Study of the Chemical and Biological Weathering Effects on Building Stones of the ancient city of Sabratha, NW-Libya

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Abstract:

This paper dealt with the study of chemical and biological weathering factors and their damages on different types of building stones of Sabratha Archaeological City. The study based on discussing group - 2 of weathering that proposed by Fitzner and Heinrichs (1999, 2000 and 2004) which known as "Discoloration/ Deposit". According to field observations, six (6) main weathering forms has been found to effect the building stones of Sabratha archaeological City which specifically are: soiling effect, biological colonization effect, biological colonization to crust effect, discoloration effect, loose salt deposits effect and hard crust deposit effect. These included nine (9) individual weathering forms which precisely are: soiling due to anthropogenic impact, soiling by droppings, colonization by higher plants, microbiological colonization, colonization to dark-colored crust tracing the surface, bleaching, coloration, efflorescence and light-colored crust tracing the surface. The damage degrees of these weathering forms varied from non-visible to moderate with spreading degrees varied from very-limited to widespread. The linear and progradational indices of this group of weathering showed damage degrees varied from non-visible to moderate and from very-slight to moderate respectively and were widespread. Generally, the obtained results concerning biological and chemical damages on the building stones of Sabratha Archaeological City mentioned in this research, portending to some more deterioration in future and in order to protect the monuments of the city, some kind of remediation should be intervening.

Keywords: chemical & biochemical weathering effects, ancient building stones, ancient city of Sabratha.

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Introduction:

Following the classification of weathering damages on archaeological building stones proposed by Fitzner and Heinrichs (2001 - 2004) and Fitzner et. al. (1999 -2002), accordingly weathering damages of Sabratha ancient city building stones are classified into four main groups. Group-1 (Loss of stone material) which has been discussed by Ismail F., Shushan, *et. al*., (2019 a) Group-2 (discoloration/deposit) which is the purpose of this paper Group-3 (detachment) which has been also discussed by I. F. Shushan *et. al.*, (2019b) and Group - 4 (fissures and deformation) which planned to be discussed in future.

Weathering is the natural way of stone decay into smaller particles. It is a slow continuous process that affects all substances exposed to the atmosphere. Chemical weathering results from chemical changes of minerals that become unstable when they are exposed to surface conditions. Some minerals, like quartz, are almost unaffected by chemical weathering, while others, like feldspar, are easily altered. In general, the degree of chemical weathering is greatest in warm and wet climates, and least in cold and dry climates.

The important characteristics of surface conditions that lead to chemical weathering are the presence of water (in the air and on the ground surface), the abundance of oxygen, and the presence of carbon dioxide, which produces weak carbonic acid when combined with water.

Processes by chemical weathering may include: Hydrolysis "the breakdown of rock by acidic water to produce clay and soluble salts "Oxidation " the breakdown of rock by oxygen and water, often giving iron-rich rocks a rusty-coloured weathered surface", Solution " the removal of rock in solution by acidic rainwater, Carbonation " the weathering of limestone by rainwater containing dissolved CO_2 (Gore,Pamela J. W., 2013, Earle, S., 2015). Biological weathering is the process by which minerals of the rocks become broken down and altered as a result of physical and

chemical agents of organisms. Organisms may react chemically with rocks in order to obtain different types of minerals which as a result changing and altering the original material of the rocks. It has been thought that the secretion of chemical materials and weak acids by lichens and bacteria on rocks is the manner by which these organisms may obtain their diet to persist and in such way could harm and alter the rock substrate (R. D. Finlay et. al., 2019, Jie Chen et. al., 2000. Plant roots may act as destructive mediator for rocks through secretion of organic acids and enlarging the cracks.

When water inter the cracks between rock blocks and become frozen, rocks will break down. Wastes of bats, animals and birds can be also a destructive mediator for rocks as they contain chemical materials able to affect mineral particles that form the rocks. The decomposition and deterioration of organism's residues (in the form of humus) may produce acids and gases (e.g.: CO_2 NH_3, HNO_3, and organic acids) which change and weaken the original rock material and soils. All these factors may enhance the ability of water to break down and dissolve rock materials, and as a result, the rates of weathering become accelerated.

Location of Study Area:

The ancient City of Sabratha is located along the Mediterranean Sea coast, northern Libya and is situated about (70) km west of the Capital City of Tripoli within coordinates 32°47'32" N and 12°29'03"E. It is surrounded by the sea from north, Zawia City to the east, Jafara to the southeast, Yefren to the south and Zuwarah City to the west (Figure-1). 18 buildings were selected for this study (Figure-2).

Aims of the Study:

This study aims to investigate the effects of chemical and biological weathering features on building stones that establishing the ancient City of Sabratha. The study will determine the main and individual weathering forms that collaborating in the

destruction of building stones of the city. Likewise, the degree of damages and their distributions will be identified in order to appraise the risks that the City might challenges. Moreover, the study discusses the effect of linear and progradational indices of this group of weathering and determine their damage intensities on building stones of the ancient City of Sabratha.

