Environmental deterioration and conservation of Ramses III's Sandstone Temple, Karnak, Luxor

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Abstract :

Ramses III's temple contains many kinds of decay. Therefore, the current study investigates different deterioration phenomena and mechanisms of alteration which lead to sandstone decay. It also creates conditions in the laboratory similar to those of the temple to be compared to the deterioration environment of Ramses III's temple. Different scientific methods were adopted, such as EDX attached with SEM, XRD and PLM. Results show that there are many types of deterioration in the sandstone. For example, the samples reported the presence of sulphate and chloride in crystalline phase, e.g. anhydrate and dehydrate calcium sulphate (Thenardite), Na_2SO_4, $CaSO_4$, sodium chloride (NaCl) and gypsum ($CaSO_4.2H_2O$). Consequently, different treatments were used.

Key words: Ramses III, Temple, Decayed Sandstone, Grains, Treatments.

1. Introduction

1.1. Archaeological study of Ramses III Temple.

The temple of Ramses III is one of the most important archaeological sites in Luxor (Fig. 1,2). It was constructed from a Sandstone that was known as "Nubian sandstone" that was cut from Gebel El-Silsila quarries, to the south of Kom Ombo, Aswan. Therefore, this study aims to investigate sandstone in the temple of Ramses III and study the deterioration factors affecting the temple. it suggests procedures which can be used in restoration of The temple of Ramses III.

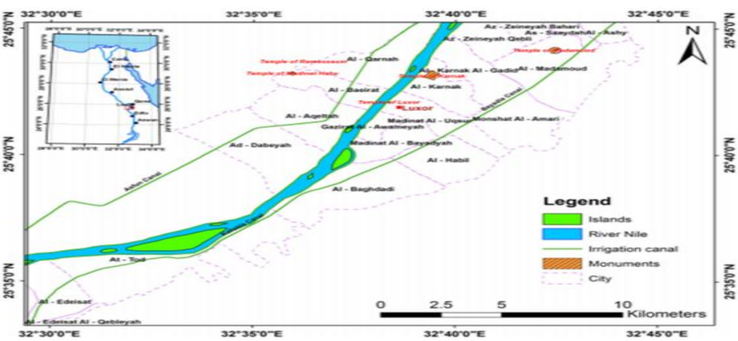

Fig. (1) A map of Luxor area (adopted from Ayman et al 2014)

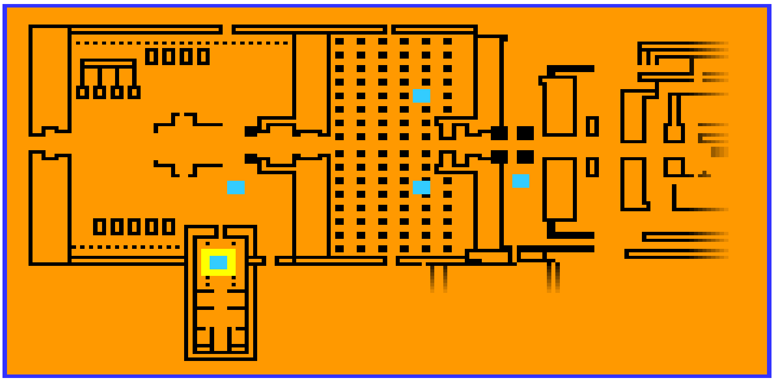

Fig. (2) Plan of Ramses III's Temple, google 2012

3. Field Observations and Degradation Causes

The effect of various agents and processes of weathering reacting with stones is shown by mineralogical, chemical, and grain-size changes in the weathered stone. The reactions are caused by the solubility of the constituent minerals, and, in part, by the porosity of the stone which either augments or retards are leached by water (Carroll et al., 1970 & Salman et al 2010); the hydration pressure of salt is very harmful to building materials (Abd El-Hady 1995).

Some deterioration factors play an important role in the degradation of sandstone at the Temple of Ramses III. the moisture sources (subsurface water) resulting from dramatic rise of water level due to the temple's location; it is currently sited 2m under the land surrounding the temple on the east bank of the Nile. Additionally, water rising is caused by leaking from the reclaimed land (Fig. 3,4,5) and wastewater. groundwater contain salts. In addition, salts materials affect some parts of the engraved stone blocks and cracks and ground water penetrates cracks and causes the surface layer to be peeled.

