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Biomineralogy of the Teeth of Egyptian Mummies

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Abstract

In the literature so far, there has been little information on mineralogical studies of teeth from old cemeteries, such as the tombs of Egyptian mummies. This publication adds to the knowledge in the field of mineralogical studies regarding vital and posthumous changes in the teeth of the people of Old and New Kingdom of Egypt. It shows the phenomena occurring in historical teeth, which are similar to those occurring in modern times. The research was conducted on approximately a dozen teeth, and the publication presents only selected, particularly interesting phenomena.

Keywords: *Egypt, mummies, teeth, biomineralogy*

Introduction

The research aimed to identify phenomena occurring both during lifetime and after death in teeth of mummies. It wasconducted on several teeth from various archaeological sites discovered in Egypt.

Literature concerning this particular subject is modest compared to overall literature on mummies, mummification, and especially religious beliefs of the Egyptians related to life after death.

Studies of teeth originating from archaeological sites have rich and multi-faceted literature. Itpertains to pathology (Ayrton, Lorat 1911, Melanba 1927, Garland 1987, Boherens et al. 1990, Chiariadia et al. 2003), relation between diet and mineral composition of bones and teeth (Hancock et al. 1989), as well as content of trace elements (Trueman, Tuross 2002). Many researchers focus on the development and structure of tooth cavities (Ames, Schour 1955, Bell 1990, Bout 2001). Scientists' interest is also related to the changes in tooth structures - their mineral, chemical and isotopic composition (Longinelli 1983, Ergenholtz 1991, Rink, Schwartz 1985, Simmer, Finchman 1995, Hornono et al. 1996, Kohn et al. 1996, Kohn et al. 1999, Gutierez - Salazar, Rejes - Gasga 2003, Muray et al. 2003, Dupin, Williams 2004, Wopenka, Pasteris 2005, Wychowański et al. 2005). Those publications show the many aspects and the significance of research not only of modern teeth, but also those of previous historical and geological periods.

Materials and Methods

The study material consisted of individual tooth samples from the old collection of the Archaeological Museum in Krakow. The author would like to thank prof. drhab. Anna Szymańska, who submitted them for research. From that collection, specimen with various types of changes were chosen for detailed examination.

In addition to examinationwitha binocular magnifier, the research was focused on the study of sections, which was carried out by polarized light microscopy (with a Motic microscope,manufactured in China), as well as studies using the FEI QUANTA 200 FEG scanning microscope combined with the EDS chemical analysis device. The research was carried out in the "low vacuum" mode.

Phase tests were performed using an X-ray diffraction method with the DRON 2.5 diffractometer manufactured in Russia. Interpretations of diffractograms were carried out using the XRA jan computer program.

Test Results Changes in Teeth Occurring During Lifetime Cavities Old Kingdom. Woman, 20

Studies of several teeth from this period indicate that even young people's teeth were badly neglected; cavities were found even in 20-year-olds (Photo 1). Similar to our times, the number and size of cavities in teeth increased with age, and the elderly often hardly had any teeth at all.

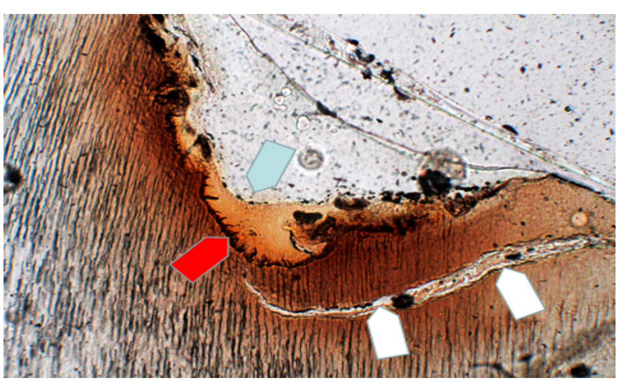
Photo 1. *Tooth used in research (two positions). Arrow shows the location of a tooth cavity.*

Microscopic Examination on Polarized Light

Interesting images were obtained from teethmicro sections. Changes in cavities developed down to the dentin, in some cases causingit to adopt a secondary color of the substance found in the cavity (Photo 2 A, B). Studies of the dentin show that the cavity is filled with clay minerals. It is difficult to say, however, whether it was done deliberately or the filling occurrednaturally after the burial. Presence of those minerals only in the cavity may suggest that it was an intentional filling.

In addition to classic cavities, secondary mineralization with an opaque material was found within dentin (Photo 2 C). Reorganization of the structure of teeth was microscopicallyobservedin many samples, visibleboth aschange in color of dentin (Photo 2 D) and change in the optical orientation of dentin structures. This phenomenon is observed as change in the direction of polarized light extinction in the parts affected by the changes (Photo 2 E).

