

Climate Effects on archaeological buildings forming the Roman temples: Dush Temple in EI- Kharga Oasis, Western Desert of Egypt as a Case Study

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Abstract

The archaeological buildings worldwide are relics that have a great historical value recording and revealing nations' events throughout thousands of years. These events are recorded through paintings, rock art, engravings and inscriptions. The construction rocks that had been used for building the archaeological site may be sedimentary, meta-sediments, or basement rocks of small or large dimensions. Climate is the act of all atmospheric events such as rainfall, temperature, wind, air pressure and humidity etc. In last few decades, the alterations about climate observed in Egypt negatively affected the archaeological buildings, the cultural riches of the country that they have been worn out by various natural effects for a long time. However, since archaeological buildings have great importance due to their identity of transferring old era information to the future generations, there should be taken special precautions against deteriorations on the monumental buildings. Weathering processes are acting physically, chemically and/or biologically on a given material based on material's properties, its geographic orientation and intensity of the predominant weathering process. The aim of the current study is to measure the climate effects on Dush temple stones. To achieve that aim the current study found out the distribution of rock's damage categories on the wall sides of Dush temple. Examining rock properties including its petrography, mineralogy, petrophysical and mechanical properties on one hand; and defining the damage category of some wall sides of this temple are considered to find out the inter-relation between the geographic orientations of the wall side with its damage category.

Keywords: Climate effects, Dush temple, archaeological buildings, weathering processes.

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1. Introduction:

Throughout the history of mankind natural stones have been widely used as a material for buildings, monuments and art objects. In the course of time, all these natural stones have been affected by several weathering factors. So the interaction between stone materials and natural or anthropogenic weathering factors controls the type and extent of stone decay (Fitzner and Heinrichs, 2002). Along El-Kharga Oasis, many of the Roman fortified settlements are situated strategically on hilltop sites such as El-Nadora, El-Ghueita, El-Zayyan and Dush temple, which incorporate temples and ruins of ancient large communities of people and/or garrison towns. Most of these chains of fortresses lie close to the road crossing the oasis. Most likely, they facilitated the development of agricultural colonies depending on groundwater resources.

The temple of Dush (Figur.1) is located 113 km of El-Kharga city and 23 km east of the village of Baris. The temple was constructed of sand stone and is oriented on a north-south axis, surrounded by mud-brick walls. The fortified enclosure attests to four different stages of construction. In 1989, the France Institute of Archeology discovered the "Dush Treasure", which consisted of necklaces, bracelets, and diadem of gold dating to the Roman period. The temple of Dush was built and decorated during the reigns of the Roman emperors Domitian (81-96 CE), Trajan (98-117 CE), and Hadrian (117-138 CE). The ancient Egyptian name of the temple was Keshet, rendered as Kysis in Greek. Numerous inscriptions in the temple show the pharaoh offering to deities, including Osiris, Isis and Horus the child, the gods to whom the temple was dedicated. An inscription of Trajan, dated to 117 CE, is carved on entrance gate of the temple. The mud-bricks structures that surround the temple attest to importance of the site during the Roman period.

The geology of the Western Desert, including Kharga Oasis, is very well documented in Knetsch and Yallouze, 1955; Said, 1962, 1990; Issawi and El-Hinnawi, 1982; Salman, 1984; Salman et al., 1984; Embabi, 2004; El-Hinnawi et al., 2005; and Salman et al, 2010. From the geologic point of view, the Upper Cretaceous-Lower Tertiary sedimentary sequence overlies nonconformably the Precambrian basement rocks. This sedimentary sequence comprises the Nubia Sandstone overlain by the Variegated Shale rock units, which are well exposed forming most bedrocks of the depression floor. These widely exposed rock units are followed upward by the Duwi, Dakhla, Tarawan, Esna and Thebes formations exposed on the eastern and the northern scarps bounding the depression. This sedimentary sequence includes different varieties of sandstone, shale and limestone with heterogeneous physical and mechanical properties. Furthermore, the Quaternary times in the study area were characterized by alternating periods of wet and dry climates, which resulted in several fluvial, lacustrine and aeolian deposits strewn on the depression floor (Beadnell, 1933; El-Sankary, 2002).

