ORIGINAL PAPER

DIAGNOSTIC STUDY OF THE DETERIORATION ASPECTS OF ROCK-CUT PANELS FROM GEBEL EL-SILSILA, ASWAN, EGYPT

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Abstract. *Gebel el-Silsila north of Aswan and is one of the most important archaeological sites in the world. It is considered the main quarry for sandstone in ancient Egypt. Also, it contains hundreds of graffiti, rock art, and rock-cut panels that suffer from several types of deterioration aspects due to the internal and the external deterioration factors dominating at the site. Different scientific methods such as: PM, SEM, XRD, EDX and FTIR have been used to study and determine the chemical and mineralogical components of those monuments and their deterioration aspects. The obtained results show that the chemical and mineralogical transformations were the main aspects in the deterioration and degradation of rock-cut panels.*

Key words: *Gebel El-Silsila, Aswan, Sandstone, Rock-Cut, mineralogical.*

1. INTRODUCTION

Gebel el Silsila is located about 18 km north of Kom Ombo and 65 km north of Aswan in Upper Egypt, between (24°39.1´- 24°39.4´ N) and (32° 55.6´- 32° 55.9´ E) [1], it covers a vast area on both banks of the Nile (Fig.1a,b) where it reaches its narrowest point [2] as the width of the river measures only about 350 - 400 m. These geological and topographical features have given the site its name, Gebel el-Silsila or (Mountain of the Chain) as known in Arabic, is derived from the ancient word (Khol-khol) which meaning in ancient Egypt barrier or frontier, in the Roman times changed to "Sil-sil or Silsili" [3] but the oldest historical name for the site was Kheny or Khenu, perhaps (Rowing-Place) in ancient Egypt.

Gebel el Silsila is considered the largest quarry for raw material of Nubian sandstone in the ancient Egyptian history. The amount of stones extracted from this quarry during Pharaonic times is estimated about eight million tons [4]. These extracted stones were used as the principal building material for temples and other monuments in Upper Egypt [5].

Gebel el Silsila is one of the fewest places which contain different types of archaeological remains such as the Predynastic cemetery, rock-cut temples of Horemhab and Ramesses II, two Scale of the Nile dating from Roman times, thirty-two rock-chapels from 18th Dynasty, numerous statues in the shape of unfinished ram headed sphinx, a huge number (about 300) of Hieratic, Demotic inscription from Greek and Coptic graffiti, in addition to rock - carvings from prehistoric times [6]. Furthermore Gebel el Silsila was a site as a sacred place, and the crocodile god Sobek was the principal deity in the area.

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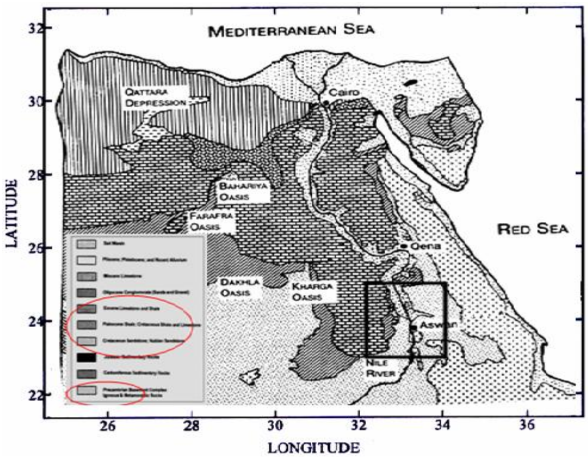
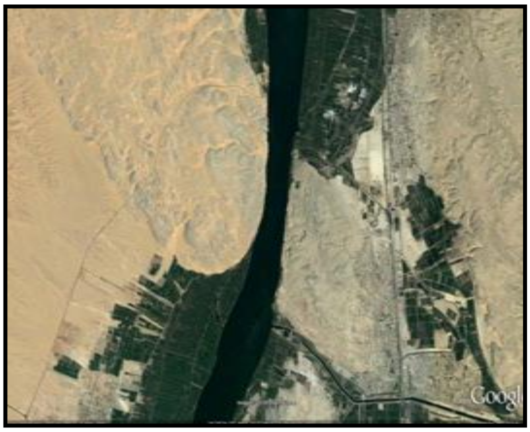
The study of rock panels on both banks of the Nile indicated that there are panels at Silsila East from the Seti I, Ramesses II, Merenptah and Ramesses III [1]. Seti I' reign panels record the provisioning of a mission of 1.000 persons who were sent to the quarry to cut the stones [7].

