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Results of the mineralogical investigation of bandage of Egyptian mummies.

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Investigation supported by grant AGH no 11.11.140.158

Introduction

The bandages used for preservation of body of mummies in Egypt are the document of religious ceremony as well as document of technical possibility of conservation of human tissues and other body[1-15]. The mummification is the record of binding up techniques and mineral component use.

Presented investigation was focused on identification of minerals present at Vadi Natrum where salts for mummification were explored at dynastic time.

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Mineralogical as well as other examination of bandages constitute the main part of publication.

Moreover the extracts obtained form bandages were tested for identification as well as for comparison with natural salts used for mummification.

Mentioned investigation was performed using classical mineralogical methods.

Material for investigation

First part of examination was focused on mineral samples of various types of salts collected at Vadi Natrum as the place of natron exploration at dynastic time.

Second and main part of investigation was devoted to bandages representing various degree of secondary transformation starting from perfectly preserved up to completely destroyed ones.

Third part of investigation was performed on water extract obtained from bandages.

Bandage devoted for investigation originated from tombs of Sakkara New Kingdom. Samples showed various phases of alternation starting from perfectly preserved up to secondary altered and now representing powder because of bacteria and fungus activity.

During examination additionally the way of weave of well preserved bandages was determined.

On the surface of some bandages, sometime strongly altered, one can see small fragments of mummified tissues. These tissues were tested histologically.

Substances used for mummification were extracted from bandages using distilled water.

Research method

Technological examination of samples

Minerals as well as bandages were examined using complex methods.

1. Digital microscope.

The observation of structures of minerals and bandages as well as their destruction was performed under digital microscope Interplay. Observed phenomena were documented with photos.

2. Scanning Electron Microscopy (SEM)

This method was used for determination of the rests of mineral and organic material present at and between fibres of bandages. SEM Jeol 540 was used for investigation. Tested samples were fixed to special holder and coated with gold or carbon at vacuum conditions. Together with observations of grains documented by microphotographs the EDS analyses have been conducted.

2. X- ray examination

This investigation was focused on determination of mineral phases present in natural samples collected at Wadi Natrum. Investigation was performed on natural samples (SEM) as well as powdered samples using DRON 2.5 diffractometer of Russian production. Interpretation of X-ray patterns were done using XRAYAN computer program X-ray patterns are included

3. Investigation of structure of bandages

Investigation was performed by prof. Maik (Polsish Academy of Science Div. Łodź). Authors are grateful for description and interpretation of results as well as for discussion concerning mentioned problems.

4. Histological examination of tissues present on bandages

Mentioned investigation was performed by prof. Stachura and his team. Authors are thankful for these interesting examination as well as interpretation of results.

Biological microscope

Preparation of samples

Investigation

Fragments of tissue present on the surface of bandages were prepared for examination using following procedure:

1. Primary fluid softening the material under study:

Ethyl Alcohol 96% - 3 parts
Formalin 1% - 5 parts
5% sodium carbonate - 2 parts

12 –18 h – until material is gummous

2. Discard 1/3rd of sotening solution and replace with the same volume of 96% ethyl alcohol 3 h
3. Ethyl Alcohol 80% 3-6 h
4. Fenol 8% (in 96% ethanol) 15-18 h
5. Ethyl Alcohol absolute 2 h
6. Ethyl Alcohol absolute 2 h
7. Ethyl Alcohol absolute 2 h
8. 1:1 Ethyl Alcohol absolute: Amylacetate 1 h
9. Amylacetate 6-18 h
10. Amylacetate 6-18 h
11. Amylacetate 6-18 h
12. 1% celloidin (in bensomethyl) 24 h
13. Benzol ½ h
14. Benzol : paraffin (54°C) 1:1 3 h
15. Paraffin (54°C) 1-2 h

16. Paraffin (54°C) 15-18 h
17. Paraffin embedding
18. Cutting 3 μ slides
19. Routin staining with hematoxylin and eosine

Parallel slides immunostained for desmin (intermediate filament protein present in muscle cells).

5. Examination of extracts obtained from bandages

This technique was used for determination of mineral and organic substances present in bandages

Extracts of substances from bandages were obtained using distilled water and benzine. After preliminary preparation of bandages using UV and microwaves samples (bandages) were mixed with distilled water and benzine during 48 hours. Obtained extracts were filtered on drains.

Water extract was tested using ASA method for determination of metals. Next it was evaporated and deposited sediment was examined using X-ray diffraction, SEM as well as infrared examination. Solid phase after filtration was

burned and rests were dissolved in mixture of HCl and HF. Obtained liquid was examined using ASA method.

