Open Journal of Geology, 2017, 7, 51-68
http://www.scirp.org/journal/ojg
ISSN Online: 2161-7589
ISSN Print: 2161-7570

Diagnosis and Damage Assessment of Weathered Quartzite Colossi of 18th Dynasty from Karnak Temple, Egypt

Abd Elhakim A. El-Badry[1], Abdelkareem E. Ahmed[2], Nabil A. Bader[2*]

[1]Ministry of State for the Antiquities Affairs, Cairo, Egypt
[2]Conservation Department, Faculty of Archaeology, South Valley University, Qena, Egypt
Email: *nabil.abdeltawab@arch.svu.edu.eg

How to cite this paper: El-Badry, A.E.A., Ahmed, A.E. and Bader, N.A. (2017) Diagnosis and Damage Assessment of Weathered Quartzite Colossi of 18th Dynasty from Karnak Temple, Egypt. *Open Journal of Geology*, **7**, 51-68.
http://dx.doi.org/10.4236/ojg.2017.71004

Received: October 11, 2016
Accepted: January 15, 2017
Published: January 18, 2017

Abstract

The Egyptian Pharaonic temples are traditionally made of different stones (limestone granite, diorite, or sandstone and quartzite) shaped into large heavy blocks or as Colossal statues. One of these is the colossi of Thutmose II and Amenhotep III at Karnak temple which made out of red quartzite from Gebel el-Ahmar, located at north-east of Cairo. Quartzite is one of the famous stones that were widely used during the heights of ancient Egyptian civilization. The Colossi of Thutmose II and Amenhotep III were subjected to many exogenous and endogenous deterioration factors which causes of a severe damage of the stone materials. In this study we documented the weathering of these quartzite colossal statues using field recording and laboratory analysis to evaluate their conservation state. Weathering and deterioration aspects noted through light optical microscope (LOM), polarizing microscope (PM) and scanning electron microscope (SEM). The mineralogical characterization was performed using X-ray powder diffraction (XRD) and Energy dispersive analysis (EDX). The mineralogy and weathering study of quartzite on the Colossi of Thutmose II and Amenhotep III illustrate a succession of geochemical processes which have taken place at the colossi and it revealed that, they need for quick intervention.

Keywords

Colossi, Quartzite, Karnak Temple, Deterioration, Conservation Concepts

1. Introduction

The experimental studies in decay of Quartzite Colossus in Egypt are extremely rare and all agreed that the deterioration of these statues is a complex process in which physio-chemical and biological mechanisms are usually considered the main factors, it generally starts before discovering with alteration processes due to the synergetic action of archaeological environment during burial in land which leads to immediate deterioration and after discovering by moisture, wind, sunlight and thermal cycles. Casciati S. and Osman A. 2004 [1] revealed the strong influence of ambient vibration for damage of Memnon Colossi using the finite element method and the results indicated that the distributed cracks characterizing the current state of the structure, play a significant role in the static and dynamic response of the monument. Casciati S., Borja R.I 2005 [2] presented a methodology for non-linear dynamic SFSI analysis of an important landmark, the South Memnon Colossus. Knox W.O.B. *et al.* 2009 [3] try to study the source of quartzite of Memnon Colossus by mineral fingerprinting using the method of heavy-mineral analysis, they points conclusively to a Gebel Ahmar as a source for the two Colossi. Heldal T. *et al.* 2005 [4] studied the silicified sandstone quarries of Gebel Gulab and Gebel Tingar at Aswan, an examination of the extraction sites indicates an overwhelming use of fire-setting to extract the stone during the Pharaonic Period and to a lesser extent the wedging technique applicable to the Roman exploitation. Raza M. *et al.* 2010 [5] studied the weathering history of quartzite. Paper reports the results of a geochemical and petrological study of Naharmagra quartzite that are the oldest known clastic sedimentary rocks of the Aravalli craton and the data are used to assess the influence of sorting and recycling, source rocks weathering and composition of provenance. Frütsch F., 2011 [6] studied the weathering of quartzite under cryogenic conditions SEM and TEM studies. This paper trying to highlight the deterioration and diagnosis assessment of weathered Quartzite Colossi of 18th Dynasty from Karnak temple; the results are not only novel but also essential for the future restoration project.

1.1. Archeology of the Quartzite Colossi

Quartzite Colossal built in Karnak temple by the pharaohs of Thutmose II (sometimes read as Tuthmosis II) and Amenhotep III (18th Dynasty) to represent a huge doorway of the main entrance of Karnak temple, where the two principal axes of the complex intersected, one last resting place for the god before he set out on his journey south (Blyth, E., 2006) [7] (**Figure 1**). The colossus to the west of the Eighth Pylon doorway, immediately beside the door of the pylon is made out of red quartzite, representing Thutmose II sitting on his throne in regal position with his hands on his knees [8], at the belt and side of the throne are the cartouches of Thutmose II. Remnants of a small statue of his daughter, princess of Mut-Neferet, that she was dead at the time of erection the statue, stand at the right leg of the King in smaller scales. The upper part of the statue to the chest area or center was missing, its 7 m height, without the base and restored by Thutmose III in the year 22 of his reign [9]. It was found in the upper part of the excavation, but a very bad condition and was placed on a bench near the statue site. The 2nd Quartzite huge statues at Karnak temple is the two colossi of Amenhotep III. The colossi were erected in front of southern gate of 10th pylon of Karnak and facing the south, both of them bearing the names of the king

Amenhotep III. Amenhotep son of Hapu prepared these colossi for the celebration of his Lord's first jubilee (Heb-sed) [10]. The base of western colossus (which was to be originally Amenhotep III) was reused by the king Horemheb, who restored the western quartzite pedestal with sandstone blocks (Talatates) of Amenhotep IV and decorated again its previous lack face with his scenes, offerings and gods [11]. Both colossi were quite damaged, may have been fallen victim to earthquakes in the past and that were accompanied by a vast array of fragments left were they fell. After the collapse of these colossi, just the quartzite pedestals still in their original place, while all fragments moved to put on modern Mastaba (built by archaeologists made of cement and red brick) east of Khansou temple in southern part of Karnak temples. In spite of great hardness and toughness of Quartzite, which makes it difficult to work, the ancient Egyptian artist had carved many of the inscriptions with sunken reliefs on both sides of the colossi and pedestals, a horizontal line of text on the facade of the quartzite pedestal, on both sides of the ankh of the axis was done, gives the cartouches of Nebmaatre (Amenhotep III) which are labeled fraction of Ra on the side with the setting sun and heir of Ra on the side with the rising sun. Each holds a panther paw in their left hands, while with the right they present their speech. In the center on both sides of the disk, two falcons wearing the double crown are perched on the Horus name of the king framed by the ka which rests on an ensign holder provided with two arms, one of which holds up the long staff crowned with the emblem of the royal ka. On the west face of the quartzite pedestal, the first eight nomes of Lower Egypt are represented.

