Wooden tools and fire technology in the early Neanderthal site of Poggetti Vecchi (Italy)

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Excavations for the construction of thermal pools at Poggetti Vecchi (Grosseto, Tuscany, central Italy) exposed a series of wooden tools in an open-air stratified site referable to late Middle Pleistocene. The wooden artifacts were uncovered, together with stone tools and fossil bones, largely belonging to the straight-tusked elephant *Paleoloxodon antiquus*. The site is radiometrically dated to around 171,000 y B.P., and hence correlated with the early marine isotope stage 6 [Benvenuti M, et al. (2017) *Quat Res* 88:327–344]. The sticks, all fragmentary, are made from boxwood (*Buxus sempervirens*) and were over 1 m long, rounded at one end and pointed at the other. They have been partially charred, possibly to lessen the labor of scraping boxwood, using a technique so far not documented at the time. The wooden artifacts have the size and features of multipurpose tools known as "digging sticks," which are quite commonly used by foragers. This discovery from Poggetti Vecchi provides evidence of the processing and use of wood by early Neanderthals, showing their ability to use fire in tool making from very tough wood.

digging stick | early Middle Paleolithic | charring | boxwood

This study is focused on the wooden artifacts found in the stratified site of Poggetti Vecchi in southern Tuscany (central Italy) that was dated to the final Middle Pleistocene. A stratified succession of seven units, six of which are archeological levels, was discovered during the construction of a thermal pool. The lowermost archeological unit (U 2) is a paleosurface where wooden and stone tools were found interspersed among a concentration of fossil bones, mostly of the straight-tusked elephant *Paleoloxodon antiquus*. Some wooden and stone tools were also found in U 6. Radiometric datings suggest that the Poggetti Vecchi succession accumulated during a time spanning the latest marine isotope stage 7 (MIS7) interglacial and the whole MIS6 glacial. A multidisciplinary research has been conducted on the paleoenvironmental conditions at the time of the formation of the site (1). Due to the low resistance to decay of wood, prehistoric wooden tools, and especially early Middle Paleolithic ones, are very rarely found. Wooden spears are known from a few European localities. The most numerous ones are those from Shöningen (2, 3), whereas individual items were recovered from Clacton-on-Sea (4) and Lehringen (5). In the latter two sites, spears were found associated with remains of *Paleoloxodon*. Although fragmentary, the wooden finds of Poggetti Vecchi are an important collection of hitherto unknown tools of this type and age. The study enabled the reconstruction of the morphology and the manufacturing techniques. Analysis of the finds, which was complicated by the poor state of preservation, has been supplemented by experimental archaeology and ethnographic comparisons. The Poggetti Vecchi wooden tools differ morphologically and dimensionally from other ones known so far. They are possibly multipurpose sticks, not necessarily weapons, and were produced with the use of fire.

The Site and Paleoenvironmental Context

Poggetti Vecchi is located near Grosseto (southern Tuscany) in a confined, depressed plain at the foot of an 11-m-high hill. Warm water springs occur locally (6), connected with the intense geothermal system present in many areas of southern Tuscany (7). In 2012, diggings for a thermal pool exposed an about 3-m-thick succession of lithostratigraphic units. A following systematic excavation over an area some 60 m^2 wide, supervised by the Soprintendenza Archeologia of Tuscany, encountered a stratified succession of alternating lacustrine and colluvial deposits. Seven stratigraphic units have been recognized, named U 1–U 7 from the bottom upward, most of which are mudstones, more or less calcareous, deposited during successive lake-level fluctuations. The succession is confined within a quite narrow, east/west-trending depression that formed a shallow embayment carved into older alluvial beds. U 1 consists of 60 cm of marginal lacustrine mudstone. An erosional surface separates it from U 2, a paleosurface formed with low sediment input. U 2 contains the oldest anthropic evidence of the site, represented by stone tools and wooden sticks, interspersed with bones of large vertebrates, especially *P. antiquus*. Typologically, the stone artifacts (about 200) of U 2 are only broadly indicative of an early Middle Paleolithic age. Several tens of tiny flakes are interpreted as

Significance

Wood is a widely available and versatile material, which has admittedly played a fundamental role in all human history. Wood, however, is most vulnerable to decomposition. Hence, its use is very rarely documented during prehistory. The present study yields new insights into the cognitive abilities of the early Neanderthals in wooden tool production and pyrotechnology. The early Neanderthals from the late Middle Pleistocene site of Poggetti Vecchi (central Italy) were able to choose the appropriate timber and to process it with fire to produce tools. The artifacts recall the so-called "digging sticks," multipurpose tools used by all hunter-gatherer societies.

