ACTA IMEKO
ISSN: 2221-870X
December 2023, Volume 12, Number 4, 1 - 7

Analysis of the ivory remains from the Etruscan tumulus of Carmignano (Central Italy) using 3D digital microscopy

Jacopo Crezzini[1], Massimo Tarantini[2], Maria Chiara Bettini[3]

[1] *Università di Siena - Dipartimento di Scienze Fisiche della Terra e dell'Ambiente - U.R. Ecologia Preistorica - Strada Laterina 8, 53100 Siena, Italy*
[2] *MiC - Soprintendenza archeologia, belle arti e paesaggio - Piazza Pitti 1, 50125 Firenze, Italy*
[3] *Museo Archeologico di Artimino 'F. Nicosia' - Piazza S. Carlo 3, 50015 (Carmignano, PO), Italy*

ABSTRACT
The Tumulus of Montefortini is an Etruscan tomb located in Carmignano (Central Italy), which is believed to date from the 7th century BC. The tumulus is an oval burial mound 80 metres long and 11 metres high, which houses two tombs. More than 10,000 ivory fragments, that were likely part of a rich grave good, were recovered from this site. The main raw material exploited was probably the proboscidean dentine given the presence of the "Schreger lines" on the surfaces of many specimens. In this work we analyzed a sample of this archaeological assemblage using a 3D digital microscope. This noninvasive procedure allowed to investigate the main micromorphological and micromorphometrical features of the proboscidean dentine in a relatively brief time, preserving the integrity of the archaeological finds. Unexpected results regarding to the Schreger structure were obtained from this analysis. Data collected in the present work will be useful to evaluate, through further analysis of the examined sample, the accuracy and reliability of the 3D digital microscopy in the characterization of the proboscidean taxa exploited in the past.

Section: RESEARCH PAPER

Keywords: Proboscidean dentine; Schreger lines; 3D digital microscope; ivory; Etruscan tumulus

Citation: Jacopo Crezzini, Massimo Tarantini, Maria Chiara Bettini, Analysis of the ivory remains from the Etruscan tumulus of Carmignano (Central Italy) using 3D digital microscopy, Acta IMEKO, vol. 12, no. 4, article 21, December 2023, identifier: IMEKO-ACTA-12 (2023)-04-21

Section Editor: Michela Ricca, University of Calabria, Italy

Received April 21, 2023; **In final form** July 3, 2023; **Published** December 2023

Funding: This work was supported by MiC - Soprintendenza archeologia, belle arti e paesaggio - Piazza Pitti 1, 50125 Firenze, Italy and the Federal Office of Culture of the Swiss Confederation (Project FH2106)

Corresponding author: Jacopo Crezzini, e-mail: jacopocrezzini@gmail.com

1. INTRODUCTION

Proboscidean dentine was often exploited by humans in the past to produce artifacts. The physical characteristics of this material related to its composition, mostly made up of collagen fibres that provide elasticity and reinforce the rigid inorganic matrix composed by carbonated hydroxyapatite, makes this substance an ideal medium for carving and sculpting [1]-[2]. Despite this, the study of ivory remains in archaeology represents a challenge for the archaeologists due to the value of these remains and to the fundamental need of non-destructive investigation techniques to preserve the integrity of the archaeological finds.

The ivory worked by ancient populations can have different origins. The canines of hippopotamus, walrus, and boar and the incisors of elephants and their extinct relatives are the most widely exploited teeth in the human past. The identification of elephant ivory can be made visually by unaided eye if it is not heavily carved through the detection of a "chequered pattern". This peculiar structure, called more commonly "Schreger pattern", is present on the transversal cross-section of tusks of several proboscideans and results from corrugation of the sinusoid dentinal tubules [3]. When these tubules intercept the cut-surface on the transversal section, the interception point sequences forms two different sets of lines that curve clockwise and counter-clockwise [4]. The Schreger structure is an autapomorphic feature of the clade *Elephantoidea*. African (*Loxodonta* spp.) and Asian (*Elephas maximus*) elephants, along with their extinct relatives (e.g., mammoths, *Mammuthus* spp.) belong to this clade (order *Proboscidea*). The only presence of Schreger structure makes it possible to identify the proboscidean ivory but it doesn't allow to distinguish the exploited species.