1.2. Uses of Quartzite (Silicified Sandstone) in Ancient Egypt

In spite of great hardness and toughness, which makes it difficult to work, quartzite was used not infrequently in ancient Egypt in sculptures and architecture from the Old kingdom to Roman period (Bloxam, 2007) [12]. It was used as grinding stones and occasionally for pounders and other tools, but also as an ornamental stone (James A. Harrell, 2012) [13]. Later quartzite was used in a wider range of objects such as Pylons, obelisks, stelae, offering tables, sarcophagi, colossal statuary, shrines and false door (Verner, 2002) [14]. The first utilitarian use of quartzite sandstone was the Middle Paleolithic time in Upper Egypt and Lower Nubia by the early Nile Valley dwellers as tools (such as abrasive rubbers, grinding stones and borers to hollow stone vessels). The use of quartzite was almost exclusively by royalty and the elite. Some examples include Life-sized statue of 4^{th} Dynasty of King Djedefre, which has been connected with the emergence of the title "Son of Ra" during his reign (Bloxam, 2007). The rock is technically known as Quartzite (orthoquartzite) or "silicified sandstone". Unmetamorphosed quartz sandstone (clastic rock) with a silica cement (Prichystal, 2010) [15]. Some geologists prefer to call this rock 'siliceous sandstone' to distinguish it from metamorphic quartzite, but Egyptologists have long referred to it simply as "quartzite". The geological term "quartzite" usually refers to a metamorphic rock although the quartzite used by the ancient Egyptians is entirely of the sedimentary variety (Aston, *el al.*, 2000) [16]. Quartzite is composed of quartz (a crystalline form of silica) grains solidly cemented with chemical silica, so the cement and the grains are of the same material as a result of the silicification process, which made the rock much harder and more durable than the" original" arkosic sandstone (Klemm and Klemm, 2008) [17]. Egyptian quartzite is usually white, with reddish, yellow, and orange varieties, the colors being produced as a result of iron oxides content, according to (Kozloff and Bryan, 1992) [18]. Quartzite or silicified sandstone was essentially quarried at two locations in Egypt from Pharaonic times to the Roman era at Gebel el-Ahmer, and Aswan quarries complex. According to (Harrell, *et al.*, 1996) [19], the Gebel el-Ahmer, (30˚3.15'N, 31˚17.8'E) located at north-east of Cairo, is one of the most well-known ancient Egyptian quarrying areas. Gebel el-Ahmer or Red Mountain today the name has changed to Gebel Akhdar, because of the increasing amount of planting and construction work (Storemy, P. 2009) [20]. While the Aswan quarries complex, Gebels Gulab and Tinger near ruins of St. Simon's Monastery; on west bank opposite Aswan (24˚6.4'N, 32˚52.6'E), the stone is light gray to mainly various shades of brown, fine-medium-grained, occasionally pebbly, quartz-cemented (orthquartzite), belonging to (Umm Barmil Formation of the Nubia Group, Upper Cretaceous) (Harrell, *et al.*, 1996).

1.3. Conservation State

The structural behavior of large, monolithic, ancient monuments consisting of heavy stone blocks connected one to the other by the gravity load alone, without using mortar. These monuments derive their stability from the contact pressure and the corresponding shear friction acting between the heavy stones which form the monument body. Such a rationale, coupled with the relatively low height-to width aspects ratios of their elements, has allowed these monuments to survive for thousands of years, with few exceptions (Casciati and Osman, 2005). Like the previous example, the quartzite sandstone Colossus of Amenhotep III, 20.95 meters tall in the past, after its a total collapse, now both of his feet rested on the pedestal made from a separate block of the same quartzite, still in its original position, the rest of statues fall down, and moved to put on modern Mastaba (built by archaeologists made of cement and red brick). The Colossi of Amenhotep III and Tuthmosis II were subjected to many exogenous and endogenous deterioration factors. Deterioration of historical monuments is a complex process, which is the result of the interaction between physical/mechanical, chemical and anthropogenic deterioration factors in addition to their nature, composition and properties which causes of a severe damage of the stone materials. It is worth mentioning that quartzite sandstone of these Colossi came from Gebel el-Ahmer near Cairo, and now at Karnak temple, Luxor, which represents a different pattern of climate, so the main external deterioration factor in the new site is the daily and annual temperature variation. The recording meteorological data showed that, isolated air temperatures ranging up to 53˚C during the summer months, during the whole year the air temperatures 40˚C are common and decrease to about 20˚C during nights during the same months and varies from less than 5˚C during winter nights with the exception of November to February rain occasional Thundershowers. The result of these cycles of expansion and shrinkage producing stress and strains on quartzite sandstone minerals, leading to cracks, macrocracks and fissures (**Figure 1(a)**, **Figure 1(b)**), vertical fractures (**Figure 1(c)**) and contour scaling (**Figure 1(d)**) in these colossal statues and its pedestals. The formation of cracks not only caused decrease the stiffness of the structure of these colossi but also the material mass also decreases. The Quartzite statues in Karnak also suffer from roughening (**Figure 2(a)**), pitting and surface punctures (Perforations) (**Figure 2(b)**), granular disintegration and exfoliation (**Figure 2(c)**). Field observation indicated also, the wall reliefs at the statues suffer from Coloration, discoloration and staining (**Figures 3(a)-(c)**), according to the experiments of (Moody, 1976) [21] the color of quartzite sandstone change from brown to red at highly periodical temperatures, and that comes about when limonite and other ferric oxides which are present as impurities are losing water and are being altered to ferrous oxides including hematite, this causes the rock to be blotched. Microbiological colonization by higher, Vascular plants and roots are growing near the colossus of Tuthmosis II, (**Figures 4(a)-(c)**) which disfigured the statue and caused both mechanical and chemical deterioration.

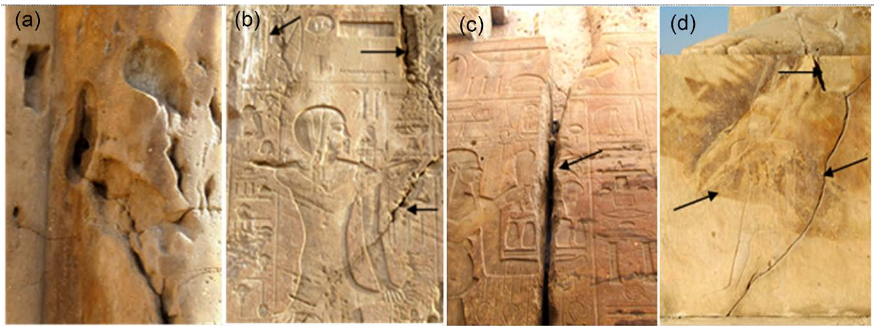

Figure 1. Deterioration features of quartzite colossi at Karnak temple; (a), (b) cracks, macrocracks and fissures, (c) vertical fractures, (d) contour scaling.

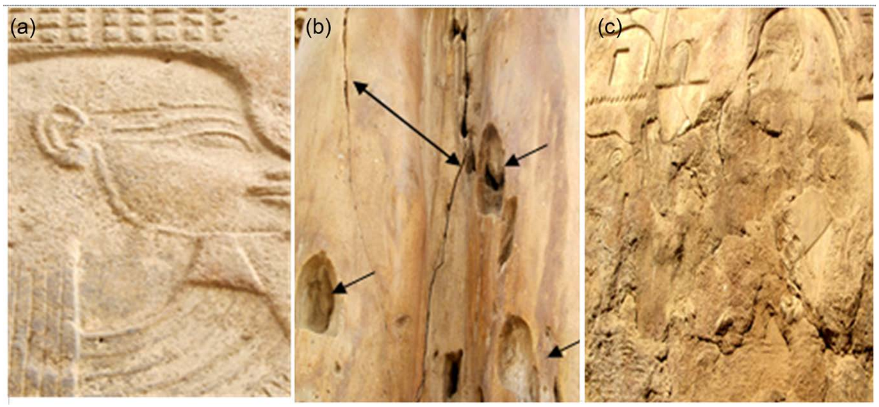

Figure 2. The Quartzite statues in Karnak suffer from; (a) roughening, (b) pitting and surface punctures (Perforations), (c) granular disintegration and exfoliation.

