# Conservation Science and the role of Engineering Geology in studying material properties; a case study of the Székesfehérvár Ruin Garden

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**ABSTRACT**: The protection of monuments that have been already considered as important for a nation's cultural heritage is nowadays required. In order to choose the best conservation strategy i.e. methods and products, a thorough research is necessary for understanding deeply the causes of deterioration of the construction. In the implementation of the research related to the properties of building stones, engineering geology plays an important role. The case study of the Székesfehérvár Ruin Garden can be an illustrative example due to the size of the monument, its different phases of construction in the Middle Ages and the several identified lithotypes found in the remained part of the construction. Several samplings were carried out for the identification of the lithotypes. For the most important of them, various methods were used aiming to determine the phycico-mechanical properties of the stones such as the characterization of pores, water absorption, uniaxial compressive strength and micro-drilling resistance. Mapping of selected wall sections has been implemented as well, depicting the distribution of the various lithotypes and the observed decay and weathering forms.

*Keywords*: conservation science, engineering geology, material's properties, building stone, Székesfehérvár Ruin Garden

## 1. INTRODUCTION

The Székesfehérvár Ruin Garden is a unique assemblage of monuments belonging to the cultural heritage of Hungary due to its important role in the Middle Ages as the coronation and burial church of the Kings of the Hungarian Christian Kingdom. It has been nominated for "National Monument" and as a consequence, its protection in the present and future is required.

Moreover, it was reconstructed and expanded several times throughout Hungarian history. By a quick overview of the current state of the monument, the presence of several lithotypes can be found among the remained building and decorative stones. Therefore, the research related to the materials in order to understand their composition, structure, origin and behavior is crucial not only for the conservation of that specific monument but also for a series of other historic structures in the Hungarian territory.

## 2. CULTURAL HERITAGE AND CONSERVATION SCIENCE: CURRENT ISSUES

By cultural heritage we mean everything that originates in the past of a historical and/or artistic importance. In some cases it can be called tangible as for an object, a collection of objects housed in a museum or a monumental building, in some others intangible, for instance the customs and traditions of a nation. For both tangible and intangible occasions, whatever is considered as cultural heritage by a generation needs maintenance in the present and future.

As it is well known and observed all materials suffer from deterioration over time. This natural process is accelerated by various different factors. The most important ones are:

a. change of exposal conditions
b. harsh environmental conditions e.g. freeze-thaw circles, salt crystallization, atmospheric pollution
c. severe destructions by human actions e.g. demolished buildings during wars.

Thus, every remaining object or building of a historical and/or artistic importance requires conservation for the benefit of present and future generations.

Before any treatment can take place, the deterioration of an object needs to be established. This will start with making a survey of the object followed by analising the cause which can be determined as well, putting the results of the study in persepective of treatments that can be taken. This treatment, based on the monitoring of the most crucial factors related to the deterioration of a certain object, aims to slow down the rate of the process. To have a succesful project, a collaboration among three general profesions is needed: a scholar (e.g. art historian or archaeologist) a conservator (in some countries also called the restorer) and a conservation scientist. The choices one can make for treatments are preventive conservation; where changing the environmental conditions are taken into account and no treatment on the object takes place. Active conservation where eg treatment like impregnation is part of the treatment. With restoration the treatment focusses on changing the object and visibly bring it back to a determined former state in order to illustrate better its use and its historical and/or artistic meaning. At this point, the importance of a very thorough understanding of the materials is already evident. Here comes the duty of the conservation scientist; a scientist who applies knowledge to the protection of cultural heritage with a background in one of the natural sciences or engineering whose role is to:

- study, investigate and monitor cultural heritage and its environment with respect to conservation and preservation,
- define, develop and evaluate conservation concepts, materials, measures, methods and techniques and develop standards and guidelines,
- provide diagnosis before, during and after conservation interventions,
- conduct research on causes and mechanisms of deterioration and interpret scientific results
- communicate the scientific principles of conservation and promote scientific research in conservation,
- co-operate with other disciplines,

and in order to perform the functions, one needs:

- be conversant with the phenomenological approach to problem solving,
- formulate and carry out research,
- turn theory into practical solutions,
- work in an interdisciplinary team and
- communicate effectively.

(see “Bologna Document”, 1999)

It is worth mentioning that during the conservation of cultural heritage the process is different when the object to be studied and conserved is a fine art object versus a monument. With a fine art object e.g. a simple pottery made from terracotta, the materials are relatively simple to understand while it becomes more complicated in some other occasions as for instance a whole monumental construction which is comprised of different building materials e.g. building stones belonging to different lithotypes and mortars of different composition and also other works of art e.g. mural paintings and mosaics.