Methodology:

This research will apply the systematic scheme used to classify the group –2 of weathering so-called " Discoloration Deposit" introduced by (Fitzner and Heinrichs, 2002, 2004). Intensity of different individual weathering form damages will be estimated and contour maps for every kind of damages throw-out the city will be constructed. Linear and progradational indices will be estimated according to (Fitzner and Heinrichs, 2002, 2004).

Stratigraphy of the Study Area:

The area of study is covered by rock units limited between the Late Triassic and Quaternary.

The rock succession scheme of the area of study is the same as that used to classify the rock succession of Gharyan area " Jabal Nafusa" and surrounding areas suggested by El - Hinnawy and Cheshitev (1975) shown on Figure-3.

Figure (1): Location of the study area (yellow arrows)

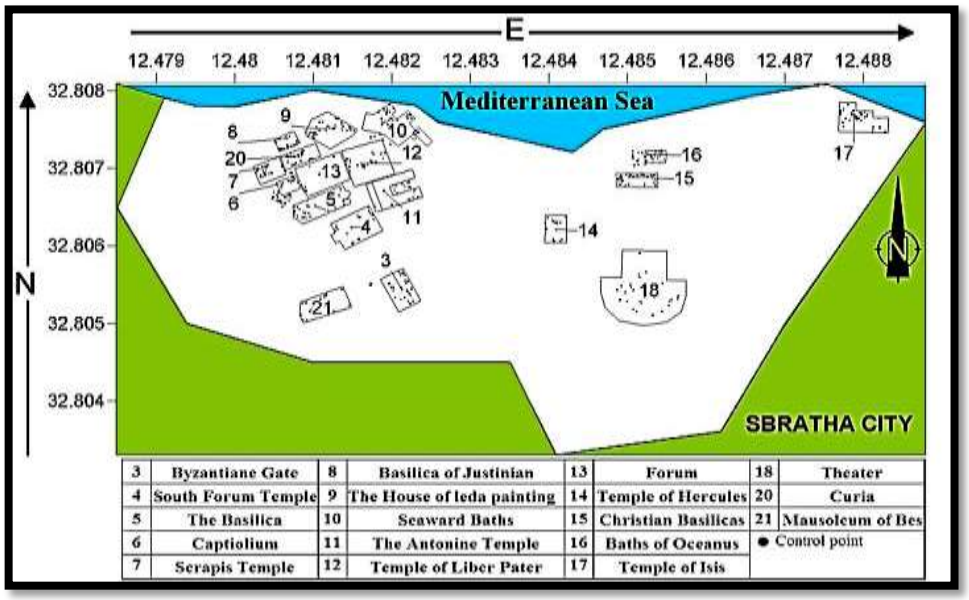


Figure-2: The (18) buildings selected for study within Sabratha Archaeological City

