A Preliminary study on material properties of the Zerzevan Castle, Turkey

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Abstract. Zerzevan is a recently discovered castle, situated on a rocky hill in the province of Diyarbakır, southeastern Turkey. Like many other Medieval defensive artifacts, Zerzevan Castle has also erected to protect the site against the incursions of enemies and to dominate the land. Zerzevan Castle, as a former military base of the Roman Empire, consists of such remains as churches, tombs observation towers, cisterns, arsenal, canals and city walls. The archaeological excavations conducted in the site revealed the existence of various underground structures, among them a temple of Mithraism, a mystery religion. The temple is considered as the first and unique Mithraeum located on the eastern border of the Roman Empire. The castle has been constructed by employing natural stones. Similar to that of the stone artifacts around the world, the Zerzevan Castle has also suffered from stone deterioration and stability problems. The present study aims to characterize stone used in the Zerzevan Castle as a building material. The study also aims to characterize the provenance of the stone material utilized in the monuments of that archaeological site. For this purpose, samples were collected from the building façade and stone quarry located on the site. The samples then used to determine their petrographic, chemical and some of the physico-mechanical properties. The preliminary results demonstrate that the stone employed in the construction of the Castle is calcitic dolomite. Moreover, the great similarities in chemical compositions of the samples collected from the building and the quarry indicate that the stone material employed in the construction was most probably extracted from the nearby quarries.

1. Introduction
The need for protection is a basic concern for humans and the spaces they inhabit. In this respect, fortresses fulfill a human need. For ancient settlements, defensive structures were a vital necessity for the inhabitants to protect themselves against enemies. The term fortress is used here in a broad sense to refer all military structures built for defensive purposes. It was assumed that, especially in the early Medieval period, communities depended on their fortified sites.

The positioning of fortresses was influenced by a variety of factors such as visibility, topography and proximity to stone quarries, roads and water. Therefore, fortresses in the Medieval periods were mostly built on cliff tops, slopes, hillsides or river banks, especially to monitor and control their surroundings. These structures were primarily erected to protect the site against the incursions of enemies and to dominate the land [1].
Southeastern Anatolia, which was also the easternmost border of the Roman Empire, occupies a remarkable position at the midpoint of geostrategically important locations. The region, therefore, has been dominated by a variety of civilizations and become the scene of great battles that shaped the history of the region. As a result of the struggles, lots of military structures have been erected to protect the region. Zerzevan is a castle (also known as Samachi), which has been recently discovered is among those military structures designed for the defense of the territory during the Roman period. The Castle is located on a 124-meter-high rocky hill in the province of Diyarbakır, southeastern Turkey (Figure 1). Although the site has been mentioned in some texts of the travelers [2–5], it has not been well recognized until the present days. In their published works between the dates from 1766 to 1911, the travelers have mostly mentioned the Zerzevan castle regarding its structures, lack of identical information (e.g., inscriptions) and finally the existence of the village, namely Demirölçek, located in a close distance to the castle.

Like the Diyarbakır City Walls (which has been recently added to the UNESCO’s World Heritage List-ca., 40 km northwest of the site) this military settlement has also occupied a remarkable position at the midpoint of geostrategically important locations from Amida (Diyarbakır) to Dara (Mardin) in ancient times. Strategically positioned, the site was also along the ancient trade roads starting from the Edessa (Şanlıurfa) to Nisibis (Nusaybin) [6,7]. As a result of its dominant position over the entire valley and controlling a wide area, the settlement served as a strategic Roman border garrison for the long periods.

Figure 1. Aerial view of the Zerzevan Castle

The excavation campaign of this military settlement has been launched in 2014. The discovered remains and some fragments of the city walls spread over a large area. It is found that the settlement occupies an area of ca. 0.25 square kilometers [6]. There are various architectural remains and artifacts located within the site, including defensive towers, churches, arsenal, administrative buildings, rock altar, vaulted tombs, street-alleys and houses (Figure 2). Water cisterns, canals, underground shelters and rock tombs are the other remains unearthed so far at the site. There are also fragments of a 12-15 meter high and 2,1-3,2 meter thick city walls, encircling all these above mentioned remains [6].
The excavations conducted in the site has also revealed the existence of a 35 square-meter Mithras temple, a mystery religion, carved into the bedrock. The temple is considered as the unique Mithraeum located on the eastern border of the Roman Empire [6].

