ORIGINAL PAPER

AN ANALYTICAL STUDY OF GRANITIC PICTOGRAPHS AND PETROGLYPHS IN THE OPEN AIR SITE, SOUTH EGYPT

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Abstract. *The analytical study of granitic pictographs and petroglyphs on rock cliffs in the open air site by polarized microscopy (PM), scanning electron microscopy coupled with energy dispersive X-ray spectrometry (SEM-EDX), X-ray diffraction analysis (XRD), infrared spectroscopy (IR) and microbiological study proved that, salts and transformation the feldspars to clay minerals are the main deterioration aspects at the unfinished obelisk quarry south Egypt.*

Keywords: *pictographs, petroglyphs, IR, salts, fungi.*

1. INTRODUCTION

1.1. SITE DESCRIPTION

The southern part of Egypt contains large numbers of ancient quarries, such as those concentrate in Aswan, which contains the quarries of various stones and rocks; sandstone, dolerite, diorite, granodiorite and granite [1] **(**Fig. 1**)**, most of them have rock art. One of the famous quarries is the unfinished obelisk, lies in the northern granite quarries at eastern Aswan, that quarry derived its name from abandoned colossal obelisk in situ dating to the18th dynasty, the reign of Hatshepsut or Thutmose III, due to large cracks in the obelisk's body [2].The importance of the site is summarized in; it is one of the most important archeological sites contains (quarrying tools, different techniques of stone extraction, unfinished objects), it was a source for supplying the ancient Egyptians with the raw materials of granite for the establishment their civilization, and also, contains very important rock art or graffiti. In this respect could divided not only according to artistic techniques but also to topographic locations [3], according to the first division the rock art divides to petroglyphs and pictographs on natural rock surfaces [4] and could be found inside caves and rock shelters (interior sites) and /or rock cliffs and boulders (exterior sites) or open-air sites according to the topographic locations. The unfinished obelisk quarry is one of the rare open-air sites all over the world which contains both kinds of rock art; petroglyphs and pictographs carried out on the granitic bedrock and rock boulders. The petroglyphs or engravings scatter on rock cliffs at the site, such as the engraving of Thutmose III, which contains the royal decree to cutting obelisks from the quarry in year 25 of his reign [5], and scratch marks are related to the ancient Egyptian calendar. While the pictographs or paintings locate above granitic bedrock face extends for about 45 meters, and represent in rock paintings (Fig. 2) of obelisks and boats, standing obelisks in different levels and sizes, boats carrying obelisks and large

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blocks of granite from the quarry, geometric figures, group of work level lines and hieratic dates, group of ostriches, group of dolphins [6]. All the previously mentioned pictographs were carried out by red, black pigments on the granitic bedrock by the medium.

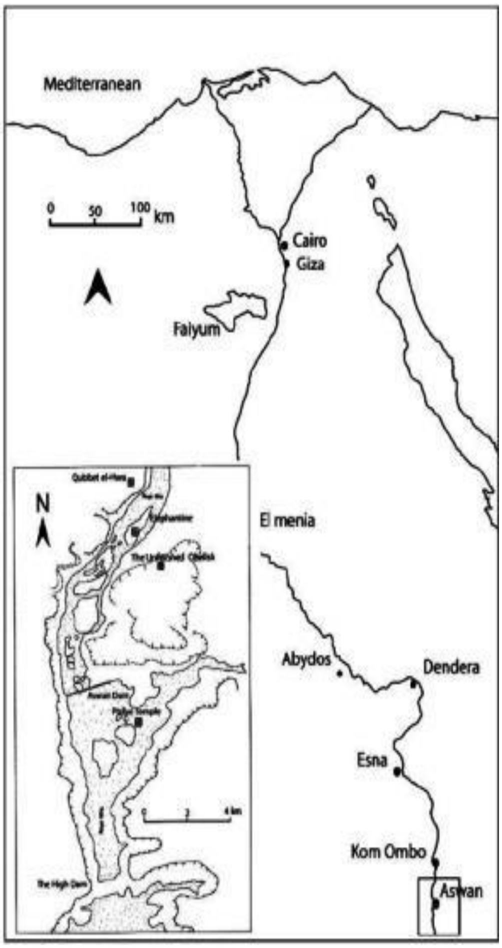


Figure 1a. Map of Egypt and study area after [6].

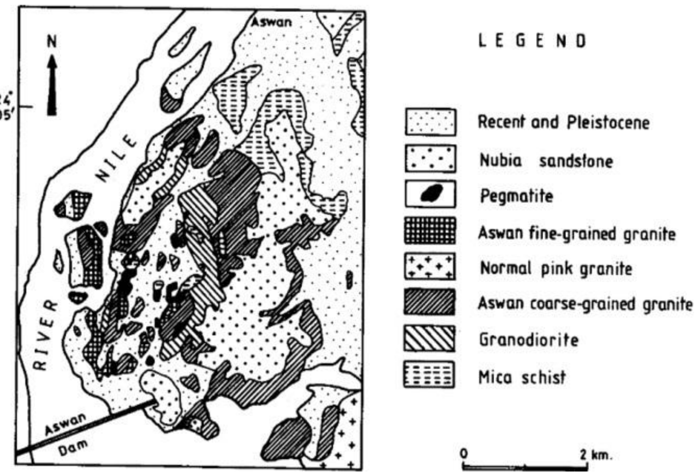


Figure 1b. Geological map of Aswan area, after [1].

