Deterioration Factors that Affect the Mural Paintings at Memi's Burial Chamber in Saqqara, Egypt

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[Abstract]

Saqqara was the main necropolis of Memphis that was the capital of ancient Egypt during the time of the Old Kingdom, and it has a lot of tombs dating back along the ancient Egyptian history from the time of the first and second dynasties to the Greco-Roman period. Some of the ancient Egyptian tombs from the fifth and sixth dynasties have decorated burial chambers. One of them is the tomb of Memi that might date back to the late fifth dynasty and the beginning of the sixth dynasty. Although his burial chamber has three beautiful decorated walls, the most of the decorated plaster fell down off the bed rock walls. There are some deterioration factors that have affected the mural paintings at Memi's burial chamber, some internal and the other external, and they led to the deterioration of the mural paintings. High humidity is one of the most dangerous factors that carries salts out of the inside structure of the bed rock to the surface and under the plaster, when humidity decreases. It leaves salt under the plaster, that pushes the plaster and causes it to fall down. The internal structure of the bed rock has clay minerals that are affected by the presence of high humidity that leads those minerals to swell and push the plaster off the bedrock walls. Gypsum plaster was used at Memi's burial chamber, whose main components of the plaster are gypsum, sand, calcite and clay minerals. Those components are inhomogeneous and they led to different effect by weathering factors. The thickness of the plaster at Memi's burial chamber varies according to the regularity of the bedrock. However, in general, the thickness of the plaster is thin and the thinness makes it easy to be cracked and broken when it falls off the walls. As a result of high humidity, there is a clear growth of microorganisms on the bedrock walls

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and the plaster. Salts such as gypsum and halite are the worst problem in the burial chamber because they crystalized to form pins that pushed the plaster to separate and fill off the bed rock walls.

1 Introduction

Saqqara is one of the most famous and important archaeological sites in Egypt and all over the world. It was the necropolis of Memphis that was the capital of ancient Egypt during the time of the Old Kingdom, while kings of the fourth dynasty established their necropolis in Giza. The necropolis of Memphis extends in the western desert about 80km long from north to south, which includes Abu Rawash, Giza, Abusir, Saqqara, Dahshour and Meidum.[1] In Saqqara, kings from the Old Kingdom built their tombs and pyramids and the officials and nobles built their tombs near the tombs and pyramids of their kings[2]. Saqqara has a lot of monuments that open to visitors such as the tombs of Mereruka, Kagemni, Ptahhotep. The officials and nobles in the late fifth and the sixth dynasties built their tombs in two parts, the upper part being a big Mastaba that contains a lot of rooms, the lower part a burial chamber that can be reached through a shaft or a sloping corridor.

2 Materials and Methods

There were some methods that could be used to achieve the purpose of the papers which is to identify the deterioration factors that affect the mural painting at Memi's burial chamber. A digital optical microscope made in China was used to study texture of the original plaster, and a data logger (HOBO pro, v2) was set at the burial chamber to illustrate and record the rate of temperature and relative humidity. They helped investigate the effect of both factors on the deterioration of the mural paintings and plaster. XRD device (Pananalytical X-pert pro with cu anode [working at 40 mA / 45 kV]) was used to perform mineralogy of the bedrock at the shaft and the burial chamber. That helped understand different causes of the mural paintings deterioration. Petrographic study was done by using polarizing microscope (Olympus GX71, equipped with a 1.3 mega pixels CMOS camera, with focus range 10mm, C.N made in Japan) to study the crystallization of the bedrock minerals and to prove if they have any effect on the deterioration of the mural paintings. EDX (Column pressure 60 PA, low vacuum, in backscattered mode BASED) was used to analyze and all elements of bedrock and impurities. Microorganism tests were done to identify different kinds of microorganisms that caused deterioration products on the surface of the mural paintings.

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[1] Selim Hassan, *Ancient Egypt from Prehistory to Ihnas Period* [Arabic], Cairo, 1992, p.121.
[2] Z. Y. Saad, *Royal Excavations at Saqqara and Helwan (1941-1945)*, SASAE 3, pp. 25- 54, 105-256, 1947.

3 Memi's Burial Chamber

Memi's tomb is located to the west of king Djoser pyramid at Geser Al-mudir site. It is thought that it is dated back to the late fifth dynasty or the beginning of the sixth dynasty because of the style of construction. It consists of two parts, the mastaba which was built from limestone and the burial chamber which was cut in the bed rock underground. The burial chamber can be reached through a sloping passage. It is about 3.90m wide, 5.55m long and 2.60m height. The entrance up is 70cm height and 80cm wide. The sloping passage is 11.02m long and the entrance down is 1.30m height and 65cm wide. There is still the limestone sarcophagus which is located in a niche to the west wall of the burial chamber. It is 3.02m long, 1.40m wide and 1.25m height. The cover of the sarcophagus is 3.20m long, 1.45m wide and 45cm height. There are three walls of the burial chamber covered with awesome paintings on eastern, northern and southern walls. The plaster is so thin, and it is less than 1mm in some places. Salts are the worst problem in the burial chamber because they crystalized to form pins that pushed the plaster to separate and fall off the bed rock walls.

4 Architectural and Historical Documentation

Archaeological documentation aims to define the exact history of the burial chamber. Although nothing was found to show which period the burial chamber dated back to, and the name “Memi” was usual to be used at the time of the Old Kingdom and the Middle Kingdom. From the burial chamber and the decoration inside it, it can be said that Memi's burial chamber dated back to the time of the Old Kingdom (from the end of the fifth dynasty to the sixth dynasty). More historic study is still needed to ensure the exact time.

Architectural documentation of the burial chamber could be done by measuring its dimensions. The technique that was used to cut into the bedrock can help us to understand how the ancient Egyptians could understand the bed rock in Saqqara about its good layers and its bad ones, how this played a role in choosing the best layer to cut the burial chamber. It also tells how the ancient Egyptians planned burial chambers at that time to save their body and allowed their soul to find the place in the after world, how they could arrange their burial chambers to serve his beliefs. We can see that the ancient Egyptians could cut a place to be used to contain the limestone sarcophagus. Deterioration forms could be shown on the architecture drawing about all cracks, detached edges and missing parts. They could be shown in details in figs. 6-11. Photographic documentation is one of the most important ways of documentation as it starts even before conservation and restoration work during excavation; it is an accurate recording for mural paintings through the excavation to the end of conservation work. It recorded work steps every day and can show any changes that happened to the mural paintings during the work. It is sometimes difficult to understand the work steps just through reading as words don’t usually give us an accurate image of what happened during the work.

However, photographs can tell more and more details about the conservation of this burial chamber. Photos, which were taken before starting conservation, show that a lot of cracks had occurred in the mural paintings. During working, every step was photographed to record the work details and to avoid faults due to unexpected occurrences next stages. USB digital microscope was used to take some detailed photos of the pigments and plaster. It helps to show how stable the plaster is and how good the colors are fixed on the plaster surface. It also helps to show fine cracks that are in the plaster and pigments layer which cannot be seen by the naked eye. 3D drawing was done through one of the 3D applications in details for the burial chamber, which helps to understand the dimensions of the burial chamber without entering inside, and it also helps to investigate how deep the burial chamber is from the surface of the site.