During a field visit of Gebel el Silsila, It was observed that the majority of the rock- cut panels lay on the west bank of Nile, and varies in shape, size, artistic technique and technology [8]. Some of them had a very thin of a preparatory layer which so-called white wash for receiving pigments while the others are just inscriptions. Sometimes the ancient artists used the mortar to repair the defects in the rock panels through filling the gabs.





a) b)

Figure 1. a) Schematic geological map of Egypt with location of Gebel el-Silsila [9]; b) Location of Gebel el-Silsila (after Google earth), The Nile (arrow).

2. DETERIORATION STATE OF ROCK PANELS

An extensive survey was carried out by visual inspection, collecting and recording meteorological data, sampling for analytical procedures. It was found that the rock panels suffer from several deterioration factors, including internal and external deterioration related to physical and mechanical properties of sandstone such as: geological structures include lamination, type and an amount of cement material, the existence of clay minerals and salts in sandstone [10]. Gebel el Silsila is located in a desert environment having arid continental climate conditions characterized by extreme temperature, intensive solar radiation, violent wind, thermal fluctuations, in addition to sudden rains and high relative humidity, condensation and evaporation due to the passing River Nile through the site. So, the rock panels suffer from several degradation and deterioration aspects such as; cracks, fissures and fractures that affected the solidity and stability of the rock panels (Fig. 2a) [11, 12], loss of the white wash and the mortar (Fig. 2b,c), discoloration due to dissolution process of the mineralogical components and / or wet and dry deposition of different pollutants (Fig. 2d), erosion the lower parts of rock panels by the water of river Nile (Fig. 2e), the subsidence and the inclination of rock panels due to the presence of the clay minerals and the saturation the rock cliff with water [13, 14] (Fig. 2f), bird droppings (Fig. 2g), aesthetic disfigurement by growing of the vascular plants (Fig. 2h), in addition to vandalism through visitors' scribbling and scratching, removing the inscriptions [15, 16], looting and cutting the rock panels for selling (Fig. 2i-k) there to damaging due to an appropriate of archeological documentation [17].

Figure 2. Deterioration aspects of rock- cut panels at Gebel el-Silsila: a) Fissures and cracks; b) Loss of white wash; c) Loss of mortar; d) Discoloration and rising moisture; e) Erosion by the water of the Nile during flood and fractures in rock cliff; f) The inclination and the subsidence; g) Soiling by bird droppings; h) The vascular plants; i) Visitor's scribblings by scratching; j) Removing the inscriptions; k) Looting and cut for selling.

3. MATERIALS AND METHODS

Deteriorated samples of sandstone, white wash, and the mortar were collected for procedure the study by different scientific methods; PM, SEM-EDX, XRD, and FTIR to identify the chemical, mineralogical components and the deterioration aspects of rock - cut panels structure.

4. RESULTS

4.1. PETROGRAPHIC EXAMINATION

The deteriorated sandstone samples examined by polarizing microscope (PM) showed that, the sandstone is essentially composed of quartz grains, at least the majority of the volume, those quartz grains range from moderate to ill-sorted, from sub-rounded to sub-angular in the shape and medium but mostly fine-grained (Fig. 3a). The photographs show that, the sandstone is highly porous and cemented by iron oxides (Fig. 3b). Sometimes the iron oxides appear as nodules coated the rim of quartz grains due to the deterioration of iron oxides, furthermore the samples contain calcite as a secondary mineral(Fig. 3c). The sandstone also contains a few grains of plagioclase feldspars. One of the main deterioration aspects of the stone that, corrosion of quartz grains, intra-fractures and cracks within the quartz grains due to mechanical weathering (Fig. 3d).The micrographs revealed also slightly altered plagioclase grains to clay minerals (mostly sericite) (Fig. 3e) and multiple crossed-cracks in plagioclase (Fig. 3f).