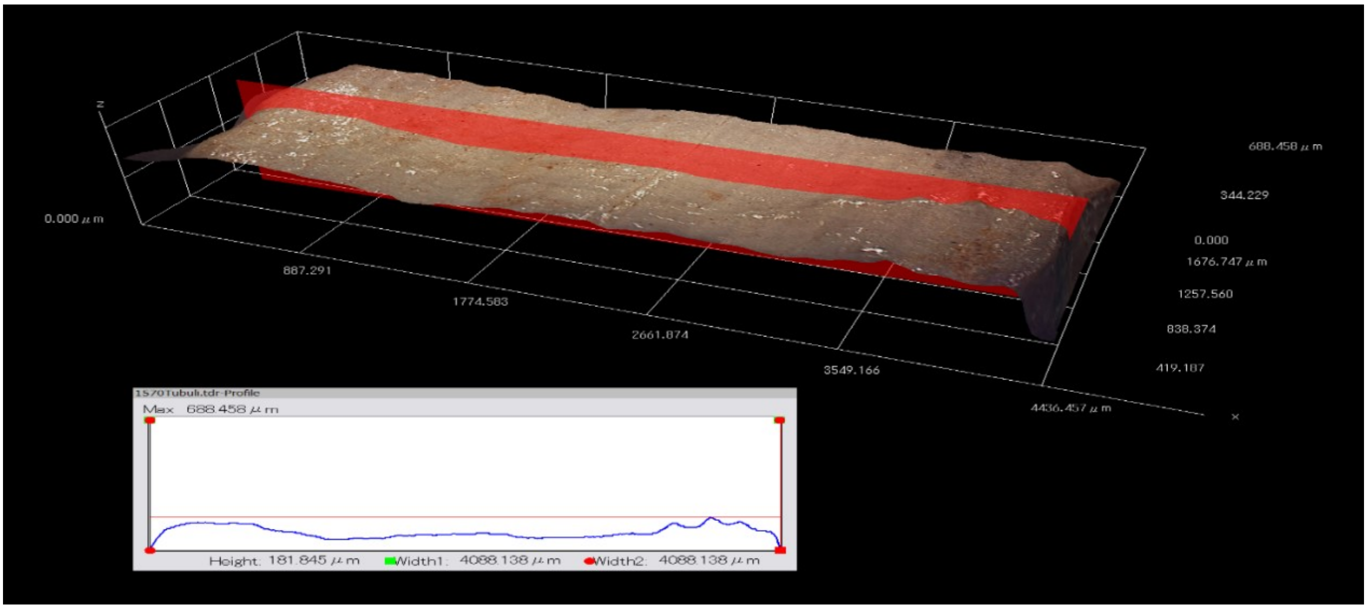

Figure 1. Evaluation of the development of the dentine surface on a 3D high resolution image.

In 1952, Penniman [5] was the first to recognize a difference in the Schreger pattern between mammoths and elephants, observing the disposition of the Schreger lines. The crossing of these lines in fact forms several minute diamond-shaped parts with "outer" and "inner" angles open toward the distal and the proximal regions of the tusk. They are called Schreger angles [6] and Espinoza and Mann [7]-[8], though not addressing conservation questions, used their different values, to differentiate between present-day African and Asian elephants, and extinct *Proboscidea* (mammoths).

In addition to the angles, Trapani and Fisher [9] consider two other features of the Schreger pattern to separate between different *taxa*: the qualitative appearance of their pattern ("X", "V" or "C") and the "wavelength" of dentinal tubules; they test the power of these features to discriminate mammoths from mastodons, "fossil" (*Mammuthus* spp.) from "modern" (*Elephas* and *Loxodonta*) dentin, and the two extant proboscidean genera from one another. This exam was carried out on a transverse thin section oriented perpendicular to incremental growth laminae and extending from the tusk axis to the outer zone (cementum). Trapani and Fisher [9] attested that the characterization of the Schreger pattern can represent a useful tool for discriminating proboscidean *taxa*, but this is complicated by spatial variation in the pattern that occurred in different zones of the tusk. For this reason, the identification of isolated, whole tusks, where the location of thin-section is known, is relatively easy, but it can be represent a challenge for tusk fragments and worked artifacts.

Trapani and Fisher [9] demonstrated that assessing of multiple features of the Schreger structure, especially at multiple locations on a single specimen, can help to avoid this bias. Moreover, the authors indicated that multivariate consideration of Schreger pattern features (when it is possible) provides an effective tool for discriminating between ivory from different proboscidean species even without tusk location information; in particular, the correct assignment of a specimen to its *taxon* was possible in 73 % – 93 % of cases [9].

In the last decades some scholars have used chemometric methods as trace element analysis [10]-[11] and non-destructive Raman spectroscopy [12]-[16] to distinguish tusks and artifacts of *Loxodonta*, *Elephas*, and *Mammuthus* from each other.

In this work we reconsider the diagnostic value of the Schreger's pattern by investigating with a 3D digital microscope an ivory sample from an archaeological context.

Micromorphological and micromorphometrical observations were carried out on a preliminary sub-sample to evaluate the power of this non-destructive technique in the investigation of the proboscidean dentine.

2. MATERIAL AND METHODS

The material analysed in this work, as a part of a restoration project, is represented by 1752 ivory remains (no larger than 5 cm) forming part of a large sample constituted by more of 10,000 fragments coming from the Etruscan tumulus of Montefortini (Carmignano, Central Italy) [17].

It is a mound erected around the middle of the 7th century BC. It is a monumental building: 70 meters in diameter by at least 15 meters in height. Entirely artificial, it proves the importance of the two dead here buried a decade or two apart in two different burial chambers [18]. Not by chance, scholars speak of "princely figures" [19]. At a time when Etruscan was actively involved in Mediterranean trade ("Orientalizzante" period), these "princes" were able to acquire extraordinary wealth. The high quality and quantity of carved ivories in high and low relief, but also engraved and fretwork among the grave goods of the older of the two tombs, the high quality and quantity of carved ivories in high and low relief, but also engraved and fretwork, is truly remarkable [18].

The Schreger lines on these ivories were identified by unaided eye on a good amount of remains. Despite this, some fragments were excluded from analysis due to the presence of concretion on the surfaces or to the lack of "plane" cross-sections. The presence of microscopic irregularities in fact, due for example to concretions or to the roughness of surface, can cause the recording of micromorphological and micromorphometrical features different to those actually formed by the Schreger structure.

