CLASSIFICATION AND VISUAL ANALYSIS OF WEATHERING FORMS OF STONE IN KADIKALESİ, KUŞADASI

A Thesis Submitted to
the Graduate School of Engineering and Sciences of
İzmir Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in Architectural Restoration

by
Işıl TALU

July 2005
İZMİR

We approve the thesis of Işıl TALU

Date of Signature

…………………………………………………….. 20 July 2005
Assoc. Prof. Dr. Hasan BÖKE
Supervisor
Department of Architectural Restoration
İzmir Institute of Technology

…………………………………………………….. 20 July 2005
Assoc. Prof. Dr. Başak İPEKOĞLU
Co Advisor
Head of Department of Architectural Restoration
İzmir Institute of Technology

…………………………………………………….. 20 July 2005
Assist. Prof. Dr. S. Sarp TUNÇOKU
Department of Architectural Restoration
İzmir Institute of Technology

…………………………………………………….. 20 July 2005
Prof. Dr. S. Zeynep MERCANGÖZ
Department of Art History
Ege University

……………………………………………………..................
Assoc. Prof. Dr. Semahat Özdemir
Head of the Graduate School of Engineering and Sciences

ACKNOWLEDGEMENTS

This thesis would not have been possible if not for the guidance, support, strength, and love of many people.

First, I would like to offer my sincerest thanks to my thesis advisor Assoc. Prof. Dr. Hasan Böke for his continuous support, expertise, encouragement and instructions throughout the period of my research. Likewise, I must gratefully acknowledge the helpful interest and support of my thesis to Co-adviser, Başak İpekoğlu, head of the Architectural Restoration Department.

Studying a case like Kadıkalesi needed a long period of data collecting, consulting many issues, and making multidisciplinary inquiries. Here, special thanks are due to Prof. Dr. Zeynep Mercangöz who gave her knowledge and photographs about Kadıkalesi and her hospitality and permission to prepare this thesis.

There are many friends from Çiğli municipality, who have encouraged and supported my work, and I wish to thank them; Hale Kayalioğlu, Mine Islakoğlu, Mehmet Akbaş, Boray Akar and all my colleagues.

I would like to thank Gökhan Gündüzoğlu for the support for 3D views of my study area. I would also like to thank Deniz Küçükdumlu who came to help whenever I had problems with my computer.

I would also like to thank my dear classmates for the support and friendship Elif Uğurlu, Kerem Şerifaki, Özlem Aslan, Sevinç Çulcu. I would like to express my gratitude to my friends Ahu Aydoğan, Serap Kılınçarslan, Büge Dabancalı for their continuous encouragement and patience during this thesis study. I am thankful to a special friend Karim Ahmed Murad for his support and love.

Finally, I am grateful to my family for their loving support, encouragement, and patience that made much of the work on this thesis not only tolerable but also achievable.

ABSTRACT

Identification of the state of deterioration at stone monuments is one of the main steps, which should be carried out for planning of conservation studies.

In recent years, most of the study concerning the classification and mapping of weathering forms observed at stone monuments have been carried out either by detailed classification or sketchy methods.

Due to the large area of the archaeological site, identification of the weathering forms of stones and their progress should be done in easy and rapid way to decide urgent interventions. This study was aimed to propose a visual presentation technique for classification and mapping of weathering forms of stones that it could be applied easily in archeological sites. For this aim, a method has been developed in the archeological site of Kadıkalesi (Anaia). The method was derived from detailed and sketchy classification methods. Both methods were united in order to form an intermediary scale for the visual classification and mapping forms observed at stone monuments.

The proposed method for classification and mapping of weathering forms of stone in this study would be suitable for archeological sites. The most frequently observed weathering form in Kadikalesi is biological colonization, which is major cause of the loss of stone blocks and fissures. The deposition of the soluble salts, which could be originated from soil and marine aerosols and clay minerals, which ensures suitable conditions for the biological growth, are the other major causes of the stone, brick and mortar deterioration. This study indicated that during and after excavation in an archeological site, deposited soil and soluble salts on the stone surfaces should be cleaned to prevent rapid deterioration. Repairing or sealing cracks, cavities of stones, hand pulling wild grass will also prevent rapid deterioration of stones by the formation of higher plants.

ÖZET

Taş anıtların koruma çalışmalarının planlanmasında en önemli adımlardan biri bozulma türlerinin ve derecelerinin belirlenmesidir.

Geçmiş yıllarda, taş anıtlarda gözlenen bozulmaların sınıflandırılması ve haritalandırılması ile ilgili çalışmaların çoğu detaylı sınıflandırmalar veya yalnızca temel noktaları belirten yöntemlerle gerçekleştirilmiştir.

Arkeolojik sitlerin geniş alanlara sahip olmaları nedeniyle; taşlardaki bozulmalar ve bu bozulmaların ilerlemeleri, acil müdahale kararlarının alınabilmesi için kolay ve hızlı bir biçimde belirlenmelidir. Bu çalışma, taş bozulmalarının sınıflandırılması ve haritalandırılması için arkeolojik alanlarda kolaylıkla uygulanabilecek görsel bir sunum tekniği önermeyi amaçlamaktadır. Bu amaçla, taş malzemedeki bozulmaların sınıflandırma ve haritalandırması üzerine yapılan yöntemler birleştirilerek, bozulmaların sınıflandırılması ve haritalandırılmasında kullanabilecek ara ölçekte bir yöntem oluşturulmuştur. Geliştirilen yöntem, Kadıkalesi (Anaia) arkeolojik alanında gözlenen bozulmaların belirlenmesi amacıyla uygulanmıştır. Bu çalışmada taş malzemelerde gözlenen bozulmaların sınıflandırma ve görsel analiz çalışmaları için önerilen yöntem diğer arkeolojik alanlar için de uygun olacaktır.

Kadıkalesi’nde en çok gözlenen bozulma formu taş malzemede kayıplara ve çatlaklara neden olan biyolojik oluşumlardır.

Topraktan ve deniz aerosollerinden kaynaklanan çözünebilen tuz birikintileri ve biyolojik oluşumlara uygun ortam sağlayan kil minerali tabakaları, taş, tuğla ve harçlardaki bozulmaların temel nedenleridir. Bu çalışma, arkeolojik alanlarda gerçekleştirilen kazı çalışmaları esnasında ve sonrasında meydana gelebilecek hızlı bozulmaları engellemek için toprak ve çözünebilir tuz birikintilerinin taş yüzeylerinden temizlenmesi gerektiğini göstermiştir. Ayrıca, taşlardaki çatlakların, oyukların onarılması veya kapatılması ve yabani otların temizlenmesi, taşlarda bitki oluşumları nedeniyle meydana gelebilecek bozulmaları önleyecektir.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1. Aim of the Study

The interventions to be carried out in historic buildings must be based on scientific principals of conservation and must aim at preserving their aesthetic and historic documental value. In this sense, use of original materials is the basic approach.

Documentation of historic buildings is the primary stage in the process of preservation work. Such documentation must include the type of the materials used, the different types of deterioration observed, and their probable sources as well as the problems encountered in the building. It is essential to determine these conditions with respect to the definition of the works to be done for the purpose of conserving the historic building's materials. What works are to be done urgently and in the long-term and what should be done for them are defined based on the data derived from this documentation.

Intervention decisions for the conservation of stones in historic buildings start with the identification of the present conditions of the buildings. These conditions cover finding out the geological characteristics of the area upon which the structure was constructed, the climatic conditions, the effects of air pollution and natural disasters as well as the condition of use of the structure during its lifetime and the interventions carried out during this period. These studies are followed by the definition of the deteriorations observed in the original materials, their classification and distribution in the building and finding out their sources. After these stages, it is important to identify physical, mineralogical, and chemical properties of the original materials, their durability, sources of deterioration and mechanisms, and their production technologies. This stage is followed by studies on the selection of new materials to be used in interventions, their production and durability, compatibility with the original material and whether they are reversible or not. These works are the main procedures, which determine the effectiveness of interventions to be carried out. Of these procedures, definition and classification of the deteriorations observed in the stones at the area is necessary to plan the works to be done for the preservation of the stones.

This study was aimed to propose a visual presentation technique for classification and mapping of weathering forms of stones so it could be applied easily in archeological sites. For this purpose, a case study has been carried out in the archeological site of Kadıkalesi (Anaia).

1.2. Limits of the Study

This study is limited to three bastions contained in the archeological site of Kadıkalesi (Anaia). In the scope of this study, the weathering forms observed in the study area were classified and mapped. The identification of chemical, physical and mineralogical properties of stones and mortars used in the construction of the walls were taken into consideration in the laboratory studies. For this purpose, the samples of mortar and stones were collected from the vault and interior ground of bastion and city walls for laboratory studies.

The progress of weathering forms observed in Kadıkalesi was also documented between the years 2003-2005. This comparison aided the decisions that there is a need for urgent interventions.

1.3. Method of the Study

In recent years, most of the study concerning the classification and mapping of weathering forms observed at stone monuments have been carried out by using a systematic classification method developed by Fitzner et al. (Fitzner et al., 1992, Fitzner, 2002). This method has application difficulties such as requiring teamwork by experts, remarkable financial support, and conceptual confusion of the terms when translated into other languages

Considering the difficulties, Warke et al., (2003) recommended and applied a new method of classification and mapping of deteriorations on stones eliminating these difficulties. This method is easily applicable, prevents the occurrence of conceptual confusion and facilitates monitoring the progress of deterioration in structures. However, when compared with the Fitzner Method, the deterioration forms are not defined in detail.

The method used in this study was derived from the studies carried out by Fitzner and Warke (Fitzner et al. 1992, Fitzner, 2002, Warke et al. 2003). Both methods were united in order to form an intermediary scale for the visual classification and mapping forms observed at stone monuments. The pre-field studies were the first step of this method including measuremenets and site recording and reference sheet. The measurement of the study area was done by total station and scaled photographs. The identification of chemical, physical and mineralogical properties of stones and mortars used in the construction of the walls were taken into consideration in the laboratory studies

CHAPTER 2

CLASSIFICATION AND MAPPING OF WEATHERING FORMS OBSERVED ON STONE MONUMENTS

The stone weathering takes place through chemical, physical, mechanical, and biological, process. Physical weathering breaks stones into smaller pieces. Types of physical weathering include salt crystallization, freeze thaw cycles, thermal expansion, and loads, rot pressure of plants and microorganisms, etc. (Shaffer 1972)

Chemical weathering erodes the stones changing their compositions by chemical reaction. Chemical weathering of the stone takes place through dissolution, hydrolysis and oxidation processes of the stone minerals. Chemical weathering is mostly due to the effects of air pollution.

Biological weathering can be described as a disintegration of stone and stone minerals due to the chemical and/or physical actions of an organism. Action of some organisms changes the stone color or slow down the decay process of stone. Biological weathering takes place by the action plants, animals, fungus, algae, bacteria, lichen etc.

In nature, more than one process takes place and it is difficult to verify the main causes of the weathering. Investigation of the causes of weathering forms of stones in the historic buildings is an interdisciplinary work including the study of many researchers from different disciplines as architectures, engineers, chemists, biologists, archeologists, art historians, etc.

2.1. Classification and Mapping of the Weathering Forms on Stone

The classification and mapping of weathering forms observed at stone monuments have been carried out for a few decades using different presentation techniques. These studies developed different frameworks for classification and mapping studies, but the systematical classification of weathering forms was developed by Fitzner et al. (Fitzner et. al. 1992; Fitzner 2002). The weathering forms of stones are divided into 4 groups in this study. These groups are: loss of stone materials, discoloration-deposits of the material, detachment of the material, and fissures-deformations. These groups are mainly divided into 25 sub-groups (Table 2.1.).

Table 2.1. Classification of weathering forms observed on stones
(Source: Fitzner et. al., 1992; Fitzner 2002)

Loss of stone materials	
Back weathering	*Uniform loss of stone material parallel to the original stone surface.*
Relief	*Morphological change of the stone surface.*
Break out	*Loss of compact stone fragments*
Discoloration/deposits	
Discoloration	*Alteration of the original stone color*
Soiling	*Soil deposits on the stone surface*
Crusts	*Strongly adhesive deposits on the stone surface*
Loose salt deposits	*Poorly adhesive deposits of salt aggregates*
Biological colonization	*Colonization by microorganisms or higher plants*
Discoloration to crust	*Transitional form between discoloration and crust*
Soiling to crust	*Transitional form between soiling and crust*
Loose salt deposits to crust	*Transitional form between loose salt deposits and crust*
Biological colonization to crust	*Transitional form between biological colonization and crust*
Detachment of material	
Granular disintegration	*Detachment of individual grains or small grain aggregates.*
Crumbly disintegration	*Detachment of larger compact stone pieces of irregular shape.*
Flaking	Detachment of small thin stone pieces parallel to stone surface.

Table 2.1. (Cont.)

Contour scaling	*Detachment of larger, platy stone pieces parallel to the stone surface, but not following any stone structure*
Detachment of stone layers dependent on stone structure	*Detachment of larger stone sheets or plates following the stone structure.*
Detachment of crusts with stone material	*Detachment of crusts with stone material sticking to the crust.*
Granular disintegration to flaking	*Transitional form between granular disintegration and flaking*
Granular disintegration to crumbly disintegration	*Transitional form between granular disintegration and crumbly disintegration*
Flaking to crumbly disintegration	*Transitional form between flaking and crumbly disintegration*
Crumbly disintegration to contour scaling	*Transitional form between crumbly disintegration and contour scaling*
Flaking to contour scaling	*Transitional form between flaking and contour scaling*
Fissures / Deformation	
Fissures	*Individual fissures or systems of fissures due to natural or constructional causes.*
Deformation	*Bending / buckling of mainly thin stone slabs.*

The observed deteriorations were classified according to categories of intensity. Thus the equivalent appropriate measures were also defined. Damage categories were divided into 5 main groups (Fitzner et al. 1992; Fitzner 2002) (Table 2.2.).

Table 2.2. Classification of damage categories
(Source: Fitzner 2002)

Damage Category		*Appropriate Measures*
1	*Very slight damage*	*Routine monitoring*
2	*Slight damage*	*Preventive measures under consideration* *Careful monitoring*
3	*Moderate damage*	*Conservation measures and repair of stone advisable* *Intensive monitoring essential*
4	*Severe damage*	*Intervention essential* *All options of conservation, repair and replacement/protection by removal under consideration*
5	*Very severe damage*	*Replacement/protection by removal*

The classification and mapping method developed by Fitzner et al. was used at many stone monuments. One of the initial examples was accomplished on cut-stone monuments in Petra. Probable deteriorations of the monuments, which could possibly be observed in the future, were identified by the classification and mapping method. These studies have been carried out since 1994 (Fitzner et al. 1994). Heinrichs did the latest study on the assessment of the progress of the weathering forms in 2004 (Heinrichs 2004). Before 2004, the research studies that were carried out between the years 1994-2000 are listed as follows: the definitions of the weathering forms in 1994, the evaluations of the weathering forms in 1998 (Fitzner, B. and Heinrichs, K. 1998), the characterizations and ratings of the weathering forms in 1999 (Fitzner, B. and Heinrichs, K. 1999); and finally the litho types and the deteriorations of the cut-stones in 2000 (Heinrichs, K. and Fitzner, B. 2000).

The weathering forms and material properties of the famous soapstone sculptures in Congonhas and the quartzite masonry of two important baroque monuments in Ouro Preto were investigated by Fitzner et al. (Fitzner et al. 1993) The observed weathering forms were registered and mapped by means of a classification scheme at the investigation area. Mapping results were presented as an example for each of the investigated objects. The representative stone samples were also collected from the monuments to characterize the stones by laboratory analysis. The correlations between the laboratory results and weathering forms of the stones were carried out (Fitzner et al. 1993).

In Germany, the mapping method of Fitzner was applied on about twenty historical monuments showing different weathering behaviors of soapstones with different characteristics. The observed weathering forms were defined and mapping and classification schemes were formed. The mineralogical compositions and the porosities were determined, and the relationship between them and the weathering forms was discovered (Fitzner et al. 1993).

Similarly, the observed weathering forms of the limestone used in the construction of the north façade of the historical Thann Collegiate Church were determined with Fitzner's mapping method (Fitzner et al. 1993). The petrographical and physical properties of limestones were identified to find out, the relationship between them and the observed weathering forms.

The classification method was used on the observed weathering forms of various limestones of Elausis Temple, which was constructed between the Helladic period and the Classical (periklean) period in Greece (Galan et al. 1997). Gray micritic limestone, yellow limestone, gray biomicritic limestone, yellow-brown limestone and yellow-brown fossiliferous dolomite and white and white- gray marbles with low porosity were commonly used in the temple, which all formed the Attika's geological structure. The classification of the natural stones used in its construction was determined with respect to the mechanical, physical, micro-structural characteristics obtained by the laboratory analysis (Galan et al. 1997).

The base investigation was undertaken in the Holly Tomb Cathedral in Görlitz depending on the mapping and the evaluation of the observed weathering forms in Cretaceous Silesian soapstone. Furthermore, the porosity and the petrographical characteristics of soapstones were analyzed (Fitzner et al. 1995). Similarly, Fitzner et al. applied the weathering forms of the Globigerina limestones used in the construction of megalithic temples in Malta with the same classification system. The most important deterioration types were caused by Malta's marine location and the effects of salt on the monuments. (Fitzner et al. 1997)

The weathering forms were precisely defined and evaluated by the mapping studies of the sandstone materials used in the construction of St. Paul and St. Peter churches in Zeitz. The physical and petrographical characteristics of stones were also identified by laboratory studies to determine the chracatacteristics of replacement materials. Thus, the characteristics of the replacement materials were determined (Fitzner et al. 1998).