In the areas affected by changes associated with development of cavities, small grains of secondary minerals are observed, with microscopic features and high interference colors typical for carbonates (Photo 2 F). To confirm this observation, trace amount of material from one of the cavities was taken for X-ray phase analysis. The resulting diffractogram (Fig. 1) confirmed that there is calcite ($CaCO_3$) in the cavity,in addition to the main component - apatite. This is interesting because tooth apatite and calcite crystallize in different crystallographic systems. The reconstruction of apatite into post-apatite calcite is associated not only with leeching phosphorus from the structure of dentin, but also with volume changes in dentin. Secondary post-apatite calcite takes up a different volume in the dental cavity than the original apatite. This in turn causes the structure of the dentin to weaken.



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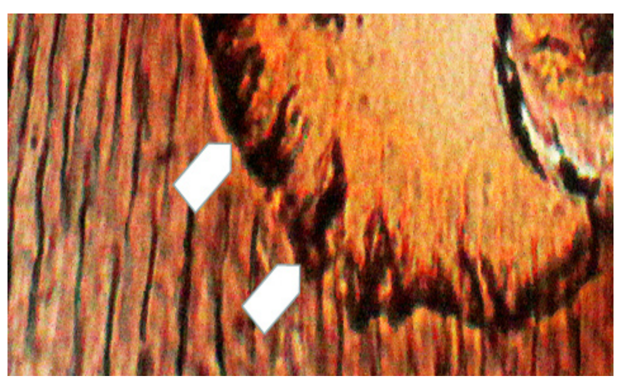

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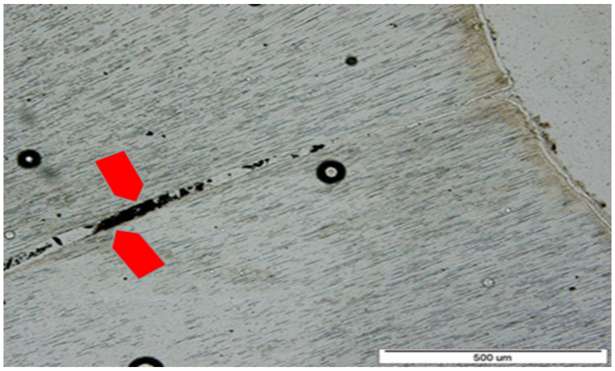

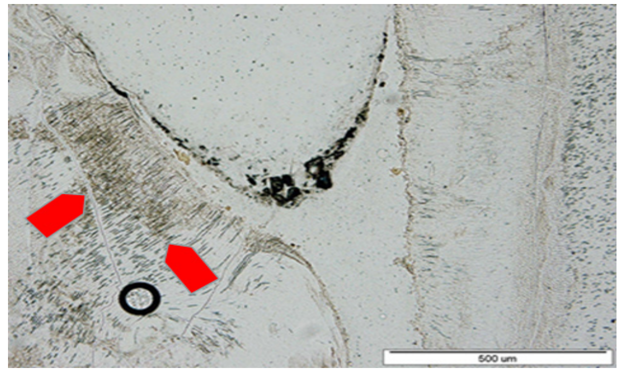

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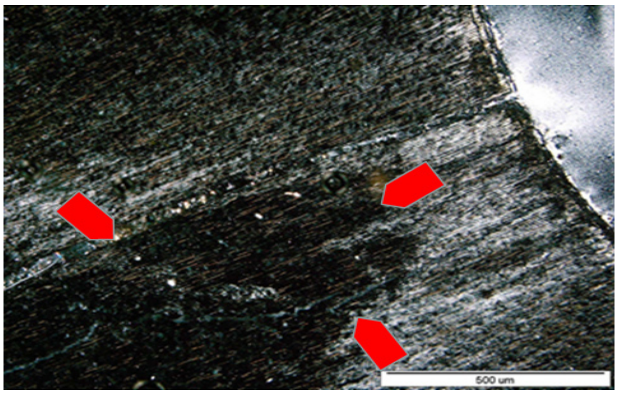
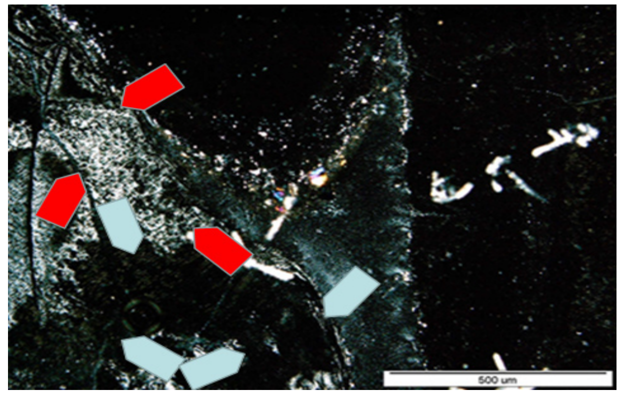