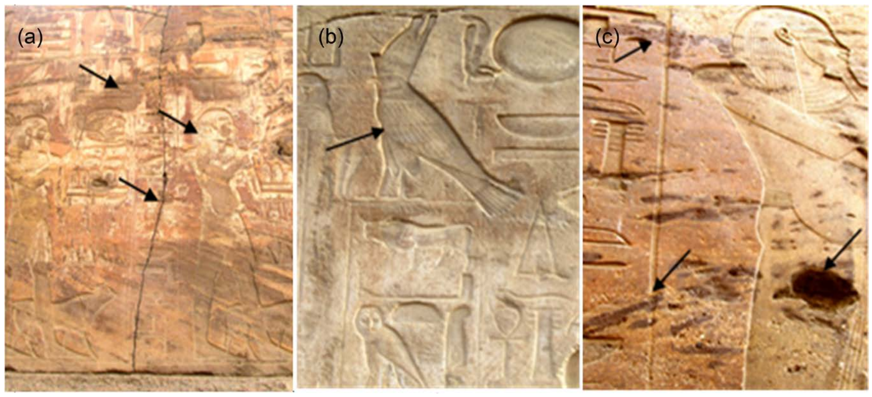

Figure 3. Discoloration of quartzite colossi at Karnak temple, and staining; (a), (b) coloration and discoloration of relives, (c) Loss of iron-rich component.

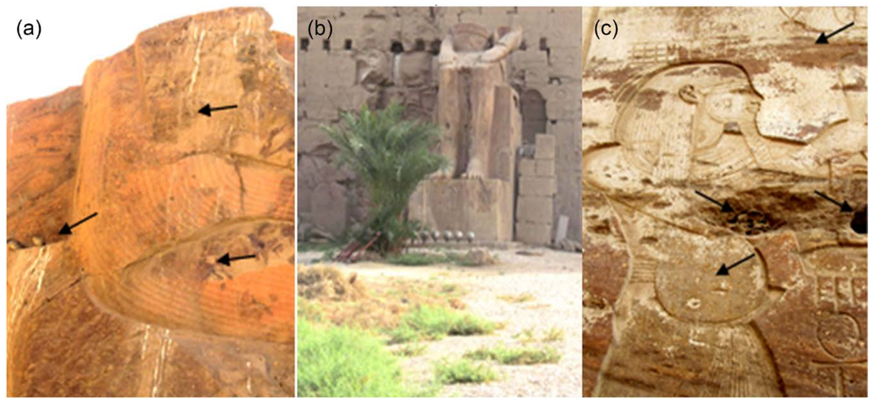

Figure 4. (a) Soiling, staining and bird droppings, (b) Vegetation & higher plant growing near the colossus of Tuthmosis II, (c) Filled lacunas with ancient mortar, soiling and loss of plaster layer (coating).

2. Experimental

Different series of laboratory tests were applied to samples in order to determine their basic characteristics. A representative sampling from Amenhotep III and Tuthmosis II at Karnak temple were performed. It was cared to collect samples as small as possible in size from removing the fragments removed from the statues. Quartzite fragment and polished cross sections were examined using Leica DM 100 stereomicroscope under normal reflected light at 40× to 100× magnification. The photomicrographs recorded with a Leica EC3 12 megapixel digital camera. Thin sections were prepared from quartzite fragments, each about 0.8 cm in diameter. The minerals and texture of quartzite samples was determined using Olympus BX51 TF Japan petrographic microscope attached with digital camera under magnification 20× up to 40×. The Samples were investigated by Scanning Electron Microscope (SEM). Observations were done using JEOL JSM 6400 coupled with an EDX. Semi quantitative analyses of elemental composition were obtained using an EDAX, X-ray energy dispersive spectrometer analyzer with at an acceleration voltage of 200 v-30 keV. Mineralogical structure quartzite were determined by X-ray diffraction (XRD) analyses performed by PW 1840 diffractometer equipped with a conventional X-ray tube, CuKα radiation, 40 kV, 25 mA, point focus.

3. Results

3.1. Light Optical Microscope (LOM) Results

Stereomicroscope image of quartzite samples illustrates fine grains of quartz on the matrix (quartzite texture) and different texture of quartzite. The weathered sample contains high concentration of leached iron oxides (yellow color Limonite) and voids, high portion of iron oxide (yellowish brown color), large grains of silica and losses cement between grains. The image illustrates large chert pebbles in quartzite's texture. It also the samples suffer from several deterioration of its structural coherence. Granular disintegration, fractures was detected clearly (Figures 5(a)-(f)).

3.2. Petrographical Investigation

Superior general observation from the petrographic study of thin sections of quartzite samples taken from colossal statues at Karnak temple revealed that, the quartzite consists mainly of monocrystalline grains of quartz detrital, which represent the majority of rock texture. The quartz grains range from moderately to well-sorted from rounded to sub-rounded in the shape and from fine to very coarse in size. These grains are enclosed by thin rim of dark material, this external color resulting from the occurrence of iron oxide; limonite, which easily distinguished in the micrograph by its dark color. Limonite distribution varies in the samples and is limited exclusively to the spaces between the original sand grains (Figure 6(a), Figure 6(b)). The quartz grains are cemented by one of two types of the silica cement; a very common type in the sections is known as, syntaxial quartz overgrowth; is composed of relatively large quartz crystals that have grown in crystallographic continuity with the individual detrital quartz

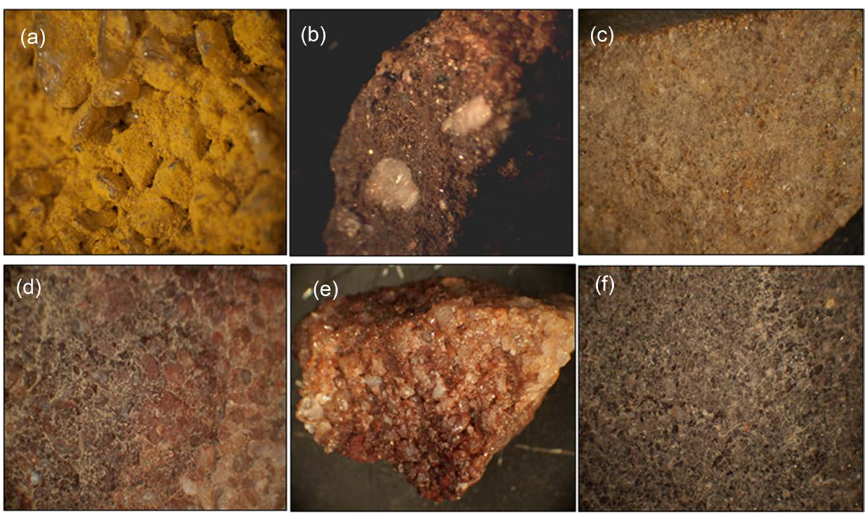

Figure 5. Micrographs of investigated quartzite samples by LOM (4×); (a) Granular disintegration and fractured, (b) large chert pebbles in quartzite's texture, (c) fine grains of quartz on the matrix (quartzite texture), (d), (e) Iron oxides staining the texture of quartzite, (f) different texture of quartzite.

grains that they surround. Quartz overgrowths are separated from the core by thin layer of iron oxide (**Figure 6(c)-(e)**). The other type is microcrystalline quartz fringe, which composed of clusters of small quartz crystals that radiate out wards from the surface of the sand grains. Quartz grains are cemented by chalcedony crystals (first generation) and later by quartz overgrowth, and highly packed and interlocked forming a mosaic texture. Some of these grains show wavy extinction as a common feature in this quartz, this feature indicates that the quartz was subjected to strong stress (**Figure 6(f)**, **Figure 6(g)**). The rock also contains a few grains of feldspars like plagioclase, little of these grains still fresh, whereas the main grains are altered to clay minerals. A few of micritic calcite grains that filling the pores. One of the most important features in this rock is the presence of chert fragments, which vary in size from fine to very coarse. Some micrographs reveal that the deterioration of quartzite from thin sections represented by corrosion, intrafractures, cracks within quartz grains as a result of mechanical stress (**Figure 6(h)**, **Figure 6(i)**), in addition to alteration of plagioclase crystals to clay minerals especially kaolinite as a result of chemical weathering (**Figure 6(j)**, **Figure 6(k)**). Some weathered grains stained by iron oxide, which gives them brown pigmentation as a result of hydration and dehydration processes of iron oxides. In general, the rock has subjected to mechanical deformation in addition to chemical weathering.