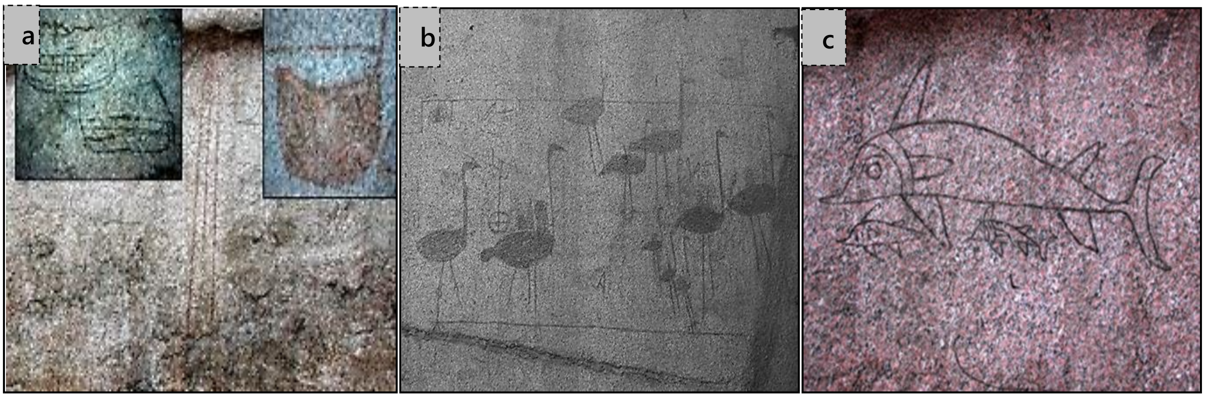


Figure 2. Pictographs at unfinishedobelisk quarry: a) Obelisks and boats; b) The group of ostriches with red pigment; c) Dolphins with black pigment.

1.2. CONSERVATION STATE

Pictographs and petroglyphs at the open air site enivironment at unfinished obelisk quarry had been exposed to either burial, aerial (exogentic) environments and endogenetic factors, whereas endogenetic related to the physical, mechanical, and chemical properties of the rock itself, and exogentic factors include environmental agents such as wind, sunlight, temperature, moisture, rain vegetation, biotic, human being agents, in addition to the rising ground water table from the canal at the site (Fig. 3a) which helps the water and moisture to penetrate along the vertical, horizontal fractures and cracks in granitic bedrock and caused severe damage for rock art such as; salt efflorescence (Fig. 3b), growing the vegetation and higher plants, furthermore anthropogenic deterioration factors play an important role in the deterioration of rock art through application of some substances to increase photographic contrast between the scenes and rock substrate (surface) during the documentation process, which is called the physical enhancement [7] some of these materials include the use of water and chalk (Fig. 3c), both of them have been used for documenting the petroglyphs at the quarry and they caused a serious damage, fading the rock surfaces and destroying the radiocarbon dating. Another factor of anthropogenic deterioration is that quick discovery and sudden exposure for rock art panels during excavations from burial to aerial environment, both have different conditions and caused the deterioration resulted in environmental shock. The quick discovery caused quick dryness for panels from moisture and its water content, causing the fading of the paintings and salt crystallization forms such as efflorescence, etc.

Figure 3. Deterioration factors affecting rock art at the quarry: a) Rising of ground water table; b) Salts efflorescence and vegetation; c) Wrong documentation using chalk.

Figure 3. Deterioration forms of studied pictographs: d) White and black areas due to rains; e) Detachment of the superficial stratum from the support; f) Loss of details.

The third anthropogenic deterioration factor represented in using inappropriate treatment with a solution of Paraloid B 72 for consolidation the support of pictographs (wetted granite) directly after its discovery from the burial environment [8]. All the previous conditions lead to a lot of deterioration forms of rock art at unfinished obelisk quarry in

Aswan (Figs. 3d-f) such as: exfoliation, granular disintegration, detachments, salt crystallization, aesthetic disfigurement, and chemical alterations. Aesthetic disfigurement through deposit minerals on the surface that may cover the art and appearance of white and grey or black areas or rain channels on pictographs due to rains or runoff water [9], which also dissolves soluble pigments, causing paintings to fade [10] more than that this water can also dissolve minerals and precipitate salts on or near the surface [11-18].These salts contribute to the weathering of rock art through thermal expansion, hydration and crystallization pressures [19] in the form of detachment scales of superficial stratum of rock art as a result of sub florescence, that is the most dangerous kind of salt crystallizations [20] salts could be lead to loss of some rock paintings details due to quick evaporation of saline solutions with aid of sand-blasting by wind. Granite has a low thermal conductivity [21, 22] noted that the temperature of the granite surface in Aswan reached near to 80ºC during the summer, that led to weathering processes through thermal shock and thermal stress fatigue, through repetition on a diurnal or seasonal scale, this caused the granular disintegration or the production of new fractures in the support of rock art [23,24].