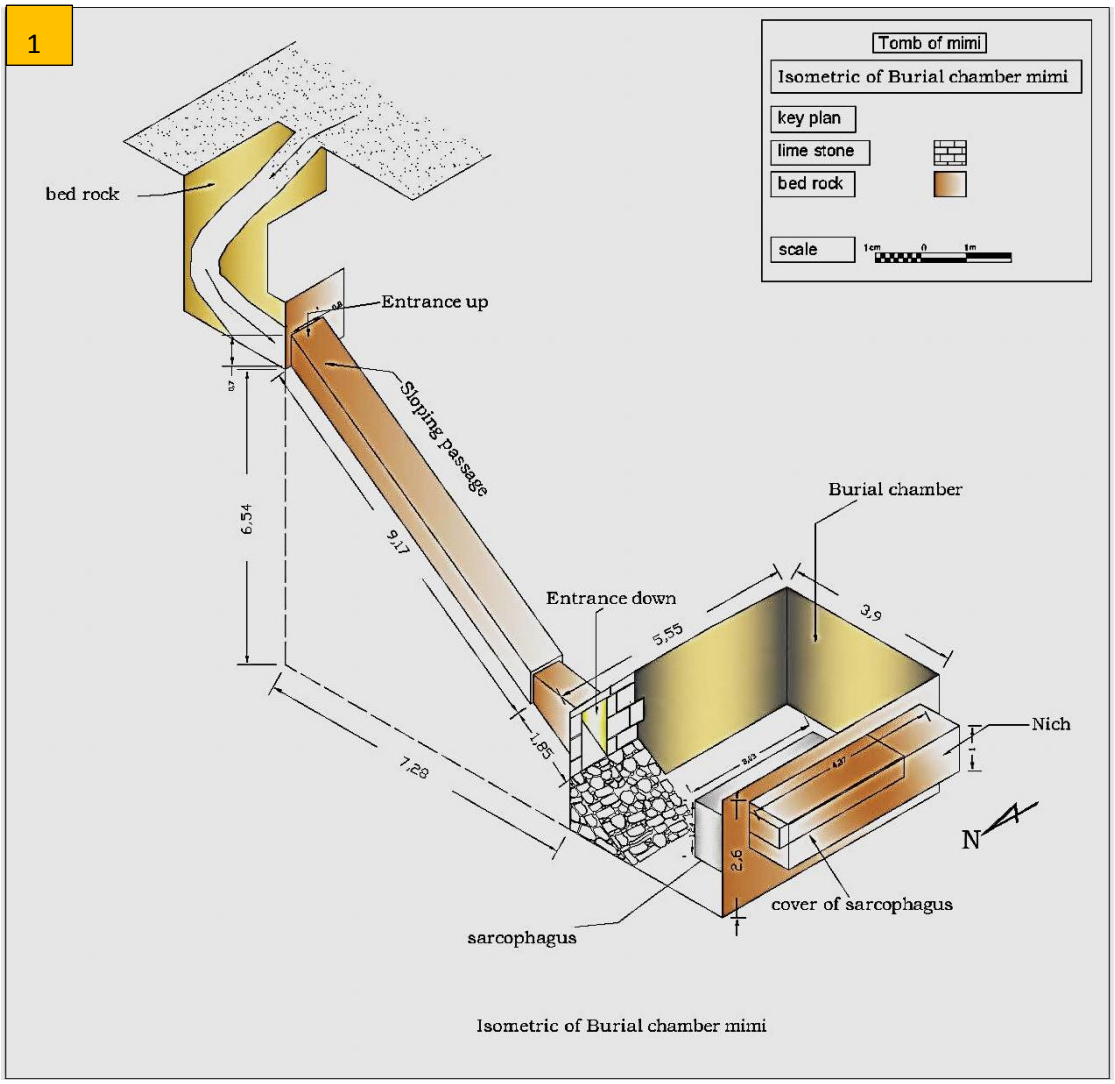


Fig 1 3D drawing of the burial chamber

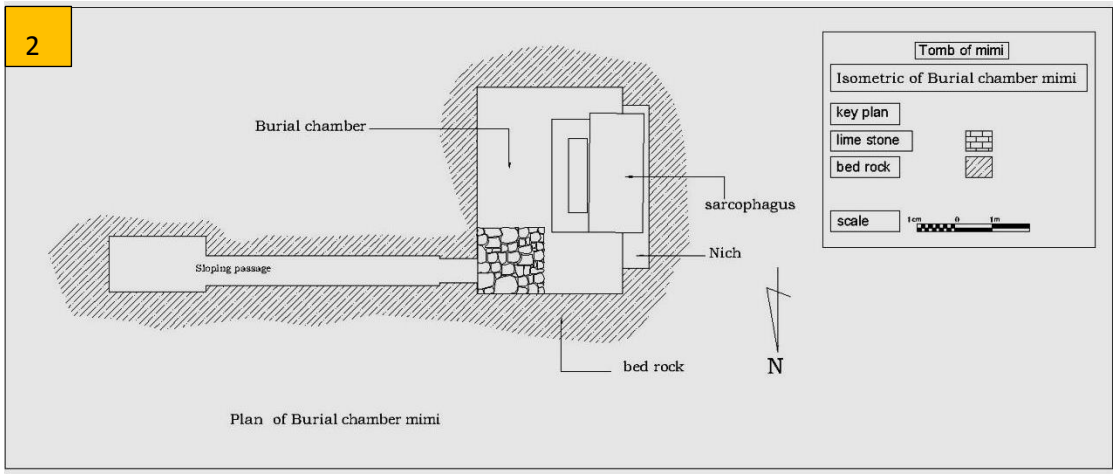
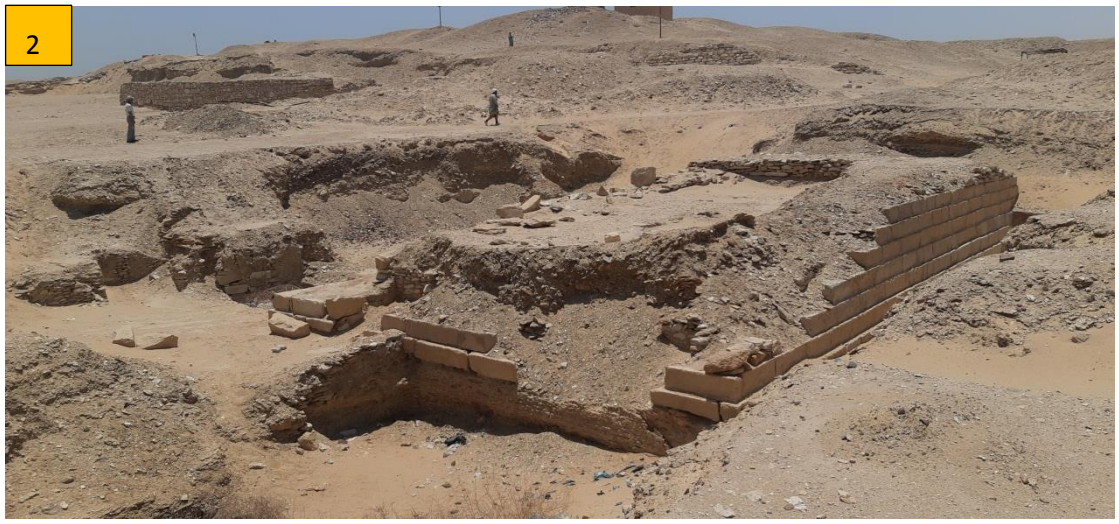


Fig 2 Plan of the burial chamber



Photos 1-3 Location of Memi's burial chamber in Geser Al-moudir

Photo 4-6 Preparing work to open Memi's burial chamber

Photo 7-9 Preparing work inside Memi's burial chamber

5 Deterioration Factors inside the Burial Chamber

Although the burial chamber is 6.54m underground from the entrance level, salts have been crystalized in the shape of pins in the most places of the burial chamber walls. So, it was important to study the environment inside the burial chamber to discover what caused salts to crystalize in this shape that has its damaging effect on the mural paintings.