The exam of 3D high resolution images carried out in this work allows the exact evaluation of the development of the dentine and to consider only the Schreger structures located on a plane surface (Figure 1).

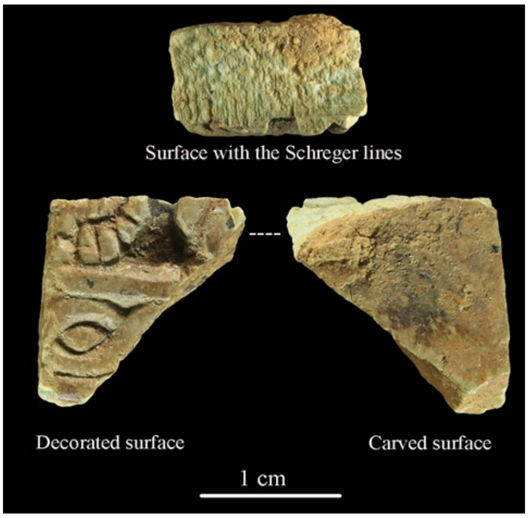

Figure 4. An example of the archaeological specimens considered in this study (Ph. Stefano Ricci).

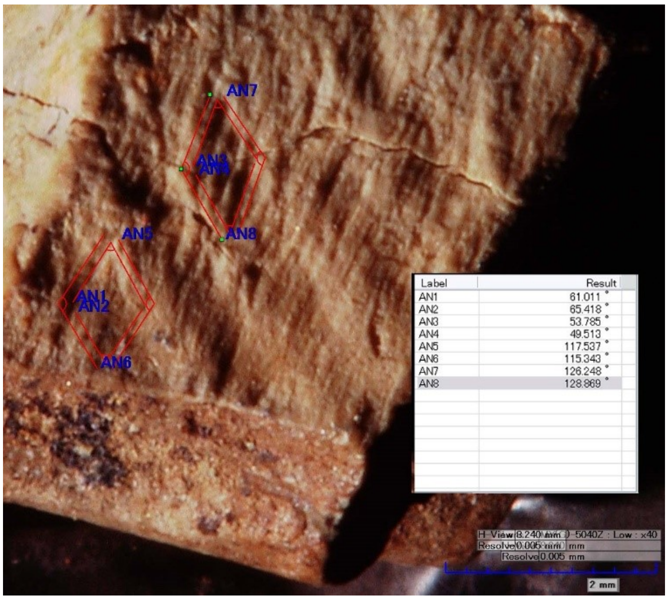

Figure 2. Values of the Schreger angles recorded close to the cementum dentine junction.

Therefore, we considered the observation of the Schreger structure in only 35 specimens. Moreover, the analysis comprised only the fragments in which at least one carved and/or decorated surface was still visible, in order to exploit the presence of these surfaces as reference for the orientation of the examined remains (Figure 4) [17].

The images were captured using a Hirox KH-7700 digital micro-scope equipped with an MXG-10C body, an OL-140II lens and an AD-10S Directional Lighting Adapter. The Schreger angles were examined to 100 magnifications, while for the exam of dentinal tubules a 140 magnification was necessary [17]. The Auto Multi Focus tool enables the creation of a series of images from different planes (up to 120) and, through the overlapping of focus levels, to construct a 3D composite image [20], [21].

This procedure allows us to examine in detail the Schreger pattern, and, where possible, we consider its main parameters: the values of the angle of intersection of Schreger lines, the qualitative appearance of their pattern and the "wavelength" of dentinal tubules [9].

Unlike other protocols used for this purpose, the method proposed in this work is characterized by a non-invasive investigation of the samples. The scan of the ivory surfaces and the collection of the micro-measures were performed in a relatively brief time and without any preparation or modification (etching, staining, preparation of thin sections [4]) of the samples.

3. RESULTS

Figure 3 and Table 1 show the values of the Schreger angles identified in the examined sample ($n = 19$). All the four angles of every observed rhomboid shape were collected (Figure 2) [17]. It is possible to observe two main clusters of data: one including values higher

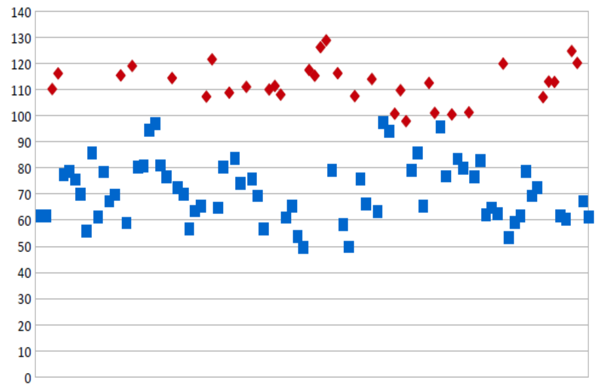

Figure 3. The distribution of angle values recorded on 19 samples (see also Table 1): the angles open toward the decorated or carving surfaces are indicate with blue squared.

Table 1. Values the Schreger angles recorded on 19 ivory fragments.