The Upper Cretaceous Nubia Sandstone at Kharga Oasis is a highly dissected, laminated and cross-bedded unit. It is generally composed of alternating sets of relatively coarse and fine grains, which shows marked heterogeneity and different geotechnical characteristics leading to the observed differential weathering. This unit is composed entirely of quartz (quartz arenite) with trace amounts of feldspar and rock fragments (Abd El-Whab, 1999). They are mainly of barchan type of as much as 15 m in height, 200 m in length and 150 m in width, which develops distinct morphological features. These dune belts are considered part of the southern extension of the great sand dune called Ghard Abu Moharik (Embabi, 2004). Smaller barchan dunes, sand sheets and sand heaps are also frequent in the inter-dune areas. These dunes are formed by the prevailing northerly to northwesterly winds. Movement of such dunes is the most serious obstacle for the cultivated lands in this area. Many efforts have been made to solve the problem of dune migration using parallel groups of reed fences or asphaltic materials for fixation (Hilmy et al., 1980).

The rate of movement of the dune depends mainly on the dune size and the amount of moisture in the surroundings (Embabi, 1986). These dune belts continue through the Kharga depression where several groups of barchan belts are formed and extend southward far beyond the depression (Salman et al, 2010). Climatic variations and their consequent earth-surface processes represent the most prominent factor delineating the environmental impact on the study area in the present hyperarid South Western Desert of Egypt in the Eastern Sahara. Geological, archaeological and paleoclimatic reconstructions indicate that the climate of the Eastern Sahara during the early to mid-Holocene (9300–4500 years BP) was much wetter than today (Haynes, 1982; Szabo et al., 1995; Yu and Harrison, 1996; Claussen and Gayler, 1997; El-Baz et al., 2000). This wet phase was characterized by rapid onset with the formation of a mosaic of freshwater lakes and swamps leading to groundwater recharge of the Nubian aquifer (Pachur and Hoelzmann, 2000). In contrast, its termination shows depletion of the aquifer during several centuries when exploitation of the non-renewable groundwater resources represented the adaptation strategy of the Neolithic population. In addition, increasing aridity became pronounced about 3000 years ago (Besler, 2000), which was expressed in sand dune reactivation and migration further south in the Western Desert of Egypt (Salman et al, 2010).

2. The study Area:

The temple of Dush is located 113 km of El-Kharga city and 23 km east of the village of Baris. The village of Baris belongs administratively to the New Valley Governorate. It's located in the southern part of the western desert of Egypt. It lies between 22°28'14" and 26°00'00" N, and between 30°37'00" and 30°47'00" E (Figure.1).

The area covers about 1300 square kilometers. Pilot studies were carried out on the Dush temple, composed of sandstones originating from the great sand sea. It is bounded by the Eocene limestone plateau from the east and north, where steep cliffs form a sharp boundary to the depression floor (El-Sankary, 2002). This limestone plateau stretches along Middle and Upper Egypt with an elevation of up to 550 m above the sea level and about 400 m above the depression floor at the study area. However, towards the south and west, the depression floor merges gradually into the Nubia Sandstone open desert. Geomorphologically, the landscape is considered as neither high plateau in the northern and eastern boundaries, or low-lying depression floor, meanwhile the pediment areas in-between, are considered as badlands (Salman et al. 2010).