2. MATERIALS AND METHODS

Several weathered samples of granite and paintings flakes from rock art surfaces at unfinished obelisk quarry were studied by analytical methods. Petrographic investigation was performed by Polarized Microscopy (PM) using Olympus BX51 Tf microscope (Japan), under 40X magnifications; Scanning Electron Microscopy coupled with Energy Dispersive X-Ray Spectrometry (SEM-EDX) was used for morphological investigation using a SEM JEOL JSM 6400 system; X-Ray Diffraction (XRD) was performed to identify the mineralogical, chemical components, alteration features, and deterioration of samples, using a diffractometer type Philips PW 1840, operated at 35 kV with Cu Kα radiation wavelength of 1.540598 Å; in addition, in order to determine the painting medium was used infrared spectroscopy (IR). Biodeterioration investigation was carried out in order to define the microorganisms classes found in the samples, as well.

3. RESULTS

3.1. POLARIZED MICROSCOPY

Petrographic study for several weathered samples revealed that the granite is granular texture and consists of quartz, potash feldspar, plagioclase feldspar, with minor amounts of biotite, hornblende, and iron oxides. Biotite and hornblende represent the colored minerals in the samples; they occur as minor constituents of the rock. Biotite occurs as subhedral to anhedral flakes and shows wavy extinction and the alteration of some biotite to iron oxide (hematite) which stained the rock with brownish color, the samples contained both zircon and hornblende crystals. The samples exhibit alteration of the biotite to clay minerals (green chlorite) (Fig. 4a). Quartz occurs as fine to coarse (i.e., 0.4-1.5 mm diameters) and forms interlocking anhedral crystals filling the interstices between feldspars. It is mostly fresh; however, some of the quartz grains contained wide fractures as a result of mechanical stress, marginal corrosion as a result of chemical solutions has been observed in some of the quartz grains, sometimes the biotite altered to sericite (Fig. 4b), while albite crystals contained many cracks. The minerals such as allanite present in some samples, as well as feldspars, are represented by plagioclase, microcline and microcline perthite. The plagioclase is highly weathered to clay minerals and largely replaced by very fine particles of sericite appearing in pale grey. Potash feldspar is represented by microcline, which occurs as fine to coarse subhedral to anhedral crystals; characterized by cross-hatching twinning, sometimes occurs as elongated crystals as a result of mechanical strain or stress, with marginal corrosion. The large grain of microcline is strongly altered to kaolinite (Fig. 4c) as a result of chemical weathering, microcline perthite occurs as subhedral to anhedral crystals, mostly cracked.

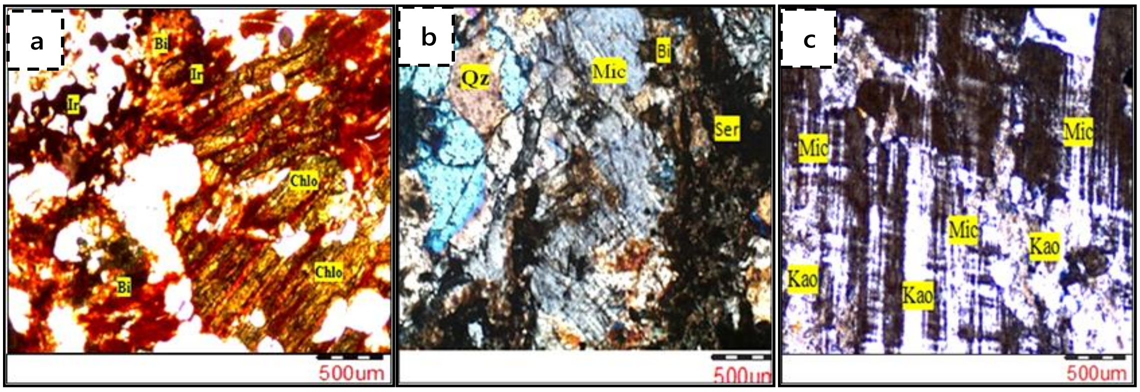


Figure 4. The PM examination of granite samples: a) Biotite altered to iron oxides and chlorite; b) Quartz, microcline and biotite grain altered to sericite; c) Microcline cross hatching twining altered to kaolinite.

3.2. SCANNING ELECTRON MICROSCOPY INVESTIGATION

The investigation of weathered granitic samples was performed by SEM technique (Fig. 5) and revealed that the major deterioration represented in abundance of soluble salts in addition to a high degree of weathering for the rock as follows; different microcracks which have long and narrow sharp ended cracks, in addition to transgranular and intergranular fractures which caused the disintegration and decohesion among the mineral grains. Cavities and vugs are very large and deep inside the stone's structure and lead to increasing the porosity causing the granite to become permeable and accelerate the rate of deterioration. A widespread coating of different salts is the major weathering feature such as sodium chloride and varied phases of calcium sulfate. Halite crystal usually occurs in cubic form, produces a kind of vuggy pockets, while calcium sulfate phases (gypsum and anhydrite) occur in the cluster and distributed in the cavities and vugs and penetrate towards inside. Extensive penetration of fungal hyphae inside the stone's structure, which caused pitting or alveolar weathering inside feldspars and biotite grains.