The vast changes in temperature caused the decay of sandstone. Disintegration and weakness of sandstone cause collapse or partly collapse in the internal grains of the stone (Ismail, 2001, Mahmoud, et al 2010 & Nabil, 2014). Furthermore, the salt deterioration caused many problems in the temple of Ramses III. Salts found on the paintings and stains

(Fig.6). Some minerals dissolve, move to and leak out from the surface of the walls. They help in accelerating deterioration than the grains of quartz constituting the main constituent mineral.

It was observed that sandstones in the temple of Ramses III suffered from many problems, such as: rising humidity, destructive drainage of water, intensification of moisture) (Fig.4) and nutrients (e.g., organic and inorganic materials). Furthermore, they were left without any kind of treatment until now.

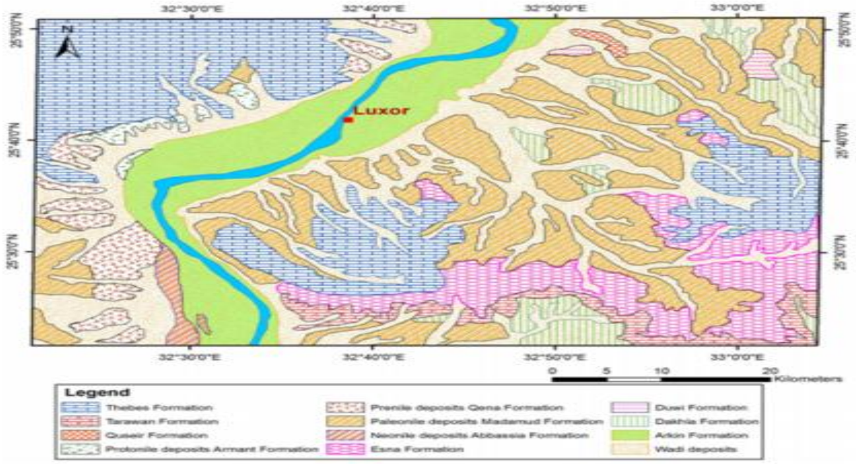

Fig. (3) A geologic map of Luxor area
(adopted from Ayman A et al 2014)

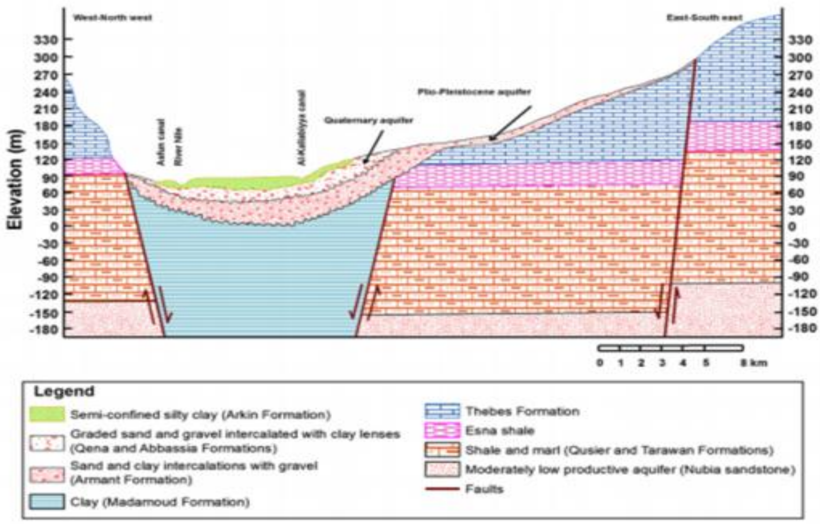

Fig. (4) Simplified hydrostrstratigraphic section representing Luxor area
(adopted from Ayman A et al 2014)

Gypsum is a key component in black weathering layers on sandstones, especially calcareous ones. It is commonly attributed to SO_2 derived from air pollution or SO_4 from mortars, but the presence of fly ash may also play a role (Nijland et al 2003). The calcitic sandstone shows serious signs of decay (i.e., gypsum formation, exfoliation, discoloration, salt efflorescence…etc.) (Nord et al 1995). For example, soil decay is caused by changes in groundwater level which lead to enlarging or shrinkage of clay (Salman 2010). Different investigations that were conducted to determine the porosity of the stone illustrate porosity characteristics and changes due to deterioration or the use of treatments (Pascua et al 1999). Fluctuation of ground water and salts exposed to sunshine and the micro-organisms that appear on the surface's layers cause deterioration and leave out some clay particles and materials causing discoloration of the stone. In addition to natural weathering causes, many aspects of deterioration are human-made such as using the site as a quarry. There are also soot from burning weeds' waste by the inhabitants (Fig.7).