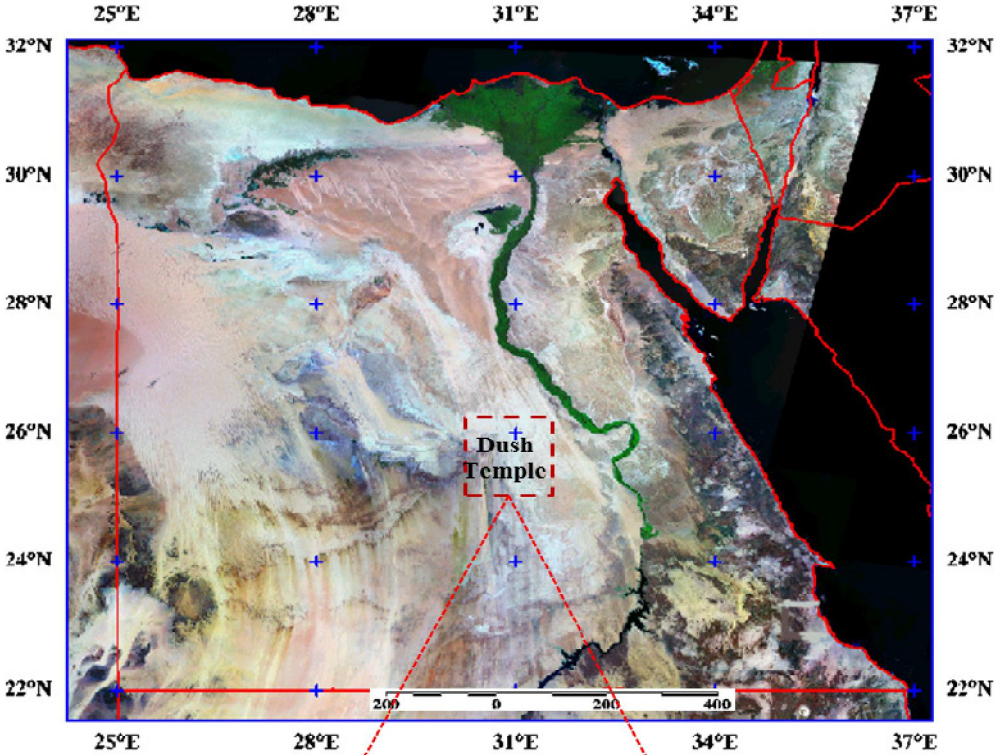
3. Materials and methods:

The current study is based on raw climate data, field study, and laboratory analysis in order to interpret the scale, pattern of deterioration and weathering process. Furthermore, profound knowledge of the material properties and the weathering behavior of the natural stones used are necessary, as well as knowledge of weathering factors and weathering processes which initiate and control this weathering behavior.

A set of three satellite images of Kharga and Baris Oasis from the MSS (1972), TM (1987), ETM+ (2010), The Landsat images (MSS, TM, and ETM+) have a Universal Transverse Mercator projection (WGS-84). These images have been interpreted to construct a surface geologic map in the light of the available topographic maps, previous geologic works and field study, which was carried out for two times, from January 2012 to February 2014, its include sample collection, measuring the weathering rate and taking photographs. A total of twelve fresh and weathered stone samples were collected from Dush temple.

These samples were crushed and milled in an agate mortar to avoid contamination and were studied by X-Ray diffraction analysis (XRD) to identify their mineralogy. The samples included the hard rock and the weathered materials. Eight thin sections representing the rock samples of Dush temple, detailed microscopic examination of the rock thin section were carefully examined under polarizing microscope to determine their texture, mineralogical composition. All climate data used in this study is represented by original data, according to unpublished data from Egyptian Meteorological Authority to El-Kharga from 1941 to 2000 and from 1941-2050 as a long term of estimating temperature data only. The climate data consisted of solar radiation, mean monthly and annual records of temperature types (maximum, minimum, absolute). Annual means are the means of all 12 months from a respective year; seasons were defined as follows:

Winter is the mean through December-January-February; spring through March-April-May; summer through June-July-August; and autumn through September- October-November. The winds data come in a standard format and represent the annual average of the percent of hourly occurrence of surface wind measured at 10 m height above ground and are arranged into 12 wind speed classes in 12 directions (Table 3).



(Figure.1) Location map of Egypt showing Baris Oasis and Dush temple

4. Results and Discussion

The study area is characterized by tropical arid climate. The maximum day time temperature fluctuates within a wide range, reaching up to 45–52 °C in summer months, meanwhile in winter, the minimum temperature may drop to as low as zero at night.

Dush temple is highly influenced by wind action because it has been built on a hill top 45 meter in hyper arid climate and exposed to wind without any obstruction. Wind is the most important factor of weathering and deterioration of Dush temple stones especially if it is carried with sand particles of high hardness. The impacts of wind are highly shown on the building stones at the arid climate like Dush temple.

The Climate is by nature a rather complex theme, because of the manifold earth atmosphere interaction which considerably varies over space and time and finally creates a specific type of climate at a particular location (DOMRÖS and GONGBING, 1988) (Attia El-Tantawi, 2005). The climate in the area under investigation is mostly hot during the day (50.3 °C), and windy at night (140 km/hr).