Benzine extract was evaporated after filtration on drain. Organic deposit was devoted to investigation with the use of infrared spectroscopy.

Results of investigation

A. Mineral composition of salts from Vadi Natrum

Microscopic observation performed using SEM (Photo 1, 2) confirmed the samples are composed of various minerals but halite is dominating. Trona as the main mineral used for conservation of mummies was in all samples accompanying phase (Fig. 1 A-B). This results suggest that for preparation of mummies the mixture of minerals was used rather than pure trona or maybe part of deposit containing pure trona was completely explored at dynastic time.

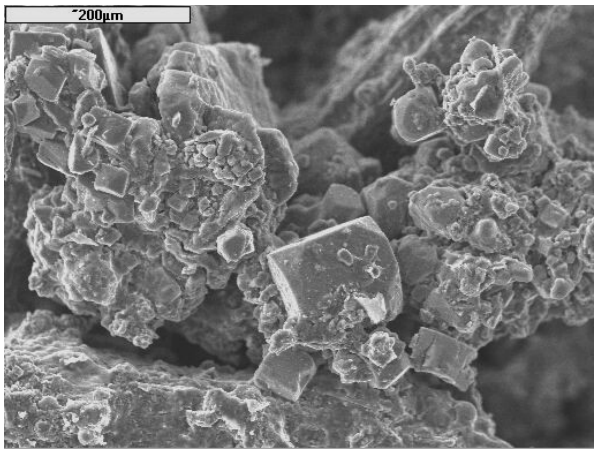
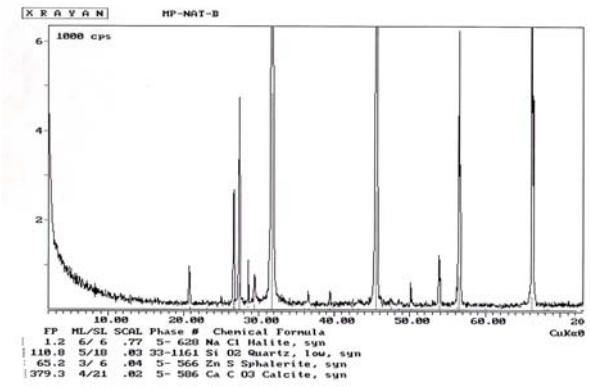
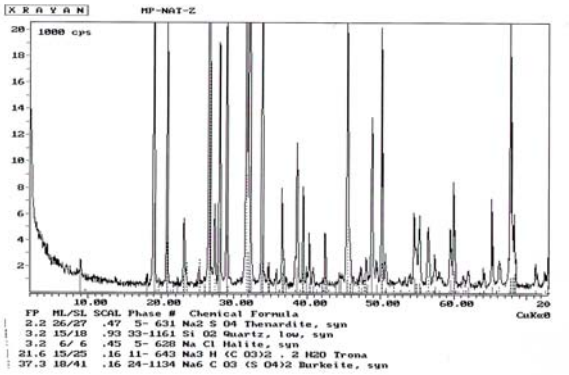


Photo 1 The structure of sample 1



A



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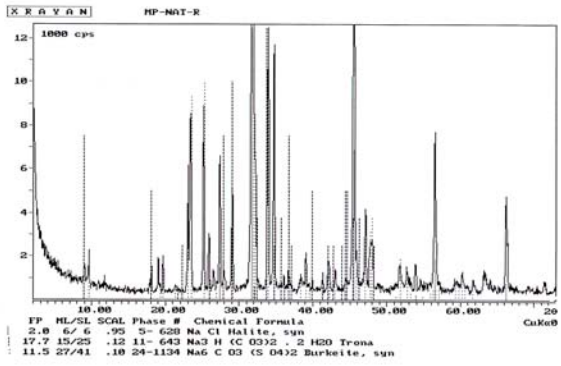

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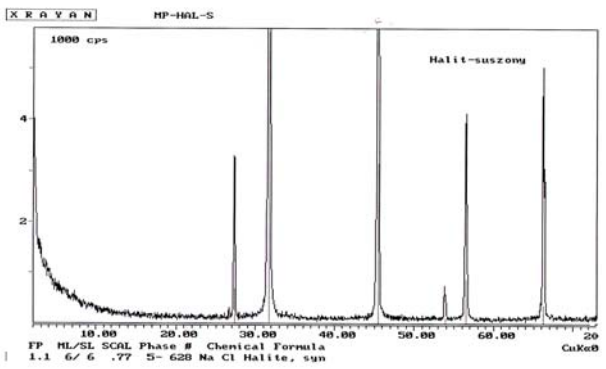

