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THE IMPACT OF THE CLIMATIC CONDITIONS ON THE DECAYING OF JORDANIAN BASALT AT UMM QEIS: EXFOLIATION AS A MAJOR DETERIORATION SYMPTOM

El-Gohary, M.A.[1], Al-Shorman, A.A.[2]

[1]Conservation dept., Faculty of Arts, Sohag University, Sohag, 82524, Egypt
[2]Faculty of Archaeology and Anthropology, Yarmouk University, Jordan

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Corresponding author: m_1968_algohary@yahoo.com

ABSTRACT

Climatic conditions (temperature, relative humidity, wind blowing and rainfall) are the main factor of deterioration affecting the archaeological building in Jordan. The annual averages of climatic elements in the Umm Qeis area during the last 30 years are 15.49 C° temperature, 24.63% relative humidity, 283 mm rainfall and 16.63 knots for the wind speed. These factors represent some of the most serious factors affecting the deterioration cycles of building materials in general and archaeological materials in particular. This study investigates the effect of climatic conditions on the acceleration of weathering processes in Jordan, focusing on the exfoliation as a major deterioration symptom affecting basaltic blocks used in western theater of Umm Qeis archaeological site. The techniques used in this study include Digital Caliper, EDX, XRD, Polarized microscopy and SEM. The results have shown that the samples suffer from several deterioration factors that lead to severe deterioration forms through different mechanisms. These forms include exfoliation, material loss, mineral weathering, crust formation and crystallization of soluble salts. Exfoliation form was divided into 4 categories according to the rate of exfoliation grades and the thickness of exfoliated layers: Complete, High, Moderate and Slight. On the other hand, the basalt artifacts in the study area have been affected by other aggressive factors of damaging mechanism such as thermal dilatation, ice pressure, vibration, microbiological infection. All of these deterioration factors lead to a breakdown in its essential components and create different weathering products such as salts and some loosen decay products.

KEYWORDS: Basalt, Jordan, Exfoliation, Climatic conditions, Decay products, Deterioration

INTRODUCTION

Weathering of basaltic rocks has led to the alteration of their elemental and mineralogical composition, as well as their physical and mechanical properties, which create some difficulties for engineering purposes (Dearman, 1995; Price, 1995). Some scientific attempts were done to correlate the geotechnical and geochemical parameters within a single weathering sequence in order to develop the suitable models of the interrelationship between weathering processes and the resulting aspects of the weathered basalt. (Chigira et al., 2002; Sumner and Nel, 2002). In Jordan, there are several archaeological sites constructed by basalt blocks particularly in the Northern part, such as Umm Qeis, Umm El Jimal (De Vries, 1990) and Pella (Khouri, 1990), which represent the most brilliant ancient Greco-Roman cities of the Decapolis. These sites suffer from different factors of deterioration; particularly the effects of climatic conditions. Preliminary investigations showed severe and conspicuous deterioration, affecting the basalt stones in western theater in Umm Qeis, so this site was chosen representative of the whole site. Basalt is an extrusive igneous rock (Nockolds, et al., 1985), formed deep under the earth crust during volcanic eruptions (Mackenzie, et al., 1982), through primary or secondary origins (Hall, 1996). It consists mostly of plagioclase feldspar and pyroxene (Merschat, 1997). The basaltic magma mostly cools quickly giving the crystals little time to grow resulting in very fine grained minerals and texture (Raymond, 2002). Hence, the magma from which it is made erupts through the earth's crust cooling in the air (Barker, 1983). In the study area, basalt was used as an essential building material both in some columns, Ottoman houses foundations, the Northern Theater, and the Western theaters. Deterioration phenomenon affecting monumental stones is not a recent problem (Rossi-Manaresi, 1982). It created different types and forms of damage, such as material loss, mineral weathering, crust formation, crystallization of soluble salts and exfoliation (El-Gohary, 2006). In addition, the deterioration process of stones passes through several kinds of damaging mechanism: thermal dilatation, ice pressure, vibration, microbiological infection (Hammer, 1995). Furthermore, it is well known that the deterioration of silicate rocks has been identified as an important process affecting long-term climatic models through different environmental effects such as rainwater, wind blown, temperature fluctuation (Wheeler, et al., 1997), and the global geochemical cycles of many elements (Krishnaswami and Singh, 2005). From the specialized point of view, the mineral dissolution and surface sorption in most kinds of monumental stone do not occur in isolation. These processes occur synchronously and are accompanied by a host of other natural aspects such as the growth of secondary minerals (Pistiner and Henderson, 2003). Moreover, there are several harmful mechanisms of deterioration essentially due to air temperature, sun light, wind erosion, freeze-thaw mechanism, salt crystallization and rain water. All of these factors and their mechanisms may enhance different deterioration forms such as salt effects, granular disintegration, scaling or exfoliation, mineral re-crystallization, etching and pitting forms, crustation, and corrosion of the stone surfaces.