E F

Photo 2. *Micrographs of a tooth. A - micrograph of a microsectionmade at the site of the cavity (red arrow) shown in Photo 1. Visible crack in the dentin (white arrows). In the cavity, small amounts of clay minerals (orange) are preserved,containing iron (Fe^{3+}) which colors the area brown. B - magnification of the lower part of cavity with visible darker clusters of organic matter (arrows). A-B: polarizing microscope, polaroidspartially X. C - stratification of dentin along nutrient tubules filled with secondary dark minerals (arrows). D - dentin with small aggregations of dark organic matter. Polarizing microscope, polaroidspartially X. E –area of structural changes within dentin, visible microscopically as twisting of a polarized light beam. Polarizing microscope, polaroids X. F - secondary minerals on the border between enamel and dentin (blue arrows), and (mineral) changes withindentinvisible as twisting of polarized light. Polarizing microscope, polaroids X.*

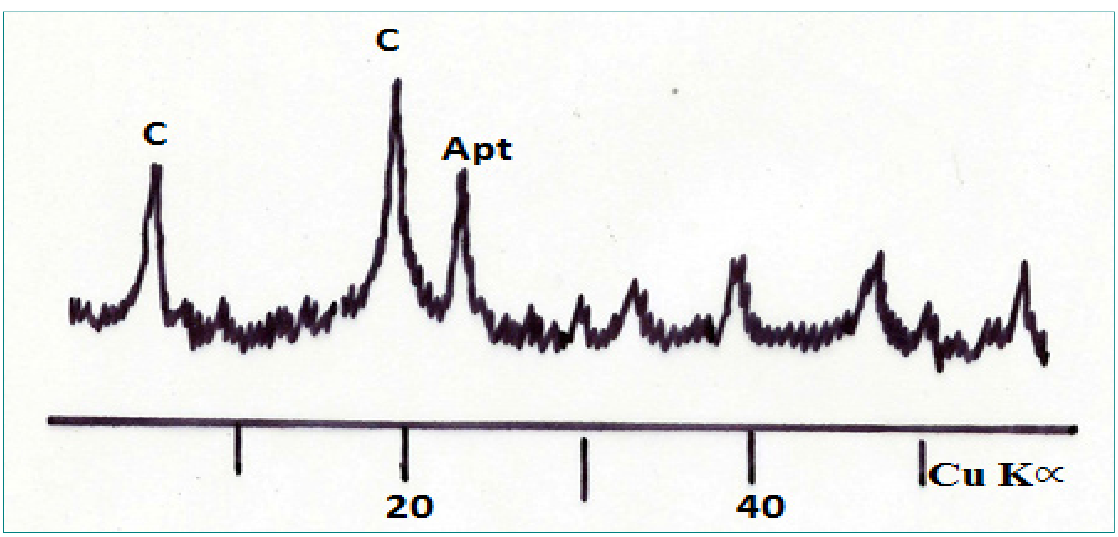
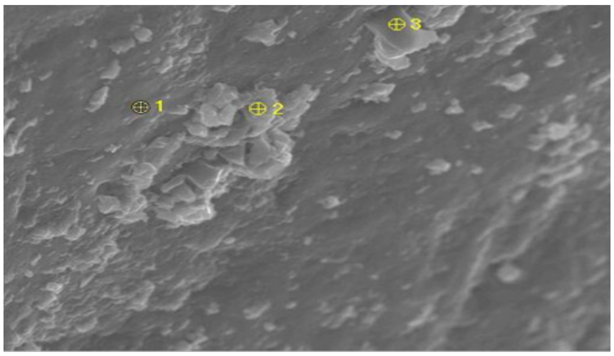


Fig 1. *X-ray diffractogram of the substance found in the tooth cavity (see Photo 2 A), C - calcite, Apt - apatite.*

Studies of selected teeth using the SEM-EDS method proved to be just as interesting and revealed many details. It turned out that the enamel surface (Photo 3 A), which ismademostly of apatite (Photo3 B),is covered in some places by fine grainsof quartz (Photo3 C).Some of those undoubtedlycome from the area of the grave, but others, in shapes close to idiomorphic, may be associated with secondary processes that are difficult todescribe at this stage.

It has also been found that Ca/P ratio in enamel, even within one tooth, can vary without showing visible destructive processes. This phenomenon is difficult to explain at this stage of research.

