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Wooden hafting technology in the early Neanderthal site of Poggetti Vecchi (Italy)

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ABSTRACT

The invention of hafted tools, between about 500 Ka and 250 Ka years ago, was a fundamental technological innovation that has shaped human social, cognitive, and biological capabilities. Despite the recurrent evidence of hafting observed on lithic tools, handles from this period are rare since they were probably made of perishable materials. Three exceptional wooden sticks interpreted as handles have been found in the Poggetti Vecchi site, allowing a deeper investigation of the technical capabilities of the early Neanderthals who frequented the site around 170,000 years ago. The handles and the lithic tools with hafting traces were analysed using a techno-functional approach, suggesting that they could have been attached to each other to create a specific composite hafted tool. The efficiency of the composite hafted tool was tested through a detailed experimental programme. The results highlighted, for the first time, the complex production processes used to create a composite hafted tool that could have been used to butcher the carcases of the large fauna that are well attested at the site.

1. Introduction

The emergence of hafted tools constitutes a major technological advance, reflecting human cognitive ability to manage and integrate complex operational sequences involving different materials (Barham, 2013; Key et al., 2021). A hafted tool consists of elements specifically designed to be joined in a single implement: the active part of the tool is made of hard material, generally stone or more rarely bone/antler, while the handle, the prehensile part of the tool, is made of wood or hard, animal material (Fairlie, 2017). These two elements are held together by one or more binding agents (adhesive and/or animal or plant fibres). The advantage of hafted tools over hand-held ones is greater mechanical efficiency due to the increased strength and precision achieved by the extension of the arm (Coe et al., 2022). A further advantage is that the handle makes the tool safer to use, giving greater protection to the hand by increasing the distance from both the active part of the tool and from the processed materials during particularly dangerous actions, such as butchering (Barham, 2013).

From a behavioural perspective, the hafted tools represent a conspicuous effort in terms of design and manufacture. The production of both the active part of the tool and the handle requires a series of productive phases, from the selection and collection of the raw materials to the processing, which could take place in different times and places, applying specific reduction sequences (Ambrose, 2010). Finally, the two items need to be appropriately shaped before being joined to create the hafted tool. These aspects imply a certain technological complexity, which among hunter-gatherer groups could reflect the relation between the variability of subsistence risks and mobility strategies (Read, 2008; Kelly, 2013).

In the archaeological record, most of the evidence related to the hafted tools is indirect; the presence of handles is frequently assumed on the basis of traces detectable on the stone tools (Rots, 2010, 2013). These traces can be related to the binding and the abrasions between the active part and the handle, or to a specific use of the stone tool that implies the hafting: for example, impact fractures suggest the use of lithics as inserted projectile items (Rots, 2016). Indirect evidence of hafting is attested in South Africa since about 500 Ka (Wilkins et al., 2012), where stone flakes found in Kathu Pan 1 are interpreted as spear tips. The only possibly older indirect hafting evidence comes from the site of Gesher Benot Ya'aqov in Israel dated to 8–700 Ka, (Alperson-Afil

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and Goren-Inbar, 2016). The latter attribution is, however, based solely on evidence of morphological modifications of the lithic tools consistent with hafting, while use-wear analyses are missing. Hafting traces on lithic tools become more representative during the late Middle Pleistocene (MIS 7), in Europe and the Near East and in eastern and southern Africa (Boëda et al., 1999; Barham, 2013; Rots, 2013; Rots and Van Peer, 2006; Wilkins et al., 2012; Wilson et al., 2020; Lombard, 2005, 2007, 2008), revealing the technical and cognitive development of both *Homo neanderthalensis* and *Homo sapiens.*

Adhesive residues found on stone tools and wooden handles are considered direct hafting evidence. The most ancient evidence of the use of adhesive is that of the tar-covered flakes from Campitello (Mazza et al., 2006). Wooden handles have been found in peculiar submerged or subaquatic archaeological contexts, as well as in very few extremely dry contexts. The oldest evidence could be represented by the clamp shafts found in Schöningen (Thieme, 1997, 1999; Leder et al., 2024), while more recent findings are known since the Upper Palaeolithic (Barham, 2013; Caruso Fermé and Aschero, 2020).

In this scenario, the site of Poggetti Vecchi (Grosseto, Italy) provides new evidence about early Neanderthal hafting techniques. The site, dated around 170 Ka (Benvenuti et al., 2017), at the beginning of the MIS 6, is already well known for the discovery of several wooden artefacts (Aranguren et al., 2018), preserved thanks to the presence of a thermal spring. These artefacts have been interpreted as digging sticks: multipurpose tools diffused among hunter-gatherer groups. Moreover, the site preserves abundant faunal remains, mainly attributed to *Palaeoloxodon antiquus,* in association with lithic tools used for butchering activities and occasionally revealing hafting use-wear traces (Aranguren et al., 2019). A detailed review of the wooden items highlighted the presence of three sticks with recurrent morphological patterns possibly associated with their use as handles. To verify this hypothesis, an interdisciplinary study of the three wooden sticks was performed, as well as a specific re-evaluation of the hafting traces on the lithic tools. Moreover, an experimental programme was developed to identify the production process used to shape the handles and the morpho-technical aspects of the binding, and to test the efficiency of the sticks as handles. Our results support the hypothesis that the three sticks were used as handles, offering new insights into the interpretation of human capabilities in a period when the climatic crisis required the development of innovative behaviour.

2. Material and methods

The Poggetti Vecchi site is located near Grosseto (southern Tuscany, Italy) in a confined, depressed plain at the foot of an 11-m-high hill (Benvenuti et al., 2017; Aranguren et al., 2018, 2019). The site is radiometrically dated to the late Middle Pleistocene, around 171,000 years BP. Warm water springs occur locally, connected with the intense geothermal system present in many areas of southern Tuscany. In Unit 2 a concentration of stone and wooden tools, interspersed among an accumulation of fossil bones largely belonging to the straight-tusked elephant *Palaeoloxodon antiquus*, was found at the bottom of a pond fed by hot springs (for details see Supplementary Material_S1). As regards the lithic tools, production was ultimately aimed at creating thick, retouched flakes (Aranguren et al., 2019, p.41). From a techno-typological perspective, the level of standardisation is very low. The lithic tools were chiefly used for cutting soft materials and probably also for butchering; some of them also show macro- and micro traces possibly related to the former presence of hafting.