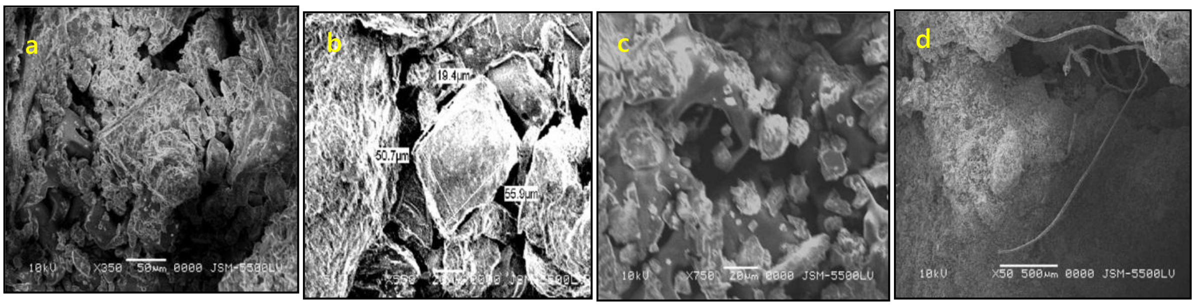


Figure 5. SEM micrographs of studied samples: a) Large, deep cavities inside the stone's structure; b) Cubic crystal of sodium chloride; c) Crystals of anhydrite and gypsum; d) Fungal hyphate inside stone structure.

3.3. X-RAY DIFFRACTION ANALYSIS (XRD)

X-ray diffraction results of weathered granite samples (Fig.6) identified the presence of quartz SiO_2 as major mineral in most of the samples, while the minor minerals are represented by feldspars (albite, $NaAlSi_3O_8$ and microcline, $KAlSi_3O_8$) biotite, $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$, in addition to anhydrite $CaSO_4$, calcite $CaCO_3$ and halite (NaCl) which represented the weathering products in samples.

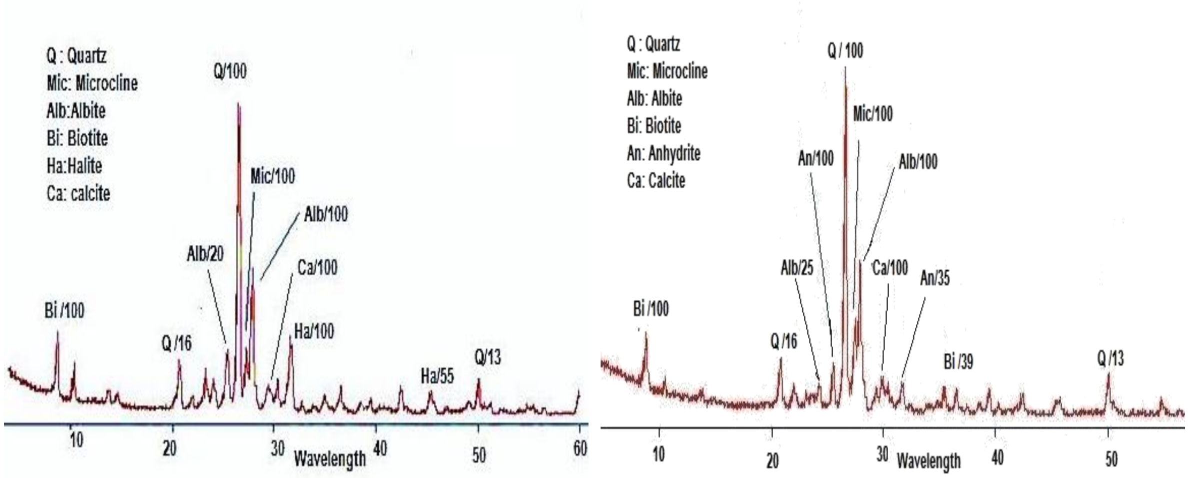


Figure 6. XRD patterns of granite samples from the site.

3.4. ENERGY DISPERSIVE X- RAY ANALYSIS

The results of EDX analysis of studied samples (Fig. 7) have indicated that the granite contains high iron (Fe) content, high concentrations of calcium (Ca), high sulfur (S), and chloride (Cl). In addition, sodium (Na), and a high amount of potassium (K) and Aluminum (Al) and low ratio of Ti were indicated.