Exfoliation is considered one of the major deterioration forms, affecting the basalt stone in the study area Fig (1-a, b). It is a natural formation of fractures or rock peeling due to the release of pressure upon reaching the surface (Walker, 2005), or detachment of larger stone layers sheets (Fitzner and Heinrichs, 2002). It mostly occurs on the rock surface and firstly appears as small depressions in the rock and enlarges to form natural steps. In the archaeological field, exfoliation represents one of the most recognizable weathering symptom not tied to differential erosion that affect several kinds of stones especially basalt and granite through different mechanisms -physical, chemical and biological.

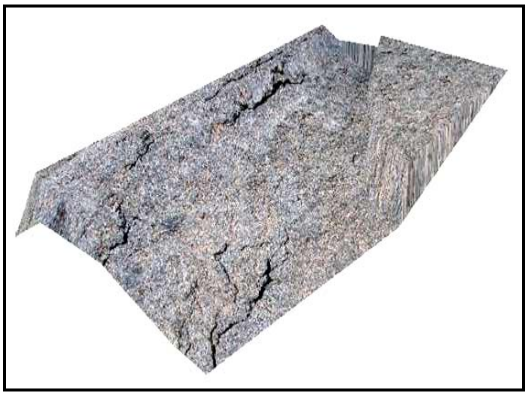

Fig (1-a) A 3D of exfoliation form of basalt artifacts in Umm Qeis.

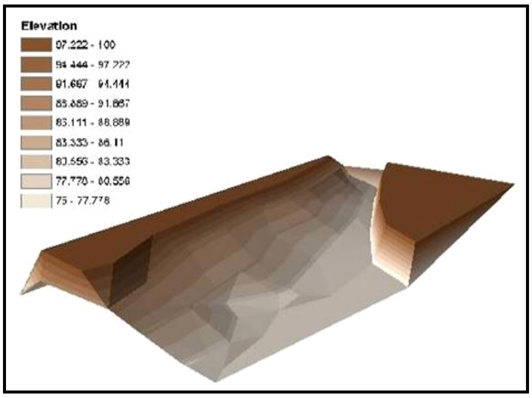

Fig (1-b) A TIN "Triangualr Irregular Network" of exfoliation form of basalt artifacts in the study area.

The physical mechanism is considered one of the most severe deterioration forms affecting the monumental rocks caused by expansion, contraction, cracking mechanisms (Chernicoff and Whitney, 2002) leading to exfoliation symptom (Riba and Ridout, 2004; Wilder, and Wunsch, 2003). The chemical mechanism of exfoliation resulted from salt bursting occurring in the cities characterized by moderately humid climate, where water penetrates the stone pores either as liquid or as a vapor (Arnold and Zehnder 1989). Moreover, it may be created if the salts are trapped behind a relatively impermeable coatings and unsuitable conservation materials such as a water repellent and acrylic creating "sub-efflorescence salts". The biological mechanism may be created through the effects of some microbiological activates resulted from some bacterial species such as *cryptoendolithic cyanobacterial* layer (Büdel, et al., 2004). All of the previous factors lead to different grades of exfoliation.

AREA OF STUDY

Umm Qeis or Gadara fig (2), which covers an area of approximately 1100 × 450 m. (Guinée, et al., 1996), is considered one of the most famous Greco-Roman cities of the Decapolis. It is situated 110 km north of Amman on a broad promontory, 378 m above sea level (Weber, 1990). In ancient times, Gadara strategic location linked a number of key trading routes connecting Syria and Palestine. Different archaeological surveys (Kerner, 1997) indicate that it was occupied as early as the 7th century BC. It was described through several Greek and Polybius historians as being under Ptolemaic control at the time. In 63 BC, Pompey liberated Gadara and annexed it to the Roman league of the ten cities "The Decapolis" (Ministry of Tourism, 2001). The site has many archaeological features representing different civilizations such as Theaters, Streets, Bathes, Basilicas, and Islamic monumental gates (Kerner, 1993). This study examines the scientific relationships between the environmental setting and the deterioration factors affecting the basalt stone in the Western theater Fig (3), which is considered one of the most important Greco-Roman structures at Umm Qeis (Lux, et al., 1993) (Karasneh and El-Dahesh, 1993).

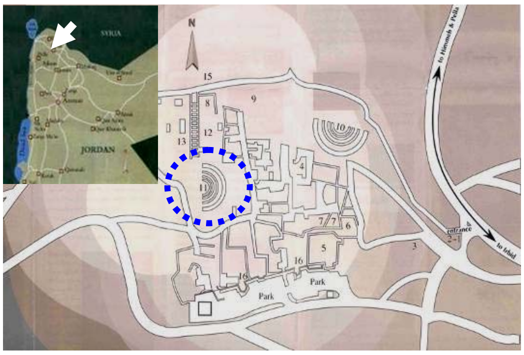

Fig (2) a general view of Umm Qeis archaeological site

Fig (3) a general view of basaltic monumental theater in Umm Qeis

Extreme Climatic Conditions in Umm Qeis

Elements of the climatic conditions are considered among the most external deterioration factors affecting the stone buildings depending upon its geographical location (D'ossat, 1982). Generally, the climatic conditions in Jordan are predominantly of the Mediterranean type - hot dry summer and cool wet winter, with two short transitional periods in November and April. The annual average of climatic elements in the study area during the last 30 years are 15.49 C^{o} temperature, 24.63% relative humidity, 283 mm rainfall and 16.63 knots for the wind speed (J M D, 1988; J M D, 2006).