3.3. Scanning Electron Microscope (SEM) Results

The quartzite is a very compact and hard stone due to the secondary silicification processes which lead to deposit the silicic acid (quartz) in the open interstitial spaces of the sandstone grains. Scanning Electron Microscope Investigations of some weathered samples show that, there is a high variation and high contrast in the thickness and distribution of the cement material in the same sample; some areas have a very thick layer from the cement while others loosen the cement (**Figure 7(a)**).This kind of deterioration phenomena lead to formation of large cavities between mineral grains. The structural interlocking of quartz grains and loosens the high amounts of cements leading to high porosity and internal spaces that give the increase of granular disintegration (**Figure 7(b)**). The increase of porosity also is due chiefly to the intern mineral porosity and it is related to the rate of leaching of the elements, which responsible for the decay of quartzite especially in its overgrowth structure (**Figure 7(c)**). Large cavities and vugs also originate from the dissolution processes and losing the binder material or cement between quartz grains, these cavities and vugs in the samples vary in the shape from rounded to irregular and in the size from microscopic to macroscopic scale in diameters, **Figure 7(d)** shows that the most mineral grains are loosened from each other. SEM micrograph shows microfractures within minerals grains and inside individual grain of quartz in addition to dissolution pits and etching the grains boundaries (**Figure 7(e)**). The high percentage of loosen in the cement, the presence of high proportion of cavities and fractures in addition to the quartz overgrowth structure of the weathered samples help to the decay process in the shapes like separation and dislocation of quartz grains and the formation of the residual pores (Figure 7(f)). Many cracks, fractures and cavities in addition to the high porosity allow to the saline solutions from soil or ancient restoration mortars like gypsum (dissolving of soluble minerals like

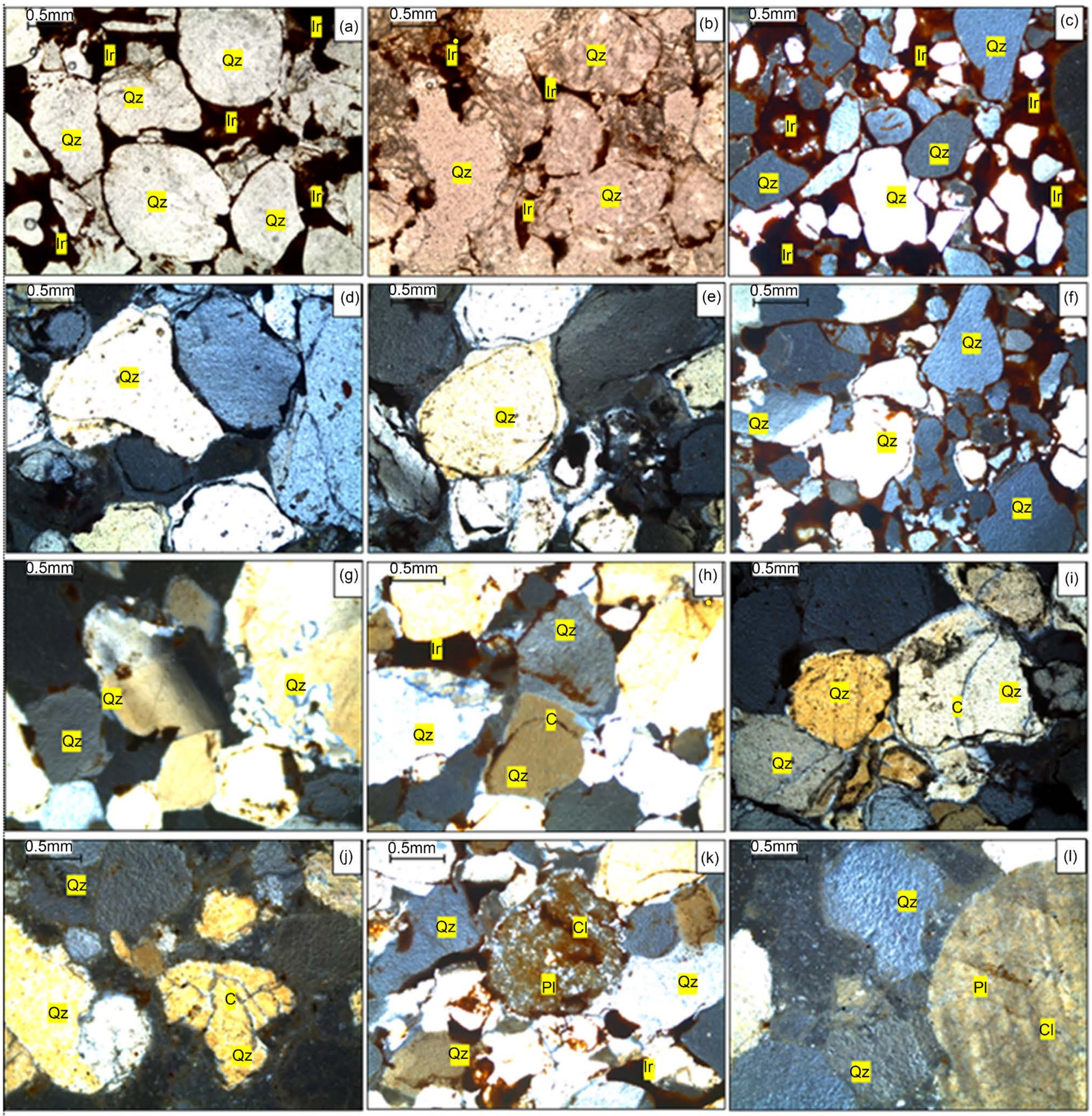

Figure 6. Petrographic view of quartzite thin section, (a) The interstitial spaces between rounded sand grains have been filled with small quartz crystals, thin layer of iron oxide, (b) Thin layer of iron oxides; limonite (darker material) outlines the quartz detrital grains, (c) Sub-rounded to rounded, poorly sorted quartz grains with common quartz overgrowths & thin layer of iron oxide, (e), (e) Syntaxial quartz overgrowths, (f) Well-sorted quartz grains, secondary quartz with wavy extinction phenomena in quartz grains, (g) Wavy extinction phenomena in quartz, (h) the quartz detrital grains contain some cracks, with thin layer of iron oxides; limonite (darker material), (i) Syntaxial quartz overgrowth crystal contain crack, (j) Corrosion, intrafractures, cracks within quartz grain, (k) Plagioclase crystal altered to clay minerals (Kaolinite), (l) Large crystal of plagioclase altered to clay minerals (Kaolinite).

gypsum in rainwater) to penetrate towards inside, and lead to more destruction to the stone structure (**Figure 7(g)**). The microorganisms play an important role in the collapse of internal structure of quartzite with the formation of pitting due to the presence of hyphate growth and penetration inside the stone texture (**Figure 7(h)**).