Among the numerous wooden tools (tot.34), mostly referred to digging sticks, three tools with specific morphometric characteristics were also found. These implements may have had a different function, not conceivable at the time (Aranguren et al., 2018, p. 2056) (Fig. 1).

The stone tools with hafting use-wear traces are analysed here in detail as are the three handles, in order to verify the relations between them and evaluate their compatibility as composite hafted tools.

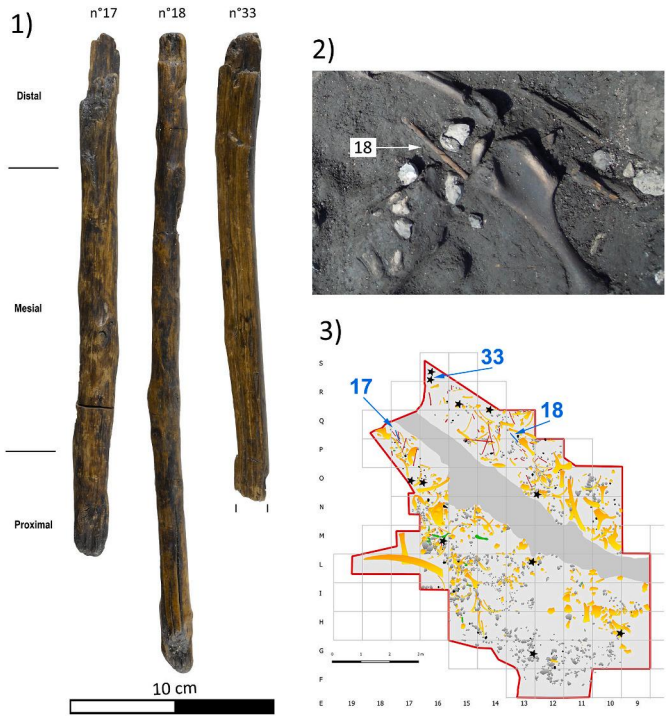

Fig. 1. Poggetti Vecchi (Grosseto, Italy): 1) three boxwood sticks interpreted as handles; 2) archaeological finding context of wooden handle no. 18; 3) Map of Unit 2 indicating the three wooden handles (blue arrow) and the eleven stone tools (black star) with hafting traces (modified from Aranguren et al., 2019).

2.1. Stone tool analysis

The lithic sample showing evidence of hafting from Poggetti Vecchi has been studied by recording data widely acknowledged in literature (see among others Inizan et al. 1999; Boëda, 1994; Rots, 2003, 2010, 2013; Marreiros et al., 2015) useful for a techno-functional interpretation (Boëda, 2013): a) colours, texture, and appearance of raw material for provenance analysis b) blank type (i.e. core, flake, etc.); c) general dimensions (length, width, thickness); d) type and positioning of the butt; e) lateral profile (for instance, straight, twisted, curved); f) presence and positioning of technical features (i.e. cortex, 'débordant' side, fractures, and so on); g) direction and sequence of the scars; h) retouch patterns (i.e. localisation, direction, angle, morphology etc.). To perform the use-wear investigations the artefacts were gently washed in soap and water and then regularly treated with alcohol during the microscope analyses. Three items with more evident traces were further cleaned using ultrasonic cleaner (model VWR USC300TH); particularly, each item was individually treated in a solution of distilled water with 1% of acetic acid for 15 min. This made it possible to obtain better pictures of the traces, avoiding any possible interpretative mistakes due to surface alterations; l) macro-traces were analysed using a Leica DFC420 stereo microscope ranging from 10x to 100x magnifications; micro-traces were analysed with the aid of a Leica DM2500 metallographic microscope ranging from 50x to 200x magnifications. A Hirox RH2000 digital microscope was used to confirm functional details and collect high-quality images, which were compared with literature and the authors' experimental use-wear reference collection (repository: Trento University). Residues have not been detected during the microscopic analyses.

2.2. Wooden artefacts analysis

The three handles found at Poggetti Vecchi (nos. 17, 18 and 33) were analysed in several steps, from naked-eye observation to macro- and microscopic characterisation. The three items were photographed with a

Sony A7II full frame with a 55 mm micro Nikkor lens by a professional photographer from the Ministry of Culture. An initial survey of the surfaces was carried out by naked eye and using the Dino-Lite AM 4113 ZT to identify areas of interest. Subsequently, Hirox digital microscopes (Hirox RH2000) were used during the various work sessions in Faenza at the CNR-ISSMC – Institute of Science and Technology of Ceramic Materials, and at the Laboratorio Bagolini Archeologia, Archeometria e Fotografia (LaBAAF) of Trento University. The traces observed on the surfaces of the sticks were accurately described and recorded noting their position, taking pictures, and in some cases by creating a 3D surface reconstruction.

For the observation of traces, the previous experience acquired in the study of digging sticks was fundamental, especially for the identification of processing traces and fire evidence (Revedin et al., 2020).

All the data were compared with field documentation and with the original drawing of item no. 18 made immediately after the excavation (Supplementary Material_S2). This information was useful for corroborating the data presented here and for excluding from diagnostic patterns any unintentional modifications that could occur on the sticks after their discovery.