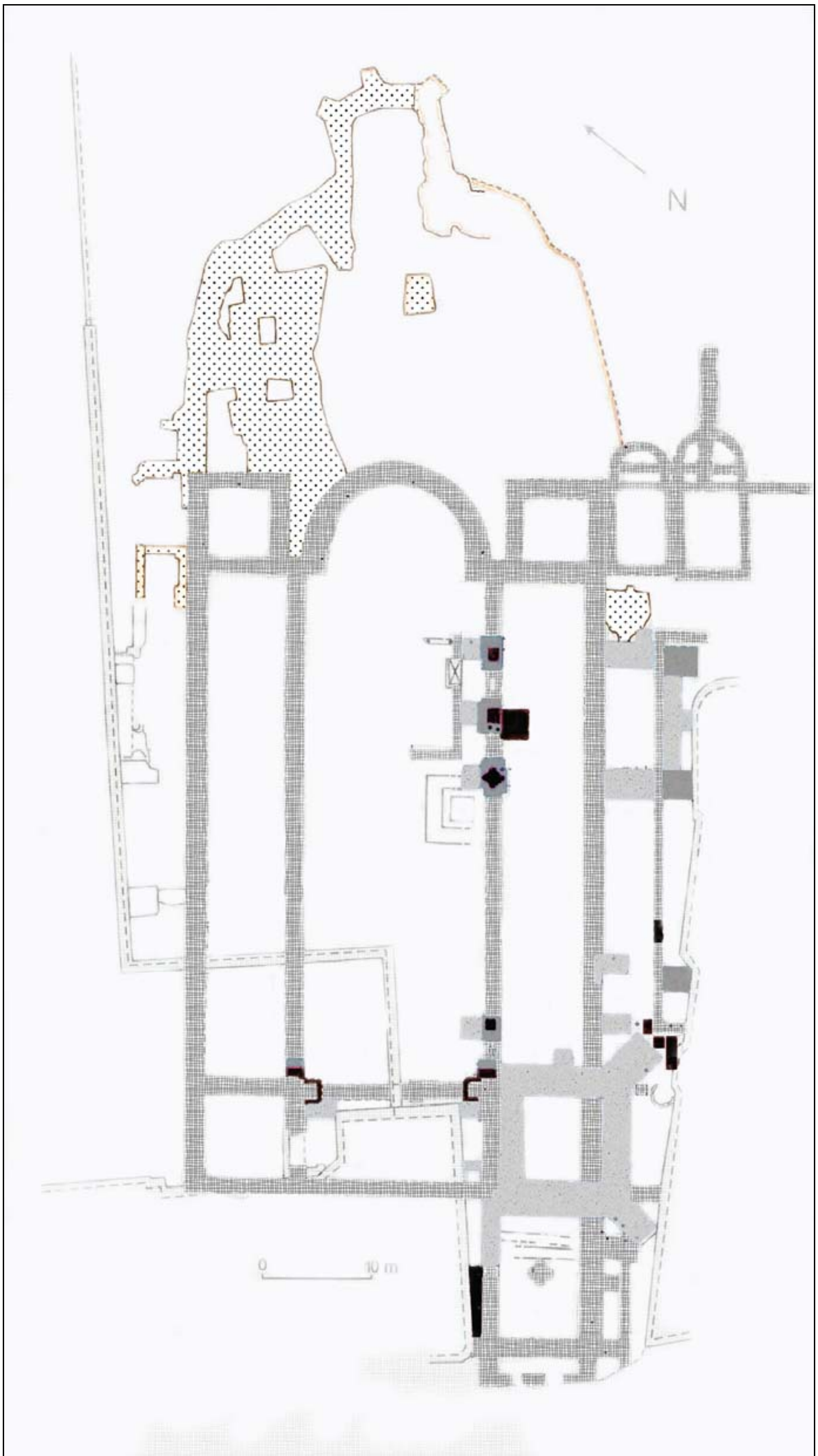
In the latter case, the role of engineering geology in the field of cultural heritage has proven to be relevant. Its application can be found in a wide range of studies. It can refer to geotechnical studies concerning the ground water table; this is crucial for the stability of the building and the materials used in the construction since it is widely known that water is one of the most severe factors causing deterioration. It can be also focused on the study of the properties of building materials in order to create a better understanding of the weathering and the degree of deterioration. Regarding the last one, the study of the building stones found in the Ruin Garden of Székesfehérvár is a good illustrative example for a better understanding of the significance of engineering geology in the cultural heritage field.