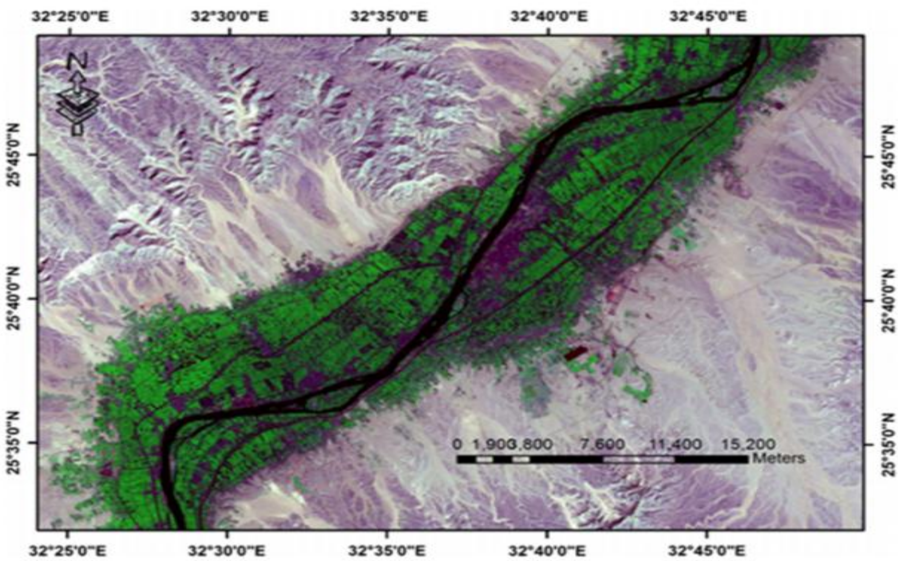

Fig. (5) Landsat image (Landsat 7ETM+); showing agricultural areas with a green color (adopted from Ayman A et al 2014)

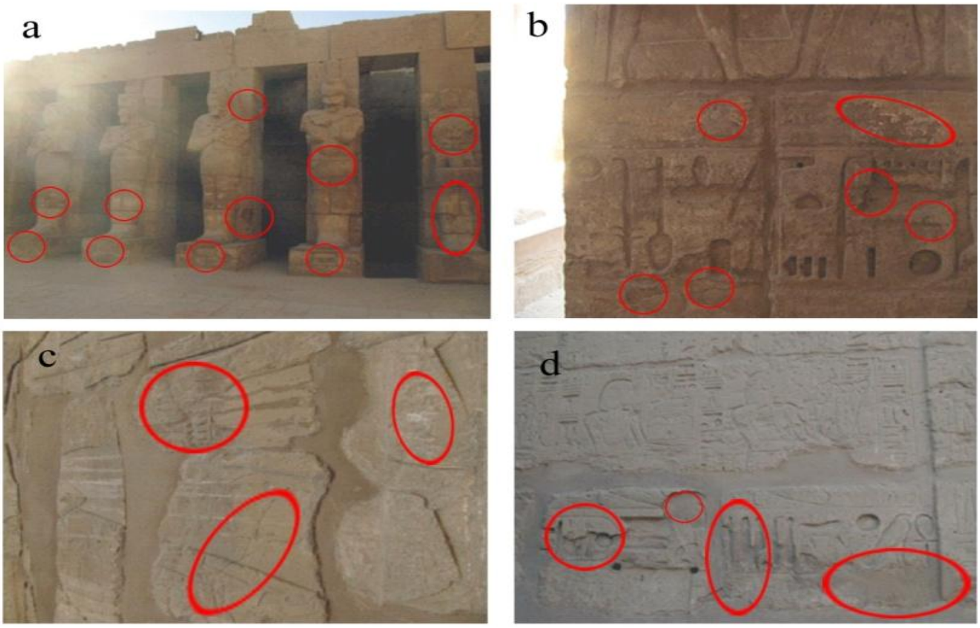

Fig. (6): Decoration and its aspects on the walls of Ramses III's temple (a): salt layers covering the relives of the temple, (b): hard crusts observed on the surface, (c& d): macro-cracks spread on the surfaces