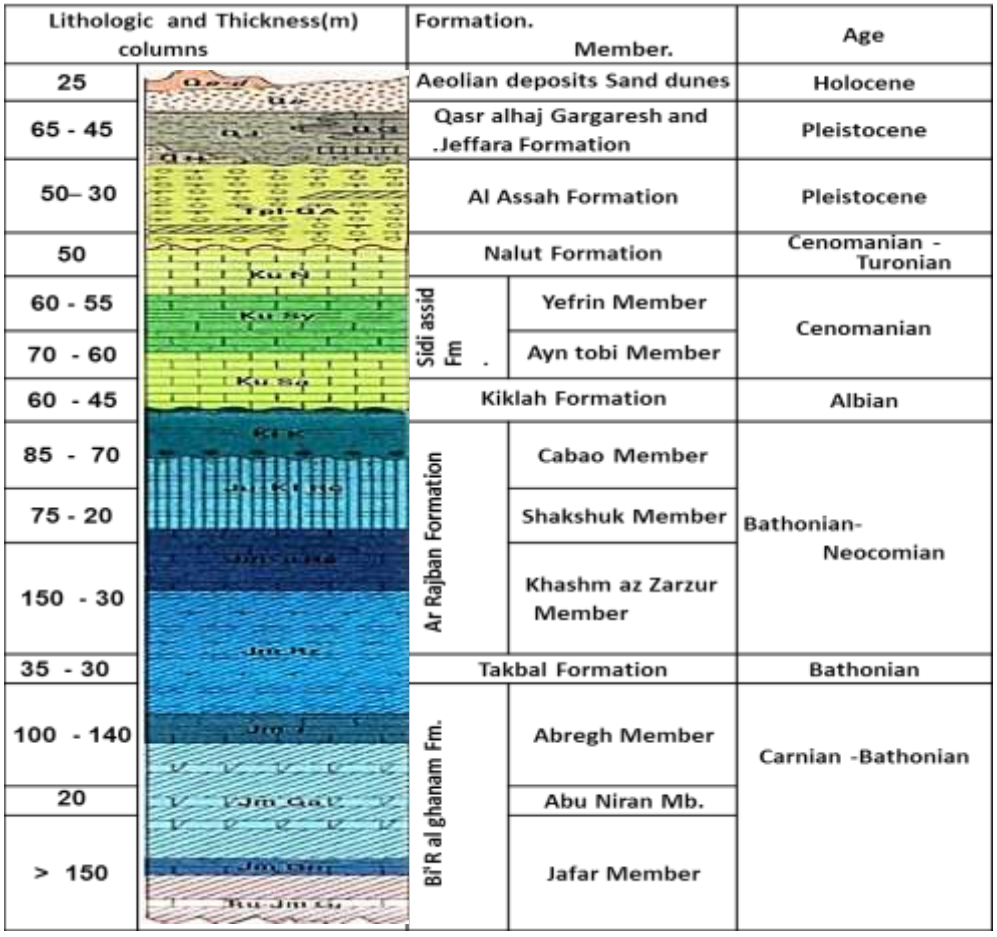


Figure (3): The stratigraphic succession of study area (El-Hinnawy and

Presentation of Results

According to field investigations done within the area of study and referring to the scheme proposed by (Fitzner & Heinrichs 2002, 2004) concerning group -2 of weathering "Discoloration / Deposits ", the following results were reported in table-1 and table-2 as follows:

Table (1) : Results of the main and individual biological and chemical weathering forms and their damage degrees on building stones of Sabratha Ancient City, in accordance with (Fitzner et. al., 2002).

Group of Weathering Forms					
Group-2: Discoloration/Deposits					
Main Weathering Form	Individual Weathering Form	Damage Degree	Effect Type	Widespread Degree	Occurrence and Characters
Soiling (dirt depositson stone surface)	Soiling due to anthropogenic impact	very-slight to non-visible	Chemical	widespread	southern parts of Arch. Sabratha City= very-slight damage, Temple of Isis + middle & northern parts= non-visible damage (Pl-1"Map-1")
	Soiling by droppings	non-visible	Bio-chemical	very-limited	SE Temple of Isis + NE Theater (Pl-1"Map-2"), (Pl-3"Fig-1")
Biological Colonization (colonization of stone buildings by plants & micro-organisms)	Colonization by higher plants	moderate to very-slight	Biological	widespread	Centre +SW= moderate NW+NE= slight E+SE= very-slight (Pl-1"Map-3"), (Pl-3"Fig-2")
	Microbiological colonization		Bio-Chemical		S-Centre= moderate SE+SW+Centre= slight NE+NW+E= very-slight (Pl-1"Map-4"), (Pl-3"Fig-3")
Biological Colonization to Crust (transitional form between biological colonization & crust)	Microbiological colonization to dark-colored crust tracing the surface	very-slight to non-visible	Biological		Centre +S + NW + SE = very-slight damage, N-C+ NE= non-visible (Pl-1"Map-5"), (Pl-4"Fig-1)

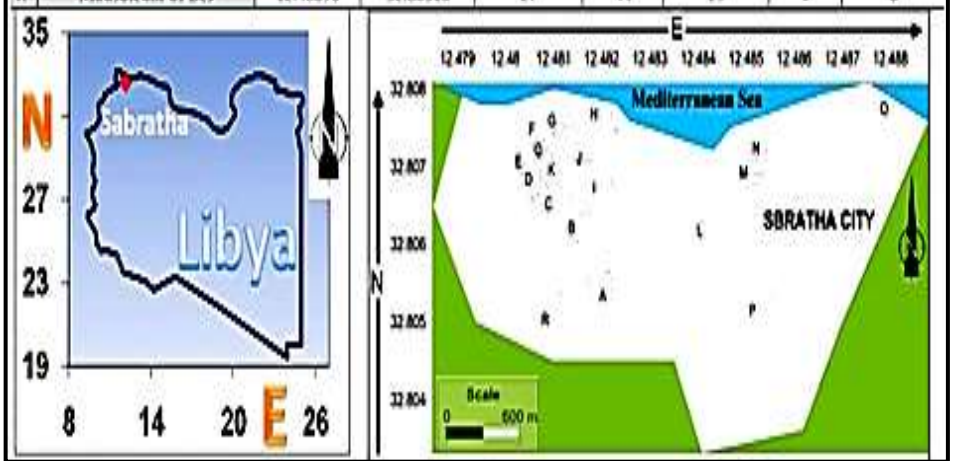
Discoloration "Staining" (change of the original color of stone building)	Bleaching		Chemical	very- limited	NW + W-C = very-slight Rest of buildings= non-visible, (Pl-1"Map-6")
	Coloration	moderate to very-slight	Bio-Chemical	widespread	S = moderate N = very-slight C = slight, (Pl-2"Map-7"), (Pl-4"Fig-2)
Loose Salt Deposits (deposition of less consolidated salt clusters)	Efflorescence	non-visible	Chemical	limited	Temple of Isis, Christian Baslicas, Temple of Hercules, Baths of Oceanus, Theater, Forum, Byzantinane Gate, Curia, Mausoleum of Bes (Pl-2"Map-8")
Crust (deposition of highly consolidated crusts on stone surfaces)	Light-colored crust tracing the surface	very-slight to non-visible		Less widespread	Scrapis Temple = very-slight. Rest of buildings = non-visible. (Pl-2,"Map-9"), (Pl-4"Fig-3)

Table(2): Results of the linear and progradational indices and their damage effects on building stones of Sabratha Ancient City.