3.4. X-Ray Diffraction Analysis (XRD)

X-ray diffraction results of quartzite samples from colossal statues identified, presence of quartz as major mineral in all samples and iron oxide (Hematite), Anhydrite and Titanium oxide (anatase) respectively are the minor minerals in weathered samples. Anhydrite is assumed to be the result of transformation of the gypsum, which caused the surface layer detachment. The cause of presence in the deterioration of these statues, the increasing in the mount of iron and Titanium oxides are the results of weathering of the quartzite (**Figures 8(a)-(d)**).

3.5. Energy Dispersive X-Ray Analysis (EDX)

The comparison between the results of EDX analysis for weathered and unweathered samples (**Table 1**) shows that, the higher concentration of iron, calcium, sulpher and Titanium oxide (**Figure 9**) The high iron concentration may be resulted from ferromagnetic minerals; the apparent depletion in Fe_2O_3 may be attributed to removal of iron oxides attached to statues, in which transforms ferric iron to the more soluble ferrous type which cause the staining with reddish brown colors. While the increase of calcium and Sulphur due to gypsum which transformed into anhydrite at relatively high ambient temperatures. The increase of Titanium (Ti) and Potassium (K) correlated with the content of alumina or alteration processes (Pettijohn1963) [22] On the other hand there is a depletion or loss of in the silica due to its dissolution by the weathering, in addition, the potassium is most readily fixed in clay mineral.

4. Discussion

Thin section investigation indicated that, the samples are petrographically characterized as orthoquartzite, the samples consists many of monocrystalline grains of quartz detrital. The quartz grains range from moderately to well-sorted from rounded to sub-rounded in the shape. These grains are enclosed by thin rim of dark material (probably iron oxides which easily distinguished in the micrograph by its dark color). The grains are cemented by chalcedony crystals (first generation) and later by quartz overgrowth, and highly packed and interlocked forming a mosaic texture. Feldspar grains are found. The investigated elements of quartzite samples indicated that, unweathered samples composed of SiO_2 ranges from 75 - 96 but weathered ranges from 30 - 53, Fe_2O_3 ranges from (unweathered 0.7% - 18%) weathered (20% - 41%), TiO_2 ranges from (unweathered none %, weathered (0.57 - 2.99). CaO is present in low ratio in unweathered samples (0.58 - 1.74) but reaches 5.22% - 13.13% in weathered samples, this may related to calcitic secondary cement in the stone. High concentration of sulfate SO_3 (4.76 - 11.07) was found in the weathered samples. Traces elements were also detected, the significant one are K_2O, P_2O_5, MnO with average values 1.78 - 3.57, 0.07 - 2, 0.15% - 34% respectively. LOM micrograph indicated large chert pebbles in quartzite's texture.

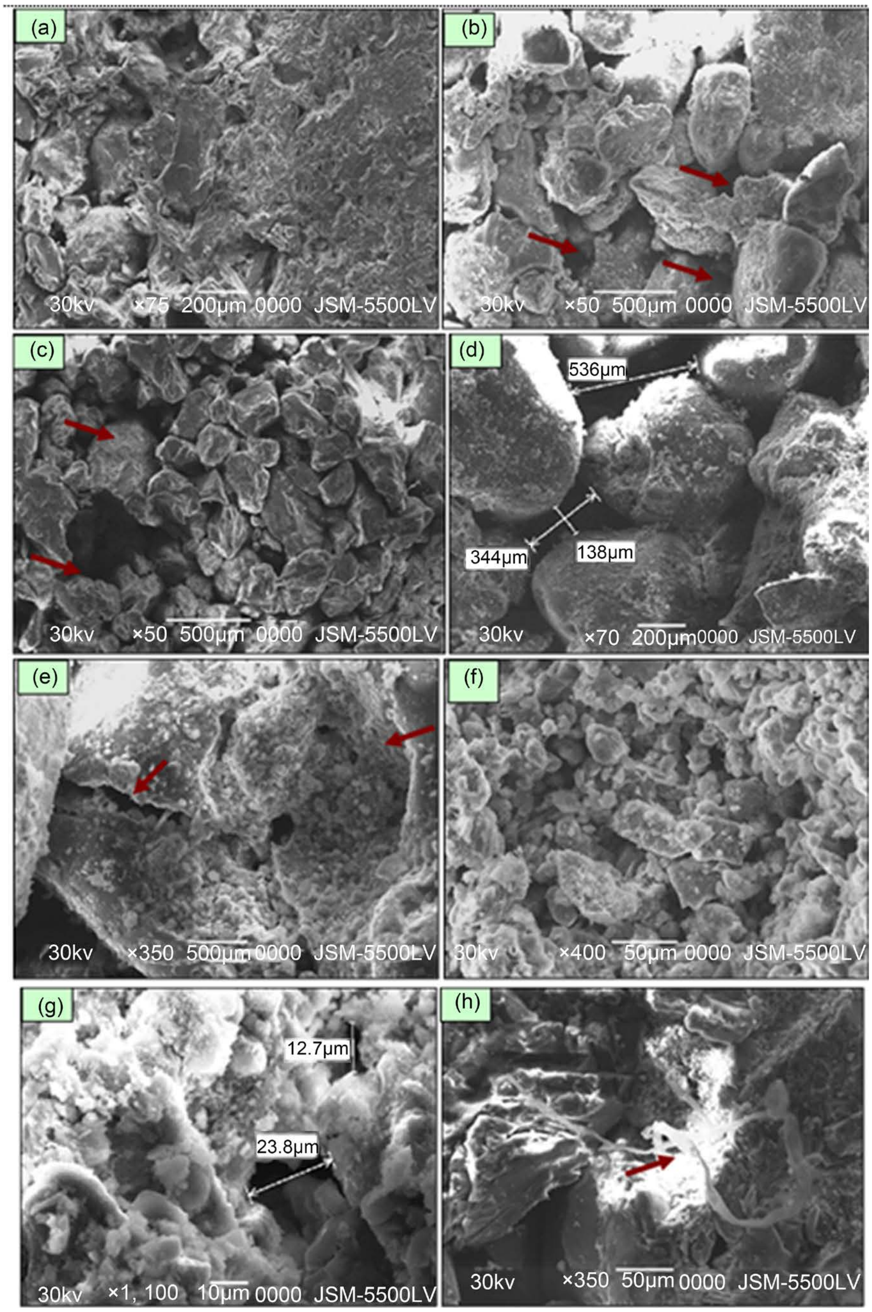

Figure 7. SEM micrographs of quartzite samples from colossal statues at Karnak temple, (a) leaching and heavy concentration of the cement (right) resulting from silicification processes, (b) the structural interlocking of quartz grains, loss of the cement and formation large cavities between quartz grains, (c) quartz overgrowths and completely leaching of the cement causes large cavities, (d) cohesion between quartz grains due to dissolution of the cement, (e) etching, microfractures and dissolution pits within quartz grain, (f) dislocation, separation of the grains, formation of anhydrite and residual pores, (g) salts and deep cavities in quartzite texture, (h) collapse of internal structure of stone with presence of fungal hyphate.

