Impact of coastal environmental conditions on building materials of The Roman Theater at the archaeological site of Sabratha, Libya.

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Abstract:

Sabratha's port was established, perhaps about 500 BC, as a Phoenican trading-post that served as a coastal outlet for the products of the African hinterland.The Phoenicians gave it the Lybico-Berber name 'Sbrt'n. Sabratha became part of the short-lived Numidian Kingdom of Massinissa before being Romanized and rebuilt in the 2nd and 3rd centuries AD. The Emperor Septimus Severus was born nearby in Lebtis Magna, and Sabratha reached its monumental peak during the rule of the Severus. The city was badly damaged by earthquakes during the 4th century, particularly the quake of AD 365. It was rebuilt on a more modest scale by governors. Besides its magnificent late 3rd century theatre that retains its three-storey architectural backdrop 'The Roman theater at Sabratha in Libya is today one of the most impressive Roman monuments in North Africa. The Sabratha Theater is distinctive for its sculptured pulpit, which is decorated with a variety of mythological, historical, and genre scenes. A UNESCO placed the site in its "World Heritage List" The research aim to study the material building which used in the theatre such as limestone's, marbles and mortars, and effects of coastal environmental conditions which collapsing, disintegration and damage it by using analysis, investigations and materials tests such as XRD, XRF, PM, and SEM to identification of elements and minerals composition and its alteration. Physio-mechanical properties of building materials was also evaluated

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INTRODUCTION:

Sabratha is a city port located on the mediterranean coast of Libya. Together with Oea and Leptis Magna, these cities formed the so-called Tripolitania (three cities). The archaeological site is located 1.5 km away from the modern city and it has typically Roman characteristics, including the regular provision decumanus and cardus, the presence of a forum with some temples and other monuments. The theatre is located east of the monumental area (fig.1) and it dates in principle between the second and third century. A.D, therefore originating from the Severian period. The Roman theatre of Sabratha, built in the II c. AD, was rebuilt in the years between 1930-1940 at the command of the Italian governor of Libya, Italo Balbo, and was a sign of the past Roman Empire. The project was handled by two Italian archaeologists Caputo and Guidi. The photogrammetric survey was performed in August 2009, but in other projects the found accuracy is in the order of 1/1000 the object distance, say one centimeter every ten meters of distance from the object. can even be done with simple and low-cost instruments in a quick Manner .and a geometrical survey, the

Fig. (1) The Roman Theater and the other archaeological sites in Sabratha and the remains of the Roman town stretch along the sea shoreSea level changes for the Mediterranean region along the coasts of northern Africa.

building has a maximum diameter of 92.60 m, and consider the largest in Libya and with a capacity of 5000 spectators, built in limestone with a backdrop of 108 Corinthian columns, and a series of superb marble reliefs adorning the front of the stage.[1], many extravagant monuments were erected by Emperor Commodus. The Temples of Liber Pater, Hercules, Serpais, and Isis, the Basilica of Justinian, the Capitolium, and Mosaics of the House of Jason Magnus are some of these notable, sacred monuments that remain, despite the religious disputes of the 4th century B.C. and the earthquake of 365 B.C., which ultimately led to the city's downfall. Being located approximately 50 miles outside of Tripoli [2] sandwiched between two earthquakes – was unmistakably Roman. After the first earthquake. In the 1st century AD, the city's architects turned towards Rome for inspiration, resulting in the Roman character so strongly evident today.(fig.2).

Fig. (2) The Roman Theater and the other archaeological sites in Sabratha.

[1]Cecilia Pisa,Fabiana Zeppa,and Gabriele Fangi: Polytechnic University Marche, Ancona, Italy Sabratha, Libya North african Horizons -day escorted tour departing November, 2012,38, .p 7.

[2] Raabe, Ashleigh W. M.A.:Astudy of the theater reliefs Imagining Roman-ness at Sabratha by The University of North Carolina at Chapel Hill , 2007, 118 p.1442306

The Italian restoration

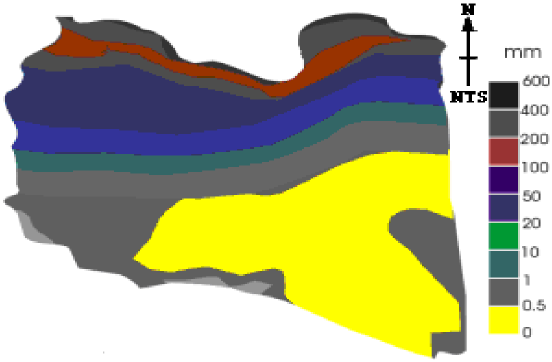
After an excavation lasting 4 years and cataloging work of over two years, the colossal undertaking restoration was ordered by the Governor of Libya, Italo Balbo, in the 1930s. It was begun by Giacomo Guidi and completed by Giacomo Caputo in 1936, with the requirement to make the theater again suitable for public ceremonies and events, as was the political will of the Italian government. The restoration was based on archaeological reconstruction of certain elements, which are provided by the monument itself, and also by making extensive use of the mounting method. In this case the old structures are embedded into the new ones for a more light reading and storage, providing additions to the work. One keeps not only the "where and how it was", but also lets the observer compulsorily recognize at first glance the use of new material, limited to the indispensable response to architectural features. This is the first example of a philological restoration**.**

preservation of the columns of the scene. The mentioned restoration technique thus allowed the analysis and classification of restored shares properly distinguished from the originals ones, whose employment is in most cases arbitrary, especially the walls of the north side of the monument. The missing original bricks (45x45 cm in size), during the restoration were replaced by other blocks whose size is exactly half of the original one. In addition to other elements, where the distinction between new and old material could not be made immediately, a recognizable symbol was made, making the distinction possible. The same is true for the front stage, usually spectacular architectural setting fixed 22.75 m high, almost completely rebuilt and considered unique to the different theaters throughout the Roman world in which the scenes are collapsed or disappeared for centuries (Guidi, 1935, Caputo, 1959).(fig.4-8).

Climate

The climate is mostly dry and desert-like in nature. This is a southern wind blowing the climate in Libya is greatly influenced by the desert to the south and the Mediterranean Sea to the north. In

Fig. (3) Yearly average rain fall in Libya



the winter the northern areas and the mountain peaks to the south can be fairly cold. During summer it is generally, the coastal areas are refreshing with temperatures of between 25°C and 27°C. This is a hot, very dry, sand-laden wind that can rise the temperatures in a

Table (1) shows weather averages in Tripoli

Month	Average Sunlight (Hours)	Temperature Average Record Min Max Min Max	Discomfort From Heat and Humidity	Relative Humidity Am pm	Average Precipitation (mm)	Wet Days (+0 25 mm)
Jan	5	8 16 1 28	-	68 59	81	11
Feb	6	9 17 3 33	-	71 60	46	7
March	6	11 19 4 38	-	65 57	28	5
April	7	14 22 6 41	-	62 57	10	2
May	8	16 24 6 43	Moderate	58 62	5	3
June	10	19 27 10 44	Medium	57 70	3	1
July	11	22 29 16 46	High	54 72	0	0.2
Aug	11	22 30 17 44	High	72 69	0	0.3
Sept	8	22 29 15 45	Medium	67 67	10	2
Oct	7	18 27 10 41	Medium	65 59	41	5
Nov	5	14 23 6 36	-	66 53	66	7
Dec	5	9 18 1 30	-	65 55	94	11

matter of hours to between 40°C and 45°C. temperature in the Libyan desert can be extreme; , recorded an air temperature of 57.8

°C (136.0 °F), generally accepted as the highest recorded naturally occurring air temperature reached on Earth[3] .There are sand dunes throughout Tripolitania; From the interior of the African continent come the red (Heix) sands, composed mainly of very fine quartz granules. But there are also the sea sands, white, with rounded, rough textured and more calcareous grains, less able to retain water than the continental sands. Sea winds, blowing mainly from the northeast, form vast seashore dunes along the entire coastline, winter rainfalls ranging from 200 to 400 Mm/yr with moderate temperatures and high relative humidity.(fig.3-table1).

Groundwater :

Groundwater aquifers are either renewable or non-renewable. The renewable aquifers are those located in the northern zones and fall within areas under high precipitation rates. They range in age from Quaternary to Cretaceous and contribute more than 2,400 million m3 per year against an annual recharge of less than 6.5 million meter cube per year. This imbalance has provoked a continuous lowering of groundwater levels accompanied by deterioration in water quality due to seawater intrusion and invasion of saline water from adjacent aquifers (Salem, 2005).