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possible byproducts of a retouching activity that took place on site. Wooden artifacts found on the paleosurface U 2 were mostly concentrated in a relatively small area (some 17 m^2 wide) at the western end of the excavation. They were all horizontally and randomly oriented, and in contact with the elephant remains (Fig. 1 and Fig. S3 *A*, *d*). Some of them were found even under the bones. The poor state of preservation of the wooden artifacts rendered their recovery and following analysis very difficult (*Supporting Information*).

Thermal activity affected this marginal lake area already between U 1 and U 2, and grew progressively stronger from U 3 and U 4 onward. U 4 has been radiometrically U-dated to 171 ± 3 ka based on pisoliths and electron spin resonance/U-series–dated to 170 ± 13 ka on a left lower molar of *Bos primigenius*. These radiometric datings indicate that the Poggetti Vecchi succession accumulated during a time spanning the latest MIS7 interglacial and whole MIS6 glacial, when the climate was globally deteriorating (1). Subsequent to U 4, the lake level dropped and then rose again. This led to the depositional and ecological conditions indicated by U 6, when organic-rich mudstones settled in the Poggetti Vecchi depression. A few wooden artifacts were found at the base of U 6, and therefore possibly accumulated on the lake bottom. From the paleoenvironmental viewpoint, the fossil mammals are suggestive of extensive open grasslands inhabited by large grazers, such as *P. antiquus* and *B. primigenius*. The red deer *Cervus elaphus* and the roe deer *Capreolus capreolus* browsed in sparse groves. The different kinds of herbaceous plant pollen, particularly of Poaceae, which dominates the spectra along all of the stratigraphic succession, indicate that the site was surrounded by a highly diverse grassland. Hygro- and hydrophytes attest to the presence of wetlands in the plain and in proximity to the site. Tree pollen is scanty, and *Buxus* pollen is also present. Pollen grains from U 1, from the top of U 2, and from U 6 reveal an abundance of freshwater ferns but also a high variety of wetland plants, which confirms the indications of the periodic occurrence of freshwater bodies and seeps given by the mollusk and ostracod assemblages (1).

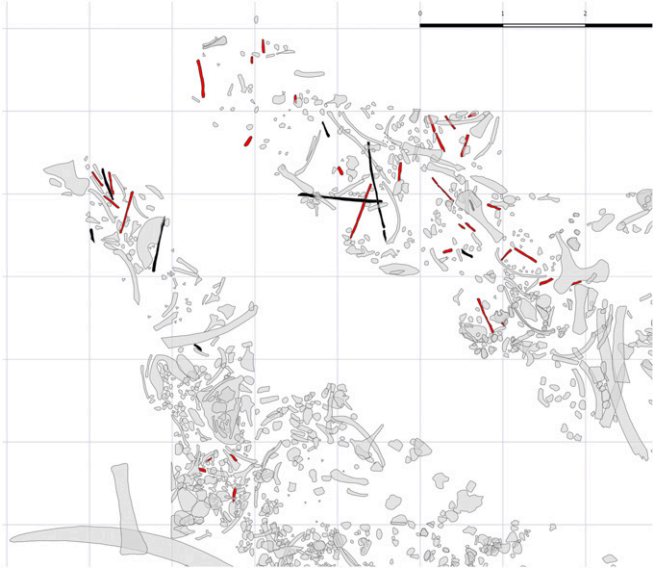

Fig. 1. Poggetti Vecchi, U 2: details of the paleosurface divided by an erosion channel. The spatial distribution of wooden tools is shown; those charred are shown in black, those not charred are shown in red, and all of the other findings are shown in gray.