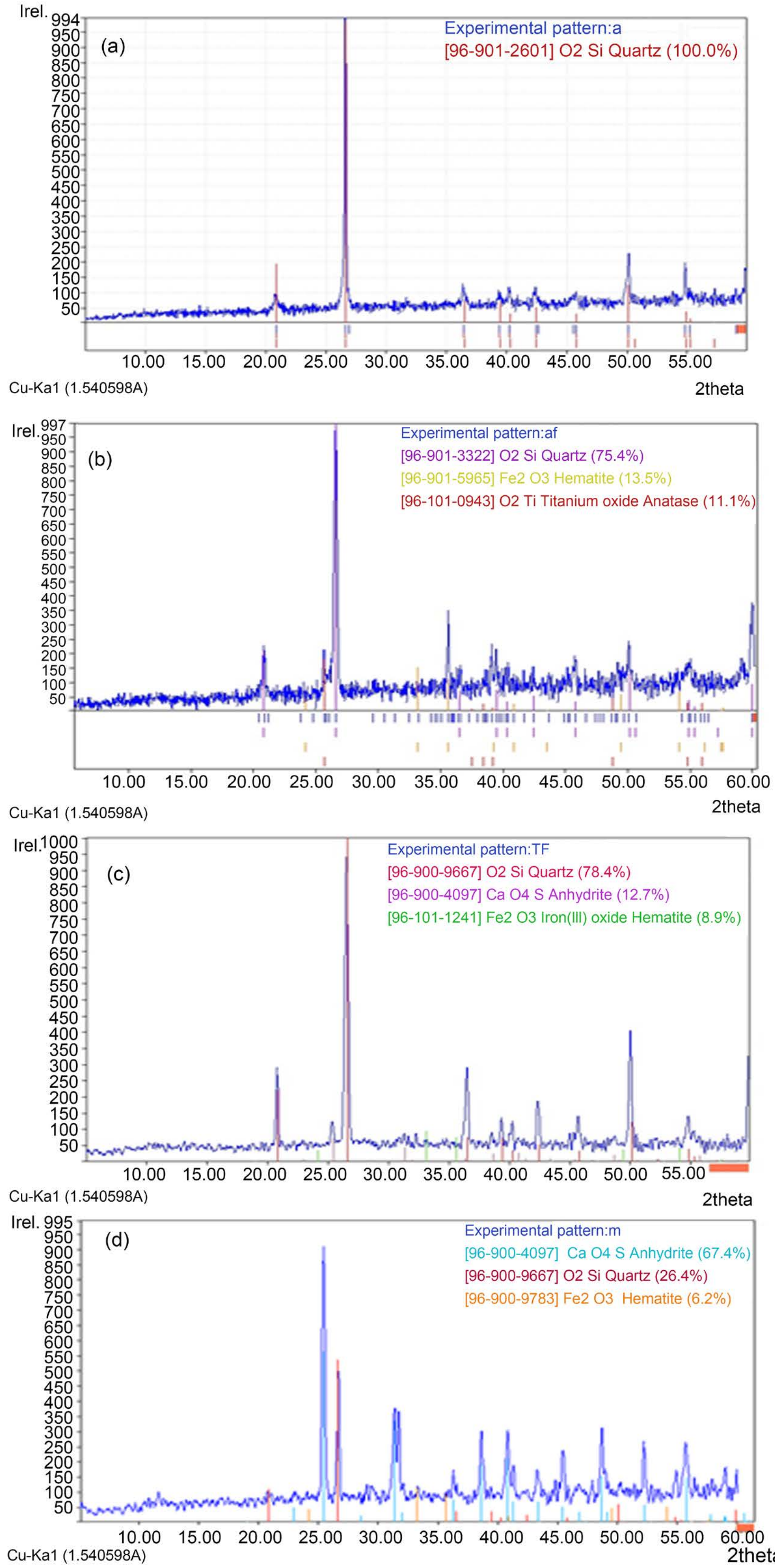

Figure 8. XRD patterns of quartzite samples taken from colossal statues at Karnak temple; (a) unweathered sample, (b), (c) weathered sample (b) from AmenhotepIII and (c) from TuthmosisII) (d) plaster sample.

Table 1. EDX results of quartzite sample taken from colossal statues at Karnak temple.

Sample Elements	Unweathered quartzite			Weathered quartzite		
	Sample A	Sample H	Sample T	Sample A	Sample H	Sample T
SiO_2	75.6161	80.3904	96.8049	30.7362	53.7381	38.2700
Fe_2O_3	7.5902	18.5606	0.7870	41.4712	31.3137	20.1962
TiO_2	-	-	-	2.9939	0.5712	2.0325
SO_3	1.6469	0.2767	0.7760	4.7662	4.8754	11.0763
CaO	1.7473	-	0.5846	7.2570	5.2240	13.1372
Al_2O_3	3.6297	0.2645	0.1165	2.9744	1.3479	6.5288
Na_2O	2.3585	0.1916	-	0.0303	-	0.4878
MgO	1.3314	-	-	0.6060	0.0089	1.4148
K_2O	1.7864	-	-	3.6143	0.5018	3.5728
P_2O_5	0.5542	0.0719	0.5924	1.5852	1.9015	2.0074
MnO	-	0.1528	-	0.3318	0.2653	0.3442
Cl	3.7393	0.0914	-	3.6334	0.2521	0.9320
BaO	-	-	0.3384	-	-	-

XRF and LOM study declared that, the ratio of the component of fresh samples from the quartzite statues at Karnak temple similar to a large extent with those components and structure in quartzite especially from Gebel el-Ahmer quarry according to Klemm, R. and Klemm, D. 2008. XRF also revealed a high concentration of sulfate S (7.88%) and calcium Ca (7.27%) ions which may be attributed to the crystallization of gypsum and anhydrite salts which caused big problems in the relives at the statue. In addition, the high amount of potassium (K_2O) and Aluminum Al_2O_3 attributed to ph-silicate group which a production of alteration process of feldspar in the Quartzite to clay minerals. The low ratio of magnesium ions MgO, TiO_2, P_2O_2 was detected. The source of magnesium may be from groundwater contamination and dissolution of dolomite or leaching from clay sediments from Esna shale (Nabil A., 2014) [23]. The presence of titanium oxide and Diphosphorus Dioxide in quartzite due to atmospheric pollution and it plays an important role in deterioration.

Considering the analyses which have done to the quartzite samples taken from colossal statues at Karnak temple and field observations, it can be concluded that, these colossal suffer from a lot of deterioration aspects related to many exogenous and indigenous factors. The first reason for the deterioration was earthquake, both colossi of Amenhotep III were quite damaged, may have been fallen victim to earthquakes in the past and that are accompanied by a vast array of fragments left were they fell, after the collapse of these colossi, just the quartzite pedestals still in their original place, while all fragments moved to put on modern Mastaba (built by archaeologists made of cement and red brick) east of Khansou temple in southern part of Karnak temples. (Kebeasy, 1990) [24] Stated that the damages in the Luxor and Karnak temples were related to some historical earthquakes. However, evidence of an earthquake in 27 B.C near Luxor possibly and caused the destruction for many historical monuments in the region, one of them was the colossi quartzite statues of Amenhotep III. The fallen parts of the statues were buried in contact with saline mud for long time and this mechanism response for the degradation of statues. Penetration of saline ground water into the statues through capillary and moisture played a severe role in the degradation of the stones and the results are decomposition and destruction of the outer parts of the statues.