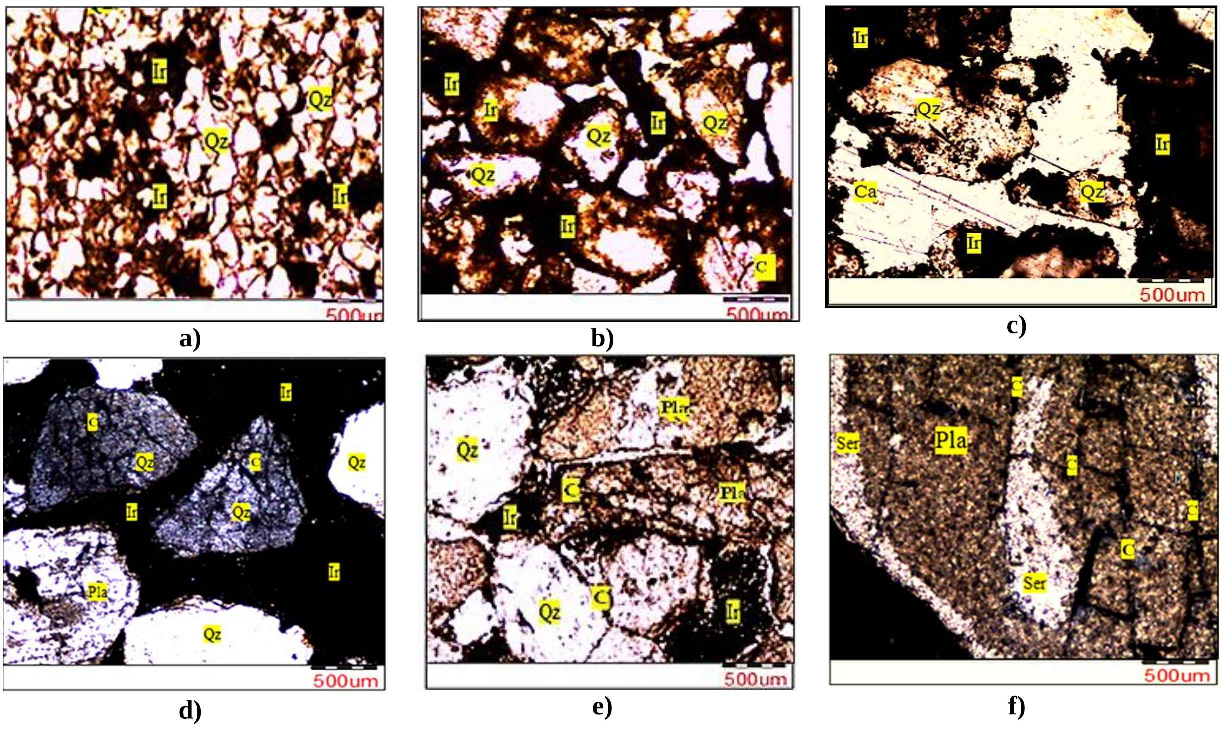


Figure 3. Petrographical micrographs of sandstone samples from rock-cut panels at Gebel El-Silsila quarries: a) Fine-grained and sub- rounded to sub- angular quartz grains; b) Quartz grains cemented by iron oxides; c) Calcite mineral and quartz grains coated with iron oxides; d)Plagioclase and cracked quartz grains; e) Poly crystallized quartz grains and plagioclase grains; f) Highly altered plagioclase to sericite.

4.2. SCANNING ELECTRON MICROSCOPE (SEM) STUDY

Micro-morphological aspects of weathered sandstone samples were studied by SEM the results show that the sandstone that represents the support of rock-cut panels from Gebel el Silsila has several deterioration aspects such as: partial or complete dissolution the cement between quartz grains, which sometime appear as fine binder among the grains which leads to create the cavities and disintegration in stone structure (Fig. 4a). The sandstone is characterized by interlocking structure of the quartz grains, fewer amounts of the cement and high porosity are from the main parameters responsible for the damage and collapse of sandstone (Fig. 4b).The other deterioration aspects cleared by SEM investigation [18, 19] that corrosion and etching the quartz grains due to saline solutions and crystallization the salts (Fig. 4c). The heavy concentration of crystallized salts, mostly sodium chloride have developed between the quartz grains and replaced the cement (Fig. 4d).