Sea – level lowering:

Along the along the coasts of Tunisia and western Libya (4 sites between Sabratha and Leptis Magna), Anzidei et al.(2010b) analyzed Punic and Roman age archeological remains. Pools, harbors,quarries, the markers that provided information on the altitude of the sea-level during the last 2 ka in these African coastal sectors. Using a eustatic change of 13 cm during the last 2 ka

[3] ADEL MOHAMED ZIDANTHE: IMPACT OF THE GREAT MAN MADE RIVER PROJECT ON UNIVERSITI TEKNOLOGI MALAYSILIBYA'S AGRICULTURAL ACTIVITIES AND THE ENVIRONMENTA project report submitted in partial fulfillment of the requirements for the award of the degree of Master of Science (Planning-Resource and Environmental Management ,FACULTY OF BUILT ENVIRONMENT UNIVERSITI TEKNOLOGI MALAYSIA, APRIL 2007.

(Lambeck et al. 2004b), They found that in Tunisia and Libya, the glacio-hydro-isostatic contribution is about 75% less than in the central and northern Mediterranean ,According to Anzidei at al. (2010b), results indicate that, along the coast of Tunisia and Libya,

local relative sea level has increased of 0.2-0.5 m since the last 2 ka.

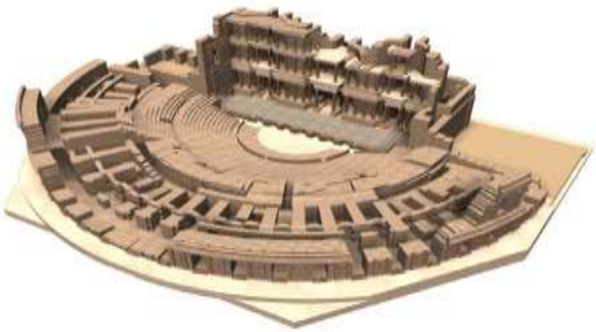


Fig. (6)
Sabratha, the textured model of the theatre (by C.Pisa 2009). obtained from photogram metric evaluation.

Besides minor vertical tectonic movements of Location of sites within the mediterranean prone to earthquakes and volcanic activity (Greece, Italy, Turkey).The hazards, damage to property and natural environments).

. At the moment, very promising proxies seem to be: archeological remains, vermetids, Lithophyllum lichenoides and Balanus sp., foraminifera, testate amoebae and diatoms as well as speleothems.

Data are based on precise measures of presently submerged archaeological markers that are good indicators of past sea-level elevation. Earthquake distribution outlines the current dynamics of the region, besides archaeological markers, in one case biological indicators such as *Strombus bubonius* and *Lithophaga* were used This value is in agreement with the observation performed by Bartoccini in 1958.(fig.4-6).

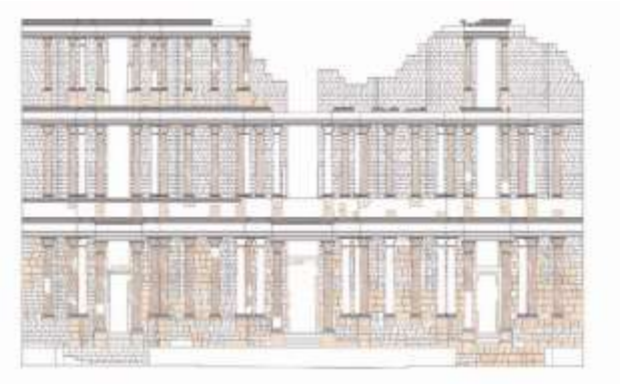


Fig. (7) The columniation of the front (by C.Pisa 2009). The original blocks and columns (in white) are distinguished from the new ones.

Fig. (8) The columniation of the Theater front the original and the new one

Effect of tectonic movements on the coast of the theater:

Gaston Johndi chief architect of the interests of ports and lighthouses studies to expand the port and improve the west, he discovered the jetties of the entire north-west of Ras El-teen, a completely submerged with sea water at depths of no more than a few most of eight and a half meters, and continued his research from 1910 until 1915 . And took the discovery of a witness to the existence of the port is the oldest of Alexandria built by Alexander the east of this place, evidence of the decline in the Earth's crust and the loss of the port under the sea, many natural disasters such as the tyranny of the sea on the coast of the city in 365 AD, which flooded part of the coastline including attic buildings by the earthquake in 956 and followed 1303 A.C., , which led to the collapse of many of the features of the city's famous Pharos lighthouse, particularly

Located effects sunken in front of the coast between Alexandria and Abu Qir at depths ranging from 5.8 meters below the sea surface which is greater depths than are attributed only to the high cosmic to the surface of the sea due to rising temperature (which up to 1.5 cm every 100 years), but to fall in the Earth's crust in front of the Delta , and the main reasons are the change in weather and geologic events that result of decrease or increase the Earth's crust due to tectonic and volcanic factors and fall of the Earth's crust
Result of the accumulation of silt on the coasts of continents and the Delta and rivers[4] has been interpreted by Jean-Yves Embraer that these blocks from the remains of ancient Alexandria lighthouse, and the last remnants of the lighthouse is the first floor of the castle which was destroyed by earthquake in the 14th century[5]

Fig. (9) Erosion of limestone by weathering are the principle factor of honeycomb and damage of limestone

Fig. (10) Deterioration and disintegration of unsuitable mortars .

[4]D / Abdul Fattah Ghonema , D / Hussein al-Sheikh, and Hazem Abochleb: Alexandria, splendor and tender time, place, human, regional body to stimulate tourism, the province of Alexandria, 2001, pp. 348-352.
[5] Henri Riad , Youssef Hanna Shehata, Youssef El-Gheriani , Revised by Dr. Daoud Abdo Daoud : Alexandria , An archelogical guide the city , second edition , revised by Youssef El-Gheriani , 1996, p.10-18.
Ahmed Abdel-Fattah: the effects of the sunken ancient Alexandria, an article in Arabic, in Alexandria throughout the ages, the regional body to stimulate tourism, the province of Alexandria, Al-Ahram Commercial Press - Qalyoub - Egypt 1999, pp. 217-222.

Deterioration and Manifestations of Theater:(fig.9-17)

Deterioration of historical monuments is the result of chemical reactions of polluted air, soil and water with the stone material. Into powder and the object gradually loses its mechanical strength and artistic form. These processes have been observed on all unique ancient monuments of Libya,[6] and observed on theater as follow:

- The spread of gardens around the stage for improving the ancient panorama, , but the network of water and increased water leakage as a result of Irrigation gardens lead to the loosening foundations under the walls of the buildings of the theater as a result of melting the bonding material limestone, And the movement of salt from one place to another.

Fig. (11) growth of plants

Fig. (12) Spallation of marble decoration slabs

- Notes the presence of longitudinal cracks in many of the blocks of the theater stone buildings, may attribute the result of movements or foundation faulty.
- Blackening many places damage as a result of Microbiology and fungi to attack the limestone, as a result of the increase in air humidity.

[6] Eleni Papanikolaou ,Panagiotis Spathis, Vassilios Melfos Basile and Christaras Semeli Pingiatoglou: PRELIMINARY OBSERVATIONS ON THE BUILDING MATERIALS AND THE DETERIORATION PROBLEMS OF THE MONUMENTS OF DEMETER AND ASKLEPIOS SANCTUARIES IN THE ARCHAEOLOGICAL SITE OF DION,in 8th International Symposium on the Conservation of Monuments in the Mediterranean Basin, Patras 2010.

- Crystallization of salts on the roofs of limestone.
- Biological damage due to rainfall on the upper parts of buildings.
- Erosion in the lower parts of the building.
- The separation of parts of the mortar used to repair and bind building blocks of stone.
- Longitudinal cracks due to increased loads on the blocks as a result shattered blocks of stone as a result of the separation of mortar Association building blocks.
- The growth of plants in the foundations of the buildings of the theater and in the ground.
- Leaching components of soluble blocks of stone.
- Loss marble streaks and marble tiles and marble motifs result of different expansion and contraction and the different thermal properties.

Fig. (13) The celebrated frieze of the stage and its plotting, performed in monoplotting mode over a cylindrical surface)

Fig. (14) extension of the archaeological ruins to the sea shore.

Crushed marble floors imbalance as a result of incorporation with the soil and cutting of borders to the broken slabs of marble and places a particular focus.

- Mortar damages the lining of the plaster and the presence of different cracks.

Fig. (15) biodeterioration of limestone

Fig. (16) biodeterioration of plasters.

