

Treatment and Conservation of Six Egyptian Archaeological Stone Sarcophagi

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0. An abstract

Tel El – Deir (tēl āl-dīr) is an archaeological site in Damietta governorate (Egypt), where many stone sarcophagi were excavated. This paper deals with the treatment and conservation processes of the selected six sarcophagi. Examinations and analyses of stone sarcophagi samples were studied using different scientific methods; firstly Petrography study by a polarizing microscope which shows that limestone consists mainly of calcite, beside fossils, iron oxides, clay minerals and some fine grained quartz. Secondly, scanning Electron Microscope (SEM) examination which shows that the crystals were worn out by the effect of the dissolving of some components, loose the binding materials between grains by the effect of salt crystallization, cavities and finally, micro cracks. Thirdly, X-Ray diffraction (XRD) analysis which shows that limestone consists of calcite, dolomite, and quartz in addition to halite traces. The restoration and conservation processes of these objects were carried out using mechanical cleaning, chemical cleaning, extraction of salts, the collecting of disintegration parts, completing of missing parts and consolidation and isolation processes.

1. An introduction:

Damietta is known in ancient Egyptian times as Dami or Damit, as Tamati in Coptic and as Tamamates in Greek. It became Damietta in European languages and in Arabic. In ancient times, it was a part of *Smabhd* Nome, a region of Lower Egypt, where the *Amun* (God of Thebes) was worshiped. It bears number (050109) in the atlas of archaeological sites of Damietta,¹ and it is considered as one of its important archaeological hills (tīlāl). It is located in Kafr Saad; new Damietta city in the north-east of Kafr El- Batekh, No. (19). The Six stone sarcophagi have been covered in the form of human form. These objects were exposed to many deterioration factors.² They were seriously affected by the archaeological environment due to the burial in soil which leads to different deterioration phenomena, fig (1).³ Due to the contact between the stone and the soil, it undergoes chemical, physical and mechanical weathering processes. Soil is the mixture of minerals, organic matter, gasses, liquids and a myriad of micro- and macro organisms.⁴ The soil texture is determined by the relative proportions of sand, silt and clay in the soil. The addition of organic matter, water, gases and time causes the combination to develop into a larger soil structure called an aggregate.⁵ At that point a soil can be said to be developed that can be described further in terms of color, porosity, consistency, reaction etc.⁶ Of all the factors influencing the evolution of soil, water is the most powerful due to its involvement in the solution, erosion, transportation and deposition of the materials of which a soil is composed.⁷ The mixture of water and dissolved and suspended materials is called the soil solution.⁸ Since soil water is never pure water, but contains hundreds of dissolved salts, organic and inorganic substances; it may be more accurately called the soil

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solution.⁹ When these sarcophagi were excavated, some of them did not contain any fractures or cracks, while others were broken into two halves or into several parts and some of them had micro cracks, fig. (2). Stone sarcophagi deteriorated because of many deterioration factors, for example, the effect of soil in the burial environment, changes in moisture and temperature, opening of sarcophagi and transferring processes from the site to the museum store. This study aims to study the mineral composition, the deterioration phenomena and introduces a scientific study for restoration and conservation processes of these six archaeological stone sarcophagi which have covers in human form.

2. State of stone sarcophagi at Tel El- Raba museum store before conservation:

The six stone sarcophagi suffered from many deterioration phenomena for example, dirt on the surface, stains and crystallization of salts, broken into two halves and broken into several parts as it shown in table (1). Fig. (3a-f).



Fig. (1) Shows the stone sarcophagi in the excavation area at Tel El-Deir.



Fig. (2) Shows the state of Stone Sarcophagi after being excavated at Tel El- Deir site which had micro cracks and were broken into two halves or into several parts.

Table (1) shows the state of the stone sarcophagi at Tel El-Raba museum store before the conservation processes:

Sarcophagus	Deterioration phenomena
No. 1	Dirt on the surface, crystallization of salts and the cover was broken into seven parts. Fig. (3-a).
No. 2	Dry clay stains; the cover was broken into two parts and efflorescence of salts. Fig. (3-b).
No. 3	Crystallization of salts on the base, clay stains and the cover was broken into two parts. Fig. (3-c)
No. 4	The base was broken into two parts from the center, crystallization of salts and clay dirt. Fig. (3-d)
No. 5	It was broken into several parts, stains, clay dirt and crystallization of salts. Fig. (3-e).
No. 6	Dirty surfaces, crystallization of salts and the cover and the base were broken into several parts. Fig. (3-f).



