

## Classification of Physical, Chemical and Biological Deteriorations Observed in Ankara Stone Monuments

Musa Tokmak<sup>1</sup>, Murat Dal<sup>2\*</sup>

<sup>1</sup>Middle East Technical University, Graduate School of Natural and Applied Sciences, Archaeometry, Ankara, Turkey

<sup>2</sup>Munzur University, Faculty of Engineering, Department of Civil Engineering, Tunceli, Turkey

musatokmak3@yahoo.com<sup>ID</sup>, \*muratdal@munzur.edu.tr<sup>ID</sup>,

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### Abstract

There are many monuments made of stone in and around Ankara city center. Due to the geographical location of Ankara, due to its terrestrial climate, physical, chemical and biological deteriorations can be seen as one or combination of three types. Human-induced damages are just as effective as natural degradation types and even caused more damage. The monuments mentioned in this study are: Temple of Augustus, Roman Bath ruins, Julian Column and Gavurkalesi. The first three monuments are located in the Ulus district of Ankara, close to each other. Gavurkalesi is located in Dereköy in the Haymana district of Ankara. Since samples could not be taken from these monuments, the classification of the types of disruption was made to observe and the disruption types were listed by visual examination. A more detailed form of this study necessitates laboratory work. While doing such a study, the samples must be taken from the broken pieces and without damaging the monuments. The purpose of this study is to prepare a document with a preliminary preparation for the restoration of these monuments.

**Keywords:** Deterioration types, Historical monuments of Ankara, natural and building stones, non-destructive testing

## Ankara Taş Anıtlarında Gözlemlenen Fiziksel, Kimyasal ve Biyolojik Bozulmaların Sınıflandırılması

### Öz

Ankara il merkezinde ve çevresinde birçok taş eserlerden yapılmış anıtlar bulunmaktadır. Ankara'nın coğrafi konumu gereği karasal bir iklimde olması sebebiyle bu taş eserlerde fiziksel, kimyasal ve biyolojik bozulmalar tek tek görülebildiği gibi kimi tarihi eserlerde bu üç bozulma türü aynı anda da olabilmektedir. İnsan kaynaklı zararlar doğal bozulma türleri kadar etkili ve hatta daha fazla tahribata sebep olmuştur. Bu çalışmada konu olan anıtlar şunlardır: Augustus Tapınağı, Roma Hamamı kalıntıları, Julian Sütunu ve Gavurkalesi. İlk üç anıt Ankara'nın Ulus semtinde olup birbirlerine yakın konumdadırlar. Gavurkalesi Ankara'nın Haymana ilçesine bağlı Dereköy mevkindedir. Bu eserlerden örnekler alınmadığı için bozulma türlerinin sınıflandırılması gözleme yoluna gidildi ve bozulma türleri ayrı ayrı olarak listelenmiştir. Bu çalışmanın daha detaylı bir şekli mutlaka laboratuvar çalışması gerektirmektedir. Böyle bir çalışma yapılırken örnekler mutlaka kopan parçalardan alınıp eserlere zarar verilmeden yapılmalıdır. Bu çalışmanın amacı, bu anıtların restorasyonu için bir ön hazırlık içeren bir doküman hazırlamaktır.

**Anahtar Kelimeler:** Bozulma çeşitleri, Ankara'nın anıtsal yapıları, doğal ve tapı taşları, tahribatsız muayene

### INTRODUCTION

Preserving cultural-historical stone buildings is very important for their transfer to future generations. Cultural heritage refers to archaeological monuments, architectural structures and other historical sites. These structures undergo various deterioration problems with

various environmental and atmospheric effects. In this study, the deterioration caused by physical, mechanical, chemical, biological and human effects are classified, and macro and micro scale deteriorations are examined.

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Historical cities and their unique monuments are the achievements of the past. We learn from the stones about other detailed information on the construction processes of buildings. Nowadays, it is difficult to protect historical buildings with rapid population growth, rapid urbanization and public works. Necessary information should be given about the cultural heritage of all members of the society and the sensitivity required for its protection should be instilled to all generations. For that reason, a good quality education is needed. The educated technical personnel should be more trained in the best possible way, as architects and engineers who are sensitive to the historical and natural environment, knowledgeable and interdisciplinary are needed to restore the restoration of degraded historical buildings (Khooshroo et al., 2017).