SEM – EDS Studies



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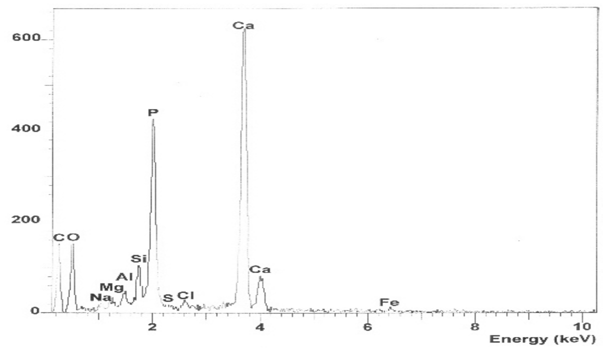

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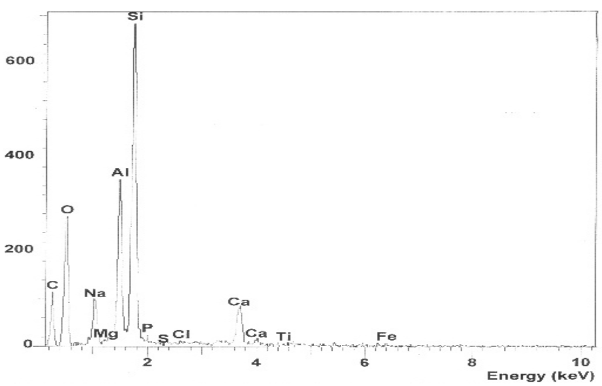

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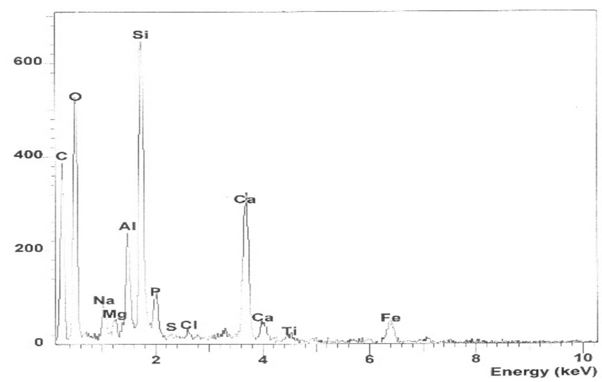

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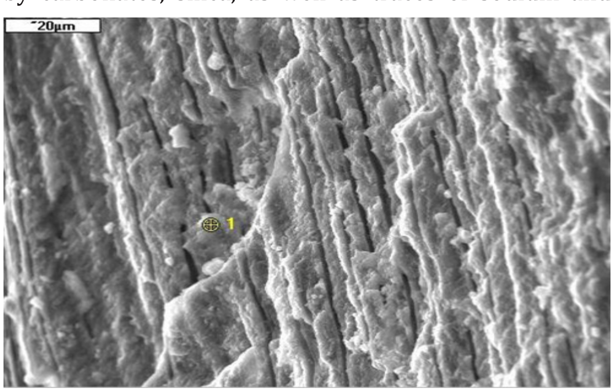
Photo 3. *A – Micrograph of enamel. B, C, D - chemical analyses of the enamel surface. EDS.*

Biomineralogical phenomena observed in dentin are also interesting (Photo 4 A). They pertain to not only changes in its structure, but also to filling of tubules, mainly by carbonates, silica, as well as traces of sodium and chlorine (Photo 4 B). In the latter case, the presence of NaCl (halite) is most likely related to the mummification process,where in addition to other ingredients, such as natron or resins, rock salt was also used.



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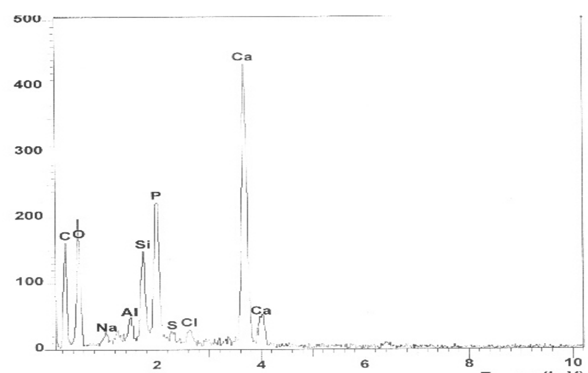

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Photo 4. *A - Micrograph of dentin. SEM. B - EDS spectrum of dentin in the spot shown in A.*

For comparative studies and to investigate the phenomenon of tooth destruction, teeth of mummies from the New Kingdom period were also examined. Selected test results of the teeth of a 40-year-old male are presented below (Photo 5).

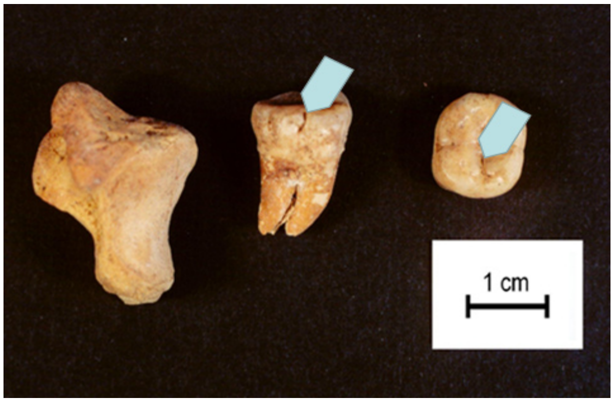


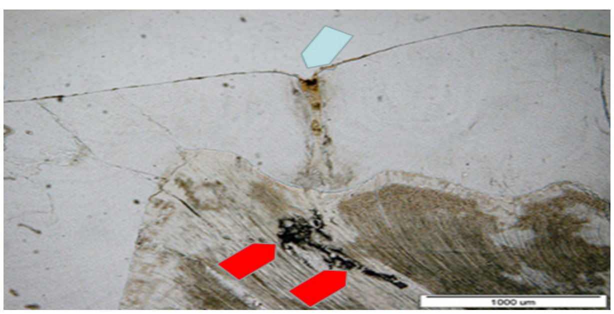
Photo 5. *Bone fragment and tooth chosen for testing. Arrows show places of tooth damage.*