Samples and Angles	Angles open towards the carved and/or the decorated surfaces	Angles not open towards the carved and/or the decorated surfaces	Samples and Angles	Angles open towards the carved and/or the decorated surfaces	Angles not open towards the carved and/or the decorated surfaces	Samples and Angles	Angles open towards the carved and/or the decorated surfaces	Angles not open towards the carved and/or the decorated surfaces
Sample50AN1	61.79		Sample463AN1	80.3		Sample646AN5		97.93
Sample50AN2	61.59		Sample463AN2		108.81	Sample771aAN1	79.12	
Sample50AN3		110.24	Sample463AN3	83.61		Sample771aAN2	85.8	
Sample50AN4		116.2	Sample463AN4	74.14		Sample771aAN3	65.36	
Sample133AN1	77.37		Sample463AN5		111.08	Sample771aAN4		112.58
Sample133AN2	78.64		Sample463AN6	75.93		Sample771aAN5		101.11
Sample256AN1	75.56		Sample484AN1	69.29		Sample771bAN1	95.83	
Sample256AN2	69.85		Sample484AN2	56.56		Sample772AN1	76.82	
Sample256AN3	55.78		Sample484AN3		110.07	Sample772AN2		100.5
Sample256AN4	85.8		Sample484AN4		111.47	Sample772AN3	83.5	
Sample256AN5	61.23		Sample484AN5		108.07	Sample795AN1	80.07	
Sample256AN6	78.45		Sample505AN1	61.01		Sample795AN2		101.28
Sample340AN1	67.24		Sample505AN2	65.42		Sample795AN3	76.5	
Sample340AN2	69.85		Sample505AN3	53.78		Sample795AN4	82.92	
Sample340AN3		115.48	Sample505AN4	49.51		Sample1504AN1	62.2	
Sample340AN4	59		Sample505AN5		117.54	Sample1504AN2	64.78	
Sample340AN5		119,06	Sample505AN6		115.34	Sample1504AN3	62.58	
Sample340AN6	80,3		Sample505AN7		126.25	Sample1504AN4		119.94
Sample378AN1	80,89		Sample505AN8		128.87	Sample1513AN1	53.4	
Sample378AN2	94.42		Sample556AN1	79.27		Sample1513AN2	59.13	
Sample378AN3	96.84		Sample556AN2		116.3	Sample1513AN3	61.65	
Sample384AN1	81.05		Sample556AN3	58.4		Sample1562AN1	78.67	
Sample384AN2	76.6		Sample556AN4	49.8		Sample1562AN2	69.3	
Sample384AN3		114.47	Sample556AN5		107.54	Sample1562AN3	72.45	
Sample384AN4	72.5		Sample556AN6	75.8		Sample1562AN4		107.15
Sample455AN1	70.1		Sample556AN7	66.3		Sample1562AN5		113.11
Sample455AN2	56.8		Sample556AN8		114.07	Sample1562AN6		112.96
Sample455AN3	63.6		Sample556AN9	63.2		Sample1620AN1	61.56	
Sample455AN4	65.3		Sample646AN1	97.47		Sample1620AN2	60.25	
Sample455AN5		107.3	Sample646AN2	94.07		Sample1620AN3		124.77
Sample455AN6		121.6	Sample646AN3		100,81	Sample1620AN4		120.2
Sample455AN7	64.7		Sample646AN4		109.8	Sample1620AN5	67.26	

than 90 ° and another one characterized by values smaller than 90 ° (Figure 3 and Table 1). It was noted that the acute angles (together with five angles with value comprised between 90°-100°) open towards the carved and/or the decorated surfaces (Figure 2). Considering that these latter probably interested the tangential surfaces of the tusk [22]-[23], the orientation of the acute angles indicates that them could be considered as the Schreger angles useful to differentiate taxonomic groups of *Proboscidean* (the "outer" and the "inner" angles) [6].

This hypothesis seems to be confirmed by the analysis of two remains where a thin layer of cementum is still conserved: among the angles measured in the rhomboid shapes identified, the acute angles open towards the cementum, the outer layer of the tusk (Figure 2). The identification of the cementum-dentin junction (CDJ, [9]) allows to better define the orientation of the fragment and its location on the tusk from which it came from. So, it's possible to avoid mistakes in the consideration of the morphometrical values of the Schreger pattern which are subject to variations in different zones of the tusk [9].

In Figure 5 the wavelength of dentinal tubules measured in the Montefortini samples are reported. The values are comprised between 958.72 and 1,695 µm. A portion of cementum was detected on one of the remains in which the wavelength of the tubules was 1,154 µm (Figure 6).

In three single cases the evaluation of multiple features of the Schreger pattern on a single fragment was possible: the values of the Schreger angles and of the wavelength of the tubules, located in two contiguous surfaces of the remains (the transverse profile and the radial profile of the tusk respectively), were measured (Figure 5: a = wavelength of tubules = 1,158.5 µm, Schreger angle = 69.2°; b = wavelength of tubules = 1,250.8 µm, Schreger angle = 64.7°; c = wavelength of tubules = 1696.5 µm, Schreger angle = 65.4°). The combination of these two morphometrical data can provide other significant information regarding both location on the tusk from which the remains came from, and the *taxon* exploited for the ivory procurement [4], [9].

Finally, in two specimens we identified the presence of the "V pattern" in the Schreger structure (Figure 7) with the values of the Schreger angles no larger than 90°.