Fig. (3-a) shows deterioration phenomena of the sarcophagus No. (1) For example, the fracture of the cover into seven parts, dirt on the surface and crystallization of salts.



Fig. (3-b) shows dry clay stains; the cover of sarcophagi No. (2) Which was broken into two halves and efflorescence of salts



Fig. (3-c) shows crystallization of salts on sarcophagus No. (3) base, clay stains and the cover of sarcophagus was broken into two.



Fig. (3-d) shows the base of sarcophagi was broken into two from the center, crystallization of salts and clay dirt.



Fig. (3-e) shows the sarcophagi were broken into several parts, stains, clay dirt and crystallization of salts.



Fig. (3-f) shows dirty surfaces, crystallization of salts and the cover and the base were broken into several parts.

3. Materials and Methods

Limestone samples have been selected from the stone sarcophagi, and then they were examined and analyzed by the polarizing microscope (PLM), model (Olympus BX51 TF Japan, scanning electron microscope (SEM), using (SEM JEOL Japan) X-ray diffraction (XRD) and Energy dispersive X-ray analysis (EDX). X-ray diffractometer (Philips, PW 1840) with Ni-filtered $\text{CuK}\alpha$ radiation at operating conditions of 40 kV/30 mA and a scan speed of $2^\circ (2\theta) / \text{min}$. was used for this purpose. The physical and mechanical analyses have been determined. A chemical analysis of ground water was carried out.

4. Results:

4.1. Polarizing Microscope (PLM)

Limestone samples have been examined under the Polarizing microscope, it is found that thin sections of Limestone consist mainly of calcite including fossils, iron oxides, clay minerals and some fine grained quartz, fig.(4).

4.2. Scanning Electron Microscope (SEM)

When limestone samples are examined using (SEM), it is found that the crystals were worn out by the effect of the dissolving of some components. Samples lost the binding materials between grains by the effect of salt crystallization and sources of moisture. The internal structure of stone was deteriorated by the attack of soluble salts which leads to increase in porosity and the loss of cohesion, fig. (5).

4.3. Energy Dispersive X-ray analysis (EDX)

The results of the limestone sample shows that it consists of calcium element (Ca) with 41.62%, sulphur element (S) with 13.12%, Silicon element (Si) with 7.18% and Sodium element (Na) with 7.28% in addition to traces from other elements, table No. (2) and Figure No. (6)

Table No. (2) Shows the result of EDX analysis of Limestone sample.

Element	Na	Mg	Si	S	Cl	K	Ca	Fe	Total
Percentage %	7.28	1.51	7.18	13.12	21.12	3.24	41.62	4.93	100