Natural stones were commonly used as building materials until the 1800s, and after that date, they were widely used as coating materials in the architectural buildings. Natural stones, especially known as immortality, have been widely used in architectural structures due to their durability. Architectural structures built with stone materials have undergone various types of deterioration by environmental factors. If there are no suitable solutions for these deteriorations, the structures will face extinction. It is very important to make the most accurate damage determination. The building stone restoration must be done without damaging. For the most accurate diagnosis, alteration and damage types should be done at the first stage. Accurate diagnosis, correct analysis, correct restoration, periodic maintenance and sustainable protection are required to transfer stone architectural structures to future generations.

Natural stones used in the architectural structures are formed from mineral communities or by multiple combinations of a single mineral. For example, while granite and basalt are composed of various minerals, marble is composed of multiple combinations of a single mineral. It is important to know the technical properties of natural stones such as physical, mechanical, chemical and petrographic in architecture for the longevity of the building (Ridgway, 1999; Dal and Öcal, 2013a, b; Dal and Öcal, 2017a, b, King, 2017; Tokmak, 2017).

Ankara has been used as a residential area since the Paleolithic period. Ankara, which was used as a military base especially during the Hittite period,

was also used as a settlement in the Phrygian period. Being a settlement area in the middle of the Central Anatolia region of Ankara, which was chosen as a settlement area during the period of Turkish principalities before the Ottoman period, always attracted the attention of different civilizations (Foss, 1997). The deterioration problems were observed in the stones of many historical buildings in the Ankara region. The historical building stones are formed from andesite, basalt and marble. Chemical, physical and biological deteriorations have been seriously observed in some parts of the building blocks in Ankara monuments. The biggest reason for the deterioration observed in the building blocks is moisture, air pollution and salt accumulation observed on the building stones and in the lower layers. The fact that Ankara is in a terrestrial climate, and the large temperature and night differences are triggered by physical deterioration. Accordingly, crumbling and breaking occurred in the stones. Likewise, the presence of fossil fuels, which were used extensively in Ankara until the 1990s, caused chemical decomposition and blooming in stones. Coal, which has been used as fuel for years in Ankara, has caused a significant accumulation of sulfur dioxide and nitrogen oxide in the atmosphere. At the same time, sulfur and nitrogen gas from the vehicles in the traffic have also been effective in the destruction of the building blocks in the castle. Especially humid days and nights were effective in the transfer of sulfur and nitrogen into marble, basalt and andesite stones (Tokmak, 2005; Tokmak et al., 2006; Küçükkaya and Dal, 2008; Dal, 2010; Dal, 2011; Dal and Umaroğulları, 2014).

Augustus Temple, Julian Column and Roman Baths Remnants are located in Ankara's Ulus region. Gavurkalesi is only situated on a nearby hill in Dereköy village in Haymana. These monumental buildings have been standing for years despite Ankara's cold and continental climate. The difference between daytime and nighttime temperature, which is an important feature of terrestrial climate, is causing physical destruction on these monuments. In addition to physical and chemical deterioration, it also contributes to the destruction of stone monuments during biological degradation (Küçükkaya and Dal, 2008; Dal and Irgas, 2012; Öcal and Dal, 2012; Ergin et al., 2019). Due to the physical deterioration, some of the

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surface of the rock in the Hittite monument in Gavurkalesi have also been erased and destroyed (Dal, 2012). The lack of archaeometric work and the failure to classify the types of degradation of monuments is a shortcoming so far. The purpose of this study is to prepare a document containing a preliminary preparation for the restoration of these monuments (Öcal and Dal, 2017; Ergin et al., 2020 a, b).

Faulty materials and techniques used in restoration, air pollution caused by industrial activities, heating systems in cities, gases from motor vehicles damage building blocks in various ways. With the wrong restorations applied in the buildings, vandalism, fires, traffic, intense tourism, public works, long-term neglect and unconscious use cause damages on the stones.