Figure 2. Some of the remains at the site (Clockwise: church; houses; cisterns)

Stone is among the oldest building materials in human history. While adobe and wood have been largely employed for domestic structures; stone has been used for remarkable structures, such as temples, mosques, churches and fortresses. Although it is still unclear when the first stone-based structures were erected, recent radiocarbon dating studies conducted in Gõbekli Tepe, Turkey indicate that the construction of the iconic T-shaped limestone pillars stretches back more than twelve thousand years [8–10]. The principal construction material of the Zerzevan Castle is also stone. It has been employed in all the architectural elements. In addition to the stone material, brick, plaster and mortar were also used to some extent in the construction. Like many other historical structures, this site is also suffering from stone deterioration. Different kinds of weathering forms observed, including, crack, fractures, scaling, erosion, loss of matrix, alveolization, biological colonization and mechanical damage.
It is assumed that the stone material was extracted from a stone quarry situated close to the site and employed in the construction of this military settlement. Although the evidence of the exploitation still can be traced to some extent, most of the ancient quarries have been destroyed or covered with debris (Figure 3).

Figure 3. A view from the terraces of the stone quarry at the south section of the site

Following the excavations executed at the site, the Zerzevan Castle has become the apple of the eye for many archaeologists, architects, geographers and engineers. However, the material provenance and its characterization have yet to be investigated. To put it differently, there is no substantiated written reference for the material properties of the Zerzevan Castle. In this study, it is aimed to characterize the provenance of the stone material employed in the construction, and to determine its physico-mechanical properties. This study is a preliminary and first attempt to evaluate the mentioned properties of the stone material used in the Zerzevan Castle.

2. Material and Methods
Several field surveys were conducted in the study area to assess the origin of the stone material and collect samples from the site. After that, 3 samples (one from the stone quarry and 2 from the building façades of the different structures at the site) were collected. The collected samples were then analyzed for petrographic and chemical investigations. The petrographic analysis was performed by means of optical microscopy in the mineralogical and petrographic section of the Institute of Mineral Research and Exploration (MTA) Labs in Ankara, Turkey. The chemical analysis was performed using X-ray Fluorescence (XRF) in the geochemistry section of the same laboratory.

For the index properties, a stone block was extracted from the quarry and cut into 5 centimeters cubic samples. A total of 30 cubic samples with 5-centimeter edge lengths were used to determine such physico-mechanical properties of the stone material as effective porosity, unit weight, water absorption and saturation coefficient (Figure 4). The laboratory tests were performed in the rock mechanics and natural stone laboratories of the Mining Engineering Department at Dicle University, in accordance with the standards and suggestions [11,12].
3. Results and Discussion

3.1. Petrographic Analysis

In order to reveal the petrographic features of the rock material, two thin sections were prepared from the sample collected from the quarry and building facade. The samples then examined under the optical microscope (Figure 5). In hand specimen, the samples are characterized by yellowish, grey color. Both massive and porous types were encountered. The samples are primarily composed of dolomite. On the basis of petrographic observations, studied samples classified as calcitic dolomite. The main primary constituents of dolomite are characterized by dolomite (88.94%) to a lesser extent calcite (11.06%). Opaque minerals are also present to some extent. Under the microscope, it displays a microcrystalline texture. Xenomorphic carbonate minerals are recognized by their fine-grained size nature indicating late stage formation. The matrix is composed of a very fine-grained (a few microns to sub-micron size) dolomite crystals exhibiting an anhedral habit under the polarizing microscope. The size of dolomite crystals has a homogeneous distribution. The crystal boundaries are irregular and have contact with each other. Porosity change between medium to high. Spaces changing in size are present and appear to be not filled in most cases. Because the crystals become blurrier from the center outward, the dolomite display cloudy appearance (Figure 5).
3.2. Chemical Analysis
In order to examine the chemical composition and characterize the provenance of the stone material, 2 samples (1 from the local quarry and 1 from the building’s façade) were selected for the analysis after the petrographic examination. The results obtained from the XRF analysis have been indicated in Table 1. As Table 1 shows, the relative content variations of the major elements of the questioned samples reveal the abundance of CaO and MgO concentrations. The loss on ignition (LoI) of dolomite samples fired at 1,000 °C is 46.3 wt% for the sample collected from the local quarry and, 46.1 wt% for the one collected from the façade of the structure. The abundance of the MgO supports the petrographic investigations that the material employed in the construction of the Zerzevan Castle is dolomite. In addition to that, the comparison of the chemical constituents of the samples collected from the local quarry (S1) and the building (S2) revealed significant similarities.