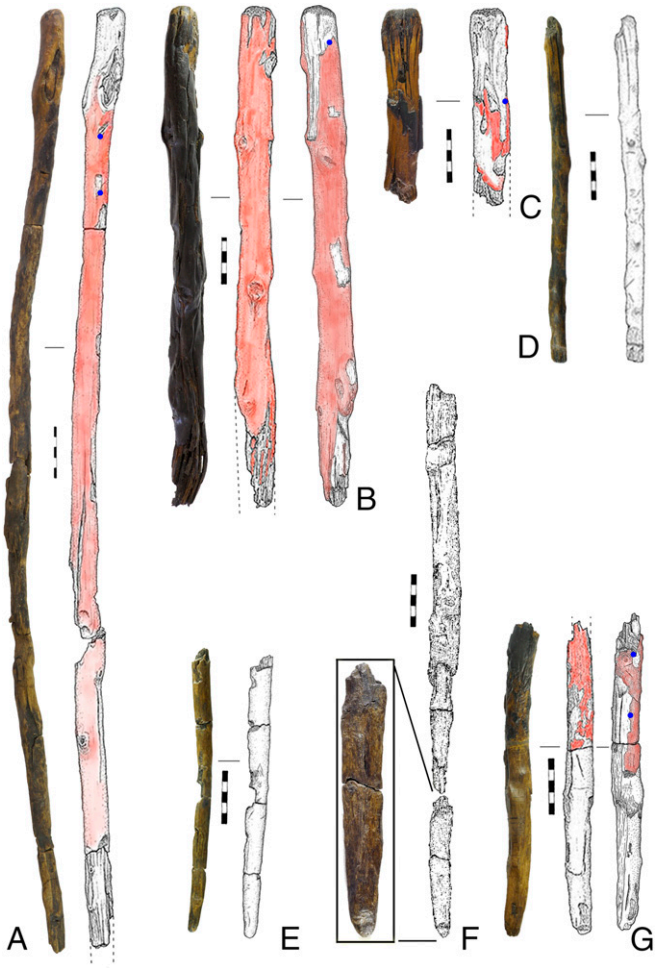

Fig. 2. Poggetti Vecchi wooden tool drawings (charred parts are shown in red, blue spots indicate measurements of film thickness) and photographs. Handles: no. 2 (*A*), no. 9 (*B*), no. 50 (*C*), and no. 18 (*D*). Pointed tips: no. 55 (*E*), no. 41 (*F*), and no. 3+28 (*G*).

The Wooden Artifacts

Fifty-eight wooden remains (46 from the paleosurface U 2 and 12 from U 6), ranging in size from a few centimeters to over 1 m, were found at Poggetti Vecchi. *Buxus sempervirens* L. (boxwood) is the predominant wood at the site (47 of the 55 identified items). The remaining eight wooden fragments are of deciduous oak (*Quercus* sp.), ash (*Fraxinus* sp.), juniper (*Juniperus* sp.), and *Populus*/*Salix*. They likely derive from the local vegetation (1). Thirty-nine boxwood items have been identified as tools showing clear evidence of human manufacturing. Straight branches were intentionally selected; small lateral branches were carefully removed, and the bark was scraped off. The manufacture is also testified to by the presence of traces on the wooden surfaces: cut marks near lateral branches and striations along the shaft.

Some of them have the ends worked in the shape of a blunt point or a handle, and can hence be defined as sticks. A "stick" is commonly a roughhewn branch, around 1 m long and with a diameter such that it can be easily gripped in the hand and employed for different purposes. All of the sticks were made from straight branches with a diameter from 2.5–4 cm. The natural tapering shape of the branches was used to fashion a point at the thinner end (diameter of about 1.5 cm) and a rounding edge that we call a "handle" at the thicker end (Fig. 2).

The artifacts are almost all incomplete and display various types of fracturing. Some reveal the characteristic fraying of the

fibers produced *ab antiquo* on the intact wood, while other clear-cut fractures were made in a subsequent phase on already decayed wood and can be attributed partly to sediment pressure and partly to the exposure of the wood during excavation.

The micromorphological appearance of the wood indicates profound decay caused by bacterial attack, clearly visible at fiber level. The fiber cell wall was thinned by the digestion of the polysaccharidic structural component, mostly the cellulose. The degree of decay is between class III and IV, according to the sample (8). The reduction of the amount of cellulose is confirmed by the appearance of the wood fractures, which are neat and not fibrous as in sound wood.