D

Fig. 1 X-ray patterns of tested samples. A – sample 1 - halite, quartz, calcite, B – sample 2 – thenardite, quartz, halite, trona, burkeite, C – sample 3 – halite, trona, brukeite, D - halite

Conclusions

Mineralogical examination showed that in Vadi Natrum halite is the only one mineral present in pure form i.e. without admixtures (Fig. 1D). Most probably it was often used for preparation of mummies too. This supposition is confirmed by results of examination of bandages present below. On the other side most tested samples represent mixtures of minerals where halite is dominating mineral. Trona (natron) is present as admixture mostly minor or is absent at tested samples. Maybe in the past (at dynastic time) deposit of Vadi Natrum contained more trona (natron) and the main amount was explored, but if not we may suppose that for mummification were used rather mixtures of salts.

B. Structure of bandages

Results of observation and examination of structure and way of production of tested bandages are collected in form of table (no 1).

Generally structure of bandage from tomb 402 is well preserved. It is light in colour but at some places one can see traces of organic substance making bandage brownish (Photo 1 a, b).

The structure of material is perfectly seen under digital microscope even with the use of small magnification. Thickness of thread is constant and oscillate between 0.2-0.3 mm. Thread is delicately twisted (Photo 1 b). Whole

Photo 1a Macroscopic picture of well preserved bandage.

Photo 1b The structure of bandage from photo 1a. Digital microscope, magnification 50 x.

structure of material is perfectly and thoroughly made. Alternation – destruction - of bandage due to its age is practically not seen.

Bandage from other tomb showed traces of decoration seen near of the edges of material (Photo 2a). It is not as well preserved as bandage described before. The condition and preservation of material is well seen under slightly bigger magnification where one can see delicate alternation of thread as well as their maceration (Photo 2b). The thickness of threads oscillates due to these processes as well as due to deformation because of stress.

Photo 2a Edge of bandage. Natural size.

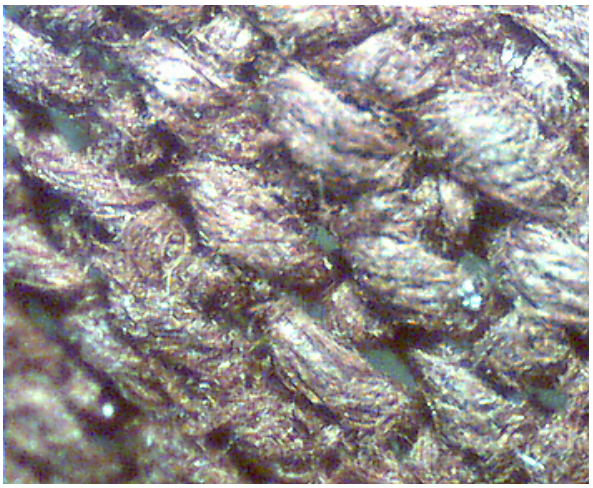

Photo 2b The structure of decorated edge of bandage with small white mineral concentrations. Digital microscope, magnification 60 x.

Moreover between separated thread one can see small light concentrations of mineral substances. They were tested using EDS method (see next chapter).

Strongly deformed and altered bandages are most frequent type of material present between tested samples. Degree of alternation and destruction leads at some cases to full destruction of structure of bandage. This type of samples is sometime represented only by relicts of bandages mixed with secondarily formed dark powdered substance. (Photo 3a). These phenomena concern mostly bandages filling up places after soft tissues i.e. after lungs, brain etc.

Photo 3 a. Completely changed and powdered bandage filling up place after lungs of mummy.

Photo 3b. Deformed, strongly damaged and macerated threads of bandage showed above. Digital microscope, magnification 60 x.

Together with partially preserved relicts of threads one can see traces of mineral concentrations as well as forms typical for fungus. Because of this samples were treated with greatest care. Moreover fragments of such damaged bandages were devoted for more detailed SEM and EDS examination.

Preliminary examination of fragments of bandages showed the presence of fragments of tissues fixed into their texture (Photo 4a). They are of various colours mostly brown, but some of them showed green colour. Preservation of these tissues was various. Mentioned samples were devoted for histological examination described in next chapters.

Photo 4a Surface of bandage with green fragments of skin tissue. Digital microscope, magnification 8 x.

Photo 4b. Structure of bandage (with fragments of skin see photo 4a) damaged by fungus. Digital microscope, magnification 60 x.

While examination performed under the microscope at small magnifications showed strong damage of structure of material specially at places of presence of fragments of tissues (Photo 4b).

