Open Journal of Geology, 2015, 5, 828-845
Published Online November 2015 in SciRes. http://www.scirp.org/journal/ojg
http://dx.doi.org/10.4236/ojg.2015.511071

Mechanisms of the Deterioration of the Wall Reliefs at Shenhur Temple, Upper Egypt and Concepts for Conservation

Nabil A. Bader

Conservation Department, Faculty of Archaeology, South Valley University, Qena, Egypt
Email: nabil.abdeltawab@arch.svu.edu.eg, drnabil_bader@yahoo.com

Received 15 September 2015; accepted 27 November 2015; published 30 November 2015

Abstract

The Roman Period temple of Isis at Shenhur was built and enhanced amid the rule of Augustus (30 BCE-14 CE) through that of Trajan (98-117 CE). It was built of two sorts of local limestone and decorated with reliefs. Examination of conservation state uncovered that it was collapsed and only partly preserved and it disposed of some still buried rooms. The temple is exposed to different deteriorations processes created by internal and external stresses because of the mineral composition of the building materials, atmosphere variables, salts crystallization and groundwater. In this study, the deterioration problems of the wall reliefs were examined for the aim of its conservation. For this purpose, the chemical, physical and structural characterization were performed by means of X-Ray Diffraction (XRD) and observation of thin section by transmitted light optical microscopy (LOM), polarized microscope, Scanning Electron Microscope (SEM) attached with EDX and thermogravimetric (DTA & TGA). Additionally, microbiological study and chemical analyses of ground water were carried out. Results demonstrated that the deterioration of Shenhur was because of the forceful activity of the environment agents and soluble salts such as chlorides and sulphates. These results and information allowed that the identification of the types of salts and deterioration features might be used in the future for conservation purposes.

Keywords

Shenhur Temple, Deterioration, Water Analysis, DTA & TGA, Salts, SEM-EDX, Conservation Concepts

How to cite this paper: Bader, N.A. (2015) Mechanisms of the Deterioration of the Wall Reliefs at Shenhur Temple, Upper Egypt and Concepts for Conservation. *Open Journal of Geology*, **5**, 828-845.
http://dx.doi.org/10.4236/ojg.2015.511071

1. Introduction

1.1. Location and History

The Roman Period temple of Shenhur, dedicated to the Great Goddess Isis, is located 20 km north of Luxor, on the east bank of the Nile. It was built and decorated during the reign of Augustus (30 BCE-14 CE). The northern exterior wall received texts and reliefs on both sides of the false door during the reign of Tiberius (14-37 CE). The eastern and western exterior walls were decorated under Claudius (41-54 CE). The final stage in the building process occurred during the reign of Trajan (98-117 CE). Excavations in and around the temple have revealed that the structure was used as a habitation during the fifth to seventh centuries CE [1]. During the Islamic period, traces of a major fire and evidence of the deliberate destruction of cultic equipment throughout the temple suggested that the process was not a peaceful one and that the pharaonic cult was struck down hard by Christianity. The modern Arabic place name (Shenhur) derives from the ancient Egyptian name of the site, P3Š (n) H̱r, "the Lake of Horus", Coptic. The earliest preserved notes on the temple of Shenhur came from Nestor l'Hôte, who visited the site in 1839 and made drawings of several scenes with their inscriptions [1]. Detailed scientific interest in Shenhur only began in 1989, when Jan Quaegebeur (KU Leuven) and Claude Traunecker (Charles de Gaulle University, Lille) joined forces to undertake an archaeological and epigraphic project at the site, they led two missions to Shenhur, during which the epigraphy of the interior rooms and the excavation of both the temple interior and the lateral chapel were the main focus [2].

1.2. Architectural Description

The dimensions of the temple are 29 × 44 m (**Figure 1**). Its construction and decoration took place in several stages. The northern part of the temple (rooms I-XIII) is the oldest and is referred to as the "Augustan temple". The sanctuary's facade and the central gates leading to rooms II and IX were decorated in Augustus's reign as the cult relief on the rear wall of the temple. This small temple also harbors a number of crypts: one spans the entire width of the rear wall behind the sanctuary (room VII); another is located beneath the pavement of the *wabet*. During the reign of Tiberius, a small lateral chapel, which seemed to have been dedicated to the cult of the child-god Horudja, the son of the Great Goddess Isis was built in the southwest of the Augustan temple. This chapel could possibly have served as a "mammisi" although its full meaning remained uncertain. The originally free-standing lateral chapel was connected to the Augustan temple probably during the reign of Nero (54-68 CE), when a hypostyle hall with four columns was built between the two structures, the final stage in the building process occurred during the reign of Trajan (98-117 CE), who added a wide pronaos (13 × 29 m) fronting both the hypostyle hall and the lateral chapel. While part of this pronaos was still buried under a mound of sand supporting a railroad track employed for the transport of sugar cane, its northeastern corner was uncovered in 1997. Excavation showed that there was no second lateral chapel parallel to that of Horudja, and that the pronaos had eighteen columns, of which six were linked by inter columnar screen walls to form the facade of the building. The temple of Shenhur faces south, in contrast to the usual east-west orientation of most Egyptian temples that places them perpendicular to the Nile. However, the Nile does not strictly flow from south to north in this region, but rather from east to west; thus the temple is still oriented largely perpendicular to the Nile [1] [2]

1.3. Wall Painting

The Ptolemaic temple of Shenhur was built of inferior limestone containing fossil inclusions and preciously decorated with reliefs and inscriptions; Shenhur temple has many scenes and historical texts that are considered one of the most important sources for intermediate period study. Shenhur is located between the major cult centers of Koptos and Thebes. The temple was influenced by the theological systems of these two centers, as is evident, for example, in the decoration of its walls, which prominently display the triads of both Thebes [3]. Visual examination reveals that most of the temple murals were carved on stone and the ancient artist used sunk relief and a combination of sunk/raised relief in the murals of façades which are exposed to sunlight, while he mostly used raised relief in the internal murals. The temple has many scenes with different topics, as shown in (**Figure 2**).

1.4. Conservation State

During the inspection of Shanhur temple, different kind of alterations and degradation phenomena were evidenced, such as structural damages (failures, erosion, spoliation), biological attacks and effects of neglect of

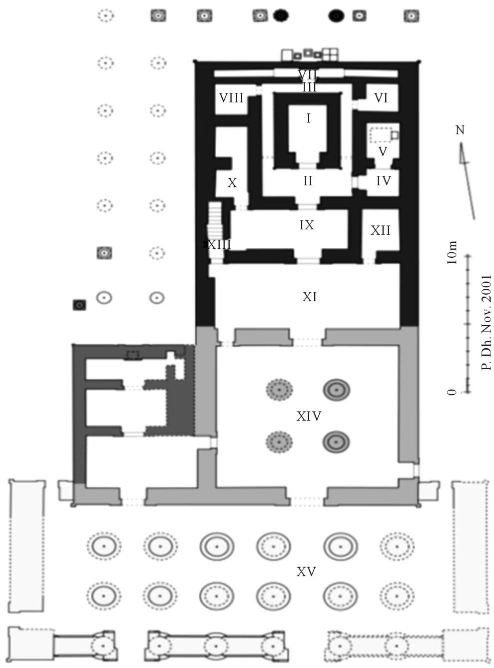


Figure 1. Ground plan of Shenhur Temple (Wendrich, W. *et al.* 2012).

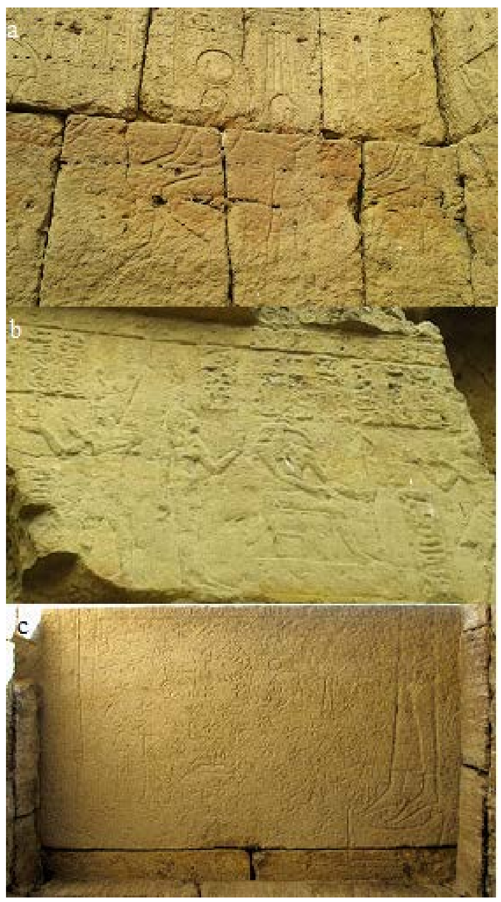


Figure 2. The wall reliefs at the temple of Shenhur. (a) Sunk reliefs on the facade; (b) Raised reliefs; (c) The astronomical ceiling of the wabet has received part of a zodiac.