The macromorphological features of the superficial layers of the sticks revealed the absence of bark. The surfaces of 12 sticks appear partially blackened. One of them (stick 49b) shows a black superficial layer, about 1 mm thick, dissected by numerous cuboid fractures typical of wood charring (Fig. S2*C*). The other sticks have a black surface layer thinner than that of the previous one (Table S1); this layer appears smoothed and, in any case, is distinctly different from the wood beneath.

To assess the nature of the blackening, some black samples from sticks 2, 3, 9, 11, 49b, and 50 were subjected to an oxidative reaction using hydrogen peroxide. This test indicated that the Poggetti Vecchi samples were charred since they remained unchanged, unlike humified wood, which decomposes and becomes lighter (9, 10) (*Supporting Information*).

Moreover, the micromorphological analysis of the black surface layer of two blackened items (sticks 9 and 49b) reveals the anatomical features of charred boxwood. The cell walls are thinner than normal and glossy and compact; the loss of the typical multiple-layered feature (composite middle lamella and secondary cell wall laminated in turn) makes them homogeneous, although the anatomical structure maintains the diagnostic characteristics for wood identification (11–15) (Fig. 3*A* and Fig. S1).

The microscopic SEM observations of the black layer also revealed the increased porosity due to pyrogenic expulsion of combustion-generated gas and wood shrinkage due to the transformation of the polysaccharide component during charring (arrows in Fig. S1).

All these points clearly indicate that some wooden tools were superficially charred.

Sample Description

The Poggetti Vecchi sticks show homogeneous characteristics. None of the large specimens is complete; nonetheless, the better preserved elements suggest the presence of a handle and a point and that the sticks ranged from around 100–120 cm in length. The sample includes four pointed tips, six handles, and 31 intermediate shafts, with the latter being some 10–114 cm long (Fig. 2, Table S1, and Movie S1). A more or less continuous charred surface of constant thickness is visible along the shafts and is absent at the worked extremities of 12 sticks. Of the four stick fragments with a pointed tip, three come from the paleosurface U 2 and one from the lacustrine level U 6. These pointed tips were broken *ab antiquo* and range from 20 to 49 cm in length. They have blunt conical extremities with a diameter of 1 cm at the tip, except the recomposed tip of items no. 3 and no. 28, which is blunted and tapered by the removal of a splinter starting from the extremity (Fig. 3*B*). Moreover, both this tip and that of no. 41 display notches probably due to use (Fig. 3*C*). Specimen no. 3+28 also reveals large portions of charred surfaces along the shaft, more than 10 cm from the tip.

Six of the sticks have a handle: Four of them were broken *ab antiquo* and are 19–91.5 cm long. The worked extremity is planoconvex in shape with rounded edges (Fig. 3*E*), with the curving of their fibers clearly visible. In all these sticks, nos. 2, 9, 17, and