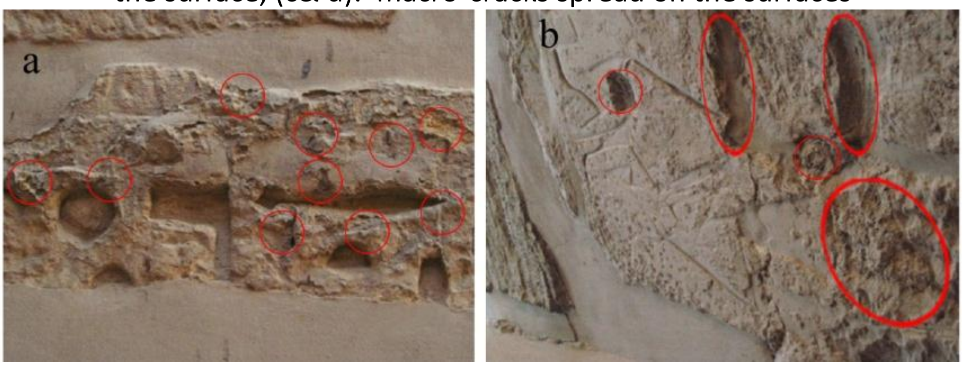

Fig. (7): decoration and its aspects on the walls of Ramses III's temple (a): salt layers covering the relives of the temple, (b): hard crusts observed on the surface and macro-cracks spread on the surfaces

3. Methods and Materials

The composition of framework grains shows much about the history of deriving sand grains, nondestructive samples were collected and analyezed by XRD, SEM with EDX and study under PLM (Parker 1988; Cox et al 1974; Hajpa et al 2004; Andrew et al 1999; Rebricova et al 1995). In addition, a block of an engraved sandstone in the temple of Ramses III was used. The samples were estimated using (ASTM C97) (Andrew 1999).

3.1. Petrographic Examination

Petrographic thin sections were prepared and optically analyzed using Leitz polarizing microscope. Optical microscopy was very useful for identifying the mineral composition, different litho types and the exact stratigraphy of the samples. It provided information on the decayed layers and their size, color and texture. Additionally, the characteristics of minerals, cement materials and textural and digenetic features of the samples were further examined.

3.2. Scanning Electron Microscope (SEM-EDX)

In order to identify their textural, mineralogical changes and altered stone surfaces, images of crusts and salt samples were analyzed using (SEM JEOL JSM5500LV). They were coated with gold and a (10 KV) detector of (6587 model) was used.

3.3. X-ray diffraction (XRD)

Mineralogical composition for the bulk samples powder were determined using X-ray diffraction (Philips X-ray diffraction equipment model PW/171) with monochromator, Cu k -á radiation (1.542 =ɿÅ) at 40 kV and 35 mA at X-ray diffraction lab, Physics Department, Assiut Faculty of Science, Egypt. The patterns were recorded from 4 to 90°2è. In addition, reflection peaks were between 4 and 902Ɵ, of 0.06◦/min speed. Corresponding spacing (d,Å) and the relative intensities (I/I°) were also obtained [Moore and Reynolds,1997].

3.4. Determination of physical and mechanical properties of the sandstone:

The specimens used for physical and mechanical properties were cubic of 5cm edges and were estimated using (ASTM C97).