Studies that were carried out indicate that the processes of teeth destruction during lifetimehave a significant impact on the secondary phenomena of teeth destruction - after the life processes have stopped.

In addition to the typicalcavities, in teeth from the New Kingdom period the studies revealed structural processes of enamel damage related to its cracking.

Most phenomena of posthumous destruction are related to the degree of teeth damage developed while alive.

Enamel cracking in living teeth leads to formation of crackswhere secondary substances penetrate right down to the dentin (Photo 6 A, B). Regardless of whether those substances got into the cracks in life or after death, they react with enamel and dentin both chemically and mechanically. Chemically, they facilitate dissolution of hydroxyapatite, the main building block of teeth, which is stable at pH>6.6,but slowly dissolves in acidic environment. Crystallization of mineral substances in the cracks leads in turn to the increase of their volume. The crystallization powers of, for example, secondary carbonates (Photo 6 C) are so strong that they cause destruction of tooth structures. Sometimes these changes are very subtle and difficult to recognize. In microscopic observations they show as a change in the color of dentin near the damaged part of the tooth (Photo 6 D).



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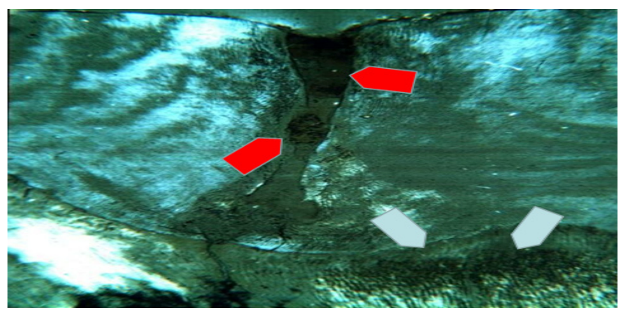

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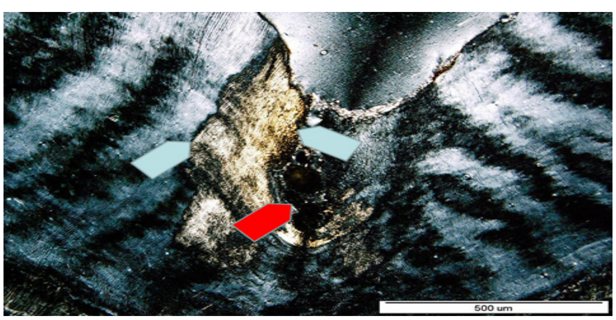

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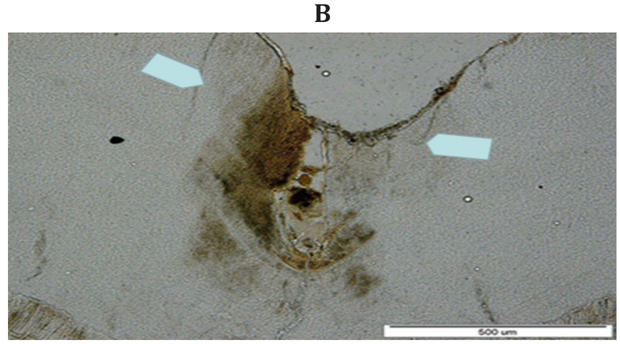

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Photo 6. *A –micrographof lateral enamel crack in the tooth crown (blue arrow). Deep changewithin dentinis visible under the crack (red arrow). Polarizing microscope, polaroids partially X. B – micrograph of the same crackin a different place. Opaque secondary minerals filling the crack (red arrows) and changes in dentin under the crack (blue arrows) are visible. Polarizing microscope, polaroidsX. C– micrograph of a cavity in tooth enamel (crown - red arrow) with secondarily evolved post-phosphate carbonates (yellow cluster - blue arrows). Polarizing microscope, polaroids X. D - the same spot (Photo 6 C) seen in normal light. Areas within the enamel affected by the changes are visible (blue arrows). Polarizing microscope, 1 polaroid.*

On some teeth, both from the Old and New Kingdoms, trace amounts of tartar were found. In tartar, minerals - phosphates, oxalates and probably carbonates - are mixed with a highly altered and oxidized organic substance showing as dark brown under the microscope (Photo 7). It means that this ailment was already known in Pharaonic times, just as it is today.