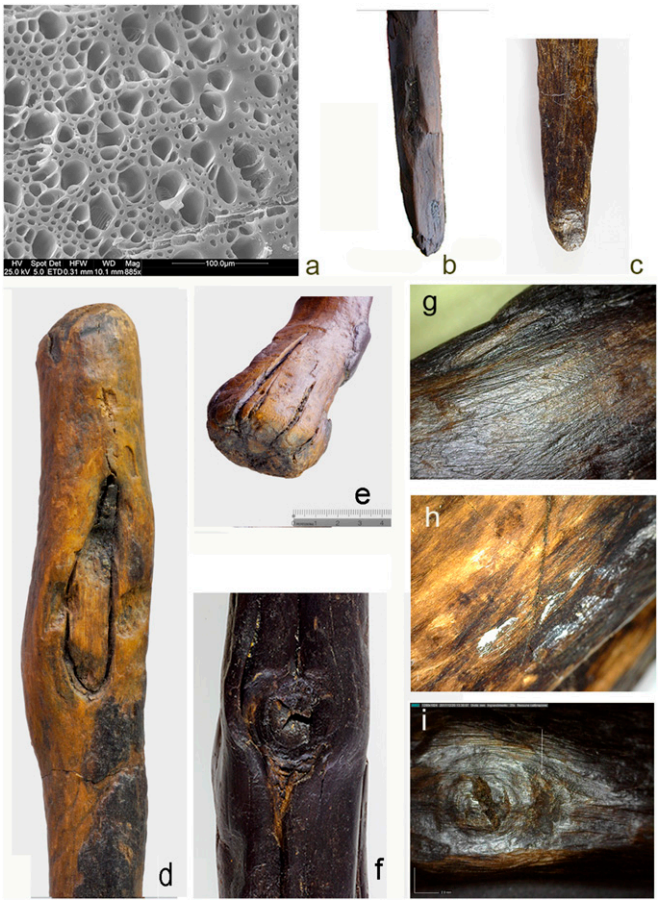

Fig. 3. (*A*) SEM image of the cross-section of the charred outer layer of one (49b) of the Poggetti Vecchi sticks made from *B. sempervirens*. The anatomical structure of boxwood is unchanged; however, with respect to fresh wood, the cell walls of its fibers and vessels are thinner, homogeneous, and compact despite the handmade fracture surface. This is the typical aspect of charred wood at SEM. (*B*) Removal of a splinter starting from the tip of point no. 3+28. (*C*) Notch on the tip of point no. 41. (*D*) Detail of handle no. 2. (*E*) Detail of handle no. 50. (*F*) Detail of flattened knot of stick no. 9. (*G*) Scratches on stick no. 14. (*H*) Cut marks on stick no. 2. (*I*) Cut marks located in the area of the knot on stick 33.

50, the wood surface is charred, although not as far as the rounded tip (Fig. 2 *A* and *C*).

Stick no. 2 is almost completely preserved (Fig. 2*A*). It was sandwiched under a phalanx of *Paleoloxodon* and stick no. 11, which lay upon its handle, and stick no. 6, which lay under it. The handle was shaped from a portion near a bifurcation with a large branch, which was stripped, leaving a hollow scar (Fig. 3*D*).

Two other artifacts, no. 18 and no. 33, have similar rounded, handle-shaped extremities but differ both in morphology and dimensions from the sticks described so far. No. 18 is complete, 35.5 cm in length and 2.5 cm in diameter, with both ends rounded and partially preserved. One of them has a 2-cm-long notch carved halfway through its diameter at the distal extremity (Fig. 2*D*). A second artifact, no. 33, is similar, but with only one of its rounded extremities preserved and with a similar notch carved into it, alongside traces of charred external layers of wood. These patterns suggest that these artifacts may have had a different function, currently not conceivable.

Some of the stick shafts are particularly long: For example, no. 26 measures 106 cm in length and no. 11 is 114 cm long (Fig. S3 *A*, *a*). The latter stick was probably complete (including the tip, which was removed by a sudden resurgence of spring water

during the excavation), measuring some 120 cm in length (Fig. S3*A*). Its handle, at its larger extremity, is not as rounded as in other sticks: A 13.5-cm-long splinter has been removed from it, and the wood surface for a length of 20 cm from the extremity, where a series of prominent knots is still preserved, is charred (Fig. S3 *A*, *b*). The rest of the shaft has been freed from its side branches, and its outer surface has been smoothed. The other wooden shaft fragments are shown in Table S1. They are 10 cm or more in length, and are similar to the other wooden tools in terms of wood, diameter, and surface modification.

The Operational Sequence

To reconstruct the operational sequence for the fabrication of the Poggetti Vecchi wooden tools, a preliminary analysis of the signs of manufacturing was carried out using low-magnification microscopy.

In the Poggetti Vecchi sample, the most evident traces are indeed those related to the process of manufacturing the sticks, particularly the removal of the bark and branches and the shaping of the tips (points and handles).

The presence of a burnt film on some of the artifacts has led us to conjecture that in addition to stone tools, fire was used in the manufacture of the sticks, as documented in ethnography and hypothesized for prehistoric spears (4, 16).

The experimental study was carried out to assess whether the use of fire was functional to the process of manufacture of the boxwood sticks featuring this morphology, and to compare the result with the archaeological sample (*Supporting Information*).