- Overlap in the sea areas around the ancient Roman Theater and the extension of effects into the sea and its presence under water.
- Erosion of marble and the separation of salts and granules as a result of thermal expansion.
- Accumulation of blocks around the theater and the remains of the crowns.
- Longitudinal cracks in the upper parts of building.
- Formation of decorations and ornaments architectural homogeneity of the old mortar between the columns block of stone columns.
- Erosion of the components is soluble in marble.
- The spread of fungal colonies of black and brown and yellow on the Mortars and blocks.

- Loss Mortars used in the restoration and updating and linking open places, gaps and holes.
- Circular openings in the appearance of blocks of different diameters attributed to the role of insect and work it as a nest within them.

Fig. (17) deteriorated of plasters

- The spread of shrubs within the blocks scattered around the theater, which distorts the panoramic view.
- The presence of an iron fence around the theater, which must be re-developed and planned around the area's historical center.
- Loss of sculptural details of the statues in the theater.
- Accumulation of some sand on the blocks around the theater.

Materials and Methods

X-Ray diffraction analysis

The samples of limestone, marble and mortar were collected from building materials which used in the construction of the theater , and lime mortar which bonds the courses of building materials , and to identify the minerals components, to explain the mechanisms of damage and its manifestations, and the analysis results has shown in the tables (2) and(fig. 18-23).

X-ray fluorescence Analysis

The samples were collected from the building materials of marble, limestone and mortar, and link layers of lime in order to identify the

Table (2) shows the mineral composition of samples collected from the theater buildings by XRD analysis method

NO	Kind of samples	Location	Identified of Minerals
١	Limestone	North of theater	Calcite $CaCO_2$ Quartz SiO_2 Halite NaCl Gypsum $CaSO_4.2H_2O$ Forstrite Mg_2SiO_4 Kaolinite $Al_2Si_2O_5(OH)_4$
٢	limestone	The gate of the theater	Calcite $CaCO_2$ Quartz SiO_2 Halite NaCl Gypsum $CaSO_4.2H_2O$ Fledspar $KAlSi_3O_8$
٣	Mortar of limestone		Calcite $CaCO_2$ Dolomite $CaMg(CO_3)_2$ Quartz SiO_2 Halite NaCl Gypsum $CaSO_4.2H_2O$ Kaolinite $Al_2Si_2O_5(OH)_4$
٤	Gray marble	Marble decoration	Calcite $CaCO_2$ Dolomite $CaMg(CO_3)_2$ Hematite Fe_2O_3 Gypsum $CaSO_4.2H_2O$
٥	White marble	The theater stage	Calcite $CaCO_2$ Dolomite $CaMg(CO_3)_2$ Quartz SiO_2 Forsterite Mg_2SiO_4 Halite NaCl Hematite Fe_2O_3
٦	Mortar of marble		Calcite $CaCO_2$ Quartz SiO_2 Halite NaCl Gypsum $CaSO_4.2H_2O$

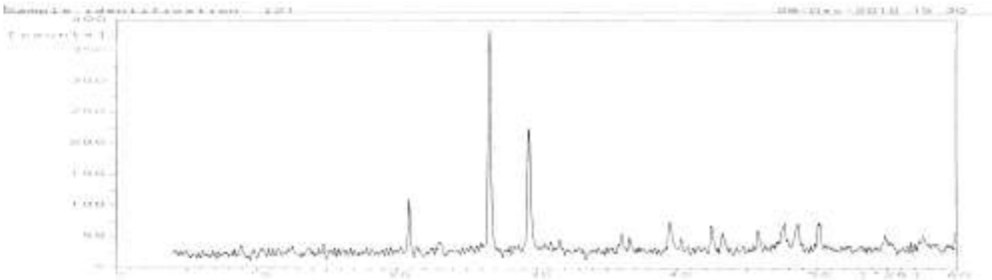


Fig.(18) XRD pattern of limestone Sample, used in the north of the theater .

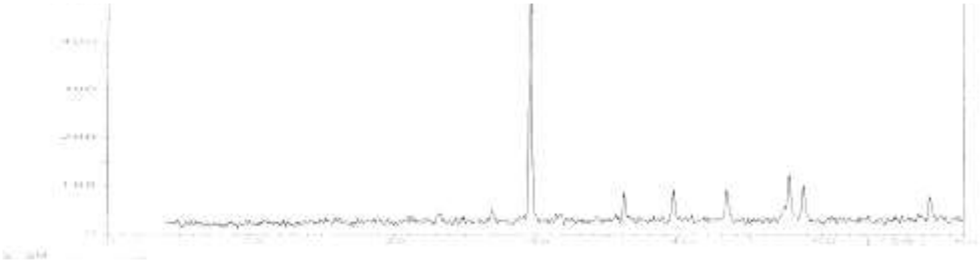


Fig.(19) XRD pattern of limestone Sample, used in the gate of theater .

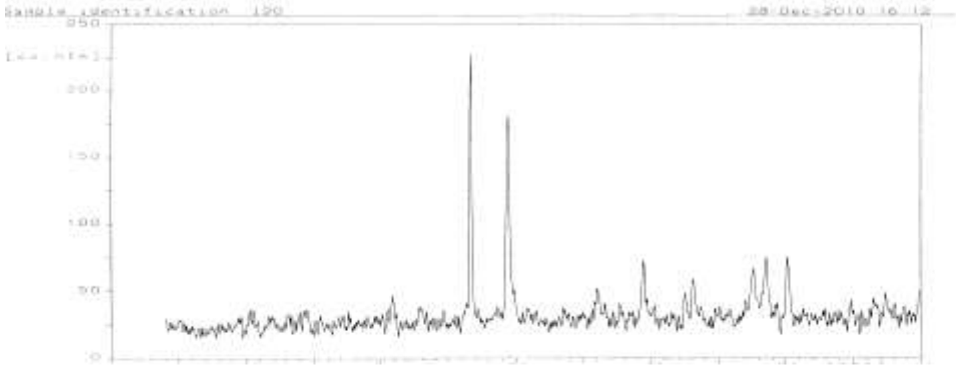


Fig.(20) XRD pattern of mortar of limestone , used in the theater .

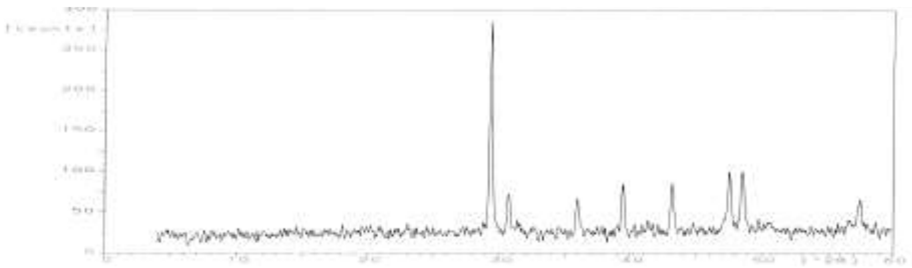


Fig.(21) XRD pattern of Gray marble in decoration , of the theater .

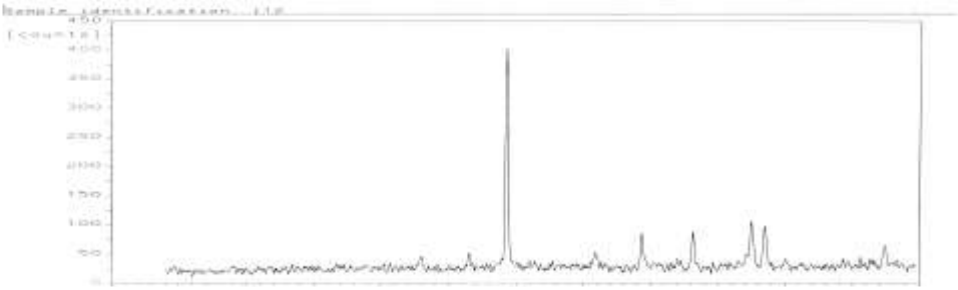


Fig.(22) XRD pattern of white marble , used in stage of the theater .

