Comparative observations on fossil tusks from three Quaternary Greek localities using scanning electron microscopy

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SUMMARY: The structure of Proboscidean tusks, from the Quaternary Greek localities of Tilos (45 ka BP up to 4-3.5 ka BP), Aliveri (Pleistocene), and Vlachioti (Lower Pleistocene), are compared on the basis of the dentinal tubule density and the tubule maximum diameter. In addition observations are made on sections perpendicular to the long axis of the tusk, with special concern to the preservability of the specimens. Although the taphonomic conditions play a very important role in this respect, a correlation also seems to exist between the above measurements and the degree of permeability and preservability of tusks. In addition, the values measured exhibit a reverse correlation with the tusk size. In fact the tusks of the dwarf elephants from Tilos, which are extremely brittle, have the largest density and tubule diameter.

1. Scope, material and methodology

The scope of this study is to compare the microstructural features of tusk samples from three Quaternary Greek localities. The material examined includes fragments of several fossil tusks of the dwarf elephants from the island of Tilos (Dodekanese), dated between 45 ka BP up to 4-3.5 ka BP, fragments of three Pleistocene tusks from Aliveri (Euboia), and of one Lower Pleistocene tusk found in the area of Vlachioti (Lakonia, Peloponese).

The dentinal tubule density and tubule maximum diameter are measured on SEM microphotographs of the tusk fragments, obtained from stub samples. Also, qualitative X-ray microanalyses (EDS) are considered in conjunction with the structural characteristics, to reach conclusions regarding the permeability and the preservability of the tusks.

The circumferential plane of a tusk reveals the perpendicular sections of the dentinal tubules. On this plane, measurements are taken of the dentinal tubule density and the tubules' maximum diameter. The dentinal tubule density is known to change depending on the distance from the pulp cavity. In fact, toward the outer surface of the tusk, the dentinal tubules branch, anastomose and fuse (Halstead 1974; Raubenheimer *et al.* 1998). Consequently, measuring the density of the tubules, at random distances from the pulp would not provide comparable results. To overcome this, all the measurements, in this study, are taken near the cementum – dentine junction (CDJ). The result is to observe only the outermost layer of dentine.

2. Observations

The tusks from Tilos had originally been attributed to *Palaeoloxodon antiquus falconeri* Busk (Symeonidis 1972). This name however refers to the dwarf elephants found on the island of Malta. Since no migration can been proved between the two islands, this name can not be used for the elephants of Tilos. Theodorou (1983) discusses this issue and temporarily accepts the use of the same name, until further material can be examined (Theodorou & Symeonidis 2001).

The specimens examined include large fragments of several tusks. Measurements of length and diameter of these tusks could not be taken.

At several points along the long axis of the tusk, and at a distance of about 4.5 mm from the periphery (CDJ), stubs were created to examine the circumferential and perpendicular plane. The mean dentinal tubule density of these specimens measures at 33,203 dt/sq mm (dentinal tubules per square millimeter), with a range from 21,200 dt/sq mm to 45,500 dt/sq mm. Also the mean dentinal tubule maximum diameter is 2.5 µm.

The SEM backscatter images of the sections perpendicular to the long axis of the tusk reveal alternate dark and light bands (Figs. 1 and 2). Microprobe analysis shows that, in the areas,

Fig.1 - SEM image of a perpendicular section of a tusk from Tilos. Morphologically there are no bands observed.

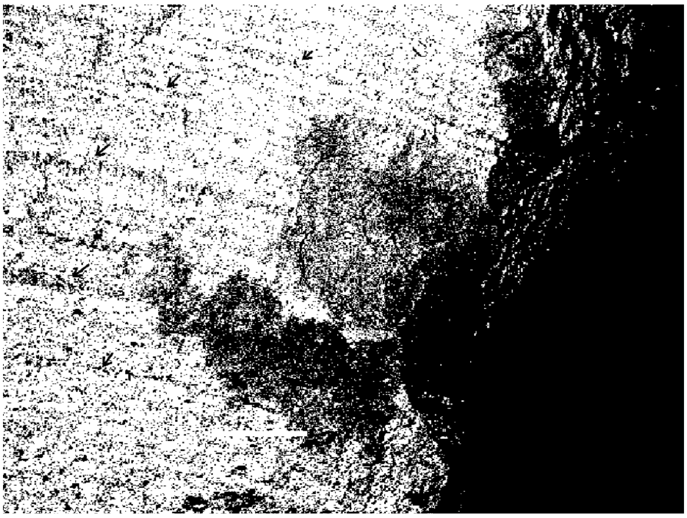

Fig.2 - SEM backscatter image of the same area as in fig. 1. The sample exhibits differences in the composition that are expressed as alterations of dark and light bands (arrow).

which appear dark, the dentine has formed porous spaces between the hydroxyapatite crystals, where the deposition of $CaCO_3$ has taken place.