Due to their state of preservation, only a limited variety of cut marks and scratches [as defined by Nugent (17)] could be observed on the Poggetti Vecchi artifacts (Fig. 3 *G–I* and Fig. S4 *G* and *H*). Some of the scratches observed on the shafts of the sticks were probably produced while removing the outer bark: In fact, similar traces were obtained during the experimental tests (Fig. S5 *E* and *F*).

The operational sequence evidenced by the experimental study is as follows:

The first stage involved the selection of a specific type of wood: boxwood. Boxwood is indeed probably the heaviest, hardest, and stiffest wood among European timbers (Table S2).

Fresh branches of boxwood were cut directly from the plant using experimental flint tools morphotechnically comparable to the archaeological ones. This action causes severe damage to the proximal part of the branch, the part identified by archaeological observations as the handle.

The handle was shaped by cutting off the damaged proximal part of the stick; this action was performed using a heavy chipped stone (Fig. S5*A*).

The lateral ramifications of the branches were then removed using cutting flakes (Fig. S5*B*). The archeological specimens reveal that the surface of residual knots was also often flattened (Fig. 3*F*). Some of the cut knots display cut marks located in the area of the axil, as well as the negative imprint caused by ripping off the branch downward (Fig. 3*I*). The experimentation phase demonstrated that scoring the axil with a lithic flake helped to reduce the size of the portion removed when the branch was stripped off (Fig. S5*B*).

Fire was used to accelerate the boxwood manufacturing. The use of fire facilitates the removal of the burnt outer bark using thick flakes or abrasive stones (Fig. S5*C*) and flattens the smaller knots. On the archaeological samples, cut marks and scratches can be observed along the shafts (Fig. 3 *G–I*) similar to those found on the experimental stick (Fig. S5 *E* and *F*). In view of their position in areas that are not evidently functional, these signs, like the presence of charred wood on the surface, also appear to be related to the process of stripping the bark.

The pointed tip was worked on the thinner end of the stick by charring and shaping the wood using abrasive stones.

The handle was rounded by scraping the burnt edge of the stick with abrasive stones; this action also helps to bend the wood fibers from the edges toward the inner part of the handle (Fig. S5 *D* and *G*).

Direct exposure to flame appears to be the most efficient method, since the combustion process can be visually monitored, avoiding potential damage to the stick. This method of direct control of the exposure to fire prevents an excessive and inhomogeneous carbonization of the wooden support and produces a thin carbonized black film, similar to that observed on the Poggetti Vecchi remains (Fig. S4 *A–F*), visible on the surface of the burnt stick.

Discussion

To date, the best-preserved and documented Paleolithic wooden artifacts are the weapons found at Shöningen (3). Other prominent finds are the tip of a spear found about 100 y ago at Clacton-on-Sea (4) and a spear found out of stratigraphic context at Lehringen (5). Other wooden items, which have been identified as possible weapons, have been recovered from Cannstatt I, Stuttgart, Germany (18); Bilzingsleben, Germany (19); Ljubljansko Barje, Slovenia (20); and Florisbad, South Africa (21).

Fragments of wood with traces of modification (use or processing) were recorded from the Acheulean site of Kalambo Falls (22) as well as from Torralba (23).

Sharpened tips are observed in Lower and Middle Paleolithic wooden artifacts (Clacton-on-Sea, Schöningen, and Lehringen), which have thus been identified as spears or throwing weapons: Some are equipped even with two tips. The tips of the spears from Clacton-on-Sea, Schöningen, and Lehringen are off-center, a possible expedient to strengthen them. On the contrary, the tips of the Poggetti Vecchi wooden sticks are all blunt, never sharpened. Three tips have a round section, and only no. 3+28 has a planoconvex section obtained by removing a splinter.

The artifacts of Poggetti Vecchi are unique in being much shorter than wooden spears, in being made from boxwood, and in having handles that show a combination of morphological and functional traits, unknown so far. These features suggest that the artifacts of Poggetti Vecchi were used for a different purpose and not as throwing weapons.

