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Ivory identification in the archaeological contexts: a case study using the 3D digital microscopy

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***Abstract* – The study of ivory remains in Prehistory and Protohistory represents a challenge for the archeologists due to the scarcity of these remains and to the fundamental need of non-destructive investigation techniques to preserve the integrity of the archaeological finds. In this work we preliminarly analyse a small sample from a wide archaeological assemblage composed of more than 10.000 ivory fragments from an Etruscan tumulus (Carmignano, Central Italy). The presence of "Schreger lines" on the surfaces of many specimens testifies that the main raw material exploited was the proboscidean dentine. Through the use of a 3D digital microscope it was possible to investigate the main micromorphological and micromorphometrical features of the dentine. The use of this non-invasive technology could be a powerful tool to obtain important information on proboscidean *taxa* exploited for ivory in the past.**

Keywords: 3D digital microscope, Schreger structure, ivory, proboscidean taxa

I. INTRODUCTION

African (*Loxodonta* spp.) and Asian (*Elephas maximus*) elephants, along with their extinct relatives (e.g., mammoths, *Mammuthus* spp.), belong to the mammalian taxonomic order *Proboscidea*. These *taxa* produce ivory that is made up of collagen and carbonated hydroxyapatite [1]. Collagen fibres reinforce the rigid inorganic matrix and they also furnish elasticity to the material. The combination of these properties with the relative softness of the dentine makes this substance an ideal medium for carving and sculpting [2]. On transverse profiles of several proboscidean tusks a “chequered pattern” can be seen by unaided eye [3]. This structure, called more commonly “Schreger pattern” is an autapomorphic feature of the clade *Elephantoidea* [4]. The Schreger bands are evident in transversal cross-section of tusk and result from corrugation of the sinusoid dentinal tubules. When these tubules intercept the cut-surface on the transversal section, the interception point sequences form two different sets of lines that curve clockwise and counterclockwise [4].

The crossing of these lines 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 [5] and they can be used to differentiate between nowadays African and Asian elephants, and extinct *Proboscidea* (mammoths) [6]. In addition to the angles, Trapani and Fisher [7] 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. Regardless of the *taxon* analysed, a transverse thin section oriented perpendicular to incremental growth laminae and extending from the tusk axis to the outer zone (cementum) was prepared.

Trapani and Fisher [7] showed that the Schreger pattern provides a powerful tool for discriminating proboscidean *taxa*, but this identification is complicated by spatial variation in the pattern that occurred in different zones of the tusk. Identification of tusk fragments and worked artifacts is therefore more challenging than that of isolated, whole tusks, where the location thin-section is known.

Despite this, assessing multiple features of the pattern, especially at multiple locations on a single specimen, can help to avoid this bias, even in cases where location on the tusk is unknown. Furthermore, the results of the work of Trapani

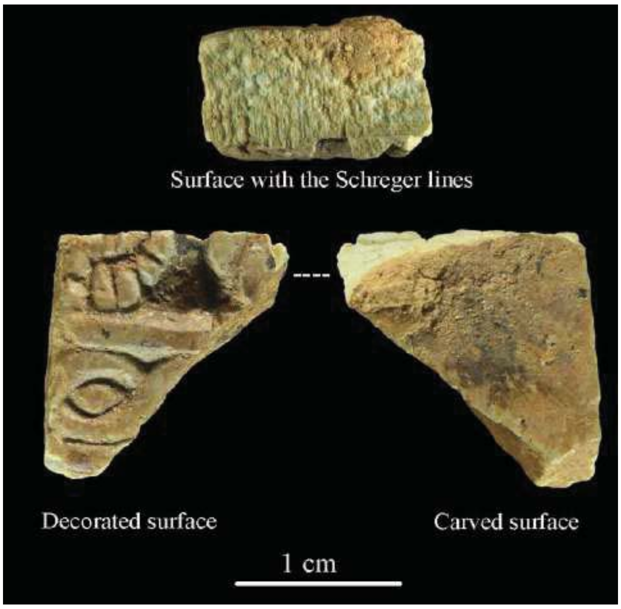

Fig. 1. An example of the archaeological specimens considered in this study (Ph. Stefano Ricci)

and Fischer [7] indicate that a multivariate consideration of Schreger pattern features (when it is possible) provides an effective tool for discriminating between tusk material of different proboscidean *taxa* even without tusk location information; correct assignment of a specimen to its *taxon* was possible in 73–93% of cases.