MATERIALS AND METHODS

Twenty-four samples representing the various grades of exfoliation were collected from different sites of the theater. The depth of the samples was measured and evaluated using a digital caliper. The same samples were analyzed by (EDX) attached to (SEM) microprobe analytical units model FEI Quanta 200. Where, the foliated samples of basalt were prepared and coated by gold, and then they submitted to the analyzing procedures using back-scattered technique (Gordon, Dorn, 2005), this technique is far more useful for mineralogy than the secondary electron and normally used in scanning electron microscopes. This is because its images obtained with a detector placed above the specimen contain a great deal of compositional information (atomic-number contrast) which dominates the topographic information. Thus its primary feature is number, while the topography of the surface is only a superimposed secondary feature. On the other hand, in Secondary election images, compositional information is usually completely masked by the dominant topographic contrast (Robinson and Nickel, 1979). These techniques define the sample elemental ratios that contain several elements, either as a stable element in the basalt composition or as alteration products. Moreover, XRD instrument (model 6000-Shimazu X ray diffractometer) is considered one of the most reliable techniques for the identification of mineral composition of natural stones (Fitzner, et al., 1994) based on the studying the crystalline structure of the materials (Parkes, 1986); Also, polarizing microscopy was used in the identification of the petrographical characteristics of the different kinds of stones (Shotton, 1971) providing several properties and defining their optical behaviors (Tite, 1975). On the other hand, 4 meteorological variables, temperature (T), relative humidity (RH), rainfall (RF) and wind speed (WS) do not contribute equally to the deterioration of basalt stones.

We assumed that each variable has a specific weight compared to the rest in order to determine the weighting factor for the 4 variables; we statistically analyzed the meteorological data of the last 30 years in Jordan using principle component analysis (PCA). PCA is a method that is used to transform a set of correlated variables into a smaller set of uncorrelated variables and thus producing the linear combination of variables that account for the most variance, the results of the PCA are shown in Tables (1 and 2). Based on KMO test (KMO: Kaiser-Meyer-Olkin Measure of Sampling Adequacy. This measure varies between 0 and 1, and values closer to 1 are better. A value of 0.5 is a suggested minimum.), there is an adequacy in sampling as KMO is more than 0.5. The Bartlett test with 0.000 significance indicates that the correlation matrix is not an identity matrix and, thus, accepting the loading factors Table (3).

Table (1): The correlation matrix of the meteorological variables as obtained by the PCA

Correlation	T-Score	RH-Score	R F-Score	W B-Score
Temperature-Score	1.000	-.410	-.586	.053
Relative Humidity-Score	-.410	1.000	.554	-.076
Rain Fall-Score	-.586	.554	1.000	-.050
Wind blow-Score	.053	-.076	-.050	1.000

Table (2): KMO results explain the Kaiser-Meyer, df, Sig, aprox chi-sq and respective values

Kaiser-Meyer-Measure of sampling adequacy.		663
Bartlett test of sphericity	**Aprox. Chi-Square**	36.364
	df	6
	Sig.	0.000

Table (3): the PCA components explain what components are used

Meteorological Factor	Component
	1
Temperature Score	.804
Relative Humidity Score	.787
Rain Fall Sore	.873
Wind speed Sore	.140

The 4 metrological variables were collected from 14 meteorological stations all over the country compared with the data collected from the station of Irbid city in

Northern Jordan for a period of about 30 years. The values were scored according to Table (4), a GIS map (a map that shows only one subject or a theme) was obtained for each metrological variable using the Inverse Distance Weighting (IDW) interpolation, which assumes that each input point has a local influence that diminishes with distance. It weighs the points closer to the processing cell greater than those farther away. For example, the values at the archaeological site of Umm Qeis are estimated based on the values of the surrounding stations giving 100 as a maximum value for each layer.

Table (4): The scoring system for the meteorological variables (Each raw in the table represents the range of the values in the meteorological variables that satisfies the assigned score in the first column)

Factors / Score	Recorded Values			
	AT °C	**RH %**	**RF mm**	**WS knot**
20	0 - 4.99	0 – 35.99	0 – 0.45	0 – 1.19
60	5 – 10.99	36 – 50.99	0.46 – 36.99	1.2 – 4.99
80	11 - 13.99	51 – 63.99	37 – 60.99	5 – 8.99
100	More than 14	More than 64	More than 61	More than 9

The loading factors that were obtained using PCA are used to obtain the weighting factors. Each loading factor's value is divided by the sum of all values to obtain a weighting factor. This method yields a sum of 1 for all of the weighting factors as shown in the next formula:

DI = $0.309^* T + 0.302^* RH + 0.335^* RF + 0.054^*$ **WS**. This has yielded a maximum **Deterioration Index of 100.**

RESULTS

1. Digital Caliper

Measurements proved that the investigated samples contain different categories of exfoliation according to the kind of affected mechanisms where Complete Exfoliation "CE" is characterized by complete disintegrated features and the presence of some dusting of clay minerals with thickness between 19.8–20 ± 0.15381mm (Fig. 4-a).