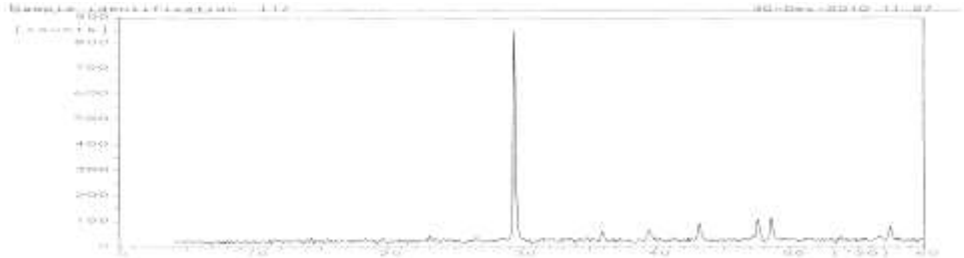
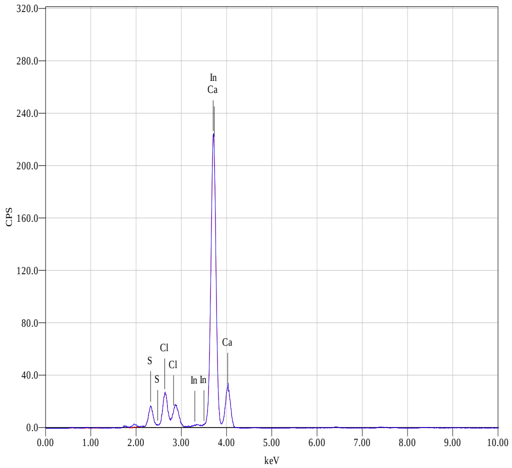


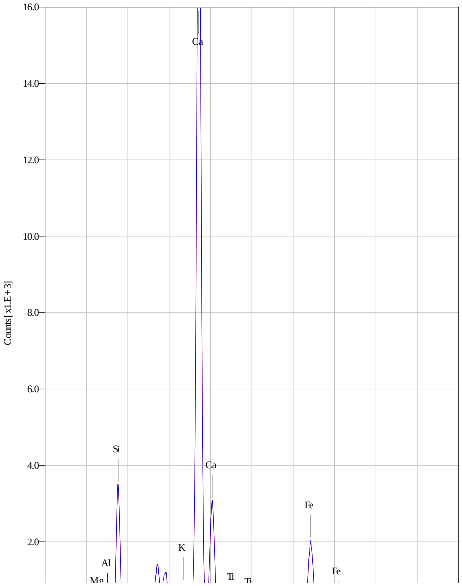
Fig.(23) XRD pattern of mortar of marble , used in the theater .

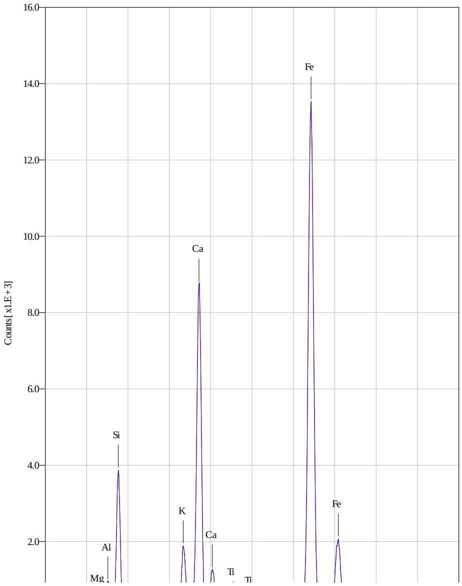
elements constituent, and the interpretation of damage mechanisms and shown in tables (3-4) .



Element	Line Type	Energy	ms%	mol%	K	Net	Error%
SO_3	K	2.31	3.9429	2.7662	0.0123661	5468	0.0699
Cl	K	2.62	3.8889	6.1612	0.0283380	9658	0.0691
CaO	K	3.69	90.6142	90.7582	0.3121657	89563	0.1528
In_2O_3	L	3.29	1.5541	0.3144	0.0111517	1014	0.3529

Table (3) XRF analysis of limestone sample taken from the gate of the theater.





Element	Line Type	Energy	ms%	mol%	K	Net	Error%
Mg	K	1.25	1.0891	1.6991	0.0005322	476	1.7510
Al	K	1.49	3.7981	5.3392	0.0027913	5345	0.2272
Si	K	1.74	11.6579	15.7439	0.0108449	38767	0.2165
K	K	3.31	2.6888	2.6082	0.0035652	12319	0.1423
Ca	K	3.69	73.6066	69.6581	0.0748370	308276	0.1505
Ti	K	4.51	0.7888	0.6246	0.0003724	2006	0.1875
Fe	K	6.40	6.3708	4.3269	0.0047146	35005	0.1058

Table (4) XRF analysis of marble sample taken from the stage of the theater.

The polarized microscope examinations:

Samples taken from marble and limestone rock was making a thin-sections and examined under normal light and polarized to identify the mineral composition and petrography structure study, for minerals' consistent of rocky sections as shown in fig (24-31).

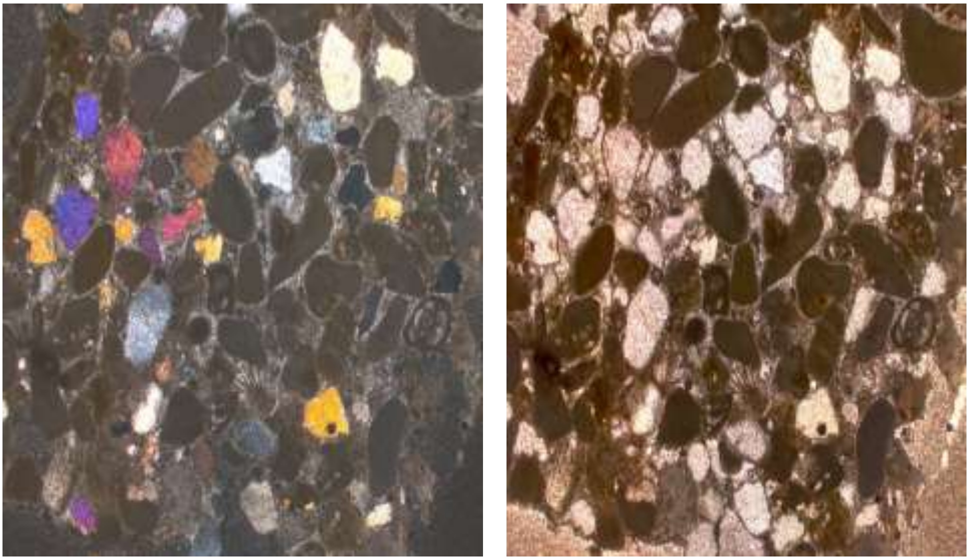


Fig.(24) P.m. view of limestone sample consists of Calcite ,Quartz , Miliolidae sp.and OstracodaX ,Quaternary Quinqueleoculina chell fragment 40X. And the same sample under ordinary light.

Fig.(25) P.m. view of limestone Spherical Quartz grains , Calcite , microcline, shell fragment and high porosity before compaction X40

Fig.(26) Oolitic grainstone Quartz , grain Calcite ,spary calcite structure peloids , structure less peloids, Superficial Ooides Composite Ooides ,and shell fragments.

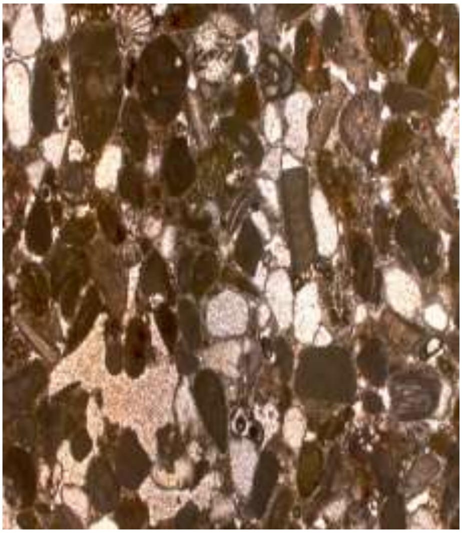


Fig.(27). P.m. view of limestone sample consists ofspary Calcite ,Quartz , Miliolidae sp.and OstracodaX ,Quaternary Quinqueleoculina chell fragment and ooides

Fig.(28) P.M. view of white marble contains Calcite , Dolomite and Quartz.

Fig.(29) P.M. view of white Calcite (two sets of cleavages ,Dolomite ,and Quartz

Fig.(28) P.M. view of white marble contains Calcite , Dolomite and Quartz.

Fig.(29) P.M. view of white Calcite (two sets of cleavages ,Dolomite ,and Quartz

Fig.(30) P.M. view of gray marble remains of class Malacostraca subphylum crustacea phylum Arthrapoda Balanus sp. , vermetids, and Lithophyllum

Fig.(31) P.M. view of gray marble remains, vermetids ,Gastropod shells, *Lithophyllum, foraminifera*

Scann examination:

Examined samples of marble and limestone by electron microscope scanner under different enlargements, to identification the inner structure of granules and crystals [7]

, and the impact of structure factors, damage different, and the mutual interactions between the chemical components of internal and external, and its impact on the different characteristics of marble and limestone, as shown in the fig (32-41).