5.1 Weathering inside the Burial Chamber

It is known from different measurements of temperature and humidity in different places in Saqqara that humidity always be higher especially in summer months (records in the South Tomb is more than 70%, in the fifth level of the Step Pyramid is more than 80%). It goes down in autumn, winter and spring months to be in the safe rates in the South Tomb and in the Step Pyramid, about 60%. In Memi's burial chamber when it was first entered to start working, the relative humidity was about 92%. So, it was necessary to measure temperature and humidity rates inside the burial chamber for that reason. A digital appliance for immediate temperature and humidity measurement rates was put up inside the burial chamber. Measurement can be seen in Table 1. From the measurement, it can be seen that the highest degree of temperature was 31^{c} and the lowest was 26^{c}, that the highest rate of relative humidity was 88% and the lowest was 80%. It was also necessary to reduce the rate of humidity immediately as it would be difficult for restorers to work in that high rate of humidity. It was felt that breathing was so difficult, that the humidity was still very high inside the burial chamber. Therefore, a local handmade scooper was put up inside the burial chamber. After putting it up, humidity rates began to get down until it became in the safe ranges and to the stable rates between 60 % and 63%. It is a safe rate for mural paintings and for starting consolidation work. From these records, it can be concluded that temperature degrees are nearly stable inside Memi's burial chamber. However, humidity was very high, to be exact higher than the safe rates during the first period of work. It is one of the reasons for salts to move from inside the bed rock to the surface and to crystalize under the plaster, causing it to be pushed and fall down to the ground.

Although there is clear evidence that rain water causes deterioration in Memi's burial chamber, it is well known that Saqqara plateau has a lot of different structure layers that contain faults and cracks that may allow rain water to penetrate through those cracks, to carry salts to the surface of spaces in the plateau such as in Memi's burial chamber.

Date	8am	9am	10am	11am	12pm	1pm	2pm
1/8/21	26c/83%	26c/85%	26c/85%	27c/86%	27c/87%	28c/87%	29c/87%
2/8/21	27c/85%	27c/85%	28c/86%	28c/86%	29c/87%	29c/87%	29c/87%
3/8/21	25c/86%	26c/86%	26c/87%	27c/87%	27c/87%	28c/87%	29c/87%
4/8/21	26c/87%	26c/87%	26c/88%	27c/88%	27c/88%	28c/88%	29c/86%
5/8/21	26c/85%	26c/85%	26c/86%	27c/87%	27c/87%	28c/87%	28c/87%
8/8/21	25c/87%	25c/87%	26c/87%	27c/87%	28c/87%	28c/86%	29c/87%
9/8/21	26c/85%	26c/85%	26c/86%	28c/86%	29c/87%	31c/87%	31c/87%
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12/8/21	26c/85%	26c/85%	26c/85%	27c/86%	27c/87%	28c/87%	29c/87%
15/8/21	26c/87%	26c/85%	26c/85%	27c/86%	27c/87%	28c/87%	29c/87%
16/8/21	26c/83%	26c/85%	26c/83%	27c/80%	27c/80%	28c/80%	29c/80%
17/8/21	26c/81%	26c/78%	26c/76%	27c/75%	27c/73%	28c/71%	29c/70%
18/8/21	27c/70%	27c/68%	26c/68%	27c/66%	27c/65%	28c/64%	31c/63%
19/8/21	28c/64%	26c/63%	26c/61%	27c/60%	27c/59%	28c/58%	29c/59%
22/8/21	27c/62%	26c/60%	26c/60%	27c/61%	27c/62%	28c/60%	29c/61%
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24/8/21	29c/63%	28c/60%	29c/60%	29c/61%	30c/62%	28c/60%	29c/61%
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29/8/21	27c/62%	26c/60%	26c/60%	27c/61%	27c/60%	28c/60%	30c/62%
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31/8/21	27c/62%	26c/60%	26c/60%	27c/61%	27c/60%	28c/60%	29c/61%
1/9/21	27c/62%	26c/60%	26c/60%	27c/61%	27c/62%	28c/60%	29c/61%
2/9/21	27c/62%	26c/60%	26c/60%	27c/62%	27c/62%	28c/62%	29c/61%
5/9/21	27c/62%	26c/60%	26c/60%	27c/61%	27c/62%	28c/61%	29c/60%

Table 1 Temperature and relative humidity measurement

5.2 Bed Rock Structure

It is known that the most burial chambers discovered in Saqqara were cut in Saqqara formation that is known geologically as Saqqara member. Saqqara member is formed from non-homogenous components; it is formed from different layers, pure limestone, marl limestone and shell layers. The ancient Egyptians used to cut burial chambers in marl limestone layers as it is not so hard that he could cut the burial chambers easily. Marl limestone in Saqqara is formed mainly from calcium carbonate, though the presence of clay minerals[3], iron minerals and some crystallized salts (such as gypsum and halite)[4]. There are many kinds of clay minerals in Saqqara formation such as montmorillonite that has its dangerous effect on the stability of

[3] D. M. Moor, and R. C. Reynolds, *X-ray Diffraction and the Identification Analysis of Clay Minerals*, New York, pp. 97-112, 1989.

[4] C. Caple, "Towards a Begin Reburial Context: The chemistry of Burial Environment," *Conservation and Management of Archeological Sites*, Vol 6, pp. 3221-3231,2004 .

mural paintings[5] in addition to salts, especially gypsum and halite that have their damaging effect on the mural painting and this is so clear in Memi's burial chamber. However, shell layers can be seen in some burial chambers such as Idout's burial chamber because of the difference of the thickness of layers from one place to another. According to optical observation, the bed rock layers at Memi's burial chamber have two main layers that are not so different in colors; one is yellowish and the second is yellowish to whitish. EDX analyses of the bed rock show that Ca is about 33%, C is about 10.28% and O is about 49.94%, which indicates that the main component of the bedrock is calcite ($Ca_2 Co_3$). There are also Si is about 3.03 %, Al is about 1.06% and Fe is about 1.26%, which means there are clay minerals, quartz and some traces of iron oxides. From the result above, it is clear that the bed rock inside Memi's burial chamber is marl limestone that contains clay minerals and traces of iron oxides as impurities. The petrographic study shows (through photos of the thin section samples) the difference of percentage of calcite, quartz and clay minerals. Calcite can be seen in white color, quartz can be seen in blue color and clay minerals can be seen in green color. Calcite grains vary in size and shape, there are long and irregular shapes, and some are found inside shells, the most of them come from marine deposits, because quartz grains are in different shapes and different sizes, most of them being irregular shapes. The green colored shapes which appear as a background are clay minerals. It can be seen that clay minerals differ in quantities from place to place. Analysis of salts samples by using EDX unit shows also that there are Ca 16.32%, S 6.89%, Na is 1.01% and Cl 0.46%. From the results, it is clear that salts that formed in the shape of pins and push the plaster to fall off the bed rock walls are compensation of both halite and gypsum. However, the presence of gypsum is more than the presence of halite. From that study, it can be shown that the formation of the bed rock inside Memi's burial chamber played a damaging role in deterioration of the mural paintings.