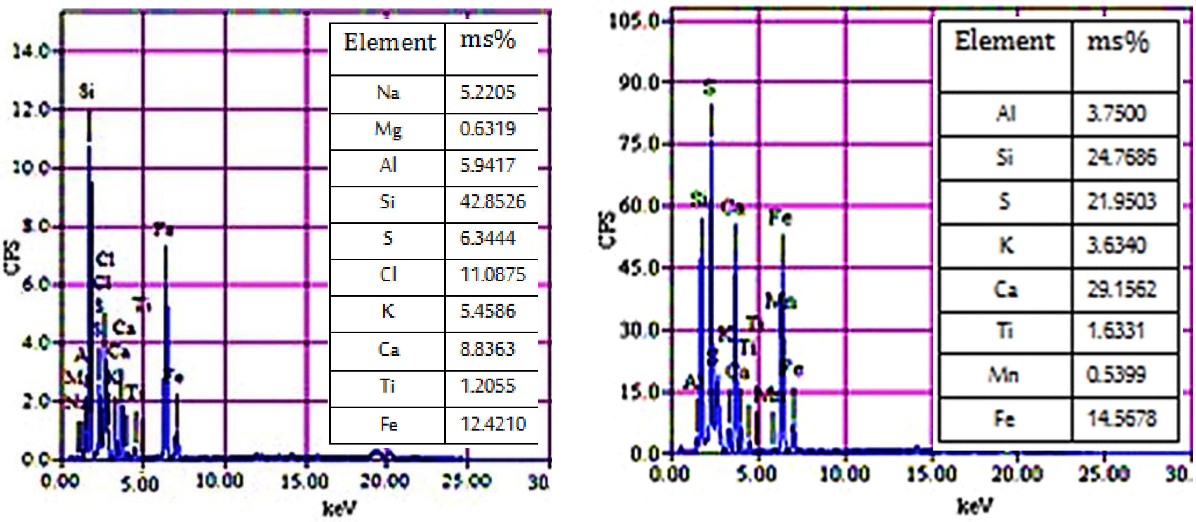


Figure.7. EDX patterns of granite samples from the unfinshied obelisk quarry.

3.5. INFRARED SPECTROSCOPY

IR spectra of black and red pigments (codes B & Z respectively) from the pictographs on granitic bedrock at unfinished obelisk quarry show absorption bands at the following wavenumbers (λ): 3546, 3409, 3200, 1625, 1618, 1384, 1381, 1092, 1030, and 1024 cm^{-1} as shown in Fig. 8 and Table 1. By comparison study with, glue albumen, egg-yellow and Arabic gum IR data shows that the medium, which was used in studied pictographs, was Arabic gum. According to [8] the previous pigments consisted of hematite (Fe_2O_3) as red pigment and carbon (C), as a black pigment.

Table 1. IR results of studied pictographs.

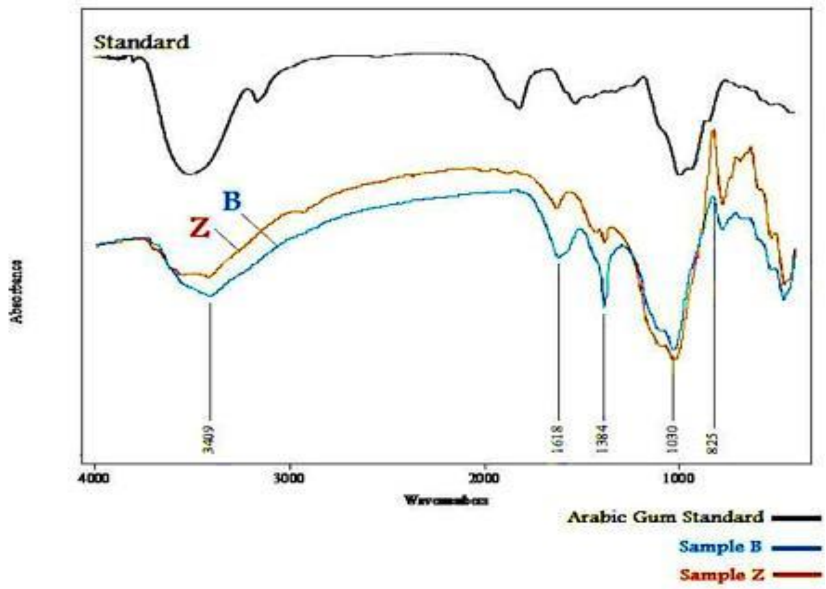


Figure 8. IR spectra of pigments and medium of studied pictographs.

Wavenumber [cm^{-1}]			**Assignment of functional groups**
Black **(B)**	Red **(Z)**	Arabic gum	
3409	3546-3413	3600-3200	O-H Stretching band
1618	1625	1650	O-H Bending band
1384	1381	1480-1300	C-H Bending band
1030	1092-1024	1300-900	C-O Stretching band

3.6. MICROORGANISMS ISOLATION AND IDENTIFICATION

Microbiological analyses revealed the presence of bacteria and fungi at average contamination levels (Fig. 9), for the isolation of fungi, plate count method was used, the plates contained Czapek's agar medium [25],the same method was used for the isolation of bacteria by using nutrient agar medium (NA) [26]. The Isolated fungi were identified at least to the genus level depending on their morphological characteristics using light microscopes according to [27], the fungal strains isolated from the weathered granite belong to the genera: *Aspergillus niger*, *Aspergillus flavus, Alternaria alternate*, *Paecilomyces carneus, and Cladosporum uredinicola.*Also,*Gram positive- sporing form of Bacillus sp*., *Bacillus insolitus, Bacillus alcalophilus,* bacteria were identified.

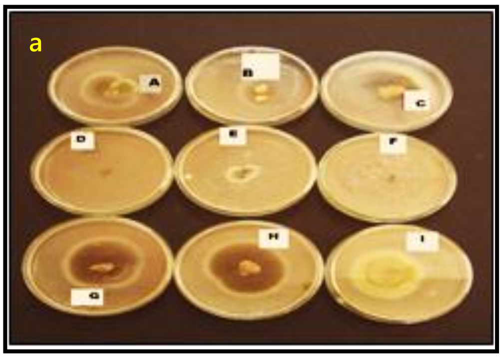
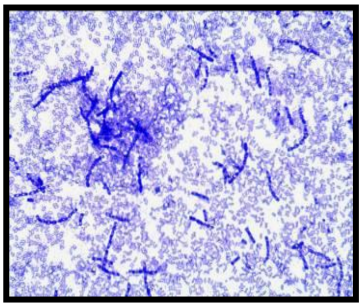
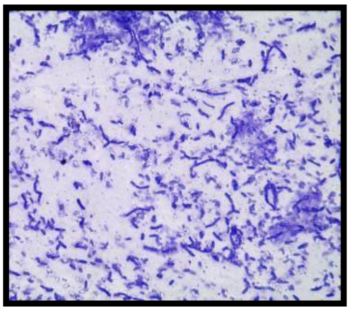


Figure 9a. Petrie dishes of bio-colonization.