## 3. HISTORICAL BACKGROUND AND SHORT DESCRIPTION OF THE MONUMENT: THE SZÉKESFEHÉRVÁR RUIN GARDEN

The Székesfehérvár Ruin Garden is located in the centre of the city of Székesfehérvár, 65 km southwest of Budapest (Fig. 1) which, in the Middle Ages, was the Royal residence of the Hungarian Christian Kingdom. The Ruin Garden is comprised of a provostal church, the “Royal Basilica” as it is called today, royal tombs and related ecclesial and lay buildings. It was founded by the first King of the Christian Kingdom, King Stephen I (1000-1038) approximately in 1018 and it used to serve as a burial and coronation church for the Hungarian Kings and was the home of the royal treasury and relics. Between the 11$^{th}$ and the 15$^{th}$ centuries it was reconstructed several times. The first phase of construction underwent during the 11$^{th}$ - 12$^{th}$ centuries, at the age of the Arpad Dynasty. During the Arpadian Age, in the 12$^{th}$ century, the first rebuilding took place. Several Destructions by fires was the reason for the first gothic reconstruction that started in 1318, in the Age of the Anjou Dynasty. Another fire in 1327 led to the second Gothic reconstruction (14$^{th}$-15$^{th}$ centuries). The last expansion of the temple was implemented by King Matthias in the 2$^{nd}$ half on the 15$^{th}$ century, in a Late-Gothic style. (Biczó, 2005).


**Fig. 1**. Map of Hungary with the location of Székesfehérvár

The buildings that border the excavation area today on the northwest part of the ruin garden belong to the Episcopal palace which is now situated on the past western part of the temple. The Turkish occupation (1543-1688) was the beginning of the destruction of the church assemblage, which went on by using it as a storage facility and even as a quarry until its final demolition by the bishop and the municipality of Székesfehérvár during the 18$^{th}$-19$^{th}$ centuries (Dercsényi, 1943). First excavations were carried out in the 19$^{th}$ century by János Érdy and Imre Henszlmann. The next century excavations took place in the 30’s by the architect Kálmán Lux. In the 60’s, the process restarted under the supervision of the archaeologist Alán Kralovánszky and since 1993 the archaeologist in charge has been Piroska Biczó. The total site of the excavated ruins is roughly 4700 m$^2$. (Figs 2 and 3).




| | | | | | |
|---|---|---|---|---|---|
| | $11^{th}$-$12^{th}$ centuries | | 12th century | | $14^{th}$ century |
| | $14^{th}$-$15^{th}$ centuries | | end of $15^{th}$ century | | buildings today |

**Fig. 2.** Map of the Székesfehérvár Ruin Garden (after Bartos et al., 2004)

**Fig. 3.** Views of the Ruin Garden: a) & b) parts of the uncovered area,
c) & d) parts of the covered area.

4. MATERIALS

The main building materials that have remained in the site are blocks of building stone. Traces of historic mortar also exist and in a small area of the ruins a number of bricks has survived. Due to the historic use of the basilica, tombstones have been also found among the ruins of the construction. The complexity of the monument is remarkable thanks to several reasons; besides the several construction phases that ruins belong to, many different kinds of lithotypes has been identified by studying the blocks of building stones. A total of 56 representative blocks has been sampled so far, coming from different construction phases. The most widely used stones are limestones, the use of rhyolite is also comparably wide, while marble and sandstone is more limitedly found. Further details concerning the petrographic characteristics of the stones have been achieved by polarizing microscope (Table 1).

| **Lithotypes** | **%** |
|---|---|
| Ooidal Peloidal Limestone | 25 |
| Shelly Limestone | 20 |
| Polimict Sandy Calcarenite | 13 |
| Red Compact Limestone | 11 |
| Foraminifera-bearing Limestone | 7 |
| Travertine | 7 |
| Fine Limestone with Quartz Sand | 3 |
| Rhyolite | 7 |
| Marble | 5 |
| Silica-cemented Red Sandstone | 2 |

**Table 1**. Main categories of the identified lithotypes with their percentage out of the total of the samples.

Taking into consideration the high frequency among the identified lithotypes, the research concerning the materials properties has been focused on the most widely found ones: the ooidal peloidal limestone

(Oolitic Limestone-OL, Fig. 3b), the shelly limestone (also called Fossiliferous Limestone-FL, Fig. 3a), the polimict sandy limestone (Sandy Calcarenite-CS, Fig. 3c) and the red compact limestone (Red Limestone-RL, Fig. 3d).