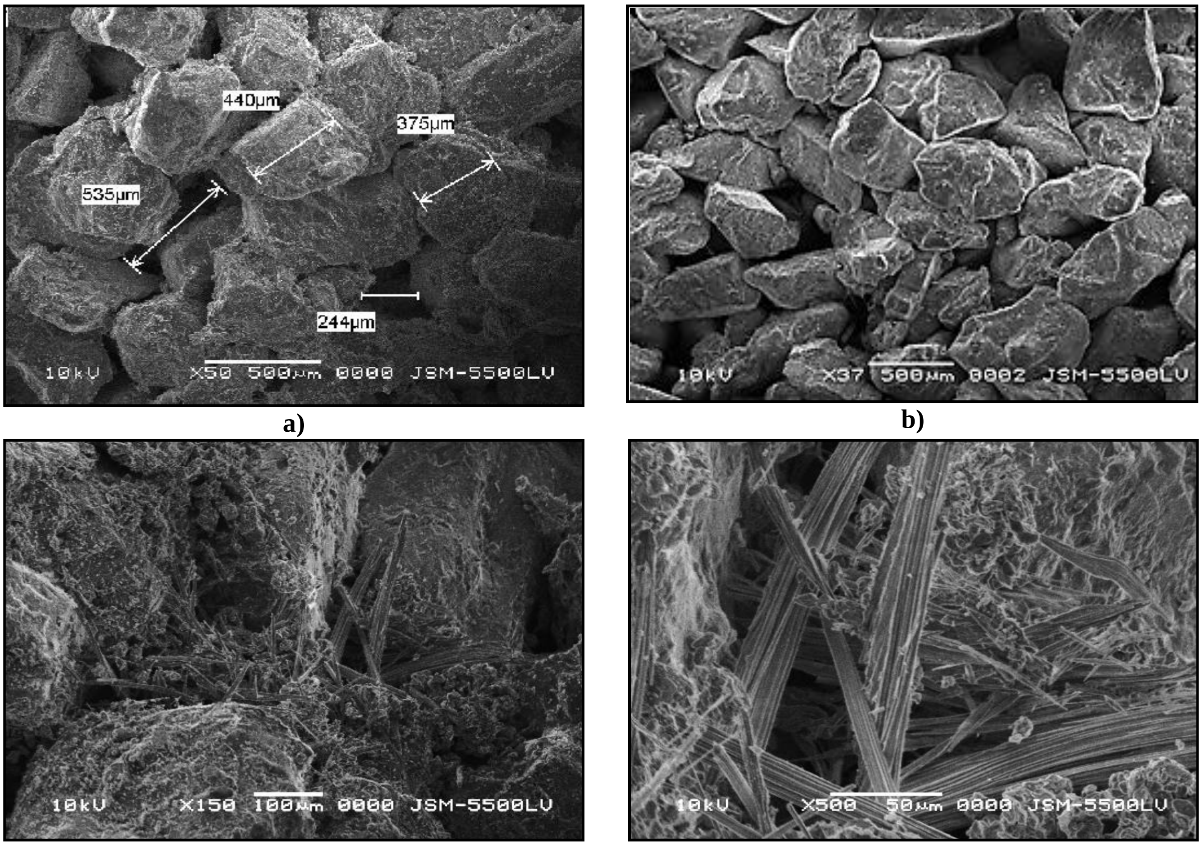


Figure 4. SEM micrographs of sandstone from rock-panels at Gebel El-Silsila quarries: a) The fine binder among the quartz grains and cavities; b) The interlocking structure of quartz grains; c) Corrosion of quartz grains and salts; d) Heavy concentration of crystallized halite.