## MATERIAL AND METHOD

Roman baths remnants, Julian column and Augustus temple remnants are situated very close to each other. Only Gavurkalesi is located in the Haymana district of Ankara. The physical, chemical and biological factors affecting these structures vary according to the stone types, which are the building materials in which the monuments are made. In this study, these types of degradation are described by visual observation (Fitzner et al., 1992). It has been studied as a systematic method for mapping surface defects.

Being a method that does not damage to the historical structure, it provides valuable information before the works to be done for the protection of the structure. The classification of decomposition forms has been published as a list as a result of the examination of different types of stones and is now widely used. In this study, the Fitzner method was applied and the deterioration types are divided into four parts.

### Definition and observation

The building stone can be degraded from chemical, physical, mechanical and biological reasons (Caneva and Salvadori, 1988). The deterioration starting from the outer surface of the stone to the inner surface may sometimes be on the outer surface from the inner surface. Many factors such as the porosity structure of the stone, the relationship with some of the porosity networks, the temperature of the environment and atmospheric

pollution are effective in stone deterioration (Crocì, 1998). In humid and hot weather, chemical degradation is dominant and degradation is rapid. However, physical degradation is more effective in cold-dry weather, and the degradation rate in stones is slower (Fitzner, 1994). To describe the deterioration that seen on the monuments, four main groups and subgroups were given below as a list (Fitzner et al., 1995).

### Group I: loss of material

Deterioration in the form of fracture, material losses that occur in the stone and breaks during the construction of the structure are the main factors. The edges of the floor of the Julian column and the surface of the column were broken due to one of the main reasons mentioned above (Figure 1). The loss of material, which appears uniformly parallel to the original surface of the stone, is seen intensely on Roman objects (Figure 2).



**Figure 1.** Loss of material in the form of fracture observed at the edges of Julian column



**Figure 2.** Loss of material on the upper part of the stone due to physical decomposition in Roman tombstone of the Roman period

This type of deterioration is particularly intense in areas where there is physical detachment. This kind of decomposition is dominant in places where the temperature difference between day and night is great as well. Such deterioration problems are also present on the lower surfaces of the Augustus temple (Figure 3).

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**Figure 3.** Ruptures that are the type of physical decomposition observed on the lower surfaces of the Augustus temple

Factors such as rainwater and wind can lead to the loss of a proportional form of material on the surface of the stone, and the shapes and letters on the surface of the monument stone disappear over time. Such distortions are called "roundness (Rr)". The material loss of the lion statue in the Roman baths can be seen, especially due to the rounding in the face part (Figure 4).



**Figure 4.** Distortion of roundness due to erosion in the face of a lion statue in Roman baths remnants

The greatest damage of the roundness is seen in Hittite figures in Gavurkales and the figures of Hittite soldiers are stripped from the stone surface due to erosion and lose their original shape (Figure 5).

As a result of the granular disintegration of the stones due to the erosion, they are present in the form of "rounding", it can especially be seen at the edges and the upper parts of the monument stones. The relief-type degradation, "roundness", is similar to erosion-induced distortions. Rounding is also



**Figure 5.** Loss of material due to deterioration and rounding of Hittite military figures in Gavurkalesi over time from the original form

a loss of material in corners. In the picture below, rounding is shown on the upper surface and edges of the Roman andesite stone block of the Roman period (Figure 6).



**Figure 6.** Deterioration resulting in loss of material due to deposits on the andesite stone inscription in the Roman bath remnants

The gaps or holes that can be seen on between the stone surfaces can be of various sizes. Due to structural reasons, the holes that are uncovered on the surface of the stone to mount an element accelerate the deterioration on

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the surface of the stone over time and may come to break on the surface of the stone. In particular, due to the restoration of the surface of the Augustus temple, too many holes were opened (Figure 7). This is why material losses are common. Such deterioration can also trigger other types of deterioration. For example, chemical substances may accumulate in the stone pits due to atmospheric pollution (Figure 8).