Considering these results, in this work we use a 3D digital microscope to investigate the ivory specimens from an archaeological context. Micromorphological and micromorphometrical observations were carried out on a preliminary sub-sample in order to evaluate the power of this non-destructive technique in the investigation of the main features of the proboscidean dentine.

II. MATERIAL AND METHODS

The material analysed in this work is a fraction of a large sample constituted by more of 10.000 fragments of ivory coming from the Etruscan tumulus of Carmignano (Central Italy). To date we have examined more of 1500 fragments no larger than 5 cm.

In this work we perform a 3D digital microscope analysis of these specimens to test the power of this technique in the investigation of the proboscidean dentine.

Despite the identification of the Schreger lines by unaided eye, some fragments were excluded due to the presence of concretion on the surfaces or to the lack of plane cross-sections. The exam of an high 3D composite image allows the exact evaluation of the development of the surface of the dentine in order to consider only the Schreger structures located on a plane section. The presence of microscopic irregularities (due for example to concretions or to the roughness of the fractured plane, identifiable thanks to the 3D high resolution images) can cause the recording of micromorphological and micromorphometrical features different to those effectively formed by the Schreger structure.

So it was possible to get reliable observation of the Schreger structure in only 29 specimens. Moreover, the analysis comprised only the fragments in which at least one carved and/or decorated surface was still visible (Figure 1).

The images were captured using a Hirox KH-7700 digital microscope with an MXG-10C body, an OL-140II lens and an AD-10S Directional Lighting Adapter. The Schreger pattern was examined to 100 magnifications, while for the exam of dentinal tubules a 140 magnification was necessary [8], [9]. 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.

This application permits us to characterize the multiple features of the Schreger pattern. In particular we consider the values of the angle of intersection of Schreger lines, the qualitative appearance of their pattern and the “wavelength" of dentinal tubules [7].

For these measures any preparation or modification (etching, staining, preparation of thin sections [4]) of the samples were not necessary. Unlike other protocols used for this purpose, that proposed in this work is characterized by a non-invasive investigation of the samples. Moreover, the morphological and morphometrical data were collected in a relatively brief time.

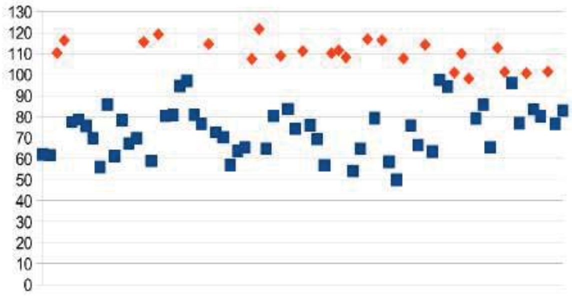

Fig. 2. The distribution of angle values recorded: the angles open toward the decorated or carving surfaces are indicate with blue squared

III. RESULTS AND DISCUSSION

Figure 2 shows the values of the angles of the Schreger pattern identified in the examined sample. These values are related to all the four angles of every observed rhomboid shape (Figure 3). Two main clusters of data are observable:

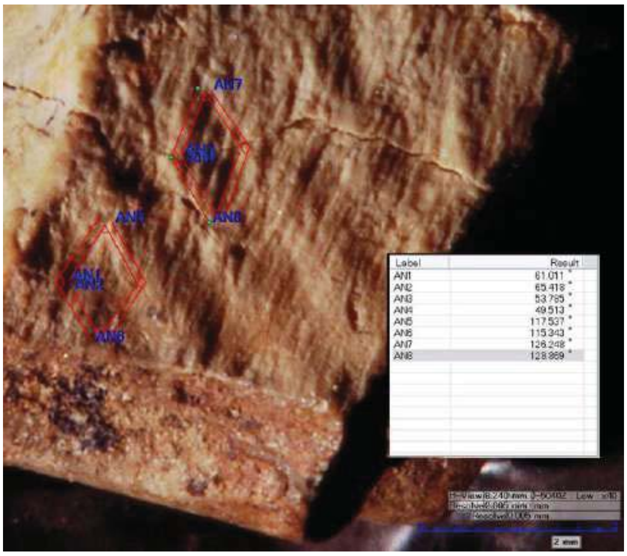

Fig. 3. Values of the Schreger angles recorded close to the cementum-dentin junction