Pilot studies were carried out by mapping of weathering forms at Karnak and Luxor temples, which were constructed with sandstone.

The mineralogical and petrographical properties of the stones of the art monuments in Saint Petersburg were identified as essential parts of restoration works on the basis of the mapping of the weathering forms (Bulakh et al. 2002).

The mapping of weathering forms was used on more than six hundred Islamic monuments in Cairo, Egypt, which have been in the world heritage list since 1997. An extensive application of the mapping method was used for obtaining detailed record, documentation, and quantitative evaluation of weathering forms, the stone deterioration categories and index studies on limestone monuments. The diagnosed weathering types were identified as loss of stone material, deposits on stone surface, detachment of material and structural discontinuities. The loss of stone material and detachments caused by the effects of rising damp and salt crystallization were observed in the lower parts of the structures (Heinrichs 2004).

The pre-historical Bangudae Petroglyph located in the Korean Republic Ulsan area is an important national heritage. The in-situ measurements, laboratory analyses and mapping studies were prepared for the purpose of comprehensive damage diagnosis. The risk estimation and diagnosis studies were accomplished for the observed weathering forms of carvings, which have been under water for two centuries. Also, the determination of macroscopic characteristics, mineralogical compositions, porosity, micro-structural characteristics, textural characteristics of stones and the relationships between them and the deteriorations were presented (Fitzner 2002; Fitzner et al. 2004).

The mapping method developed by Fitzner was applied in master and doctoral thesis studies and restoration education in Turkey (Tavukçuoğlu 2002). A detailed study on mapping was accomplished in the tuff cut-stone materials used in Ağzıkarahan (Tavukçuoğlu 2002). The distribution of the weathering forms on stone materials, highly deteriorated parts, the sources of dampness, and the affected areas were determined. Consequently, the precautions and the essential studies for applying these precautions were determined.

Dorsey et al.(1999) accomplished a detailed study of weathering forms as an illustration of modeling and rendering of the changes in stone caused by deteriorations. The modeling and rendering studies of the observed deteriorations caused by the effects of dampness and air pollution in marble, sandstone and granite were demonstrated. In the scope of this study, the mechanical and biological weathering forms were not taken into consideration. The study of Dorsey suggests using a new modeling and presentation technique for the purpose of demonstrating damages on weathered stone. On the other hand, these studies generally remained in laboratory scale.

Many researchers have used the systematic classification and mapping method of Fitzner since 1992. However, this method consists of a detailed interdisciplinary study. Application of this method requires a long-term work and has application difficulties involved, such as necessity of qualified operators, financial problems, and conceptual confusion when the terms of the system have been translated into different languages. Finally, focusing on the application difficulties, a new method was suggested for classification and mapping of weathering forms called UAS system (Warke et.al. 2003).

UAS system is a simple classification system for visual determination of deteriorations in stone materials. The scheme of UAS system is derived from TNM staging method for cancer diagnosis. TNM stands for tumors, nodes, and metastases. This system determines the rate of the progress of a disease schematically and shows the precautions to be taken depending on this.

A “site recording sheet” study is the first stage of the classification and mapping studies. This pre-field study requires area descriptions of where the building was located, the age of the building, the façade that was studied, the treatments applied before, the stone material used in construction and affecting factors, the observed deterioration types, evidence of biological deterioration, alteration types and all the information noted on the site recording sheet for every façade. The present condition of the construction and the observed deteriorations are drawn after acquiring the information.

In UAS scheme, the term “U” describes a unit and, defines individual stone blocks. The term “A” describes an area and defines adjoining stone blocks. The term “S” describes a spread which defines the size of deterioration all over of the façade. The identification of the deteriorations in stone materials and the probable interventions are determined using the UAS system (Table 2.3.). Application of this system was done in the sandstone of St. Patrick's Church.

Table 2.3. UAS staging system adapted from the TNM stating system
(Source: Warke et al., 2003)

	U	A	S
STAGE 1	U2 U1	A0 A0	S0 S0
STAGE 2	U1 U2	A1 A1	S0 S0
STAGE 3	ANY ANY	A3 A2	S0 S0
STAGE 4	ANY	S1	S1

A numerical set of values defining the intensity and size of the deteriorations as in TNM staging method was placed under every classification category. The interventions and suggestions given below were developed for every level (Warke et al. 2003).

" U0: No deterioration detectible.
U1: Some surface alteration with minimal breakdown affecting only parts of individual blocks.
U2: Well-developed surface alteration and/or obvious surface breakdown
U3: Well-established surface breakdown with loss of original stone surfaces affecting Up to 10% of the façade.

A0: No involvement of surrounding blocks detectable.
A1: Positive involvement of surrounding/connecting blocks.
A2: Positive involvement of surrounding/connecting blocks affecting between 10-20% of the façade.
A3: Extensive localized involvement of connecting blocks and beyond affecting 20-40%of the façade.

S0: Deterioration is restricted to specific sections of the façade.
S1: positive deterioration affecting distant unconnected portions of the façade involving more than 50% of the total surface area."

Different intervention recommandations were developed through different stages for every level, which is equivalent of every set of values. They are;

“Stage1: A façade in this condition would require only localized remedial treatment concentrating on individual stone blocks. A staging classification of 1 may also indicate that no active intervention is required with only periodic reassessment of the façade advised.

Stage2: Section specific remedial action would be required in this case but the extent of intervention should be relatively limited because of the lack of distant involvement within the façade boundaries.

Stage3: Significant intervention will be required with up to 50% of the total façade surface showing evidence of the deterioration. Although the extent of deterioration is severe, appropriate conservation treatment should prolong the life expectancy of the structure.

Stage4: Serious deterioration affecting more than 50% of the total façade surface with stone decay detected on unconnected, distant portions of the façade. On a stage 4 category of façade, considerable intervention will be required to restore stonework. If the structure is of limited historic and/or architectural merit then consideration should be given to provision of palliative rather than restorative treatment.”

The reliability of the stage assignment was supported by the addition of certainty factors. It reflects the breadth and sophistication of diagnostic procedures employed (Warke et al. 2003).

This method has some advantages when compared with Fitzners’ method. They are;

- Enables us to obtain a common terminology and evaluation methodology
- Is an easily applicable method and provides good classification as in condition of a building without qualified operators
- Can be translated into different languages easily and hinders conceptual confusion
- Hinders loss of time in the studies of classification and identification.

2.2. Overview of Kadıkalesi

2.2.1. History of Kadıkalesi

Kadıkalesi is an outpost fortress located in the summerhouse development in Kuşadası, Aydın. It is 10 km from Davutlar Village. It is approximately 8 km from Kuşadası in Karaova plain. Kadıkalesi had been called as Anaia before Ottoman Empire period. Based on an Epheros story, the name of Anaia originates from an Amazon who had died in this area (Cramer 1832).

Anaia Castle was situated opposite Samos Island and it dominated the sea crossing (Cramer 1832). The harbor of Anaia was 3 miles away from Anaia City (Figure 2.1.) (Philippson. 1910-1913). It was settled on a 24-25 meter-high mount and it is 250 meter from the sea. The fortress, which was erected on a sloping mount at least 4,000 years ago, generally had an irregular form.

Figure 2.1. Location of Kadıkalesi

(Source: Philippson. 1910-1913)

The fortress had been located right on the coast, and it protected the Byzantine town of Anaia against the attacks coming from the sea. Anaia was used for defense against pirates in the 3rd century. It was a place where Turkish, Genoese and Greek pirates met (Bratianu 1929). The Byzantines left Anaia to the hands of Venetian and Genoese merchants for commercial purposes following two treaties signed in 1261(Heyd 1923). The Turks probably dominated the town from 1304.

2.2.2. Architectural Characteristics of Kadıkalesi

The general shape of Kadıkalesi is irregular polygon (Figure 2.2.). The fourteenth, fifteenth and sixteenth bastions were bigger than the others and had circular shapes. The main entrance was located near the 16th bastion. It had simple wings. Near the main door was a semi-circle bastion with 17.45-meter height. Inside the bastion was another semi-circle, which was 3meter high. It seems that much destruction occurred in the second bastion. At the start of the wall, it was 9.3 m wide. The third bastion was 7.65 meter wide and it was protected at the foundation level. The interior room of it was a semi-circle and had a niche with a two-meter depth. The fourth bastion was one of the biggest with a 9.45m diameter. The dimensions of the interior room were 4X5 m, and it was covered with a pointed arched vault. The walls of the room were covered with plaster. To reach this room, 0.97meter-wide stairs were used. The exterior walls of the bastions were built with faceted stone. The condition of the fifth bastion was much better. It had an oval shape. The sixth bastion had an interior room. The corner bastion 7 had a two-storey interior room, both of which collapsed. Bastion 8 and 9 in the north side were damaged. Bastion 10 was damaged too. Bastion 11 was 8.1m wide and its interior room was 3.9m wide. The corner bastion 12 was 6.75m wide from the start of the wall. Bastion 13 was badly damaged and could not be investigated because of the plants outside. The biggest bastion was bastion 14 with its 11.5m diameter. It had many storeys. The kuntinen had 2.7-2.8m wall thicknesses.

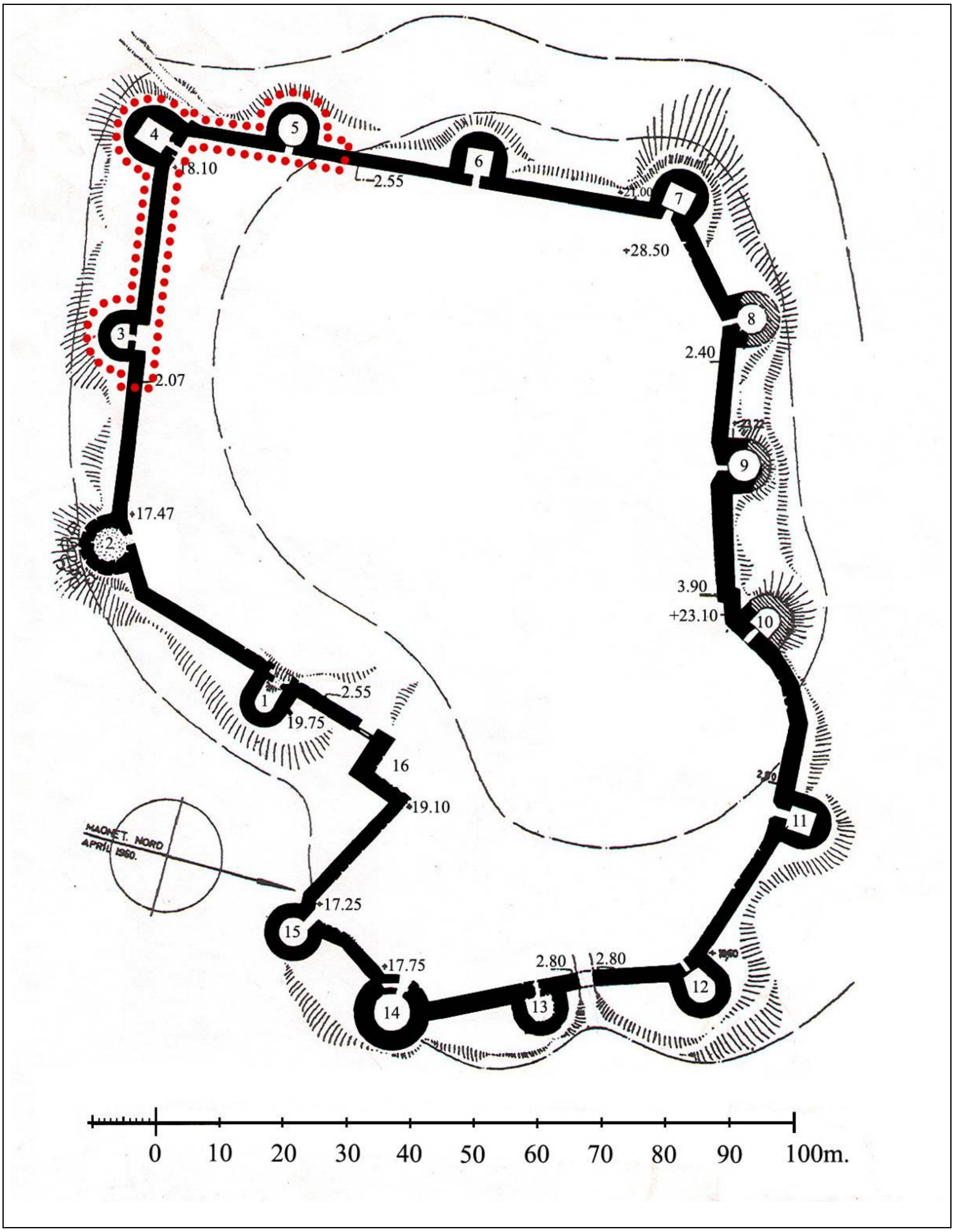


Figure 2.2. Plan of the studied area in archeological site of Kadıkalesi

(Source: Müller-Wiener 1961)

2.2.3. Construction Technique and Material of Kadıkalesi

The castle was constructed with alternate construction system. All the bastions were constructed with rubble stone and lime mortar. Bricks were used around the rubble stones and limestone blocks. The brick rows were irregular. Sometimes it was seen that the bricks had been placed near the stones in a vertical position. This construction technique had been common since the 12^{th} Century. In the interior section, the construction technique of wall casting was applied. The vertical timbers were observed in all the bastions and walls. According to the materials used and the wall construction technique, the fortress dates back to the 12^{th} and 13^{th} centuries. The ruins and the wall construction technique applied in the fortress date back to Manuel 1 Komnenos Age.

2.2.4. Present Condition of Kadıkalesi

At present, the structure has remained in a summerhouse location. The upper section seems to have demolished from a certain altitude, and the sections, which had formed the spaces within the structure, disappeared. The excavation works carried out in Kadıkalesi since 2001 still continue.

Serious plantation formations have been observed in the present condition of the structure. There are deteriorations in stone, brick and mortar materials due to humidity and salt. Main deteriorations observed in the structure have been identified as breaks in the stone material, draping of mortars, cracking, biological colonization, and alveolar weathering.

CHAPTER 3

METHODOLOGY OF THE CLASSIFICATION AND VISUAL ANALYSIS OF STONE WEATHERING OBSERVED IN KADIKALESİ (ANAIA)

In this chapter, the used methodology that applied to archeological site of Kadıkalesi has been given in detail.

3.1. The Measurements

The measurements were done in order to obtain detailed drawings of the façade which the work to be carried out. The study area was determined as the third, fourth, fifth bastions and the walls between them. They were measured in a closed polygonal set-up, using a total station. To obtain scaled measurements, the scaled photographs of each five m eter parts of the facades were taken.

Photographs were transferred into AutoCAD program and the facades were drawn using the data recorded by the total station. 3D views of the studied area were also drawn using NetCAD 4.0 GIS program.

3.2. Site Recording and Reference Sheet

Site recording sheet study was prepared for making staging assessment of the study area. The information concerning the location and the age of Kadıkalesi, the façade, which was studied on, the stone materials used in construction, the observed deterioration types were described in site recording sheet. One site recording sheet was prepared for the third and fourth bastion and the city wall between them and for the fourth and fifth bastions and the city wall between them. The “site recording sheet” proposed by Warke et al. was used in this study (Table 3.1.) (Warke et al. 2003).

Table 3.1. Site Recording Sheet used in Kadikalesi
(Source:Warke et al., 2003)

Operator: *IŞIL TALU* ***Date :***

Building: *Kadıkalesi*

Description, site and age details:

Kadıkalesi is settled on Davutlar housing estate in Kuşadası / Aydın. In the prolonged periods history Kadıkalesi is named as Anaia. Kadikalesi is the name that given by the time of the Ottom Empire. The history of Kadikalesi is dated to Byzantine period in 12. -13. Century.

Façade: *bastion 3-4-5 and city walls between them*

Previous treatment:

The only known previous treatment is out of the studied area. The treatment is on the door side the castle. This side was re- constructed.

Stone type and any predisposing factors (if known):

Limestone,brick, marble (in the early age's exp. B.C. 3000)

Deterioration features:

- *Efflorescence and fissures in the individual stone blocks*
- *Discharge of mortar is assigned.*

%55 of the façade affected by these types of deteriorations

- Evidence of biological growth:

%90 of the façade

Other alteration features:

A sketch of the façade may be provided overleaf

3.3. Experimental Studies

The aim of the laboratory studies is to determine the mineralogical, chemical and the basic physical properties of the stone and mortars used in the walls in order to propose the characteristics of intervention mortars and stone used in the conservation work of the walls.

3.3.1. Sampling

Lime mortars and stones were collected from the walls of the Kadıkalesi (Figure3.1.). Each was labeled by the abbreviations of the mortar (M) and stone in the walls (Table 3.2.).