High Exfoliation "HE" is characterized by high features of spalling with the presence of some dusting and red spots with thickness between 7.14–7.24 ± 0.03559 mm (Fig. 4-b).

Moderate Exfoliation "ME" is characterized by moderate spalling index and weak surfaces of basalt with the presence of some dusting layers that contain some salts pits and microbiological layers with thickness between 5.73–5.78 ± 0.00400 mm (Fig. 4-c).

Slight Exfoliation "SE" is characterized by slight degree of spalling with the presence of some salts and brown veins along joint surface, with thickness between 2.70–2.74 ± 0.01500 mm (Fig. 4-d).

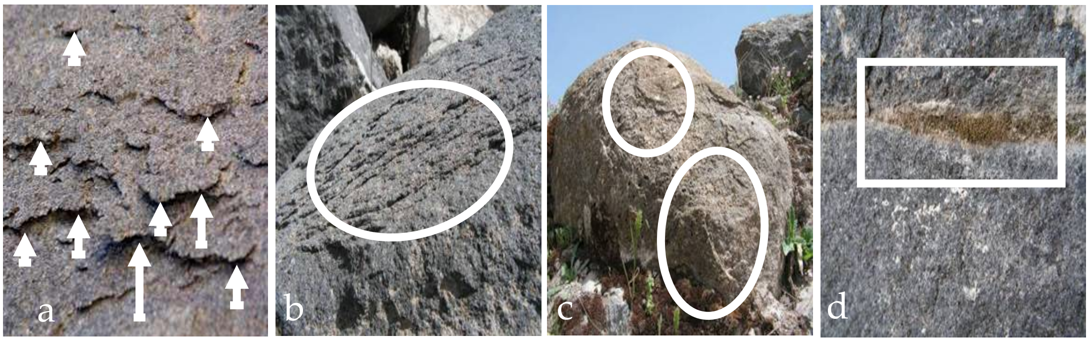

Fig (4): The exfoliation symptom affecting Basalt stones in Umm Qeis

2. EDX Attached to SEM Results

These indicate that the samples contain different symptoms of exfoliation grades and chemical transformation shapes that are essentially due to several mechanisms of deterioration as shown in (Fig. 5-a, b, c, d).

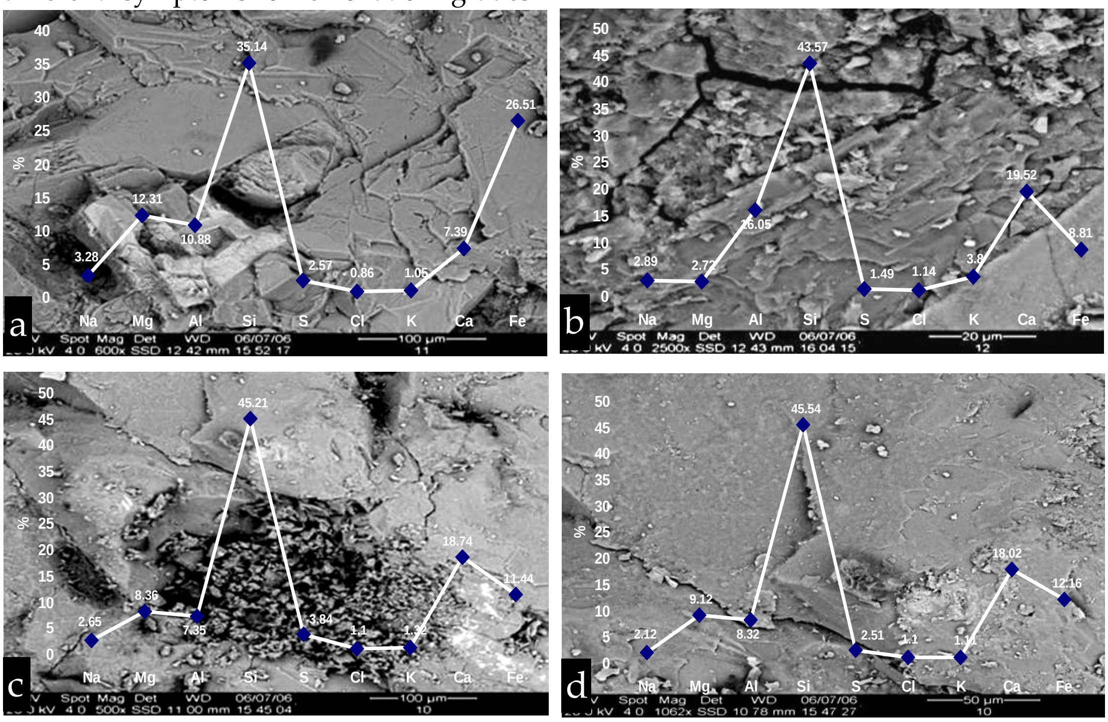

Fig (5- a, b, c, d): Back-scattered electron micrographs of deteriorated basalt samples and element contents % in each sample showed by white line