4. DISCUSSION AND CONCLUSIONS

This preliminary work encourages us to develop the analysis of ivory specimens coming from Prehistoric and Protohistoric contexts through the 3D digital microscopy. Indeed, through this procedure all the microstructures of the Schreger pattern, together with the state of conservation of the investigated micro surfaces, can be identified in a relatively brief time and without invasive or destructive treatments of the samples. Despite these results the validation of our approach as non-invasive protocol useful for the discrimination of *Proboscidae taxa* in archaeological samples needs further analyses. Micromorphological and micromorphometrical data relating to Schreger structures achieved in the Montefortini remains seems to be compatible with the mammoth (*M. primigenius, M. meridionalis, M. trogontheri*) and *Anancus arvensis* dentine [4]-[9] (Figure 3, Figure 2, Figure 5, Figure 6, Figure 7 and Table 1).

Espinoza and Mann [8] showed that mean Schreger angle value is above 100 degrees in the extant elephants while the extinct proboscideans have an angle average below 100 degrees. In particular, Schreger angle of mammoth was reported to be 73.21 ± 14.71 and of African ivory was 124.15 ± 13.35. Similarly, the Schrenger outer angles values are lower than 85° for *Anancus arvensis* and less than 90° for *Mammuthus lamarmorai* [6], [24].

Moreover, Espinoza and Mann [7] specify that since specimens from both extinct and extant sources may present angles between 90 degrees and 115 degrees in the outer Schreger pattern area, the differentiation of mammoth from *Loxodonta africana* and *Elephas maximum* should never be based upon single angle measurements when the angles fall in this range. In this same interval also fall the variability range of Schrenger outer angles for *Palaeoloxodon antiquus* and *Elephas falconeri* [6].

However, the Schreger angles measured in the ivory fragments of Montefortini are mainly represented by acute angles.

The wavelength of dentinal tubules in the Montefortini samples are comprised between 958.72 and 1,695 µm (Figure 5). Mammoths typically have wavelengths of 1 mm or greater [9]. But if the wavelength of the tubules is not considerable a good *proxy* to the discerning of proboscidean *taxa* [9], to assess

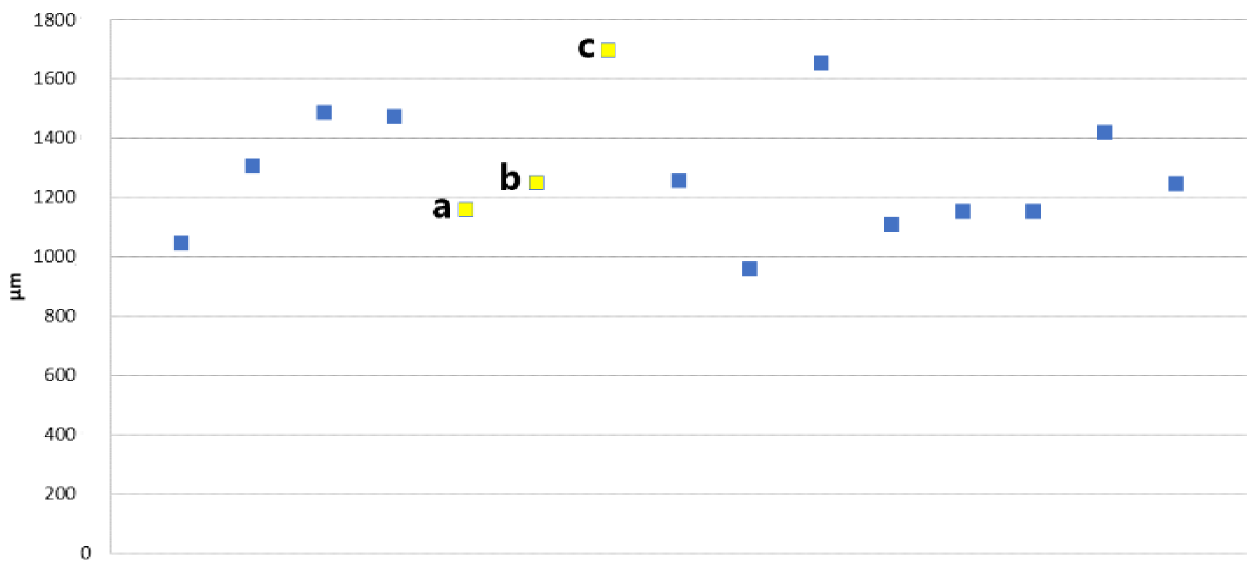

Figure 5. Values of wavelength of tubules recorded on the remains of Montefortini (the yellow square indicate the specimens in which the values of the Schreger angles and of the wavelength of the tubules were recorded, see the text).

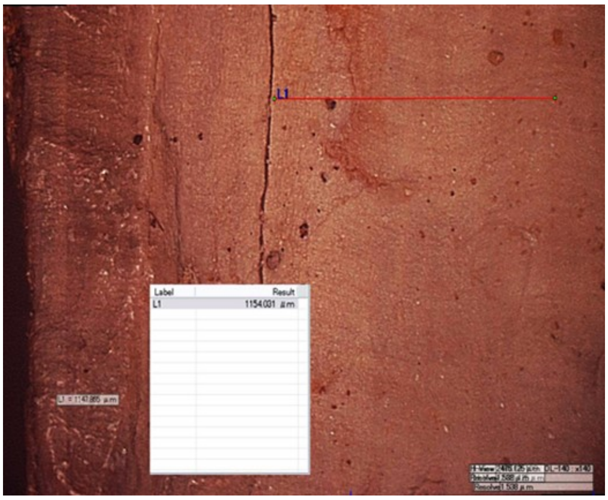

Figure 6. Wavelength of the tubules in proximity of the cementum.