7Safaa ABD EL SALAM :Studia Universitatis Babeş-Bolyai, Geologia, Special Issue, MAEGS Wall paintings from the 2nd Century A.D. in Sabratha: an optical, microchemical and chemical study,(Libya), 2009,p.16.

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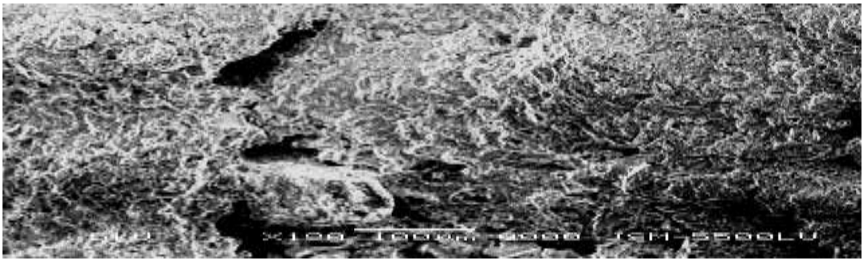


Fig. (32) SEM show Quartz and Calcite binding the grains which attack by weathering

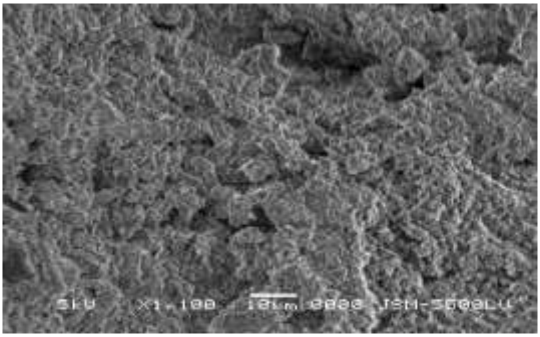
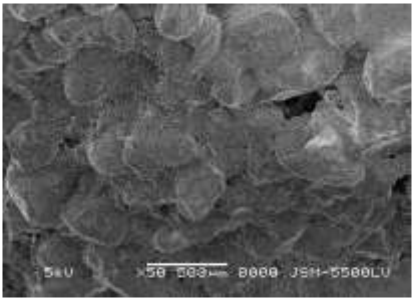


Fig . (33) Calcite as binding materials and Quartz as fillers after carbonation process occurred .



- Fig. (34) Calcite as binding material in the Lime mortar after carbonation process occurred .

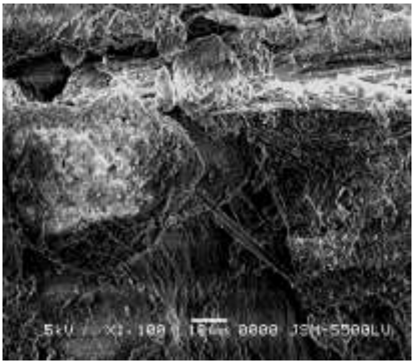


Fig. (35) crystallization of salts (Halite and Gypsum) in limestone.

Fig. (36) crystallization of Halite and Gypsum which caused disintegration of the lime mortar

Fig. (37) Quartz as filler material in the lime mortar embedded in Calcite as binding material after carbonation process of the slacked lime

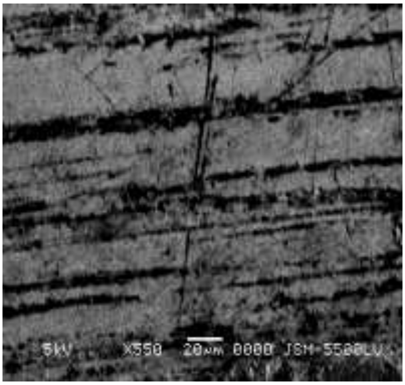


Fig. (38) laminated marble shows Calcite and Graphite.

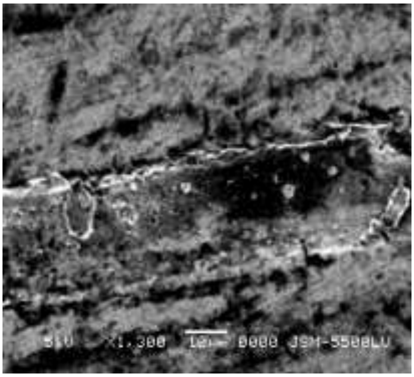


Fig.(39) cracks in gray marble in the weak zone (laminated connections layers) by natural weathering .

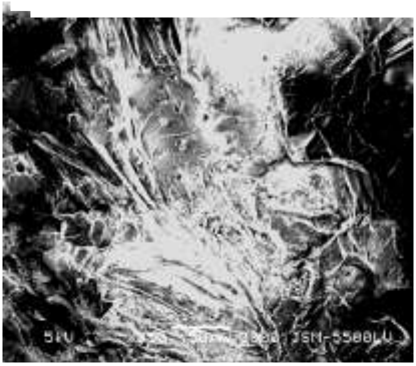


Fig.(40) Calcite and Halite crystals in marble

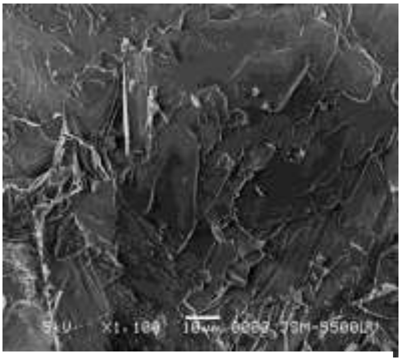


Fig. (41) Calcite and Halite crystals.

Stereomicroscope examination:

The stereo microscope is an optical microscope variant designed for low magnification observation to produces a three-dimensional visualization of the sample being examined Stereomicroscopy overlaps macro photography for recording and examining solid

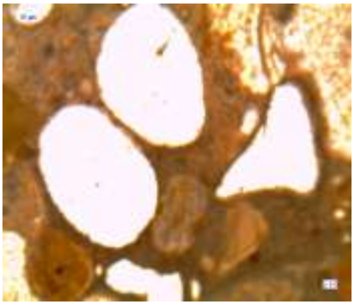


Fig. (42) Stereomicroscope view shown limestone sample Calcite and spherical Quartz crystals.

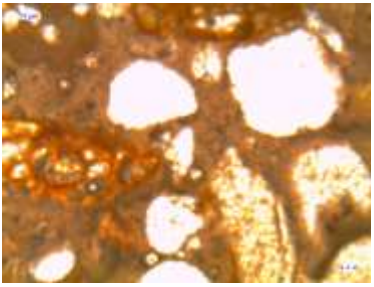


Fig. (43) Stereomicroscope view limestone sample shown Calcite and Quartz crystals.

samples with complex surface topography, and essential for analyzing the detail, study the surfaces of solid specimens or to carry out close work such as dissection, manufacture or inspection, and fracture surfaces as in fractography.Examined samples of the materials used in the theater, such as marble and limestone, to identify the appearance of metal components and the inner structure and the extent of vocabulary influenced by the surrounding environment, as shown in the fig (42-47).

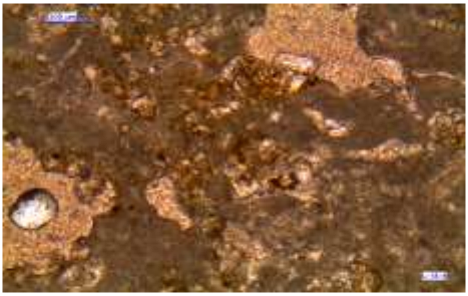


Fig. (44) Stereomicroscope view shown of marble sample Calcite and erosion of surface .

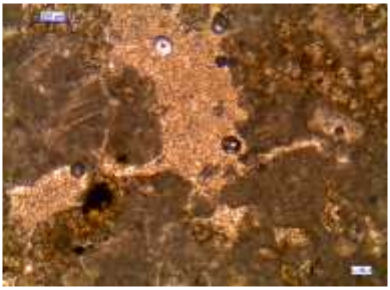


Fig. (45) Stereomicroscope view shown of marble sample Calcite and Quartz crystals.

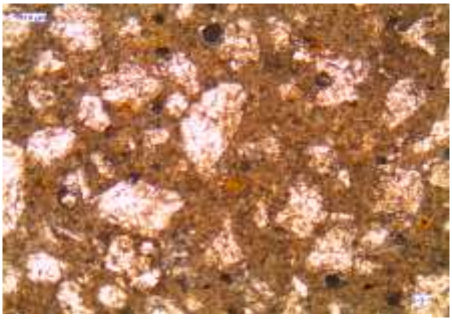


Fig. (46) Stereomicroscope view shown of mortar sample sperical Quartz crystal.