4. Results

4.2. Petrographic Investigation

Petrographic investigation of sandstone samples by (PLM) revealed that the sandstones in Ramses III's temple mainly consisted of polycrystalline quartz grains. This displayed more sandy varieties, less cemented ones and high porosity. Their color varied from light yellow to brown yellow result the existence of ferrous oxides as (FeO (OH). Also, this investigation revealed that they suffered from many aspects of deterioration. This displayed chosen and disintegrated quartz grains (Fig.8) as the main component. It illustrated that quartz crystals were classified subrounded to angular and from fine to medium. chemical process affect the quartz crystals and mechanical process breakages that caused some cleavages and micro-fractures dissecting quartz grainsinto many sub-individual grains, surrounded by feldspars. Some particles of calcite and gypsum were also found. Consequently, the sandstones of the temple could be known as quartz arenite. (Fig. 8).

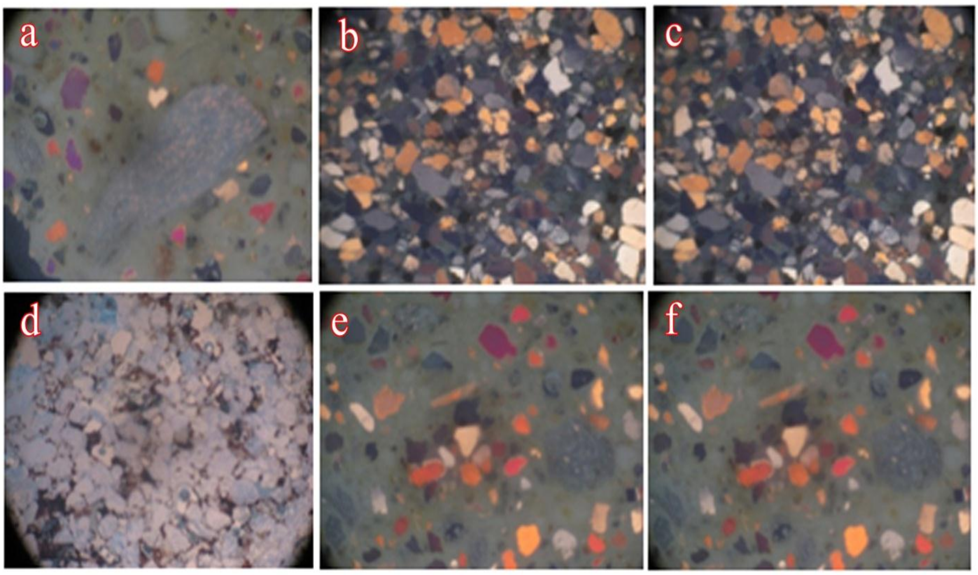

Fig (8): Photomicrographs (C.N., 65X) of thin-sections of the sandstone samples. (a,b & c): the fine-grained quartz embedded in a matrix rich in amorphous silica. (d,e &f): large grains of quartz.

4.3. **Scanning Electron Microscope (SEM-EDX)**

43.1. EDX Analysis

Analyses by EDX were applied to study sandstone and salts and evaluate their percent (table1 and Fig.9). An EDX micro analysis of the samples illustrated the arrangement of their elements. Concentration of Samples collected studied as follow: Si (69.32-76.93 %), Al (11.01-12.77 %), Fe (4-23-8.88%), K

(2.23-4.81%), Ti (1.87-3.1%), Ca (.93-1.8%) and S(1,03-1.04%). Results helped in understanding decay mechanisms which affect the temple. They indicated that the building material of the Ramses III temple was sandstone which contains Si (silicon) ; its key element. absence of chlorine (Cl) and sodium (Na) refered to no formation of halite (NaCl) on the buildings. low concentrations of sulfates (S) (1.03-1.04 %) and calcium (Ca) (.93-1.8%) ions that might be helped in the formation salts ; gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4.1/2H_2O$) on the buildings. moderate amounts: Aluminum (Al) (11.01-12.77%) and potassium (K) (2.23-4.81%) could be attributed to feldspars and phyllosilicates group. Furthermore, small quantities of titanium were observed. The presence of relatively high amounts of iron (4-23-8.88%) and small amounts of titanium (1.87-3.1%) might be related to the origin of these sandstones and the atmospheric pollution; they played a significant role in deterioration.