Group-2: Discoloration/Deposits			
Weathering by Chemical & Biological Agents			
Weathering Index	**Damage Degree**	**Widespread Degree**	**Occurrence and Characters**
Linear Index	Moderate to Non-visible	widespread	S-C parts + Byzantinane Gate = (moderate), SE, SW, NE, W-C parts = slight NE, NW = very-slight Isis Temple, Sea Baths = (non-visible), (Pl-2,"Map-10") Note: increasing damage intensity away from sea coast.
Progradational Index	Moderate to very-slight		S, Byzantinane Gate = **(moderate**) Forum, Baslicas, Temple of Hercules, Baths of Oceanusm Curia, Scrapis Temple, Mausoleum of Bes, Christian Baslicas, Theater, Captiolium, Antonine Temple, Bisilicas of Justinine (**slight**) Rest of buildings = (**very-slight**) (**Pl-2"Map-11"**) **Note**: increasing damage intensity away from sea coast.

Table(3) (: (%) estimations of deterioration intensities caused by different types of damages belonging to group-2 of weathering (discoloration/deposits) that effects buiding stones within Sabratha Archaeological City in accordance with (Fitzner et. al., 2002).

Group-II	Sites	Coordinates		Group-II Damage Categoreis				
		X - (Eastern)	Y - (Northern)	Very slight %	slight %	Moderate %	Sever %	Very sever %
A	Byzantlane Gate	12.48213	32.80544	8	14	25	53	0
B	South Forum Temple	12.48149	32.80624	5	77	18	0	0
C	The Basilica	12.48103	32.80652	17	46	14	23	0
D	Captiolium	12.48062	32.80681	18	28	54	0	0
E	Scrapis Temple	12.48041	32.80702	22	61	18	0	0
F	Basilica of Justinian	12.48067	32.80739	42	17	41	0	0
G	The House of leda painting	12.48117	32.8075	59	41	0	0	0
H	Seaward Baths	12.48195	32.80757	84	16	0	0	0
I	The Antonine Temple	12.4819	32.80671	43	13	44	0	0
J	Temple of Liber Pater	12.48162	32.80706	47	29	24	0	0
K	Forum	12.48108	32.80692	20	39	42	0	0
L	Temple of Hercules	12.48409	32.80621	23	32	0	44	0
M	Christian Basilicas	12.48502	32.80689	53	16	31	0	0
N	Baths of Oceanus	12.48526	32.80718	38	0	62	0	0
O	Temple of Isis	12.48788	32.80764	59	41	0	0	0
P	Theater	12.48518	32.80527	23	64	13	0	0
Q	Curia	12.48082	32.80715	19	44	37	0	0
R	Mausoleum of Bes	12.48096	32.80516	27	44	29	0	0



Table(4): Estimations of deterioration intensities caused by different types of damages belonging to group-2 of weathering (discoloration/deposits) that effects buiding stones within Sabratha Archaeological City in accordance with (Fitzner et. al., 2002). (for numbers "1-25", please refer to table-5)

Location details				Weathering Deterioration - Group 2																						
				Discoloration / Deposits																						
				Soiling										12		13										
No.	Site	Coordinates		1	2	3	4	5	6	7	8	9	10	11	14	15	16	17	18	19	20	21	22	23	24	25
3	Byzantine Gate	12.48213	32.80544	4	1	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0	2
4	South Forum Temple	12.48148	32.80624	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0	0	0	2
5	The Basilica	12.48103	32.80632	3	1	2	0	0	0	1	0	0	0	0	0	0	1	0	0	0	2	4	0	0	0	2
6	Capitolium	12.48062	32.80681	3	1	2	0	0	0	1	0	0	0	0	0	0	1	0	0	0	3	3	0	0	0	2
7	Serapis Temple	12.48043	32.80702	2	1	2	0	0	1	0	0	0	0	0	0	0	1	0	0	0	2	3	0	0	0	2
8	Basilica of Justinian	12.48067	32.80739	2	1	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	3	0	0	0	1
9	The House of leda painting	12.48127	32.8075	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	1
10	Severan Baths	12.48199	32.80757	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	1
11	The Antonine Temple	12.4819	32.80671	3	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	3	0	0	0	1
12	Temple of Liber Pater	12.48162	32.80706	2	1	1	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	1
13	Forum	12.48108	32.80692	1	1	2	0	0	1	0	0	0	0	0	0	0	1	0	0	0	2	3	0	0	0	2
14	Temple of Hercules	12.48149	32.80621	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	0	0	0	1
15	Christian Basilicas	12.48502	32.80689	2	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	1
16	Baths of Oceanus	12.48526	32.80715	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0
17	Temple of Isis	12.48788	32.80764	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0
18	Theater	12.48518	32.80527	3	0	2	0	0	2	1	0	0	1	0	0	0	1	0	0	0	2	1	0	0	0	2
20	Curia	12.48082	32.80715	2	1	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	3	0	0	0	1
21	Mausoleum of Bes	12.48096	32.80516	3	1	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	3	0	0	0	1

Table (5): Explaining the drterioration types (from 1 to 25 that mentioned in table-4) as a part of Group-2 of weathering (discoloration/deposits) that effects buiding stones within Sabratha Archaeological City in accordance with (Fitzner et. al., 2002).