Other fragmental Paleolithic wooden artifacts, quite more recent than those from Poggetti Vecchi, have been recovered from Border Cave (South Africa). The tools are ^{14}C-dated to 40,986–38,986 y B.P. (24). One of them, ∼18 cm long and about 1.5 cm in diameter, has been interpreted as a digging stick, based on the comparison with the ethnographic Fourie collection of Kalahari San digging sticks. It is described as having "an elongated facet almost entirely removed by a longitudinal break emanating from the tip" (ref. 24, p. 13218 and figure S17). This description perfectly fits the Poggetti Vecchi point no. 3+28 as well (Fig. 3*B*).

Much more recent, although still referable to an archeological context of Late Stone Age hunter-gatherers, are the numerous wooden implements found at Gwisho (Zambia). Five fragmentary tools have been identified as digging sticks and are morphologically similar to the Poggetti Vecchi artifacts, as well as to quite smaller ones that are still used by the local peoples (25).

All in all, the morphometric characteristics of the Poggetti Vecchi wooden tools (rounded handles, blunt points, and dimensions) recall those of the so-called digging sticks (e.g., refs. 4, 17, 26–28). These tools are commonly part of the daily life

equipment of foragers (17). Digging sticks are frequently included in Australian, African, and American ethnological collections (e.g., refs. 4, 17, 24, 25). They have a blunt point at one extremity and a roughly rounded handle at the other (only rarely are both of their extremities pointed), and are usually made from the hardest wood available in the area. The sizes vary locally; for example, digging sticks of the Australian Bindibu are around a meter long or slightly longer (99–137 cm) (ref. 29, p. 407), whereas bushmen use shorter ones (25). The same applies to the Hadza, who manufacture artifacts that are around 136 cm long and some 1 kg in weight and become 7 cm shorter at every gathering trip; the sticks are finally discarded when they measure around 77 cm (16). Digging sticks are multipurpose tools used not only for gathering plants (roots and tubers) and as a pestle but also for hunting small game, especially burrowing animals. Their possible uses, however, are multiple; for example, the Australian so-called "waddy" or "nulla nulla" have the same characteristics but are sometimes considered as hunting weapons rather than digging tools (Fig. S4*C*). Digging sticks are mostly used by women and regarded as women's personal property, in the same way as spears are regarded as men's personal property (16, 29, 30). These tools have many possible utilizations, and the wear traces detected on them are virtually impossible to associate with a specific kind of use. Use traces are even difficult to distinguish from those of fabrication (17). Use may account for the presence of notches on two pointed tips (no. 3+28 and no. 41). Precisely in view of the multifunctional character of the digging sticks and the difficulty of identifying specific use-wear traces, it is not at present possible to make hypotheses about their use at the site, even though they are certainly of anthropic and not natural input, since the U 2 paleosurface corresponds to a period of low or almost absent sedimentary supply (1).

Some of the sticks reveal a more or less continuous blackening of the surface. The analysis of some of these tools (nos. 2, 3, 9, 11, 49b, and 50) demonstrated that this blackening is due to the action of fire. The burning affects a very superficial portion of the shaft (maximum of 1 mm). The other blackened exemplars also reveal a film of similar appearance and depth, so that it can be assumed that for these artifacts too, it was due to burning.

"Because fire is a natural phenomenon, the identification of burned remains at an archaeological site is generally not considered to be, on its own, convincing evidence for human use of fire" (31).

The action of fire of natural origin on the paleosurface can be ruled out for the following reasons:

Traces of combustion are totally absent in the sediment of U 2 (1) and on faunal remains.

In some cases, the wooden artifacts with traces of combustion were in contact with other wooden artifacts and bone remains that showed no signs of fire (Fig. 1). It is impossible that a natural fire would involve only a few elements and in such a partial manner.

It can therefore be hypothesized that the wooden tools were charred elsewhere and subsequently intentionally introduced into the site by man.

The decisive elements in favor of intentional burning are as follows:

The recurrent localization of the burning along the shaft but not at the ends (tips and handles), where it has been removed in the working. The absence of burning on the tips rules out the use of the tool in the fire (e.g., as a skewer), and hence accidental burning.

The traces of working (scratches and cut marks) on the burnt surfaces (Fig. 3*G* and Fig. S4*H*), proving that the use of fire was a phase in the process of fabrication of the digging sticks.