Results of mineralogical and chemical examination of bandages

Scanning Electron Microscopy (SEM) and EDS method

Observation of structure of well preserved bandages confirmed perfect structure of material (Photo 1c). Even small threads – elements of structure of thicker threads is perfectly seen and look like done a few days ago.

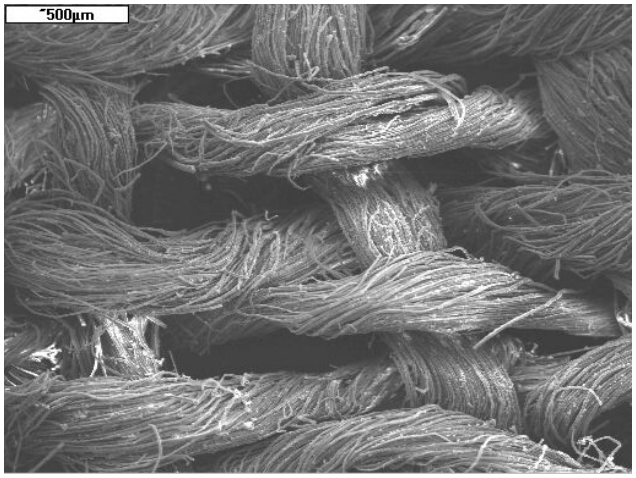

Photo 1c Structure of very well preserved bandage. SEM, magnification about 50 x.

Semi quantitative chemical examination of bandage from this tomb showed absence of minerals used for conservation of body EDS spectra confirmed the presence only of traces of following elements (Fig. 2): Ca, Cl, Fe, P. This means that the bandage under consideration is “clean”.

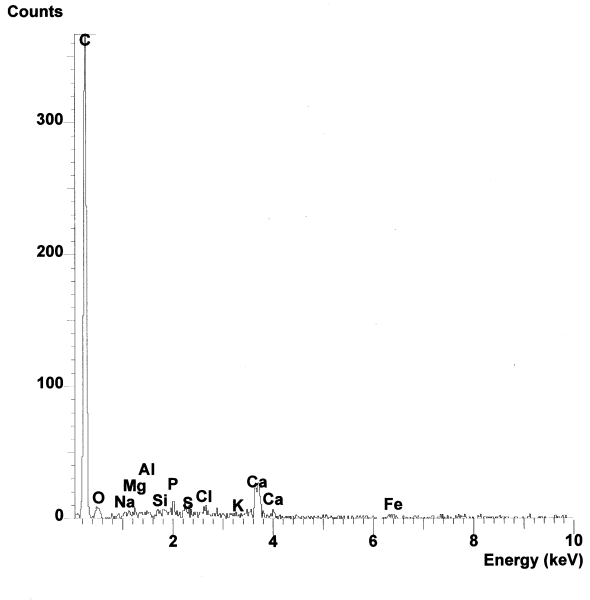

Fig. 2 EDS spectrum of well preserved bandage, not fixed with minerals or organic substances (bituminous). Tomb 402.

Examination of decorated and slightly altered bandage showed the presence of fungus between thread (photo 2c)

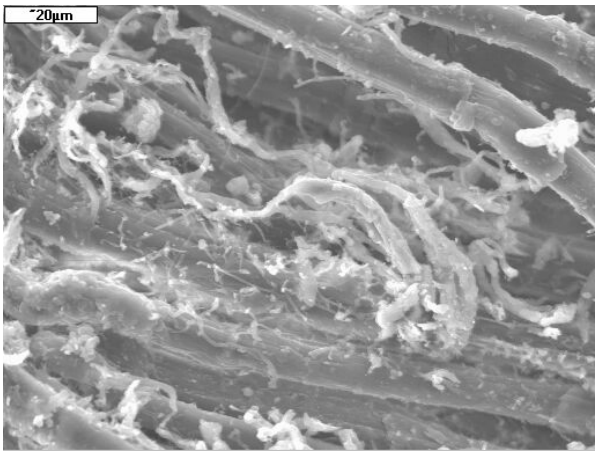

Photo 2c Elements of fungus(irregular fibres) between threads of altered bandage. SEM, magnification about 1000 x.

Chemical analyses done using EDS method (Fig. 3) confirmed the presence of Ca and Cl as dominating elements fixing bandages from this tomb. Together with them one can see Na, P and traces of Si, Fe and K.