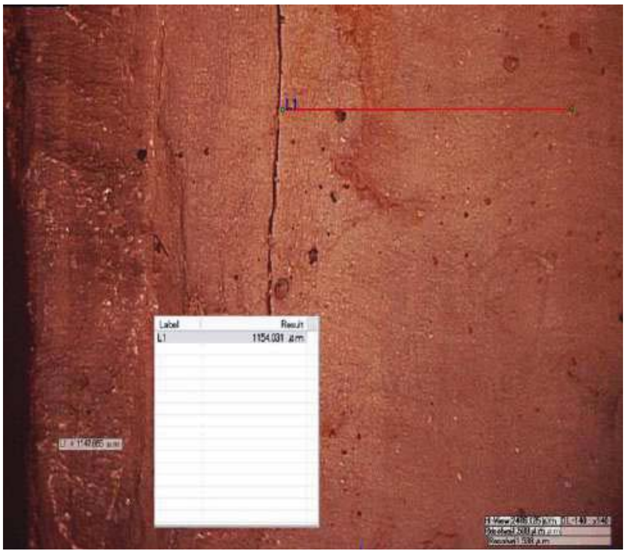

Fig. 4. Wavelenght of the tubules in proximity of the cementum-dentine junction

one including values higher than 90° and another one characterized by values smaller than 90°. It was noted that the acute angles (together with five angles with value comprise between 90°-100°) open toward the carved and/or the decorated surfaces (Figure 3). Considering that these latter probably interest the tangential surfaces of the tusk [10], [11], 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 toward the cementum, the outer layer of the tusk (Figure 3). The identification of the cementum-dentin junction (CDJ, [7]) permits to better define the orientation of the fragment and the location on the tusk which it come 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 [7]. Again, a portion of cementum was detected on one of the remains in which the wavelength of the tubules was recorded (Figure 4).

Only in a one single case 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 remain (the transverse profile and the radial profile of the tusk respectively), were measured (wavelength of tubules= 1158.5 µm, Schreger angle=69.2°). The combination of these two morphometrical data can provide other significant information regarding both location on the tusk which the remains come from, and the *taxon* exploited for the ivory procurement [4], [7].

Finally in a specimen we identified the presence of the "V pattern" in the Schreger structure (Figure 5) with the values of the Schreger angles no larger than 90°.

IV. CONCLUSIONS

This preliminary paper encourages us to develop the analysis of proboscidean dentine through the 3D digital microscopy. In particular this technology could represent a useful tool for the characterization of ivory specimens coming from Prehistoric and Protohistoric contexts. Indeed, through this protocol all the micromorphological and micromorphometrical features of Schreger pattern, together with the state of conservation of the investigated microsurfaces, can be recorded 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. Data relating to Schreger structures achieved in the Montefortini remains is compatible with the Mammoth dentine (values of the Schreger angles, wavelengths of tubules, presence and characteristics of the "V" pattern, Figures 2, 3, 4 and 5) [4], [5], [6], [7]). Although in the Etruscan contexts the presence of raw materials and objects from northeastern Europe is attested [12], our data represent an unespected result if we consider the "easier" access that the Etruscan people could had to the ivory derived from the extant elephants thanks the intensive trades carried out by this people with the Asian and African populations [13], [14]. Beside an enlargement of

Fig. 5. The "V" pattern of the Schreger structure recorded on a remain of Montefortini

our analysis on a wider sample of Montefortini, further analyses of the examined sample (i.e. palaeogenetics, chemical characterizations of the dentine, radiometric data) and the evaluation of ethnographic/experimental methods adopted in the ivory (processing (cut of the tusk, identification of the tusk's surfaces usually exploited for carving and decorating) are then necessary to evaluate the power of the 3D digital microscopy in the identification of the *Proboscidean taxa* exploited for the ivory in the past.

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