The uniform and reduced thickness of the blackened film (Fig. S4 *A*–*F*). Only a controlled exposure to the action of the fire can produce this type of result. Experimentation has, in fact, shown that the exposure to fire of the wooden artifacts has to be constantly controlled to avoid excessive and inhomogeneous carbonization.

The use of fire and scraping was already hypothesized for obtaining the spear tips of Lehringen, and especially of Clacton-on-Sea (4, 32–34). In none of these cases, however, is there any evidence of charring. This hypothesis is grounded on ethnographic comparisons and experimental testing, as well as on the consideration that the use of fire was already known by those times (35). Studies on the changes of the mechanical properties of wood have shown that fire makes wood occasionally slightly harder but, at the same time, quite more fragile and weak (36, 37). The so-called "skewer" of Schöningen was originally indicated as a "burnt worked wooden stick" (ref. 3, p. 217), but these data are not confirmed in a recent paper (38).

The Poggetti Vecchi sticks therefore provide evidence of the use of fire for working wooden implements by an early Neanderthal population.

Ethnographic comparisons generally indicate the joint use of fire and grinding stones for fabricating digging sticks. The Australian aborigines (17, 29), the Hadza (4, 16), and Californian Indians (4) usually made digging sticks by controlled charring in a fire and then scraping. The Poggetti Vecchi boxwood sticks were likely manufactured using the same technique. Boxwood is far harder and more difficult to work than spruce wood and pinewood (which were used to make the Schöningen spears) or yew wood (which was employed for the Lehringen and Clacton-on-Sea artifacts) (Table S2). Boxwood was likely sought for deliberately because of its peculiar properties, despite the difficulty in working it, which presumably required a specific pyrotechnological knowledge. Experimental tests confirmed that fire is needed to work this type of wood, especially for manufacturing points and handles of the kinds found at Poggetti Vecchi. The working procedure is painstaking. It requires a complicated operational chain, from the selection of the particular wood to its working employing stone tools and fire, with an investment of time and effort, similar to that required by the so-called "curated technologies" (39) for making lithic implements.

Conclusions

The radiometric dating of about 171,000 y B.P. for Poggetti Vecchi's U 4 provides an *ante quem* age for the archeological assemblage from U 2. Based on this crucial chronological information, the wooden artifacts can be confidently attributed to an early Neanderthal population. The Poggetti Vecchi digging sticks are multipurpose tools, the most ancient to date, which were probably used for many hunting-gathering activities. They might have been part of the toolkit that early Neanderthals normally carried along with them, as foragers usually still do today. Because digging sticks are generally associated with gathering activities, especially with those performed by women, in recent foraging cultures, we speculate that their occurrence at the site indicates that the Poggetti Vecchi area possibly offered rich plant and animal resources, favored by the hot springs, in a period getting colder, and hence was frequented not only by the hunters but by the whole human group. Despite the difficulties met in dealing with it, boxwood was preferred to other softer woods (e.g., ash, oak) that were possibly available in the surroundings of Poggetti Vecchi, perhaps precisely for its physical and mechanical characteristics. This most suitable wooden raw material was skillfully manufactured into sticks using complex technical competences, including the use of fire. Any new evidence of the use of fire for technological purposes substantially contributes to the present debate on when humans first controlled

fire (40). Its exploitation is attested to with certainty only since the dawn of Neanderthals at the Middle–Late Pleistocene boundary (35, 38, 40, 41). Poggetti Vecchi offers the earliest evidence of pyrotechnology in the fabrication of wooden tools, providing us with significant insight into the behavior and abilities of early Neanderthals toward human modernity (42, 43). It also gives us the opportunity to improve our understanding of the patterns of resource exploitation strategy suggested by wooden and lithic assemblages, considering that the latter are normally "overestimated" in the material culture and social organization of Paleolithic hunter-gatherers (44).

Methods

The methods used for this study are reported in the literature. In particular, to assess the presence of a charred surface, samples from the black surface layers of some sticks were subjected to an oxidative chemical test specifically developed from what is available in literature (9, 10). Moreover, SEM analysis was also performed. The charred wood and fresh wood of a modern stick were observed using the same equipment (SEM FEI Quanta 200) and the same magnifications already used for the previous observations on archaeological specimens, and then compared with these previous observations. Details are provided in *Supporting Information*.

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