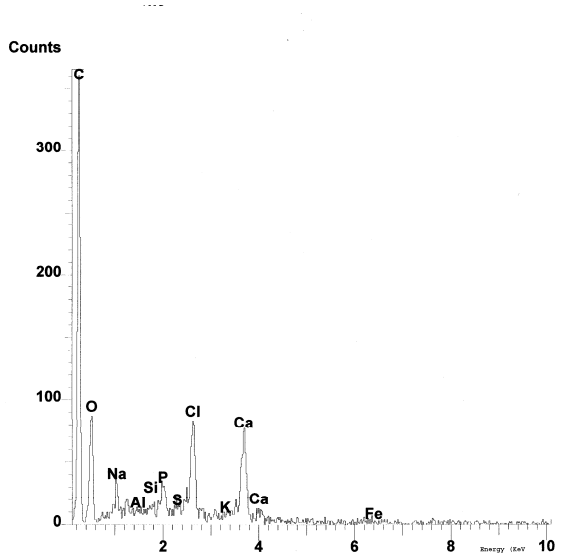

Fig. 3 EDS spectrum of elements present in bandage from tomb no 377.
Ca and Cl are dominating elements used for mummification of person from this tomb.

SEM observations of bandage from other tomb (Photo 3c) confirmed that tested parts of this material are completely altered into powder composed of traces threads, elements of fungus as well as bacterium. This means that bandages present on the body of mummy or very near of the body were at

conditions much more useful for destruction than parts of bandage located slightly further.

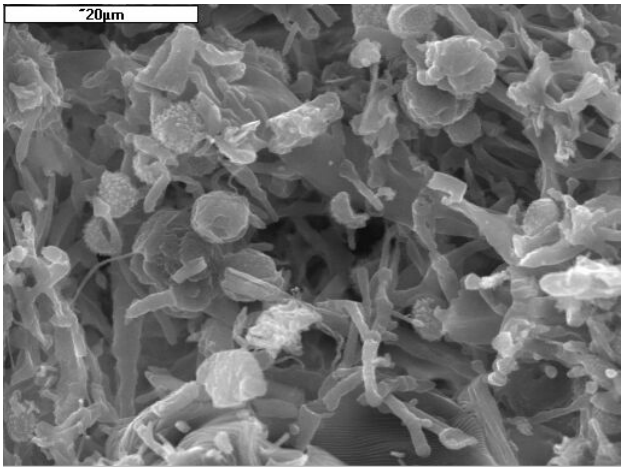

Photo 3c. Microscopic picture of completely altered bandage. One can see bacterium (white spots) and elongated elements of fungus. SEM, magnification about 2000 x.

Chemical analyses performed with use EDS method confirmed the presence of following elements in damaged bandages from tomb 401: Ca, Cl, P, Fe, Al, Na, Mg, S (Fig. 4).

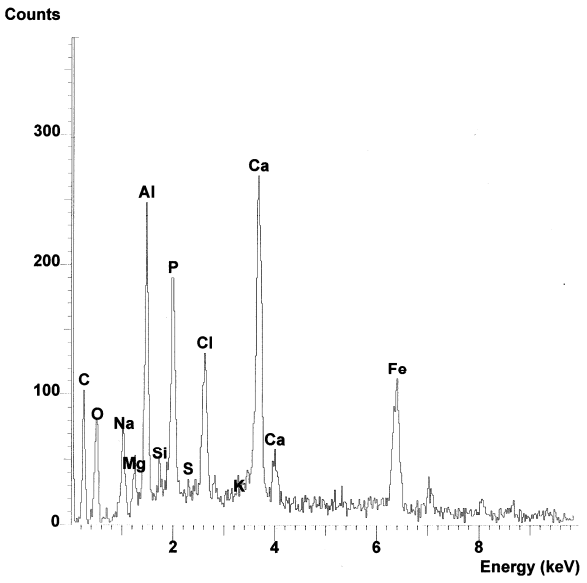

Fig. 4 EDS spectrum of bandage strongly altered by bacterium and fungus

Elements as Ca, Na and Cl are most probably present due to use of minerals for mummification of body. Observations and analyses suggest that processes of destruction of mummified body developed mostly because of bacteria and fungus activity. Mentioned process lead to the migration of same elements from

tissues of mummified body to surrounding bandages. This phenomenon concerns mostly P (migration from bones and probably Fe (traces of blood). The presence of other elements as Mg, Si, Al is of unknown origin.

Results confirm that destruction of human tissues was the main reason of destruction of surrounding bandages.

Examination of bandage from next tomb done with the use of SEM helped recognize their altered structures under the places where are present fragments of skin tissues.