3. XRD Results

They show that the samples contain several phases of minerals such as major phases which contain Laboradorite *[Na Al Si_3 O_8. Ca Al_2 Si_2 O_8]*, Plagioclase *[Na-Al-Si-O-Ca-Al-Si-O]*, Microcline *[K Al Si_3 O_8]*, Biotite *[K $(Fe,Mg)_3$ Al Si_3 O_{10} $(OH)_2$]*, Pyroxene *[Ca Al_2 SiO_6]*, Mica Bityite [*Ca-Al-Li-H-OH-Al-Be-Si-O]*. Minor phases that include Gypsum *[$CaSO_4$ $2H_2O$]*, Serpentine *[Mg_3 Si_2 O_5 $(OH)_4$]*, Serpentine Aluminian *[Mg-Al-Si-Al-O-H]*, Olivine Hyalosiderite *[$(Mg_{0.6}$ $Fe_{0.4})_2$ SiO_4]*, Olivine Forsterite *[Mg_2 SiO_4]*, in addition to some of trace phases such as Witherite *[$BaCO_3$]*, Diopside *[Ca Mg $(SiO_3)_2$]* and Calcite *[$CaCo_3$]*, resulting from some effects of salt and chemical weathering and using some incompatible materials in some conservation works. Finally, some non detective phases, as shown in Figs. (6-a, b, c, d).

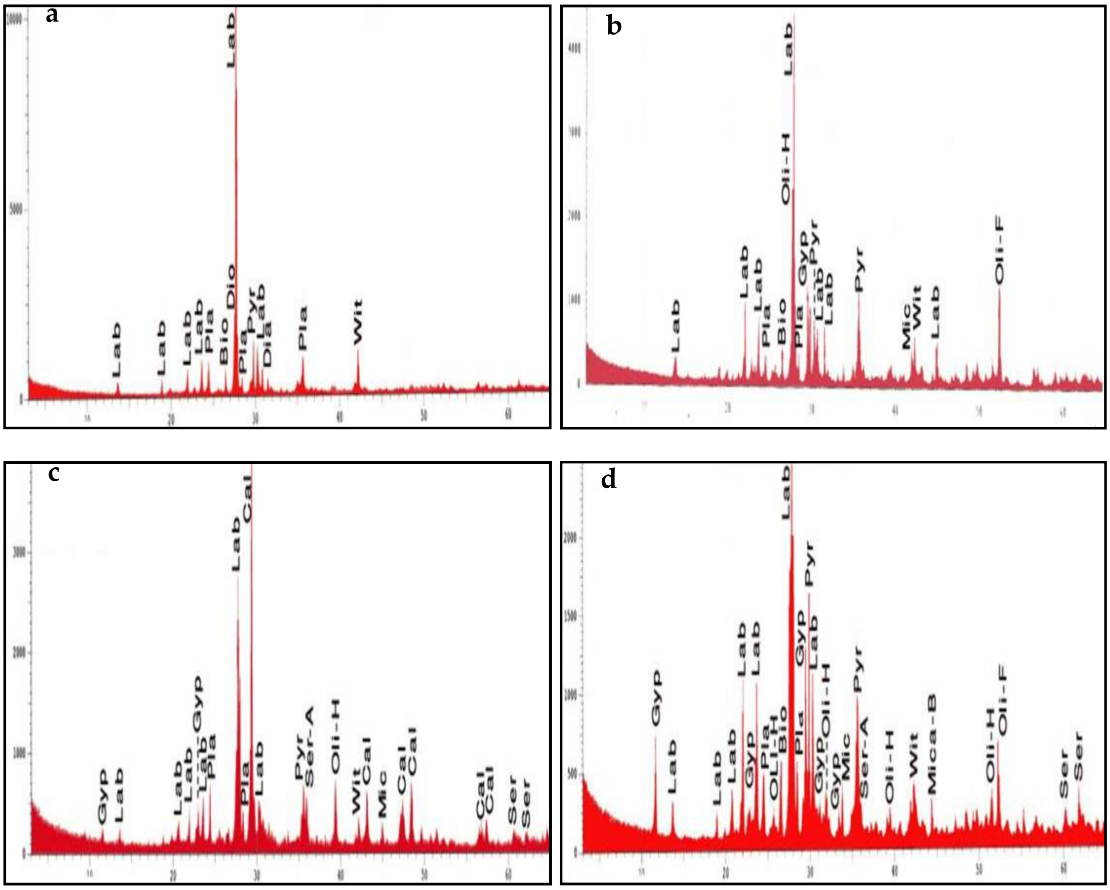

Fig (6): XRD patterns of deteriorated basalt samples

4. Polarizing Microscopy

This shows that the samples contain Plagioclase minerals particularly Labradorite, Olivine, Pyroxene crystals, Iddingsite and Serpentine, where the latter two are essentially due to alteration cycles. Furthermore, some secondary Calcite crystals which fill some voids through $CaCo_3$ solutions were identified as well as some salty minerals (Witherite and Gypsum) as shown in Fig (7-a, b, c, d)

5. Results of the GIS Modeling

These are shown in Fig (8-a, b, c, d, e, f) and prove that there are large differences in the effects of climatic condition affecting all archaeological sites in Jordan generally and the area of our case study in particular.