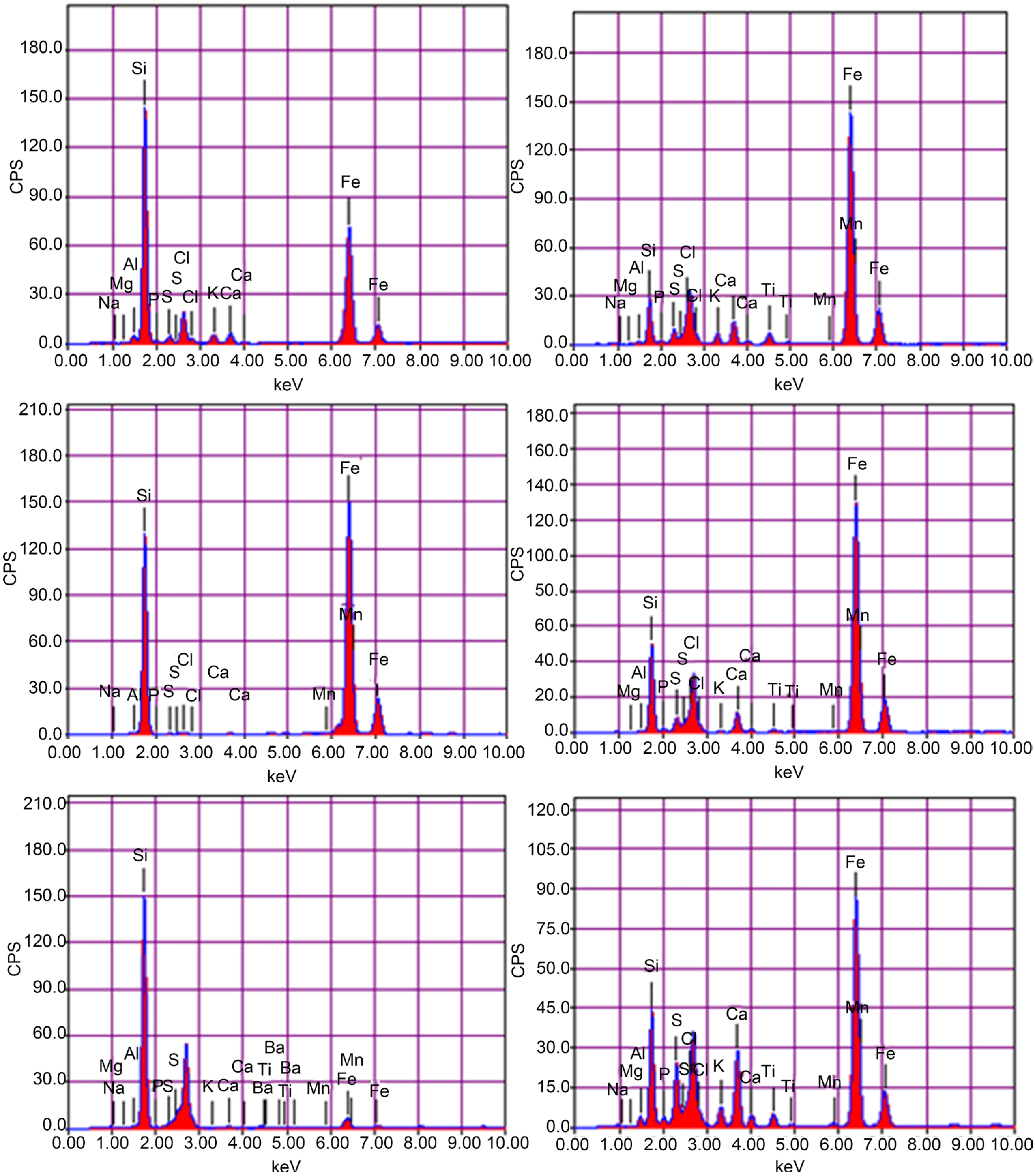

Figure 9. EDX patterns of quartzite samples taken from colossal statues at Karnak temple.

Thin section investigation indicated a few grains of feldspars like plagioclase, little of these grains still fresh, whereas the main grains are altered to clay minerals and XRF analysis indicated low proportions of K_2O in unweathered samples but reaches 3.57% in weathered samples, this may be due to alteration of feldspar to clay minerals. 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 sandstone and quartzite. The aggregation/disaggregation or swelling/shrinking of the clay particles occurs when these particles interact with water causing a whole series of identifiable pathologies in the stone.

Salt weathering is one of the principle deterioration factors in quartzite colossi. XRD and XRF result indicated halite and sulphide $CaSO_4$ salts in the component of quartzite. The contamination of the sandstone with soluble salts, mainly sodium chloride and calcium sulphate bears a considerable risk for the preservation which causing several damages and cracks. Water penetrates those cracks and causes the surface layer to peel off, detachment of the superficial layers of relives and cause large stone blocks to fall off and SEM micrograph reveled that. Many cracks, fractures and cavities in addition to the high porosity were found which allow to the saline solutions from soil or ancient restoration mortars like gypsum (dissolving of soluble minerals like gypsum in rainwater) to penetrate towards inside, and lead to more destruction to the stone structure. Large cavities between mineral grains also were detected. The structural interlocking of quartz grains and loosen the high amounts of cements leading to high porosity and internal spaces that give the increase of granular disintegration. SEM micrograph shows also microfractures within minerals grains and inside individual grain of quartz in addition to dissolution pits and etching the grains boundaries.

5. Conclusions

From the paper we concluded that:

- Quartzite or silicified sandstone was essentially quarried at two locations in Egypt from Pharaonic times to the Roman era at Gebel el-Ahmer, and Aswan quarries complex.
- Optical observation and lab analysis indicated that, The Colossi of Amenhotep III and Tuthmosis II were subjected to many exogenous and endogenous deterioration factors as result of the interaction between physical/mechanical, chemical and anthropogenic deterioration factors in addition to their nature, composition and properties.
- The main weathering mechanisms involved in the quartzite colossi and its pedestals was cracks, macrocracks, fissures, vertical fractures and contour scaling and the sunken relives in the colossi suffer from roughening, pitting, surface punctures (Perforations), granular disintegration and exfoliation. Field observation indicated also, the wall reliefs at the statues suffer from Coloration discoloration, and staining.
- XRF, LOM, PM study declared that, the ratio of the component of fresh samples

from the quartzite statues at Karnak temple similar to a large extent with those components and structure in quartzite especially from Gebel el-Ahmer quarry, these means, the source of quartzite colossi of Amenhotep III and Tuthmosis II was Gebel el-Ahmer quarry.

- The lab analysis indicated that, the statues suffer from salts weathering, especially sodium chloride and calcium sulphate which causing several damages and cracks.
- SEM indicated network of cracks and macrocracks inside the colossi and quartz grains which caused decrease the stiffness of the structure of these colossi and material mass decreases.