2.3. Experimental programme

An experimental programme was designed to acquire skills and technical knowledge functional to the interpretation of production processes and to verify the functional potential of the wooden archaeological handles. The experimentation was aimed at reproducing the composite tool and evaluating the related use and gestures on the basis of archaeological evidence found at the Poggetti Vecchi site (for all details about the experimental protocol see Supplementary Material_S3). More specifically, wooden handles and lithic artefacts with characteristics similar to archaeological ones were reproduced, while for the binding we relied on archaeo-ethnographic comparisons (Caruso Fermé & Aschero C. 2020; Piqué et al., 2018; Conard and Rots, 2024). The experimentation took place over separate sessions investigating three main aspects.

1) Production of the wooden handle: reconstructing the operational sequence for the production of wooden handles; understanding the methods for creating the notch comparable with those on the archaeological wooden artefacts.
2) Manufacturing of the composite tool: identifying how experimentally reproduced flint tools could be attached to the experimental handles. This activity was based on the evidence of hafting and ligatures observed on archaeological handles, integrating this evidence with ethnographic literature (Hodge, 1912; McCullough, 1989; Grønnow, 2017; Piqué et al., 2018; Deacon and Deacon, 1980; Kvavadze et al., 2009).
3) Use of the composite hafted tool: testing the efficiency of hafted tools for butchering of medium/large animals; obtaining recurrent traces on experimental wooden handles functional to interpreting the traces observed in the archaeological record.

The experimental lithic tools were produced using local raw materials, while boxwood was used to shape wooden handles, as attested in the archaeological record. The experimental sessions were documented through pictures and video recording. Additionally, a detailed journal recording specific aspects or unpredicted variables that occurred during the activity was compiled. Particular attention was paid to differences in gestures and movements performed during both the production process and the use of the tools. The experimental materials were macro- and microscopically analysed as described above for the archaeological materials.

3. Results

3.1. Stone tools assessment

The chief characteristics of the lithic industry of palaeosurface U2 of Poggetti Vecchi have already been reported in a previous study (see Aranguren et al., 2019). Overall, the lithic industry is characterised by the predominant presence of retouched artefacts that can be formally classified in the categories of scrapers and denticulates. The retouching is variable, often featuring steep or flat-concave retouch morphologies and extending along the edge in either a regular or irregular manner, in the latter case acquiring a notched appearance; the two types of retouch can be observed on different edges of the artefact, and sometimes on the same edge. The presence of the two types of retouching – steep or flat-concave – made it possible to hypothesise a morphologically non-standardised production of lithic blanks, followed by a selection of the artefacts to be transformed into cutting tools by creating an active edge using flat retouch, with the chief purpose of reproducing an acute angle on the edge of the artefact (Aranguren et al., 2019). Conversely, the steep retouch – continuous or notched – is used to shape the original outline of the flake to give it a sub-parallelepidal or rectangular form; in addition to the steep retouch, other techno-functional characteristics of the lithic artefacts, for instance, débordant or overpassed edges, fractures and butts contribute to configuring morphologically standardised artefacts. There are about 30 retouched artefacts on which use traces were detected (Aranguren et al., 2019) and the majority of them show evidence of longitudinal activity on soft animal material (Figs.2.3 and 3.1). It is interesting to note that the few artefacts that appear to have been used to work wood are the only ones showing morphologies discordant with the characteristics described for the other artefacts.

11 of the retouched artefacts show traces that we believe are due to hafting, particularly evident in three artefacts (Figs. 2 and 3). The hafting traces are located around the perimeter of the artefact with the exception of the active edge, which always features the association of flat-concave retouch and cutting traces. The hafting traces are not very varied, being generally in the same position and with the same development on all the artefacts on which it was possible to observe them: the macro-traces are present on the edges of the lower surfaces of the flakes, and are characterised by limited and sporadic rectangular or trapezoidal abrasions terminating in a steep-type fracture (Figs. 2.1 and 2.2); the micro-traces are generally not very developed, located on the edges with the appearance of slight abrasion of the edge. The most evident characteristic consists of scars of variable length, not particularly developed and with defined direction showing that they are parallel to each other (Figs. 2.1,2,4, Figs. 3.3 and 3.5). It is interesting to note that the direction of these scars is never towards the active edge while, at the same time, they go in every other direction as if to cover the entire surface of the artefact. Such traces are rarely found on the rear surface of the artefacts or in the retouch negatives; when they are (Fig. 3.3), a variability in the groups of scars can be observed, moving in different directions, even from the same edge, while still remaining parallel with each other in each group.

3.2. Wooden handles assessment

The three handles are described here in detail reporting their finding context, general features (i.e. raw material, overall dimensions, macroscopic features), specific notch patterns (Supplementary Material_S4), and state of preservation, also describing the traces observed on their surface. Traces are distinguished based on the archaeological evidence and by comparing the available literature (Nugent, 2006; Revedin et al., 2020 and compare with Milks et al., 2022), as follows: 1) Scratches: incisions sub-parallel to the wood fibres with v-shaped section; 2) Channels: grooves, wider than the previous ones, with a flat cross-section and sub-perpendicular to the wood fibres; 3) Abrasions: areas with scrubbed surface and small exfoliations; 4) Polishes: areas