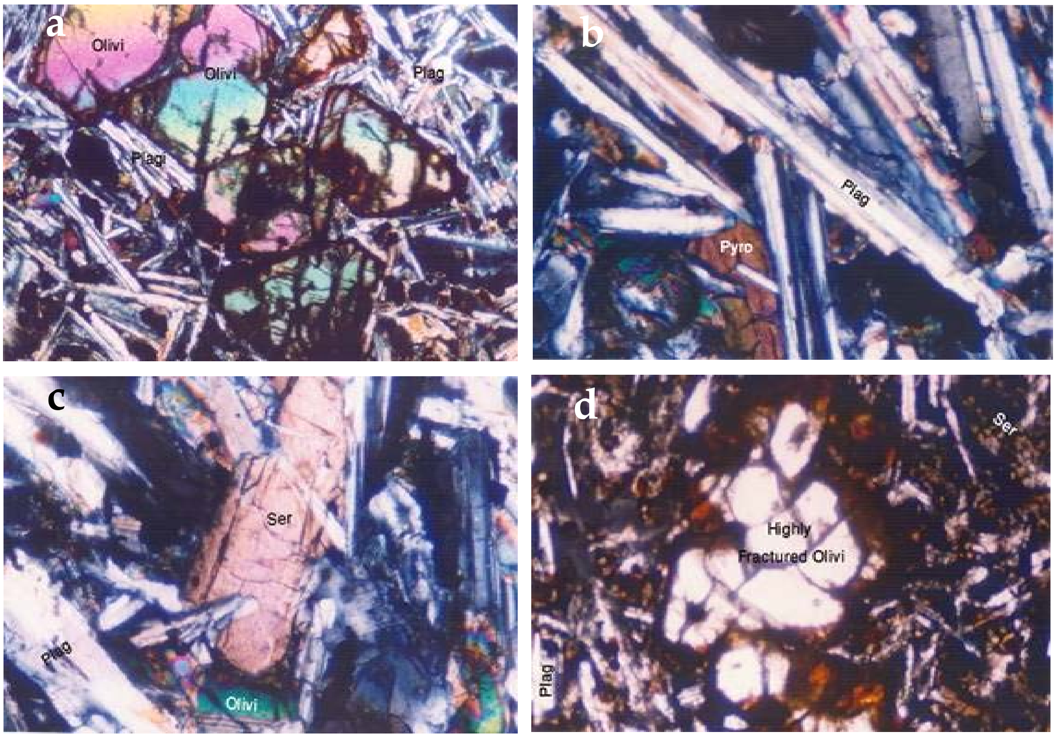

Fig (7- a, b, c, d): Some petrographic features of basalt artifact samples

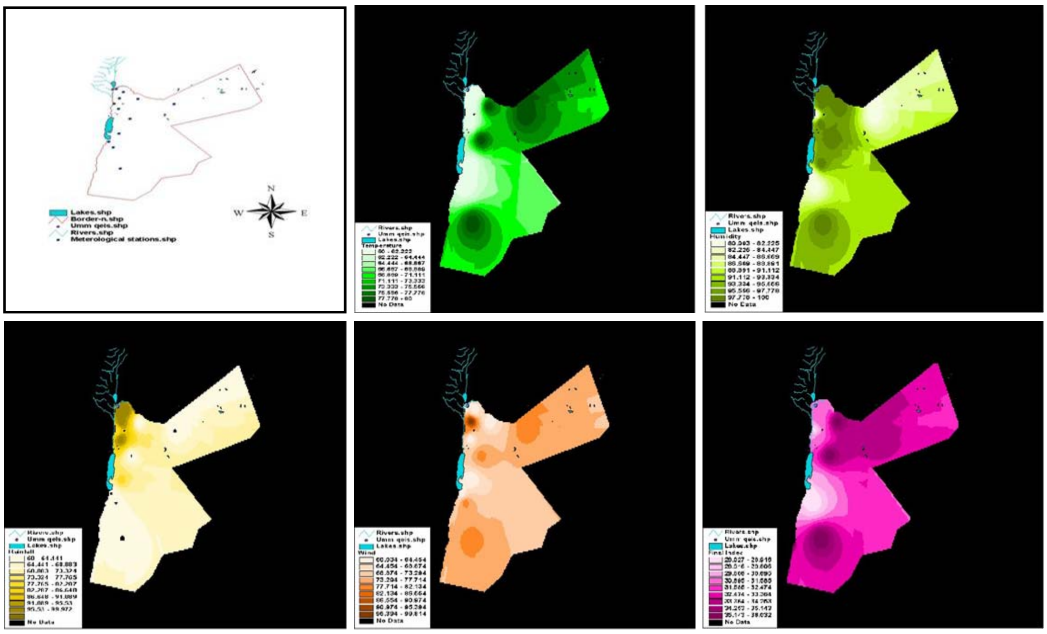

Fig (8): a) the map of the 14 meteorological stations; the interpolated layers of Temperature (b); Relative humidity (c); Rainfall (d); Wind speed (e); and (f) the Deterioration Index.