Deterioration No.	Deterioration Type
1	Coloration (Dc)
2	Bleaching (Db)
3	Soiling by particles from atmosphere (pl1)
4	Soling by particles from atmosphere (pl2)
5	Soiling by particles from water (wl)
6	Soiling by dropinigs (gl)
7	Soiling due to anthropogenic impact (al)
8	Soiling by particles from atmosphere to dark-colored crust tracing the surface (pl-dkC)
9	Soiling by particles from atmosphere to dark-colored crust changing the surface (pl-diC)
10	Efflorescence (Ee)
11	Subflorescence (Ef)
12	Dark-colored crust (d)
13	Light-coloubred crust (h)
14	Dark-colored crust tracing the surface (dkC)
15	Dark-colored crust changing the surface (diC)
16	Light-colored crust tracing the surface (hkC)
17	Light-colored crust changing the surface (hiC)
18	Colored crust tracing the surface (fkC)
19	Colored crust changing the surface (fiC)
20	Microbiological colonization (Bi)
21	Colonization by higher plants (Bh)
22	Colonization to dark-colored crust tracing the surface (Dc-dkC)
23	Colonization to colored crust tracing the surface (Dc-fkC)
24	Efflorescences to light-colored crust tracing the surface (Ee-hkC)
25	Microbiological colonization to dark-colored crust tracing the surface (Bi-dkC)

Table (6): Approximations of the linear (Lin) and progradational (Prog) deterioration indices for group-2 of weathering that effecting building stones within Sabratha Archaeological City.

Code	Sites	X-Axis	Y-Axis	Lin (Group-II)	Prog (Group-II)
A	Byzantiane Gate	12.4821	32.8054	3.2	3.4
B	South Forum Temple	12.4815	32.8062	2.1	2.2
C	The Basilica	12.481	32.8065	2.4	2.6
D	Captiolium	12.4806	32.8068	2.4	2.5
E	Serapis Temple	12.4804	32.807	2.0	2.1
F	Basilica of Justinian	12.4807	32.8074	2.0	2.2
G	The House of leda painting	12.4812	32.8075	1.4	1.5
H	Seaward Baths	12.482	32.8076	1.2	1.2
I	The Antonine Temple	12.4819	32.8067	2.0	2.2
J	Temple of Liber Pater	12.4816	32.8071	1.8	1.9
K	Forum	12.4811	32.8069	2.2	2.3
L	Temple of Hercules	12.4841	32.8062	2.7	2.9
M	Christian Basilicas	12.485	32.8069	1.8	2.0
N	Baths of Oceanus	12.4853	32.8072	2.2	2.4
O	Temple of Isis	12.4879	32.8076	1.4	1.5
P	Theater	12.4852	32.8053	1.9	2.0
Q	Curia	12.4808	32.8072	2.2	2.3
R	Mausoleum of Bes	12.481	32.8052	2.0	2.2

Table (7): Assessment of the weathering damage categories and the recognition of linear (Dl-lin) and progradational (Dl-prog) indices of group-2 of weathering (discoloration/deposits) that influence building stones within Sabratha Archaeological City in accordance with (Fitzner et. al., 2002).