maintenance work related both to aggressive climatic and ground water resulting from dramatic rise of the water level. The major causes of deterioration and degradation of Shenhur murals are variation in temperature and humidity. According to the bio-climatic provinces of Egypt, the area is hyper-arid with mild winters and hot summers [4]. This variations in the long run caused different biological, physical and chemical alterations such as; crumbling, splinting and crumbling to splintering, mortars loss of cohesion and walls cracking, single and multiple scales, disintegration and exfoliation, alveolar weathering and pitting, presence of salt efflorescence and sub-efflorescence as shown in (**Figures 3(a)-(f)**). The visual inspection show also, the wall reliefs suffer

Figure 3. Detonation features at the wall reliefs of Shenhure temple. (a) Splitting and crumbling to splintering; (b) Mortars loss of cohesion; (c) Single and multiple scales (d) The detachment of reliefs, exfoliation and disintegration; (e) Alveolar weathering, pitting and coloration; (f) Efflorescences to light-colored crust tracing the surface; (g) Soiling the stone surface by coloration; (h) Soiling by pollution; (i) Weathering out of stone components (fossil inclusions) rendering a large portion of the inscriptions illegible.

from coloration, soiling by particles from the atmosphere, soiling by anthropogenic impact soot from fire and soiling by particles from water as shown in (**Figure 3(g)**, **Figure 3(h)**). Furthermore, impacts of human-made deterioration corruption can be found in the evacuation of great limestone blocks from the temple (spoliation or stone robbing). Lime-burning activities destroyed most of the hypostyle hall, pronaos, and lateral chapel, built of better quality limestone for the lime-burning activities to produce lime. Traces of the burning of lime have been found in the form of layers of ashes mixed in with small fragments of limestone beside Shenhur temple in the southern part. The northern part of the temple was constructed with low quality local limestone, containing many fossilised shells. The fossil inclusions in the stone, however, have led to an uneven pattern in weathering, rendering a large portion of the inscriptions illegible (**Figure 3(i)**). The wall reliefs at Shenhure temple suffer from extensive microbial colonization. It demonstrated a phenomenology of adjustment varying from green, brown and dark duff patinas (**Figure 4(a)**, **Figure 4(b)**). These phenomena might be linked to different microbial colonization and microflora. Different types of micro-organisms surficially distribute on the lower parts of the walls and some of microorganisms prefer to grow in the fissures and cracks present in the wet blocks of stone. Microbiological colonization by higher, vascular plants and roots are growing in the temple which disfigured the blocks (**Figure 4(c)**) hid their reliefs and caused both mechanical and chemical deterioration. Because of these aspects the aesthetic beauty of the relives is genuinely influenced. The neglect of maintenance work in the temple and left prey groundwater impact exert a powerful human influence are the dangerous deterioration factor at Shenhur temple. In this work an incorporated investigative methodology has been utilized for the assessment of stone materials degradation in the Greek–Roman temple of Shenhur by method for the combined utilization of surface and mass strategies with a specific end goal to protection form.

2. Materials and Methods

2.1. Sample Preparation

Some illustrative degraded stone materials were taken from Shenhur temple specifically ex-postured to the activity of meteorological agents. Besides, samples of degradation induced by solvent salts were taken from diverse surfaces. Several samples were collected under aseptic conditions from wall painting for microbiological tests. Water sample was obtained from the interceptor drain dewatering at Shenhur temple. The gathered specimens were analyzed over to recognize the diverse weathering forms, their products such as salt profiles and salt types.

Figure 4. Biodeterioration of wall reliefs of Shenhur temple. (a) Microbiological infestation causing discoloration; (b) Microbiological colonization to dark-colored crust tracing the surface; (c) Concentrated microbial colonies on the surface of stone; (d) Colonization by higher plants.

2.2. Analytical Procedure

The samples were defined by various techniques as follows:

Light Microscope: Stone materials were studied via stereomicroscopy where a three-dimensional image with transmitted light using Leica DM 1000 for the dark field observation and photomicrographs recorded with a Leica EC3 camera.

***Light Polarized microscope* (*LPM*)**: Thin sections were prepared from limestone, each about 0.8 cm in diameter. The minerals and texture of limestone samples were determined using Olympus BX51 TF Japan petrographic microscope attached with digital camera under magnification 20X up to 40X (Geology department, Faculty of Science, Cairo University).

Scanning electron microscope: Freshly fractured samples of the stone materials samples were performed by JEOL JSM 6400 scanning electron microscope (SEM). The samples were cut at 50mm with flat surfaces and coated with Au and 10 kV voltage was used. The SEM combined with dispersive X-ray spectrometry (EDX) investigation (Philips with Be window) detector and coupled with EDS PV6587. Analyses were performed at 25 keV with 35o take-off angle. More reliable analyses are these for elements contained in concentrations >0.1%. An error of around 5% to 10% is accounted, for the major elements.

***X-ray diffraction* (*XRD*)**: The mineralogical composition of samples was determined by X-Ray Diffraction (XRD) with a Philips PW-1840 powder diffractometer with CuKα radiation was used. Patterns were obtained by step scanning from 5.025˚ to 59.985˚ 2θ, with a goniometer speed of 0.300˚/sec, operating at 40 kV and 25 mA.

Thermogravimetric Analysis: Thermo Gravimetric and Differential Thermo Analysis (TGA-DTA) were done to gauge gypsum and calcite contents and to characterize the clay minerals in the limestone at Shenhur temple. A Perkin Elmer STA6000 device was used for the thermogravimetrical analysis (TG/DTG). Approximately 10 mg of was scratched off the limestone and placed in aluminum crucibles. The temperature program ranged from 10˚C to 1000˚C, at a heating rate of 10˚C·min^{-1} under nitrogen atmosphere. The temperature, weight, change in wt., and the thermal behavior of each mineral were recorded on the chart.

Biodeterioration study: 6 biofilm samples were taken in April 2105, with a sterile scalpel from black, dark green, brown patina, rosy discoloration and remains of birds., all samples placed into sterile plastic vials and transported to laboratory, where they grow on different media (for fungi and bacteria). Capek's agar media was utilized to get an immaculate culture of organisms from the specimen taken from the samples [5]. Following 7 days colonies were observed. The fungi were identified according to Domsch *et al.* 1980) [6]. Nutrient agar medium (NA) was used to obtain bacteria. A sterile scalpel was used to sample thicker alterations. Care was always taken to remove these specimens used in the microscopic investigation and elemental analyses. During the sampling procedures, the daytime and nighttime average temperature was 25˚C in Mars.

Groundwater analysis: As part of the study, groundwater sample was collected from an interceptor drain dewatering at Shenhur temple. The sample was taken during April 2015 in sterile bottle so as to keep away from any contamination or evaporation. It was investigated for different physicochemical parameters to determine TDS (Total Dissolved Solid), EC (Electrical Conductivity), Concentration of several cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+},) and the major anions (Cl^{-}, NO_3^{-} SO_4^{2-}, CO_3^{2-} and HCO_3^{-}) were determined.

3. Results and Discussion

3.1. Limestone Samples

Shenhur temple was built a few stages; it was built of a few limestone varieties extracted from the mountain range contiguous of the temple site. No less than two distinctive limestone varieties have been utilized for the construction of Shenhur temple, yet numerous moves between the variant sorts are noticeable. The limestone was sampled in two groups based on their physical appearance and architectural use in Shenhur temple. The different limestone varieties vary considerably in material properties, state of preservation and requirements for conservation [7]. Analytically the samples were classified into two stone types showing different petrographic-microscopic features, mineralogical and textural characteristics and chemical major and trace elemental compositions.

Petrographical studies were carried out on the samples collected from Shenhur temple according to the difference of facieses in the field. The petrographical investigation by polarized light (PL) and crossed nicols (XN) prism showed that, the investigated samples represent two main different groups. These groups were Arenite and grainstone. (**Figure 5**) showed photomicrographs of the studied samples of the temple illustrating their texture and their mineral composition. Petrographical description of these groups was as follows.