4.3. XRD MINERALOGICAL ANALYSIS

Some deteriorated samples of rock-cut panels (sandstone, white wash and mortar) were studied by XRD as following: The results of sandstone (Fig. 5a-c) declared that sandstone consists of quartz (SiO_2) the dominant mineral, in addition to microcline ($KAlSi_3O_8$), calcite($CaCO_3$), as secondary minerals, in addition to kaolinite($Al_2Si_2O_5(OH)_4$) and halite (NaCl) as traces. While the white wash samples (Fig. 5d,e) essentially comprise of calcite ($CaCO_3$) in addition to quartz. Furthermore the XRD analysis of the mortar for gaps filling (Fig. 5f,g) compose of the anhydrite ($CaSO_4$) in its majority, in addition to quartz (SiO_2), kaolinite ($Al_2Si_2O_5(OH)_4$) and halite (NaCl) as secondary minerals.

4.4. ENERGY DISPERSIVE ANALYSIS EDX

EDX proved that sandstone contains different elements of minerals in various quantities such as: Si, Fe, Ca, Al, plus Cl, Na and S (Fig. 6a-c). While the white wash consists of the following elements: Ca, Si, Fe, S, Al, plus Ti and Cl (Fig. 6d,e).On the other hand the analysis of mortar samples by EDX show various elemental of minerals in descending order: Ca, S, Si, Fe, Al, Ti, and K (Fig. 6f,g).