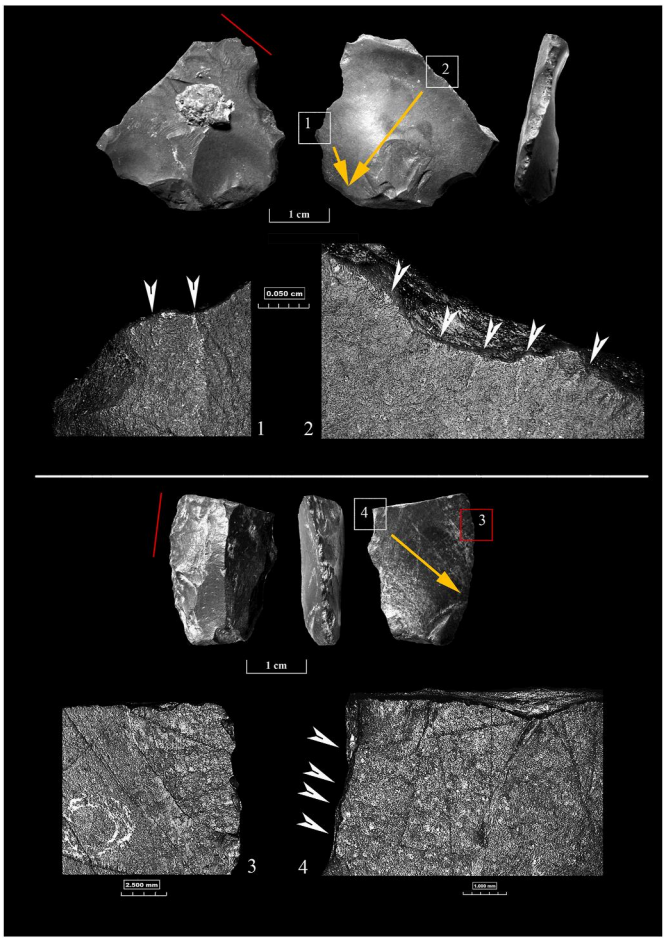

Fig. 2. Stone tools from Poggetti Vecchi with use-wear traces: white squares indicate the position of the hafting traces shown in pictures 1, 2, and 4, white arrows show the scars due to hafting; the red square indicates the position of the use traces (cutting of animal tissue) shown in picture 3; the red lines indicate the extension of the active edge; the yellow arrows indicate the direction of the hafting scars.

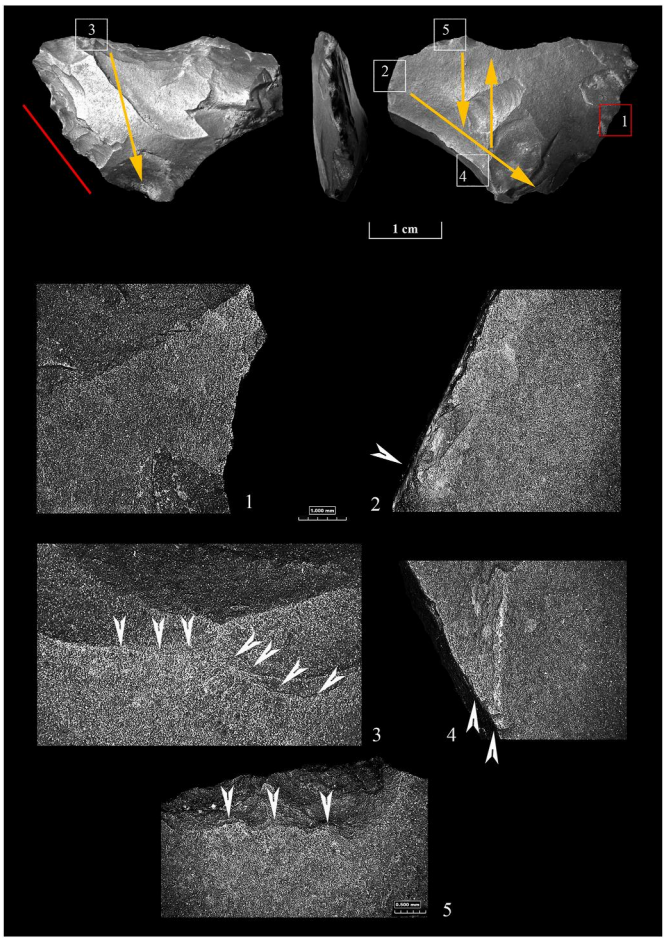

Fig. 3. Stone tools from Poggetti Vecchi with use-wear traces: white squares indicate the position of the hafting traces shown in pictures 2–5, white arrows show the scars due to hafting; the red square indicates the position of the use traces (cutting of animal tissue) shown in picture 1; the red lines indicate the extension of the active edge; the yellow arrows indicate the direction of the hafting scars.

characterised by a polished surface.

Item no.17 was found in square Q17 of palaeosurface U2 (Figs. 1.1 and 1.3); it is made of boxwood, the bark is absent, the knots are flattened, and the surface is partially burnt. The proximal part appears roughly rounded. The distal end was reassembled by refitting a splinter detached during the excavation. The distal part is rounded, and there is a carved notch. The maximal dimensions of the notch are 2.3 cm length, 1.6 cm width, 0.4 cm thickness. The longitudinal surface is flat, and follows the alignment of the fibres. The transversal surface is strongly inclined showing some internal damage. Before restoration, the stick measured 30 cm in length and 2 min. 2.5 max. in diameter. After restoration, the length of this item was considerably reduced (27.6 cm) and its diameter flattened, with a current maximum size of 1.8 cm.

Concerning the observed traces, abrasions can be observed on the distal part behind the notch, several channels can be observed from the notch to the mesial part of the shaft. Numerous scratches can be observed along the shaft, covered in some cases by transversal channels (Fig. 4).

Item no.18 was found in square Q13 of palaeosurface U2 (Figs. 1.1 and 1.3); it is made of boxwood, the bark is absent, and the knots are flattened. On the proximal part has a dulling end, while on the distal part there is a carved notch (length 1.7 cm, width 1.4 cm, thickness 0.5 cm). The longitudinal surface follows the fibres but is not perfectly flat due to the presence of a tiny 'tongue'. The transversal surface is slightly oblique and is therefore not perfectly perpendicular to the fibre axis. Just below the transversal surface, a thin chip can be identified (compare Supplementary Material_S2). Before restoration, the handle measured 35.5 cm in length and 2 min - 2.5 max in diameter. After restoration the length was considerably reduced (32.5 cm), as was the diameter (1.3 cm min - 1.8 max).

Surface observation revealed the presence of several channels all around the distal part, as well as several abrasions partially rounding this area. Numerous scratches can be observed along the shaft, in some cases also obliterated by transversal channels. There are traces of polishing on the edge of the notch. A series of thin, slightly oblique traces can be observed on the 'tongue' inside the notch, consistent with abrasion activity (Fig. 4).