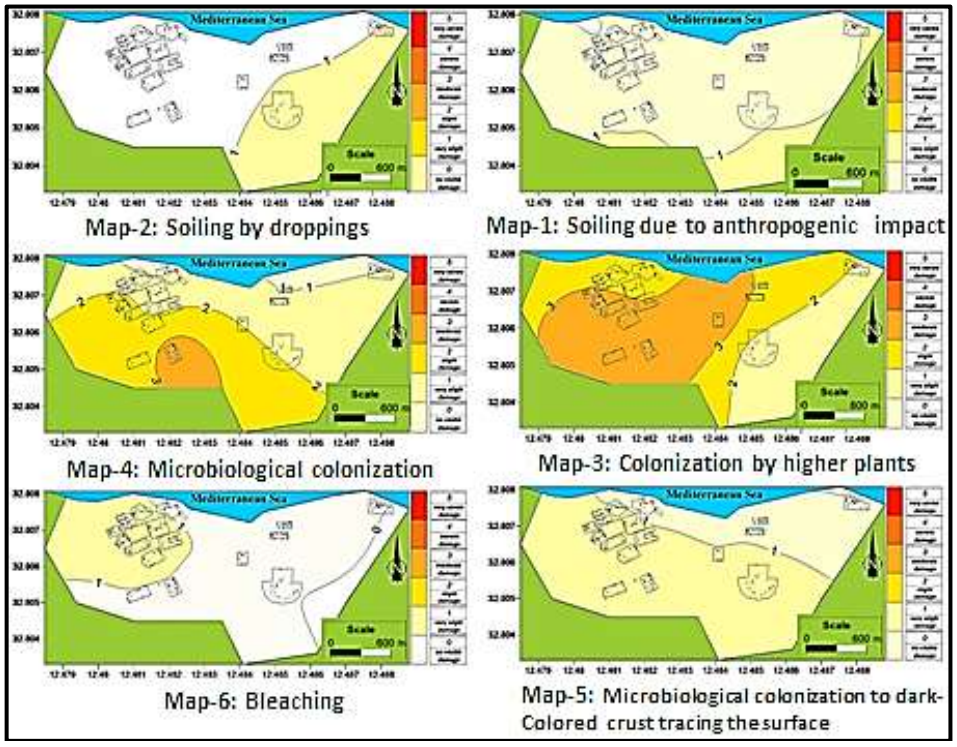


Plate (1) Contour maps showing the distribution of damage intensities of different biological and chemical individual weathering forms that influence building stones of Sabratha Archaeological City (map-1 to map-6).

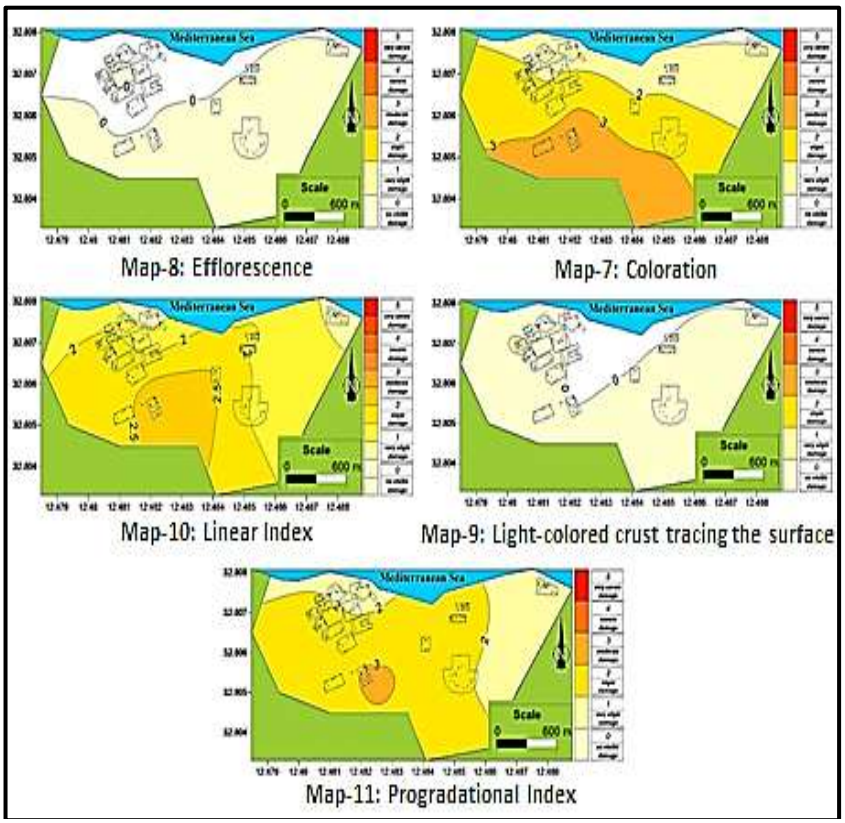


Plate (2) : Contour maps showing the distribution of damage intensities of different biological and chemical individual weathering forms that influence building stones of Sabratha Archaeological City (map-7, map-8, map-9). Maps (10 & 11) representing the distribution of damage intensities of the linear and progradational indices of group-2 of weathering (discoloration/deposits). Note: {the color and degree of damage intensities as indicated from bottom to top as follows:

white color = 0 (no visible damage), cream color = 0-1 (very-slight damage), yellow color = 1-2 (slight damage), orange color = 2-3 (moderate damage), light red color = 3-4 (sever damage), dark red color = 4-5 (very sever)}.