Climate conditions are the most significant factor affecting the weathering process. To preserve a stone cultural heritage for a long time, it is necessary to examine how the rock is weathered, based on the climate condition at El-Kharga Oasis. Generally, climate in Egypt is commonly described as arid and semi-arid, characterized by hot, dry summers, moderate winters and erratic rainfall. According to Koeppen's climate classification, Egypt experiences the 'hot desert climate type' (BWh) in the southern and central parts of the country and the 'hot steppes climate type' (BSh) along the coast. Most parts of Egypt are occupied by the Sahara desert, which represents the most extensive area of severe aridity on globe (Domroes et al, 2005).

El-Kharga region is the driest on the earth's surface, where the incident solar radiation is capable of evaporating over 200 times the amount of precipitation (Henning and Flohn, 1977). Temperatures range from 52°C in summer to 15°C in winter and potential evapotranspiration is as high as 5 mm/d (Hereher et al, 2014). Wind blows from the north-northwest direction with moving capacity to drift sand dunes, which is a common phenomenon encroaching upon farmlands, roads and settlements in the depression.

Additionally, the climate of El-Kharga Oasis is largely determined by the interaction of the location, Air pressure and wind belts and great sand seas. As from a global perspective, the sun's mean angle is highest, on average at the equator and then becomes progressively lower polewards; mean temperatures gradually decrease with increasing latitude in Western desert.

The air pressure distribution which is responsible of the wind patterns affects the annual temperature and precipitation. Wind is produced by the differences in the air pressure and the weather systems, such as weather fronts and storms controlled by wind patterns. The solar radiation reaches the study area as little as possible in the winter. The rate increases gradually about ($18.5 \text{ MJ} / \text{m}^2 / \text{day}$) in El-Khargastation and about ($19 \text{ MJ} / \text{m}^2 / \text{day}$) in El-Dakhla station. In Spring, the sun is moving outwardly from the Tropic zone , heading north towards the equator , leading to increase the amount of the solar radiation during the spring, where the amount of solar radiation at El-Kharga station is ($27.5 \text{ MJ} / \text{m}^2 / \text{day}$) , while in El-Dakhla station is ($27.6 \text{ MJ} / \text{m}^2 / \text{day}$). The amount of solar radiation during the summer doubles that record during the winter, where the amount of solar radiation at El-Kharg station about ($29.7 \text{ MJ} / \text{m}^2 / \text{day}$) in summer. The sun movement to the south during the autumn reduces the amount of solar radiation to all parts of the study area, it's about ($22.3 \text{ MJ} / \text{m}^2 / \text{day}$).

The temperature is vary considerably, especially in summer; when they may range from 7°C at night, to 52°C during the day. While the winter temperatures in deserts do not fluctuate so wildly, they can be as low as 0°C at night, and as high as 25°C during the day. Egypt's official heat record is 50.3°C measured by British colonial officials at El-Kharga Oasis on June 9, 1961 would be Egypt's national heat record. The study area is part of the most hyper arid region in the world. There is essentially no precipitation. Winds are predominantly from the north. The temperature ranges from 5°C to 26°C in winter and from 26°C to 45°C in summer.

According to (soliman, 1998) the interaction of wind with sedimentary rock monuments manifest it several forms, including: scratching; differential weathering; undercutting and shaping. Aeolian differential weathering is manifested in all parts of sand and lime stone formed Dush temple, where that sand and lime stone are less hard and easily eroded due to speed of the wind. According to (Hossam Ismael, 2015) an increasing in wind velocity may affect the deterioration of building stone in other way. Higher velocity of wind (up to 140 km/hr) accompanied by sand and dust from the great sand sea can increase the air temperature suddenly about 20°C within two hours and consequently the degree of weathering can be increased. The thermal expansions do not occur only because of hot weather at afternoon but also freezing process as a result of decreasing of temperature at night, the frozen dew fall in cracks presents a cotten effect, enlarges the cracks and causes to have broken pieces of stones (Abd El-Aziz, 2012). But thermal expansion can also occur in larger zones of the rock itself. The rocks surface is more affected by insolation than the deeper part of the rock.

Thus, thermal expansion depends on the orientation of exposure of a rock wall (south, west, north, and east). When this event takes place for several times, the broken upper layers of stones will be observed. Freezing-thawing process has a significant effect on deterioration of stones used at the regions facing with daily and seasonal temperature changes (Yaldiz, 2010).