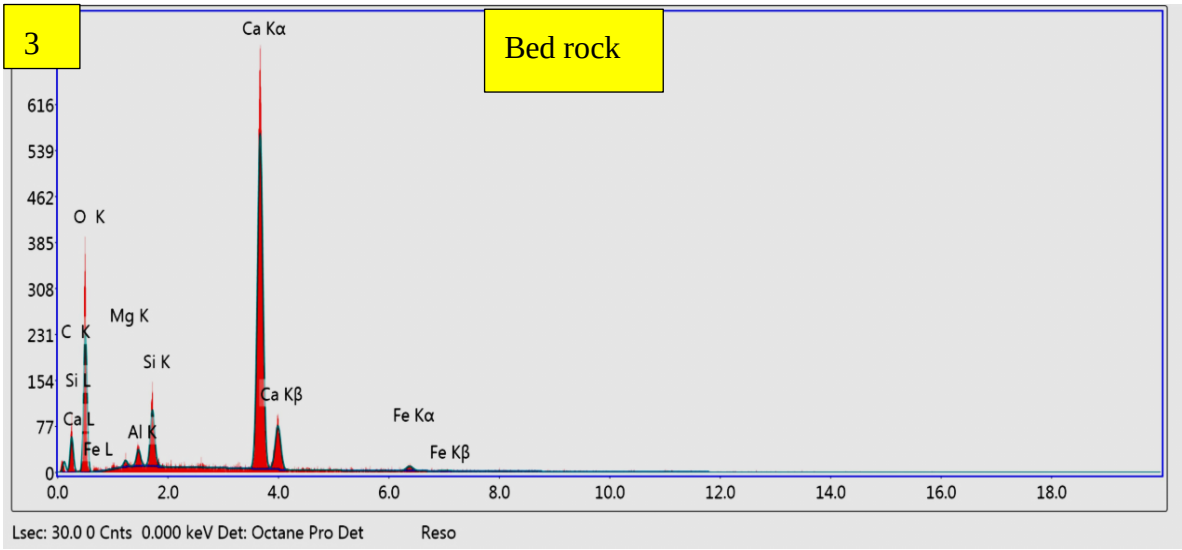


Fig 3 EDX pattern shows the components of the bedrock inside Memi's burial chamber, there are calcite, quartz and clay minerals, there are also little traces of iron oxides

[5] A. F. El-Banna, and J. Pininska, "The Impact of Swell Properties of Esna Shale on Ancient Monuments of the Dier El-Bahari" in *Geotechnical Engineering for the Preservation of Monuments and Historic Sites*. 1997.

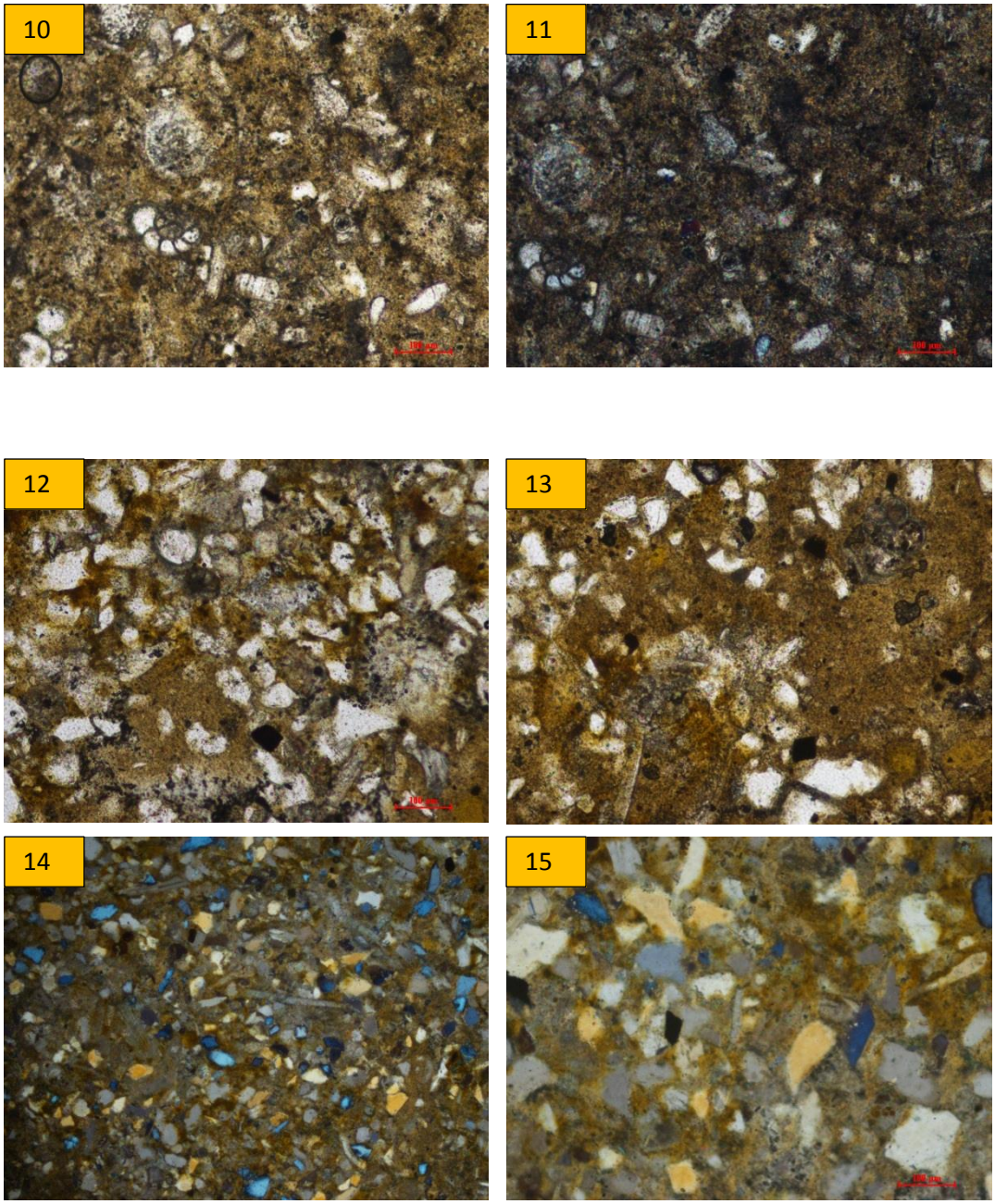


Photo 10-15 Petrographic of the main components of the bedrock inside Memi's burial chamber, calcite in white color, quartz in blue color, clay minerals in green color, marine shells seen also; the percentage of the each component differing in each sample