Arenite limestone (1st Group) is medium to fine grained, it was used at northern part of the temple. The rock of this group was yellowish soft limestone. It is moderately to well-sorted with hematite coating imparting the strong red color. It consisted essentially of calcite with quarts grain size between 0.5 mm - 1 mm and contain less than 10% - 15% matrix. Porosity is 5% - 10% with small pore size. Cementing material is predominantly calcite and subordinate hematite. It consists of microscopically calcite rich with iron oxide in the ground of mud texture. Calcite crystals (85%) appear in dark grey due to clay minerals. There are also fragments of fossils with recryctallized calcite. Clay occurs as films associated with hematite cement.

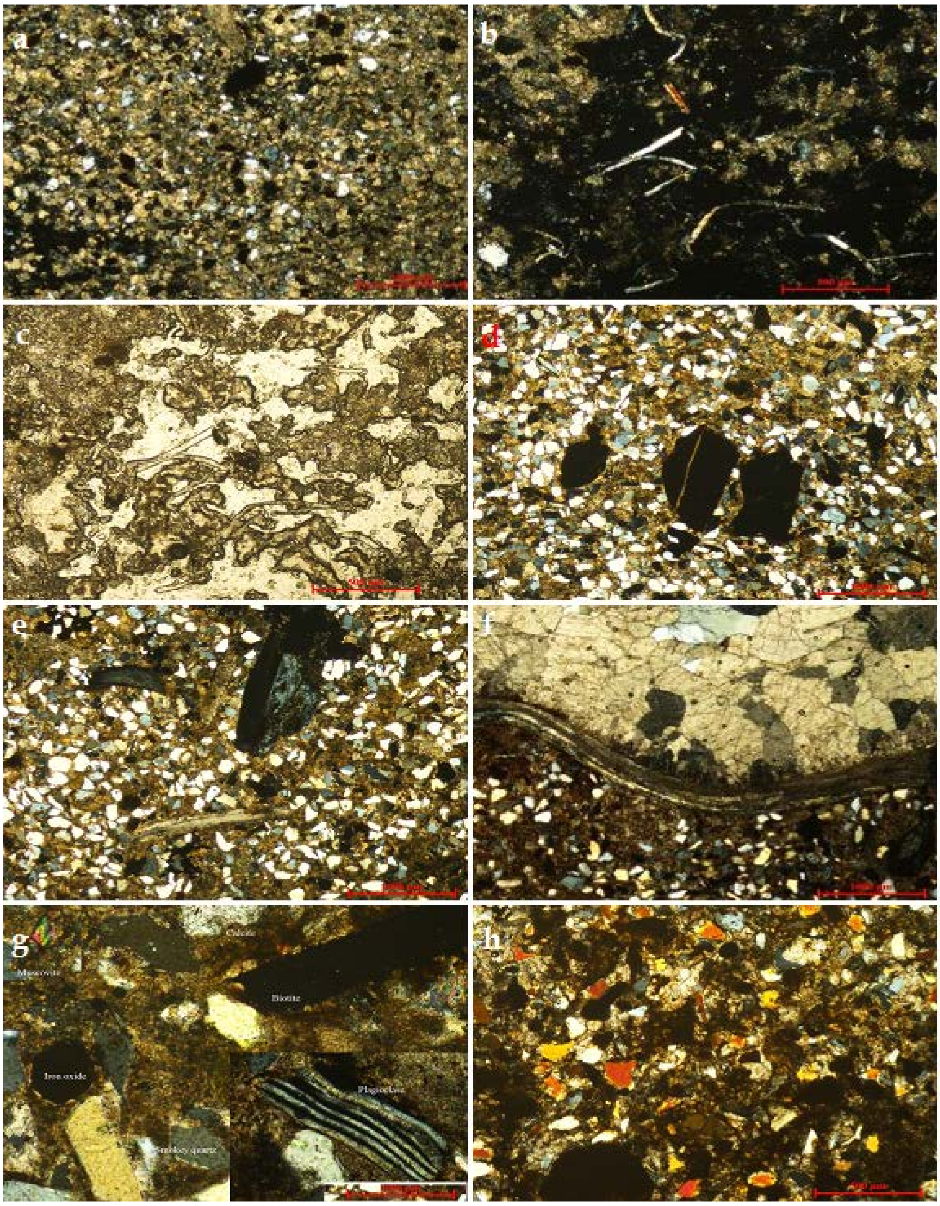


Figure 5. The examination of limestone samples under polarized microscope: (a)-(c) The examination of the 1st group used in northern part of the temple, (a) grains of calcite with up 10% quartz, (b), (c) fossil fragments, (d)-(h) the 2nd group used in southern part of the temple shows, (a) angular to sub angular quartz grained, (b) biotite grains coated with iron oxide C—plagioclase altered to clay; (c) plagioclase, Muscovite, biotite, iron quartz, (d) fragments of fossils with recryctallized calcite, (e) reddish from correlation.

Micrite (2^{nd} Group) sampled from the southern part (hypostyle hall, pronaos, and lateral chapel) represents the light to grey limestone with hard inclusions in a splinter matrix. Limestone texture is homogenous. The cementing material is predominantly calcite and subordinate hematite. Calcite grains are sub angular to sub rounded, with normal optics 6% - 10% quartz grains. Accessory minerals are limonite/ with traces of hematite, chlorite, clay and shapeless aggregates of ferric nature are also observed. There are irregular intercalations of clay minerals.

Optical microscopy LOM supportively demonstrates that the weathered samples have undergone rehashed cycles of warming and cooling because of the semi-dry atmosphere of Qena. The exposed surfaces have undergone physical disintegration as assessed from macroscopic visual analysis, the samples suffer from several deterioration of its structural coherence. The photograph shows cracks and microcracks to scales, cavities, disintegration, loosing of chosen among the grain resulting of needles of salts between grains and accumulation of different kinds of dirties. Optical microscopic investigation of the surface crust reveals the presence coloration, microbiological infestation and dark-colored crust changing the surface (**Figure 6**).

XRD mineralogical analysis (**Figure 7**) further defines limestone as mainly composed of calcite ($CaCO_3$) as most abundant phase with quartz (SiO_2), Microcline ($KAlSi_3O_8$), iron oxide (Hematite Fe_2O_3), halite (NaCl) also, clay minerals, the recent somewhat filling the porosity as watched minutely.

Petrographic and mineralogical perceptions were further particularized and measured by major and traces basic compound organizations controlled by EDX [8]. The major component chemistry offers intimation to the provenance sort and in addition weathering states of the mother rock [9].

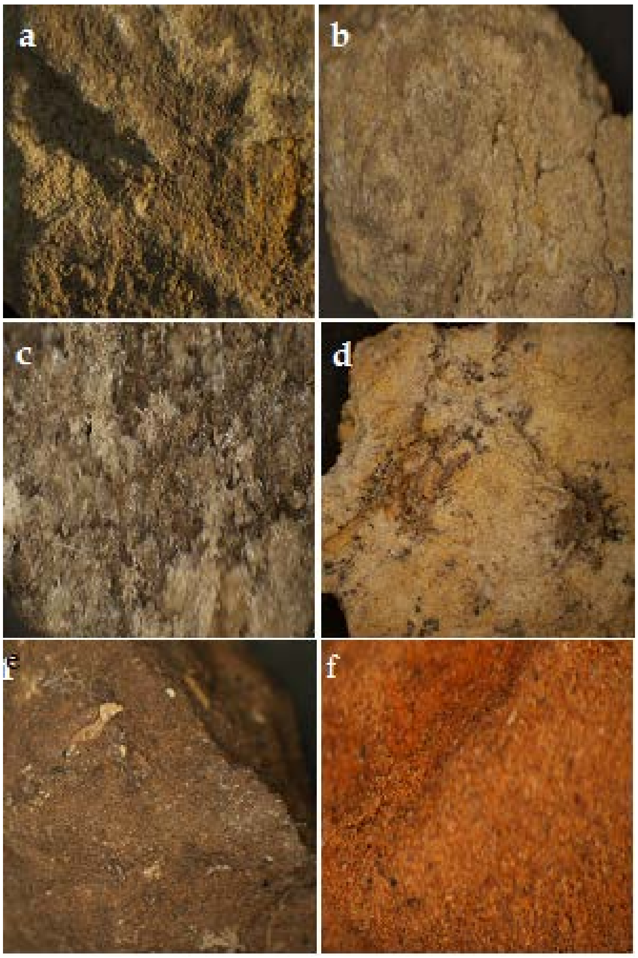
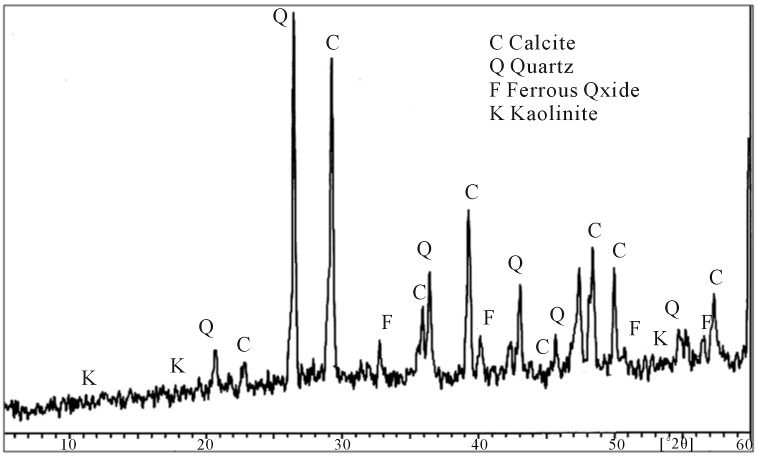
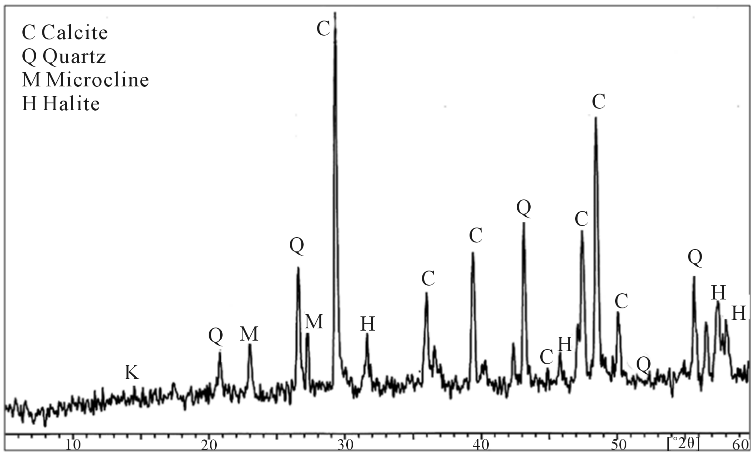