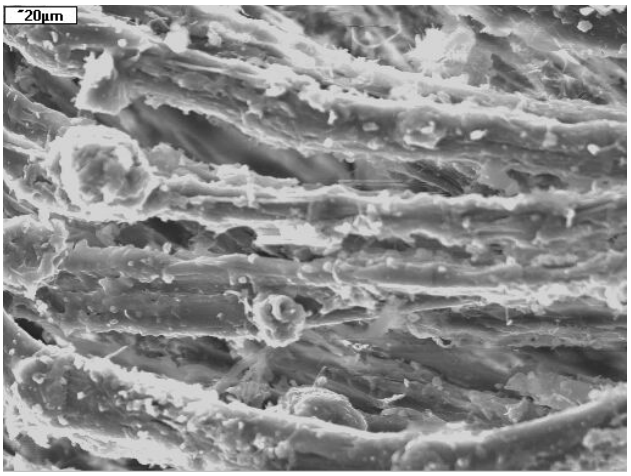

Photo 4c. Microscopic picture of threads under fragments of skin tissue contacting with bandage. One can see reduction of diameter of threads and presence of various biological unidentified compounds. SEM, magnification about 750 x.

The threads of this bandage are under fragments of skin strongly altered or even completely destroyed and generally show reduction of diameter (Photo 4c). The surface of threads as well as spaces between them are full of bacteria and

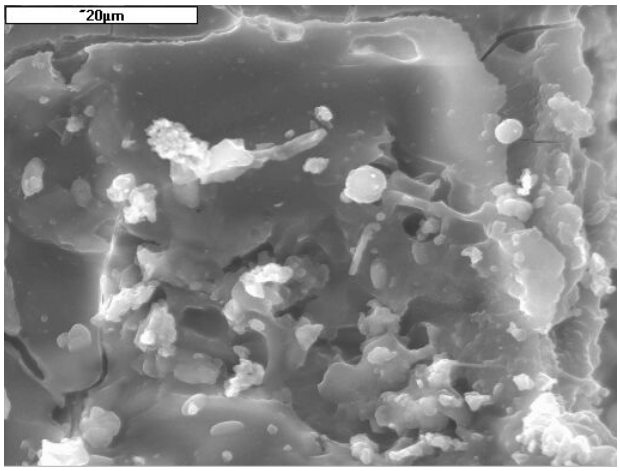

Photo 4D. Fragment of not identified human tissues mixed with bacteria present on the surface of bandage. SEM, magnification about 2000 x.

elements of fungus. The alternation of bandage under tissues is much more advanced than at other places where tissues do not connect with bandage. This means that independently on mummification the processes of destruction were much faster at places where bandages contact tissues than at other places.

EDS examination of bandage present just under the tissues (photo 4D) as well fragments of tissues give interesting results (Fig. 5A, B) and showed great differences of chemical composition.

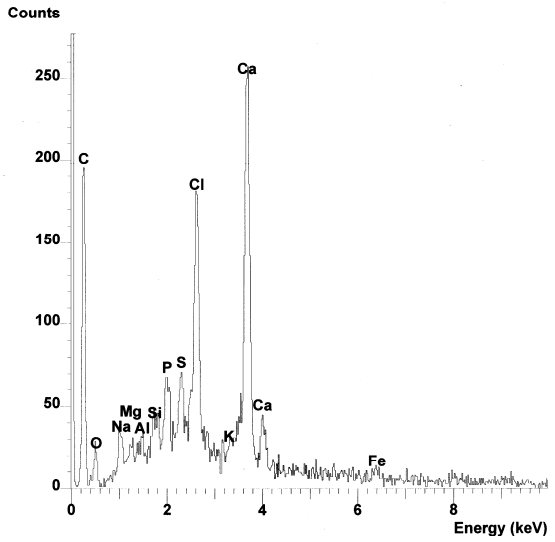

Fig. 5A EDS spectrum of threads under fragments of tissues (see photo 4c), tomb no 404.

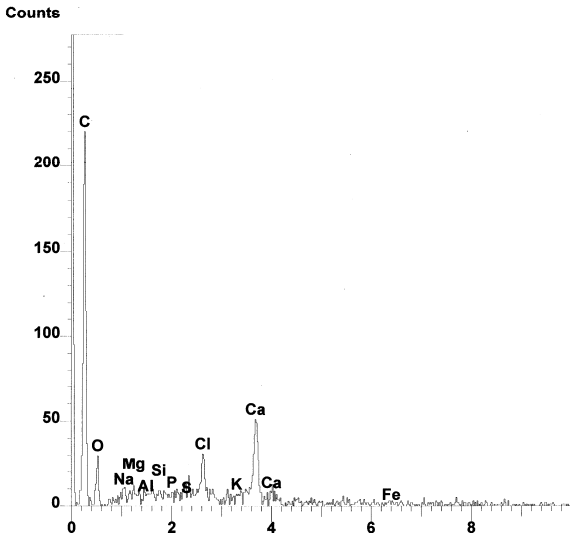

Fig. 5B EDS Spectrum of tissue present on bandage from tomb no 404.

of chemical composition. The bandage present just under the tissue contain high amount of CaCl while the tissue contain less of these elements.