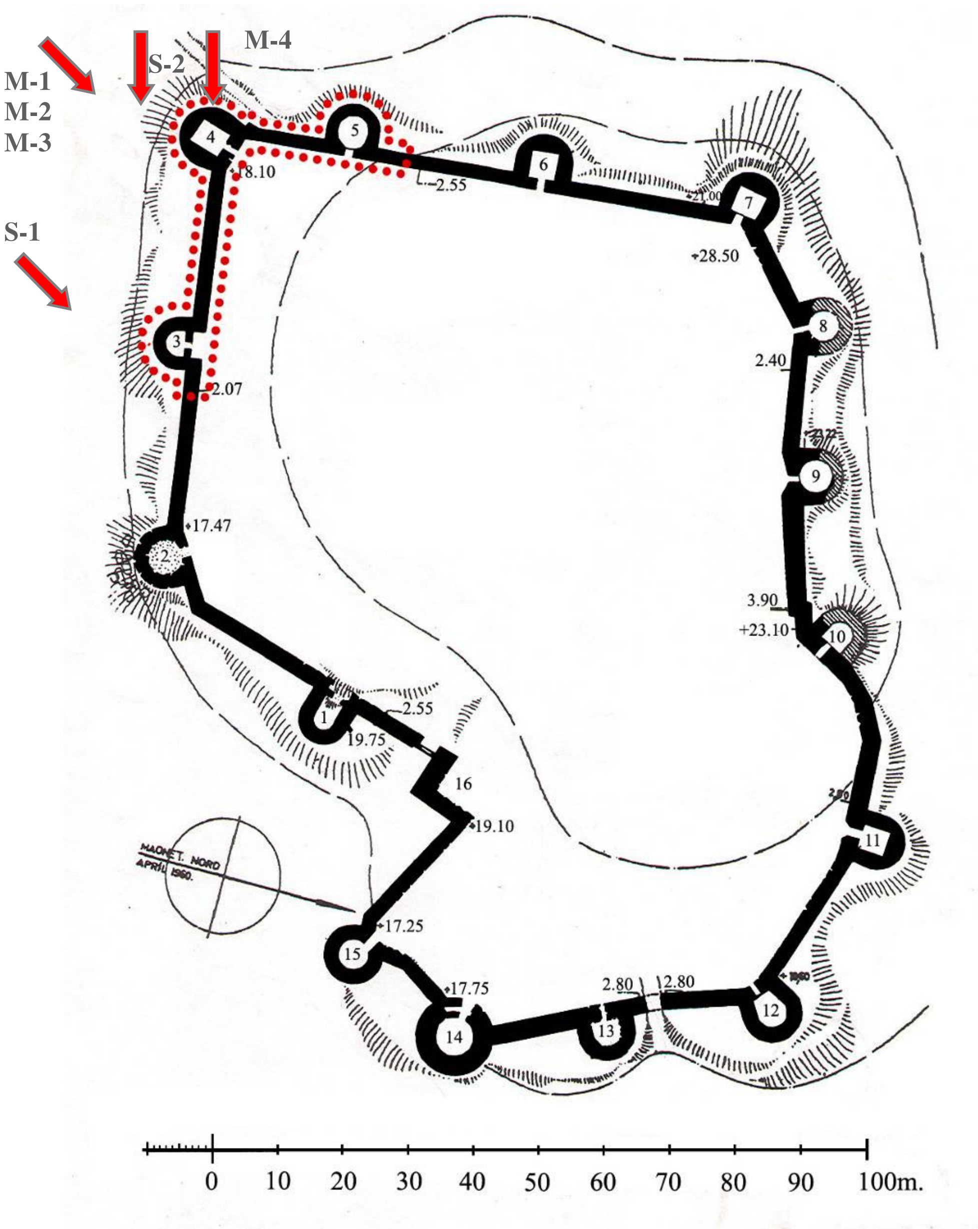


Figure 3. 1. Plan of the studied area of Kadıkalesi
(Source: Müller-Wiener 1961)

Table 3. 2. Definition of the collected stone and mortar samples

Sample:	**Definition:**
M-1	Bastion 4 – interior wall mortar
M-2	Bastion 4-vault exterior surface mortar
M-3	Bastion 4-interior ground mortar
M-4	Mortar of the city walls between 4-5 bastions
S-1	Sound wall stone
S-2	Deteriorated wall stone

3.3.2. Determination of Physical Properties of the Stones and Mortars

Basic physical properties of bulk densities and porosities of mortars and stones were determined by using RILEM standard test methods (RILEM 1980, TSE 699). Bulk density is defined as the apparent density, which is the ratio of the mass to its bulk volume. It is expressed in grams per cubic centimeters (g/cm^3). Porosity is the ratio of the pore volume to the bulk volume of the sample, and is usually expressed in percent (%). Porosity and density are calculated by the following formula (RILEM 1980, Teutonico 1988) :

$$P(\%volume) = [(m_{sat} - m_{dry})/(m_{sat} - m_{arch})] * 100$$

$$D\ (g/cm^3) = (m_{dry})/(m_{sat} - m_{arch})$$

where,

m_{sat} : saturated weight (g)

m_{dry} : dry weight (g)

m_{arch} : the weight of the sample in water (g)

3.3.3. Determination of the Mineralogical, Microstructural and Chemical Compositions of the Stones

Mineralogical compositions of stone samples were determined by X-ray Diffraction (XRD) analysis performed by using a Philips X-Pert Pro X-ray Diffractometer. Their chemical compositions and microstructural properties were determined by Philips XL 30S-FEG Scanning Electron Microscope (SEM) equipped with X-Ray Energy Dispersive System (EDS).

3.3.4. Determination of the Raw Material Composition of the Mortars

Lime-aggregate ratios and particle size distributions of the aggregates were determined in order to define raw material compositions of mortars.

Ratios of lime and aggregates in mortars were determined by dissolving the carbonated lime of mortar samples with dilute hydrochloric (HCl) acid, followed by filtering, drying and sieving of aggregates (Jedrzejevska 1981, Middendorf and Knöfel 1990). Percent acid soluble carbonated lime and insoluble aggregates were calculated with the following formula:

Acid insoluble Aggregates % $= [(M_{sam} - M_{agg}) / M_{sam}] \times 100$

Acid Soluble carbonated lime % $= 100 - \text{Insoluble}\ \%$

where;

M_{sam} : Weight of the mortar sample

M_{agg} : Weight of the aggregates

Percent lime and aggregate ratio was calculated by the using formula as follows:

Aggregate % $= (100 \times \text{Insoluble}\ \%) / [((\text{Acid Soluble}\ \% \times M.W._{Ca(OH)2}) / M.W._{Ca(CO3)}) + \text{Insoluble}\ \%]$

Lime % $= 100 - \text{Aggregate}\ \%$

where;

$M.W._{Ca(CO3)}$: Molecular weight of $Ca(CO_3)$ which is 100.

$M.W._{Ca(OH)2}$: Molecular weight of $Ca(OH)_2$ which is 74.

Particle size distributions of the aggregates were determined by sieve analysis (Teutonico 1988). The aggregates were sieved through a series of sieves (Retsch mark) having the sieve sizes of 53µm, 125µm, 250µm, 500µm, and 1180µm by using an analytical sieve shaker (Retsch AS200). Subsequently, each of the particles retained on each sieve was weighed respectively and each of their percentages was calculated.

3.3.5. Determination of Color and Shape of the Aggregates

Aggregates were examined visually by a zoom stereo microscope (Olympus SZ40) equipped with video camera, photo micrographic system and computer. Images of the aggregates with particle sizes of <1180µm were taken in order to determine their shapes and colors.

3.3.6. Mineralogical Composition of Fine Aggregates

Mineralogical compositions of fine aggregates (less than 53µm) were determined by X-ray Diffraction (XRD) analysis performed by using a Philips X-Pert Pro X-ray Diffractometer.

3.3.7. Determination of Pozzolanic Activity of Fine Aggregates

Pozzolanic activities of fine aggregates (less than 53µm) were determined by electrical conductivity measurements (Luxan et al. 1989). In this method, the differences in electrical conductivities (mS/cm) were measured before and after addition of less than 53-micrometer aggregates into saturated calcium hydroxide solution [20]. The aggregates showing to a difference in the electrical conductivity of more than 1.2 mS/cm are accepted as good pozzolana (Luxan et al. 1989).

3.4. Methodology Used in the Classification and Visual Analysis of Weathering Forms of Stones

The classification and mapping of the stone deterioration observed in Kadıkalesi were studied taking the studies of Fitzner and Warke into consideration (Fitzner et al. 1992, Fitzner 2002, Warke et al. 2003). Both methods were united in order to form an intermediate scale for applying the classification and mapping techniques.

The UAS staging system scheme modeled from TNM staging system by Warke et al. was used in the classification and mapping studies of Kadıkalesi without modification. (Table 3.3.). The definitions and maps of the weathering forms, main and individual weathering forms, damage categories (Table 2.2.) defined by Fitzner were taken into consideration in the scope of this study (Fitzner et al. 1992, Fitzner 2002, Warke et al. 2003). Damage categories and appropriate measurements determined with respect to UAS staging system.

In UAS scheme, the term "U" describes a unit and, defines individual stone blocks. The term "A" describes an area and defines adjoining stone blocks. The term "S" describes a spread defines the size of deterioration all over of the façade. The identification of the deteriorations in stone materials and the interventions and suggestions were developed for every stage. (Warke et al. 2003).

Table 3.3. UAS staging system scheme developed by Warke et al
(Source:Warke et al. 2003).

	U	A	S
STAGE 1	U2 U1	A0 A0	S0 S0
STAGE 2	U1 U2	A1 A1	S0 S0
STAGE 3	ANY ANY	A3 A2	S0 S0
STAGE 4	ANY	S1	S1

The decision about which treatments will be appropriate for a given combinations in Table 3.3. can be summarized as follows

- The combination of U1 or U2 with A0 and S0 is equivalent to stage 1, which suggests continuous monitoring and localized treatment.
- The combination of U1 or U2 with A1 and S0 is equivalent to stage 2, which suggests limited specific intervention.
- The combination of any unit level with A2 or A3 and S0 is equivalent to stage 3, which suggests significant intervention up to %50 of the area.
- The combination of S1 with any unit and area is equivalent to Stage 4, which suggests intervention considering restoration or replacement of stonework.

The, main weathering and individual weathering forms described by Fitzner (Table 2.2.) (Fitzner 2002) were used in every unit defined by Warke in this study. (Warke et al. 2003):

The definitions of the weathering forms were used without modification (Fitzner 2002). The progression rates of the weathering forms given above were used to identify the average damage rates. Average damage rates were used for the determination of unit levels. The definition of the average damage rates was done visually. The parameters of the average damage rates are;

- Volume is used for scaling the deteriorations of break out
- Mass is used for scaling the deteriorations of soiling, crust, salt deposit, granular disintegration, crumbling, detachment of the material
- Depth is used for scaling the deteriorations of back weathering, relief.

- Dimension number are used for scaling the deteriorations of fissures.

According to the parameters used in the identification study, the average damage rates are explained as follows:

- U0 refers to non-visible damage.
- The slightest damages were grouped in U1 level. Besides, U1 refers the deteriorations spread up to %10 of the studied area (Very slight damage).
- More severe damages were grouped in U2 level. Besides, U2 refers deteriorations spread between %10-40 of the studied area. (Slight damage)
- Most severe damages were grouped in U3 level. Besides; U3 refers deteriorations spread more than %40 of the studied area. (Moderate damage)

The definitions of the terms “area” and “spread” which were done by Warke et al. were used in the classification and mapping studies. The definitions for each level as follows:

A0: no involvement of surrounding blocks

A1 : positive involvement of blocks

A2 : positive involvement of blocks surrounding/connecting affecting between %25-50 of façade

A3 : positive involvement of blocks surrounding/connecting affecting between %50-75 of façade

S0: the deterioration is restricted to specific sections of façade

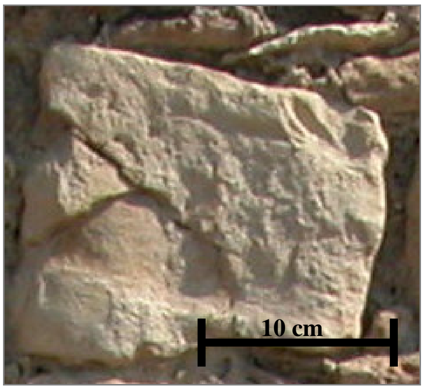
S1 : positive deterioration of blocks affecting distant unconnected portions of façade involving more than %75 of the total surface components

According to the application of the used method on Kadıkalesi case, the observed weathering forms of stone in Kadıkalesi were given in table 3.2.

Table 3.4. The observed wethering forms of stone in archeological site of Kadıkalesi

Loss of stone material
Back weathering
• Due to loss of scales (Figure 3.2.) • Due to loss of crumbs/splinters (Figure 3.3.) • Due to loss of stone layers (Figure 3.4.) • Due to loss of crust (Figure 3.5.)
Relief
• Rounding/ notching (Figure 3.6.) • Alveolar weathering (Figure 3.7.) • Weathering out o Dependent on stone structure (Figure 3.8.) o Weathering out of stone components (Figure 3.9.) • Clearing out of stone (Figure 3.10.) • Roughening (Figure 3.11.) Pitting (Figure 3.12.)
Break out
• Due to constructional cause (Figure 3.13.) • Due to non-recognizable cause (Figure 3.14.)
Discoloration/deposits
Coloration (Figure 3.15.)
Loose of salt deposits: • Efflorescence (Figure 3.16.)
Soiling (Figure 3.17.)
Crust • Colored crust tracing the surface (Figure 3.18.) • Dark colored crust changing surface (Figure 3.19.)
Biological colonization: • Wild grass and higher planting (Figure 3.20.)
Detachment
Splintering (Figure 3.21.)
Crumbling (Figure 3.22.)
Scaling (Figure 3.23.)
Fissures, Deformation
Fissures independent on stone structure (Figure 3.24.)

A



B

Figure 3.2. Back weathering due to loss of scales

Figure 3.3. Back weathering due to loss of crumbs/splinters

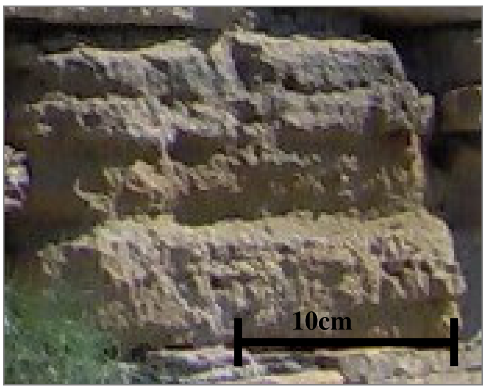
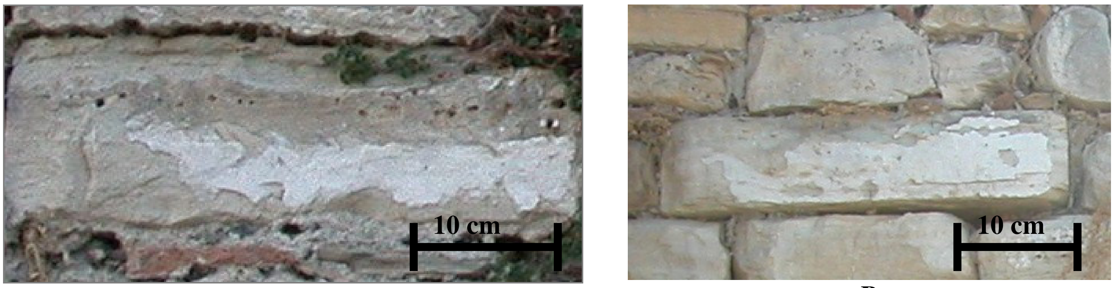


Figure 3.4. Back weathering due to loss of stone layers



A **B**

Figure 3.5. Back weathering due to loss of crust (A, B)