Item no.33 was recovered in square S16 of palaeosurface U2, but its precise position was not recorded (Figs. 1.1 and 1.3); it is made of boxwood, the bark is absent, the knots are flattened and the surface is partially burnt. On the distal part there is a carved notch (length 1.9 cm, width 1.8 cm, thickness 0.3 cm). The proximal part is fractured, and the item is also broken longitudinally. Both fractures appear to have occurred during manufacturing or use. The distal part is partially rounded. The surface created by the longitudinal cut follows the fibres but does not cover the entire diameter of the wood, as it has one part perfectly flat and another only roughened. The transversal surface is perpendicular to the axis of the fibres and there is a groove at the angle

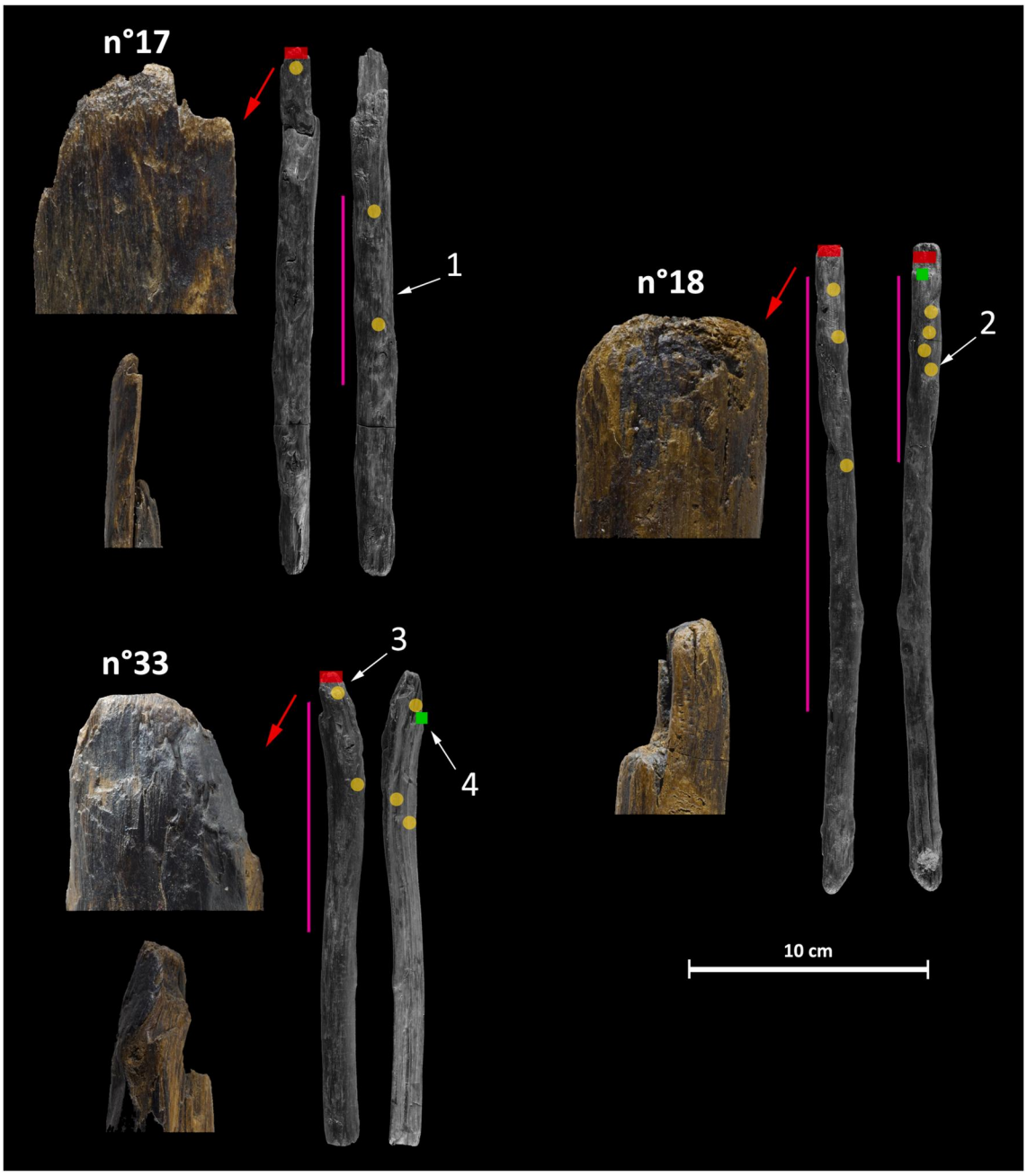

Fig. 4. Handles from Poggetti Vecchi with detailed pictures of the distal part showing abrasions, lateral profile, and positioning of the other use-wear traces: purple line - presence of scratches, red rectangle - position of abrasions; yellow dot – position of channels; green square – position of polishing; white numbers – positions of the pictures in Fig. 6.

between the transversal and longitudinal surfaces. Before restoration the item measured 26 cm in length and 2.5 cm in diameter. After restoration the length was considerably reduced (23 cm), as was the diameter (2 cm max.).

Analysis of the surface shows abrasions and polishing traces near the notch and on the edge of the distal part of the shaft, comparable with item no.18. There are several wide channels in the distal part also on the fracture. Numerous scratches can be observed along the shaft, sometimes obliterated by channels (Fig. 4).

The three items described here are part of the wooden artefact assemblage found at Poggetti Vecchi and share some characteristics with the well-known digging sticks: a) the surface of the stick is debarked; b) the side branches have been removed and the knots have been flattened; c) where they are preserved, the distal and proximal parts are rounded, in two cases out of three also using fire. Nevertheless, they have specific characteristics that allow them to be described as a homogeneous set: a) the dimensions of the sticks are always consistent (length between 30 and 35 cm and diameter between 2 and 2.5 cm); b) the distal part always has a carved sub-quadrangular notch of identical size (Supplementary Material_S5), a morphology that cannot be produced by natural activity (compare Supplementary Material_S3); c) while scratches are localised all along the shaft, channels, polished areas and abrasions are largely positioned on the distal part and around the notch, suggesting the presence of a binding.