Mg, Na, S, Fe, Al are present in bandage in small quantity but in tissues are practically absent. This means that bandage absorbed more elements from substances used for conservation then tissues of body or bandages are mineralized secondary by substances migrating around the body after burial.

C. Results of histological examination of tissues present between bandages

Examination of biological fragments present on the surface of bandages and examination of tissues confirmed the presence of microorganisms. Because of alternation of tissues their certain identification is impossible.

Histological examination revealed mostly bandages mixed with waxy material dispersing in grains of various size and proteinaceous material. The only “tissue” material was resembling muscle tissue but immunostaining for

desmin (intermediate filament protein characteristic for muscle) was negative (Photo 5A, B). In addition, central position of nuclei was noticed which in humans is seen only in the heart muscle fiber. For this reason a plant origin of fibrous tissue structures has to be considered.

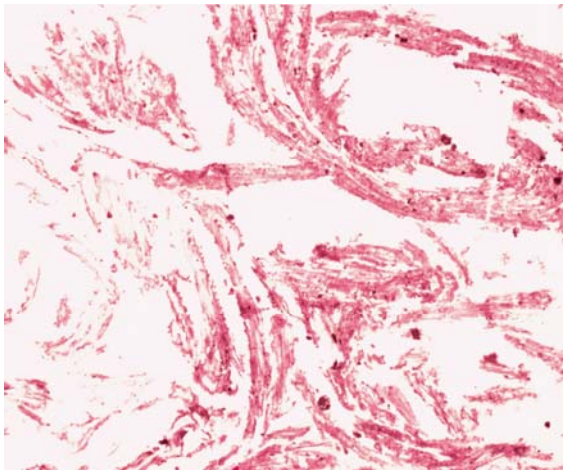

Photo 5A Microscopic picture of fibrous tissues (muscle under the skin?) from bandage. Tomb no 404. Biological microscope, magnification 100 x

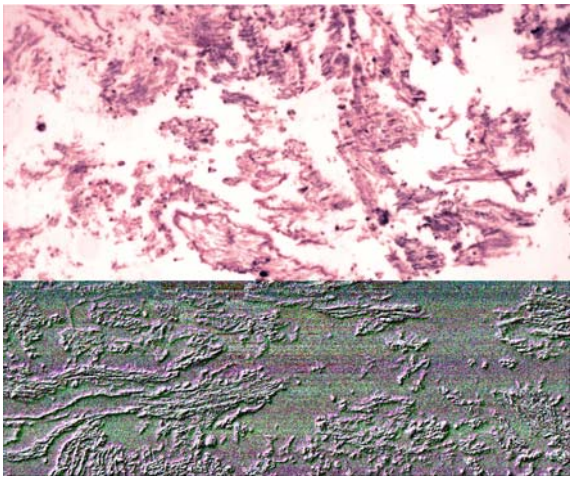

Photo 5B Microscopic picture of muscle tissues (?) from bandage. Tomb no 401. Biological microscope, magnification 100 x

Histological investigation confirmed difficulties concerning identification of tissues due to very small size of biological fragments. Together with mineralogical and chemical data it showed that impregnation of tissues with various substances was much more delicate than impregnation of bandages surrounding.

Conclusions

Examination confirms the structure of bandages is very similar in all tested samples. This means that technology of production of materials for bandage was advanced and had long tradition. Procedures of production were strictly preserved.

Various degree of preservation of bandages used for mummification is the result of secondary alternation by micro organisms. Bandages saturated with organic compounds used for mummification are much stronger damaged than natural bandages. This means that organic substances used for mummification were probably nutritive for bacterium and fungus.

Mineralogical tests suggest that bandages present near of the body and in the body filling for example space after lungs are much stronger mineralised (saturated with substances used for mummification) than bandages present far from body.

Bandages strongly altered by micro organisms show minerals and their chemical composition because secondary processes are not comparative with primary chemical composition, just after mummification.

Obtained results suggest that most probably only mummies were mummified (mixed with mineral and organic components) while mummified body was coated only with clean bandages not mixed with salts and other. The saturation of bandages with mentioned substances is secondary due to migration of ions out form mummies body. Bandages present near of body contain much more salts represented mostly by NaCl and $CaCl_2$ than bandages constituting external cover of body.