A **B**

Figure 3.6. Rounding/ notching

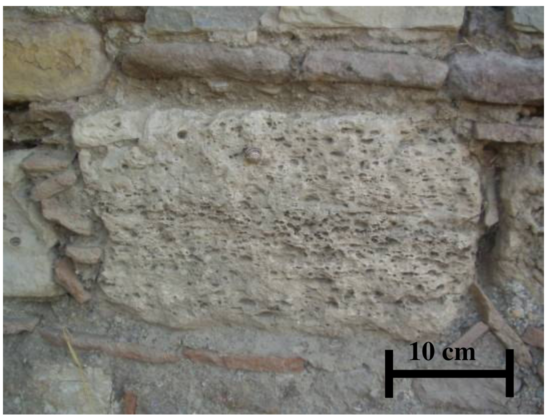


Figure 3.7. Alveolar weathering

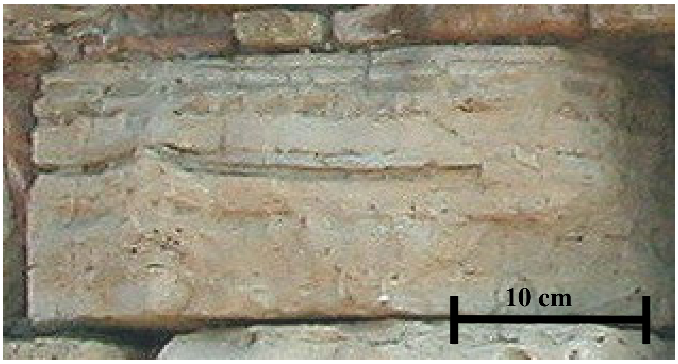


Figure 3.8. Weathering out dependent on stone structure

Figure 3.9. Weathering out of stone components

Figure 3.10**.** Clearing out of stone

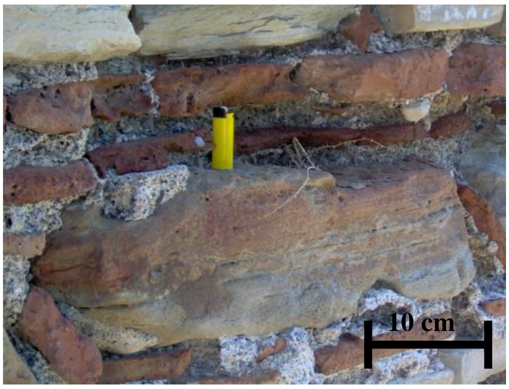


Figure 3.11. Roughening

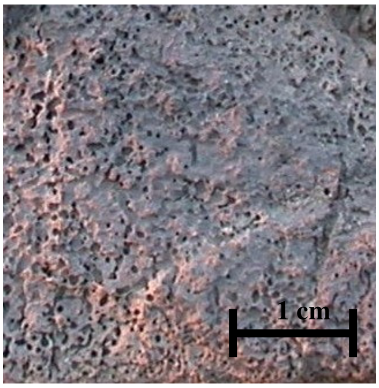


Figure 3.12. Pitting

Figure 3.13. Break out due to constructional cause

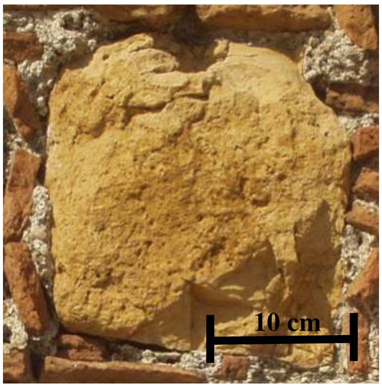
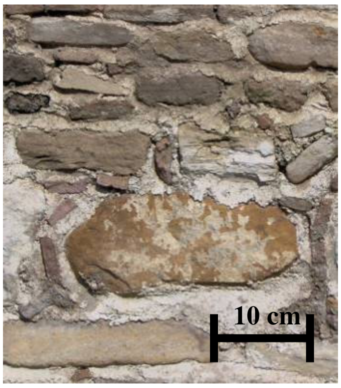


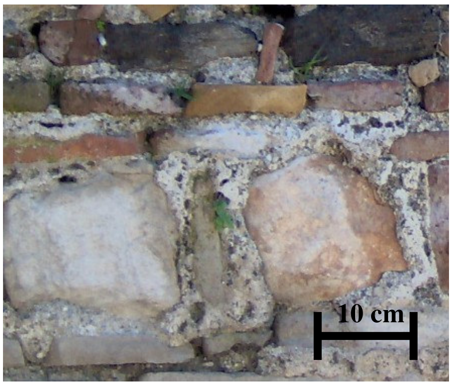
Figure 3.14. Break out due to non-recognizable cause



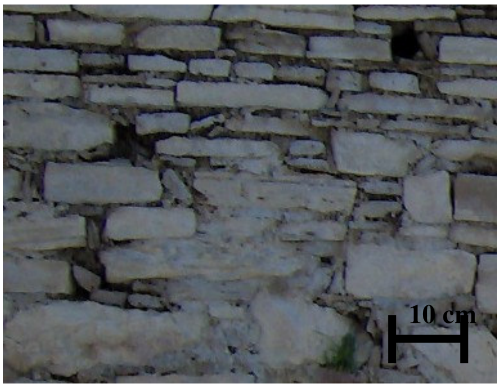
A

B

Figure 3.15. Coloration



A



B

Figure 3.16. Efflorescence (A, B)

Figure 3.17. Soiling

Figure 3.18. Colored crust tracing the surface

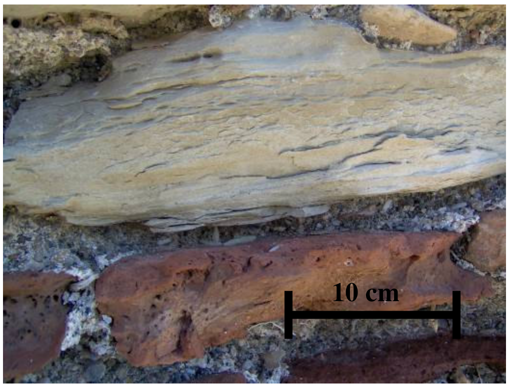
A **B**

Figure 3.19**.** Dark colored crust changing surface

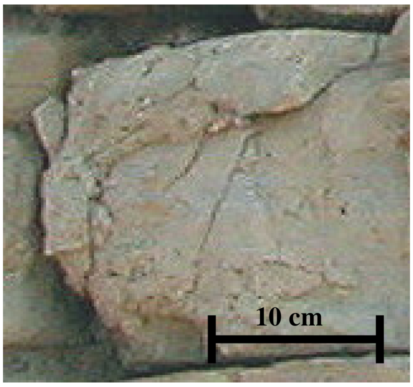
A

B

Figure 3.20. Wild grass and higher planting



A



B

Figure 3.21. Splintering:

Figure 3.22. Crumbling

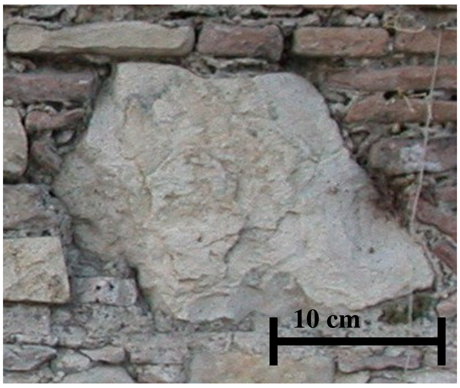
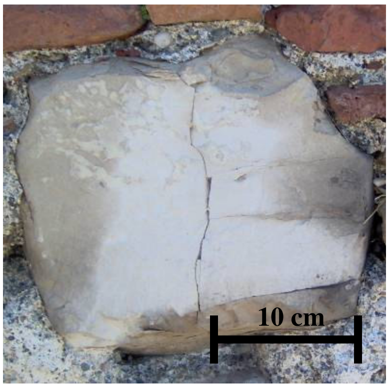
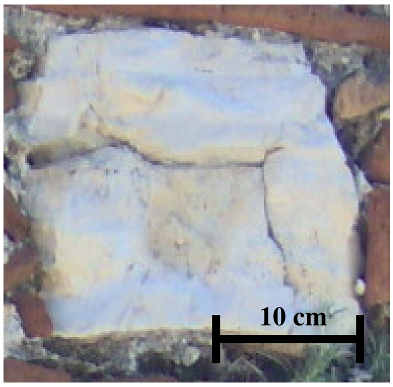


Figure 3.23. Scaling



A



B

Figure 3.24. Fissures independent on stone structure (A, B)

3.5. The Determination of the Progress of Weathering Forms

The progress of weathering forms observed in the studied area during the four-year period between 2002-2005 has also been documented by photographs.

CHAPTER 4

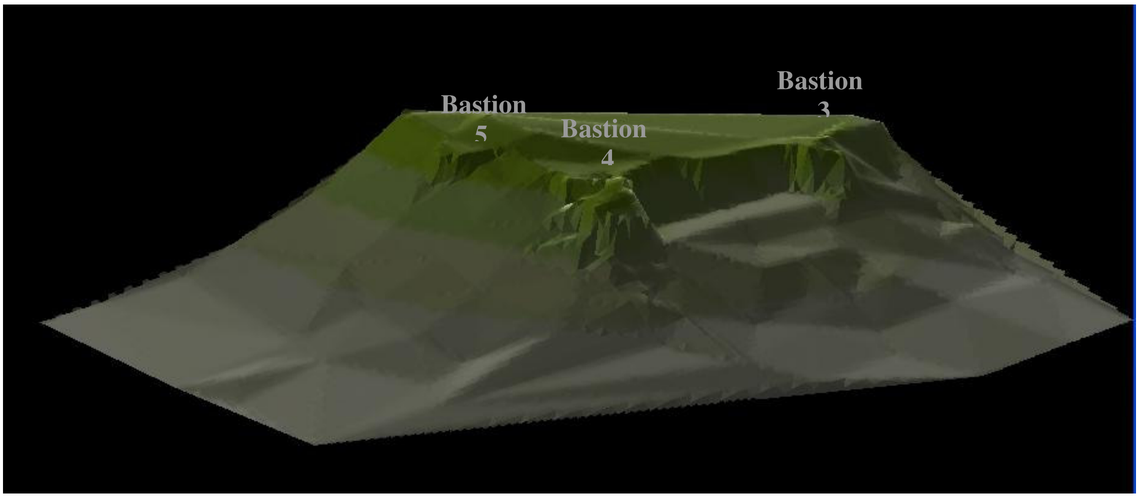
RESULTS AND DISCUSSIONS

The excavations and research have been continuing at Kadıkalesi area since 2001. The application of the methodology of the classification and mapping of weathering forms in study area of Kadıkalesi has been given in this chapter. The 3D views and 2D measured drawings of the facades were shown.

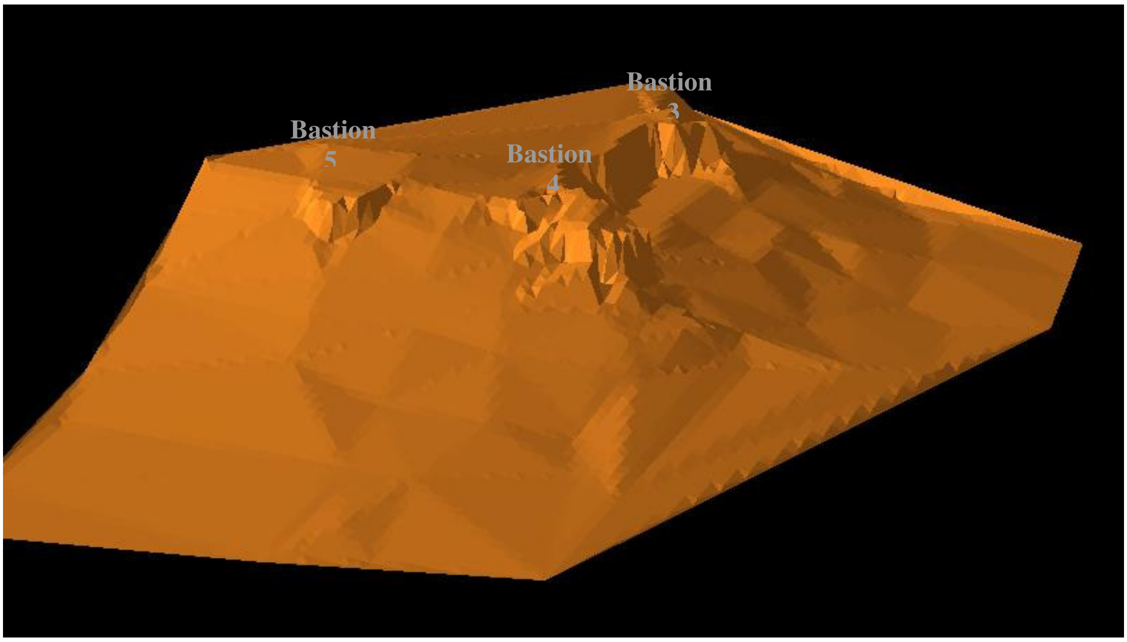
Besides, the observed weathering have been illustrated on 2D drawings of the facades in 2003. A new mapping legend was used to determine the type and spread of the deteriorations and suggested intervention stages. The progress of weathering forms observed in the studied area during the four-year period between 2002-2005 have been documented by photographs and given in this chapter.

4.1. Three-dimensional View of the Area

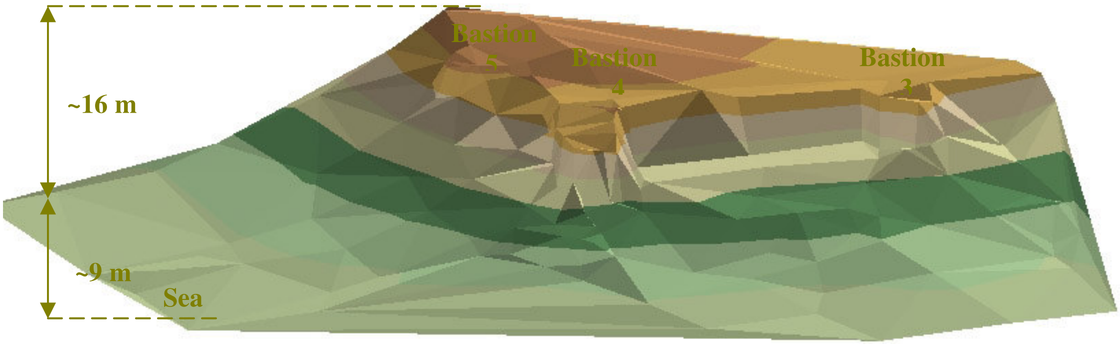
The study area was modeled with NetCAD4.0 GIS program. The data recorded by total station transferred into NetCAD4.0 GIS in order to evaluate 3D drawings of the facades. With respect to 3D drawings and data recorded by total station it is defined that the elevation between the highest point and lowest point was 16m heights. The elevation from the sea is approximately 25m heights from the highest point of the facades. On the other hand the mesurements didn't matched with the country levelling scale.



A



B



C

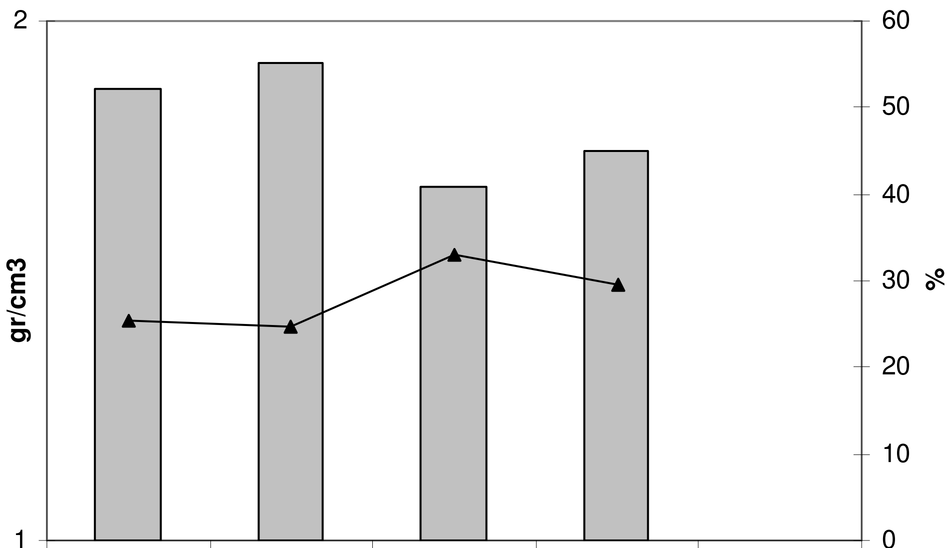
Figure 4.1. 3D views of the investigation area (A, B, C)

4.2. Properties of Stones and Mortars

4.2.1. Physical Properties of the Stones and Mortars

Density and porosity values of mortars were in the range of 1.4-1.9 g/cm^3 and 31-54 % by volume respectively. Density values of the interior ground mortars (M-3) of the bastion were lower and the values of the porosity were bigger than other wall mortars. The density and porosity values of the mortars of the bastion 4 interior walls, bastion 4 exterior surface of the vault, and the mortar of upper southeast city wall were almost in the same ranges (Figure 4.2.).

The porosity values of the stone samples taken from slightly damaged area were identified approximately 3 percent and density values were identified 2.4 g/cm^3. The porosity values of the stone samples taken from moderate damaged area were identified 4 percent and the density values are identified 2.4 g/cm^3. The increase in the porosity accesible to water may indicate the sign of deterioration.



	M-1	M-2	M-3	M-4	
Density	1,9	1,9	1,7	1,8	
Porosity	25,4	24,7	32,9	29,5	

Figure 4. 2. The percentage of the porosity and density values of mortars

4.2.2. Mineralogical and Chemical Compositions of the Stones

Light gray color of limestone blocks were generally used in the walls of castle. The XRD patterns show that stones are mainly composed of calcite with minor amounts of quartz (Figure 4.3.). Micro structural analyses carried out by SEM showed that stone was composed of micritic calcite crystals (Figure 4.4.).

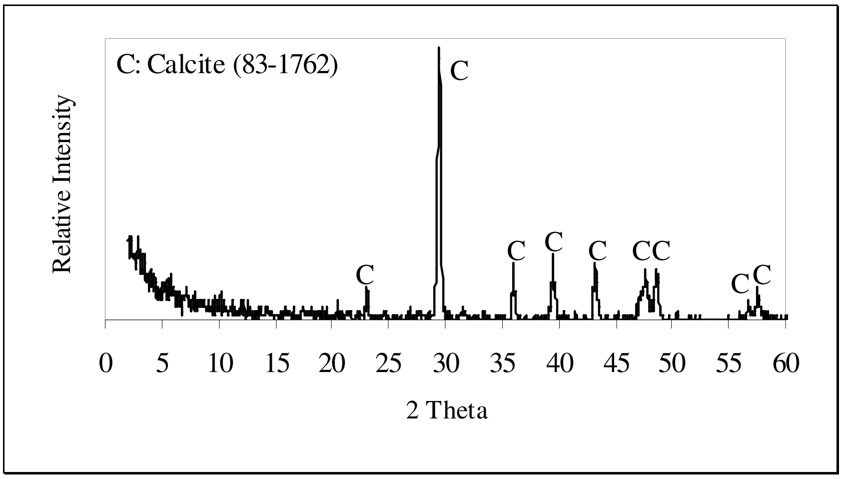


Figure 4.3. XRD patterns of limestone.