Figure 6. LOM photograph of limestone samples. (a) Disintegration; (b) Loosing of chosen among the grain and cracking; (c) Needles of salts; (d) Microbiological infestation; (e) Accumulation of different kinds of dirties; (f) Coloration.



(a)



(b)

Figure 7. (a) (b) XRD pattern of limestone sample from Shenhur temple.

EDX analysis (**Table 1** & **Figure 8**) indicated huge contrasts among the considered samples, further building up their distinctive inceptions. The arenite limestone is predominantly made out of calcium with calculable measures of Si, Al, Fe (51.18, 23.40, and 11.96 respectively) and negligible amount of Mg, K, Mn and Ti while the micrite limestone contains a comparatively high amount of Ca (75.80) and low amounts of silicone (11.32), Fe (4.40), Al (1.74), K (2.40) and Mn (1.35). The comparative analysis of two kinds (arenite and micrite, show that, The silica cemented arenite limestone is more safe on account of solid between granular bonds while micrite actually ingests dampness and swells which debilitates between granular bonds and easily undergoes chemical decay. EDX analysis shows that, the micrite contains phosphate, it occurs mainly as phosphatic shell dirties and probably to a lesser extent as detrital apatite and probably also replaces silicon in silicate minerals. The fossil inclusions in the stone have led to an uneven pattern in weathering, rendering a large portion of the inscriptions illegible. The high amount of potassium (K) and Aluminum (Al) attributed to clay minerals content. Iron (Fe) was identified in coloration brown samples, which was present as cement, it was dissolved by water and deposited at the surface making a coloration tracing the surface of reliefs. The presence of Heavy metals (Ti, La and Ba) in the samples as traces elements characteristic of Egyptian rocks [4]. High manganese (Mn) (2.00%) was noted in all samples which attributed to shale or phyllite. The presence of magnesium (Mg) in group 1, suggests a somewhat dolomitic carbonate in the cement.

SEM examination of limestone affirms that there is extensive variety of crumbling components as indicated in (**Figure 9**) for example, breaking down between calcite grains. Disintegration of calcite grains and loss in the binding materials between grains by the impact of salts crystallization, little gaps and cracks, restricted holes.

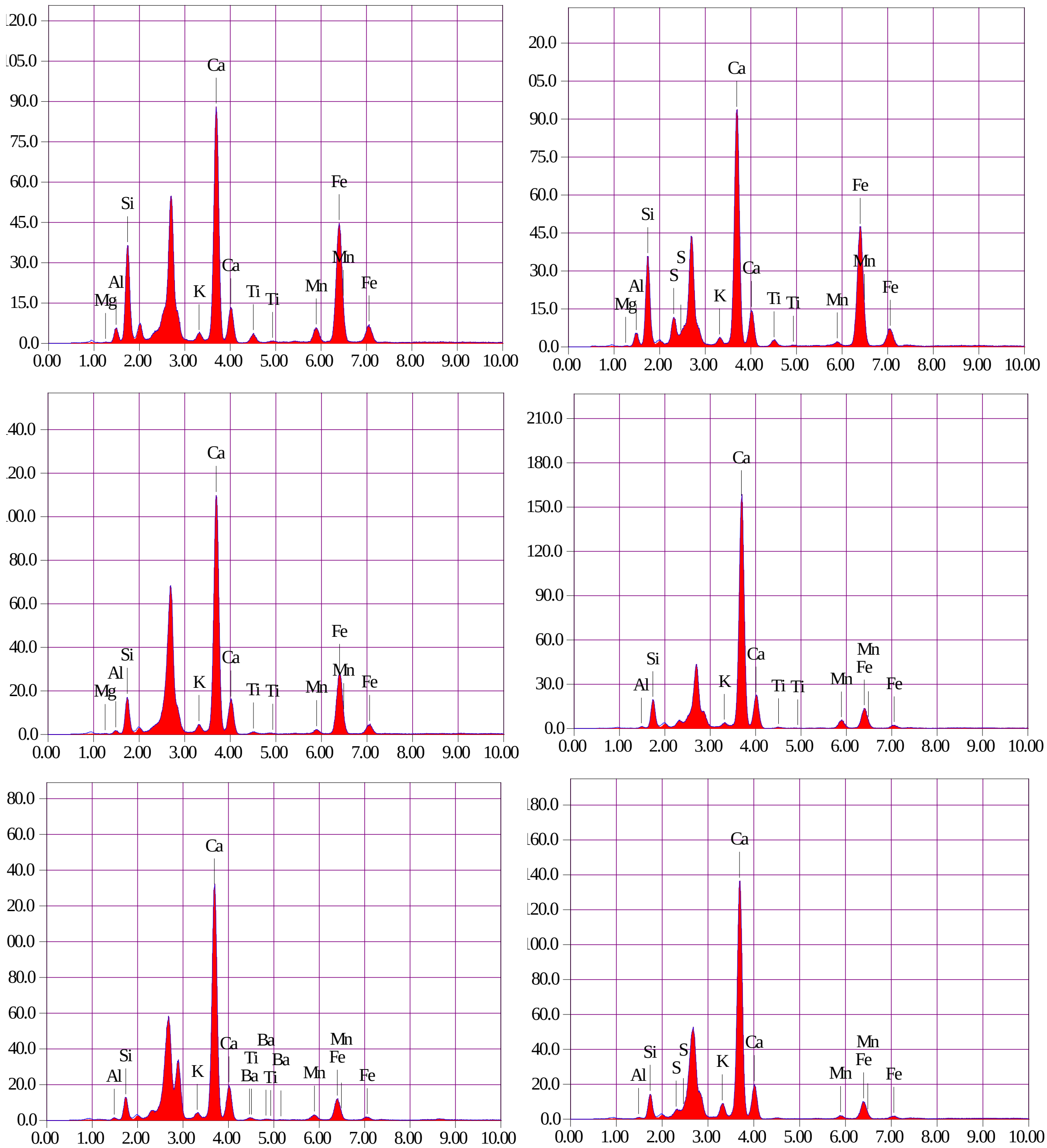


Figure 8. The patterns of EDX of limestone samples at Shenhure temple.

The clay minerals are additionally exiting among the calcite grains; likewise, it demonstrated the substance of gypsum in the specimens is because of the transformation of calcite into gypsum. Examining study likewise showed growth of hyphae of growths and remains of alga.

Thermogravimetric **study** of limestone from the Roman temple of Shenhure has been carried out. In (**Figure 10(a)**) TGA curves for limestone from northern area illustrated. The limestone shows a regular decrease in weight followed by a step at 900˚C - 1000˚C due to the decomposition of calcium carbonate. The sample shows a step near 400˚C, which is probably due to the loss of structural water. The total mass loss for the limestone may be related to the loss of 1.5 molecules of water from calcium sulfate dehydrates ($CaSO_4{\cdot}2H_2O$) (the hydrated salt represents approximately 60% of the initial mass). This is followed by the slow loss of the remaining

Table 1. Chemical element composition of samples determined by EDX analysis (%).

