolved absorption peaks in the range 3,000-2,800 229 230 cm-1, which differ from the signals obtained by measuring our samples that exhibited intense and 231 sharp methyl and methylene stretching modes. This result led to the deduction of the possible addition of a further organic compound to the adhesive, such as beeswax. This hypothesis can be 232 tested by comparison of the collected spectra of samples 1, 34 and 64 with beeswax reference 233 spectra (Fig. 20). In the literature, the spectra of beeswax (see also IDs IWX00075, IWX00090, 234 IWX00096 and IWX00099 in the IRUG database) are characterized by well-defined and intense 235 methyl and methylene bands, as well as by distinctive carbonyl bands centred at about ~1,740 and 236 \sim 1,715 cm-1, which were also present in our samples. Among the collected spectra, a variability of 237 the relative intensity of the methylene/methyl/carbonyl bands can be observed, mainly characteristic 238 239 of beeswax (Fig. 20), with respect to the broad bands extending from about 1,650-1,550 cm-1 and 1,450–1,350 cm–1, which are characteristic of tree/plant gum (Fig.2o). This finding can be 240 explained by the different percentages of the two organic fractions used to prepare the adhesive 241 mixture, with further consideration of the different degrees of degradation and aging originating 242 from long-term interaction of the organic material constituting the adhesives with the burial soil⁴⁶. 243 The diverse extent of degradation of the samples could have been influenced by differences in soil 244 composition, pH, humidity or water percolation of the stratigraphic units where the ten backed 245 pieces were buried for thousands of years. Identification of the gum fraction would have been easier 246 with access to the ~1,200-900 cm-1 spectral region, where C-O-C and C-OH stretching modes 247 248 diagnostic of polysaccharides are located 46. In this spectral region, very intense and structured bands can be seen for all 10 measured backed pieces. This feature, characterized by a main peak at 249 1,030 cm-1, a shoulder at 1,080 cm-1 and two distinctive peaks at 800 and 780 cm-1, can be 250 attributed to Si-O stretching modes of silicates, which are the main components of clays. 251 Specifically, the sharp peaks at 3,694 and 3,622 cm-1 are distinctive vibrational features of well-252 crystallized water molecules among the layers of kaolinite⁴⁷. 253

The red colour of the residues on the backed pieces led us to hypothesize the presence of iron 254

compounds. To verify this hypothesis, SEM/EDX analyses were performed for a soil sample from 255 layer DII and samples 106 (from spit E-D) and 1 (from layer EII-I) after FTIR analysis 256

(Supplementary Fig. 4b,e,h). 257

EDX measurements of the soil and sample 106 confirmed the presence of silicon, aluminium, 258 magnesium, sodium, calcium, iron and phosphorus, which are all characteristic of silicates. The 259 iron-to-silicon ratio increased from 0.37 ± 0.01 to 4.52 ± 2.01 from the soil to sample 106, reaching 260 a value of 7.64 \pm 0.45 in sample 1 (the standard deviation was calculated as the average of three 261 measurements per sample). The positive trend of the iron-to-silicon ratio from the soil to sample 1 262 is consistent with a colour transition from light brown to intense red (Supplementary Fig. 4a,d,g), 263 revealing that the iron content of the samples is much higher than the one of the burial soil and that 264 it contributes to red pigmentation of the residues on samples 1 and 106, which can be identified as 265 ochre. 266

To further verify that ochre (also known as red earth) is the source of the red colour, some red soil 267 deposits collected from Grotta del Cavallo were analysed by FTIR spectroscopy in the FIR-MIR

268

269 region. These deposits belong to the same stratigraphic units (layers E and D) as the analysed

backed pieces (see Supplementary Fig. 1). In Supplementary Fig. 5, we report the FIR-MIR spectra 270 of two of the analysed red deposits. It is possible to identify peaks centred at about 535 and 433 271 cm-1, as well as a broad band around 325 cm-1, that are distinctive of iron oxides. The collected 272 spectra can be correlated with the IRUG ochre spectrum IMP00365 (red earth made by kaolinite 273 and hematite). Supplementary Fig. 5 also reports the FIR-MIR spectrum of the soil sample from 274 layer DII, also analysed by SEM/EDX (Supplementary Fig. 4). This sample does not show the 275 276 spectral features characteristic of ochre, accordingly with the minimal iron content revealed by SEM/EDX analysis; instead, it is mainly characterized by a mixture of silicates and phosphates. As 277 a matter of fact, the silicate peaks described above can also be recognized in the FTIR spectrum of 278 the soil, and distinctive features of phosphates can be also identified: two sharp peaks at ~964 and 279 ~870 cm-1, a double peak at ~605 and ~564 cm-1 and a moderate absorption band in the 1,550-280 1,300 cm-1 spectral range49. The aforementioned phosphate infrared features are still evident in 281 the spectrum of the red deposit from layer D, whereas they are barely detectable for the red deposit 282 from layer E II-I. This result implies that the red deposit from layer D is partially contaminated by 283 284 the burial soil, whilethe one from layer E II-I can be considered as a purer ochre. None of the spectra reported in Supplementary Fig. 5 show absorbance peaks in the region 3,000–2,800 cm-1, 285 which are characteristic of aliphatic chains of organic compounds. This result suggests that, in both 286 the soil and red deposits, the organic matter content is below the detection limit of the technique, 287 288 thereby excluding the possibility that the organic traces on backed pieces are contamination from the burial environment. Taken together, these results led us to conclude that the residue stuck on the 289 backed pieces is a mixture of plant/tree gum and beeswax intentionally mixed with ochre and 290 applied as an adhesive. 291