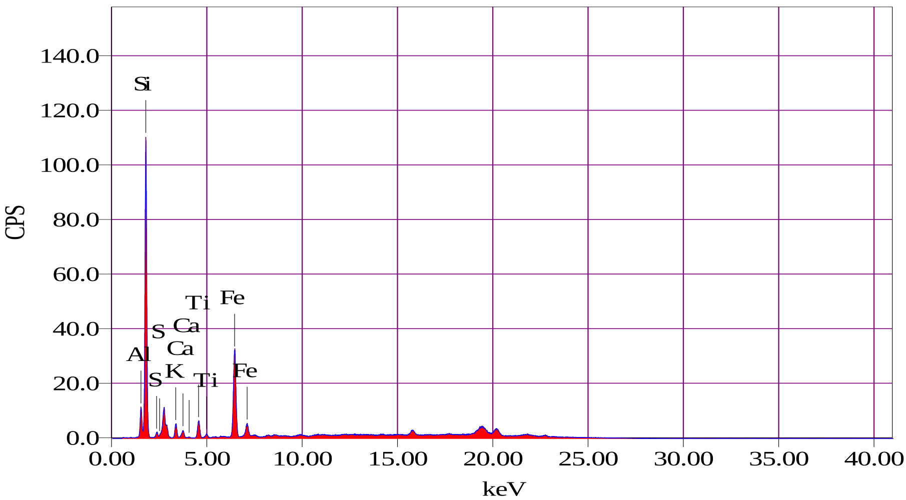

Fig. (9): EDX spectrum of the sandstones (under study)

Table (1): Quantitative EDX microanalysis (compound %) of the value spot sandstones.

Element	ms%	Oxide	ms%
Al	11.0135	Al_2O_3	12.7668
Si	69.3244	SiO_2	76.9375
S	1.0415	SO_3	1.0276

K	4.8135	K_2O	2.2285
Ca	1.8004	CaO	0.9333
Ti	3.1194	TiO_2	1.8726
Fe	8.8872	Fe_2O_3	4.2338

4.3.2. Scanning Electron Microscope

SEM micrographs show crystals of Clay minerals as micro-weathering phenomena (Fig.10. a) and in another SEM micrograph noticeable Gypsum crystals growing in the pores causing many deep pits, waxy, and hollow-faced (Fig.10. b,c,d). Big pores refer to that cement of sandstone exposed to many weathered factors (Fig.10. a, b).

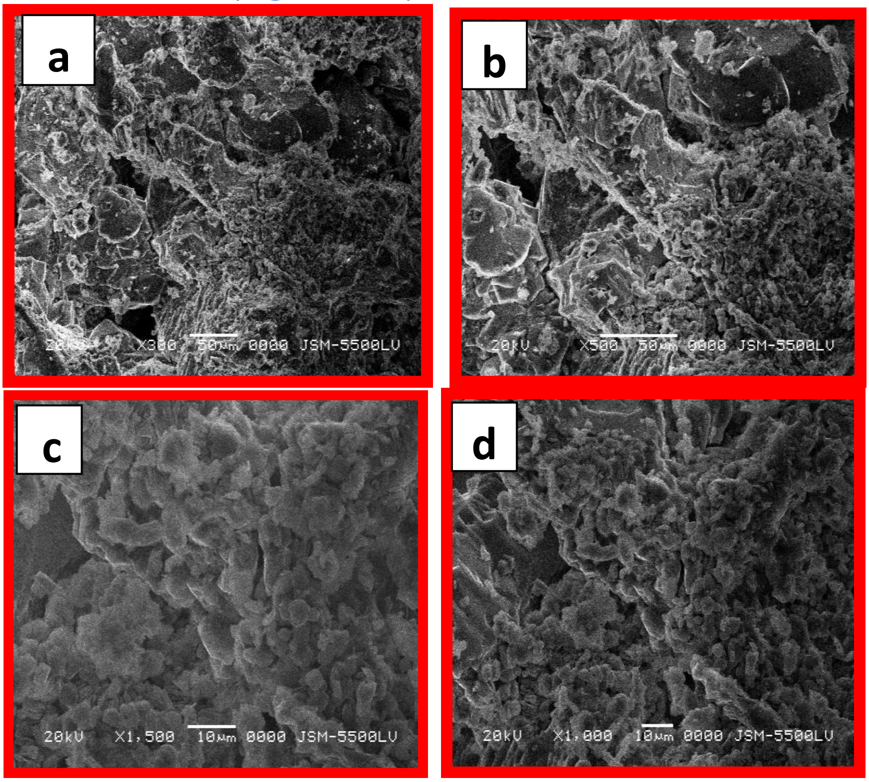

Fig. (10): SEM micrographs obtained of the damaged layers.