Moreover observation showed that presence of fragments of skin tissues (muscles) on the bandages lead to faster destruction of bandage just under the tissues .

D. Results of investigation of extracts obtained from bandages

Water extracts (see Fig. 6) obtained from bandages was tested with the use of chromatography. Tata confirmed Cl (i.e. NaCl- halite) as the main component salts used for mummification of body. Together with chloride are present anions SO_4 connected with sulphates, Other as PO_4 and NO_3 are present in bandages as product of decomposition of soft tissues

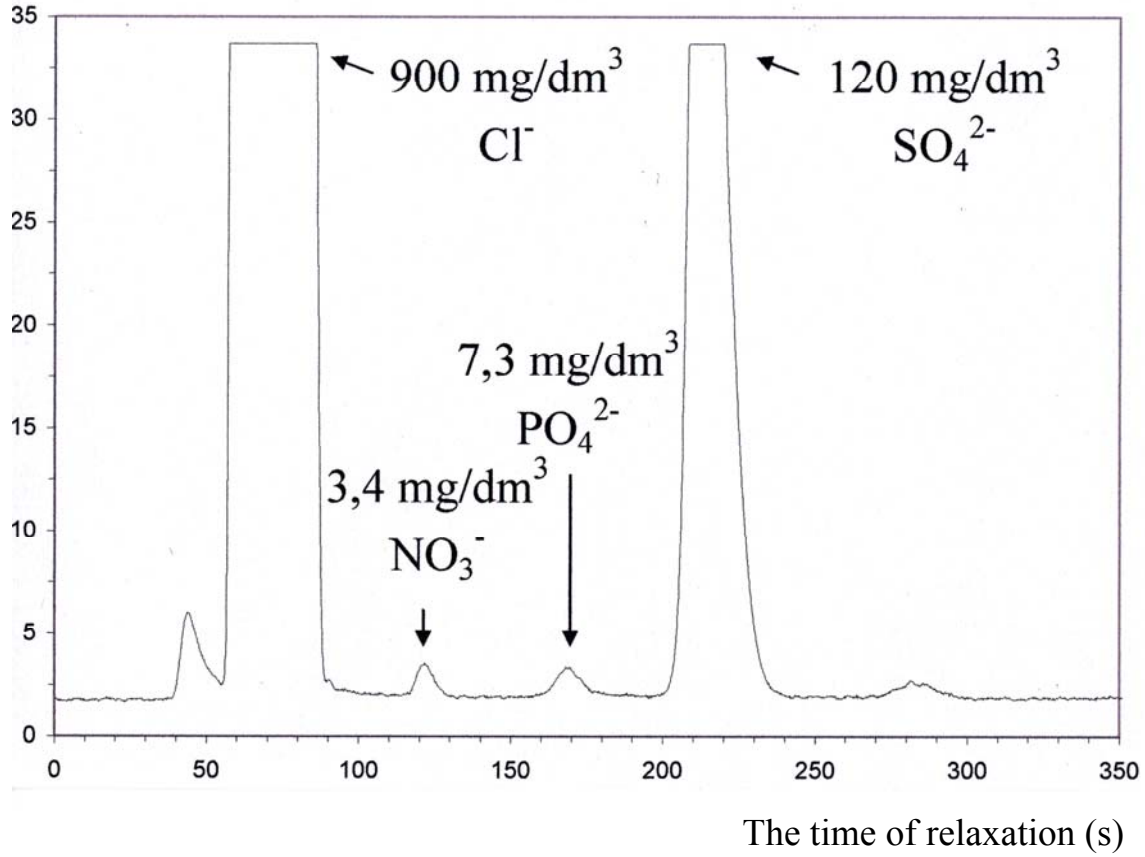

Fig. 6 Diagram showing the presence of ions at water extract obtained from bandages of mummy

Conclusions

Examination of extracts obtained from bandages suggests that rather bandages were not saturated with salts and organic substances because most of tested samples do not contain mentioned components. This means that most probably only body was specially prepared and bandages only coated mummy. Substances from mummified body penetrated secondary to bandages. This interpretation confirms analyses of bandages filling up empty places after lungs as well as extracts obtained from bandages coating body.

Acknowledgment

The authors thank Egyptian Authority for permission of presented examination. Author thanks to prof. K. Mysliwiec (Academy of Science – Warsaw) prof. A. Stachurza (Jagiellonian Uniwersity, Cracow, prof. M. Kaczmarek (Poznan University), Poznan, prof. W. Maik Lodz University for discussion and help,