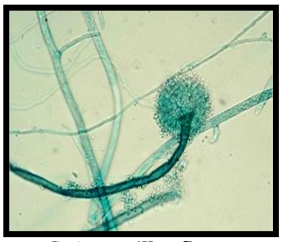


b) *Bacillus insolitus*

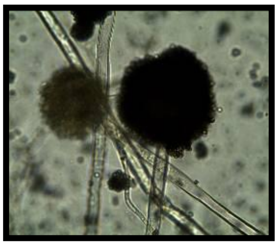


c) *Bacillus alcalophilus*

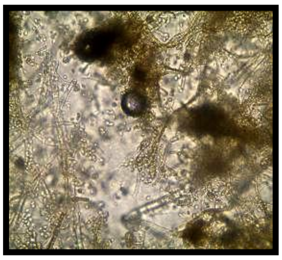
Figure 9b-c. Bacteria isolated from studied rock art.



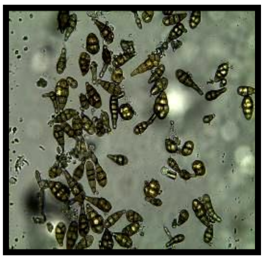
d) *Aspergillus flavus*



e) *Aspergillus niger*



f) *Paecilomyces carneus*



g) *Alternaria alternate*

h) *Cladosporium uredinicola*

Figure 9d-h. Fungi isolated from studied rock art.

4. DISCUSSION

Rock art divides to petroglyphs and pictographs, in Egypt, the vast majority are sites with petroglyphs and spread throughout the open-air sites such as deserts and quarries; sites with pictographs are very rare and they are in protected places such as; caves and rock shelters. The unfinished obelisk quarry considers one of the rare examples all over the world, which contains both petroglyphs and pictographs carried out by ancient Egyptians. That rock art suffers from drastic deterioration factors more than those predominant in interior sites such as caves. The deterioration in studied sites caused by physical, chemical and biological factors predominate in the open site environment; temperature, moisture, rain vegetation, biotic in addition to man-made factors. Anthropogenic factors include the preparation method of granite surfaces (polishing or smoothing with "grinding stone" which leads to variation and difference in its physical properties such as the perceived texture, color, and gloss [28] and also, generates structural stresses in the rock [29]. In the same manner, the nature, the mineral composition, the binder and the method of application of the pigments, all have an impact upon pictographs response to deterioration factors in the ambient environment. Liquid pigments are able to penetrate deeper inside the rock, hence they are more resistant to deterioration if compared with dry pigments and those applied as a paste easily peeled off [30]. Furthermore, the application of the physical enhancement process on petroglyphs using water and chalk. Before the previous mentioned factors; the quick discovery during excavations and sudden exposure of rock art panels from burial to aerial environment caused immediate destruction and deterioration after the discovery due to environmental shock, and the consolidation of wetted pictographs panels by inappropriate treatment with a solution of Paraloid B 72 in acetone, all the previous measures caused aggressive deterioration. It is worth to mention that, the soil of Aswan is saline, and the ancient canal at the site contributed in increasing the salty deterioration, as a source of water, saline solutions, and motivates growing vegetation and higher plants [31-33] that also could cause some accelerated weathering to rock art in situ. Population mass around the site promoted the quantity and variety of observable stone deterioration; seepage and leakage water, rising groundwater table, visual disfigurement, air pollution that, threaten the rock art in situ. The deterioration phenomena of studied rock art are varied such as; exfoliation, granular disintegration, scaling, cracks, fractures, salt crystallization (efflorescence, sub-florescence), discoloration, in addition to fading, flaking, and loss of pictographs.

Petrographic studies revealed that; the granite was subject to physical and chemical weathering; both orthoclase and microcline are slightly or strongly altered to kaolinite and sericite. This feature is cleared by the fissures and cracks that are invading the rock, most of biotite and quartz grains make the wavy extinction clear as a result of mechanical stress. Some biotite altered to chlorite or iron oxides as a result of chemical solutions and the liberation of iron oxides which stained the rock with a brownish color. Moreover, some quartz grains contained cracks may be due to the preparation process of rock art surfaces by grinding stones.

SEM investigation have revealed the deterioration of granite showed that the collapse of the internal structure of the stone, decoheshion between grains as a result of many crystallized salts especially halite, gypsum and anhydrite which exhibit macro and microcracks, fissures and pits inside the internal structure of rock, furthermore alteration of feldspars to clay minerals and the growth hayphae of biodeterioration within the stone's pores.