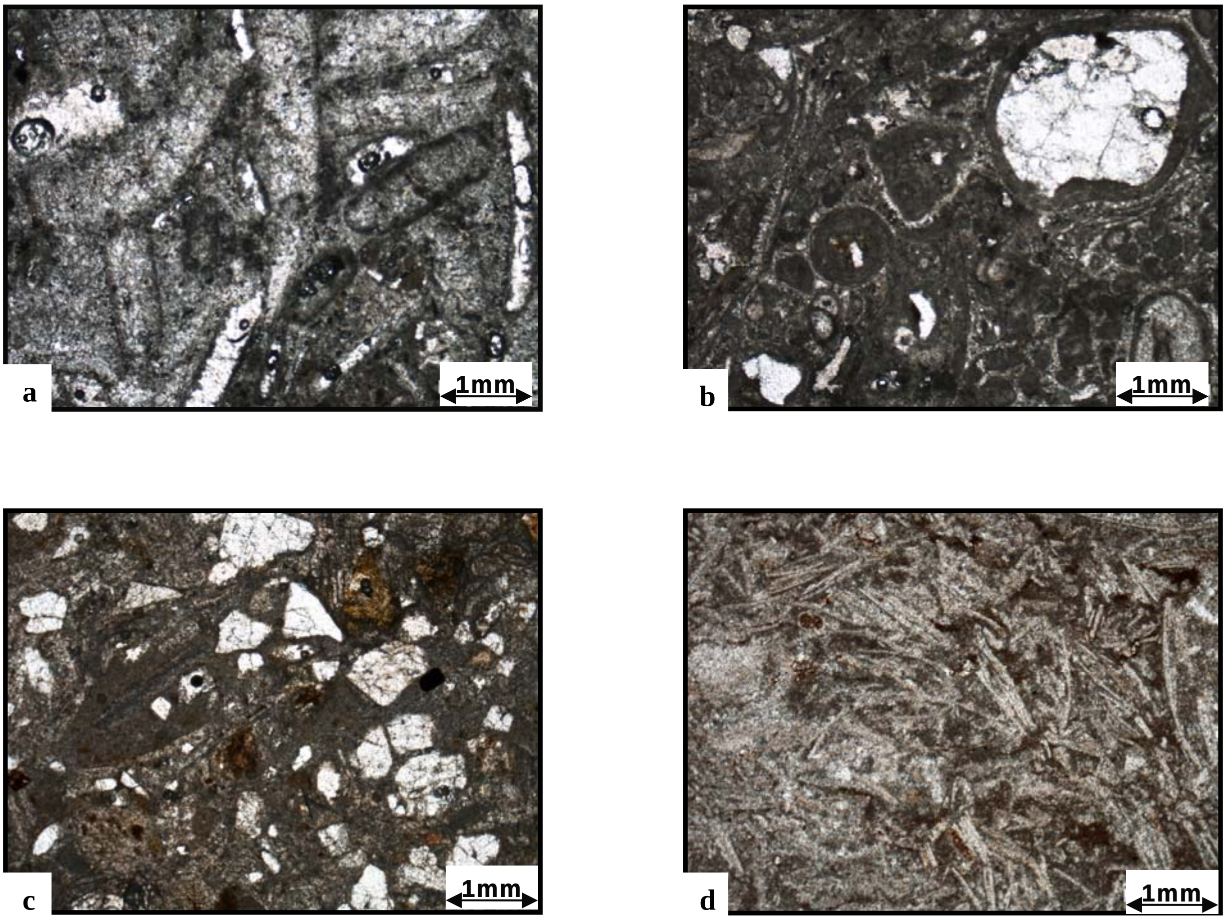



**Fig. 3**. Thin section microscopic aspects of the four main identified lithotypes 1N:
a) Bioclastic Limestone, b) Oolitic limestone, c) Sandy Calcarenite and d) Red Limestone.

## 5. METHODS

### *5.1. Poresize-distribution*

Two methods were selected for identifying the distribution of pore sizes in the materials: by nitrogen adsorption and by mercury intrusion. Both methods are used in characterizing the pore structure of materials even though they differ in principle. Nitrogen adsorption method can characterize smaller pores than the mercury porosimetry. However, there is a range pore sizes that can be characterized by both methods.

In mercury porosimetry, gas is evacuated from the sample cell, then mercury is transferred into the sample cell under vacuum and pressure is applied to force mercury into the sample. During the measurement, applied pressure and intruded volume of mercury are registered. As a result of the analysis, an intrusion-extrusion curve is obtained and parameters describing the pore structure of the sample can be calculated. 0.004-256 μm is the range of the pores' diameter that can be measured by the apparatus used for our samples.

By the nitrogen adsorption method the surface of the material is determined by measuring the number of nitrogen molecules necessary to cover in one layer all the surface of the material. By BET method the registered data can give information about the sizes of the material's pores. By the used apparatus, pores with a diameter between 0.001-0.2 μm can be identified.

*5.2. Water absorption by vacuum immersion*

Water absorption is one of the most crucial properties concerning the durability and applicability of the stone as building and decorative material in outdoor conditions. It has been determined following the RILEM CPC 11.3 standard. Samples are dried for 24 hours for obtaining their dry mass ($W_0$). The dry samples are immersed in water under vacuum for 24 hours. Afterwards, the surface of the specimens is dried (water saturated surface) and the first measurement of the wet mass takes place ($W_{SSD}$). The specimens' apparent mass is weighted also while they are submerged in water ($W_{H2O}$). The expression that gives the percentage of water absorption by the material is the following with all weights expressed in grams:

$$W_{ABS} = [(W_{SSD} - W_0) / (W_{SSD} - W_{H2O})]*100$$

*5.3. Uniaxial compressive strength*

The uniaxial compressive strength ($\sigma_c$) is expressed by the value of uniaxial compressive stress that is reached when the material fails completely. It can be measured in the laboratory by carrying out a compression test: cubic specimens of approximate dimensions 4x4x4 cm where used in the press that applied the uniaxial compressive load on the material ($P_c$). The strength can be then given by the following equation:

$$\sigma_c = P_c / S \quad [N/m^2],$$

where S is the surface of the specimen where the load is applied. This area in reality varies on compression but for the estimation of the engineering stress the surface at the start of the experiment is taking into account. Consequently, in our case, it is approximately 0.04x0.04 m.