(Table. 1)Characteristic damage according to different categories

Category Numbers	Characteristic damage	Sub-groups
0	No visible damage	Bird dropping and loose masonry
1	Very slight damage	sanding, flaking, , loose masonry, surface crust, bird dropping, graffiti, soiling,
2	Slight damage	Pitting, alveolar weathering, outbreaks, back weathering, missing insets, loss of stone material
3	Moderate damage	Large pitting Fissures, Joint,Scaling, Exfoliation
4	Severe damage	Y-shape joints, salt efflorescence, , microbiological deterioration, insect colonization,structural instability
5	Very severe damage	Fault , connected joints, anthropogenic activity, pollution, quarries, collapsed wall

The damage features at Dush Temple have been divided into 6 groups in this study. These groups are mainly divided into 25 sub-groups (Table. 1). The current study is based on the modeling of damage category of weathering forms of Kamh (2009). The benefit beyondthiscurrent study is to construct a climate conditions affecting damage categories based on detailed field measurements rather than rock sampling for laboratory (geotechnical and durability) investigations where sampling is almost impermissible, particularly for highly ranked archaeological sites.



(Figure.2) Walls pillars that are partially or fully collapsed with the original stonestill in the vicinity, usually found at archaeological site



(Figure.3) Obliteration of engravings and climate impact on constructional sandstone of Dush temple



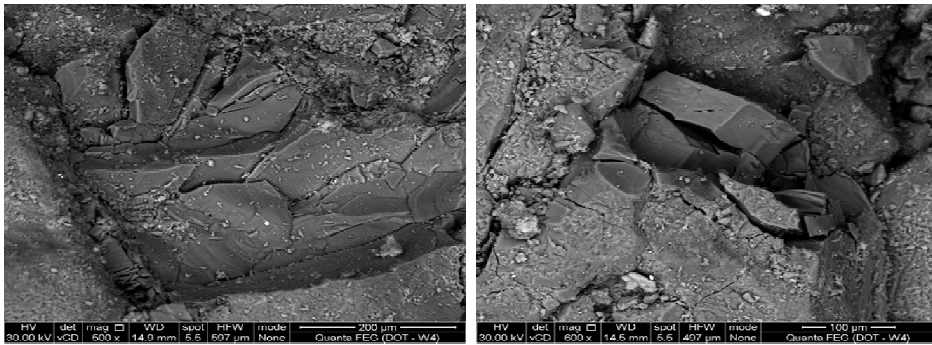
(Figure.4) Degradation of stone into thin separated layers following the beddingplanes of the rock surface



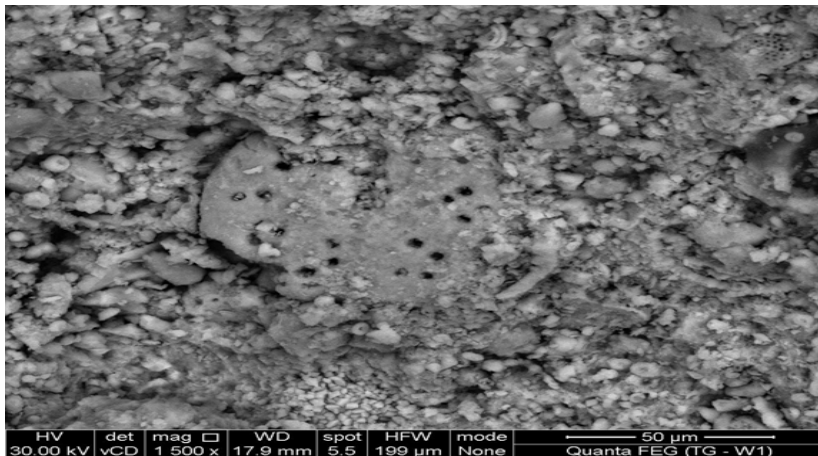
(Figure.5) Black weathering, Loss of stone material parallel to the stonesurface or profile