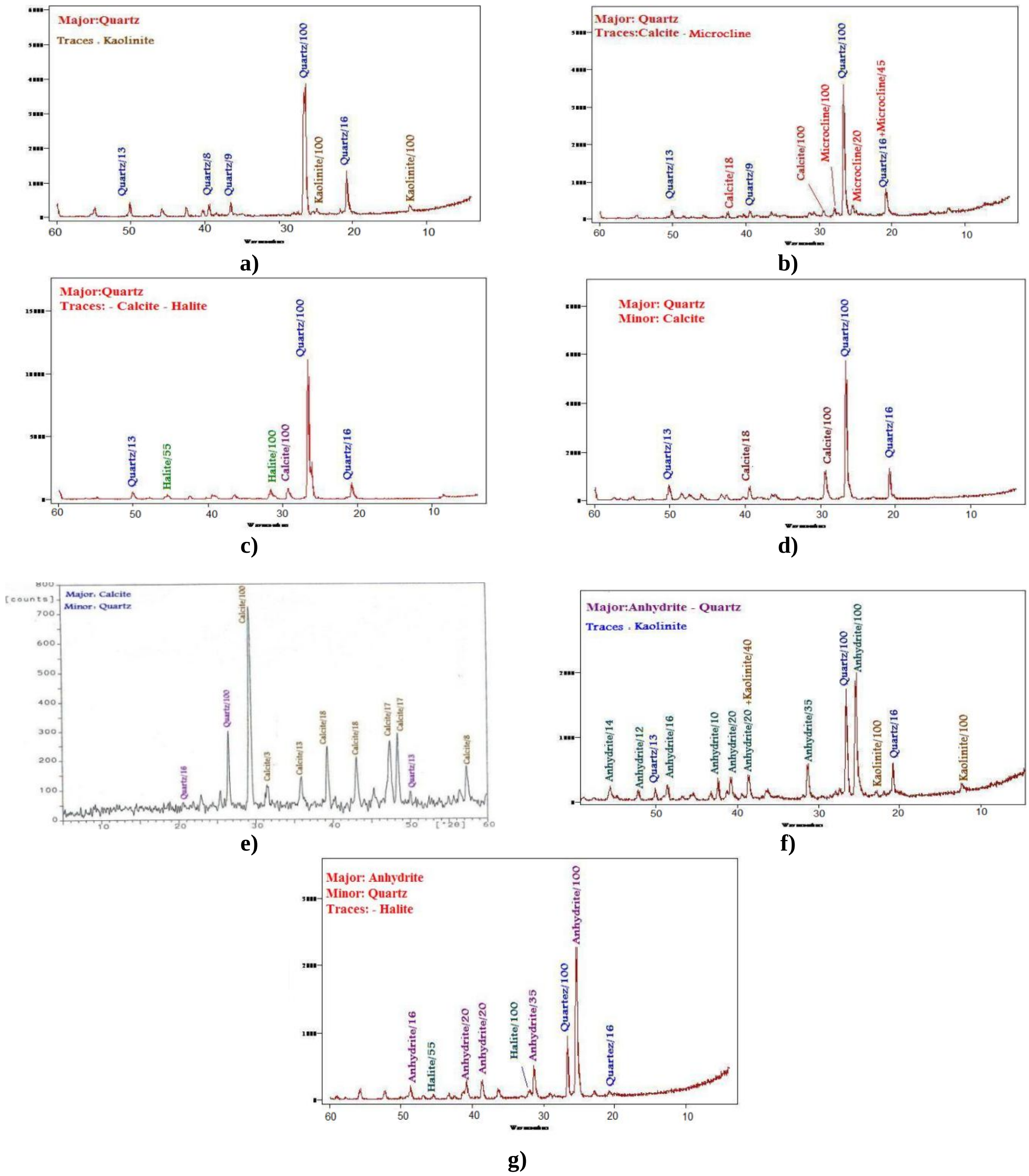


Figure 5. XRD patterns of: a) sandstone sample from the stela of the Amarna period; b) sandstone sample from the stela of Seti I; c) sandstone sample from the stela of Ramesses III; d) white wash sample from the panels of the Amarna; e) white wash sample from the panels of the Merenptah; f) mortar sample from the panels of the Amarna; g) mortar sample from the panels of the Merenptah.

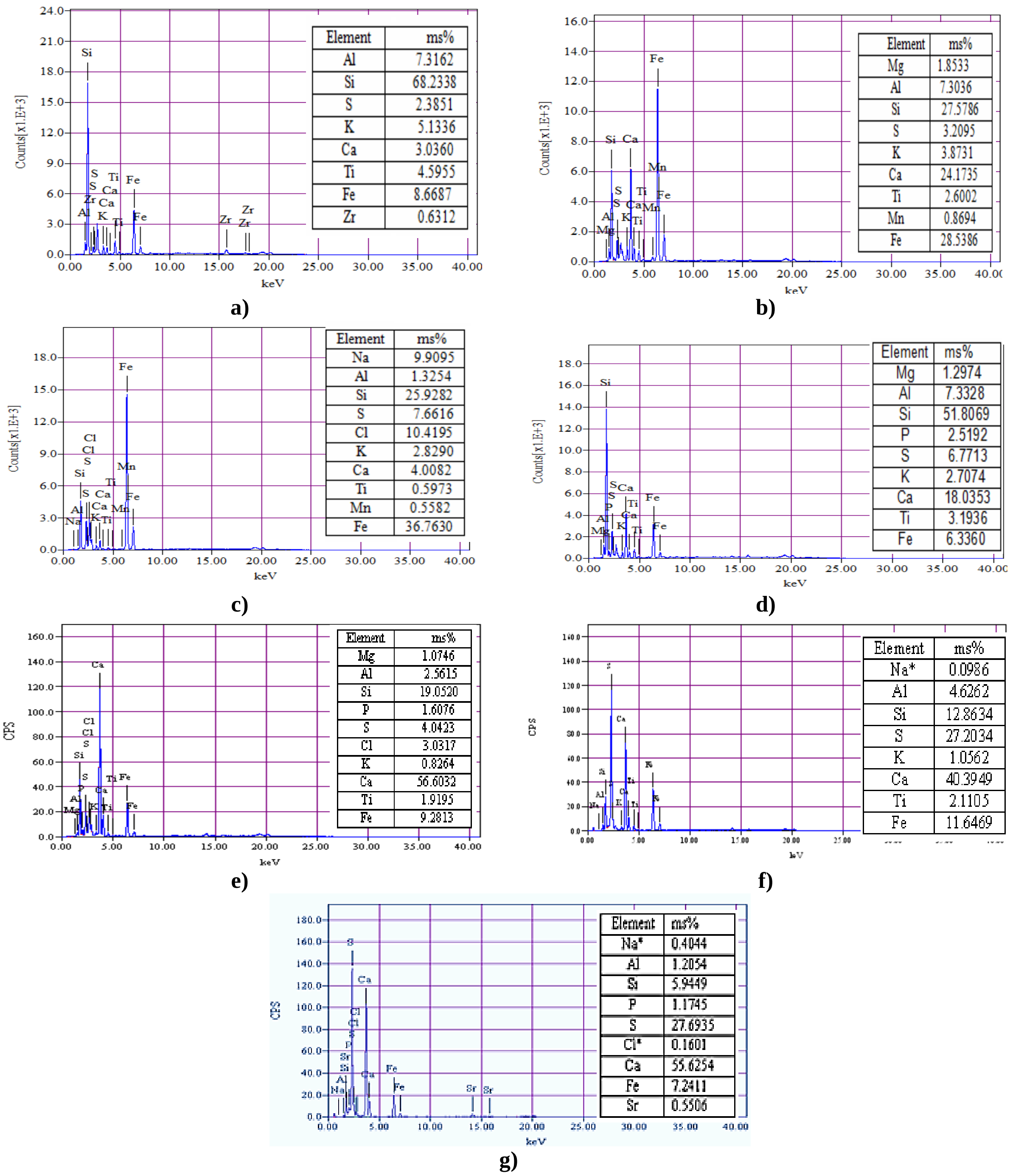
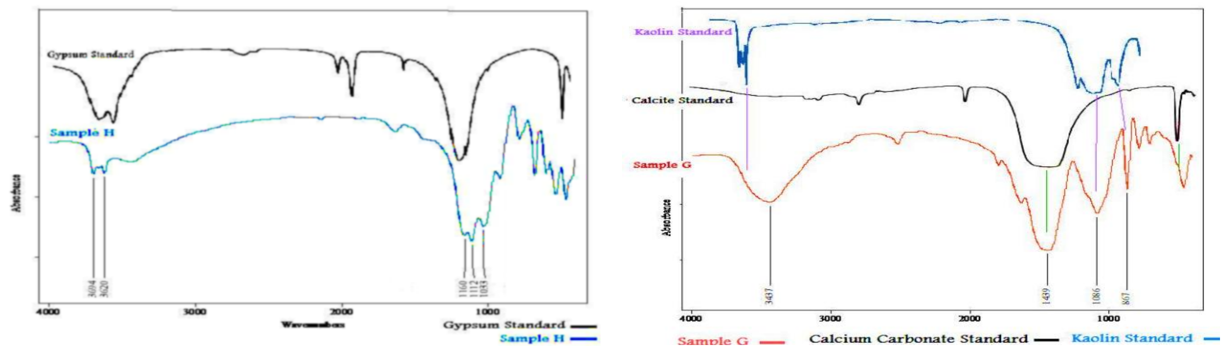