6. Recommendations

The lab analysis and field observations have shown that the quartzite statues at Karnak temple suffer from many aspects and factors of damage. Therefore, the statues need to carry out different treatments and conservation processes, such as:

- One of the most important of these factors, the presence of these colossi statues on the body and separate blocks shown in different sites of the temple which reduces the aesthetic and archaeological value, so it has to be used modern computer modeling and simulation programs (GPU··· etc.) in an attempt to conceptualize the form of those colossi and try assembled it.
- Completion of archaeological excavations around the bases quartzite statues and enriched the work of scanning integrated with statues of the surrounding area.
- Survey of the crack pattern and deformation of structure must be carried out.
- The movement of cracks must be studied by fixing dabs of plaster to the basic masonry.
- Removal of all deteriorated and deformed mortar and stone blocks must be carried out.
- Assembling discrete blocks of the Colossi of Amenhotep III (on the mastabas) with each other using an appropriate type of epoxy and steel bars.
- Completion and strengthening the bases of statues using appropriate materials and suitable blocks of quartzite stone from the same quarry Gebelel-Ahmer (Red Mountain) to compensate the loss of the deteriorated stone because the lab analysis indicated similarities between the quartzite stone of the colossi with these the kind of quartzite.
- Strengthen the weak, crumbed, separated parts of the blocks and the pedestals of quartzite statues must be carried out using suitable strengthening materials containing ethyl silicate material.
- Install separate blocks (upper part) of the statue of Thutmose II (18^{th} pylon) on the remains of the statue in the current position.
- When the impossibility of installing two colossal statues of Amenhotep III (10^{th} pylon) on the current pedestals after assembly, can be placed on modern mastabas near the current bases (pedestals).

- According to the obtained data from the lab analysis, it was found that the salt which threatened the stone was sodium chloride. So, mechanical methods (brushing) can be used for removing the fine grains of crystallized salts and scalpels were used to remove thicker layers of salts, in addition, it can use Sepollite poultice with distilled water to the stone surface for completely removing.
- and two poultices were easily removed and did not require an intervention layer of clay
- 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.
- Establish a high wall of stone near bases statues of Amenhotep III (10th pylon) to the west, to prevent vandalism and throwing more waste and human excreta after cleaning the archaeological setting and restoration of the quartzite statues.

References

[1] Casciati, S. and Osman, A. (2005) Damage Assessment and Retrofit Study for the Luxor Memmon Colossi. *Structural Control and Health Monitoring*, **12**, 139-156. http://www.interscience.wiley.com/ https://doi.org/10.1002/stc.53

[2] Casciati, S. and Borja, R.I. (2004) Dynamic FE Analysis of South Memnon Colossus including 3D Soil-Foundation-Structure Interaction. *Computers and Structures*, **82**, 1719-1736. https://doi.org/10.1016/j.compstruc.2004.02.026

[3] Knox, W.O.B., Rainer, S., Harrell, J.A., Heldal, T. and Sourouzian, H. (2009) Mineral Fingerprinting of Egyptian Siliceous Sandstones and the Quarry Source of the Colossi of Memnon. Geological Survey of Norway Special Publication, 77-85. http://www.ngu.no/upload/publikasjoner/Special%20publication/SP12_s77-85.pdf

[4] Heldal, T., Bloxam, E., Storemyr, P. and Kelany, A. (2005) The Geology and Archaeology of the Ancient Silicified Sandstone Quarries at Gebel Gulab and Gebel Tingar, Aswan (Egypt). *Marmora: An International Journal for Archaeology, History and Archaeometry of Marbles and Stones*, **1**, 11-35. http://discovery.ucl.ac.uk/id/eprint/11138

[5] Raza, M., Bhardwaj, V.R., Ahmad, A.H.M., Mondal, M.E.A., Khan, A. and Shamim Khan, M. (2010) Provenance and Weathering History of Archaean Naharmagra Quartzite of Aravalli Craton, NW Indian Shield: Petrographic and Geochemical Evidence. *Geochemical Journal*, **44**, 331-345 https://doi.org/10.2343/geochemj.1.0075

[6] Frütsch F. (2011) Quartz Grain Weathering in a Periglacial Environment: Indications from SEM and TEM Studies Using Single Grain Features. Master of Science, Freie University Berlin, Fachbereich Geowissenschaften, Institute of Geologische Wissenschaften.

[7] Blyth, E. (2006) Karnak: Evolution of a Temple. Routledge, London/New York. pp. xxvi+258.

[8] Porter, B. and Moss, R. (1972) Topographical Bibliography of Ancient Egyptian Hieroglyphic Texts, Relief and Paintings. II Theban Temples, Oxford, p. 176.

[9] Sethe, K. (1906) Urkunden der 18th. Dynastie, p. 606.

[10] Conner, D.Ó. and Cline, E.H. (2001) Amenhotep III, Perspectives on His Reign. The University of Michigan Press, Ann Arbor, p. 70.

[11] Barguet, P. (1962) Le Temple d'Amon-Rê à Karnak: Essai d'Exégèse. Impr. de l'Institut français d'archeologie orientale, Le Caire.

[12] Bloxam, E. (2007) Chapter 4: A History of Silicified Sandstone Use in Egypt from the Middle Paleolithic to Roman Period. In: Bloxam, E., Heldal, T. and Storemyr, P., Eds., *Characterization of Complex Quarry Landscapes*: *An Example from the West Bank Quarries*, Deliverable Report No. 4, QuarryScapes, Aswan, 37-50. www.quarryscapes.no/publications.php

[13] James, A.H. (2012) Utilitarian Stones. UCLA Encyclopedia of Egyptology UCLA, Los Angeles, 1-16. http://escholarship.org/uc/item/77t294df

[14] Verner, M. (2002) The Pyramids: The Mystery, Culture, and Science of Egypt's Great Monuments. Grove Press, New York.

[15] Přichystal, A. (2010) Classification of Lithic Raw Materials Used for Prehistoric Chipped Artefacts in General and Siliceous Sediments (Silicites) in Particular: The Czech Proposal. *Archeometriai Mühely*, **3**, 177-182. http://www.ace.hu/am/

[16] Aston, B., Harrell, J.A. and Shaw, I. (2000) Stone. In: Nicholson, P.T. and Shaw, I., Eds., *Ancient Egyptian Materials and Technology*, Cambridge University Press, Cambridge, 5-77.

[17] Klemm, R. and Klemm, D. (2008) Stones and Quarries in Ancient Egypt. The British Museum Press, London.

[18] Kozloff, A.P. and Bryan, B.M. (1992) Egypt's Dazzling Sun: Amenhotep III and His World.

[19] Harrell, J.A., Brown, V.M. and Masoud, M.S. (1996) Survey of Ancient Egyptian Quarries. Egyptian Geological Survey, Cairo.

[20] Storemyr, P. (2009) Whatever Else Happened to the Ancient Egyptian Quarries? An Essay on Their Destiny in Modern Time. In: Abu-Jaber, N., Bloxam, E.G., Degryse, P. and Heldal, T., Eds., *Quarry Scopes*: *Ancient Stone Quarry Landscapes in the Eastern Mediterranean*, Geological Survey of Norway, Special Publication 12, 105-124.
https://perstoremyr.files.wordpress.com/2010/09/2009_storemyr_whateverelsehappenedtoegyptianquarries.pdf

[21] Moody, D. (1976) Thermal Alteration of Quartzite from Spanish Diggings, Wyoming—A Pre-Historic Quarry. Transactions of the Nebraska Academy of Sciences and Affiliated Societies Paper 409, 8-11. http://digitalcommons.unl.edu/tnas/409

[22] Pettijohn, F.J. (1963) Chemical Composition of Sandstones-Excluding Carbonate and Volcanic Sands. In: Fleischer, M., Ed., *Data of Geochemistry*, 6th Edition, Geological Survey Professional, Washington, 440.

[23] Bader, N.A. (2014) The Deterioration Problems of the Wall Reliefs of Komir Temple, Esna, Egypt. *Mediterranean Archaeology and Archaeometry*, **14**, 201-219.

[24] Kebeasy, R.M. (1990) Seismicity. In: Said, R., Ed., *The Geology of Egypt*, AA Balkema, Rotterdam, 51-59.