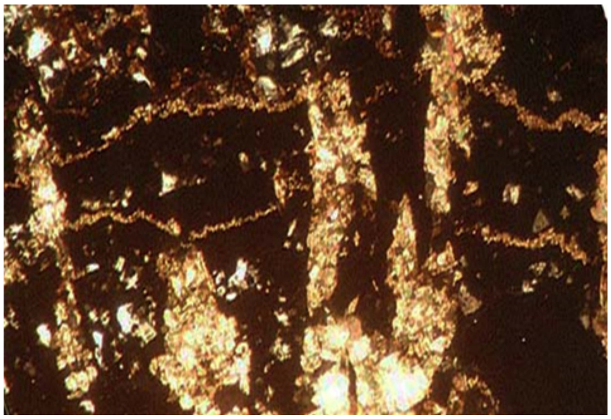
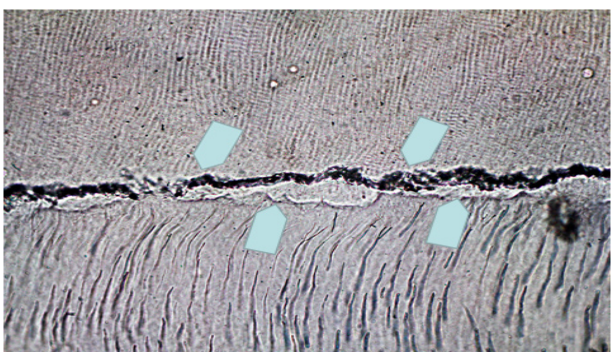


Photo 7. *Oxalate-phosphate tooth tartar; M (/?), age circa 50. Light spots - oxalates with phosphates. Dark areas - mainly altered organic substance. Polarizing microscope, partially X polaroids.*

Secondary Changes In Teeth Associated With Destruction Processes After Death Structural Changes

They were observed as various types of damage of teeth structure. One of the most common cases is separation of enamel from dentin, leading to destruction of the tooth. The gap formed between the enamel and dentin can be empty or filled with secondary substances (Photo 8 A). Another phenomenon that was observedis development of changes in dentin that are visible microscopically as brown stains (Photo 8 B), which are associated with difficult to identify organic matter (possibly related to mummification)penetrating into the dentintubules. Other deformities are cracks in dentin arranged almost perpendicularly to the tubules (Photo 8 C), which are difficult to explain with genetics. Also of interest are subtle changes in the dentin tubules, or actually in the dentin itself between the tubules. They are observed as specific changes of interference colors (Photo 8 D). They are evidence of structural changes in the collagen-apatite substance building dentin, and they may be related to the process of collagen oxidation. However, solving this problem requires more extensive research.



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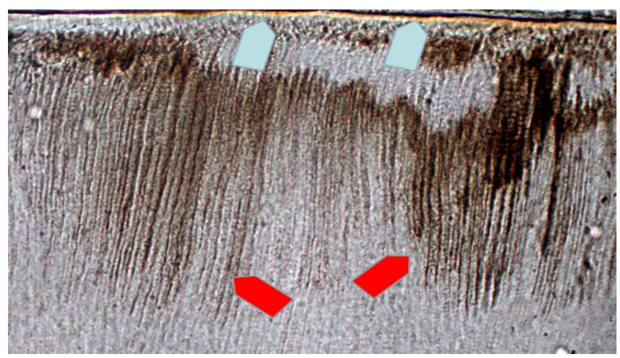

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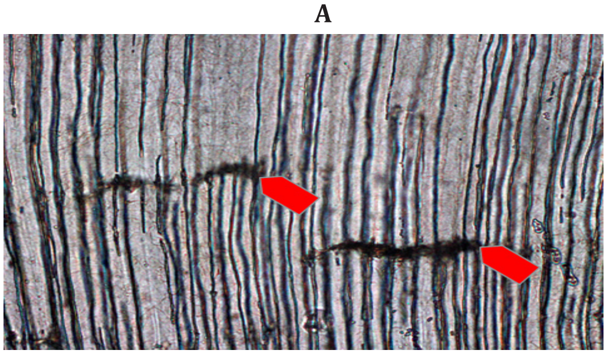

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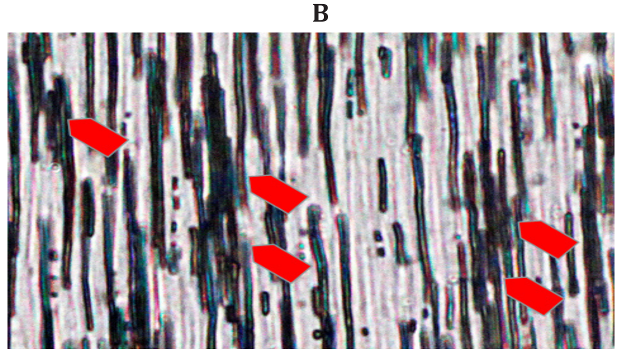