Samples	Group 1				Group 2		Salts	
wt%	A (1)	33	A	8	14	5	11	F salt
Mg	1.1801	1.1323	1.5882	---------	----------	----------	----------	----------
Al	9.1021	8.6329	3.2761	1.6271	2.3759	1.2510	----------	1.0161
Si	28.9108	26.2082	15.1123	13.1525	10.5641	10.2762	----------	3.8498
K	1.7821	1.5193	2.1256	1.2264	1.9714	4.0149	10.4399	1.0347
Ca	43.4021	44.9791	65.1746	76.8928	77.8260	77.4970	11.9224	37.4381
Ti	1.7092	1.2922	0.7562	----------	0.5439	----------	----------	----------
Mn	1.7293	0.4733	0.9078	2.1061	1.2024	0.7711	----------	0.3332
Fe	12.1844	12.4949	11.0593	4.4899	4.9418	3.7537	0.4297	1.7040
S	----------	3.2679	----------	----------	----------	1.1962	51.9580	1.3164
P						1.2432		
Ba	----------	----------	----------	----------	0.5745	----------	----------	----------
Na	----------	----------	----------	----------	----------	----------	25.1176	10.8599
Cl	----------	----------	----------	----------	----------	----------	----------	42.4478
La	----------	----------	----------	----------	----------	----------	0.1323	----------
Total	100.00	100.00	100.00	99.49	100.00	100.00	99.99	100.00

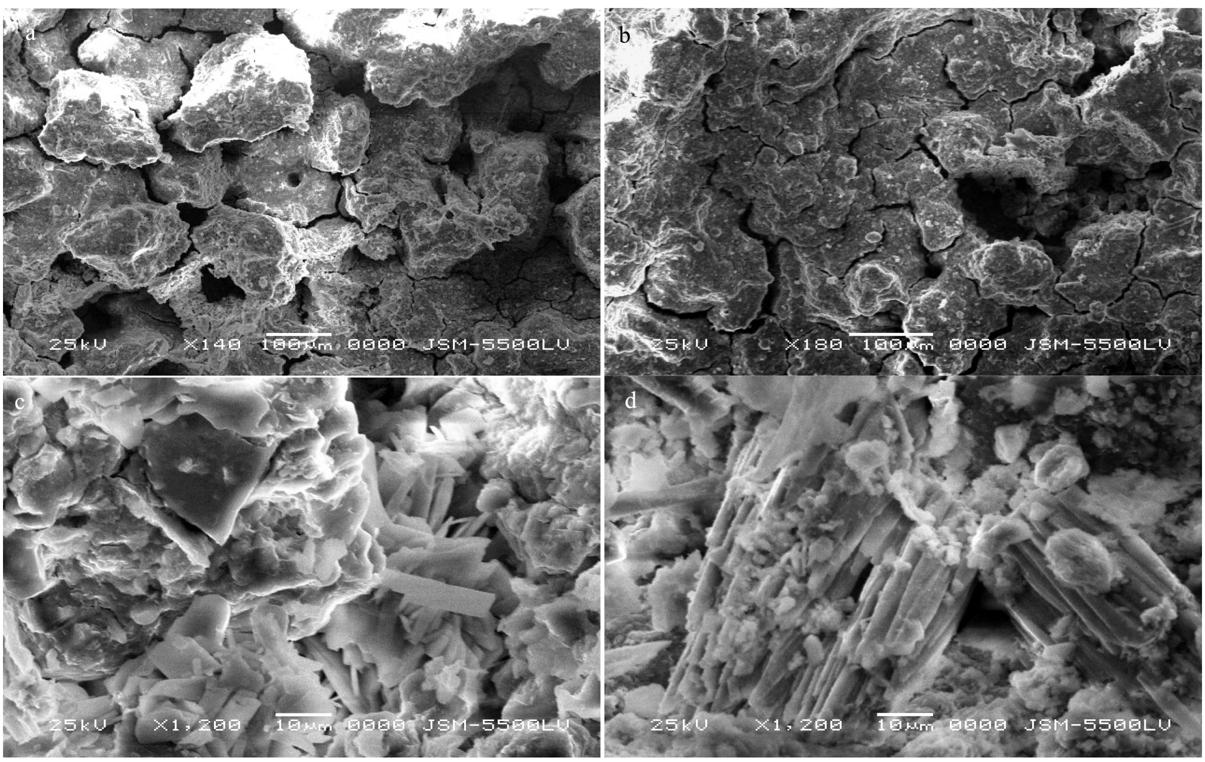
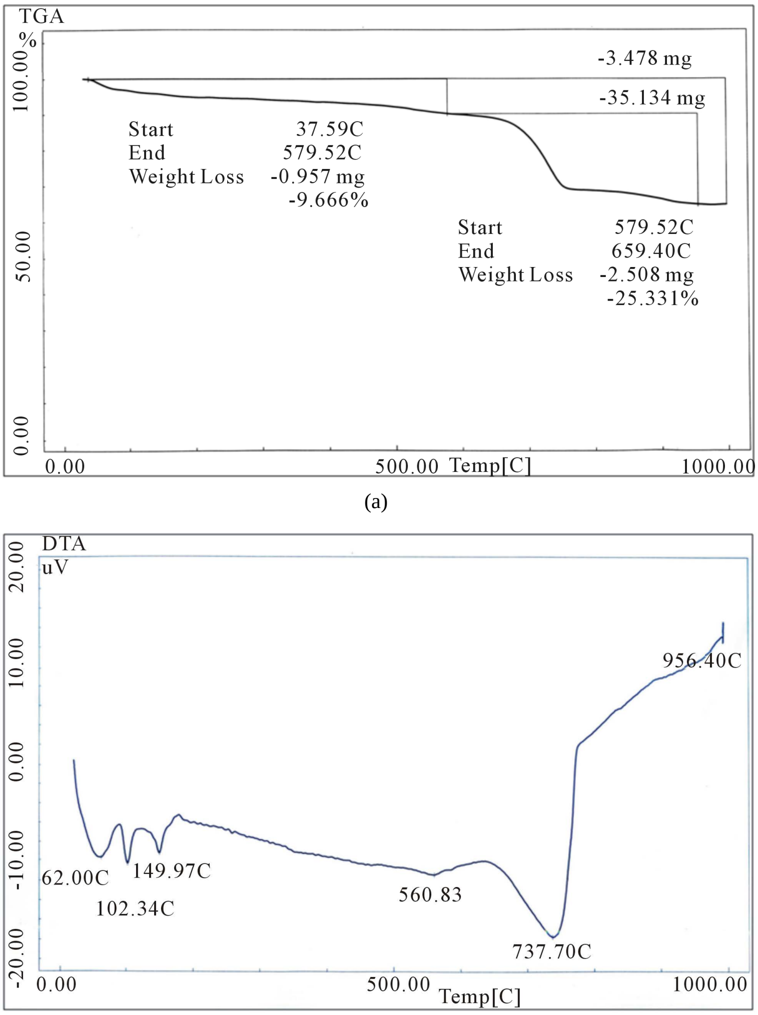


Figure 9. SEM micrographs: (a) pitting and losses of cohesion; (b) network of micro-cracks; (c) salt crystals; (d) Inter particle position of the clay mineral.



(b)

Figure 10. Show thermogravimetrical diagram of limestone sample revealed (a) TGA curves of limestone sample, (b) DTA curves.

water from calcium sulfate hemihydrate ($CaSO_4 \cdot 0.5H_2O$) between 500˚C and 900˚C. Thermal analysis results The DTA - TGA data show the clay fraction of limestone consists of kaolinite. Kaolinite exhibits two peaks, the first one is a medium endothermic peak at 579˚C due to loss of hydroxyl group and the 2nd is a very small exothermic reaction at temp.956˚C due to the structural change of the mineral. The heating cycle are graphically recorded as shown in (**Figure 10(b)**).This declares the great problem of hydric expansion and shrinkage due to absorption and loss of water. Hydric expansion is one of the most important reasons for deterioration of limestone. The aggregation/disaggregation or swelling/shrinking of the clay particles occur when these particles interact with water causing a whole series of identifiable pathologies in building stone. The swelling types of clay minerals were linked with their crystallographic structure and bonding properties, especially in the case of interlayer spaces [10] [11].