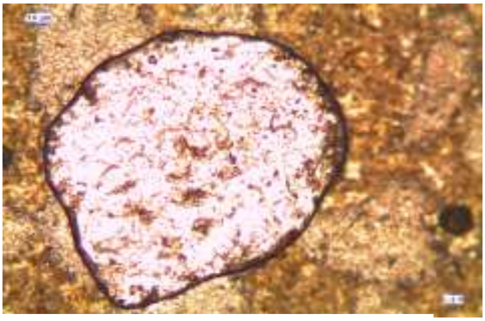


Fig. (47) Stereomicroscope view shown of mortar sample spary Calcite as bind material and Quartz crystals.

Determinations of Physical and Mechanical properties of limestone and Mortar of theater in sabratha

The physical (porosity, density, and water absorption) and mechanical properties (Compressive strength) of the limestone and lime mortar weathered samples determined (table 5).

Table (5) shows the physio-mechanical properties of weathered limestone and lime mortar from The Theater .

Type of sample	**Density** Gm/cm3	**Porosity %**	**Water Absorption** %	**Compressive strength** km/cm2
Limestone	1.67	30.5	19.7	56
Mortar Lime	1.34	24.9	21.3	32

Results and discussions:

Environment condition:

The results of table (1), which shows the temperature and humidity of the surrounding area of Tripoli and the theater where it was found through the average humidity throughout the year, equal to 64.16% am, through low-grade and was 54% in July and the major 72% in August, and during low-grade in November was 53% and the degree to major in July was 72%, show that the average length of the year, the amount ranges from 61.66% Pm, leading to an increase in relative humidity and the temperatures throughout the year, a small amount of 8 in January and the largest amount of 22° C during the months of July, August and September at an average rate of 15.33 ° C, and through the minimum temperature in January in the amount of 16 ° C, and the major figures were 30 ° C in August, with an average of 23.41° C throughout the year, so the temperature and humidity on two occasions for the growth of microorganisms, especially fungi and bacteria and the formation of colonies on the limestone.

And the average hours of sunlight during the day throughout the year about 7.41, which helps to assist in the crystallization of salts and evaporation of the moisture and prevent salt from the aqueous phase to the solid phase and in particular on the walls facing the sun and particularly the eastern and south-eastern.

Hydro geological study:

From the table. (6) shows the hydro geological structure and of the area, where consists of the column geological area of the relay layers of limestone, and sandstone and shale limestone ,nummulitic limestone , Dolomite , shale , salt and anhydrite, where the limestone is a class overriding the bottom of the theater, which considered the sources and quarry for building materials and limestone used in building the theater building It is through (fig24-47) note that large blocks of limestone quarries, which were used to where we note that the similarity between the shape and morphological and anatomical appearance such as color and grain. through microscopic examination by normal polarized and stereo microscope of which resulted the minerals composition of limestone layer as foundation basement and limestone as building materials of the theater that the major minerals was a mineral calcite and the minor is a mineral quartz in addition to the minerals

Halite, Gypsum, , Forsterite and Kaolinite , and the same mineral components of the layer limestone. Also, thin section for both rock layer under the theater and limestone used for construction, where the quality of grains and remains of living organisms and the kinds of such Miliolidae sp.and OstracodaX Quartz, structure peloids, structure less peloids, Superficial Ooides Composite Ooides, and shell fragments.

• remains of Balanus sp. , Vermetids, and Lithophyllum

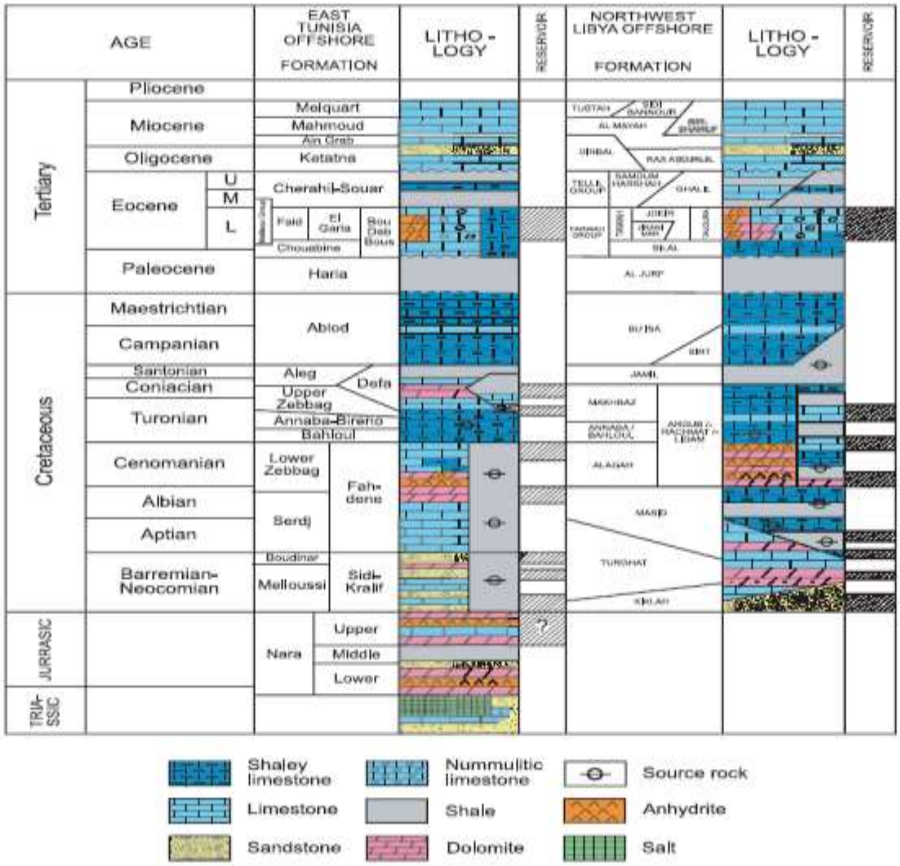


Table (6) Lithostratigraphy, Reservoirs and source rocks.
(Hussein Seddiq 2004).

XRD analysis:

Calcite is a carbonate mineral in the limestone and gray and white marble and can be either dissolved by groundwater or precipitated by groundwater, several factors including the water temperature, pH and dissolved ion concentration although calcite is fairly insoluble in cold water, acidity can cause dissolution of calcite and release of carbon dioxide gas. Calcite exhibits an unusual characteristic called retrograde solubility in which it becomes less soluble in water as the temperature increases. When conditions are right for precipitation, calcite forms mineral coatings that cement the existing rock grains together or it can fill fractures. When conditions are right for dissolution, the removal of calcite can dramatically increase the porosity and permeability of the rock, and if it continues for a long period of time may result in the formation of cavities continued dissolution of calcium carbonate-rich rocks[8] can lead to the expansion and eventual collapse of cavity systems, resulting in various forms of the dissolution carbonate rock such as limestone which the carbonic acid that causes these features is formed as rain passes through the atmosphere picking up CO_2 which dissolves in the water. Once the rain reaches the ground, it may pass through limestone that can provide much more CO_2 to form a weak carbonic acid solution, which dissolves calcium carbonate and this is the main dissolution mechanism of calcium carbonate in limestone[9] ,**Quartz** SiO_4 .It is very common in most carbonate rocks, Because of its resistance to weathering which

[8] Schmittner Karl-Erich and Giresse Pierre: "Micro-environmental controls on biomineralization: superficial processes of apatite and calcite precipitation in Quaternary soils", Roussillon, France. *Sedimentology*,1999, 46/3: 463–476.
[9] Klein, Cornelis and Cornelius S. Hurlbut, Jr.: *Manual of Mineralogy*, Wiley, 20th, 1985, p. 329.
Thompson, D.W. et al. "Determination of optical anisotropy in calcite from ultraviolet to mid-infrared by generalized ellipsometry", *Thin Solid Films*, (1998),p. 313–314.
Porter, S. M.. "Seawater Chemistry and Early Carbonate Biomineralization". *Science*,(2007),*p.* 316.

physical weathering is the class of processes that causes the disintegration of rocks without chemical change. The primary process in physical weathering is abrasion the process by which clasts and other particles are reduced in size). However, chemical and physical weathering often goes hand in hand. Physical weathering can occur due to temperature, pressure, frost etc. For example, cracks exploited by physical weathering will increase the surface area exposed to chemical action. Furthermore, the chemical action of minerals in cracks can aid the disintegration process. And **was chemically inert materia**l, Microcline ($KAlSi_3O_8$), it is a potassium- rich alkali feldspar typically contains minor amounts of sodium

Hematite is a mineral (Fe_2O_3), crystals can also occur as a secondary mineral formed by weathering processes in soil crystallizes in the rhombohederal, play an important role in many geological and biological processes,[10]

as the result of oxygen (bluegreen algae), combining and forming shale and chert[11].