### Group II: color change/accumulation

There are subgroups of this type of degradation. The subgroups are the “color change of the stone surface” and “accumulation of chemical substances on the stone surfaces such as dust and various kinds of organic and inorganic substances”. The plant roots between the gaps and cracks of the stone on the surface can cause physical/chemical/mechanical deterioration on the surface (Figure 9). Plants on the surface of Gavurkalesi were observed and these plants emerged in cracked areas caused some small cracks.



**Figure 7.** Loss of material from the stone surface due to holes in the surface of Augustus temple due to structural reasons. Particularly the stratification (accumulation) of the black color around the holes



**Figure 8.** A close view of the holes on the surface of the Augustus temple. Due to the atmospheric pollution, black-colored accumulation clearly visible around the holes

Drip type deterioration was seen especially in the Augustus temple. Pigeons are a threat to the Augustus temple because the pigeons in the Haci Bayram mosque are fed by the visitors. The presence of water-soluble salts such as sulfate, nitrate and



**Figure 9.** Plant colonization in the cracks on the surface of Gavurkalesi stone block



**Figure 10.** Contamination caused by pigeon and bird feces on the marble surface of Augustus temple

phosphate in pigeon and bird feces causes deterioration in the type of contamination on the marble surfaces of the structure (Figure 10).

Some marble surfaces on the Augustus temple have black patina (stains) formed by bacteria (Figure 11).

No algae, lichen or fungus type biological colonizations have been observed on the andesite, marble and basalt stone blocks of the monuments in Ankara. Biologic deposits have not been observed in some monuments because such biological lives prefer more than 70% relative humidity and over 10 °C or large temperature environments. The most important point is that they do not like atmospheric pollution. However, on the marble surfaces of the Roman baths stones, biological stratigraphy and stains are observed from algae and lichen species. Algae are single-celled organisms that live in the form of colonies. In general, algae that live on very damp surfaces can form a compact, tightly textured or film-like layer on the rock. Figure 12 shows algae colonies on marble surfaces.

On the surfaces of many marble gravestones in the Roman baths remnants, lichen, black algae and mushroom-like biological colonizations are seen at the same time. In particular, lichens and algae-like biological deposits that appear on the sides and upper parts of marble stones can crack the stones and cause decomposition. Particularly those organisms that love moist areas prefer to use roof surfaces. Lichen and moss formed on the surface appear orange, black and yellow (Figure 13).

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**Figure 11.** Black patina formed by bacteria on the marble block



**Figure 12.** Biofilm formation on the marble surface



**Figure 14.** Lichen, algae, fungus occurrences in Gavurkalesi stone blocks



**Figure 13.** Lichen and algae occurrences on the tombstones of Roman baths remnants

Gavurkalesi is situated in the rural area and it has more lichen-like formations, especially on the upper part of the stones around the monument. The most important factor is that the pollution in this area is less if compared with the city center. The influence of atmospheric pollution on historical monuments located in the center of Ankara prevents the accumulation of lichen, algae, fungus and algae colonization on these stone surfaces. Gavurkalesi is situated on a city away place that is not affected by pollution and traffic pollution (Figure 14).

### Group III: granular disintegration

Granular/physical dissolution (dusting, crumbling, sanding), scattering, thinning, crusting, stratification and solubility of the rocks on the stone are the main subgroups. Granular dissolution is caused by the breakage of small pieces from the stones. Particularly, the breakdown of the stone surface is accelerated by the granular dissolution wind, which is due to salting, and the existence of rain, that is erosion. Such deterioration is particularly evident on the walls of the temple of Augustus, especially near the lower floor where moisture is present (Figure 15). There was no such deterioration in other monuments.

### Group IV: cracks / deformation

This kind of decomposition refers to distortions as a result of changes occurring in the structure of the stone in its group. Cracks and deformations that occur in the stones are characteristic of this group. Cracks are observed especially in marble blocks of Roman baths remnants (Figure 16). The marble block was used as a door joist. Because of the heavy load pressure, the roofs have become tattered in vertical and horizontal directions. In addition to this, it is affected by various factors such as temperature due to the cracks by the expansion of the capillaries.