EDS analysis of the core of the stones indicated high amounts of calcium oxide ranging between 93 % and 97 % (Figure 4.5.). On the other hand the surface of the flaked parts indicated high amounts of silicon oxide (Figure 4.6.). This may explain the presence of clay minerals in that zones which the main causes of flaking of stone and the formation of biological growth (Garcia–Vallez et al., 2000, Mishra et al., 1995).

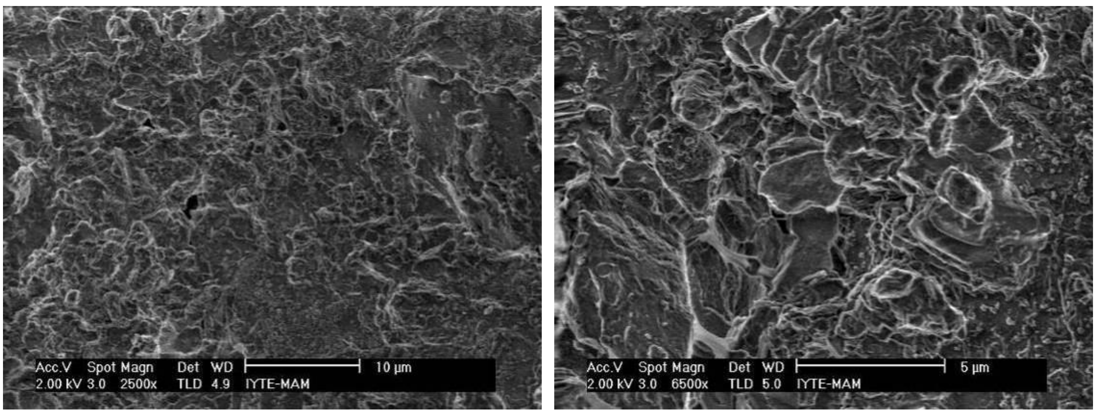


Figure 4. 4 SEM image of calcite crystals in the limestone samples.

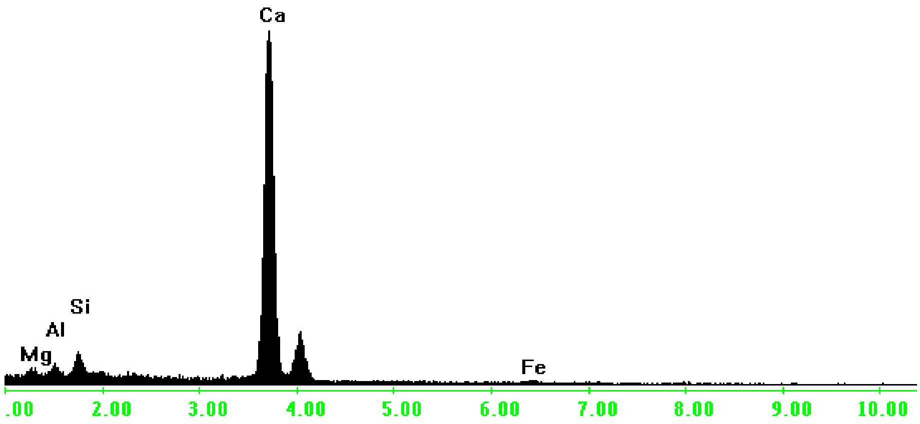
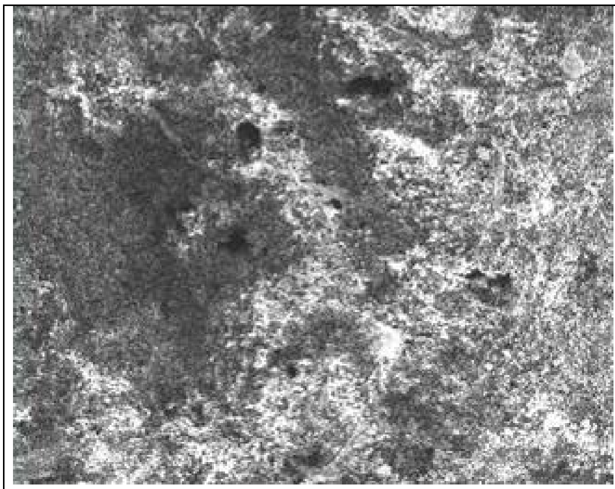


Figure 4.5. EDS analyses of the sound limestone



Element	%
C	9.11
O	46.58
Mg	1.32
Al	3.17
Si	8.73
Cl	0.99
Ca	30.10

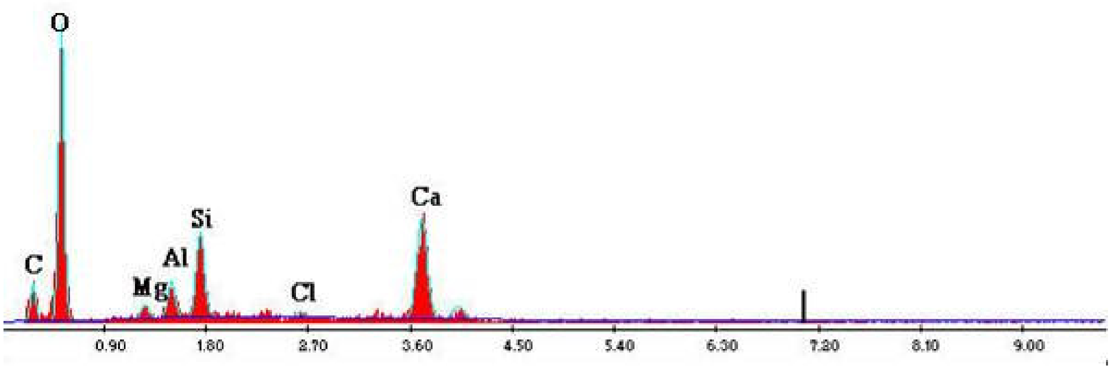
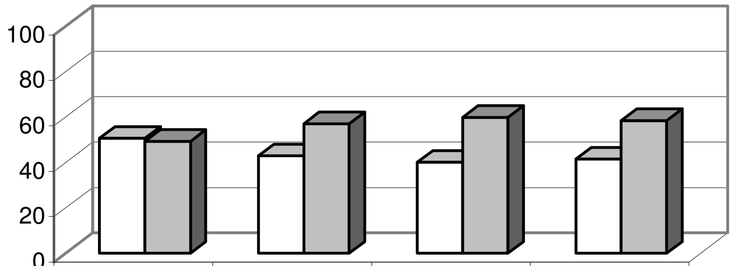


Figure 4. 6. EDS analyses of the crack surfaces of the limestone

4.2.3. Raw Material Composition of the Mortars

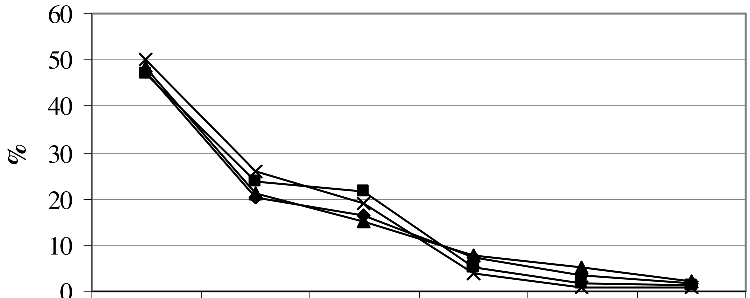
The lime and aggregates ratios of the mortars were found about 1/1 (Figure 4.7.). This may show that the same raw materials and techniques of preparation were used in the mortar preparation .



	M-1	M-2	M-3	M-4
% aggrega	51	43	40	42
%lime	49	57	60	58

Figure 4.7. Weight percent lime and aggregates used in mortars

Particle size distribution of the aggregates decreases from coarse aggregates to fine aggregates in the analyzed mortars (Figure 4.8.). Coarse aggregates which have particle sizes greater than 1180 micrometer composed of nearly fifty percent of total aggregates



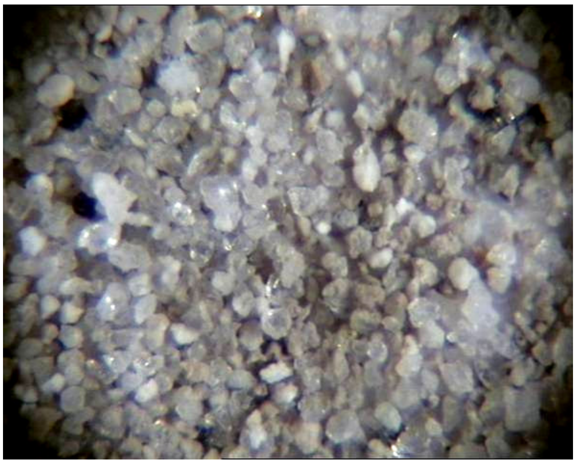
	1180µ	500µ	250µ	125µ	53µ	<53µ
M-1	48	21	16	7	4	2
M-2	47	24	22	5	2	1
M-3	48	21	15	8	5	2
M-4	50	26	19	4	1	1

Figure 4. 8. Particle size distribution of the aggregates in mortar

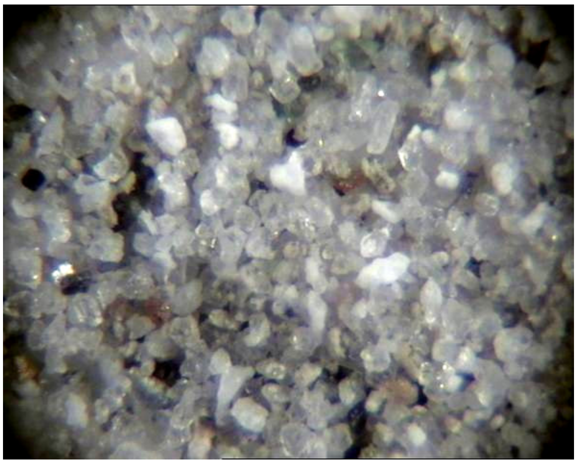
4.2.4. Color and Shape of the Aggregates

The aggregates used in the mortars were composed of semi-circular shape. They were mostly yellowish-white and transparent (Figure 4.9.) .

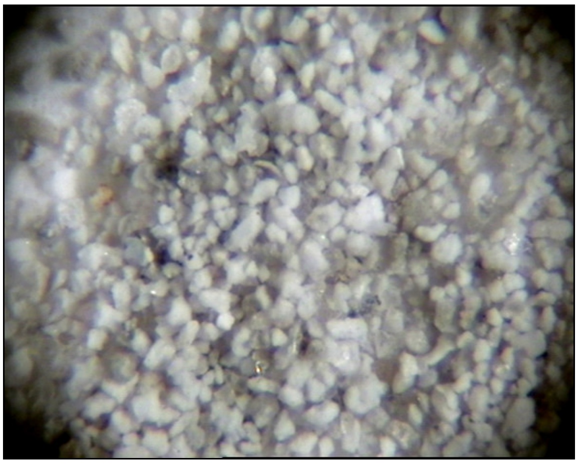
The aggregates in mortar of bastion 4 interior wall (M-1), bastion 4-vault exterior surface mortar (M-2) and between 4-5 bastions (M-4) were almost opaque and transparent. On the other hand, the aggregates in ground mortars were white.



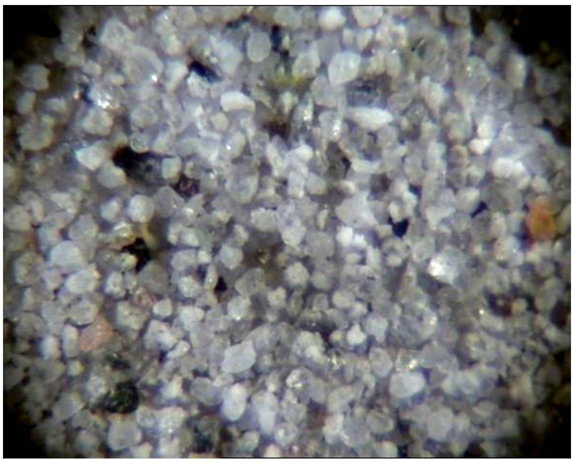
Bastion 4 interior wall mortar (M-1)



Bastion 4-vault exterior surface mortar (M-2)



Bastion 4 interior ground mortar (M-3)

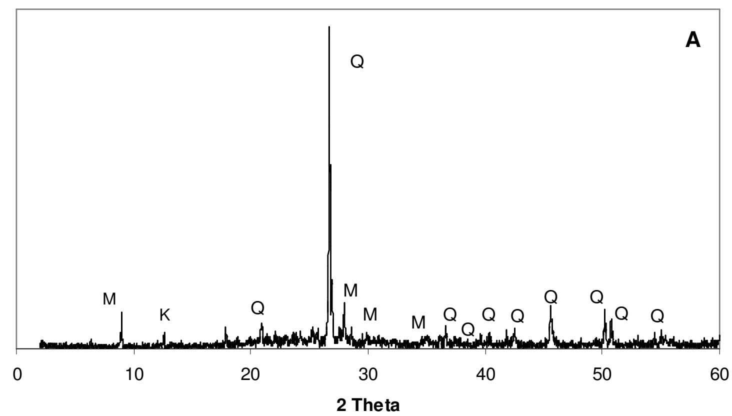


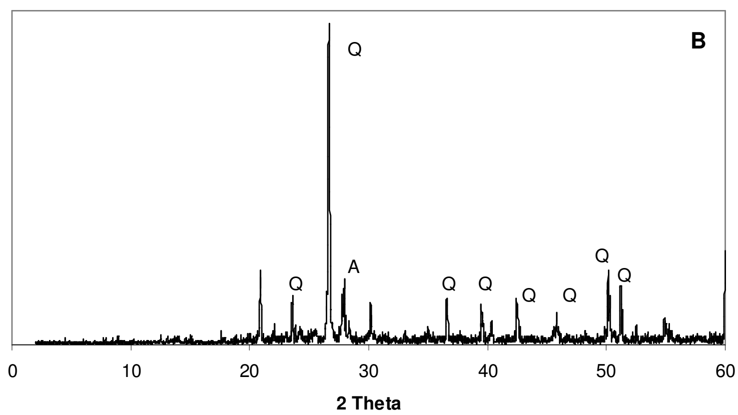
Mortar of the city walls between 4-5 bastions (M-4)

Figure 4. 9. The color and shape of the (250 micron) aggregates

4.2.5. Mineralogical Composition of Fine Aggregates

Quartz and muscovite minerals were basically observed in the XRD patterns of the all fine aggregates of mortars (Figure 4.10.). In addition, the clear diffuse band between 20-30 degrees was also observed in ground mortar aggregates. This may show the presence of pozzolanic amorphous silica verified by pozzolanicity test. The use of natural pozzolanic materials give hydraulic character of the lime mortars. Pozzolanic amorphous substances reacts with lime in the presence of water and form calcium silicate hydrate and tetracalcium aluminate hydrate. Formation of these products gives the hydraulic character mortars and improves their strength.





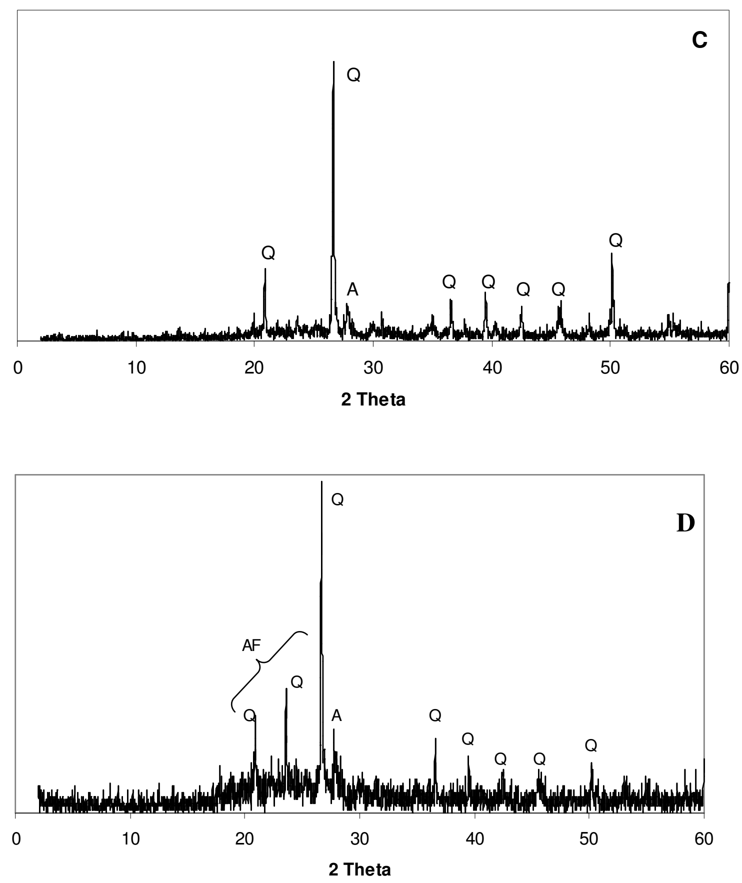


Figure 4.10. The XRD patterns of the fine aggregates (of mortar of the bastion 4 interior wall (A), the vault surface of bastion 4 (B), city walls between 4-5 bastions (C) and interior ground surface of bastion 4 (D).