*5.4. Micro-drilling resistance*

The micro-drilling resistance of the materials can be measured by a Drilling Resistance Measurement System (DRMS). The necessary force for penetrating a certain depth in time is registered by the system, while the penetration rate and rotational speed are constant. In our case, diamond drill bits were used with a diameter of 5 mm, while the same penetration depth and the same operation conditions were used for all different tested stones. During the drilling tests, the measured drilling force [N] versus the penetration depth [mm] is given in a diagram.

*5.5. Lithological maps, decay form maps*

A very important step of the research has been the mapping of the identified lithotypes and weathering forms in selected wall sections of the monument. This kind of documentation can not only enrich the knowledge of the materials and their behavior but also help in documentation during carrying out the in-situ tests that already in progress.

6. RESULTS

*6.1. Poresize-distribution*

By observing the results which characterize the pores achieved by nitrogen adsorption, all of the tested samples show a unimodal distribution with main volume accumulated in the diameter range of 0.02 to 0.2 μm. The highest volume of pores is observed in the case of red limestone (Fig. 4).

Similarly, by mercury intrusion, almost all samples show a unimodal distribution with the main volume accumulated in the range of "large" pores except for the case of red limestone which shows a bimodal one and for which a second noticeable volume of pore sizes is observed in the range of the smallest pores measured by this method (Fig. 5).