Halite It commonly occurs with other evaporate deposit minerals such as several of the sulfates , Halite crystals form very quickly in some rapidly evaporating ,resulting in modern artifacts with a coating or encrustation of halite crystals, The omnipresence of salt poses a problem in any coastal coating application, as trapped salts cause great problems in adhesion.

Gypsum $CaSO_4 \cdot 2H_2O$. mineral and as a hydration product of anhydrite in contrast to most other salts, it exhibits a retrograde solubility, becoming less soluble at higher temperatures, Gypsum is deposited from sea water, Because gypsum dissolves over time in water, gypsum is rarely found in sand, and also formed as a by-

[10] M.-Z. Dang, D.G. Rancourt, J.E. Dutrizac, G. Lamarche, and R. Provencher. "Interplay of Surface Conditions, Particle Size, Stoichiometry, Cell Parameters, and Magnetism in Synthetic Hematite-like Materials". *Hyperfine Interactions*,(1998), 117: 271–319

[11] Andreas Kappler, et al., *Deposition of banded iron formations by anoxygenic phototrophic Fe(II)-oxidizing bacteria*, Geology; November 2005; v. 33; no. 11; p. 865–868;

product sulfide oxidation, when the sulfuric acid generated reacts with calcium carbonate Its presence indicates oxidizing conditions. Under reducing conditions, the sulfates it contains can be reduced back to sulfide by sulfur reducing bacteria.

.**Dolomite** is composed often as a result of diagenesis pressure and heat [12].**Kaolinite** is a clay minerals,(dioctahedral phyllosilicate clay)produced by the chemical weathering of aluminiun silicate minerals like feldspar[13]

Forsterite (Mg_2SiO_4) is the magnesium rich end-member, crystallizes in the orthorhombic system, also occurs in dolomitic marble, which results from the metamorphism of high magnesium limestone[14]

PM Examinations

Has resulted in testing microscopic by pm and the results were also reported in the image microscopic above, which indicate the nature of the environment sedimentation prior to the cementation and compaction, which is similar to the circumstances formative rock limestone in the coastal areas of the Mediterranean Sea and the nature of building materials in the Roman Theater sabratha as well as explained above conditions composition of the limestone used in the Alexanderia tombs as follow:

[12] Kearey, Philip. *Dictionary of Geology*, Penguin Group, London and New York, (2001), p. 163.

[13] Bellotto, M., Gualtieri, A., Artioli, G., and Clark, S.M. "Kinetic study of the kaolinite-mullite reaction sequence. Part I: kaolinite dehydroxylation". *Phys. Chem. Minerals* **22** (4) (1995), p. 207–214.

[14] Klein, Cornelis;and Hurlbut, Cornelius, Jr.: *Manual of Mineralogy* (20th ed.). Wiley. (1985). pp. 373–375

Wilson, M.; Condliffe, E.; Cortes, J.A; and Francalanci, L. "The occurrence of forsterite and highly oxidizing conditions in basaltic lavas from Stromboli volcano, Italy". *Journal of Petrology* **47**. (2006), 1345–1373

Wackestone is a matrix-supported carbonate rock that contains over 10% allochems in a carbonate mud matrix. This is part of the Dunham classification of carbonate rocks. where the allochems are ooides and peloids

Allochem is a term introduced by Folk to describe the recognisable 'grains' in carbonate Rocks any fragment from around ½mm upwards in size may be considered an allochem. Examples would include ooides, peloides , fossils, pellets, oncolites embeded in Matrix of spary cacite **Ooids** are small (< 2 mm in diameter), spheroidal, "coated (layered sedimentary grains, usually composed of calcium carbonate but sometimes made up of iron or phosphate based minerals , usually form on the sea floor most commonly in shallow tropical seas these ooid grains can be cemented together to form a calcium carbonate An ooid forms as a series of concentric layers around a nucleus. The layers contain crystals arranged radially, tangentially or randomly. The nucleus can be a shell fragment, quartz grain or any other small fragment. ooids partially or totally lack clear layering and have a micritic (very fine grained) texture. Examination of such micritic ooids by SEM often shows evidence of microbial borings later filled by fine cement.[15] Pellets are small spherical to ovoid or rod-shaped grains that are common component of limestone They are typically 0.03 to 0.3 mm long and composed of carbonate mud micrite Their most common size is 0.04 to 0.08 mm. Pellets typically lack any internal structure and are remarkably uniform in size and shape in any single limestone sample. Glauconite forms under reducing conditions in sediments

[15] Folk, R.L. *Practical petrographic classification of limestones.* American Association of Petroleum Geologists Bulletin. 43,1959, pp. 1-38.
Neuendorf, K.K.E., J.P. Mehl, Jr., and J.A. Jackson, J.A., eds *Glossary of Geology* (5th ed.). Alexandria, Virginia, American Geological Institute, (2005),p. 779 .
Scholle, P.A., and D.S. Ulmer-Scholle *A Color Guide to the Petrography of Carbonate Rocks: Grains, textures, porosity, diagenesis.* American Association of Petroleum Geologists Memoir no. 77. Tulsa, Oklahoma, American Association of Petroleum Geologists., 2003,pp 474 .

and such deposits are commonly found in nearshore sands,[16] They differ oolites in that pellets lack the radial or concentric structures that characterize oolites. They differ from intraclasts in that pellets lack the complex internal structure, which is typical of intraclasts. In addition, pellets, quite unlike intraclasts, are characterized by a remarkable uniformity of shape, extremely good sorting, and small size Intraclasts,' Shale is a fine-grained composed of mud that is a mix of flakes of clay mineral and tiny fragments (silt sized particles) of other minerals, especially Quartz and Calcite are typically deposited in very slow moving water and are often found in lakes and lagoon deposits[17]
algal laminated sediments[18] ,and marine evaporates are calcite, gypsum ,halite , anhydrite , and Crustaceans (Crustacea)[19],
Malacostraca is abundant in all marine environments in all marine ecosystems[20],Diatoms are a widespread group and can be found in the sea in open water, although some live as surface films at the water-sediment interface Spatial distribution of marine phytoplankton , edge The fossil record of diatoms has largely been established through the recovery of their siliceous frustules in marine[21]

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[16] Odin, G.S.: Green marine clays. Development in sedimentology, 45. Elsevier, Amsterdam,1988.

[17] R.M. Coveney: Metalliferous Paleozoic black shales and associated strata: in D.R. Lenz ed., Geochemistry of Sediments and Sedimentary Rocks, Geotext 4, Geological Association of Canada, 2003, pp. 135-144

[18] Antun Husinec1, and J. Fred Read Microbial laminite versus rooted and burrowed caps on peritidal cycles:
Salinity control on parasequence development,
Early Cretaceous isolated carbonate platform, Croatia *GSA Bulletin*; September/October 2011; v. 123; no. 9/10; p. 1896–1907

[19] Burkenroad, M. D. :The evolution of the Eucarida (Crustacea, Eumalacostraca), in relation to the fossil record". *Tulane Studies in Geology* 2 (1) , (1963) p. 1–17.

[20] P. J. F. Davie :Class Malacostraca Introduction". ". *Crustacea: Malacostraca. Phyllocarida, Hoplocarida, Eucarida (Part 1)*. Volume 19.3A of Zoological Catalogue of Australia, 2002, _ , p. 23...