Table 1 Chemical composition (wt%) of the dolomite samples determined by XRF (S1: The sample collected from the local quarry; S2: The one collected from the building’s façade)

| Oxides | Sample | Al₂O₃ | CaO | Fe₂O₃ | K₂O | MgO | MnO | Na₂O | P₂O₅ | SiO₂ | TiO₂ | LOI |
|--------|--------|--------|-----|-------|-----|-----|-----|------|------|------|------|-----|
| S1     | 0.2    | 32.5   | 0.1 | <0.1  |     | 19.3| <0.1| 0.4  | <0.1 | 0.6  | <0.1 | 46.3|
| S2     | 0.3    | 32.6   | 0.2 | <0.1  |     | 19.5| <0.1| 0.2  | <0.1 | 0.8  | <0.1 | 46.1|

3.3. Physico-mechanical Properties
The physical and mechanical properties of the stone material can be determined by means of the laboratory tests. In the present study, the engineering properties of the dolomite samples were determined by following the ISRM (1981) suggestions and tabulated in Table 2.

Effective porosity and unit weight are both fundamental index properties of rock material that can affect its durability. The presence of pores in the fabric of a rock material decreases its strength and increases its deformability [12]. Unit weight is another important indicator for interpreting the physical properties of stone material and correlates well with porosity, strength and mineral composition [13]. Those two index properties can be measured by the same test. The effective porosity and the dry and
saturated unit weights of the dolomite samples were determined using the saturation and buoyancy techniques suggested by ISRM (1981). Based on measurements of 30 samples, the dolomite samples have effective porosities varying from 15.3% to 29.9%, with an average of 24.0% (Table 2). The majority of the effective porosity values for the dolomite samples are greater than 23%. The ranges of dry and saturated unit weights of the dolomite samples are 16.78-21.36 kN/m³ (with an average of 18.90 kN/m³) and 19.73-22.86 kN/m³ (with an average of 21.30 kN/m³), respectively (Table 2). According to Anon (1979), dolomite samples have high porosity and low unit weight [13].

Water absorption is an important parameter that affects the durability of stone material. The test was conducted to measure the amount of water that stone material can absorb under atmospheric pressure. The test was performed using the procedures suggested by RILEM (1980). During the tests, water absorptions by weight and by volume were determined for 30 dolomite samples. The ranges of water absorption by weight and water absorption by volume of the dolomite samples are 5.3% to 11.3% and 12.1% to 22.2%, respectively. The average water absorption by weight and by volume results for the questioned dolomite samples are 8.6% and 16.6%, respectively (Table 2).

The saturation coefficient of stone material is the ratio between the water absorption by weight under atmospheric pressure and the water absorption by weight under vacuum pressure. This coefficient is dimensionless and can be expressed as a decimal or as a percentage. It has been reported that a stone material with a very high saturation coefficient may be susceptible to frost damage [11,14]. Based on the test results, it is found that the saturation coefficient of the dolomites ranges between 0.46 and 0.96, with an average of 0.69 (Table 2).

| Material Properties                      | Standards Used | # of Tested Samples | Test Results |
|------------------------------------------|----------------|---------------------|--------------|
| Dry unit weight (kN/m³)                  | ISRM (1981)    | 30                  | 18.9 ± 1.06  |
| Saturated unit weight (kN/m³)            | ISRM (1981)    | 30                  | 21.3 ± 0.74  |
| Effective porosity (%)                   | ISRM (1981)    | 30                  | 24.0 ± 3.4   |
| Water absorption by weight under pressure (%) | RILEM (1980) | 30                  | 8.6 ± 2.0    |
| Water absorption by volume under pressure (%) | RILEM (1980) | 30                  | 16.6 ± 3.1   |
| Saturation coefficient                   | ISRM (1981)    | 30                  | 0.69 ± 0.08  |

(*) Standard Deviation

4. Conclusions

As a newly-discovered site, Zerzevan Castle is a hillfort, designed for defensive purposes during the Roman period. The site is located 42 kilometers southeast of the Diyarbakir city, Turkey. There are lots of remains located within the borders of the Castle such as churches, temple, cisterns, public houses and arsenal. Although the Castle is constructed of stone and became the subject of some researches, the petrographic and engineering properties of the stone material have not been studied yet.

The present paper is a preliminary attempt characterizing the provenance of the material and determining the petrographic, geochemical and some of the physico-mechanical properties of the stone material. The petrographic investigations reveal that the stone material employed in the construction of the Castle is calcitic dolomite. The geochemical analysis performed by means of XRF also supports the petrographic descriptions that the material is calcitic dolomite. In order to characterize the provenance of the building material, the chemical compositions of the stone from the building façade compared to the rock samples collected from the local quarry. The significant similarities in chemical compositions of the examined samples suggest that the stone materials employed in the constructions were most probably extracted from the stone quarries located in the south section of the site. The physico-
mechanical properties of the questioned samples demonstrate that dolomite samples have high porosity and low unit weight. It should be noted that a systematic sampling, advanced analyses and laboratory studies are still essential to characterize the provenance of the material, and to understand the performance of the building stone, plasters, brick and masonry mortars under various cyclic loads.

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