The taxonomic position of the tusks from Aliveri (M. Dermitzakis & G. Theodorou – excavation 1977) is unknown. The Schreger pattern appears extremely faint. As a result, the Schreger angles could not be accurately measured, as to provide a diagnostic characteristic. The length and diameter of the specimen could only be measured on two of the tusks examined. Both of them are missing their tip and base. The length from proximal to distal end (arch) of the tusk 9/77/1 is 82 cm, while the same measurement for the tusk 9/77/2 is 100 cm. The maximum and minimum diameters in the middle of the tusk 9/77/1 are 11.32 cm and 10.15 cm respectively, while the same for the tusk 9/77/2 measure at 19.04 cm and 14.86 cm respectively.

The stub samples are taken from a distance of about 9 mm from the circumference, at the cementum – dentine junction, and from the middle part of the tusk. The mean dentinal tubule density is 23,177 dt/sq mm. This value ranges from 17,500 dt/sq mm to 25,500 dt/sq mm. The mean tubule maximum diameter is 1.2 μm. SEM microphotographs of the perpendicular plane again reveal an alteration of dark and light bands. However, in these samples, the dark areas correspond to actual porous spaces (deposition of $CaCO_3$ has not taken place) created as a result of the sinusoidal arrangement of the tubules (Fig. 3).

The Lower Pleistocene tusks from Vlachioti belong to *Mammuthus meridionalis* Nesti Originally they were attributed to *Archidiskodon meridionalis* by Symeonidis & Theodorou (1986), but the use of the name *Mammuthus* has been proved more appropriate (Shoshani & Tassy 1996). The tusk examined has a length of 110 cm from proximal to distal end (arch). The maximum and minimum diameters in the middle of the tusk are 11 cm and 8.5 cm respectively (Symeonidis & Theodorou 1986). The stub samples are taken from various points along the long axis of tusk, but from a distance of about 7mm from the periphery (CDJ). The mean dentinal tubule density is 32,236 dt/sq mm, with a range from 25,500 dt/sq mm to 43,000 dt/sq mm. The mean dentinal tubule maximum diameter is 1.5 μm (Fig. 4).

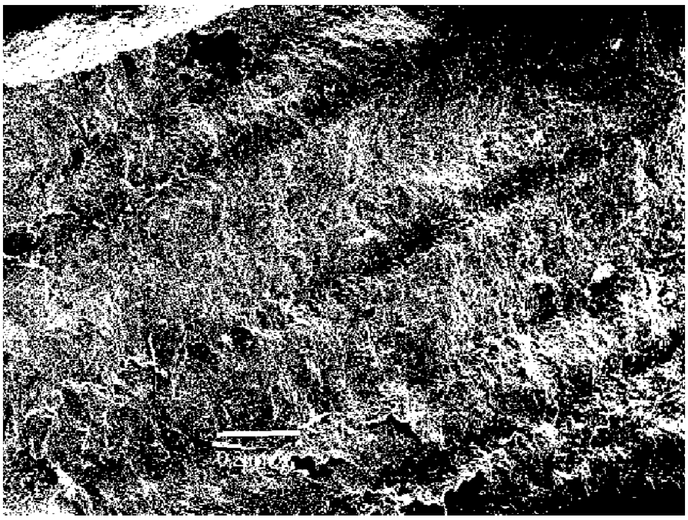

Fig.3 - SEM image of a sample from Aliveri. The alteration of dark and light bands are morphological. The dark bands (arrows) correspond to slanting of the dentinal tubules toward the circumference of the tusk.

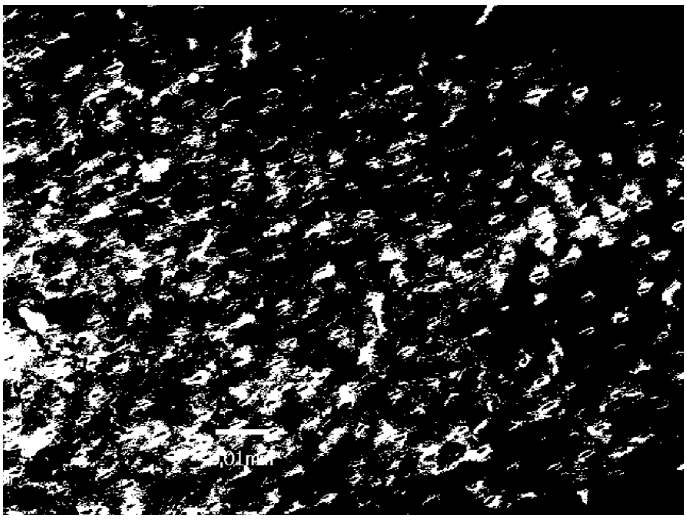

Fig.4 - Circumferential section of the tusk from Vlachioti.