3.2. Identification of Microflora

The aim of this work was the investigation of the microbial community on biodeteriorated stone samples from the Shenhure temple using both cultivation and microscope observations to evaluate the potential damage caused by these species to the stone material. Preliminary identification of bacterial isolates from limestone fragments was made on the basis of colony and cell morphology. Preliminary identification showed that Gram-positive bacteria identified as the genera Bacillus, Micrococcus, and Staphylococcus, in addition to some Gram-negative bacteria belonging to the genera Ochrobacter. The isolated fungi were identified at least to the genus level depending on their morphological characteristics on different culture media using light microscopes according to Domsch *et al*., 1980. The fungal stains isolated from the weathered limestone belonged to the genera (**Table 2**), *Aspergillus niger*, *Aspergillus flavus*, *Alternaria alternate*, *Penicillium* sp, *Cladosporum uredinicola*, *Cladosporium oxysporum*, *Cladosporium cladosporiades*, *Paecilomyces carneus*, *Rhizopus stolonifera*. Micro-organisms represent the most of the biomass in the world due to their small size for easy dispersal by air and water, their metabolic versatility and flexibility, and their ability to tolerate unfavourable conditions [12]. Bio-deterioration is considered one of very common factor which caused serious aesthetic and physio-chemical deterioration to the wall reliefs of Shenhure temple, that paintings could be defaced or destroyed by the growth of those small, parasitical plants commonly called mold or mildew which are able to produce different organic acid which cause the disintegration of the minerals constituents of stones and enhance the chemical decomposing processes. In addition to chemical deterioration, physical degradation by invading fungal hyphae between stone crystals and by the expansion and contraction of the thallus under changes of humidity and a generally destabilizing stone texture [13]. Biochemical weathering for the most part takes the type of surface scratching on minerals, biopitting, leaching or replacement of minerals, and the production of weathering compounds [14].

3.3. Soluble Salts Analysis

The groundwater is the most effective factor in the deterioration of the wall reliefs at Shenhur temple. Samples from the groundwater were analyzed for comparison with the samples from the building materials of the temple to see how much the water had affected them. The water sample obtained from the interceptor drain dewatering at the temple. (**Figure 11**) showed that the water sample is rich in sodium (Na^+), chloride (Cl^-), sulphates (SO_4^{2-}), potassium (K^+), magnesium (Mg^{2+}) and calcium (Ca^{2+}). The pH, TDS and the electric conductivity are 8.2, 570, and 9.72, respectively. The TDS-Cl data revealed that the drain water is derived from evaporation of a local Nile-like water, while the Na + K-Cl data suggest some degree of mixing and/or water-rock interaction in the system. In general, the increasing tendency of chlorides and nitrates content in the underground waters sample is in direct correlation with the agricultural land for use methods and implicitly the leachate quantity. Different factors for the water rise is encountered for the position of the Shenhur temple such as the hydrogeology of the soil, the closeness to the Nile, this temple is located somewhat distant from the western margin of the Nile flood plain where flood irrigation allows crop production on a year round basis; the high and fast thermo-hygrometric parameter changes and the location of Shenhur temple within an urban agglomeration and agricultural. The temple lays isolated on the edge of the Shenhur village in an area of approximately 13 km which belongs to the State Ministry of Antiquities, to the east of the temple lays a railway which was used to transport sugar cane, but which is now no longer in use, behind this railway starts the modern village, to the west extend fields of mainly sugar cane, but also other crops are grown in the vicinity of the archaeological area. In general, sewage water from agricultural lands and waste water from homes located immediately north and south of the temple is the main reason for the water rise in Shenhur temple.

Table 2. Identification and enumeration of bacterial growths at wall reliefs at Shenhur temple.

SAMPLE	BACTERIA CFU/G		MICROORGANISMS	
	(1)	(2)	(1)	(2)
SH1	80×10^3	------	*Gram positive Bacilli sp.*	
SH2	6×10^3	------	*Gram positive Bacilli sp.*	
SH3	40	-------	*Gram positive Bacilli sp.*	
SH4	180	30×10^2	*Gram positive Bacilli sp.*	*Gram Positive Cocci sp.*
SH5	11×10^2	29	*Gram positive Bacilli sp.*	*Gram Positive Cocci sp.*
SH6	6×10^2	40×10^2	*Gram positive Bacilli sp.*	*Gram Positive Cocci sp.*
SH7	20×10^2	11×10^3	*Gram positive Bacilli sp.*	*Gram Positive Cocci sp.*

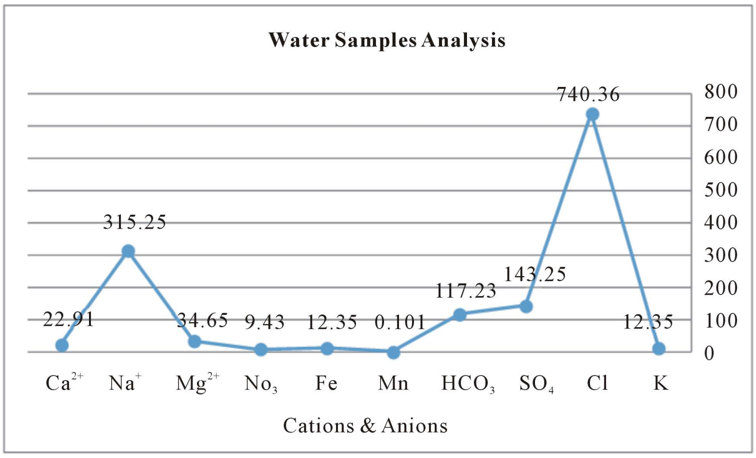


Figure 11. Show the chemical analysis of groundwater from Shenhur temple.

The degradation of wall reliefs at Shenhur temple attributed to the presence of soluble salts that have precipitated on the external surface (efflorescences) and proximity of the surface (sub-efflorescences). The deterioration of stone in Egypt is primarily due to several types of water soluble salts such as halite. This problem represents aggressive deterioration forms that take place on all stone surfaces and mortars through salinity solutions that are transferred to the stone pores. A usually complex saline solution can migrate for capillarity and can deposit salts in internal micro-pores or on preferential areas of the surface. Damages are caused by internal tensions, due to the expansion of crystals induced by humidity and temperature changes, and/or by aesthetical alteration of the surface [15]. The formation of salt crusts on calcareous stone is the most important chemical reaction involving salinity ground water to cause stone degradation. When these crusts are formed on a porous stone, it disintegrates to a powdered material, while limestone develops thick crusts instead [16]. Destructive salts are present 1.0 to 1.5 m above the ground on the outer northern wall, the inner of *wabet* (rear) and New Year's court (front) in the temple of Shenhur and salts are present also under celling directly to 1m of the temple which exposed to the sun and subjected to the aggressive action of the rain coming from the roof. The degradation induced by soluble salts on stone materials in the Shenhur temple was studied by sampling efflorescences from infected places.

The XRD pattern (**Figure 12**, **Figure 13**) of salt efflorescences confirmed the sodium chloride (NaCl) is the most widespread and abundant salt in the wall reliefs. XRD analysis confirmed the presence of sulphates species in the form of Bassanite as predominant crystalline phase ($CaSO_4 \cdot 1/2H_2O$), and Thenardite (Na_2SO_4) along with calcite ($CaCO_3$). A similar XRD pattern was recorded for salt efflorescences from a mortar samples.

EDX elemental composition of salts powders from the wall relief surfaces is listed in **Table 1**, (**Figures 13(a)-(e)**) essentially consist of chlorine (Cl), calcium (Ca), sulfur (S), sodium (Na), aluminum (Al), iron (Fe), potassium (K) and Manganese (Mn). The chlorine and sulphate ions are attributed to the halite, gypsum, bassanite and thenardite salts formed within the wall reliefs. The high concentration of sodium (10.85%) and chlorine (42.44%) may be attributed to the crystallization of halite salt on the wall reliefs. The source of these ions may be due to contamination of groundwater and dissolution of halite salt. The EDX analysis also revealed a high concentration of sulfate (3.26% - 51.95%) and calcium (11.92% - 37.43%) ions which may be attributed to the crystallization of gypsum, bassanite and thenardite salts on the wall reliefs. The precipitation and growth of halite (NaCl) on stone surfaces and in pore systems due to the seepage of underground water is widely observed by SEM. Halite was identified in SEM micrographs as two phases, euhedral prismatic crystals and cubic one. Sulphates crystals were identified by SEM micrographs as blocky-shaped and rectangular crystals grow between grains of limestone. Scanning electron micrographs (SEM) revealed the salt deposits on the relief surface cause several alterations such as cracks, pores and losses of cohesion between grains.

The salt commonly comes from the soils beneath caused by the nearby Nile and the irrigation channels in the farm land rising humidity from the underground water level can affect earthbound structures and partly buried parts and is carried up into walls by rising damp [6]. When the dampness evaporates from the walls, the salts are left behind, slowly accumulating to the point where there are sufficient to cause damage. Repeated wetting and drying with seasonal changes lead to the cyclic precipitation of salts and the progressive decay of the reliefs.