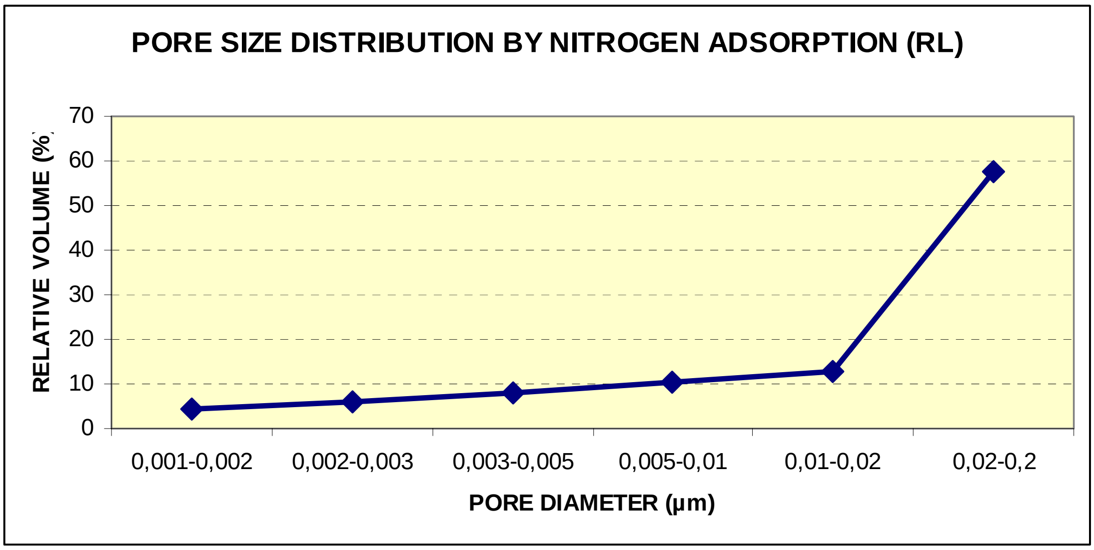



**Fig. 4.** Pore size distribution by nitrogen adsorption for a representative sample of red limestone

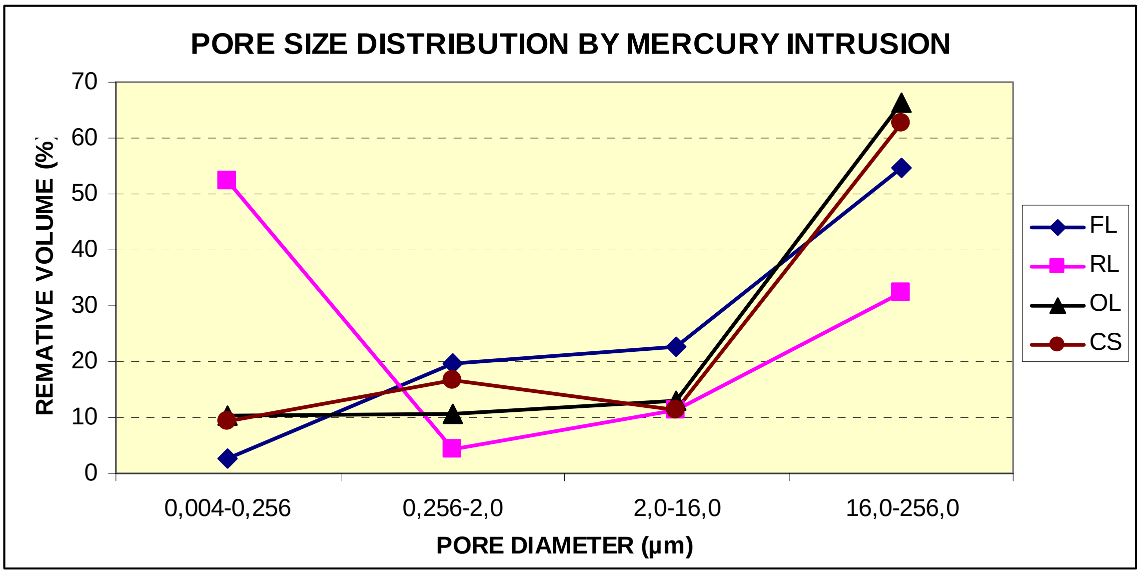



**Fig. 5.** Pore size distribution by mercury intrusion for representative samples of the main identified lithotypes

*6.2. Water absorption by vacuum immersion*

As expected, water absorption is relevant to the results achieved by the observing the structure of the material, either macroscopically or microscopically; the more compact the material is, e.g. red limestone, the lower its capacity of water absorption is (Fig. 6).

*6.3. Uniaxial compressive strength*

The various lithotypes experienced different values of compressive strengths by means of uniaxial compression test under laboratory conditions. The range is from less than 10 MPa e.g. the porous oolitic limestone to more than 60 MPa e.g. the red compact limestone (Fig. 7).

*5.4. Micro-drilling resistance*

By analyzing the data of the in-situ test, the average drilling resistance can me calculated for each tested material (Fig. 8) with again the most extreme values observed for the oolitic limestone and the red limestone. Furthermore, important information about the decay patterns can be retrieved as well. For instance, regarding the oolitic limestones, the presence of a superficial crust is observed, attributing a higher drilling resistance approximately in the first 1.5 mm of the tested blocks while for the red limestone, minor alterations might be observed in the topmost 1 mm (Fig. 9).