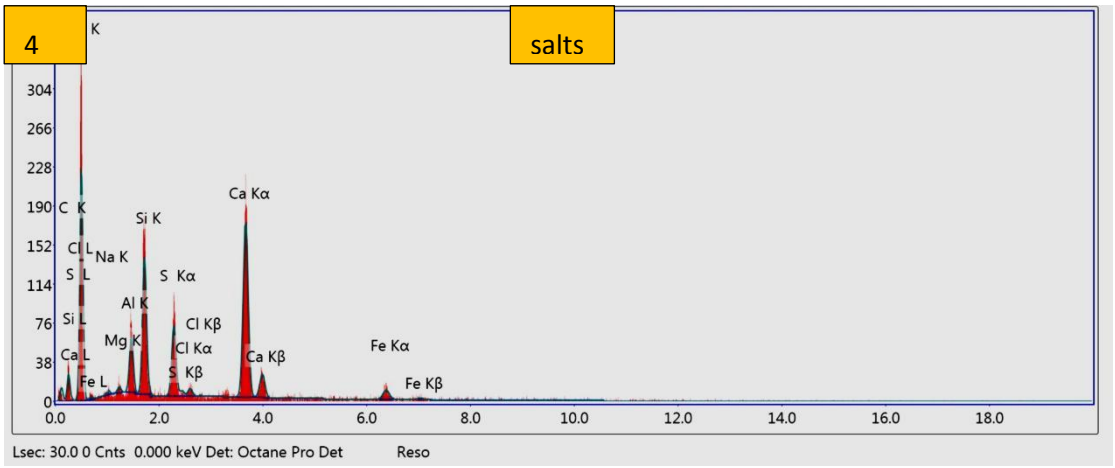


Fig 4 EDX pattern of the components of salts samples inside Memi's burial chamber; calcium and sulfur that means gypsum, sodium and chloride that means there is halite

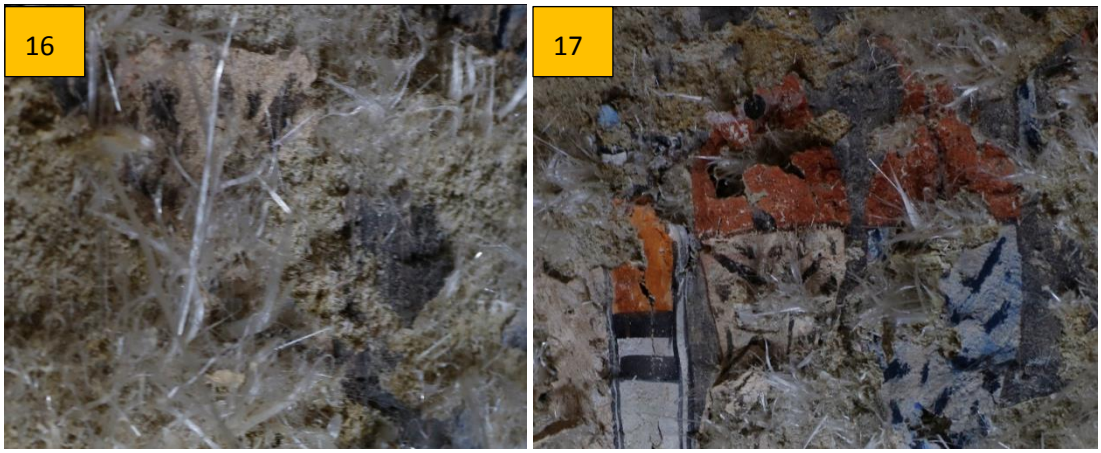
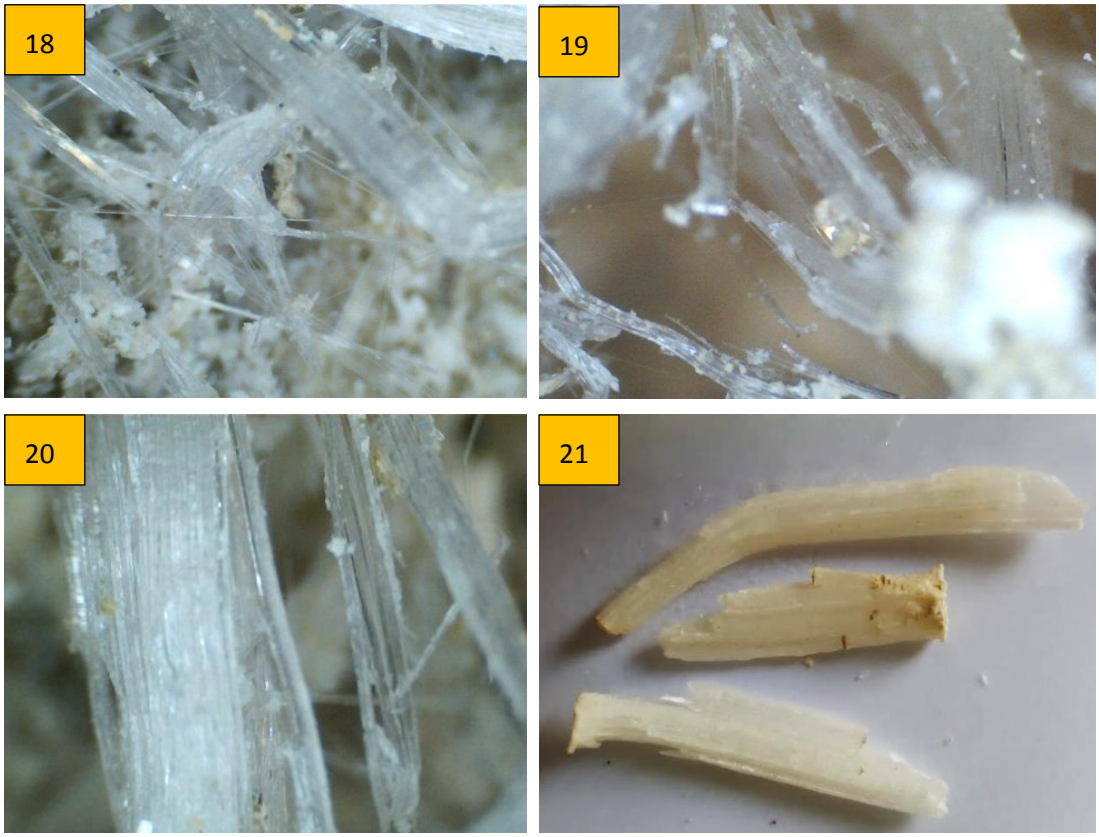


Photo 16-17 Crystallization of salts on the surface of the bedrock



Photos18-20 Digital optical microscope of crystals of salts.
Photo 21 Samples of salts for EDX analysis

5.3 Components of Plaster

Gypsum plaster was used from the Old Kingdom; it was also used in the Middle Kingdom and the New Kingdom, while lime plaster was used from the Late Period and the Coptic Period[6]. The plaster used at Memi's burial chamber was probably the same as used in the time of the fifth and sixth dynasties. Gypsum was used as a binding material at that time, sand was used as filling material in little quantities because plaster was needed to be smooth and fine enough for the pigments to be applied on, calcite was also used as a filler to make the plaster more smooth and more fine. There are also clay minerals that were not probably added on purpose. Fig 5 shows the main components of the plaster at Memi's burial chamber, although they were traces in the main components of the plaster. Those materials have their own physical and chemical characteristics, which means each of those materials can be affected by deterioration factors in different levels. The fluctuation of relative humidity and temperature with their different effects on both components of the plaster and components of the bedrock can cause fine cracks in the plaster[7]. The presence

[6] Lukas, *Ancient Egyptian Materials and Industries* (1965), pp. 314-331.