XRD analysis has shown that granitic support consists of quartz, microcline, albite, and biotite as main components plus calcite as a secondary mineral, in addition to anhydrite and halite salts, anhydrite has resulted from the transformation of the gypsum, which caused the surface layer detachment. Also, both anhydrite and gypsum mostly have been associated with seepage water from the ancient canal and air pollution. Some authors have specifically postulated that these crusts are formed by the combination of sulfates from air pollution and Ca from feldspars [34, 35]. X-ray diffraction patterns also revealed the weathered samples contained a high amount of aggressive salt, sodium chloride (NaCl) due to salts from the soil and the water from the ancient canal recently discovered at the site and was used by the ancient Egyptian to facilitate the transportation granite blocks from the quarry to the Nile [36].

EDX investigation revealed that; the bedrock is highly weathered by as follows; high iron (Fe) content due to alteration process of iron oxides; convert ferrous-iron to ferric iron [37] which cause coloration of granite with brown, beige to red colors. A high concentration of calcium (Ca) may be attributed to calcite, originated from decomposition of feldspars. The relatively high sulfate (S) and (Ca) contents in the samples may be attributed to the crystallization of calcium sulfate salts (anhydrite and gypsum). (Na) ions perhaps attributed to sodic or plagioclase feldspars components in granite, furthermore the high content of chlorine (Cl) and sodium (Na) in the samples suggested that the degradation of granite was also due to the crystallization of sodium chloride NaCl. On the other hand, the results of EDX also revealed that the decrease of silica (Si) content in the studied samples and this loss is due to the alteration process. In addition to the high amount of potassium (K) and Aluminum (Al) respectively attributed to feldspars content of the rock and the presence of titanium (Ti) and potassium (K) correlated with the content of alumina or alteration processes.

Infrared data have shown the fact that the medium used in granitic pictographs was Arabic gum.

Biodeterioration studies have revealed that; the isolated fungi and bacteria from the granitic rock art were of these species: Fungi such as Aspergillus Niger, Aspergillus flavus, Alternaria alternata, Paecilomyces carneus and Cladosporium uredinicola, bacteria such as; Bacillus alcalophilus and Bacillus insolitus. these genera of microorganisms were cleared by SEM, and their growing correlated with environmental factors and presence of feldspars in granite as a source of nutrients for them [38] also they play aggressive role in physical and chemical weathering of rock art through they contribute to acid dissolution, oxidation, chelation by organic acids or other substances produced by the fungi [39] and physical fracturing induced by root hyphae.

5. CONCLUSIONS

These studies were conducted at several suggestions and recommendations, as follow:

- re-design development schemes for population mass adjacent to the unfinished obelisk site to minimize their impact upon the archaeological site or move it away;
- completion of the archaeological excavations in the site via systematic methods;
- re-habitation of rock art site through design site management contains footpaths or walkways, (boardwalks), guidance signs, informative signs, low fencing to guide visitors over a site and barriers around the panels as protective procedures;
- legislation should forbid the inappropriate methods in archaeological documentation of petroglyphs by application physical enhancement process using water, chalk and other substances;
- recording methodologies should use non-destructive techniques that don't cause damage to rock art being recorded;
- before conservation procedures of rock art sites, it's necessary to assess the current condition, the risks from humans, natural causes, environmental pollution, and the adjacent setting;
- first, before the conservation works begin, it is necessary to prevent contact with groundwater from the ancient canal and keeping water out of the petroglyphs through change the waterway in the canal or design a pipeline system or using covered drainage;
- removing and cleaning vegetation and higher plants in the site mechanically and chemically by using chemical pesticides;
- consolidation of the weak granitic rock art with ethyl silicate; Estel 1000 15% in white spirit by suitable mean pipette, brushing or Injection [40];
- removal soluble salts by suitable poultices cleaning with a protective layer of long fiber tissue paper (Japanese or hemp) for protecting water sensitive pigments in pictographs;

- dry biological colonization must be removed by dry brushing then applying chemical treatment with suitable pesticides to forbid the growth of the microorganisms in the future;
- monitoring the site to observe any re-colonization, if this occurs in any substantial way, then the repetition of treatment may be required;
- applying water diversion system through opening natural drainage lines or drainage channels using sand, cement, and the rock on the roof of granitic bedrock for allowing the water to run off far away from the panels;
- applying the dripline technique using appropriate silicone water repellent on vertical panels to prevent them from direct water erosion (flow) by rains effects;

Redirecting water emanating from cracks or fissures through using silicone building sealant to fill narrow cracks or fissures, while large ones must be filled with Schlarge foam product then silicone sealant applying [41].