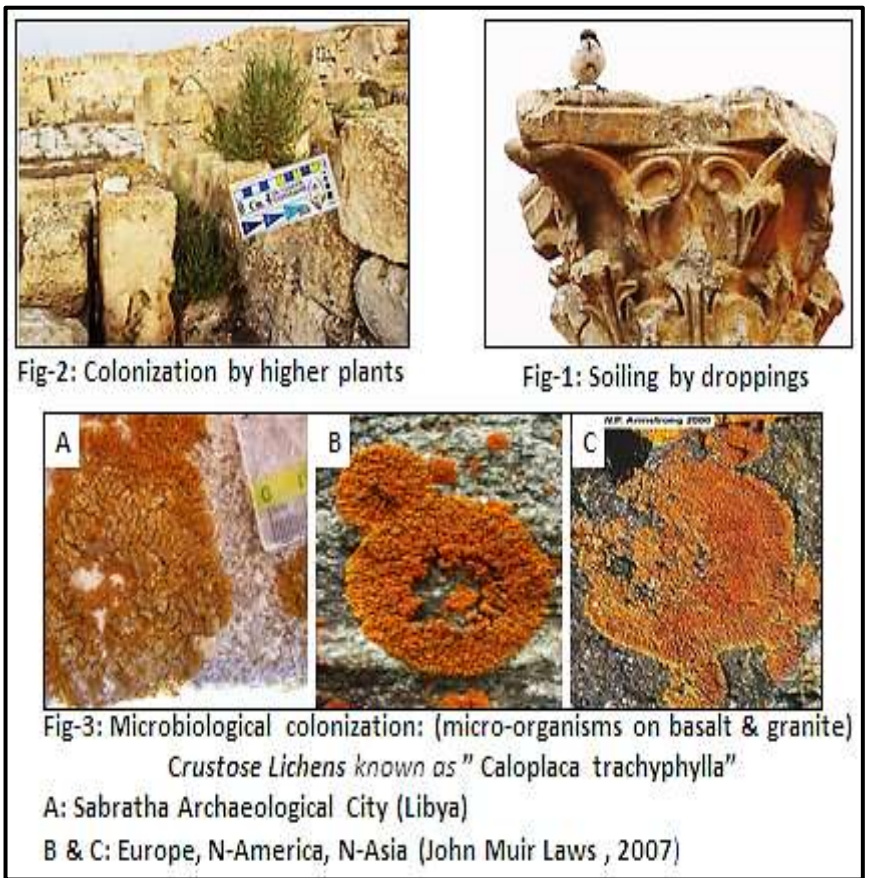


Fig-2: Colonization by higher plants

Fig-1: Soiling by droppings

Fig-3: Microbiological colonization: (micro-organisms on basalt & granite)
Crustose Lichens known as" Caloplaca trachyphylla"
A: Sabratha Archaeological City (Libya)
B & C: Europe, N-America, N-Asia (John Muir Laws , 2007)

Plate (3): Soiling and biological colonization weathering forms that effect building stones of Sabratha Archaeological City.

Fig-3B & 3C are comparable examples of nicrobiological colonization from Europe, North America and Northern Asia

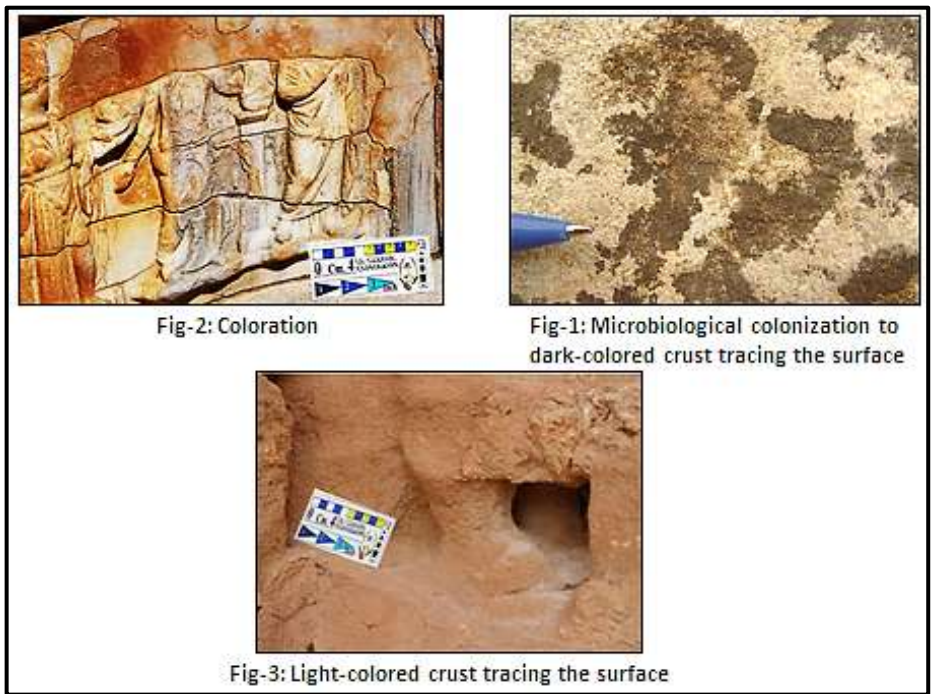


Plate (4): Biological colonization to crust, discoloration and crust weathering forms that effect building stones of Sabratha Archaeological City.

Discussion

Weathering of ancient stone buildings in Sabratha City through "soiling" was apparent in two ways: 1- "soiling due to anthropogenic impact" which was resulted by human activities and included different types of inscriptions, decorations, paintings and sculpturing that used different types of chemical materials which altered the origin color of stone buildings 2- "soiling by droppings" resulted by wastes of the different birds that colonize the City of ancient Sabratha buildings which as a result changing the color of stone surfaces and may grooving them as well due to the reaction between chemical materials that composes bird wastes and between minerals that constitutes building stones of the city.

Weathering through "Biological Colonization " was evident by tow means: 1- " Colonization by higher plants " which had a + stone or rock fractures that form the buildings. As trees or plants grown-up, walls of buildings became departed and broken. 2- " Microbiological colonization", which had a bio-chemical effect on the building stones and has taken place by the action of a variety of micro-organisms such as: bacteria, fungi, algae, lichens and biofilms. These micro-organisms secrete weak acids which could dissolve and destroy minerals that constitute the building stones (Roger D. Finlay et. al., 2019, Jie Chen et. al., 2000). Weathering through "Biological Colonization to Crust" is observed to have a biological effect through an individual weathering form known as "Microbiological colonization to dark-colored crust tracing the surface".