[7] ريهام عدلى تلف الصور الجدارية . دراسة حالة الصور الجدار ية بكنيسّة القد سّ أبو فانا بد يرّ أبو فانا بصحراء هور بالمنيا , مصر ص 6–16 . 2012

of clay minerals in the plaster causes also deterioration as it is known that clay minerals swell by the existence of humidity and shrink again when they lose it. The presence of clay minerals also causes the occurrence of fine cracks in the plaster. The thickness of the plaster at Memi's burial chamber varies according to the regularity of the bedrock. However, in general, the thickness of the plaster is thin and it makes it easy to be cracked and broken when it falls off the walls. Photos from 22-25 by using optical Digital microscope show fine cracks in the plaster and deteriorated surface in some places

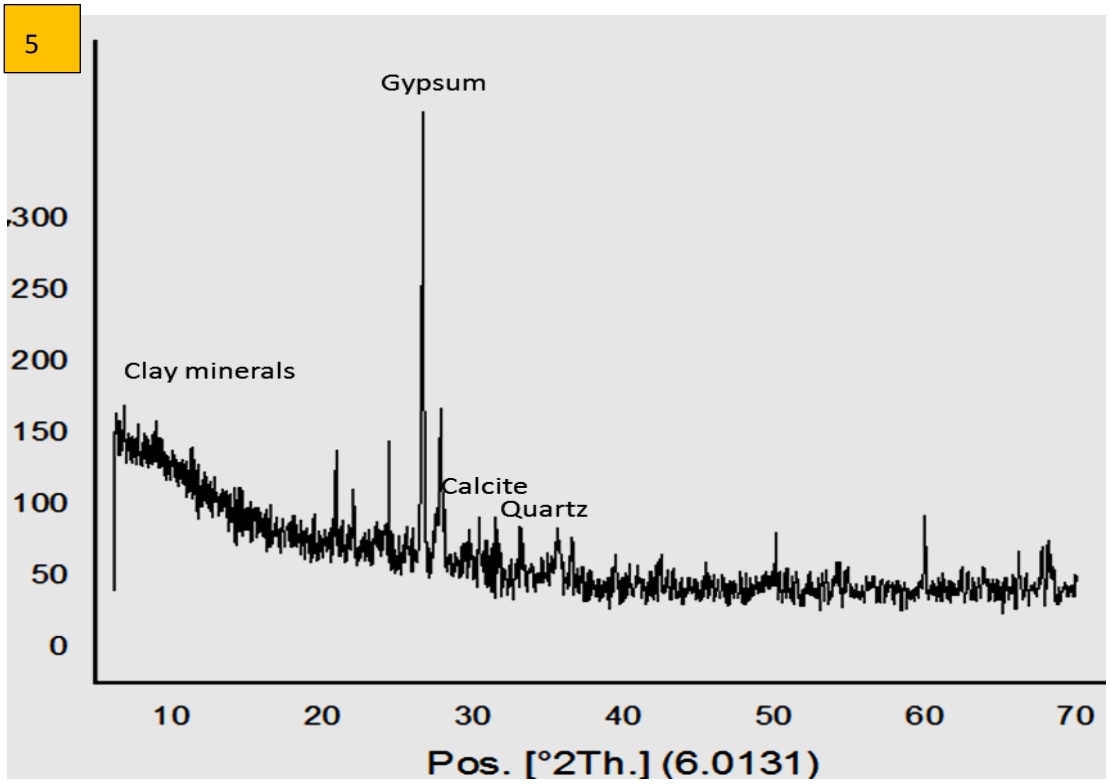


Fig 5 XRD pattern of the components of the plaster samples inside Memi's burial chamber; calcium and gypsum, quartz and clay minerals

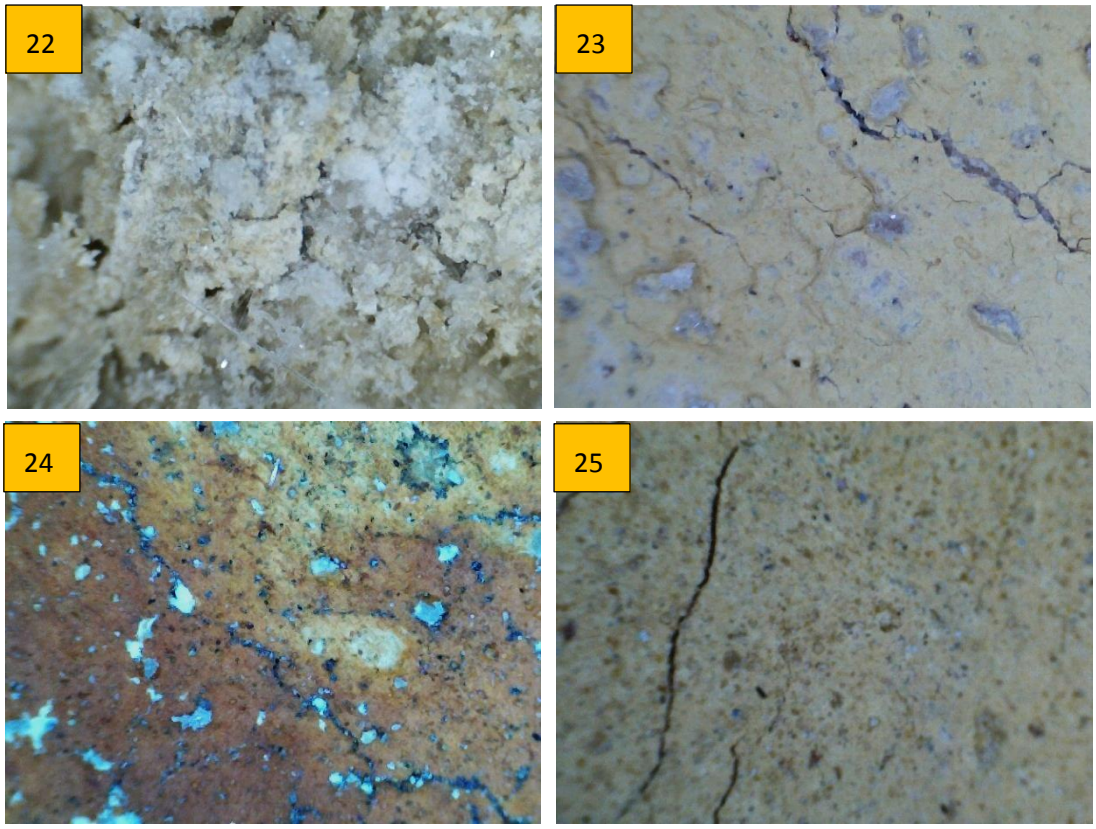


Photo22-25 Optical digital microscope of the plaster samples inside Memi's burial chamber; fine cracks seen in