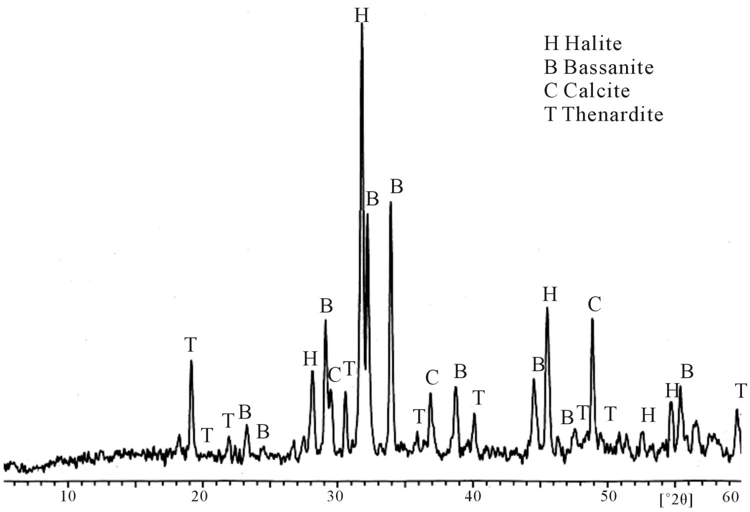


Figure 12. XRD pattern of salt sample.

NaCl can thus migrate to higher areas and penetrate into the rock structure and recrystallize under volume expansion [17]. Therefore, crystallization and dissolution cycles of the salt can be formed especially with the repetition of these cycles could induce the stone degradation by several types of deterioration forms such as contour scaling, granular disintegration and break up grains and cement [18]. In the present study, sulfates are the most common compounds of the soluble salts and responsible for wall reliefs degradation processes. Although halite exerts almost twice the crystallization pressure of gypsum it is probably less harmful to the limestone. Gypsum is very sensitive to humidity changes and hydration/dehydration phenomena can cause mechanical stresses in the stone materials structure [19]. Analysis study revealed that sodium sulfates (thenardite) and sulphates (bassanite) are the most worst affecting wall reliefs at Shenhur temple depending on the dominated degrees of temperature and humidity. In this study, it's a relation between the presence of halite and soluble sulphate. El-Gohery (2011) [20] reported previously, halite leads to sever effects on stone samples because of the synergetic reaction between it and soluble sulfate composing both thenardite and hydrochloric acid which lead to the maximum deterioration and corrosion of the stone body according to the following reaction:

$$2NaCl + H_2SO_4 \rightarrow Na_2SO_4 + 2HCl$$

Halite Pollutants Thenardite

On the other hand, sodium sulfates (thenardite) is the main component of more of efflorescence and are the most efficient factor in rock disintegration that due to the sub-florescence faces beneath stone surfaces [21]. Goudie A. S. (1977) and Tsui, N. (2003) [22] [23] have attributed the damage caused by sodium sulfate salts to the volume change and hydration pressure created when water-free thenardite (Na_2SO_4) thenardite transformed to the hydrated phase mirabillite ($Na_2SO_4 \cdot 10H_2O$) with volume increase between 70% - 250%. This increase leads to the creation of severe forms of deterioration such as salt crystallization, scaling, crumbling and flaking [24]. The concentration of sulphates, the hygrometric conditions and the porosity of limestone and mortars are all responsible for accelerating degradation induced by gypsum formation [13].

4. Suggestion and Recommendation

In order to prevent the wall reliefs' degradation in Shenhur temple, some precautions are necessary.

First of all, before the conservation work began, all areas of the temple were carefully observed and any visible alteration and degradation must be mapped, documented and registered in conservation records [10]. It is necessary to prevent the contact with groundwater/keeping water out of the stone with controlling the relative humidity and temperature of the air around the stone to prevent salt damage because any efforts that taken to protect the wall reliefs when water levels surge is worthwhile and this is not an easy task since salts originates both from the soil and from the atmosphere related to the presence of pollution oxides. This can be obtained by various ways [13].

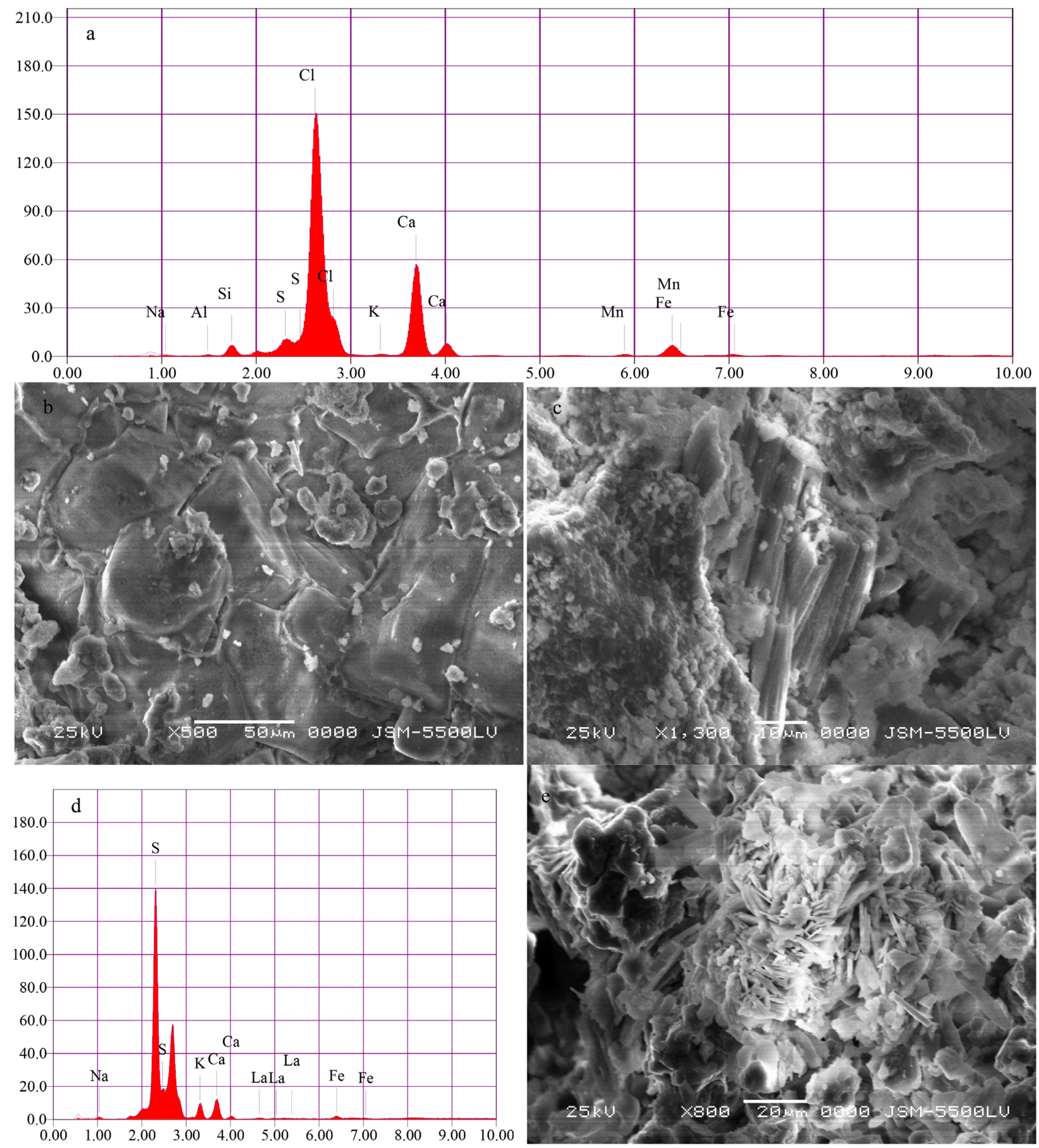


Figure 13. SEM-EDX of salts samples from Shenhur temple. (a)-(c) SEM-EDX of halite salts as euhedral prismatic crystals and cubic one; (d) (e) SEM-EDX of sulphates crystals as blocky-shaped and rectangular crystal.

Various groups are interested in understanding the hydrogeologic setting of the Shenhur region must constitute. These site characterization efforts should be coordinated to maximize the value of information to be collected by these various groups, while at the same time protecting this unique archeological treasure.

More detailed seasonal water level maps could be prepared that reveal patterns of groundwater flow, changes in water levels and quality resulting from ongoing and future changes in land use.