3. Discussion

According to results from measurements on tooth – dentine from other mammals (Forssell-Ahlberg *et al.* 1975) the diameter decreases with increasing distance from the pulp cavity. As a result the tusks of the dwarf elephants from Tilos would be expected to have the largest tubule diameter near the CDJ. Indeed, our measurements of the tubule maximum diameter show that the smaller tusks (Tilos) have the largest diameter. In order to compare samples we should therefore examine the variation of this value in the three dimensions, although the measurement near the CDJ can be useful, especially when dealing with fragments, since it could be indicative of the size of the tusk.

We observe that the Schreger pattern of alternating dark and light bands, interweaving to form a network, (Miles & Boyde 1961; Espinoza & Mann 1993; Fisher *et al.* 1998) is visible in all our specimens. However it is very easily discernible on the tusk from Vlachioti, less on the tusks from Tilos and very unclear on the tusks from Aliveri. According to Raubenheimer *et al.* (1998) the alternating light and dark bands, which macroscopically create the effect of the chequered pattern, are the result of the sinusoidal pattern of the dentinal tubules, as well as the differential compactness of the tubules between the light and dark bands. On the microphotographs of perpendicular sections from the tusks from Aliveri and Tilos the same image of alternating dark and light bands appears. In both cases the dark bands correspond to porous spaces resulting from this sinusoidal arrangement of the tubules. In the tusks from Tilos, these spaces have been filled with $CaCO_3$, while, in the tusks from Aliveri, deposition of $CaCO_3$ has not taken place. Raubenheimer *et al.* (1998) has shown that the number of dentinal tubules increases in the dark bands. As a result, the preferential deposition of $CaCO_3$ in the dark bands may be explained by the denser packing of the tubules in those areas. Indeed, the leaching out of the organic material, during the process of fossilization, would tend to create more empty spaces in the dark areas.

Macroscopically, the tusks from Aliveri appear hard and difficult to break. They have the lowest tubule density and tubule maximum diameter. The tusk from Vlachioti is also hard, but less than the specimens from Aliveri. It also has a small diameter, but a higher density. Finally the tusks from Tilos are extremely brittle and express preferential fissility along the dark zones, a lot more than the other samples. These have the highest values for diameter and density.

Comparing the tusks from Tilos to those from Aliveri, we observe that the permeation by environmental elements is exhibited only in the first case. Also the tusks from Tilos have higher values for tubule diameter and density, than the tusks from Aliveri. Consequently, the empty spaces created in the dark areas of the tusks from Tilos would be larger than on the tusks from Aliveri. Thus, it is expected that the permeability of the samples from Tilos would be greater.

4. Conclusion

The intensity of the Schreger Pattern, as it appears on fossil tusks, seems to depend on the permeability of the tissue. Salts are deposited in the areas, which, macroscopically and microscopically, appear dark, thus increasing the contrast between the dark and light bands. This preferential deposition in the dark bands seems to be due to the increased density of the dentinal tubules in those areas. However, deposition does not always take place, as in the case of the tusks from Aliveri.

The degree of permeation of a tissue by salt solutions depends on both the environmental conditions and the histology of the tissue itself. To this respect, the size and density of the dentinal tubules would partly control the deposition of salts in the tusk specimens, during the process of fossilization. Tusks that exhibit higher values for tubule density and diameter, under specific fossilization conditions, would tend to allow the deposition of salts, such as the $CaCO_3$, more than other specimens with lower density and tubule diameter. As a result, we should expect the preservation of the Schreger Pattern to be greater in those samples. Indeed, the macroscopic and microscopic observations made on the tusks examined in this study are indicative towards this hypothesis.

Concerning the preservability of the tusk specimens, this seems to correlate with the permeability of the samples. In fact, the tusks, in which the preferential deposition of salts has taken place, have the lowest degree of preservability. In addition, our observations indicate towards a reverse correlation between the dentinal tubule size and density and the degree of preservability of the tusk.

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