5.4 Salts

Deterioration by salts is one of the problems that affect mural paintings, especially mural paintings that were applied directly on the bedrock. It is so clear that salts have the most dangerous effect on the deterioration of the mural paintings at Memi's burial chamber, because salts can be seen crystalized in different shapes, they are crystalized in the shape of pins that push the plaster off the bedrock and cause it to fall down. They are also crystalized in the shape of small crystals on the surface of the plaster. It is important to review the general evolution of salt systems in walls and mural paintings to understand the special problems of mural paintings salt weathering hazard. Practically all walls and mural paintings contain

soluble salts[8], either dispersed within the porous materials or concentrated locally[9]. The principal salts that may affect mural paintings and other walls are carbonates, sulfates, chlorides, nitrates, and oxalates of sodium, potassium, calcium, magnesium and ammonia[10] . Salts may come from the bedrock or from the components of the plaster itself. As the EDX analyses shows, the presence of calcium and sulfur in large quantities, which means there is gypsum as the main source of salts at Memi's burial chamber. However, sodium and chloride, which are two elements that form halite (Na Cl), are found in little quantities.

5.5 Microorganisms Growth

Mural paintings are different according to techniques and materials that were used to create them. Components of plaster and pigments are suspended in water or binders and applied on the damp substrate. There may also be inorganic components, which helps the micro organisms such as bactria and fungi to colonize and grow on the surface of the mural paintings in certain conditions of high humidity and mild temperature[11]

As there was high humidity levels inside Memi's burial chamber, it was clear that there would be micro biology growth on the bedrock and the plaster. Therefore, two samples were taken by using swaps from the surface of the plaster. The result was that there are six different kinds of microorganisms may lead to the degragradation and deformation of the mural paintings at Memi's burial chamber. Tables No 2-3 show species of microorganisms that grow in Memi's burial chamber..

[8] David Benavente, Thermodynamic Approach for the Salt Crystallization Transitions by Changes in Climate, Crystallization of Porous Media Cryspom, pp. 145-165, May 2008.

[9] Mahmoud, H, H, M, Stratis, J, A, Minperiodlogical Characterization of the Weathering Crusts Covering the Archaeological Wall Paintings of Karank Complex Temples, Upper Egypt, 37th Symposium, Siena, Italy, pp. 158-169, 2008.

[10] Basem , *op, cit*, pp. 230-248, 2011.

[11] Orio Ciferri, Microbial Degradation of Paintings, p. 2, *American Society for Microbiology*, 1999.

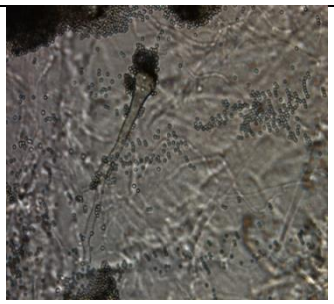
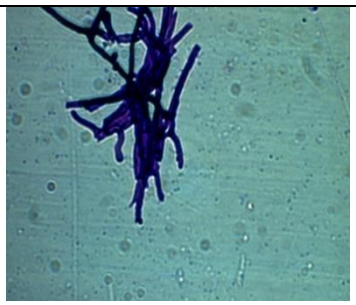
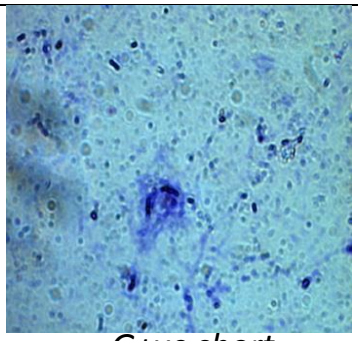
 *Aspergillus fumigatus*	 *Streptomyces vinaceus*	 *Saccharopolyspora hirsute*
 ***A**spergillus niger*	 *Penicillum janthinellum*	 *G+ve short bacilli spore former*

Table 2 Microphotos of the microorganisms that grow at Memi's burial chamber

Swab number	Media used	
	Potato dextrose agar	Nutrient agar
MM1S1	*Aspergillus fumigatus* *Aspergillus flavus* *Penicillum janthinellum*	*G+ve short bacilli spore former*
MMiS2	***A**spergillus niger*	*Saccharopolyspora hirsute*

Table 3 Swap numbers and media used to identify kinds of microorganisms at Memi's burial chamber

6 Conclusison

From the previous study, it can be investigated that there are many different deterioration factors that led to the degradation of the mural paintings at Memi's burial chamber, both extrnal and internal. Mineralogical structure of the bed rock has its damaging effect on the mural paintings because there are different clay minerals that swell with the presence of high humidty and push the plaster to separate and fall off the bedrock walls. There are also pin shaped crystalized salts such as halite and gypsum that push the plaster and cause it to separate and fall off the bed rock walls. The components of the plaster are gypsum, calcite, sand, and traces of clay minerals, and iron oxides. Those materials have their own physical and chemical characteristics, which means each of those materials can be affected by deterioration factors in different levels. The Fluctuation of relative humidity and temperature with their different effects on both components of the plaster and components of the bedrock can cause fine cracks in the plaster. The presence of calcium and sulfur in large quantities means there is gypsum as the main source of salts at Memi's burial chamber. On the other hand, sodium and chloride which are two elements that form halite (Na Cl) are found in small quantities. So, it is clear that salts have the most dangerous effect on the deterioration of the mural paintings at Memi's burial chamber because salts can be seen crystalized in different shapes, also in the shape of pins that push the plaster off the bedrock, which cause it to fall down. They are also crystalized in the shape of small crystals on the surface of the plaster. Although there is no major change in temperature degrees and it is nearly stable at Memi's burial chamber, humidity was very high, even higher than the safe rates during the first period of work. It is one of the reasons for salts to move from inside the bed rock to the surface, to crystalize under the plaster and to cause it to be pushed and fall down to the ground. There are six different kinds of microorganisms may lead to the degragradation and deformation of the mural paintings at Memi's burial chamber.