Figure 7. The "V" pattern of Schreger structure recorded on a remain from Montefortini.

multiple features of the pattern (and more in general of the dentine), especially at multiple locations on a single specimen, can help this exam, even in cases where location on the tusk is unknown [9].

In mammoth the wavelength greatly increases at low Schreger angle and near the tusk axis [4], [9]. The wavelengths reach maximum values (about 2,175 µm) at lower Schreger angles (near the pulp cavity). The length decreases (about 1,100 µm) towards the tusk surface and thereby towards higher values of Schreger angles [4]. In the three specimens of Montefortini's sample where the evaluation of multiple features of the Schreger pattern was possible, the relation between the wavelength of the tubules and the angles is compatible with these data, and it can suggest the possible provenance of the fragments from a mammoth tusk region located at 1-2 cm from the surface [4]. Moreover, the value of the wavelength (1,154 µm) measured on the single remain where a portion of cementum was detected is analogous to the value indicated by Abelova for the microtubules located near the surface of a mammoth tusk [4].

Regarding to the qualitative appearance of the Schreger pattern, *Elephas* lacks the "V" pattern common near the tusk axis in *Mammuthus* [9], [24]. The structure of this qualitative pattern depends mainly on its associated Schreger angles and in *Mammuthus* it occurs at low angle values in the vicinity of the pulp cavity and again at angle values between 25–90 degrees [4]. Among the Montefortini remains the "V" pattern was observed on two specimens and the values of their associated Schreger angles were comprise between 68-75 degrees (Figure 7).

Data illustrated above can represent an 'unexpected' result in the identification of the ivory exploited at Montefortini. This considering two fundamental aspects related to its origin from diverse proboscidean species:

-The availability of this material and the ease/difficulty with which it could be recovered by the Etruscans

-The physical characteristics that makes this substance an ideal medium for carving and sculpting

Regarding to the first point several species of extinct proboscideans are widely documented in Pleistocene deposits in Italy [25] and nearby regions. Among these, *taxa* characterized by micromorphological and micromorphometrical data of the Schreger structures compatible with those recorded in the Montefortini samples are comprise (e.g. *Mammuthus primigenius, Anancus arvensis, Mammuthus lamarmorai).* Remains of *Elephas* (*Palaeoloxodon) antiquus* and *Mammuthus primigenius* are attested in Italy from the northern province of Ferrara [26] to as far south as Apulia [27] including Tuscany [25], and along the Mediterranean coast from Marseilles to Liguria [28]-[29]. Additionally, the "dwarf mammoth" (*Mammuthus lamarmorai*) population are attested in Sardinia [24], where the Etruscan presence is well documented. The Etruscans probably could recover ivory from these Italian Pleistocene proboscidean species though mining, construction, and agricultural activities as well as by natural geological processes like alluvial deposition and erosion of riverbeds. Natural deposits, whether exploited directly by Etruscans or included in trade networks with neighbours such as Gaul, should be considered as sources of ivory in Etruscan contexts. Despite this we don't believe that for the Etruscan people this "fossilized" ivory could represent a useful raw material to produce artefacts. The fossilization can have altered the physical characteristics of this material that makes it an ideal medium for carving and sculpting. We refer here mainly to its composition, mostly made up of collagen fibres that give elasticity and reinforce the rigid inorganic matrix composed by carbonated hydroxyapatite. We have not found any documentation regarding to ivory remains referable to *Palaeoloxodon antiquus*, *Anancus arvensis*, *Mammuthus primigenius* and the "dwarf mammoth" (*Mammuthus lamarmorai*) from Italian and Middle European Pleistocene contexts exploited in experimental works or in historical and present-day manufacturing. These observations seem to confirm our hypothesis regarding this "fossilized" ivory not being an ideal medium to be exploited by the Etruscan for carving and sculpting activities.

On the contrary the mammoth ivory preserved in permafrost in the North-eastern Europe may have not suffered of these modifications thanks to the highly conservative conditions related to its peculiar deposition. Still today, the use of mammoth ivory recovered from the permafrost is widespread both in experimental works and in artisans' activities (sometimes encouraged by policy to contrast/limit the illegal market of ivory from *Elephas maximum* and *Loxodonta africana*). The people who process this material evidence how, once the tusks are dragged out from the permafrost, their elasticity and the other physical characteristics are like those of the present-day elephants' tusks [22].

Despite this, although in the Etruscan contexts the presence of raw materials and objects from north-eastern Europe is attested [30] - amber is also found in a mound contemporary and near that of Montefortini [31] - we must consider also the "easier" access that the Etruscan people could had to the ivory derived from the extant elephants thank to the intensive trades carried out by this people with the Asian and African populations [32]-[33]. This brings us to consider seriously at least two possibilities:

1) The possibly biases that can occur in the recording of the micromorphological and micromorphometrical characteristics of Schreger pattern on tusk fragments and worked artifacts where the location and the orientation of the observed surface is unknown.

2) The possibly overlapping between the Schreger pattern from the extant elephants and *Mammuthus* recorded in specific zones of their tusks.

With regard to this latter possibility Singh et al. [34] investigated all angle values of various ivory samples of extant elephant from three different zones of the tusk (namely central, middle, and outer). They showed that the middle and inner angle mean values were found to overlap in *Loxodonta africana* and *Elephas maximum* with values comprised between 65 and 90 degrees [34]. The comparison of these data with the values of Schreger angles measured in the Montefortini sample support an alternative hypothesis regarding the origin of the raw material exploited by the Etruscan people: it could be ivory of African or Asian elephants, in particular, the middle and/or the inner parts of their tusks (although this contrasts with the acute angles recorded near the cementum in two of our sample).