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Photo 8. *A - separation of enamel from dentin (arrows), B - changes in the dentin stained brown under the enamel/ dentin boundary (arrows). C - cracks in dentin filled with secondary, opaque minerals (arrows). D - changes in collagen-mineral structure of the zone near the tubules, observed as changes in polarized light color. Polarizing microscope, partially X polaroids.*

Recrystallization of Teeth and Crystallization of Secondary Substances, Including Mummifying Substances (Salt) in the Teeth and on Their Surface

Phenomena of structure modification observed microscopically in some dentinsareconfirmation of changes in the collagen-apatite structure of dentin. Such phenomenon is visible in polarized light at high magnifications (Photo 9).

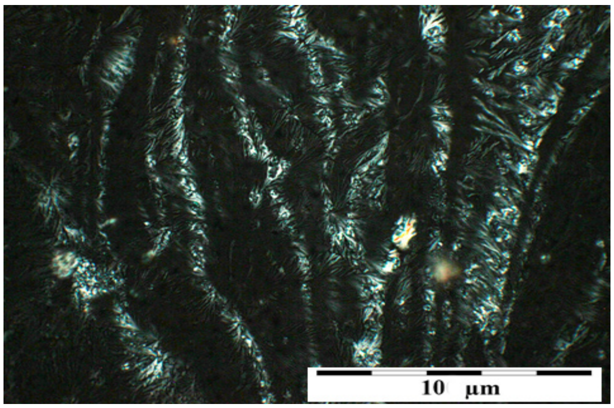

Fig 9. *Phenomenon of recrystallization of dentin apatite-collagen mass visible under polarizing microscope as a characteristic structure with a specific method of light extinction. Polaroids X. Old Kingdom, M, agecirca 45.*

Previous research (chemical analysis by EDS) already showed presence of sodium and chlorine in the dentin tubules, suggesting that salts used for mummification had penetrated also to the dentin structure. The SEM-EDS study of another tooth of a woman from the New Kingdom (Photo 10) allowed at high magnifications for recognition of salt microcrystals on the surface of the enamel, in the hollow of its upper part.

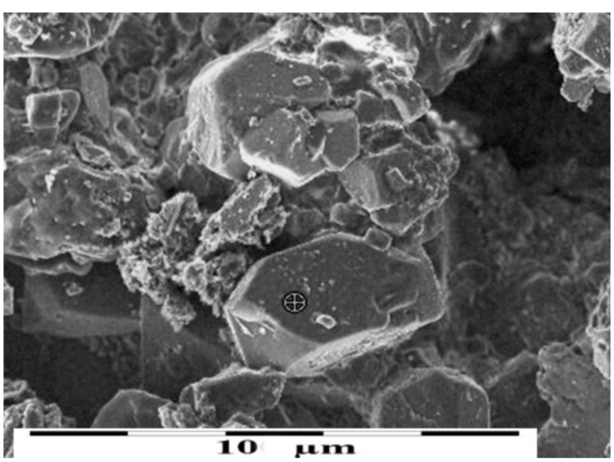

Fig 10. *Halite and natron crystals from tooth surface. New Kingdom. Woman (age?)*

Summary

The observed changes in the structure of the examined teeth indicate that they are the result of several overlapping factors. Those factors affected the teeth both during life and after the burial. Changes developed during the lifetimesignificantly affect destruction of teeth after the life processes stop. This process is also influenced by the technology and components used in mummification, as well as the conditions in which the mummy rests in the grave (tomb).

The condition of human teeth in life is important. Research indicates that young teeth are less vulnerable to secondary changes than teeth damaged in life. It appears that the period from which the tooth comes (Old or New Kingdom) has less influence, even thoughthe difference in time between burials may reach as much as 1-2 thousand years.

Research shows that the processes of tooth destruction that develop in life did not differ in dynastic times from those observed today. There are cavities in the examined teeth that developed similarly to those in modern teeth. The secondary mineral formed in the cavities of the examined teeth is post-apatite calcite, just like today.

In one of the cavities, an accumulation of clay minerals was found, which may be seen either as an attempt to treat (fill?) the tooth or as a substance that got into the tooth in a secondary process.

It is also interesting that tartar plaque was observed on the border between the root and crown of the teeth.

Phenomena of tooth destruction after death develop more easily in the teeth of older people, which are more frequentlydamaged in life than young teeth. The various destruction processes affect, in particular, locations of tooth destruction in life, where the tooth structure is weakened.

The mummies were subjected to mummification and it is difficult to say how much this process affected the destruction or preservation of their teeth. It appears that while it favored preservation of soft tissues, it could have caused destruction of teeth (and bones). That was because the secondarily crystallizing minerals (natron, halite) could “break apart” tooth structures. By crystallizing, they could cause the enamel to separate from the dentin, or cause cracks (oblong and transverse)to appear within both the enamel and dentin. This way, theyfacilitated destruction of teeth especially in places where cavities appeared.