It is a transitional form between biological colonization and crust and takes place when humidity missing from the environment where micro-organisms lived (in this case walls of buildings are the environment). During summer and due to high temperatures, walls became dry and black remnants left over wall surfaces which may harm the building (its known that, humidity considered to be the main source for micro-organisms to extract their diet from rock material. If humidity missed, they will no longer survive). Another weathering form that was notable during field investigations within Sabratha archaeological City is the "Discoloration" or "Staining" that worked out through tow (2) individual weathering forms known as "Bleaching" and "Coloration". Bleaching is the process by which the original color of building stones is washed out or leached and as a result minerals that compose rock stones become weathered by chemical means (ex: reduction of iron and manganese compounds). While coloration is the process by which the external surfaces of ancient buildings become colored, either through chemical weathering of rock minerals that form the buildings (ex: oxidation of iron and manganese compounds) or through staining by biogenic pigments and other coloring materials coming from surrounding medium (Siegesmund, S. et.al. 2019). Deposition of less

consolidated salt clusters **(**designated as "weathering by loose salt deposits") as well as deposition of highly consolidated crusts (designated as "weathering by crust") on stone surfaces are two additional weathering forms that observed to effect buildings of Ancient Sabratha City by chemical means. Efflorescence phenomenon (belonging to the first weathering form) which is the deposition of loose salt clusters on building stone surfaces or within pore spaces of the stones have been found to affect Sabratha monuments. The source of salts is thought to be come from limestone rock blocks that used in construction or come as a result of chemical decay processes of rock blocks when come in contact with contaminated atmosphere. The growth of these salt crystals will damage the framework of the building stones slowly until become demolished. Salts have long been known to damage porous materials, mainly through the production of physical stress resulting from the crystallization of salts in pores. Salts can also damage stone through a range of other mechanisms, such as differential thermal expansion,osmotic swelling of clays, and enhanced wet/dry cycling due to deliquescent salts (Rothert, E. et. al., 2007, Siegesmund. et.al., 2019). The combined effect of physical degradation by lichen hyphae penetrating in a rock and chemical attack by organic acid with associated growth of inorganic salts leads to accelerated weathering. Different types of weathering discolorations associated with fungal and bacterial activities were observed to yield extensive corrosion and dissolution of mineral surfaces beneath them (Siegesmund, S. et.al. 2019). Basically all types of building materials are colonizable by microorganisms. Often, surfaces are covered with a rigid layer composed of microbial cells and extracellular biofilm. Bio-deterioration of building material is determined by the metabolic activities of the cells as well as the impact of the extracellular biofilm (Roger D. Finlay et. al., 2019). Deposition of Light-colored crust tracing the surface of building stones of Sabratha monuments (belonging to the second weathering form) has worked through the deposition of light-colored and massive mineral crusts as a result of

precipitation processes by rain.The overall rating of weathering damages of the archaeological buildings and monuments can be delineated by the estimation of the linear and progradational damage indices. According to (Fitzner et. al., 2002, and 2004), the damage indices range between 0 and 5.0. (0: no visible damage), (0-1: very slight damage), (1-2: slight damage), (2-3: moderate damage), (3–4: severe damage), (4-5: very severe damage).

The linear damage index corresponds to the average damage category, whereas the progradational damage index emphasizes the proportion of higher damage categories (Heinrichs . & Fitzner 1999 and Fitzner et. al., 2000). Linear and progressive damage indices in Sabratha archaeological City is varied from (non-visible to moderate "from 0 to 3") and from slight to moderate "from 2 to 3") respectively, which alerts to the necessity and urgency of remediation and restoration intervention, in order to protect the archaeological buildings of Sabratha City.

Conclusions

According to the chemical and biological weathering factors that led to the deterioration of building stones of Sabratha archaeological City and based on the previous discussion, we conclude the following: It has been found six (6) main and nine (9) individual weathering forms were found to deteriorate the building stones of the Ancient City of Sabratha somehow chemically, biochemically and biologically.

These were known as: a) Soiling, which involved two individual weathering forms specifically: "soiling due to anthropogenic impact" and "soiling by droppings", b) Biological colonization, which involved two individual weathering forms specifically: "colonization by higher plants" and " Microbiological colonization" c) Biological colonization to crust, which acted through an individual weathering form designated as "microbiological colonization to dark-colored crust tracing the surface". d) Discoloration or "Staining", which performed through two individual weathering forms namely: "bleaching" and

"coloration". e) Loose salt deposits, which performed through an individual weathering form namely: "efflorescence". f) Crust, which acted through "light-colored crust tracing the surface" individual weathering form. The damage degree of these weathered forms varied from non-visible to moderate with degree of distribution varied from very-limited to widespread.

The linear and progradational weathering indices of this group of weathering showed varied degrees of damage, which was from non-visible to moderate with increasing effect away from sea coast and were widespread in such case alarming to the necessity of building stone remediation and restitutions of the archaeological City of Sabratha.

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