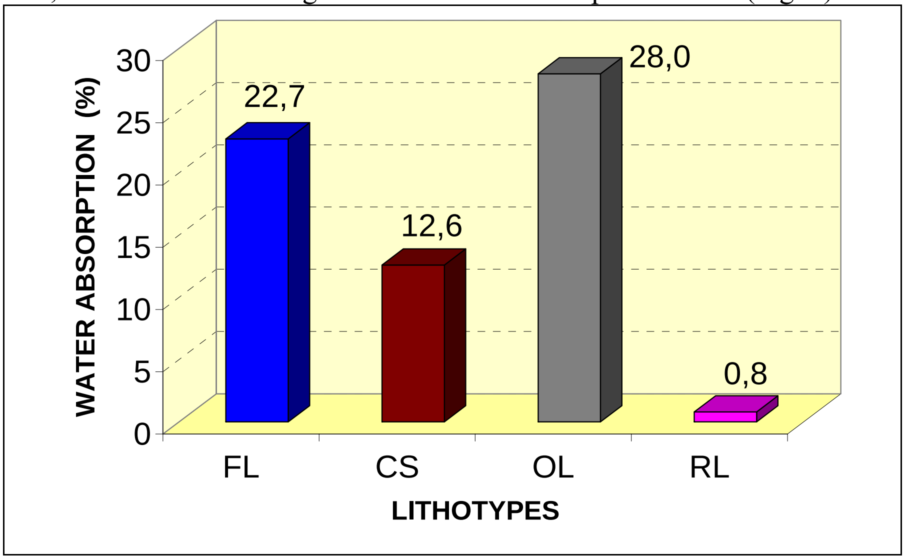



**Fig. 6.** Absorption by water by immersing under vacuum for representative samples of the main identified lithotypes

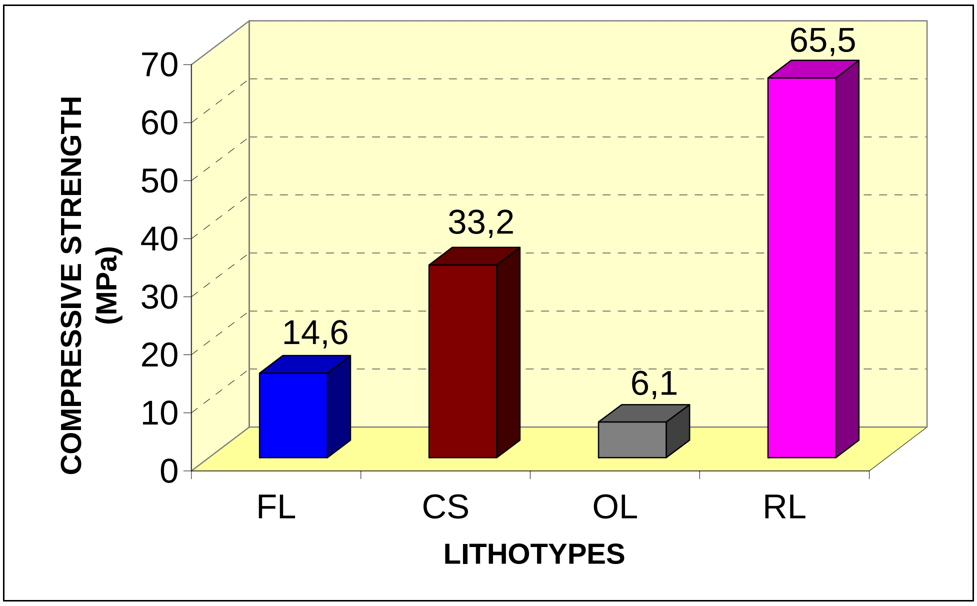



**Fig. 7.** Uniaxial compressive strengths for repsresentative samples of the main identified lithotypes

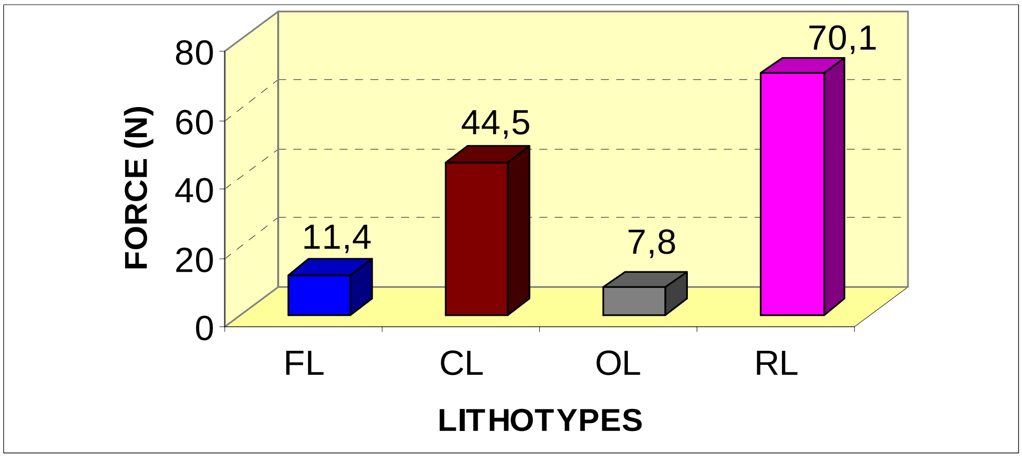



**Fig. 8**. Average values of drilling resistance for representative samples of the main identified lithotypes

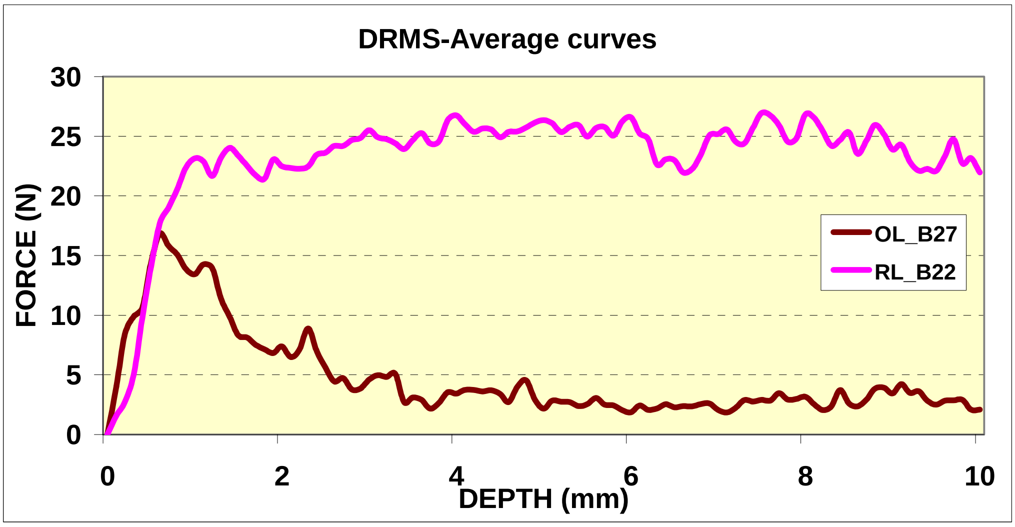



**Fig. 9**. Average curves of an oolitic and a red limestone

**Fig. 10**. Section of the northern wall of the southern structure

*6.5. Lithological maps, decay form maps*

One example of the mapping process can be the selected section of the northern wall of the southern structure (see figures 2 and 10). The main identified lithotypes are shown on the first one (figure 11) while the main decay and weathering forms observed are depicted on the second map (figure 12).