3.3. *Experimental inference and techno-functional interpretation*

The functional analysis of the stone artefacts from palaeosurface U2

enabled identification of traces connected with the possible presence of hafting. Similarly, the three wooden sticks have common morphological characteristics and evidence of possible bindings, suggesting that they may have been used as handles. We drafted an experimental protocol to verify the relation between the stone tools and the wooden handles. Reported below are the results of the experimentation, which is described in detail in the supplementary material (compare Supplementary Material_S3).

The experimental production of the wooden handles and the notches enabled reconstruction of a complex operational sequence comprising: A) selection/collection of boxwood with specific morphometric features; B) the shaping of the shaft using stone tools and fire, as previously verified also for the digging sticks of Poggetti Vecchi; C) the creation of the notch by cutting and chopping. The experimental stone artefacts, made using local raw materials in compliance with archaeological patterns, were fitted into the notch and attached using synthetic tendon and/or vegetal fibres: *Ampelodesmos mauritanicus*, *Raphia* sp., *Typha* sp., *Urtica* sp. The latter two species are present in the pollen spectrum of the site (Benvenuti et al., 2017). More specifically, *Urtica* sp.is known in Palaeolithic archaeological contexts for its use in making various types of cordage (Adovasio et al., 1996) In some cases the vegetable fibres were soaked and plaited (Hardy et al., 2020). The stone tool was attached with the ventral face towards the wood, as suggested by the use traces on the stone. The fibres used for the binding were passed over the steep edges of the stone element, leaving free the active edge which protrudes slightly from the binding. In order to verify the usage potential of the composite artefact, the tools thus produced were used at different times for activities connected with the butchering of a boar. The presence of the handle permits a cutting/ripping gesture functional to incision of the soft tissues (i.e. skin and flesh), detaching blocks of flesh; the presence of the handle also facilitates the action of cutting between muscles, making it possible to penetrate at depth the mass to be detached. The most efficient bindings proved to be *Raphia* sp., in some cases associated with tendons, and *Urtica* sp. The soaking of the completed composite tool also proves to be a significant technical aspect, since it contributes to the plasticity of the binding by enhancing adherence to the haft. Moreover, the expansion of the wood fibres makes the composite tool more solid by compressing the stone element into the binding.

The functional observation of the experimental stone artefacts (Fig. 5) highlights the presence of use traces and hafting comparable with the archaeological record. The limited working time, and probably also the impossibility of using carcasses of large dimensions like the elephants of Poggetti Vecchi, were factors that restricted the production of traces in both quantitative and above all qualitative terms. However, in addition to the butchering traces (Fig. 5.1 and 5.2), the archaeologically observed scars were also produced (Fig. 5.3 and 5.6) as well as the abrasion of the edges (Fig. 5.3 and 5.4) at the points of contact between the lithic element and the wood.

The functional observation of the experimental wood elements highlighted the presence of various traces comparable to the archaeological record (Fig. 6). In the area of the binding, numerous transversal channels can be observed, sometimes superimposed on the traces of working of the handle such as scratches and burning. Polished areas can also be observed caused by the friction of the binding on the wood surface.

4. Discussion and conclusion

The macro- and microscopic characteristics of the wooden handles and the stone artefacts of Poggetti Vecchi described in this work represent important evidence of a possible adaptive change on the part of the human groups that experienced the transition from the Middle to the Upper Pleistocene in central Tyrrhenian Italy.

Unlike previous periods, this change appears to be focalised at Poggetti Vecchi in a significant complexity of hafting techniques, and

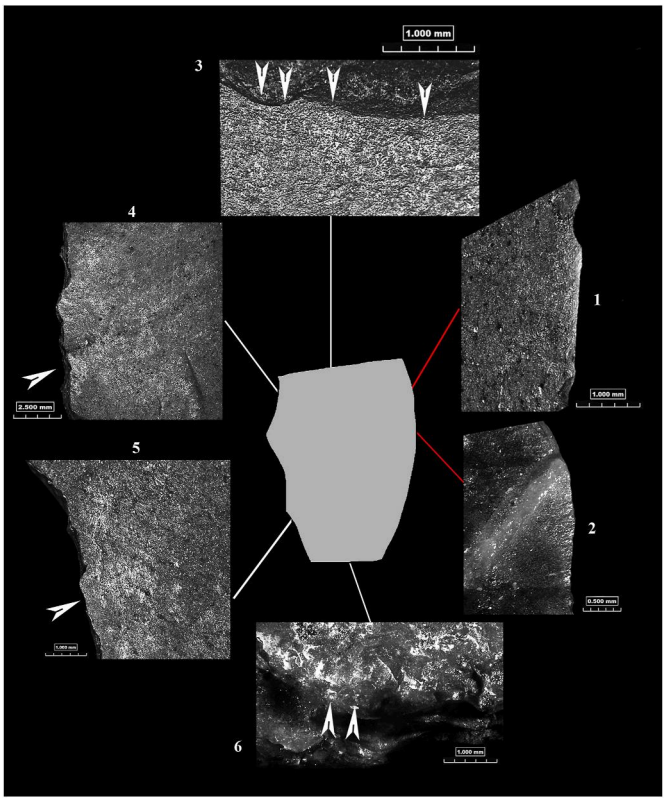

Fig. 5. Schematic synthesis of the wear traces observed on the experimental stone tools: 1 and 2 show use-wear traces due to cutting of animal tissue; 3 to 6 show scars and polish due to hafting.

hence of the production of the respective components of composite artefacts.