Probably the most sustainable solution is to change or improve the irrigation management in the area; restricting crop types. The present irrigation flood system should be changed to new systems such as sprinkler and drop methods to reduce groundwater recharge.

Construction of a sewage network in the temple area and the surroundings villages with a continuous care and detection of leakage in the drainage networks.

Continuous monitoring of physical parameters e.g. PH, electrical conductivity, is a clue of changes in groundwater chemistry to trace the source of recharge water as well as pollutants.

Completion of excavations for the remaining discovery of the ornate stone blocks of the temple. Careful observation of burial environments could save many inscription blocks from rapid degradation.

The surface could also be protected by a waterproof coating that prevents the contact with water, such as investigated.

Cleaning and removing of vegetation should be carried out to reduce the negative impacts by trees, plants, shrubs roots for all archeological remains at the site by mechanical removal for roots and rhizomes and chemical removal by using chemical pesticides as pesticide Glyphosate pesticide or Fuluazifop-p-butyl to give chance to complete the new excavation in the context of other parameters-depth of penetration and stability of surface appearance.

The microorganisms found on the Shenhur temple, in Cyanobacteria and fungi, are among the most dangerous to the stone. Thus, a future action for the removal of these microorganisms should be taken into consideration [10].

After Preventive Conservation, conservation interventions have to be individually planned and consolidation, other conservation treatments must as always only be performed after thoroughly testing all procedures, recalling the often friable nature of these unique reliefs and avoid further damages [6].

5. Conclusions

Field observation revealed that several factors were causing the deterioration of wall reliefs in Shenhur temple such as increase of the groundwater level, absence of sewage network, seepage from the irrigation system and from the increasing urban areas surrounding the temple.

In this work, building materials of the ancient temple of Shenhur were analyzed in different conservation state. An integrated use of both surface and bulk-sensitive analytical techniques showed that wall reliefs underwent both physical and chemical degradation. The chemical decomposition process is largely accelerated by the salts presence. XRD surface characterization and EDX elemental composition of limestone showed the presence of sodium (Na^+), chloride (Cl^-) and sulphate ions (SO_4^{2-}). XRD analysis confirmed the presence of sodium chloride and sulphates as gypsum, thenardite (Na_2SO_4) and bassanite ($CaSO_4·1/2H_2O$) crystalline phase. These results showed the progressive decay of wall reliefs and their transformation in complex salts known as mirabillite ($Na_2SO_4·10H_2O$) with volume increase between 70% - 250%.

References

[1] De Meyer, M. and Minas-Nerpel, M. (2012) Temple of Shenhur. Encyclopedia of Egyptology, 8542 Version 1, 1-9.

[2] Quaegebeur, J. and Claude Traunecker, C. (1994) Chenhour 1839-1993: État de la question et rapport des travaux de 1992 et de 1993. Cahier de recherches de l'Institut de papyrologie et d'égyptologie de Lille 16, 167-209.

[3] Quaegebeur, J. (1997) Excavating the Forgotten Temple of Shenhur (Upper Egypt). In: Quirke, S., Ed., The *Temple in Ancient Egypt*: *New Discoveries and Recent Research*, British Museum Press, London, 159-167.

[4] Said, R. (1962) The Geology of Egypt. Elsevier Publishing Co., New York, 259.

[5] Gupta, S.P. (2011) Biodeterioration and Preservation of Sita Devi Temple, Deorbija, Chhattisgarh, India. *International Journal of Conservation Science*, **2**, 98-94.

[6] Domsch, K.H., Gams, W. and Anderson, T.H. (1980) Compendium of Soil Fungi. Vol. 1-2, Academic Press, London.

[7] Leisen, H., Plehwe, E., L., Verbeek, C., Jurgens C. and Krause, S., (2008) Aspects of Conservation in the Excavation Site of the Athribis Temple in Egypt. *Environmental Geology*, **56**, 689-697. http://dx.doi.org/10.1007/s00254-008-1473-z

[8] Gulzar, S. C., Nawaz M., Burg, Jean-Pierre, S. and Anwer S. (2015) Mughal Sandstone Heritage of Lahore: Formulating the Future Restoration Strategy. *International Journal of Conservation Science*, **6**, 177-188.

[9] Dutta, P.K. (2007) First-Cycle Sandstone Composition and Colour of Associated Fine-Grained Rocks as an Aid Toresolve Gondwana Stratigraphy in Peninsular India, Sedimentary Provenance and Petrogenesis: Perspectives Frompetrography and Geochemistry. Geological Society of America Special Paper 420, 241-252.

[10] Colas, E., Mertz, J.D., Schneider, C., Barbin, V. and Rassineux, F., (2011) Influence of the Clay Coating Properties on

the Dilation Behavior of Sandstones. *Applied Clay Science*, **52**, 2-26. http://dx.doi.org/10.1016/j.clay.2011.02.026

[11] Abd El-Tawab, N.A. (2012) Degradation and Conservation of Marble in the Greek Roman Hadrianic Baths in Leptis Magna, Libya. *International Journal of Conservation Science*, **3**, 163-178.

[12] Cappitelli, F., Principi, P., Pedrazzani, R., Toniolo, L. and Sorlini, C. (2007) Bacterial and Fungal Deterioration of the Milan Cathedral Marble Treated with Protective Synthetic Resins. *Science of the Total Environment*, **385**, 172-181. http://dx.doi.org/10.1016/j.scitotenv.2007.06.022

[13] Adamo, P. and Violante, P. (2000) Weathering of Rocks and Neogenesis of Minerals Associated with Lichen Activity. *Applied Clay Science*, **16**, 229-256. http://dx.doi.org/10.1016/S0169-1317(99)00056-3

[14] Lee, M.R. and Parsons, I. (1999) Biomechanical and Biochemical Weathering of Lichen-Encrusted Granite: Textural Controls on Organic-Mineral Interactions and Deposition of Silica-Rich Layers. *Chemical Geology*, **161**, 385-397. http://dx.doi.org/10.1016/S0009-2541(99)00117-5

[15] Brai, M., Casaletto, M.P., Gennaro, G., Marrale, M., Schillaci, T. and Tranchina, L. (2010) Degradation of Stone Materials in the Archaeological Context of the Greek-Roman Theatre in Taormina (Sicily, Italy). *Applied Physics A*: *Materials Science & Processing*, **100**, 945-951. http://dx.doi.org/10.1007/s00339-010-5678-0

[16] Wessman, L. (1997) Studies on the Frost Resistance of Natural Stone. Lund Institute of Technology, Division of Building Materials, Lund, 17-21.

[17] Willems, H., Coppens, F., De Meyer, M. and the Collaboration of Peter Dils (2003) The Temple of Shanhûr, Volume 1: The Sanctuary, the Wabet and the Gates of the Central Hall and the Great Vestibule (1-98). Orientalia Lovaniensia Analecta 124, Peeters, Leuven.

[18] Smith, B. and McGreevy, J. (1988) Contour Scaling of Sandstone by Salt Weathering under Simulated Hot Desert Conditions. *Earth Surface Processes and Landforms*, **13**, 697-705. http://dx.doi.org/10.1002/esp.3290130804

[19] Halsey, D.P., Dews, S.J., Mitchell, D.J. and Harris, F.C. (1995) Real Time Measurements of Sandstone Deterioration: A Microcatchment Study. *Building and Environment*, **30**, 411-417. http://dx.doi.org/10.1016/0360-1323(94)00060-6

[20] El-Gohery, M. (2011) Chemical Deterioration of Egyptian Limestone Affected by Saline Water. *International Journal of Conservation Science*, **2**, 17-28.

[21] Benavente, D., García del Cura, M.A., Gracia-Guinea, J., Sánchez-Moral, S. and Ordóñez, S. (2004) Role of Pore Structure in Salt Crystallization in Unsaturated Porous Stone. *Journal of Crystal Growth*, **206**, 532-544. http://dx.doi.org/10.1016/j.jcrysgro.2003.09.004

[22] Goudie, A.S. (1977) Sodium Sulfate Weathering and the Disintegration of Mohenjo-Daro, Pakistan. *Earth Surface Processes*, **2**, 75-86. http://dx.doi.org/10.1002/esp.3290020108

[23] Tsui, N., Flatt, R. and Scherer, G. (2003) Crystal Ization Damage by Sodium Sulphate. *Journal of Cultural Heritage*, **4**, 109-115. http://dx.doi.org/10.1016/S1296-2074(03)00022-0

[24] Backbier, L., Rousseau, J. and Bart, J. (1993) Analytical Study of Salt Migration and Efflorescence in Mediaeval Cathedral. *Analytical Chimica Acta*, **283**, 855-867. http://dx.doi.org/10.1016/0003-2670(93)85299-Y