4.5. Mineralogical study by XRD

Mineralogical study were analyzed using XRD to define the components of sandston. The Results of XRD patterns showed that quartz was the main component of the temple's sandstone, with subordinate amounts of feldspar , minor content of Kaolinite, some dolomite, Calcite and gypsum and traces of smectite (Fig. 11,12). These study proved that sandstone which used in Ramses III's temple was Nubian sandstone (Saleh, et al., 1993). mechanical stress caused Damage to sandstone, which was affected by gypsum, dolomite and Calcite (Gauri, et al., 1982).

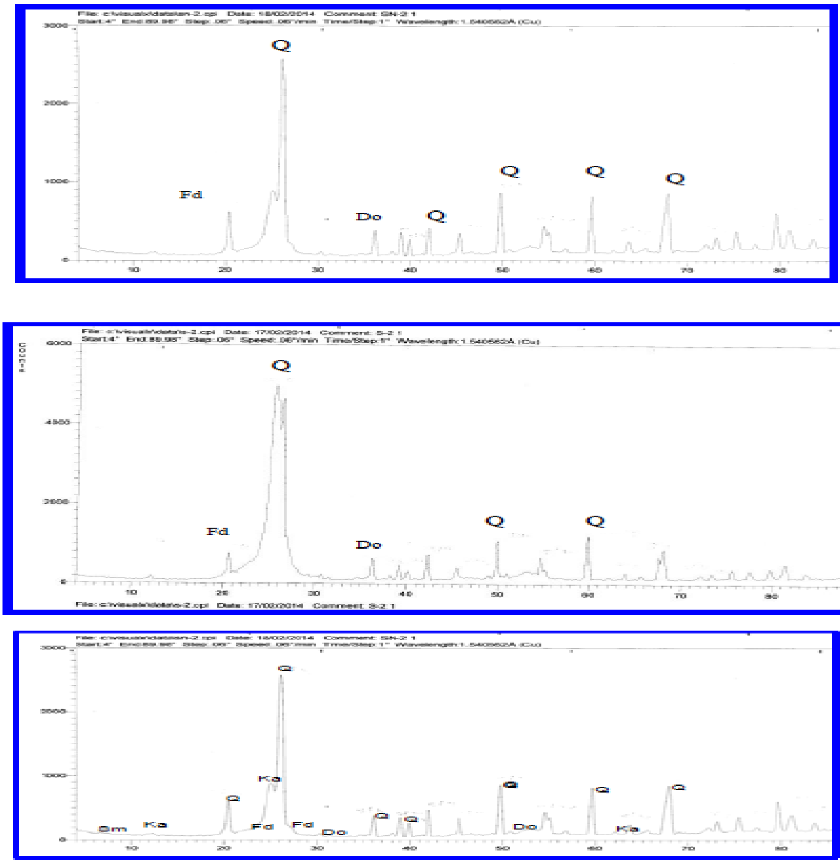

Fig (11): Representative XRD patterns of the samples; minerals were displayed as follows: Q= Quartz; Fd=Feldspars; Ka= Kaolinite; Do: Dolomite.

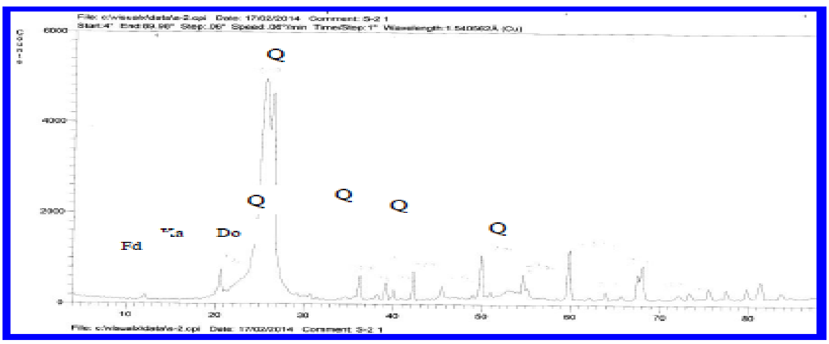

Fig. (12): Representative XRD patterns of the samples; minerals were displayed as follows: Q= Quartz; Fd= Feldspars; Ka= Kaolinite; Do: Dolomite.