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The thin and small cracks observed on the stones are also found on the basalt rocks forming the macro cracks Gavurkalesi (Figure 17), and on the marble monument stones in the remnants of the Roman baths (Figure 18).



**Figure 15.** Granular disintegration on the walls of the Augustus temple. When touched by hand, some pieces are handled like sand



**Figure 16.** Fractures on marble stone block found in Roman baths



**Figure 17.** Cracks on the basalt rock of Gavurkalesi

## RESULT AND DISCUSSION

Physical, chemical and biological deterioration causes decays in and on the stone surfaces and they are expected for material losses and destruction of non-recyclable materials in the years. Ankara is located in a continental climate, there are a lot of



**Figure 18.** Cracks on Roman marble monuments

temperature differences between day and night and the use of fossil fuels until the 1990s in the center of Ankara can be summarized as the main factors for

the stone deterioration. The most obvious types of deterioration that appear in monuments are physically-based decays. This article summarizes the types of deterioration observed in the building stones of Roman baths remnants, the temple of Augustus, the Julian column and the Gavurkalesi, which are the symbolic monuments of Ankara. It is observed that such physical deterioration is the main factor on the surface and lower parts of the Julian column, marble and stone monuments in the remnants of the Roman baths, some marble blocks in the Augustus temple and the surface of the Gavurkalesi monument. In those studied monuments, the physical degradation is faster than chemical degradation by separating the stone surface into small pieces. The stones, the surface area of which increases with physical deterioration, become smaller due to the effect of chemical deterioration, causing the separation to progress. Salts are the main factor of chemical deterioration. Algae, fungus and algae, which are biological accumulation, were observed only on the surfaces of the memorial stones in the remnants of the Roman baths. These formations, which do not have a direct destructive effect, change the texture of the stone surface in color and will cause deterioration over time if measures are not taken. Table 1 shows that the main decay types are loss of material and color change due to material accumulation. The less observed decay type on the monuments is granular disintegration. The ruins of buildings in the remnants of the Roman baths, the Julian monument and the Augustus temple are around the Ankara citadel. The weathering types and degrees are similar to comparing Ankara citadel stones' deterioration and the types of degradation observed in Fitzner's monumental deterioration (Tokmak, 2005).

There is no chemical change in the structure of the stone in physical decays. The temperature differences in the stones cause different stresses. Moisture that settles in the stones carries the water-soluble salts into the pores, and by repeating this event many times, the size of the damage in the stone moves from micro to macro. When the water settles in the stone structure, it turns into ice, it creates pressure on the stone, creating capillary cracks, and then causing larger size fragmentation.

In chemical deterioration, especially water and air pollution is effective. As a result of this deterioration, the composition and crystal structures

**Table 1.** The monuments and decay types

Monuments / Decay Types	Group I: Loss of Materials	Group II: Color Change / Accumulation	Group III: Granular Disintegration	Group IV: Cracks / Deformation
<b>Augustus Temples</b>	Holes and gaps (by human factors)	Accumulation of birds feces Black pollution accumulation in the holes	Sanding	x
<b>Julian Column</b>	Materials loss at the edges of the bottom	x	x	Microcracks (Vertical and horizontal positions)
<b>Roman Baths</b>	Roundness on the stone surfaces (erosions)	Color change by biological colonization (liken, algae, moss)	x	Microcracks
<b>Gavurkalesi</b>	Roundness on the stone surfaces (erosions)	liken, algae, fungus colonization	x	Makro cracks (Vertical positions)

of the stones change. Carbonation, oxidation, melting, base change are among the most common types of chemical degradation.

Biological deteriorations are often seen on moist and rough surfaces. Moss, algae, bacteria, lichen, fungus, herbaceous and woody plant roots, maggots, insects, birds, ants are the main biological deteriorations sources

The above-mentioned monuments were visually inspected by an in situ. Physical, chemical and biological deterioration types are classified by the Fitzner method. The effect and degree of each deterioration is different. This study has identified the problems observed in which and will be a “stepping stone” in future restoration work. Via this study, it will help in the future studies on these monuments. Also, laboratory studies must be carried out. These studies will support the visual analysis that we do now.

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