Fig 6 Deterioration products on the eastern wall

Fig 7 Deterioration products on the eastern wall

Fig 8 Deterioration products on the northern wall

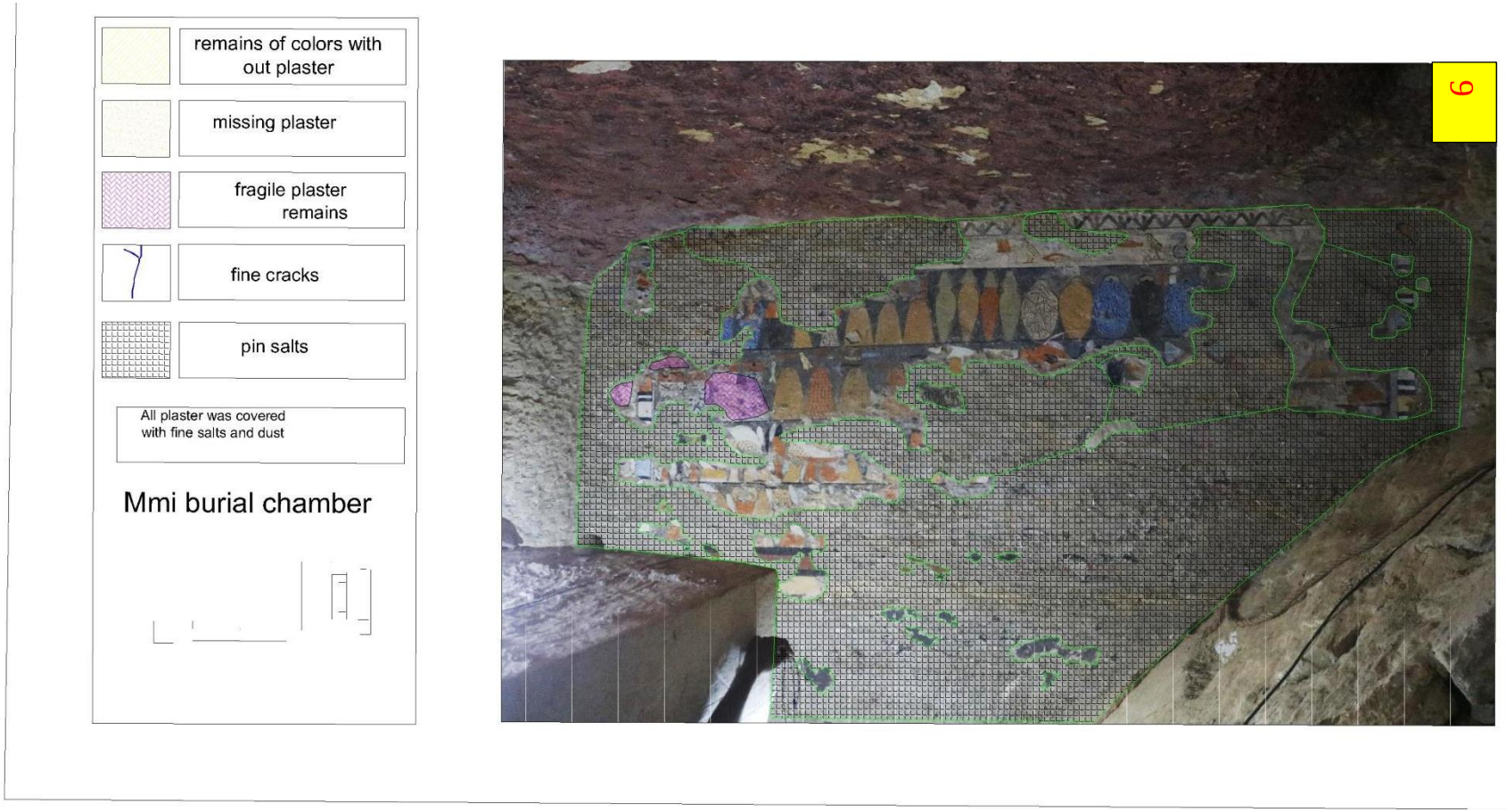


Fig 9 Deterioration products on the northern wall

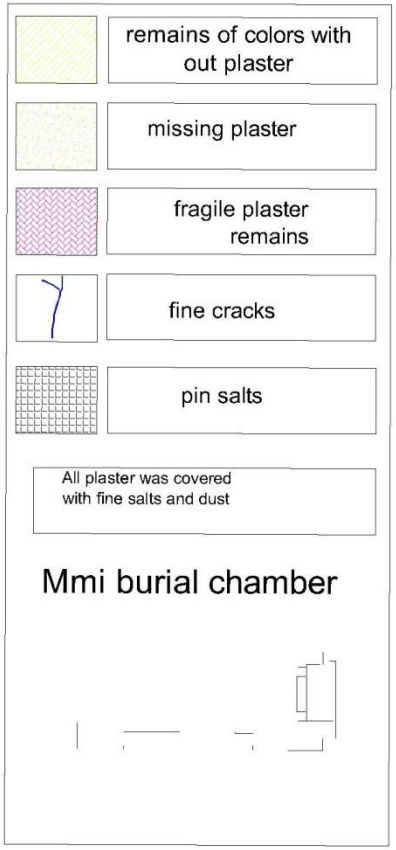


Fig 10 Deterioration products on the southern wall

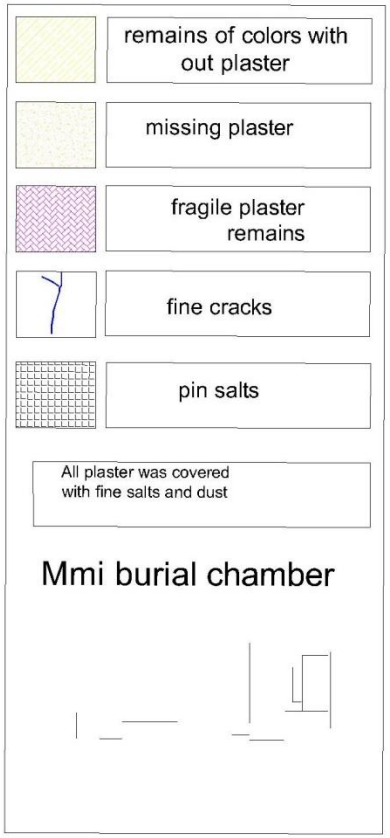


Fig11 Deterioration products on the southern wall

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References

English references:

[1] Basem, Gehan Fathy, *A Scientific Comparative Study of the Deterioration Aspects of the Mural Painting in Roman Houses in Kharga and Dakhla Oasis and the Restoration: Conservation Strategies*, 2011 [Master Thesis, Faculty of Archaeology, Cairo University]. pp. 230-248.

[2] Caple, C., "Towards a Begin Reburial Context: The Chemistry of Burial Environment," *Conservation and Management of Archeological Sites*, Vol 6, 2004.

[3] El-Banna, J. Pininska, "The Impact of Swell Properties of Esna Shale on Ancient Monuments of the Dier El Bahari" in *Geotechnical Engineering for the Preservation of Monuments and Historic Sites*, 1997.

[4] Lukas, Ancient Egyptian Materials an Industries, 1965.

[5] Mahmoud, H. H. M., J.A. Stratis**,** and N. Kantiranis, "Mineralogical Characterization of the Weathering Crusts Covering the Archaeological Wall Paintings of Karnak Complex Temples, Upper Egypt" in the 37th Symposium on Archaeometry, Siena, Italy, May 12–16, 2008.

[6] Moor, D. M., and R. C. Reynold, *X-ray Diffraction and the Identification Analysis of Clay Minerals*, Oxford, 1989.

[7] Orio Ciferri, "Microbial Degradation of Paintings," *Appl Environ Microbiol*. 65(3), 1999.

[8] Saad, Z. Y., *Royal Excavations at Saqqara and Helwan (1941-1945),* Supplément aux Annales du Service des antiquités de l'Égypte 3, 1947.

[9] Selim Hassan, *Ancient Egypt from Prehistory to Ihnas Period* [Arabic], Cairo, 1992.

Arabic reference:

[1] ريهام عدلى تلف الصور الجداريةٌ . دراسة حالة الصور الجدار ية بكنيسّة القد سّ أبو فانا بد يرّ أبو فانا بصحراء هور بالمنيا , مصر ص 6-16 -2012 .

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