DISCUSSION

Through analyzing the previous results, it becomes clear that there are several decaying features affecting the basalt artifacts in the study area. These features are essentially due to the interactions between different deterioration mechanisms; chemical, physical and biological. Where chemical break-down goes hand in hand with the physical disintegration of the rock fabric causing the mineral constituents of basalt to break down produce different types of weathering products, a number of oxides and salty crusts such as serpentine, olivine hyalosiderite, olivine forsterite, halite, gypsum and witherite. Also, the rate of the break-down is dependent on the degree of jointing and biological activities particularly with the presence of the main agents of weathering in the study area such as H_2O, CO_2, O and organic acids, which lead to form some species of metallic and organic spots once exposed to these agents as discussed before by (Dessert et al., 2001; Willmott, 1995). On the other hand, analyzing the metrological data proved that the high levels of temperature led to some deterioration processes through thermal effects as a physical mechanism or accelerating the chemical reactions affecting the silicate minerals, then total stone durability as explored before by (Pye, 2001; Winkler, 1982; Winkler, 1985).

Also, the higher run off contribute to the enhanced chemical erosion of silicate minerals (Gaillardet et al., 1999; Millot et al., 2002). Where runoff contains a large number of dissolved matters that react with different components of the stone forming new mineral phases; transforming the feldspars into various clay minerals (Löfvendahl, 1992), especially with the presence of wind erosion and certain species of microorganisms (Silverman, 1979; May and Tayler, 1991). All these factors may transport the weathered materials and expose the fresh surfaces for new weathering cycles creating suitable environmental condition for further deterioration mechanisms (El-Gohary, 1996). Moreover, the mineralogical alterations of basalt artifacts during these processes reflect the local redox conditions (Pichler, et al., 1999), in particular, *oxidative conditions* resulting from high water-rock ratios and *reduced conditions* as a consequence of lower water-rock ratios (Thompson, 1991). Also, the alternative cycles of heating and cooling create sharpness forms of exfoliations.

Based on the obtained results, the study shows that the exfoliation form is due to different deterioration factors including climatic conditions either daily, monthly, seasonally or annually through different mechanisms of cooling and heating cycles, expansion and contraction, solubility and crystallization actions and microbiological inflating actions. Also, the study shows that the exfoliation form affecting the study area is divided into 4 categories according to their rate and their final products. The *Complete Exfoliation* shows that there are some aggressive exfoliation features, major actions of chemical disintegration, minor salty components, detaching of silica element and increasing the ratio of iron especially in outer and superficial zones of basalt artifacts. All these symptoms were created as a direct result of combination of all variables of climatic conditions (AT, RH, RF and WS) that affected mainly un-sheltered area through the effect of temperature on basalt units when the temperature drops below freezing and moisture is still trapped within walls, while, water expands as it turns to ice crystals, causing exfoliation faces as presented before by (Amoroso and Fassina, 1983). In addition to destruction mechanism due to crystallization and dissolution cycles in which salt crystallization occurs at a certain distance from the surface where the rate of evaporation and the rate of re-supply of solution are in dynamic balance (Lewin, 1982).

On the other hand, the *High Exfoliation* is primarily caused by the biological actions resulted from the effects of some bacterial species and bursting mechanisms resulted from sub-efflorescence of some salt species beneath the stone surfaces and the aggressive roles of partial synergetic effects of "AT, RH and W" especially cooling and heating cycles, also drying cycles by air currents and wind actions. Within the same context the *Moderate Exfoliation* resulted from chemical and biological actions and their acid production, in addition to high ratio of salty elements resulted through the alternative cycles between AT and RF that lead to sub-effective features and some chemical reaction as discussed before by (Bradley, 1963). These cycles lead finally to salt trapping behind the surface pushing off the stone surface especially with aggressive actions of dilution and salt crystallization actions. The *Slight Exfoliation* occurres as a direct result of chemical weathering of minerals which mostly results from weak effects of deterioration factors in long term or through physical mechanisms of "RF", these results agree with that recorded before by (Moon and Jayawardane, 2004).

The obtained results by both XRD and petrographic examinations confirm that the samples of basalt artifacts contain different phases of minerals which could be divided into two phases.