[21] Lipps, J.H. (1970). "Plankton Evolution". *Diatoms occur in all oceans from the poles to the tropics; polar and subpolar regions contain relatively few species compared with temperate*=

Fossils in marble:

Ordinal marbles were affected by heat and inside small cells are destroyed. But there are some Fuslina fossils which have original structure. We can identify that marbles which have Genus of extinct fusulinid foraminiferans (protozoans with a shell) Malacostraca, Diatoms and Ostracoda as fossils in marine rocks of Late Carboniferous age (286 to 320 million years old) as shown in the pm figures. It is easy to identify Fusulina in limestone. But it is difficult to do it in real marble, because the structure in it was melted by heat, A mollusc fauna containing a neritid gastropod, *Nerinea* aff. *edoardi* PARONA, *Neoptyxis* sp., *Italoptygmatis* aff. *geinitzi* (GOLDFUSS), *Oligoptyxis* sp., *Actaeonella schiosensis* BÖHM, *Trochactaeon* sp., *Neoradiolites* sp. is described. It has been collected in the marbles of Almyropotamos in the south of the island of Euboea, Greece, and suggests an Upper Cenomanian age[22]True marbles are metamorphic rocks formed from the alteration of limestone by intense heat and pressure. Fossils are usually destroyed during metamorphism. The library stone would not contain so many fossils if it were truly marble

Identification of the fungi and bacteria:

The samples were taken and the work of a media environment in the following: -

Czepek Dox:

Sodium Nitrate 2.0 g, potassium chloride 0.5g ,magnesium glycerophophate 0.5 g, ferrous sulphate 0.10 g, potassium sulphate 0.35 g, sucrose 30.0 g ,and pH 6.8 g. Was taken 33 grams of this

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=biota. Although tropical regions exhibit the greatest number of species, more abundant populations are found in polar to temperate regions. 24 (1): 1–22

[22] GEORGES CH. KATSIKATSOS and HEINZ A: An Upper Cretaceous Mollusc Fauna from the Marbles of Almyropotamos (Euboea, Greece). KOLLMANNAnn. Naturhist. Mus. Wien, 88,AWien, April, 1987,p.103-116.

Kidwell, S. M. and Holland, S. M.: The quality of the fossil record: Implications for evolutionary analyses, Annu. Rev. Ecol. Syst., 33, 561–588,doi:10.1146/annurev.ecolsys.,33,2002,p.030602.152151.

environment and placed in a ready-liter of distilled water and added to 20 g agar, were placed in Petri dishes to grow the fungus and then placed in a incubation for three days at a temperature of 27 degrees Celsius.

Agar media and Yeast extract

Beef Extract 3 gm, peptone 5 gm, yeast extract 1gm, sodium chloride 0.5 gm, agar 20 gm, distilled water 1000mm,and pH 7

Media for actinomycetes growth

Glucose 2 gm, casein 0.2 gm ,R2HPO4 0.5 gm, MgSO4.7H2O 0.2 gm, agar 20 gm, tap water 1000 mm. and pH 6.5-6.6.

Incubation was for 5 days at a temperature of 27 degrees Celsius

Table (7) shows the species and groups of the species of Fungi from limestone, mortar and plasters samples.

Plaster	Mortar	Limestone	The species of Fungi
√	√	√	Asperigllus flavius
√	------	√	" fumigatus
√	√	------	" nigar
------	√	------	*Penicillium chrysogenum*
------	√	√	" sp
------	------	√	Cladosporium
√		√	Trichoderma sp
√	√	√	Epicoccium sp.
√	√	√	Mucor sp

Aspergillus niger is black colonies.[23] And produced the organic acids such as citric acid[24] ,

Aspergillus fumigatus is a The fungus is capable of growth at 37 °C/99 °F, and up to 50 °C/122 °F, with conidia surviving at 70 °C/158 °F,its spores are ubiquitous in the atmosphere[25]

Aspergillus flavus is grows as a yellow-green mold in culture[26]

Aspergillus serve in the production of a number of biotechnologically produced enzymes and other macromolecules, such as gluconic, citric, and tartaric acids, as well as several pectinases, lipase, amylases, cellulases, and proteases[27],

Penicillium is a genus ascomycetous fungi of major importance in the natural environment, produce pencillin a molecule that is used as an antibiotic which kills or stops the growth of certain kinds of bacteria inside the body[28], grow on limestone in low humidity and to colonize rapidly by aerial dispersion Some species have a blue color species ,

Penicillium chrysogenum is common in temperate and subtropical regions and can be found on salted limestone but it is mostly found

[23] Staiano, Maria, Paolo Bazzicalupo, Mose' Rossi, and Sabato D'Auria. :Glucose biosensors as models for the development of advanced protein-based biosensors, Molecular BioSystems ,1, 2005,p. 354-362.

[24] Andersen MR, Salazar MP, Schaap PJ, *et al*. "Comparative genomics of citric-acid-producing Aspergillus niger ATCC 1015 versus enzyme-producing CBS 513.88". *Genome Res* 21 (6) . 2011, p. 885–97.

[25] Nierman WC et al. "Genomic sequence of the pathogenic and allergenic filamentous fungus *Aspergillus fumigatus*". *Nature* 438 (7071) ,2005, 1151–6

[26] Klich MA.. *Aspergillus flavus*: the major producer of aflatoxin. *Molecular Plant Pathology* ,2007, **8**(6):,p. 713-22.

[27] Valdez JG, Makuch MA, Ordovini AF, Masuelli RW, Overy DP, and Piccolo RJ. "First report of *Penicillium allii* as a field pathogen of garlic (*Allium sativum*)". *Plant Pathology*(2006). **55** (4): 583

[28] Kirk PM, Cannon PF, Minter DW,and Stalpers JA:. *Dictionary of the Fungi* (10th ed.). Wallingford, UK: CABI,(2008),. p. 505

in indoor environments, especially in damp or waterdamaged buildings. It was previously known as ***Penicillium notatum*** [29]

Cladosporium is a genus of fungi Species produce olive-green to brown or black colonies .[30]

Trichoderma is a genus of fungi , fast growing at 25-30°C, but will not grow at 35°C.[31]

Epicoccium sp. contain generative hyphae, which are the main mode of vegetative growth collectively called mycelium strand parallels and is regulated by the movement of the spitzenkörper[32] which destroyed the grains cohesion of limestone

Mucor is a typically white to beige or grey and fast-growing. Older colonies become grey to brown in color due to the development of spores, grow in warm environments close to 37°C and often rapidly spreading[33]

Identification of bacteria:

Environments through the growth of the bacteria has been identified the following types, which helps to biological damage to the building materials used in the construction of the theater

Micrococcus Roseus , Micrococcus Luteus, Bacillus Brevis , Bacillus Megaterium , Streptomymces Sp.

Biological weathering:

Chemical weathering through release of acidic compounds (i.e. organic acids,) and of acidifying molecules (i.e. protons, organic acids) by plants growth. Also statues monuments and ornamental

[29] Andersen B, Frisvad JC, Søndergaard I, Rasmussen IS and Larsen LS.. Associations between fungal species and water damaged building materials. Applied and Environmental Microbiology, 2011, **In Press**

[30] Rivas, S. and Thomas C.M.,. Molecular interactions between tomato and the leaf mold pathogen: Cladosporium fulvum. Annual Review of Phytopathology,2005, 43: 395-436.

[31] Harman, G.E., Howell, C.R., Viterbo, A., Chet, I.,and Lorito, M "*Trichoderma* species--opportunistic avirulent plant symbionts". *Nature Reviews Microbiology* **2**. (2004). (1),p. 43–56

[32] Kumar R, Singh S,and Singh OV. "Bioconversion of lignocellulosic biomass: biochemical and molecular perspectives". *J. Ind. Microbiol. Biotechnol.* May ,2008, 35, (5),p. 377–91.

[33] Blackwell M, Spatafora JW. :Fungi and their allies, In Bills GF, Mueller GM, Foster MS. *Biodiversity of Fungi: Inventory and Monitoring Methods*. Amsterdam: Elsevier Academic, 2004, Press. pp. 18–20.

stonework can be badly damaged by natural weathering processes. This is accelerated in areas severely affected by acid rain[34].

Physical and chemical Mechanical weathering involves the breakdown of rocks, exposing new rock strata to the atmosphere and moisture, changes the composition of rocks, often transforming them when water interacts with minerals to create various chemical reactions. In this the processes of oxidation and hydrolysis are most important and weathering processes combined with erosion and re-deposition[35]

Therefore, through the mineralogical composition of building materials used in the theater, a limestone and mortar Association, a mortar of lime and by appoint properties for them and the effects of vocabulary and the surrounding environment is conducive to influence the strength of materials, which gives us a vision of how appropriate restoration materials of the environment surrounding the use of traditional materials with some additions which improve the properties of materials and increase the durability and suitability of the surrounding environment and how to improve their properties by adding some polymeric materials and the advancement of the region to be placed on the archaeological map of the world tourism to achieve comprehensive development in Libya.

[34] Uroz, S., Calvaruso, C., Turpault, M-P, and Frey-Klett, Pa : The microbial weathering of soil minerals, Ecology, actors and mechanisms. Trends in Microbiol. 17., 2009,p.378–387.

[35] Uroz, S., Calvaruso, C., Turpault, M-P,and Frey-Klett, P., A.: The microbial weathering of soil minerals, Ecology, actors and mechanisms. Trends in Microbiol. 17,2009,p.378–387