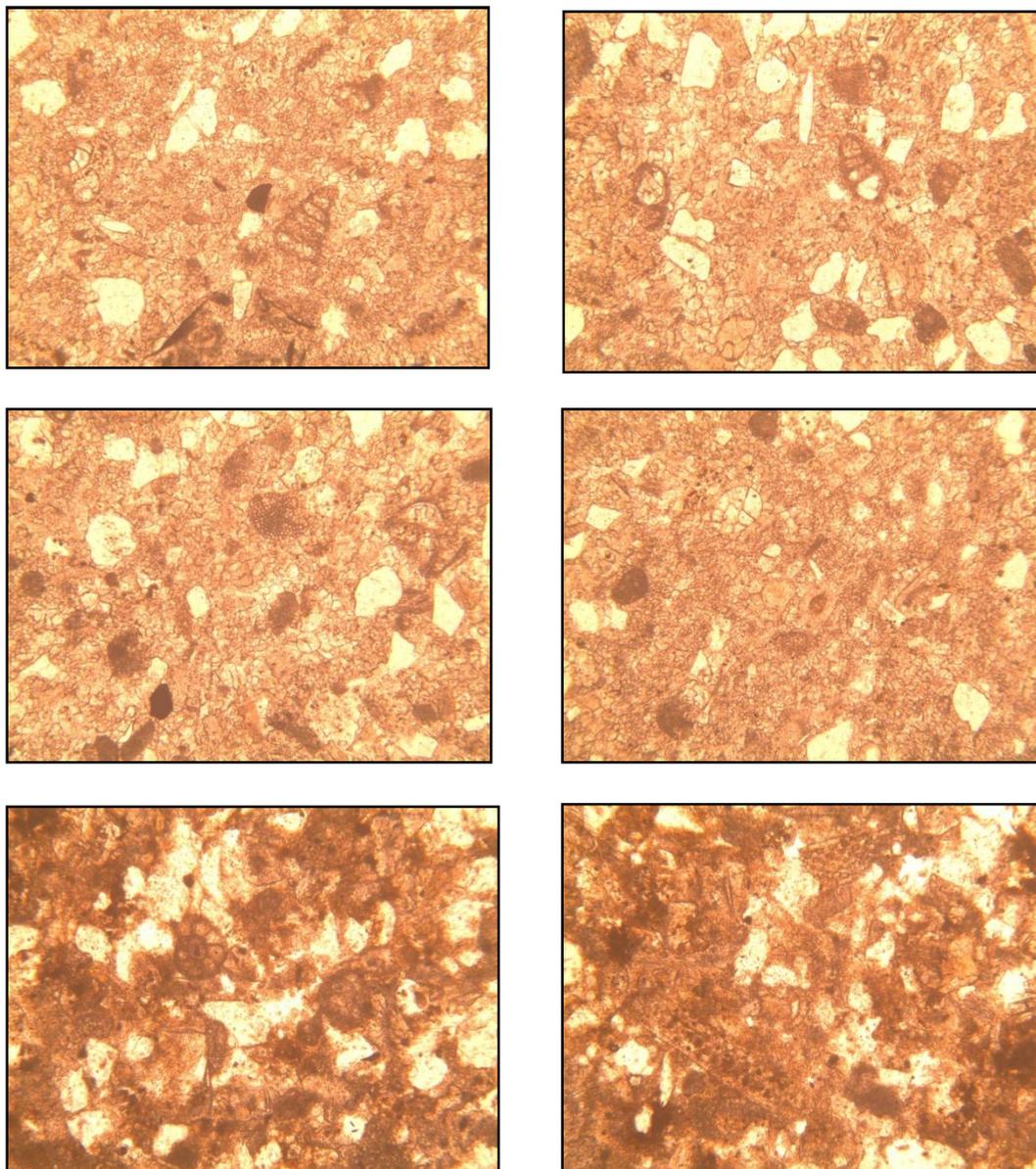
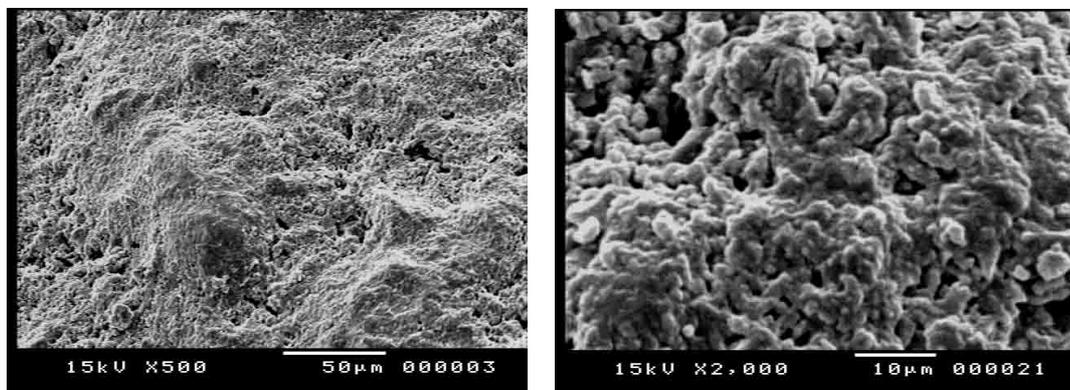


Fig. (4) Thin section photomicrographs showing iron oxides, clay minerals, fossil and grains of quartz in a mass ground of fine- grained calcite. 4X (C.N).