The major phase includes Laboradorite [$NaAlSi_3O_8$+$CaAl_2Si_2O_8$]; one of the most essential minerals of basalt (Deer, et. al., 1985), which belongs to plagioclase feldspars group (Nockolds, et al., 1985). Quartz [SiO_2]; the most abundant mineral occurs as an essential constituent of many igneous rocks (Klein, 1993). In our samples it is characterized by colorless and brittle shape. In addition, Olivine [$(Ca Fe)_2 SiO_4$] belongs to isomorphous group of orthosilicate (William Revell and Dana 1981) and is considered one of the most susceptible minerals in basalt which is characterized by high value of instability to weathering cycle's especially in aqueous environments. Also, it is the most soluble silicate mineral in certain organic acids (Fisk, et al., 2004). Most of the olivine alteration appeared similar to that attributed to chemical weathering processes as discussed before by (Smith. et al., 1987) that frequently replaced by red-brown Iddingsite (a reddish-brown mixture of silicates, forming patches in basic igneous rocks) (Parker, 1997). This mineral might be resulted from the expansion of some heavy iron accumulation as previously stated by (Twilley and Faic, 2000), or by pale green Serpentine even when the other constituents of the rock remain unchanged (Nockolds, et al., 1985). The Pyroxene mineral [$Ca Al_2 SiO_6$] (Klein, 1993) is a single-chain of inosilicate which is considered one of the primary components of basalt (Hall, 1996). In our samples, it is characterized by high index of cleavage because of the aggressive effects of weathering cycles. Furthermore, the alteration processes of pyroxenes mostly formed by the global carbon cycle through great geochemical and geodynamical parameters that followed by precipitation of carbonates. Calcite [$CaCo_3$] is mostly present as a significant secondary amount within the basaltic magmas (Tabor, et al., 2004). Howerever, in our samples it represents a secondary material resulted from lime mortar which had been used during the previous conservation works.

The minor phase contains several alteration minerals resulted from weathering processes especially chemical actions such as Serpentine, Iddingsite and Witherite, where we say that the presence of Serpentine [$MgSi_2O_5(OH)_4$] is essentially due to the alteration cycles of preexisting Olivine and Pyroxene (Ehlers and Blatt,1982). Also, the presence of Iddingsite?? [$MgO.Fe_2O_3.3SiO_2 \cdot 4(H_2O)$], composed of mixture of various hydrous silicates of iron and magnesium essentially, is due to the alteration processes of Olivine as a direct result of chemical weathering processes and is characterized by perfect cleavage and brown color. Moreover, the presence of Witherite [$BaCO_3$] (Baldasari and Speer, 1979) (a yellowish-or grayish-white mineral of the aragonite group that has orthorhombic symmetry) (Parker, 1997), it is due to the crystallization cycles that resulted from the effects of the ground water quality on the study area through ion exchange between Ba and Ca, particularly with presence of different synergetic effects of drying and wetting cycles. Finally the presence of Gypsum [$CaSO_4.2H_2O$] is due to the effects of some species of sulpher oxidizing bacteria found in Umm Qeis and the use of gypsum mortar and other unsuitable materials in the previous improper conservation works as reported previously by (El-Gohary, 2007a; El-Gohary, 2007b) in similar cases. Finally, according to Figure (8-f), the northwestern area of Jordan exhibits a higher deterioration index which gradually decreases towards the southern part of the country especially the southern tip of the Dead Sea. It is significant that the 4 metrological factors have a lesser magnitude in southern Jordan. Consequently, Basalt artifacts in southern Jordan will have a lesser deterioration and/or exfoliation. Also, the deterioration index affected the basalt artifacts in the study area in the last 30 year is 31%. This deterioration index is represented only in the 1st category of exfoliation as a result of 4 meteorological variables. In addition, it occurs in the 2nd category through the effect of T, RH and RF. On the other hand, the 3rd category is caused by both of T and RF and the last is affected by RF only.

CONCLUSION AND RECOMMENDATIONS

The study showed that the basaltic artifacts suffer from different deterioration forms resulted from the aggressive effects of climatic conditions. These forms vary between Complete, High, Moderate and Slight according to the dominated climatic elements in the study area. The intertwined variables of temperature, relative humidity, rainfall and wind speed vary all over the country of Jordan and thus their interactions produce different levels of deterioration to basalt stones as Jordan has a varied climatic regimes. The use of GIS in assessing the possible deterioration of basalt stones geographically seems to be a valid method and may help conservators in future impact assessments. The interaction of these variables appears weaker on degenerating basalt stones in southern Jordan. Form this point of view, it is important to take into our consideration some preventive actions and interventive measurements to stop or at least minimize the aggressive actions of this form. These preventive actions and interventive measurements include:

1. Allowing the historic masonry in the study area to 'breathe' effectively, through the removal of improper materials from its surface.

2. A conservation measurement implied fixation of the surfaces to the stone interior as well as a re-establishment of the capillarity; this target can be achieved through the injection of an appropriate filling material characterized by suitable adhesive strength.
3. Assessing all different climatic conditions around the site through studying the different scientific efforts must be taken into account to conserve the surrounding environment and avoid their harmful effects.
4. Collecting and placing detached exfoliation layers in their original positions using suitable materials.

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