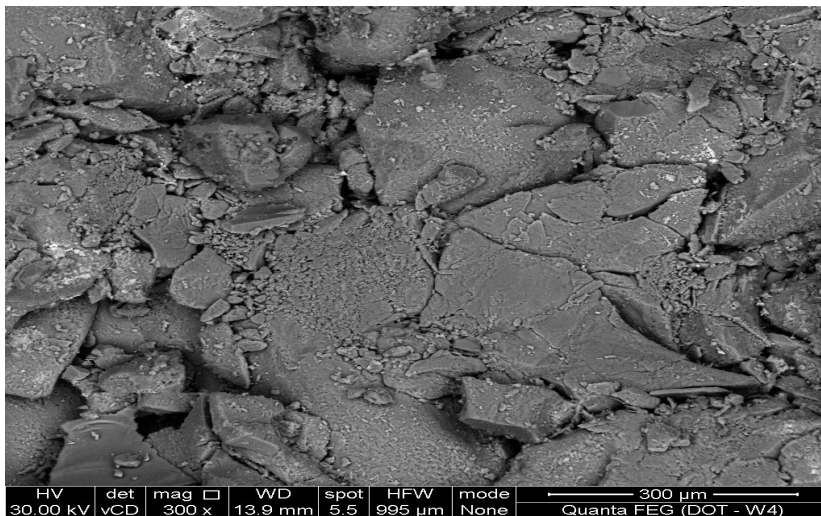
(Figure. 6) Micro-biological such as algae, lichens, moss and fungi cover total obliteration of engravings of excavated Dush temple.



(Figure.7) An identifiable crack in the stone which occurs as a result of physical weathering in macro scale the photo above and in micro scale the photos in the bottom



(Figure.8) Scanning electron micrograph of deteriorated stones of Dush temple showing micro pitting occurs initially in the deep pores

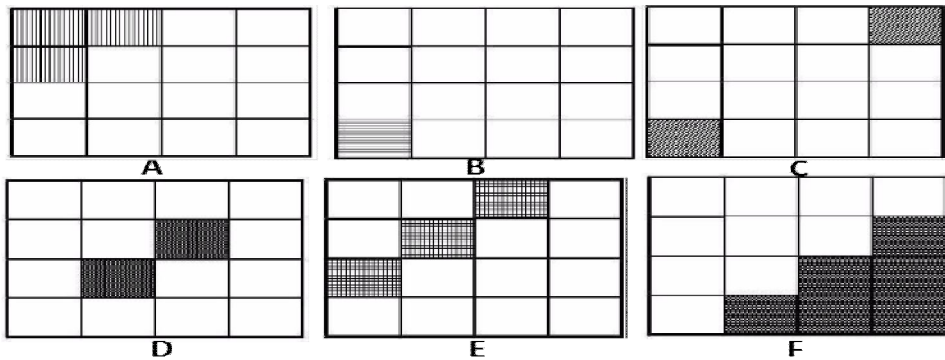


(Figure. 9) Scanning electron micrograph of deteriorated stones of Dush temple Showing micro-exfoliation grains

The field composite scales of the models for the recorded weathering forms can be used for quantitative definition of damage category of a given wall side of an archaeological site. But as the wall side never has a single weathering form, two or more of these composite scales must be combined and presented in one composite scale. Consequently, the following is a simple graphical presentation, which can also be called modeling of combination of all these composite scales (Figure.10).

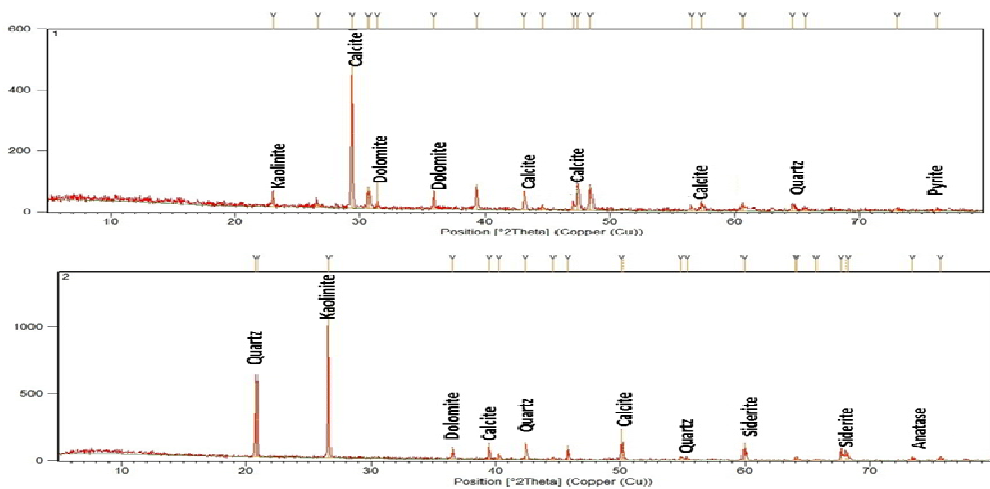
The different weathering forms that have been considered and recorded at the stone surface of dimensional stones constituting the surveyed archaeological sites according to Kamh (2009) to:

- (a) Obliteration of engravings that have been measured considering its removed thickness [mm] and wall side area [%] affected by this weathering form.
- (b) Rock meal (R.M.), in this case stone surface is partially altered to fine powder that can be easily removed by mere touch. It has been quantitatively described considering its specific mass [kg/m²] and wall side area [%] presenting this weathering form.
- (c) Salt efflorescence (S.E.), in this case salts appear at the surface of stones as white powder or crystals or even a crust. It has been quantitatively described considering salt crust's thickness [mm] and wall side area [%] presenting this efflorescence.
- (d) Cracks (Cs.), those are passing between or through construction rocks of each wall side of a given archaeological site. It is described considering its density [number of cracks/m²], its aperture width [mm], its length [m] and its inclination angle measured from the vertical position [degree].
- (e) Pitting (Pi.), which are small size pits measured at millimeter scale on the stone surface. It is quantitatively described considering its average density [average number / m²] and its average diameter [mm]. Sheets are formed, which can be detached easily from the rest of the rock body. The sheets follow the internal structure, e.g. bedding, lamination or foliation of the rock. It is quantitatively measured considering the thickness of these sheets [mm] and wall side area [%] presenting this exfoliation.
- (g) Scaling (Sc.) this weathering form is similar to exfoliation but the difference is that this form of damage does not follow the internal structure of rocks. It is quantitatively described considering the same values as considered for exfoliation.
- (h) Micro-biological cover (MiB), which takes micro-biological cover e.g. lichens, algae and fungi into consideration. This process dominates at wet basal courses of many sheltered wall sides particularly those, which are in contact with near surface groundwater. Such biological cover has an impact on appearance of wall sides of the archaeological sites with its engravings and/or paints as well as result in physical and/or chemical weathering on these construction rocks. Its impact can be examined on grain-scale for a given rock body using Scanning Electron Microscopy (SEM). Micro-biological cover is quantitatively measured for a given wall side considering the area covered by these micro-organisms [%] and side effects physical and/or chemical of it, e.g. micro-pitting, micro-cracks and grain surface etching, on samples' examination using SEM.



(Figure.10) modeling of damage features Category class affecting Dush temple based on Kamh(2009) (A) low damage category class. (B) Low to moderate damage category class. (C) Moderate damage category class. (D) Moderate to severe damage category class. (E) Severe damage category class. (F) Very severe damage category class.

X-ray diffraction examination of hard weathered samples of Dush temple reveals that the surfaces essentially consist of the same mineralogical composition of original hard rocks in addition to gypsum as the main weathered products .The sandstones’ mineralogical study has been conducted for three samples of each sandstone type using X-ray diffraction with wave length $\lambda = 1.54 \text{ \AA}$. Computerized auto-identification using MDI/ JADE7 program has been applied. It has been indicated that the stones formed Dushtempleare mainly composed of quartz, and considerable content of Ankerite[Ca (Fe+2Mg) (CO₃)₂], clay (Clinochlore), Na-Feldspar (Albite) and magnesium silicate (Figure. 11)



(Figure. 11) X-ray diffraction chart presenting mineralogical composition for stones formed Dush temple:

5. Conclusion

The main damage factors at Dush temple it seems to have been high temperature, low precipitation levels, wind speed and repeated heating and cooling. Thus, different properties of weathering in each region have to be considered in designing the way of the conservation of the stones. Detailed field measurements of characteristic values of weathering forms such as density, area percentage affected by a given weathering form, thickness of weathering form can be presented in a damage category scale. Further it can be combined in order to get a quantitative composite scale presenting all possible damage category (D.C.) classes for each weathering form.

The damage features classes of Dush temple have been divided into 6 groups in this study. These groups are: No visible damage, very slight damage, slight damage, moderate damage, severe damage and very severe damage. These groups are mainly divided into 25 sub-groups. Each damage category class has been graphically represented in a preliminary model based on a composite scale. This approach takes into consideration the combination of all individual composite scales of all weathering forms listed in this study. The numerical range of each damage category class (Low, Moderate, Severe and Very Severe) has been determined considering all weathering forms. In the investigations presented in this contribution all weathering forms are considered based on the graphical composite scale.

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