Beside a widening of our analysis to a larger sample from Montefortini, further analyses of the examined sample (i.e., paleogenetic, chemical characterizations of the dentine, radiometric data) are also necessary to evaluate the power of the 3D digital microscopy in the characterization of the proboscidean *taxa* exploited for the ivory in the past.

REFERENCES

[1] H. G. M. Edwards, N. F. N. Hassan, N. Arya, Evaluation of Raman spectroscopy and application of chemometric methods for the differentiation of contemporary ivory specimens I: Elephant and mammalian species, Journal of Raman Spectroscopy 37 (1–3) (2006), pp. 353–360.
DOI: 10.1002/jrs.1458

[2] C. Heckel, Physical characteristics of mammoth ivory and their implications for ivory work in the Upper Paleolithic, Mitteilungen der Gesellschaft für Urgeschichte 18 (2009), pp. 71–91.

[3] E. J. Raubenheimer, M. C. Bosman, R. Vorster, C. E. Noffke, Histogenesis of the chequered pattern of ivory of the African elephant (Loxodonta africana), Archives of Oral Biology 43 (1998), pp. 969–977.
DOI: 10.1016/S0003-9969(98)00077-6

[4] M. Abelova, Schreger pattern angles of Mammuthus primigenius tusk: analytical approach and utility, Bulletin of Geosciences 83 (2) (2008), pp. 225-232.
DOI: 10.3140/bull.geosci.2008.02.225

[5] T. K. Penniman, Pictures of ivory and other animal teeth, bone, and antler, Pitt Rivers Museum Occasional Papers on Technology 5 (1952), pp. 1–37.
DOI: 10.1017/S0002731600016486

[6] M. R. Palombo, P. Villa, Schreger lines as support in the Elephantinae identification, Proc. of the 1st Int. Congress, Consiglio Nazionale delle Ricerche, Rome, Italy 2001, pp. 656–660. Online [Accessed 17 November 2023]
https://sovraintendenzaroma.it/sites/default/files/storage/original/application/cd28ed2d1bd0faf55902386b4eb85096.pdf

[7] E. O. Espinoza, M. J. Mann, Identification guide for ivory and ivory substitutes, World Wildlife Fund and The Conservation Foundation. Baltimore, MD, 1991.

[8] E. O. Espinoza, M. J. Mann, Identification Guide for Ivory and Ivory Substitutes, second ed., World Wildlife Funds and Conservation Foundation, 1992.

[9] J. Trapani, D. C. Fisher, Discriminating proboscidean taxa using features of the Schreger pattern in tusk dentin, Journal of Archaeological Science, 30 (2003), pp. 429-438.
DOI: 10.1006/jasc.2002.0852

[10] V. M Prozesky, E. J. Raubenheimer, W. F. P.Van Heerden, W. P. Grotepass, W. J. Przybylowicz, C. A. Pineda, R. Swart, Trace element concentration and distribution in ivory. Nuclear Instruments and Methods in Physics Research B 104, (1995), pp. 638–644.
DOI: 10.1016/0168-583X(95)00471-8

[11] M. Shimoyama, T. Nakanishi, Y. Hamanaga, T. Ninomiya, Y. Ozaki, Non-destructive discrimination between elephant ivory products and mammoth tusk products by glancing incidence X-ray fluorescence spectroscopy, Journal of Trace and Microprobe Techniques 16 (1998), pp. 175–182.

[12] H. G. M. Edwards, D. W. Farwell, Ivory and simulated ivory artefacts: Fourier transform Raman diagnostic study, Spectrochimica Acta Part A 51 (1995), pp. 2073–2081.
DOI: 10.1016/0584-8539(95)01455-3

[13] H. G. M. Edwards, D. W. Farwell, J. M. Holder, E. E. Lawson, Fourier-transform Raman spectroscopy of ivory: II. Spectroscopic analysis and assignments, Journal of Molecular Structure 435 (1997), pp. 49–58.
DOI: 10.1016/S0022-2860(97)00122-1

[14] H. G. M. Edwards, D. W. Farwell, J. M. Holder, E. E. Lawson, Fourier-transform Raman spectroscopy of ivory: III. Identification of mammalian specimens, Spectrochimica Acta Part A 53 (1997), pp. 2403–2409.
DOI: 10.1016/S1386-1425(97)00180-7

[15] H. G. M. Edwards, D. W. Farwell, J. M. Holder, E. E. Lawson, Fourier transform Raman spectroscopy of ivory: a non-destructive diagnostic technique, Studies in Conservation 43 (1998), pp. 9–16. Online [Accessed 25 August 2023]
https://www.jstor.org/stable/pdf/1506632.pdf

[16] M. Shimoyama, H. Maeda, H. Sato, T. Ninomiya, Y. Ozaki, Nondestructive discrimination of biological materials by near-infrared Fourier transform Raman spectroscopy and chemometrics: discrimination among hard and soft ivories of African elephants and mammoth tusks and prediction of specific gravity of the ivories, Applied Spectroscopy 51(8) (1997), pp. 1154–1158.
DOI: 10.1366/0003702971941674