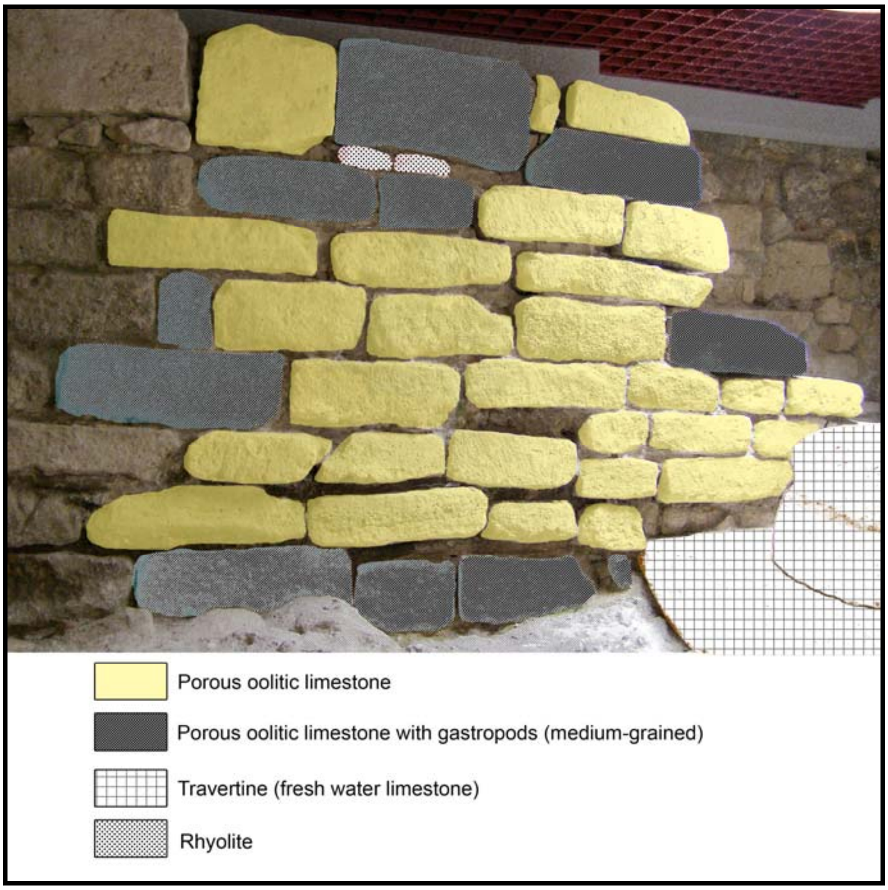



**Fig. 11**. Map of the distribution of the various lithotypes


**Fig. 12.** Map of the decay and weathering forms

## 7. CONCLUSIONS

In accordance with the historical and archaeological information the whole complex of the Royal Basilica was constructed and reconstructed several times between the $11^{th}$ and the $15^{th}$ century. Combining that information with the petrographic results of the study carried out on the extracted samples, some preliminary comments are possible. The most frequently used stone materials which can be found in almost all construction phases are oolitic limestones (OL) and fossiliferous limestones (FL). Among the samples that have been studied in the current research, red limestone is only found in the reconstruction that took place in the $12^{th}$ century, while marble, rhyolite and red sandstone sampled blocks belong only to the first construction phase ($11^{th}$- $12^{th}$ centuries).

Concerning the most frequently found lithotypes that have been tested, differences are observed related to their physical and mechanical properties. Most of them have a unimodal pore size distribution (OL, FL, CS) with the main volume accumulated in the range of larger pores able to be characterized by mercury intrusion, while the red limestone (RL) shows a bimodal one. Analyzing the values achieved by water absorption test ($W_{ABS}$), uniaxial compression test (UCS) and micro-drilling resistance measurement (DRM) a wide range of results is evident. A good correlation among the results achieved by the above mentioned methods is possible. Low porosity and $W_{ABS}$ corresponds to high UCS and DRM. The extreme values among the presented results belong to the OL and RL. This is in total accordance with the in-situ observation of the occurring decay and weathering forms with the OL experiencing most of them such as black crust, scaling, flaking and biological growth while the RL appears comparatively durable.

The knowledge of the materials' properties and their behavior has a significant importance in assessing future activities in the ruin garden area. That is inevitable when practical measures have to be taken in facing conservation of cultural heritage, especially when it needs to be faced on a monument which presents a high complexity and wide variety of materials. Thus, the application of knowledge coming from the field of engineering geology is of a high significance and in many cases obligatory in order to conclude to a proper way of protecting and maintaining our cultural heritage for the present and future generations.

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