Q: Quartz A: Albite M: Muscovite K: Kaolinite Ap: Amorphous phase

4.2.6. Pozzolanic Activity of the Fine Aggregates

Pozzolanic activity measurements of all fine aggregates in mortar showed that the diffrence in electrical conductivity values before and after addition of aggretes into lime solution was over 1.2 mS/cm which revealed their good pozzolanicity. The electrical conductivity differences were in varied in the range of 4.69 and 7.01 mS/cm. Significantly higher value was found in ground mortar aggregate (7.01 mS/cm) compared with the other mortars aggregates. The XRD analysis support also the presence of higher amounts of pozzolanic substances in the composition of fine aggregates of ground mortar.

4.3. Mapping of the Weathering Forms Observed in Study Area

The observed weathering forms were described in “unit” legend. For each unit level, observed weathering forms were identified using abbreviations on mappings. Abbreviations are as follows:

Loss of stone material

- Back weathering (bw)
- Relief (r)
- Break out (bo)

Discoloration/ deposits

- Coloration (co)
- Salt deposits (sd)
- Crust (cr)
- Biological colonization (bc)

Detachment of material

- Splintering (sp)
- Crumbling (c)
- Scaling (sc)

Fissures/ Deformation

- Fissures (f)

The involvements of the observed weathering forms of stones were shown in “area” legend (Figure 4.15,4.16) the deteriorations were shown in “spread” legend.

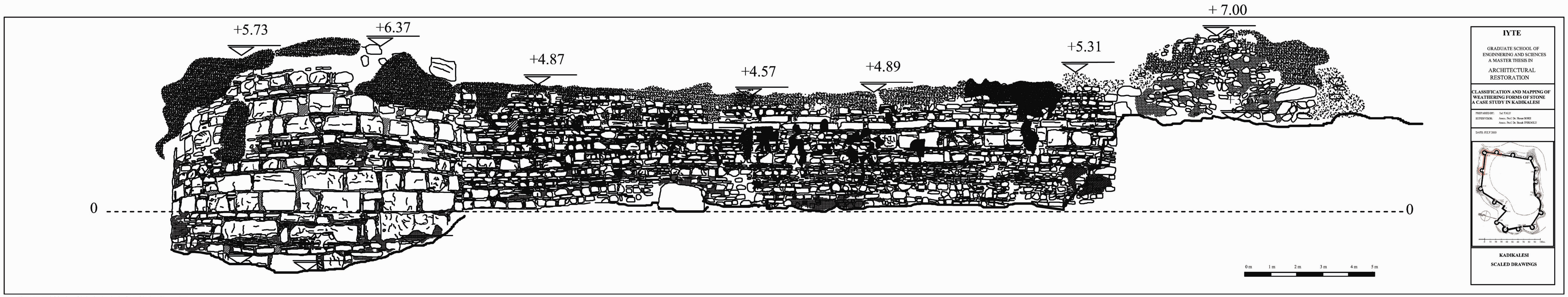


Figure 4.11. Scaled drawings of the bastion three bastion four and the city wall between them

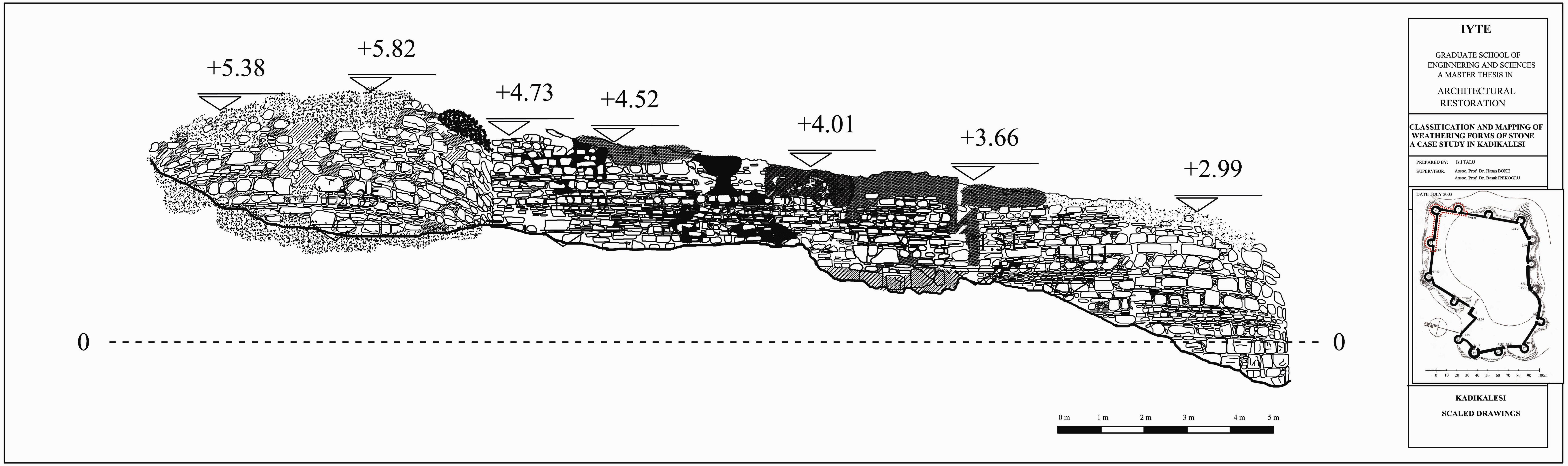


Figure 4.12. Scaled drawings of the bastion four bastion five and the city wall between them

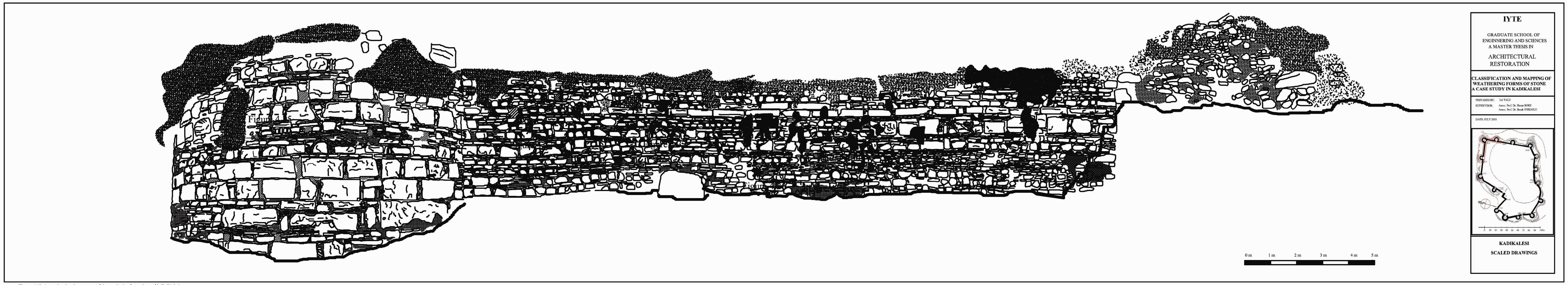


Figure 4.13. Areas showing the progress of the weathering forms observed in Kadıkalesi

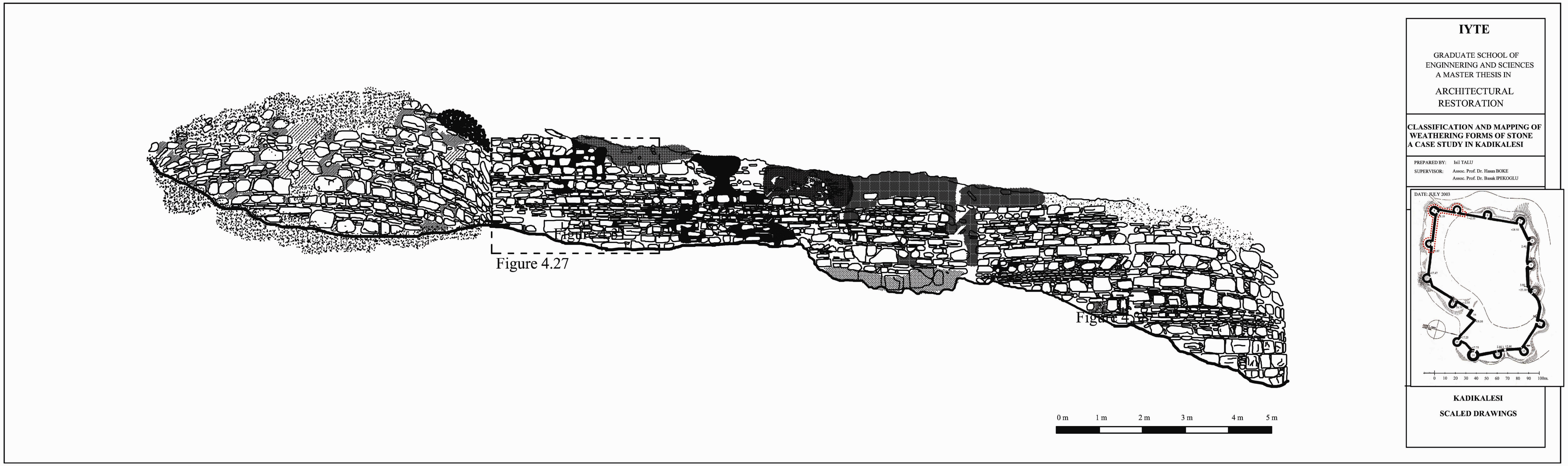


Figure 4.14. Areas showing the progress of the weathering forms observed in Kadıkalesi

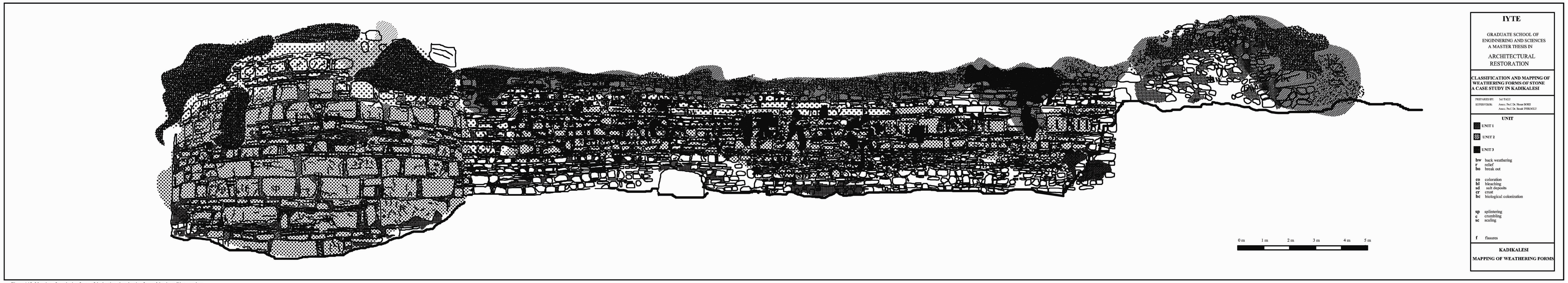


Figure 4.15. Mapping of weathering forms of the bastion three bastion four and the city wall between them

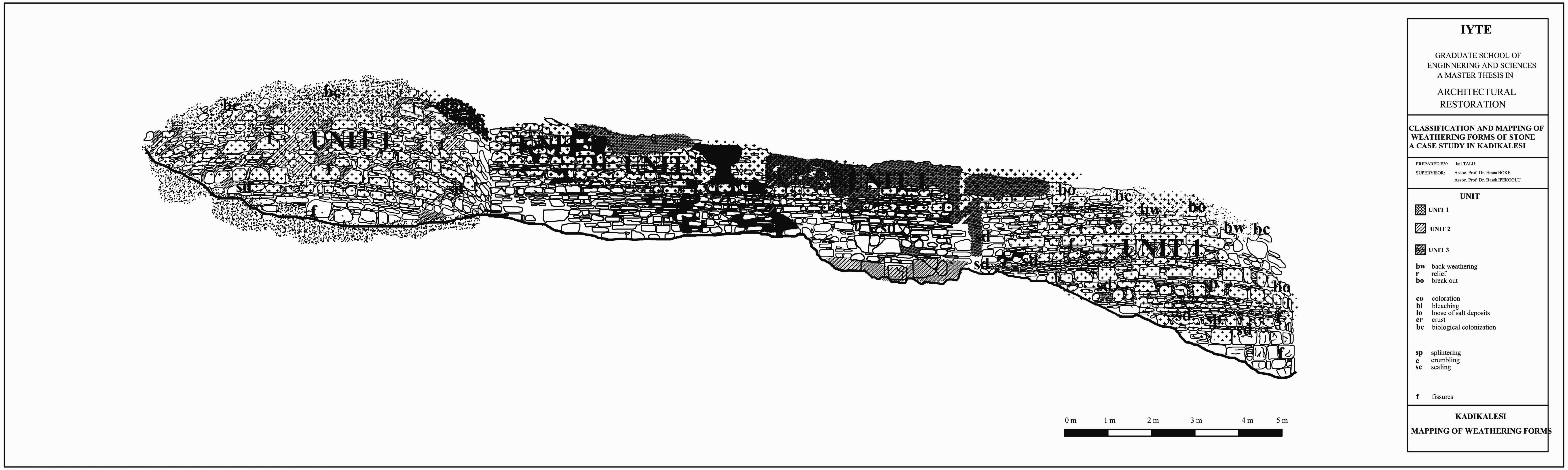


Figure 4.16. Mapping of weathering forms of the bastion four bastion five and the city wall between them

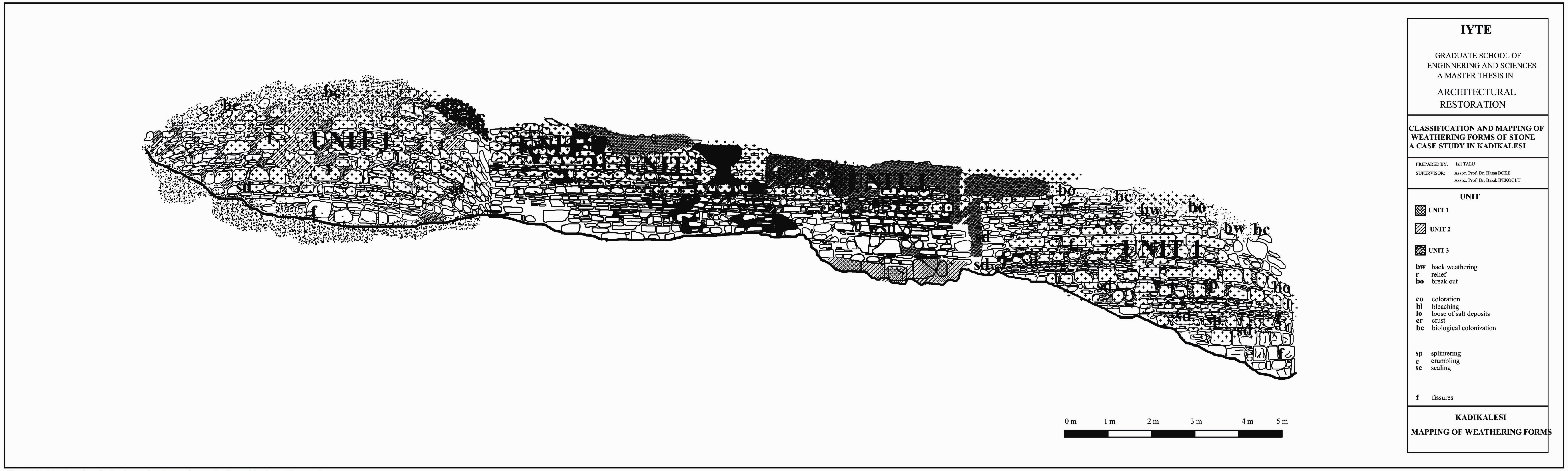


Figure 4.16. Mapping of weathering forms of the bastion four bastion five and the city wall between them

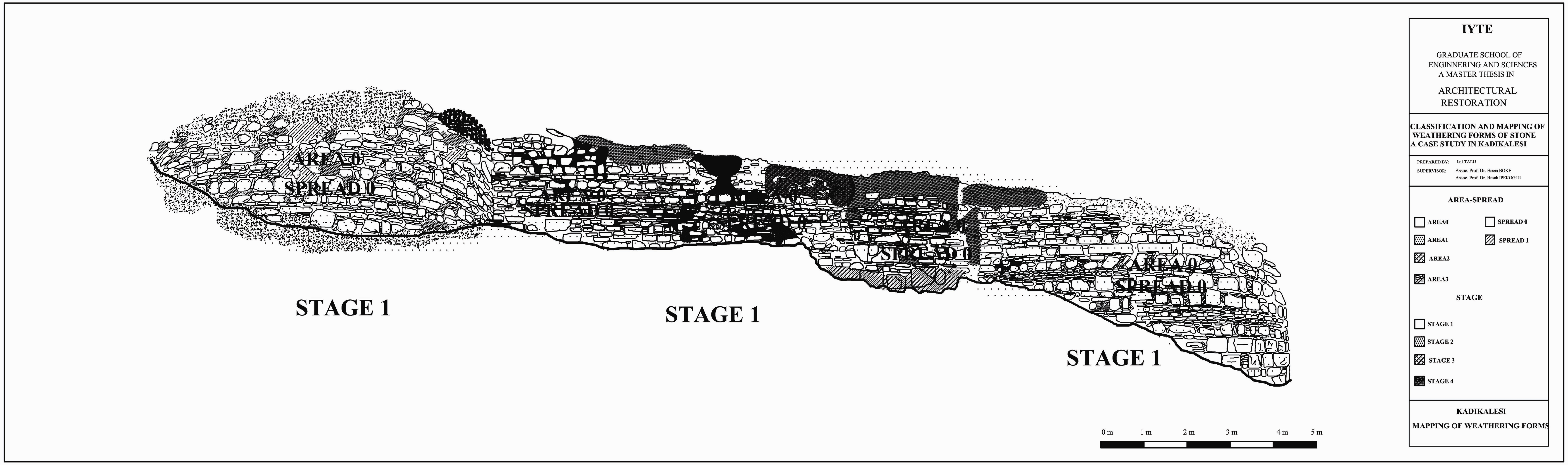


Figure 4.18. Weathering forms of the bastion four bastion five and the city wall between them

The followings were the general results of the used mapping system in studied area of Kadikalesi. The results are given separately for bastions and the city walls between them.