Figure 6. EDX patterns of: a) sandstone sample from the stela of the Amarna period; b) sandstone sample from the stela of Seti I; c) sandstone sample from the stela of Ramesses III; d) white wash sample from the panels of the Amarna; e) white wash sample from the panels of the Merenptah; f) mortar sample from the panels of the Amarna; g) mortar sample from the panels of the Merenptah.

4.4. FOURIER TRANSFORM INFRARED (FTIR) ANALYSIS

FTIR spectra of two samples of white wash and mortar from rock- cut panels at Gebel el-Silsila show absorption bands at the following wave numbers: 3437, 1439, 1086 and 867 cm^{-1} for the white wash as shown in (Fig. 7a and Table1). On the other hand the mortar sample showed absorption bands at the following wave numbers: 3694, 3620, 1160, 1112 and 1033 cm^{-1} as shown in (Fig. 7b and Table 2). By comparison study with I.R. stander shows that, the white wash which was used in studied rock-cut panels consists of calcite, kaolin and quartz, while mortar consists of gypsum.



a) b)

Figure 7. FTIR spectra of: a) mortar sample from the stela of the Amarna period; b) white wash sample from the stela of Merenptah.

Table.1. FTIR results of the stela of Merenptah sample.

Wavenumber			Functional groups
Sample G			
3437	3700-3200 cm^{-1}	kaolin	O-H stretching bands
1439	1490-1370 cm^{-1}	calcite	CO_3^{2} stretching band
1086	1140-1080 cm^{-1} 1100-1000 cm^{-1}	silica kaolin	Asymmetric Si-O-Si stretching bands
867	910-850 cm^{-1} 910-830 cm^{-1}	calcite kaolin	O-C-O bending band Si-O stretching band

Table.2. FTIR results for the previous sample.