292 Morphometric analysis. As the Uluzzian backed pieces are extremely small (Supplementary Figs. 293 6a and 7b), they are not suitable to haft onto the tips of thick wooden spears from Schöningen in Germany dated $\sim 300 \text{ ka}^{50-52}$, which were probably used as throwing spears^{53,54} (Supplementary Fig. 294 7a). It has been ethnographically shown that thrusting spears and hand-delivered spears are heavier 295 than projectile spears launched with a spearthrower or bow^{55,56}. Therefore, the Uluzzian backed 296 pieces do not function well as throwing or thrusting spear tips, which require a massive shaft. If the 297 Uluzzian backed pieces were inserted into the lateral sides of a shaft as in Magdalenian composite 298 projectiles⁵⁷, the smallness of the stone artefacts would not necessarily relate to the diameter of the 299 shaft. However, as the use-wear analysis suggested that a considerable number of Uluzzian pieces 300 were attached to the tip of a shaft as a hunting armature, the small dimensions must reflect a thin 301 shaft that is useful only for mechanically delivered spears, such as darts projected by a spearthrower 302 or arrows shot using a bow. A morphometric analysis using TCSA and TCSP values was therefore 303 undertaken to evaluate the potential projectile capability of stone tips^{20,56,58,59}. 304

TCSA and TCSP values of Uluzzian backed pieces from Grotta del Cavallo were compared with those of ethnographic North American dart tips and arrowheads^{12,13}. Because some Uluzzian backed pieces were used for cutting and scraping, the TCSA and TCSP analyses were undertaken only for the backed pieces showing DIFs (Supplementary Fig. 6b,c). The TCSA and TCSP values were calculated using the equations presented by Sisk and Shea ⁵⁹.

310

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324 Author Contributions

- A.M. and K.S. conceived and organized the project; S.B. obtained funding and directed the project;
- K.S. undertook the use-wear analysis with S.A as well as the morphometric analysis; C.S., G.B.,
- and L.V. performed the residue analysis; D.A. conducted the experiment for producing Uluzzian
- backed pieces; I.F., M.G., and A.T. provided data about the exploitation of feathers; F.B., J.C., and
- P.B. presented the results of the zooarchaeological analysis; K.S., C.S., V.S., S.R., and I.F made
 figures and illustrations; D.A., F.B., A.R., and A.M. provided permits for the analysis of the
- archaeological samples and expertise on site sequences and materials; and K.S., C.S., A.R., A.M.,
- and S.B. wrote the manuscript with contributions from all co-authors.
- 333
- **Competing interests** The authors declare no competing interests.
- 335

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- 337
- 338 Captions

Fig. 1 | Locations of the Uluzzian findings in Italy and on the Balkan Peninsula. 1, Klissoura Cave;
2, Kephalari Cave; 3, Crvena Stijena; 4, Grotta del Cavallo; 5, Grotta di Serra Cicora A; 6, Grotta

Mario Bernardini; 7, Grotta di Uluzzo; 8, Grotta di Uluzzo C/Cosma; 9, Grotta delle Veneri; 10,

Grotta di Castelcivita; 11, Grotta della Cala; 12, Colle Rotondo; 13, Grotta La Fabbrica; 14, Riparo

del Broion; 15, Grotta di Fumane. Sea level is 74 m below the presentdaycoastline (data from ref.

60). The digital elevation model is the European digital elevation model from the GMES RDA

- 345 project (https://www.eea.europa.eu/data-and-maps/data/eu-dem#tab-
- originaldata/eudem_hlsd_3035_europe). The bathymetric model is from the European Marine
 Observation and Data Network. The map was generated using ArcGIS version 10.5.
- Fig. 2 | Backed pieces from Grotta del Cavallo showing DIFs and MLITs, and sampling of residues
 on backed pieces by FTIR spectroscopy and its results. a, A simple DIF type a2. b–f, Multiple DIF
 type a2m. a(i), c(ii) and d(i) are burin-like fractures; b(i), c(i) and c(iii) are flute-like fractures; b(ii)
 is a step-terminating transverse fracture and a spin-off; e(i) and d(ii) are spin-offs; e(ii) is a stepterminating transverse fracture; f(ii) is flute- and burin-like fractures; f(iii) is a feather-terminating
 transverse fracture. a(ii), f(i) and the black lines in a and f are MLITs. b, c and e are from layer EII-
- 355 I; **a** and **d** are from layer E-D; and **f** is from layer D. \mathbf{g}, \mathbf{k} . Optical images at two different angles of
- sample 1, layer EII-I (scale bar, 5 mm) and sample 106, spit E-D (scale bar, 5 mm). Sampled areas

- are highlighted by a black box and magnified in **h** and **i** for sample 1 (scale bars, 1 mm and 0.5 mm)
- and in **l** and **m** for sample 106 (scale bars, 2 mm and 1 mm). **j**,**n**, Optical images of the scraped residues sitting on the culet of the opened diamond compression cell. **o**, Representative FTIR
- spectra of the sampled residues from samples 1, 34, 64, 75, 106 and 100a. Two selected reference
- 361 spectra of beeswax and peach tree gum are also plotted using the database from the Kimmel Center
- 362 for Archaeological Science Infrared Standards Library (https://www.weizmann.ac.il/kimmel-arch/
- 363 infrared-spectra-library). The grey shaded areas indicate the main absorption bands, characteristic
- of the organic fraction. Among them, those relating to beeswax are marked with dagger symbols,
 and those relating to plant/tree gum are marked with section symbols. For more details on the band
- 366 positions and assignments, refer to the Methods.
- 367
- 368

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Fig. 1