The bastion four (Figure 4.15, 4.16, 4.17, 4.18)

Loss of intact stone blocks in the upper parts, splintering, weathering out of stone components, break out due to constructional cause, fissures, roughening on the stone surfaces were observed in the bastion four (Figure 3.13, 3.24.). Salt deposits were identified in the sea side of the bastion (Figure 3.16.). In the upper parts of the bastion four discharge of mortars were also observed (Figure 4.19.) When considering of the state of deteriorations, stage 1 was indicated by the combination of U1 (characterizing % 40 of the façade), A0 and S0.

- The stage1 suggests continuous monitoring of the progress of stone deterioration. In this region repairing the joint mortars and cleaning of soluble salts are essential.

Figure 4.19. Discharge of mortar

The city wall between third and fourth bastions (Figure 4.15, 4.17)

The observed weathering forms were alveolar weathering, back weathering due to loss of scales, loss of stone layers and extensive loss of crust, coloration, crumbling, biological colonization and scaling in the city wall between third and fourth bastions (Figure 4.20.). When considering of the state of deteriorations, stage 1 was indicated by the combination of U1 (characterizing % 40 of the façade), A0 and S0. The upper parts of the region indicates stage two (characterizing % 20 of the façade) mostly characterizing the higher planting with the combination of U2, A2 and S0.

- The stage one suggests continuous monitoring of the progress of stone deterioration for the lower and middle parts of the façade which were uncovered after excavations recently. Deposited soil and soluble salts on the excavated stone walls should be cleaned.
- Stage two suggests limited specific interventions as hand pulling of the wild grass in the upper parts of the façade. In this part repairing the joint mortars is essential.

Figure 4.20. Coloration, biological colonization and black crust.

The bastion three (Figure 4.15, 4.17.)

The observed weathering forms were loss of intact stone blocks, fissures biological growth characterizing wild grass and higher planting(Figure 4.21,4.22.).

At bastion three joint mortars was discharged and the stones were lifted easily by hand. When considering of the state of deteriorations, stage 2 was indicated by the combination of U2 (characterizing % 70 of the façade), A1 and S0.

- Stage 2 suggests repairing the joint mortars, repairing or sealing fissures, cavities of the stones after wild grass and higher plants were pulled up.

Figure 4.21. Higher planting

Figure 4.22**.** Loss of intact stone blocks

The city wall between fourth and fifth bastions (Figure 4.16, 4.18.)

The loss of intact blocks in the upper parts of the façade, salt and clay deposits and break out were the major weathering forms observed in region. The lower and middle parts were recently excavated. Hence, these parts were in good condition when compared to upper parts. When considering of the state of deteriorations, stage one was indicated by the combination of U1 (characterizing % 25 of the façade), A0 and S0.(Figure 4.23.)

- Stage one suggests cleaning of salts and clay minerals deposited on the wall surfaces.

Figure 4.23**.** The state of deteriorations in recently excavated parts

The bastion five (Figure 4.16, 4.18.)

This region shows the weathering forms of break out, fissures and scaling. Discharge of mortar was also observed in the upper parts (Figure 4.24.). When considering of the state of deteriorations, stage 1 was indicated by the combination of U1 (characterizing % 55 of the façade), A0 and S0.

- The stage one suggests continuous monitoring of the progress of stone deterioration also repairing the joint mortars should be done.

Figure 4.24. Discharge of mortar and break out

4.4. The Progress of the Weathering Forms between the Years 2003-2005

The results of the classification and mapping studies represent an important basis for the evaluation of the weathering forms in relation to the characteristics that the study area is exposed to such as, environmental conditions, marine location and stone properties. A variety of weathering forms was observed in the area, characterizing loss of stone material, discoloration-deposits on the stone surface, detachment of stone material and fissures.

In order to understand the progress of the weathering forms observed in the study area, the state of damages between the years 2002-2005 have been compared.

The considerable frequency of efflorescences and crusts is thought to be the result of salt deposition to limestones as an important weathering factor. The degree of weathering damage appears to be dependent on the marine location. It can be stated that efflorescence is concentrated on the lower parts of the study area, which were uncovered after excavations (Figures 4.32, 4.33, 4.34, 4.35, 4.36, 4.37, 4.31, 5.40, 4.36

4.37, 4.38, 4.46, 4.47). The weathering form of crust commonly occurs in brick materials. As an example for dark colored crust, the progression from unweathered bricks to increasing deterioration of bricks shows itself with a change from brown to black. Light colored crust tracing the surface is another deterioration type found in the study area and it has less affect on stones (Figures4.25, 4.26, 4.27, 4.28, 4.29, 4.30, 4.31, 4.33, 4.36.).

The most frequently observed weathering form was identified as biological colonization, which is a characteristic of the whole study area. Also, the weathering form of the biological colonization was found to be a major cause of the loss of sound stone blocks and fissures (Figure 4.37, 4.32, 4.33, 4.36, 4.46.).

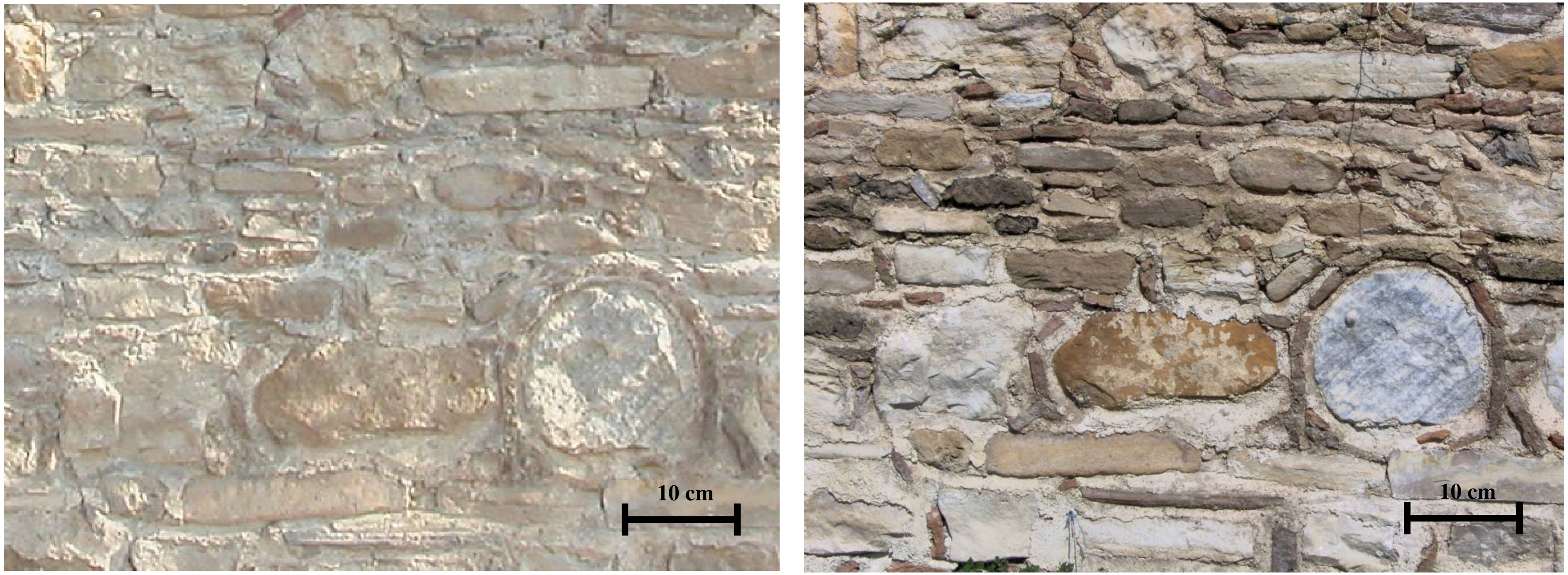
A remarkable range of break out of stone material was found to be due to loss of scales, loss of crusts, loss of stone layers and crumbs. Especially, high frequency and intensity concerning break out due to loss of crumbs was diagnosed as a deterioration feature on limestone blocks affecting % 25 of the façade (Figure 4.32.).

Alveolar weathering and weathering out of stone components are severe deterioration features observed in the study area characterizing the relief. Also, clearing out of stone observed in a smaller amount.

One of the initial diagnosed damage feature was discharge of mortar that can apparently be seen in every part of the study area. Besides, the effect of this weathering form has been increased depending on time and conditions of the study area (Figures 4.32,4.34, 4.35, 4.36, 4.31, 4.34, 4.36, 4.37, 4.46.).

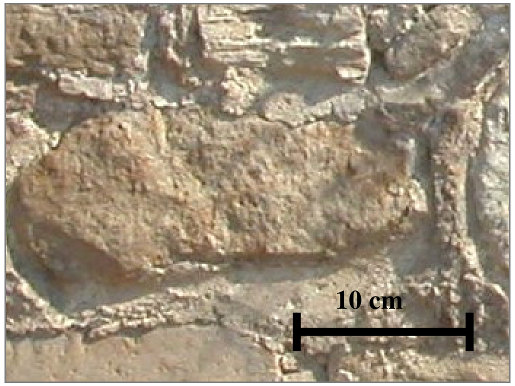
Splintering and scaling represent a slight frequency among the observed weathering forms characterizing current detachment of stone material (Figure 4.32, 4.35.).

Also, the weathering form of fissures was frequently observed in the study area (Figure 4.38.).

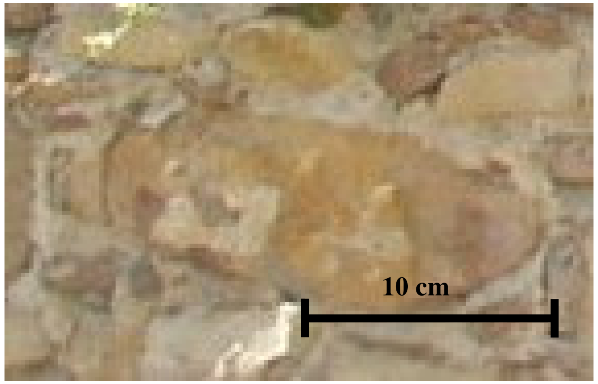


2003 2005

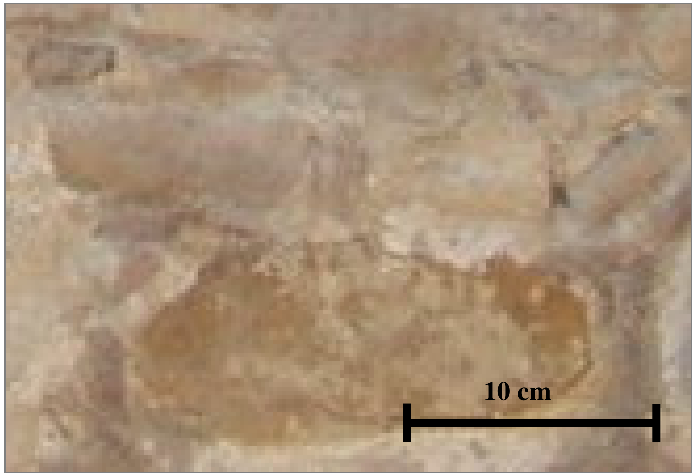
Figure 4.25. Progress of the colored and dark crust tracing the surface and discharge of mortar between the years 2003-2005



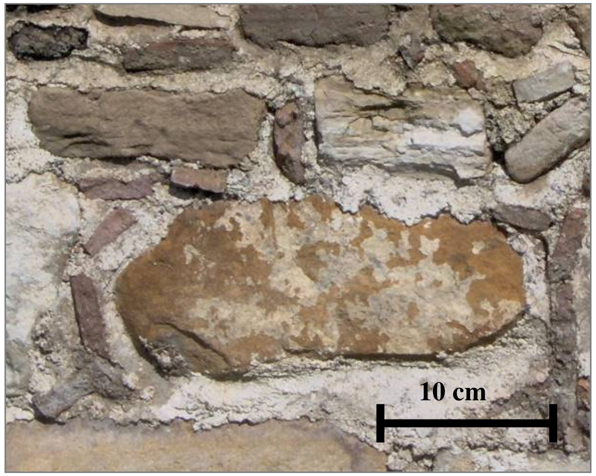
2002



2003



2004



2005

Figure 4.26**.** Progress of colored crust tracing the surface and dark crust between the years 2002-2005

2003

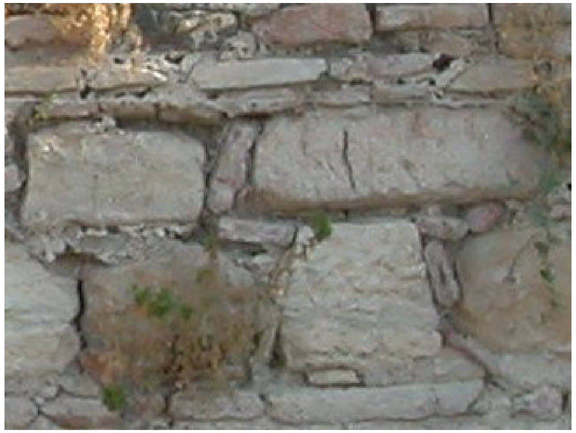
2005

Figure 4.27. Progress of efflorescences and discharge of mortar between the years 2003-2005 in the city wall between 4. and 5. bastions

2003 2005

Figure 4.28. Progress of discharge of mortar, efflorescences and rounding between years 2003-2005 in the bastion three

2002



2003

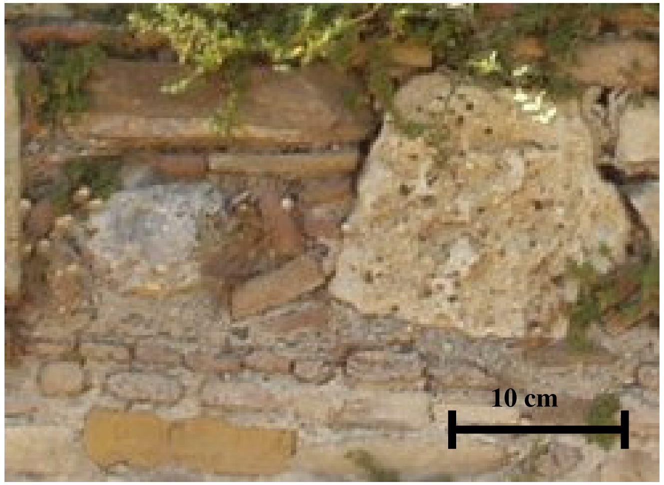
2004

2005

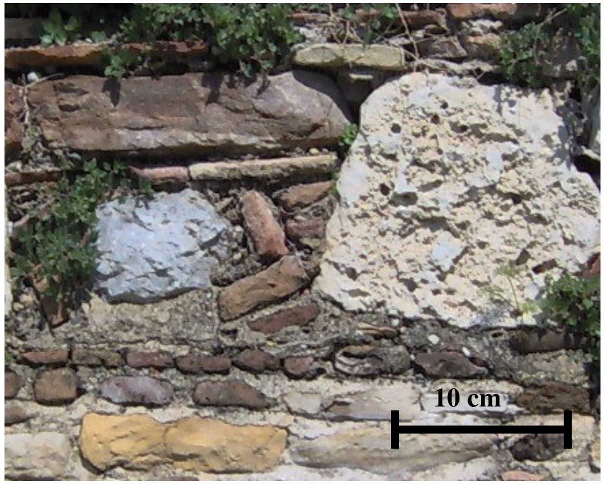
Figure 4.29. Progress of the black crust and discharge of mortar between the years 2002-2005

2002

2003



2004



2005

Figure 4.30. Progress of the black crust, biological colonization and discharge of mortar between the years 2002-2005

2004 2005

Figure 4.31. Progress of the efflorescences and discharge of mortar between the years 2004-2005

2003 2005

Figure 4.32. Progress of the back weathering due to loss of scales and biological colonization between the years 2003-2005

2005

2002

Figure 4.33. Progress of the black crust and biological colonization between the years 2002-2005

2003 2005

Figure 4.34. Progress of the discharge of mortar between the years 2003-2005


2003


2005

Figure 4.35. Progress of the splintering between the years 2003-2005


2002


2005

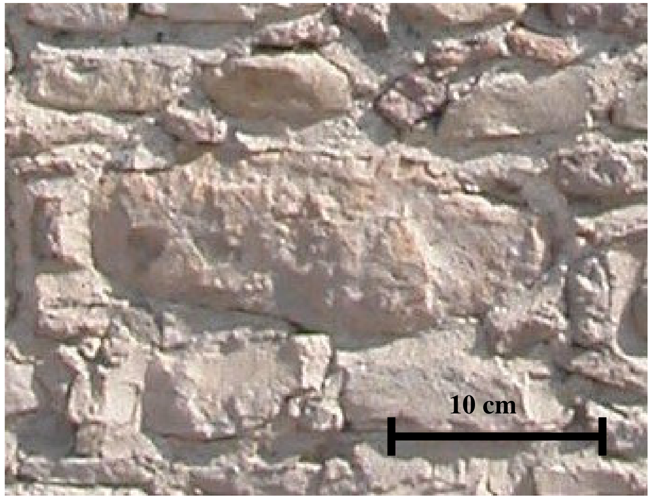
Figure 4.36 Progress of the black crust, biological colonization and discharge of mortar between the years 2002-2003

2003 2005

Figure 4.37. Progress of the black crust and discharge of mortar between the years 2003-2005

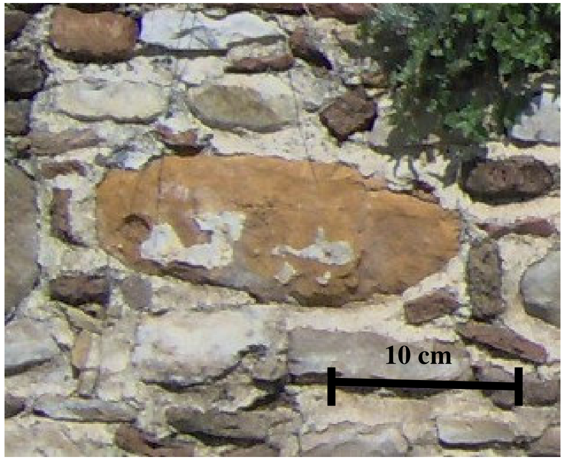
2003 2005

Figure 4.38**.** Progress of the efflorescences and fissures between the years 2003-2005



2002

2003



2005

Figure 4.39. Progress of the colored crust between the years 2002-2005

CHAPTER 6

CONCLUSION

The purpose of this study is to monitor - in an easy and secure way – the stone deteriorations at monuments and to contribute to the process of timely preventive interventions.