Wavenumber			Functional groups
Sample H			
3694-3620	3700-3200 cm^{-1}	gypsum	O-H stretching bands Antisymmetric & symmetric O-H stretching bands
1160 1112 1033	1140-1080 cm^{-1} 1100-1000 cm^{-1}	gypsum	Asymmetric SiO_4^{2-} stretching band

5. DISCUSSION

The results of XRD, EDX and FTIR analyses this study proved that sandstone represents the support of rock- cut panels at Gebel el-Silsila consists mainly of quartz [20] in addition to microcline, calcite, kaolinite [21] and halite as secondary minerals as appeared by. Furthermore the petrographical investigation indicated that sandstone was subjected to several deterioration factors at the site which led to corrosion and cracking of the quartz grains and microcline feldspars, the latter has altered to clay minerals (mostly sericite). The deterioration aspects of sandstone were emphasized through the morphological investigation by SEM, which shows that erosion and dissolution of the cement between quartz grains which lead to cavities and help the migration of the saline solutions and crystallization of sodium chloride salt. This study proved that the white wash was used as a wall plaster consists essentially of calcium carbonate [22]. The proved study also that the mortar was used for gap filling and repairing the defects in rock-cut panels consists essentially of anhydrite .The study determined several deterioration aspects which were observed in the site and through the analytical techniques used in this study as follows:

- **Mineralogical alterations –** the alteration and decomposition of potassium feldspars minerals, microcline to the sericite was observes from thin section examination, this alteration attributed to the effect of chemical weathering factors dominating at the site, which lead to the damage to the structure of sandstone [23] on the other hand the Nubian sandstone contains amount of kaolinite as accessory minerals according to XRD and EDX analyses. The clay minerals undergo a major deterioration through the swelling and shrinking stresses during wetting and drying cycles, the result is formed the fissures, cracks and granular disintegration of sandstone furthermore the existence of clay minerals and saturation the rock cliff with water lead to sloping, slumping and collapsing of rock-cut panels and accelerate rock slide [24].
- **Crystallization of salts –** the XRD, EDX and SEM indicated the presence of halite salt in the sandstone samples; this salt is common as a natural impurity in Egyptian soil and sedimentary rocks. This salt not only causes crystallization pressure in stone' pores but also plays a fundamental role as an electrolyte in the swelling process of clay minerals [25]. The repetition of dissolution and crystallization of this hygroscopic salt during wetting and drying cycles at the site cause a severe deterioration aspects of rock-cut panels such as: roughening, cracks, fractures, flakes and contour scaling [26]. Furthermore the sandstone has a high influenced by salts that lead to loss of its original weight [27].
- **Dissolution of iron oxides –** PM and EDX revealed that the sandstone contains a high amount of iron oxides (nodules) [28] the cement of quartz grains in sandstone, the temperature and moisture at the site accelerates the dissolution and conversion ferrous ion (Fe^{2+}) to ferric ion (Fe^{3+}) [29], then iron oxides leached and cause the deterioration of sandstone through various deterioration aspects such as: aesthetic disfigurement, coloration and the staining with brownish and reddish colours [10].
- **Dehydration and failure of mortars –** the analysis showed that, the mortars were used for gaps filling and repair the defects of rock-cut panels consist mainly of calcium sulfate dehydrate (anhydrite), the extreme temperatures and the heat of solar radiation at the site, that will able to decompose gypsum through dehydration to anhydrite [30]. The dehydration of gypsum takes place through two stages of chemical reactions: in the first one, gypsum is transformed to hemihydrate, which is converted to anhydrite. The dehydration process causes a dramatic change for gypsum such as: losing weight and reducing of the mechanical strengths due to change of the systematic formed crystals and broken the bonds between particles [31] and those lead to the weakness of the mortar, loss of its adherent properties and, evolution the stress in addition to formation fissures, cracks and collapse of the rock-cut panels.

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