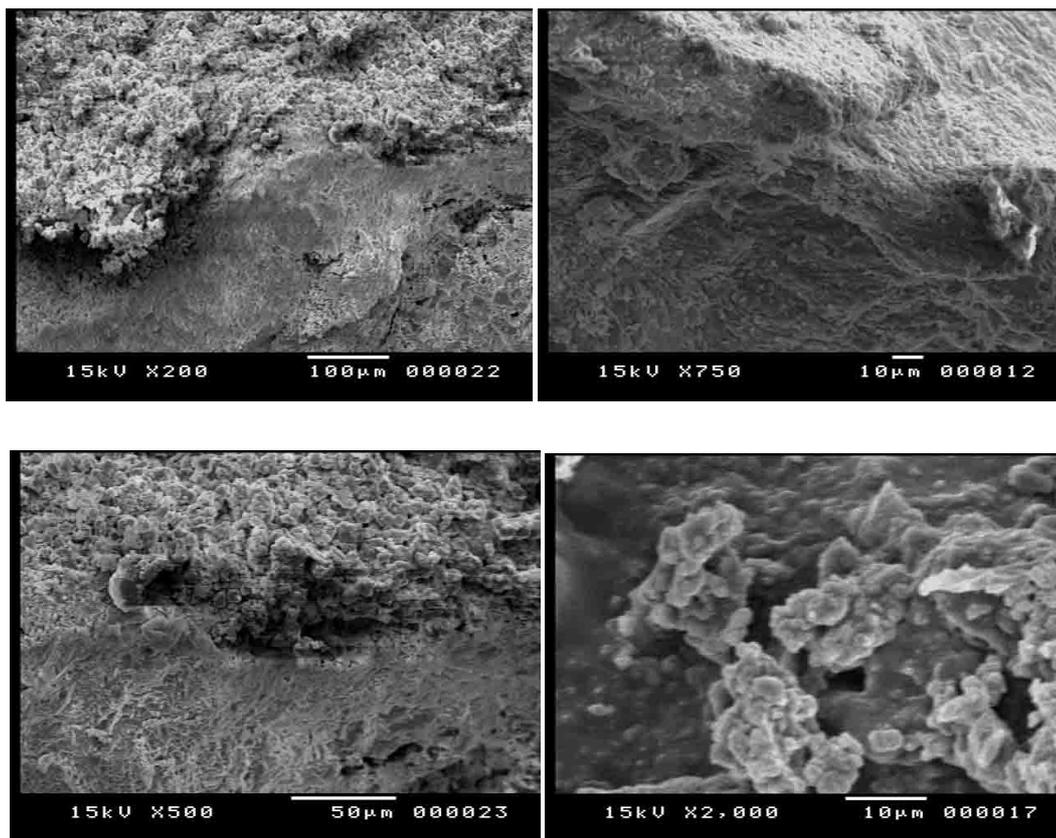


Fig. (5) SEM photomicrographs show disintegration between grains voids, dissolving of some component of stone.

4.4. X-ray diffraction (XRD)

Data of X-ray diffraction of limestone samples shows that the sample consists mainly of calcite mineral, Card No. (5- 0586), Dolomite mineral card No. (11- 078), Halite mineral card No. (5-0628) in addition to Gypsum mineral, Card No. (6-0046), and Quartz figs. No. (6) , (7).

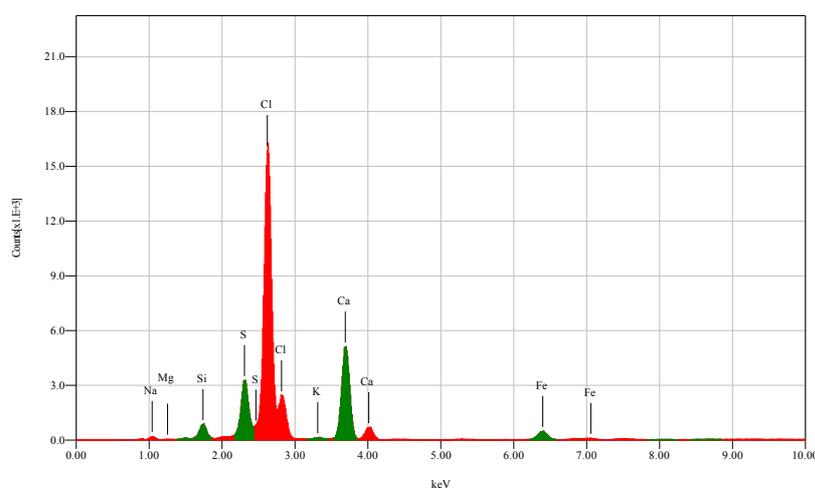


Fig. (5) Shows EDX pattern of limestone Sample.