As suggested by various authors, the production of composite tools is generally based on the assembly of several components of different types: the active tools made of stone or bone which are present in the archaeological record and recognisable from use-wear indicating hafting (Rots, 2013); handles made of wood (Barham, 2013), bone, or antler (Allain et al., 1993; Rots, 2008); binding composed of vegetal or animal fibre that can be braided or twisted, such as for instance the vegetal fibre residue on a Neanderthal tool dated to about 50 ka (Hardy et al., 2020) or the cordage production at La Draga (Piqué et al., 2018; Herrero-Otal et al. 2023); finally, glue and mastics, consisting of vegetal (tar from pine, birch etc.) or mineral (pitch) resins (Lombard, 2006; Mazza et al., 2006; Wadley et al., 2009; Degano et al., 2019; Niekus et al., 2019).

In the case of Poggetti Vecchi, the presence of at least two of the components of the composite tool was detected: the active stone elements and the handles; in this work, we believe that we can also suggest the presence of a third element: the cordage for binding. The three categories of elements demonstrate the existence of a technical system involving the integration of at least three separate operational sequences used on the different categories of material – flint for the production of the stone artefact, fibre for the production of cordage, wood for the production of the handles – which, on the basis of decisions on management and operational planning, come together in the production process of the composite hafted tool (Fig. 7).

The lithic artefacts are produced by collecting local raw material which is then knapped using direct percussion with a hammerstone to produce flakes of variable morphology. Non-retouched flakes can be useful as active tools as a result of their sharp edges, although this evidence has not emerged in the lithic assemblage of Poggetti Vecchi. Other flakes can then be retouched, generally with combinations of steep or sub-steep, denticulate or concave retouch to alter their natural

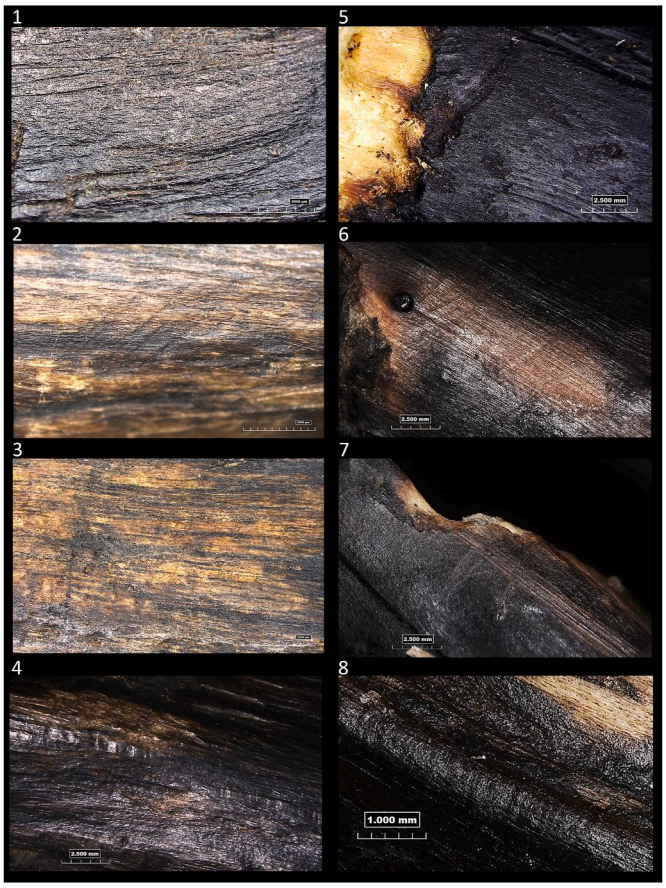

Fig. 6. Traces observed on the archaeological wooden handles (from 1 to 4; compare Fig. 4 for their positioning) compared with the traces formed on the experimental wooden handles (from 5 to 8): scratches (1 and 5); channels (2, 3 and 6, 7); polishes (4 and 8).

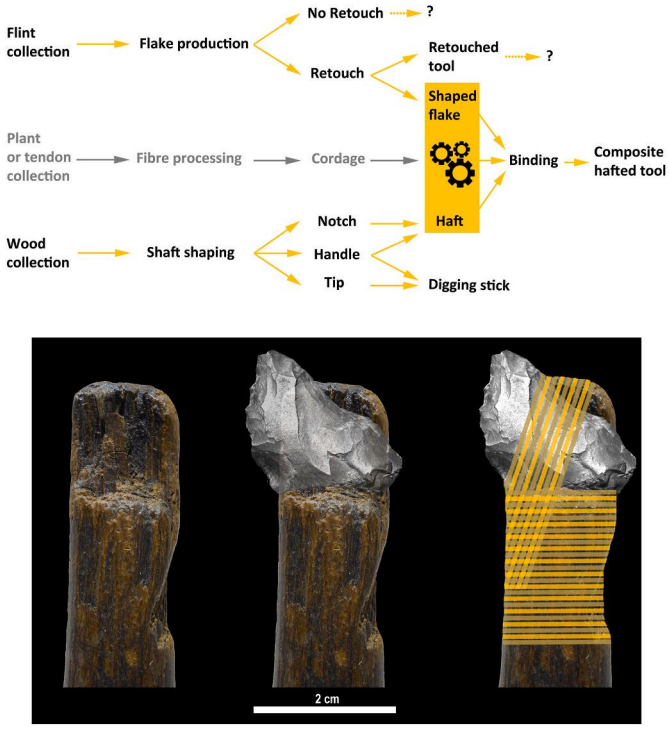

Fig. 7. – Top: Schematic reconstruction of the operational sequences used to produce the composite hafted tools of Poggetti Vecchi. The archaeologically attested phases are shown in yellow/black and the hypothetical manufacturing process of the cordage in grey. Bottom: Hypothetical reconstruction of a composite hafted tool: On the left the notch on the handle, in the centre the stone tool placed on the notch, on the right a possible binding technique based on the traces found on the archaeological artefacts (compare stone tool in Fig. 3 and handle no.18 in Fig. 4).

morphology for use as tools. The available evidence suggests that these artefacts were used for different functional purposes, such as working wood. Finally, other flakes are 'shaped' through retouching in order to produce morphologies functionally specialised for certain activities, identified at Poggetti Vecchi as the cutting of animal materials. This last category of lithic artefact becomes the active element of the hafted tools when it is fixed firmly into the wooden handle by binding.