In the desert climate, there is little chance of crystallization of minerals and other substances seeping in with moisture from the grave surroundings. Therefore, it can be assumed that some of the organic substances present in the teeth (especially opaque substances) are resins used in the mummification process.

A separate problem, demanding further research, is that of changes in the apatite-collagen structure of the teeth, showing as structural changes affecting the optical properties of dentin in polarization microscopy.

References

[1] Ames V.E., Schour I., 1955 The effect of cavity preparation alone on the human dental pulp, J Dent Res, , 34: 758.

[2] AngelandK., 1957 Tissue changes in the dental pulp. An experimental histologic study, OdontolTidskr, , 65, 1-146.

[3] Ayrton E.R., Lorat W.L.S., 1911Predynastic cemetery at el-Mohasna. London.

[4] Bell L. S., 1990 Paleopathology and diagenesis: An SEM evaluation of structural changes using backscattered electron imaging. Journal of Archaeological Science, 17, 85-102.

[5] Bocherens H., Brinkam D.B., Dauphin Y., Mariotti A., 1994 Microstructural and geochemical investigations on late Cretaceous archosaur teeth from Alberta, Canada. Canadian Journal of Earth Science, 31, 783-792

[6] Bout I., Murray P.E. , Franquin J.C. et al., 2001 The effect of variable of the restoration of cavities on odontoblasts number and dentinal repair, J Dent. 29:109-117.

[7] Chiaradia M., Gallay A., Todt W., 2003Different contamination styles of prehistoric human teeth at a Swiss necropolis (Sion, Valais) inferred from lead and strontium isotopes. Applied Geochemistryv. 18, 3, 353-370.

[8] Dauphin Y., Williams C. T. , 2004 Diagenetic trends of dental tissues. ComptesRendusPalevol, 3, (6-7), 583-590.

[9] ErgenholtzG., 1991 Iatrogenic injury to the pulp in dental procedures: aspects of pathogenesis, management and preventive measures, Int. Dent J, 41, 99-110.

[10] Garland A. N. , 1987 Paleohistology. Science and Archaecology, 29, 25-29.

[11] Gutiérrez - Salazar M., Reyes-Gasga J. 2003 Microhardness and chemical composition of human tooth. Material Research, 6, 1-7.

[12] Hancock R. G. V., Grynpas M. D., & Pritzker K. P. H. (1989). The abuse of bone analyses for archeological dietary studies. Archaeometry, 31, 169-179.

[13] HomonoM., Maeda T., Suda H., TakhashiK. (eds), 1996 Dentin/Pulp Complex, Quintessence, Tokyo, 169-175.

[14] Hess A.F., Lewis J, M, Roman B., 1932 Radiographic study of calcification of the teeth from birth to adolescence. Dental Cosmos., 1053-106

[15] Kohn M. J., Schoeninger M. J., Valley J. W., 1996 Herbivore tooth oxygen compositions: Effects on diet and physiology. GeochimicaetCosmochimicaActa, 60, 3889-3896.

[16] Kohn M. J., Schoeninger J., Barker W. W., 1999 Altered states: Effect on fossil tooth chemistry. GeochimicaetCosmochimicaActa, 63, 2737-2747.

[17] Longinelli A., 1983 Oxygen isotopes in mammal bone phosphate: a new tool for paleohydrological and paleoclimatological research? GeochimicaetCosmochimicaActa, 48, 385-390.

[18] Melanby M., 1927 The Structure of Human Teeth. Brit. Dent. J. Vol.48, 737-51

[19] Murray P.E., Smith A.J., Windsor L.J., Mojor I.A., 2003 Remaining dentine thickness and human pulp responses, Int. Endod J. , 36:33-43.

[20] Rink W. J., Schwarz H. P., 1995 Tests for diagenesis in tooth enamel: ESR dating signals and carbonate

contents. Journal of Archaeological Science, 22, 251-255.

[21] Simmer J. P., Fincham A. G., 1995 Molecular mechanism of dental enamel formation. Critical Reviews in Oral Biology & Medicine, 6, 84-108.

[22] Trueman C. N., Tuross N., 2002 Trace elements in recent and fossil bone apatite. Reviews in Mineralogy and Geochemistry, 48, 489-521

[23] Wopenka B., Pasteris J. D., 2005 A mineralogical perspective on the apatite in bone. Materials Science and Engineering:C., 25, 131-143.

[24] Wychowański P., Kolmas L., Kalinowski E., Krzywicki D., Chomicki P., Gąsiorowska M., Wojtowicz A., & Kołodziejski W., 2006 Analiza porównawcza szkliwa i zębiny ludzkich zębów prawidłowych i nadliczbowych metodą mikrospetroskopii w zakresie średniej podczerwieni. Dental and medical problems, 43, 53-57.

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