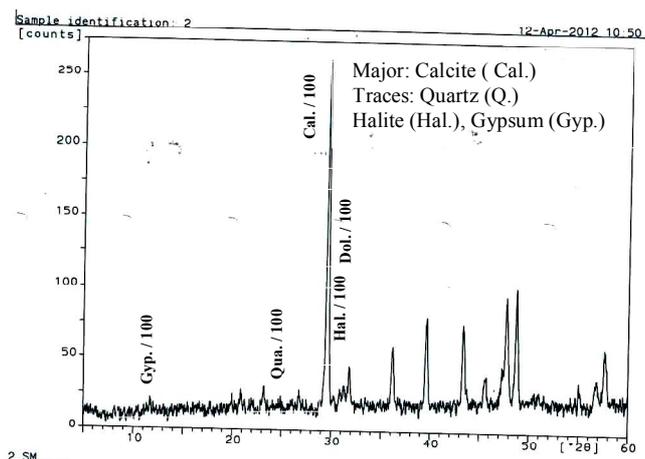


Fig. (6) shows XRD pattern of limestone sample from the stone sarcophagi.

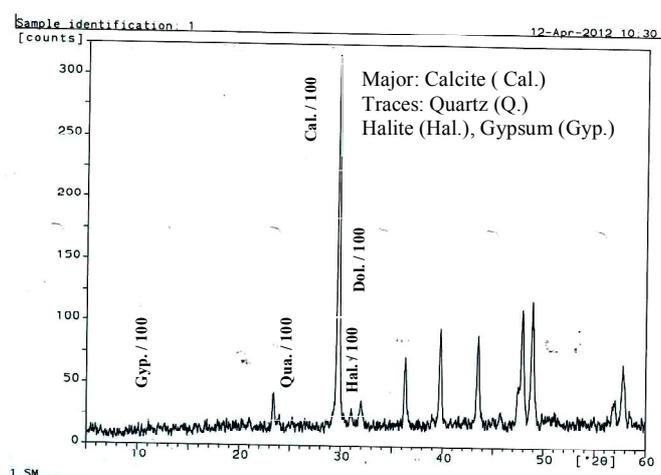


Fig. (7) shows XRD pattern of limestone from the stone sarcophagi.

4.5. Chemical analysis for ground water

A chemical analysis of the ground water sample from the excavation site shows that halite (NaCl) was found with a high percentage (1952), the total chemical analysis of this sample is shown in table No. (3)

Table No. (3) Shows the results of the chemical analysis of underground water from the site.

No.	Chemical compound	Molecular formula	Result (Pmm)
1	Total mineral soluble	Ionized salts	3269
2	Alkalinity as sodium carbonate	NaHCO ₃	479
3	Salinity as sodium chloride	NaCl	1952
4	Sulphates as sulphur trioxide	SO ₃ ⁻⁻	322
5	PH value	Log $\frac{1}{H}$ +	7.5

5. Restoration and Conservation Processes of the Stone Sarcophagi

Dirt and clay stains were removed mechanically using brushes, scalpels and spatulas.¹⁰ Salts which crystallized on the surfaces were removed mechanically by manual tools.¹¹ Soluble salts were extracted by poultices. A poultice consists of

bentonite and sand at ratio 1: 2. Poultices components have placed on the stone surfaces and covered with poly ethylene sheets and were left for two days until the stone surfaces were dried then the poultices components were removed by manual tools.¹² Stone surfaces were washed with distilled water. The process was repeated until salts were extracted.¹³ Stainless steel rods were used with Araldite and limestone powder to reinforce, fix and collect the disintegrated parts. Epoxy resin was used for fixing friable parts. Epoxy (EP 2101) is suitable for this purpose. It is a cyclo-aliphatic epoxy.¹⁴ The resin is available commercially as a 25 % solution in a mixture of isopropanol and toluene. The hardener K 2102 is an aliphatic polyamine that is mixed with the resin 1: 2 by weight. Once the two components are mixed, a temperature dependent induction time is required before application. At 20 C this time varies from 2 – 8 hours.¹⁵ The cleaning process was carried out for disintegrated parts before collecting process. A Piece of cotton with iron oxide pigment were used to determine the position of stainless steel rods on the surface of fracture parts.¹⁶ Electric drills were used in the collection process.¹⁷ Completing the missing parts was carried out using limestone powder mixed with lime and fine sand with 0.5: 1: 3 on order. Consolidation processes were carried out using ethyl silicate.¹⁸ Methyl tri-methoxy silane was used in isolation of the stone sarcophagi surfaces against moisture, figs. (8 – 15).¹⁹



Fig. (8) shows extraction of soluble salts from the stone sarcophagi using bentonite poultices.