The production of the wooden handles is a separate operational sequence. This starts with the cutting of the boxwood, selecting branches suitable to obtain instruments of standardised size (with measurements of between 2/2.5 cm diameter, excluding bark, 30/35 cm length). The wood is then worked, removing the bark and flattening the knots through the combined action of fire and stone tools, using the same process already demonstrated for the digging sticks (Revedin et al., 2020). During this process the wooden elements are also shaped by rounding one or both ends, as for the handles of the digging sticks, and by creating a notch for the insertion of the stone element. This is a fundamental part of the realisation of the composite tool, and it is in this phase that the stone component is shaped by retouching to adapt it to the morphology of the notch in such a way that what will become the active edge of the tool is in the ideal position.

Finally, although there is no certain archaeological evidence about the nature of the materials used for the bindings, Poggetti Vecchi has yielded the very first archaeological evidence for indirect proof of the binding, consisting of traces of the impressions of cordage on the wooden handles. The binding could have been made from various vegetal fibres available in the area of the site or with animal tendons. Nor, given the context of the find, can the use of adhesives be entirely ruled out, since the thermal water could have influenced their preservation.

In sum, wooden handles, cordage, and active stone tools are the products of different production sequences that could have taken place in the reference social context, for instance the production of retouched flakes and the working of the boxwood for the digging sticks (Aranguren et al., 2018). The operational sequence for the production of binding was probably also used for other activities too, although the extremely perishable material makes this difficult to document. Nevertheless, we believe that the three production sequences could have been independent of each other until it was necessary to bring them together to make specific implements, such as the composite hafted tools. The combination in a single tool of the three elements – shaped flake, cordage, and wooden handle with worked notch – was aimed at the performance of different activities linked with the butchering of animal carcasses.

The highly 'sophisticated' production of composite hafted tools to butcher animal carcasses was undoubtedly supplemented by more expedient tools such as simple flakes or more formal retouched tools which may have been used manually. But it should be mentioned that, as far as the Poggetti Vecchi evidence is concerned, the active edge of some hafted flint tools may sometimes have been rejuvenated by retouch while bound onto the wooden haft (see Fig.3.1); we can assume that these tools would have been completely worn down before they were discarded in site and thus their basic functionality was never changed.

On the basis of archaeological comparisons, the type of hafting proposed for the Poggetti Vecchi tool can be referred to the so-called 'juxtaposed haft' (Anderson-Gerfaud and Helmer, 1987, fig.28, 30; Barham, 2013, fig. 5.2) or 'notch haft' (Shea et al., 2001, Fig. 3). This type of hafting is used for both knives and scrapers and is illustrated ethno-archaeologically in Artic forager populations (Grønnow, 2017; Morrison, 1991) and more rarely in arid contexts (Hodge, 1912). In the

context of the European Lower Palaeolithic, the only evidence known to date of wooden tools consists of the artefacts from Schöningen 12 II, 12 B, and 13 DB, which are defined – albeit without a detailed functional interpretation – silver-fir socketed handles or clamp shafts (Leder et al., 2024), appearing to suggest that the stone element was slotted into the handle rather than being bound to it as in the case of Poggetti Vecchi. It is also interesting that the Schöningen handles are very different in shape from those of Poggetti Vecchi, suggesting a possibly different function or two different craft traditions in Northern Europe and the Mediterranean area. A technological evolution during the time separating the two sites cannot be ruled out either.

It should also be stressed that at least two production sequences called for a complex artisanal know-how about the engineering use of other natural resources such as fire for the production of the boxwood sticks, and of water – possibly thermal at Poggetti Vecchi – to facilitate and improve the properties of the binding between the stone tool and the wooden handle. The expertise required to work the boxwood by using fire has already been thoroughly demonstrated (Revedin et al., 2020); here it is enough to recall that this is the oldest archaeological evidence of such use in the production of wooden artefacts.

The experimental activity carried out to understand the functionality of the composite tools of Poggetti Vecchi made it possible to verify the efficacy of such instruments in butchering activities, also hypothesising the gestural performance of the same. Specifically, an important observation was made regarding the efficiency of the tools: the immersion in water of the fibres carried out both prior to the binding of the stone artefact onto the wooden handle and after the binding had been completed. The soaking of the fibres prior to binding increases their plasticity; after the binding the soaking swells the wood of the handle, giving greater stability to the stone artefact.

In the production sequences for both the wooden handles and the binding of the composite tools, knowledge of the properties of fire and water, and the artisanal mastery of their use in the production of tools can be considered as evidence of two important steps of technological improvement. These could be seen as part of the behavioural capabilities of human groups which inhabited Poggetti Vecchi, allowing early Neanderthals to successfully live in the 200 kya palaeoenvironment of central Tyrrhenian Italy.

Author contributions

Silvia Florindi, Anna Revedin and Biancamaria Aranguren: original draft preparation, data curation; Fabio Santaniello: review and editing, data curation; Stefano Grimaldi and Fabio Santaniello: formal analyses of the lithic industries; Silvia Florindi, Daniela Puzio, Anna Revedin, and Biancamaria Aranguren: formal analyses of the wooden handles; Cesare Melandri: digital microscope analysis; Biancamaria Aranguren, Silvia Florindi, Stefano Grimaldi, Daniela Puzio, Anna Revedin, Fabio Santaniello: conceptualisation, methodology, investigation, visualisation, validation; Anna Revedin and Biancamaria Aranguren: general coordination of the project.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quascirev.2024.109014.

Data availability

Data will be made available on request.

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