4.6. Physical and mechanical properties of the sandstone

Sandstones' porosity was measured and was 18-25%. The bulk density of the temple's sandstone was 1.5 – 1.87gm/cm3. The compressive strength of the sandstone was estimated for both wet and dry samples. It was estimated of 12sandstone cubic samples (5×5×5 cm). They diversity from 20 to 25 kg/Cm2 in the dry samples and 11 to 13 kg/Cm2 in the wet ones. but The (dry) strength was classified low strength to medium strength.

5. Discussion

Field study and laboratory investigations refer to the existence of deffrent types of deterioration which sandstones underwent in the temple of Ramses III. Therefore, its building materials were investigated. soluble salts were the primary cause of decay on the surface or near the surface (Brai et al 2010). Such degradation was investigated from different places using XRD and EDX indicating the presence of sulphate as anhydrate $CaSO_4$ and gypsum $CaSO_4.2H_2O$, In addition, was identified by SEM examination (Fig.10). these salts were caused by ground water carried into sandstone. Consequently, deterioration appeared on the temple's sandstone due to the mechanical stress induced by salt crystallization weakened bonds between the grains of the sandstone and spalling, (Gauri 1982).

Moisture in sandstone caused the presence of salts (Michael et al 2001). PLM photograph indicated the existence of particles of soot in the grains of Quartz that resulted from fire and from air pollution in the temple. It caused stone decay. Furthermore, the biological degradation of sandstone was studied and Bacillus bacteria and 12 fungal floras were identified. Therefore, the current investigation proved that pollution and moisture are the main causes of biodeterioration in the temple (Torraca 1981).

soluble salts, mainly sodium chloride, is the main problem for temple's sandstone (Saleh et al 1992); moisture help in halite salt into a solution and in high temperature, water evaporated and then salt crystallized. This result in micro cracks and separation of parts of sandstone (Fig.13a, b) (Maureen et al 2003). In addition, gypsum crystallized on the surface of the temple's sandstone; crusts of gypsum were found on calcareous sandstones. However, their formation effect on the stone is various (Charola et al 2007).

6- Conclusion and Recommendations

The current study clarifies that the sandstones of Ramses III's temple were exposed to aggressive deterioration factors and different sources of moisture, containing a high level of different harmful ions. Therefore, to protect them, moisture had to be controlled by dewatering under Ramses III's temple by handling causes of rising water (i.e. change nearby irrigating canals to cover the sewerage lines and buried parts of the wall stones should be excavated. Additionally, neighboring houses should be demolished by law and the new excavation should be completed. Treatment for roots using pesticides as pesticide Glyphosphate pesticide.

Many crusts and soot on the sandstone were removed using scientific techniques (Mack and Grimmer 2003) by using physical cleaning and manuals tools, such as: scalpels, brushes and sponges. In addition, water cleaning was very important to remove soot from the surface of the sandstone (Polo et al 2010). In addition, chemical cleaning was used to remove soot and nonionic detergents. Salt solutions using poultices that consisted of cellulose or paper pulp and clay to remove gypsum. It was successful to use absorbent poultice containing 10% of $Na_2S2O_3.5H_2O$ and 5% of ammonium carbonate in water. Then water and ethanol were used to wash the treatments, such as ammonium sulphate.

It was reported that Paraloid B.48 5%, using spraying technique is the best consolidate to be applied (Leisen et al

2008). In addition, installed of crusts falling from sandstone can by emulsion of primal AC33. This aims stabilize this rendering Therefore, by using mixed of sand, white cement & lime [2 : ½ : 1] and primal AC33 which used as adhesive.

Salts must be removed from the walls, not only for aesthetic side but also to conserve and protect the sandstone, using silane products for consolidation. They were used to study penetration degrees, porous, stability and appearance (Klaus, et al., 1988). replacement of the lost parts and filling gaps between stone blocks might be carried out. The best materials used were lime, sand mortar and white cement mixed with Ediobond M56 15% with water in (1:3:0.5) percent.

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