Fig. (9) shows the stone sarcophagi no.(1) before, during and after restoration and conservation processes.



Fig. (10) shows the stone sarcophagi no.(2) before, during and after restoration and conservation processes.



Fig. (11) shows the stone sarcophagi no.(3) before, during and after restoration and conservation processes.



Fig. (12) shows the stone sarcophagi no.(4) before, during and after restoration and conservation processes.



Fig. (13) shows the stone sarcophagi no.(5) before, during and after restoration and conservation processes.



Fig. (14) shows the stone sarcophagi no.(6) before, during and after restoration and conservation processes.





Fig. (15) shows the stone sarcophagi after restoration and conservation processes.

6. Discussion:

The stone sarcophagi suffered from weathering phenomena that reflect various environment factors. The X-ray analysis as well as petrography studies indicate that the mineralogical composition is susceptible to weathering and deterioration by salts that comes from the burial environmental conditions.²⁰ The rock porosity enables salts to invade deeply within the rock texture, consequently more and severe deep weathering physically and/or chemically is expected.²¹ SEM shows the disintegration of calcite crystals and the dissolution of the internal micro texture of the limestone, this fact leads to an increase of porosity and loss of cohesion of the stone, and the grains are loose from each other. In a burial environment, the stone sarcophagi were decayed by physical and chemical processes.²² The stone is physically affected by saturation with water soluble salts, abrasion and stone will also be adversely affected by acids and other substances in the ground water.²³ Changes will be resumed as soon as the stone sarcophagi were uncovered in the ground and were suddenly exposed to new environment conditions. From the moment which the stone sarcophagi were exposed to air, the process of deterioration begun again and may be obvious after as little time as a few seconds. The most damaging feature of excavation is the change in the water content of their environment. Those exposed to damp or wet deposits suffer from loss of water and those from extremely dry conditions from the presence of water. The loss of water during the excavation can have several deterioration effects. Probably the most notorious damage is due to soluble salts.²⁴ When the solution in the pores finally dries out after excavation, the salts crystallize. Damage occurs where the salt solution is so concentrated that the crystals fill up the pores exerting, as they grow, enormous pressure on the walls of the pores. Water is the most aggressive agent in deterioration of stone sarcophagi, which acts as a vehicle for weathering processes. Water dissolves and transports soluble salts within the stone causing efflorescence on the surface of the stone.²⁵ The salt crystallization and hydration processes lead to loss of cohesion between grains and causes the spalling, detachment of individual grains, pushing surface layer of stone, different types of cracks, powdering, crumbling with possible appearance of white efflorescence of salts, high failure, fragile and flaking,

exfoliation, detachment of the superficial layers and granular disintegration into powder.²⁶ According to deterioration phenomena of the stone sarcophagi and their status state the restoration processes were carried out. Restoration and conservation processes included mechanical and chemical cleaning, extraction of salts, collecting the disintegrated parts, completing the missing parts, consolidation and isolating processes. Conservation processes are very important for protection the stone sarcophagi from further deterioration and degradation.

7. Conclusion:

Examinations and analyses were sufficient to identify the deterioration factors that had affected the stone sarcophagi. Thus, these objects exposed to many deterioration factors in the burial environment which the stone sarcophagi were in direct contact with soil. The soil properties and its solution played an important role in the deterioration and degradation of the stone sarcophagi. The presence of Halite Salt (NaCl) in rising groundwater leads to dramatic changes of the stone sarcophagi, many cracks and broken parts of the stone sarcophagi as a result of the opening process. On the other hand, one of the important deterioration factors was the transferring process of these stone sarcophagi from tel el-deir site to tel el – raba site besides, the opening process of the stone sarcophagi at the excavation site. Extraction of soluble salts from the stone sarcophagi was carried out using bentonite poultices. Epoxy resin was used for collecting the disintegrated parts. Consolidation processes were carried out using ethyl silicate. Methyl tri-methoxy silane was used in isolation of the stone sarcophagi surfaces against moisture.

Notes:

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