[17] J. Crezzini, M. Tarantini, M. C. Bettini, Ivory identification in the archaeological contexts. A case study using the 3D digital microscopy, Proc. of the IMEKO TC-4 Int. Conf. on Metrology for Archaeology and Cultural Heritage University of Calabria, Italy, 19-21 October 2022.
DOI: 10.21014/tc4-ARC-2022.012

[18] M. C. Bettini, F. Nicosia, G. Poggesi, CR15. Comeana. Tumulo di Montefortini, in: Carta archeologica della provincia di Prato dalla preistoria alla fine dell'età romana, Firenze 2011, All'Insegna del Giglio ed., pp. 349-361. [In Italian]

[19] Principi etruschi tra Mediterraneo ed Europa - Etruscan princes between the Mediterranean and Europe, Catalogo della mostra, 2000, Venezia. [In Italian]

[20] F. Boschin, J. Crezzini, Morphometrical analysis on cut Marks using a 3D digital microscope, International Journal of Osteoarchaeology 22 (2012), pp. 549-562.
DOI: 10.1002/oa.1272

[21] J. Crezzini, F. Boschin, P. Boscato, U. Wierer, Wild cats and cut marks: Exploitation of Felis silvestris in the Mesolithic of Galgenbühel/Dos de la Forca (South Tyrol, Italy), Quaternary International 330 (2014), pp. 52-60.
DOI: 10.1016/j.quaint.2013.12.056

[22] E. Gyria, G. A. Khlopachev, Experimental data on the splitting and knapping of mammoth tusks and reindeer antlers, in: À coup d'éclats ! La fracturation des matières osseuses en Préhistoire discussion autour d'une modalité d'exploitation en apparence simple et pourtant mal connue, M. Christensen, N. Goutas (eds.), Société préhistorique française (Séances, 13), 2018, Paris, pp. 325–340. Online [Accessed 17 November 2023] https://www.prehistoire.org/offres/file_inline_src/515/515_P_46139_5c45ac66651b9_23.pdf
[23] G. A. Khlopatchev, Mammoth tusk processing using the knapping technique in the Upper Paleolithic of the Central Russian Plain, Proc. of the 1st International Congress. Consiglio Nazionale delle Ricerche, Rome, Italy, 2001, pp. 444–447.
DOI: 10.1016/c2009-0-21817-4
[24] M. R. Palombo, M. P. Ferretti, G. L. Pillola, L. Chiappini, A reappraisal of the dwarfed mammoth Mammuthus lamarmorai (Major, 1883) from Gonnesa (south-western Sardinia, Italy), Quaternary International 255 (2012), pp. 158-170.
DOI: 10.1016/j.quaint.2011.05.037
[25] M. R. Palombo, M. P. Ferretti, Elephant fossil record from Italy: knowledge, problems, and perspectives, Quaternary International 126–128 (2005), pp. 107-136.
DOI: 10.1016/j.quaint.2004.04.018
[26] V. Gallini, B. Sala, Settepolesini di Bondeno (Ferrara–Eastern Po Valley): the first example of mammoth steppe, in: Italy, The World of Elephants. Proc. of the First International Congress (2001), pp. 272-275.
[27] M. Rustioni, M. P. Ferretti, P. Mazza, M. Pavia, A. Varola, The vertebrate fauna from Cardamone (Apulia, southern Italy): an example of Mediterranean mammoth fauna, Deinsea 9(1) (2003), pp. 395-404.
[28] A. Moussous, P. Valensi, P. Simon, Identification de l'ivoire de Proboscidiens des grottes des Balzi Rossi (Ligurie, Italie) à partir de la méthode des lignes de Schreger, Bulletin Musée Anthropologie préhistoire Monaco 54 (2014), pp. 83-90. [In French]
[29] G. Onoratini, A. Arellano, A. Del Lucchese, P. E Moullé, F. Serre, The Barma Grande cave (Grimaldi, Vintimiglia, Italy): From Neandertal, hunter of "Elephas antiquus", to Sapiens with ornaments of mammoth ivory, Quaternary International 255 (2012), pp. 141-157.
DOI: 10.1016/j.quaint.2011.05.015
[30] S. Massini, M. L. Arancio, Ambra, dalle rive del Baltico all'Etruria - Amber, from the Baltic shores to Etruria, Roma 2012, Gangemi Ed. ISBN: 9788849275353. [In Italian]
[31] M. C. Bettini, F. Nicosia, CR14. Comeana. Tumulo dei Boschetti, Firenze 2011 All'Insegna del Giglio ed., pp. 343-347. [In Italian]
[32] C. Posth, V. Zaro, M. A. Spyrou, S. Vai, + another 34 authors, The origin and legacy of the Etruscans through a 2000-year archeogenomic time transect, Sci Adv. 7(39) (2021).
Doi: 10.1126/sciadv.abi7673
[33] G. Colonna, La cultura Orientalizzante in Etruria - The Orientalising Culture in Etruria, in: Principi etruschi tra Mediterraneo ed Europa, Catalogo della mostra, 2000, Venezia, pp. 55-65. [In Italian].
[34] R. R. Singh, S. P. Goyal, P. P. Khanna, P. K. Mukherjee, R. Sukumar, Using morphometric and analytical techniques to characterize elephant ivory, Forensic Science International 162 (2006), pp. 144–151.
DOI: 10.1016/j.forsciint.2006.06.028