With respect to this purpose, the observed deteriorations in the study area have been shown on drawings and the preventive interventions which should be done were determined. The properties of the stones and mortars used in city walls of Kadıkalesi were also identified by laboratory studies. The main conclusions and recommendations derived from this study are given below.

- Classification and mapping of weathering forms observed at stone monuments, walls, etc. in archeological sites is primary step for their conservation. Due to the large area of the archaeological site, identification of the wethering forms and their progress should be done in easy and rapid way to decide urgent interventions. The proposed method in this study would be suitable for this purpose.
- The walls of Kadıkalesi were constructed using local limestone, brick and mortars. Limestones are low porous and mainly composed of calcite and minor amounts of quartz. Lime mortars used as binder in the walls were prepared using %50 lime and %50 pozzolanic aggregates.
- With respect to the used visual classification method following results were obtained:
    - In the bastion four; stage 1 was indicated mostly. Loss of intact stone blocks spread up to %40 of the bastion , fissures spread up to % 30 of the bastion, salt deposits spread up to %40 of the bastion and discharge of mortar spread up to %55 of the facade were the major deterioration types. This area needs continuous monitoring of the progress of stone deterioration. In this region repairing the joint mortars and cleaning of soluble salts are essential.

- In the city wall between third and fourth bastions stage 2 was indicated in the upper parts of the area. In the middle parts of the area stage 1 was indicated. Biological colonization spread up to % 45 of the facade, back weathering due to loss of scales, loss of stone layers loss of crust spread up to % 25 of the facade and coloration spread up to %25 of the facade were major deterioration types of this area. This area needs continuous monitoring of the progress of stone deterioration for the lower and middle parts of the façade which were uncovered after excavations recently. Deposited soil and soluble salts on the excavated stone walls should be cleaned.
- In the bastion three stage 2 was indicated. Loss of intact stone blocks spread up to % 55 of the bastion, discharge of mortar spread up to % 55 of the bastion, wild grass spread up to %50 of the bastion were the major deterioration types. This area needs repairing the joint mortars, repairing or sealing fissures, cavities of the stones after wild grass and higher plants were pulled up.
- In the city wall between fourth and fifth bastions, stage 1 was indicated. Salt deposits spread up to %25 of the facade and loss of intact stone blocks in the upper parts spread up to %15 of the facade were the major deterioration types. This area needs cleaning of salts and clay minerals deposited on the wall surfaces.
- In the bastion five, stage 1 was indicated. Fissures spread up to %25 of the bastion, break out spread up to %25 of the bastion and discharge of mortar spread up to %35 of the bastion were the major types of deterioration. This area needs continuous monitoring of the progress of stone deterioration also repairing the joint mortars should be done.

- In some parts of the walls, mortar was discharged and the stones were lifted easily by hand. The new repair mortars should be compatible with the original ones. Limestone used in the restoration work of the walls should also be compatible with the original ones.

- Biological growth is highly active and rapid in the environment of the Kadıkalesi. Hence, higher plants, organisms and microorganisms play an important role in the deterioration of the limestone, brick and mortar.
- Wild grass are grown in the joints of stone blocks. The hand pulling of them should be carried out with maximum care. To prevent the new formation, joints mortars must be repaired and cleaned from deposited clay and soils.
- The higher plants generally grow in the cracks on the walls. Therefore, repairing or sealing cracks, cavities will prevent further growth.
- The patinas on the stones which is originated by microorganisms does not need any necessary treatments.
- The deposition of the soluble salts which could be originated from soil and marine aerosols is one of the major causes of the stone, brick and mortar deterioration. They must clean in order to prevent further deterioration
- Another cause is identified as clay minerals which ensures suitable conditions for the biological growth. Cleaning of clay minerals and soluble salts from the facades should be done.
- With respect to comparative studies of the observed deteriorations in stones, mortars and bricks of Kadıkalesi it may conclude that deteriorations progress rapidly in last three years by the action of plants, and soluble salts. If the treatments mentioned above will be carried out, the deterioration can be controlled.
- During excavation, deposited soil and soluble salts on the stone surfaces should be cleaned to prevent rapid deterioration.

REFERENCES

Alvarez, J.I., Navarro, I., Casado, P.J.G. 2000. “Thermal, Mineralogical and Chemical Studies of the Mortars Used in the Cathedral of Pamplona (Spain)”, *Thermochimica Acta,* Vol. 365, pp. 177-187.

Bakolas, A., Biscontin, G., Contardi, V., Franceshi, E., Moropoulou, A., Palazzi, D., Zendri, E. 1995 “Thermoanalytical Research on Traditional Mortars in Venice”, *Thermochimica Acta*, Vol. 269/270, pp. 817-828.

Bratianu, G.I Recherches sur la commerce génois dans la mer Noire au XIII[e] siecle, Paris Librairie Oirentaliste Paul Geuthner, 1929

Bulakh, A.G., Zolotarev, A.A., Frank-Kamenetskaya, O.V., Kaminskaya, T.N., Orlova, L.V., Fitzner, B., Mironova, A.A., Cherednichenko,T.S., Lepeshkina, N.F., Savchenok, A.I. 2002. “Bio-inert interactions: Life and Rocks, *Natural stone used in the art monuments in St. Petersburg and Pecularities of its Decay”,* Abstracts of the 1[st] International Symposium, Saint-Petersburg, Russia, (25-27 June 2002), Dannecker, W & Steiger, pp. 208-211.

Cramer, J.A., 1832.“A Geographical and Historical Description of Asia Minor;” with a map, in two volumes, Vol. I.

Dorsey J, Edelman A., Legakis J., Pederson H.K., Jensen H.W., 1999-“Modeling and Rendering of Weathered Stone” **-***International Conference on Computer Graphics and Interactive Techniques* pp. 225-234

Fitzner, B., Heinrichs,K., Kownatzki, R. 1993. “Verwitterungsverhalten am Bauwerk und petrographische Eigenschaften verschiedener Trias-Sandsteine”, Jahresberichte aus dem Forschungsprogramm "Steinzerfall - Steinkonservierung" 1991: 3-19, Förderprojekt des Bundesministers für Forschung und Technologie, Verlag Ernst & Sohn, Berlin.

Fitzner, B., Heinrichs, K., Volker, M., Campos Perez, R. 1993. “Damage investigations on natural stone monuments in Minas Gerais / Brazil”, Proceedings of the International RILEM/UNESCO Congress "Conservation of Stone and other Materials: Research - Industry - Media", Paris, (29 June-1 July 1993), E & FN SPON, London, pp. 360-367.

Fitzner, B., Heinrichs, K. 1994. “Stone and Monuments: Methodologies for the Analyses of Weathering and Conservation, Damage diagnosis at Monuments Carved from Bedrocks in Petra / Jordan”, Proceedings of the III[rd] International Symposium on the Conservation of Monuments in the Mediterranean Basin, Venice, (22-25 June 1994), Soprintendenza ai Beni Artistici e Storici di Venezia, pp. 663-672.

Fitzner, B., Heinrichs, K., Siedel, H., Wendler, E. 1995. “Herkunft, Materialeigenschaften und Verwitterungszustand des Schlesischen Oberkreide-Sandsteins an der Grabkapelle des Heiligen Grabes in Görlitz”, Jahresberichte aus dem Forschungsprogramm "Steinzerfall - Steinkonservierung" 1993: 261-282, Förderprojekt des Bundesministers für Bildung, Wissenschaft, Forschung und Technologie, Verlag Ernst & Sohn, Berlin.

Fitzner, B., Heinrichs, K., Volker, M. 1997. “Model for salt weathering at Maltese Globigerina Limestones.- in: Zezza”, Proceedings of the E.C. Research Workshop "Origin, Mechanisms and Effects of Salts on Degradation of Monuments in Marine and Continental Environment”, Bari (C.U.M. University School of Monument Conservation), (25-27 March 1996), pp. 333-344.

Fitzner, B., Heinrichs, K. 1998. “Evaluation of Weathering Damages at Natural Stone Monuments Carved from Bedrocks in Petra/Jordan - a research project 1996-1999”, *Annual of the Department of Antiquities of Jordan*, Vol. XLII, p. 341-360.

Fitzner, B., Heinrichs, K., Kownatzki, R. 1998. “Dom St. Peter und Paul zu Zeitz - Verwitterungszustand, petrographische Gesteinseigenschaften und mögliche Ersatzgesteine”, Jahresberichte aus dem Forschungsprogramm "Steinzerfall - Steinkonservierung", Band 6 / 1994-1996, Förderprojekt des Bundesministers für Bildung, Wissenschaft, Forschung und Technologie.

Fitzner, B., Heinrichs, K. 1999. “Damage Diagnosis and Preservation of Petra Monuments”, Mediterranean Magazine: Science, Training and Technology, Special issue “New Materials and Methods for the Preservation, Conservation and Restoration of the Mediterranean Cultural Heritage and the Development of an Innovative Environmental Friendly Form of Tourism”, Expert Seminar in Naples, Naples, (24-25 April 1998), Italian National Research Council - Office for Scientific and Technological Cooperation with Mediterranean Countries, Naples, pp. 13-16.

Fitzner, B., Heinrichs, K., La Bouchardiere, D. 2003. “Weathering damage on Pharaonic sandstone monuments in Luxor – Egypt”, *Building and Environment*, Vol. 38, Issues 9-10 (Building Stone Decay: Observations, Experiments and Modeling), p. 1089- 1103.

Fitzner, B., Heinrichs, K., La Bouchardiere, D. 2004. “The Bangudae Petroglyph in Ulsan / Korea - Studies on Weathering Damage and Risk Prognosis”, *Environmental Geology*, Vol. 46, p. 504-526

Galan, E., Aires-Barros, L., Christaris, B., Kassoli-Fournaraki, A., Fitzner, B. & Zezza, F. 1997. “Representative Stones from the Sanctuary of Demeter in Eleusis (Greece), Sta. Marija Ta'Cwerra of Siggiewi (Malta) and Bari (Italy) and Cadiz (Spain) Cathedrals: Petrographic Characteristics, Physical Properties and Alteration Products.- in: Zezza”, Proceedings of the E.C. Research Workshop "Origin, Mechanisms and Effects of Salts on Degradation of Monuments in Marine and Continental Environment", Bari (Italy), (25-27 March 1996), C.U.M. University School of Monument Conservation, pp. 77-85.

Garcia-Valles M., Urzi C., De Leo F., Salamone P., Vendrell-Saz M.2000 “Biological Weathering and Mineral Deposits of the Belevi Marble Quarry”-*Interneational Biodeterioraiton & Biodegradation* Vol. 46 pp. 221-227

Heinrichs, K.2004. “Assessment of Weathering Progression on Rock-Cut Monuments in Petra / Jordan”, 32nd Int. Geol. Congr., Abs. Vol., pt. 1, abs 145-4, pp. 672.

Heinrichs, K. 2004. “Impact of Weathering Processes on Building Materials: the Cairo Case Study”, 32nd Int. Geol. Congr., Abs. Vol., pt. 2, abs 228-8, pp. 1035.

Heinrichs, K. and Fitzner, B., 2000. “Lithotypes of Rock-Carved Monuments in Petra / Jordan - Classification and Oetrographical Properties”, *Annual of the Department of Antiquities of Jorda,* Vol. XLIV (edited by J.A. Sauer, M. Al-Muheisen Memorial), p. 283-312.

Heyd., W., 1885-86 “Histoire du commerce du Levant au Moyen Age**”**, edited by. Fr. Par Furay-Raynaud, 2 vol, Leipzig, (reedited in 1967).

Lindqvist, J.E., Sandstrom, M. 2000. “Quantitative Analysis of Historical Mortars Using Optical Microscopy”, *Materials and Structures*, Vol. 33, pp. 612-617.

Middendorf, B., Knöfel D. 1989. “Use of Old and Modern Analytical Methods for the Determination of Ancient Mortars in Northern Germany”, NATO, CCMS Pilot Study, Conservation of Historic Brick Structures, 3rd Expert Meeting Proceedings Book, Hamburg, (2-4 November 1989), pp. 75-92.

Mishra A. K., Kamal K. Jain, Garg K.L.1995 “Role of higher plants in the Deterioraiton of Historic Buildings” *–The Science of the Total Environment.* Vol. 167, pp. 375-392

Moropoulou, A., Zezza, F., Aires-Barros, L., Christaras, B., Fassina, V., Fitzner, B., Galan, E., Van Grieken, R. Kassoli-Fournaraki, A. 1994. “Marine Spray and Polluted Atmosphere as Factors of Damage to Monuments in the Mediteranean Coastal Environment - A preliminary Approach to the case of Demeter Sanctuary in Eleusis”, Proceedings of the IIIrd International Symposium on the Conservation of Monuments in the Mediterranean Basin, "Stone and Monuments: Methodologies for the Analyses of Weathering and Conservation", Venice, (22-25 June 1994), pp. 275-286.

Moropoulou, A., Bakolas, A. and Bisbikou, B. 1995. “Characterization of Ancient, Byzantine and Later Historic Mortars by Thermal and X-ray Diffraction Techniques”, *Thermomica Acta*, Vol. 269/270, pp. 779-795.

Moropoulou, A., Bakolas, A. and Bisbikou K. 2000a. “Investigation of the Technology of Historic Mortars”, *Journal of Cultural Heritage*. Vol. 1, pp.45-48.

Müller-Wiener, 1961. “Mittelalterliche Befestigungen im südlichen Jonien” İstanbuler Mitteilungen 11(1961), pp. 65-69.

Nikolaos, M.Z., Economou, I.G., Tzevelekos, K.P, Kikkinides, E.S. 2000. "Investigation of the Physicochemical Characteristics of Ancient Mortars by Static and Dynamic Studies", *Cement and Concrete Research.* Vol. 30, pp. 1151-1155.

Philippson, A., 1910-1913 Topographisce Katre des westlischen Klenaisen, 6 Blatt, Gothe.

Riccardi, M.P, Duminuco, P., Tomasi, C., Ferloni, P. 1998. "Thermal, Microscopic and X-ray Diffraction Studies on Some Ancient Mortars", *Thermochimica Acta*. Vol. 321, pp. 207-214.

RILEM 1980. "Tests Defining the Structure", *Materials and Construction*. Vol. 13, No. 73.

Schaffer, R.J., 1972. *The Weathering of Natural Building Stones*. Building Research Station, Garston.

Tavukçuoğlu, A., 2000. "Taş Yapılarda Malzeme Bozulmalarının Görsel Analizi – Ağzıkarahan Örneği", *Yapı Dergisi*. Haziran 2000, p. 100-106.

TSE 699 (1987) Methods of Testing for Natural Building Stones, *Türk Standartları*, Ocak Ankara, pp. 9-15.

Warke H. A., Curran, J. M., Turkingston, A.V., Smith, B. J., 2003. "Condition Assesment for Building Stone Conservation: A Staging System Approach"- *Building & Environment.* Vol. 38, Issue 9-10, pp. 1113-1123

Wiegand, T.– Schrader, H., 1904. "Priene", Berlin pp.490-491