REFERENCES

[1] Noweir, A.N., Abu El-Ela, A.M., Sewifi, B.M., *Qatar Univ., Sci. Bull.*, **10**, 395, 1990.
[2] Engelbach, R.A., *The problems of the obelisks: from a study of the unfinished obelisk at Aswan*, T.F. Unwin, Pub., London, 1923.
[3] Fortea, J.P., *Coalition*, *Newsletter*, **10,** Spain, 8, 2005.
[4] Grant, C., *Rock Art of the American Indian, New York, Crowell*, 1967.
[5] Hawass, Z., In Ikram, S., Dadson, A. (Eds.) *Beyond the Horizon: Studies in Egyptian Art, Archaeology and History in Honour of Barry J Kemp*, Cairo, 143, 2009.
[6] Kelany, A., In *Leukoslithos: Marbres et autresroches de la Méditerranée antique: etudes interdisciplinaires*, Philippe Jockey, Paris, 189, 2009.
[7] Chaffee, S.D., Hyman, M., Rowe, M.W., *Studies in Conservation*, **39**, 161, 1994.
[8] Ahmed, S.A., Abbas, H.K., *Journal of American Science*, **7**, 275, 2011.
[9] Zezza, F., *Protection Conservation of the Cultural Heritage of the Mediterranean Cities*, the Netherlands, 377, 2002.
[10] Batchelor, A., *Preservation of South African rock art*, Report for Human Sciences Research Council, HSRC, Pretoria,1990.
[11] Rosenfeld, A., *Rock art conservation in Australia*, Australian Government Publishing Service, Canberra, 1988.
[12] Radulescu C., Stihi C., *et al., Atmosphere*, **10**(10), 595, 2019.
[13] Ion R.-M., Iancu L., *et al., Coatings*, **9**, Article Number: 231, 2019
[14] Bintintan A., Gligor M., Radulescu C., *et al., Analytical Letters*, **52**(15), 2348-2364, 2019
[15] Ion R.M., Tincu S., Ion N., Bucurica I.A., *et al., Romanian Report in Physics*, **71**(3), Article Number: 804, 2019
[16] Bintintan A., Gligor M., Dulama I.D., Radulescu C., *et al., Romanian Journal of Physics*, **64**(5-6), Article Number: 903, 2019
[17] Ion, R.M., Tincu, S., Iancu, L., Grigorescu, R.M., Radulescu C., *et al., IOP Conference Series: Materials Science and Engineering*, **572**(1), 012088, 2019.
[18] Ion, R.M., Iancu L., Grigorescu R.M. *et al., Journal of Science and Arts*, **2**(43), 471, 2018
[19] Warke, P.A., Smith, B.J, *Geomorphology*, **22**, 347, 1998.
[20] Shahidzadeh-Bonn, N., Desarnaud, J., Bertrand, F., Chateau, X., Bonn, D., *The American Sicence*, Physical Society, **81**, 2010.

[21] Bland, W., Rolls, D., *Weathering: An introduction to the scientific principles.* Arnold Publishers, London, 1998.
[22] Barton, D.C., *Journal of Geology,* **24**, 1916.
[23] Vincente, A.M., Garcia-Talegon, J., Inigo, A.C., Molina, E., Rives,V.,*Conservation of Stone& Other Materials*, **I**, 320,1993.
[24] Gómez-Heras, M., Smith, J., Fort, R., *Geomorphology,* **78**, 236, 2006.
[25] Smith, N.R., Dawson, V.I., *Soil Science,* **58**, 467, 1944.
[26] Seeley, J.H., VanDemark, P.J., *A laboratory Manual of Microbiology. In: Microbes in action*. Freeman, W.H. et al. (Eds.), San Francisco, 1981.
[27] Domsch, K.H., Gams, W., Anderson, T.H., *Compendium of soil fungi.* Vol. 1-2. London: Academic Press, 1980.
[28] Sanmartín, P., Silva, B., Prieto, B., *Journal of Materials in Civil Engineering,* American Society of Civil Engineers, 2011.
[29] Pope, G.A., Meierding, T.C., Paradise, T.R., *Geomorphology,* **47**, 211, 2002.
[30] Loubser, J.H.N., *Navorsinge van die Nasionale Museum, Bloemfontein*, 7, 113,1991.
[31] Caneva, G., Altieri, A., *Proceeding of the 6th International Congress on Deterioration and Conservation of Stone,* Torun, Poland, 32, 1988.
[32] Mishra, A.K., Jain, K.K., Garg, K.L., *The Science of the Total Environment,* **167**, 375, 1995.
[33] Lisci, M., Monte, M., Pacini, E., *Lichens and higher plants on stone: a review*, El Sevier Science Ltd, 2002.
[34] Schiavon, N., *Conservation of Stone & Other Materials,* Rilem, 271, 1993.
[35] Saiz-Jimenez, C., *Deposition of airborne organic pollutants on historic buildings*. Atmos, 1993.
[36] Kelany, A., Parizek, R.R., Alexander, S.S., Gold, D.P., El-Gohary, A., Parizek, K.A., Walters, E.J., *Bulletin of the Tethys Geological Society,* **2**, 35, 2007.
[37] Akarish, A.I.M., Shoeib, A.S.A., Nageh, A., Dessandier, D., *Mechanism and forms of deterioration recoded from the granitic monumental objects of Alexandria lighthouse, Alexandria, Egypt,* Institute for Conservation and Restoration of Cultural Properties, Kansai University, Japan, 79, 2012.
[38] Rogers, J.R., Bennett, P.C., Choi, W.J., *American Mineralogist,* **83**, 1532, 1998.
[39] Viles, H., *Geomorphology,* **13**, 21, 1995.
[40] Abd El-Hakim, A.E.B., *Study on deterioration factors of rock arts carried out on the archaeological quarries sites and the methods of treatment and conservation applied on Gabel El- Silsilah and granite quarries at Aswan,* PhD Thesis, Conservation Department, Faculty of Archaeology, Cairo University,2014.
[41] Lambert, D., *Introduction to rock art conservation: a guide to the preservation of Aboriginal rock art,* Department of Environment and Climate Change, Sydney South, 2007.