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HISTORICAL GRANARIES AT TAŞKALE (TURKEY) UNDER RISK: A GEOTECHNICAL ANALYSIS

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ABSTRACT

Granaries are bioclimatic conservation structures with various forms using in different countries. In the past, granaries have been an important structure in both the storage and conservation of products (such as like wheat, barley, oats). According to the historical documents, the Taşkale village includes the studied granaries have been using as a settlement area since the Byzantine period. Recently, rockfalls have observed on the walls of the northeastern parts of these historical granaries. The geological and geotechnical features of the rock units used in these areas were determined to understand such problems. In the field, the rocks with different colours and textural characteristics have taken into account and sampling has carried out from three different levels. Laboratory studies were conducted for determining the mineralogical, chemical, petrographic and geomechanical properties. The granaries in the region carved in the fossiliferous reefal limestones and clayey-sandy limestones. These limestone levels are more sensitive to atmospheric conditions than the overlaying travertine. The aim of the study is to provide geotechnical data to use in the conservation processes of the ancient Taşkale granaries.

KEYWORDS: Granary, rockfall, capillary zone, Taşkale, central Anatolia, geological, analysis

1. INTRODUCTION

A horreum (plural: horrea) was a type of public warehouse used during the Roman period. Although the Latin term is often used to refer granaries, the Roman horrea were used to store many other types of consumables; the giant Horrea Galbae in Rome were used not only to store grain but also olive oil, wine, foodstuffs, clothing and even marble (Richardson, 1992). The oldest granaries date back to 9500 BC and are located in the Pre-Pottery Neolithic A settlements in the Jordan Valley. First examples were generally located between other buildings. However by ~8500 BC, they were moved inside houses, and by 7500 BC storage occurred in special rooms. The first granaries were builded as 3 x 3 m on the outside and had suspended floors that protected the grain from rodents and insects and provided air circulation (Kuijt and Finlayson, 2009). Thus, granaries are bioclimatic conservation structures particularly have been used in the last 2000 years in different countries across Europe and Asia. Their natural ventilation does not require energy consumption (Ecim-Djuric and Topisirovic, 2010; Saá et al., 2011).

The surrounding region of the Taşkale granaries includes cave settlements (e.g. Manazan caves) dated back to 2-3. centuries B.C., however the region used as a settlement since the Roman period and have been been using as a village since the Seljukid period (Tapur, 2009; Asrav, 2015). The architectural structure of the studied wall including the granaries has a space used as a chapel during the Early Christianity period; however, later on, it started to be used as a mosque that called 'Taş Cami' (Stone Mosque) (Asrav, 2015). This indicates a religious continuity in the same place occupied by the different societies with different religions. Due to this long history, the granaries and the surrounding areas are under conservation as an archeological site (Tapur, 2009).

Although, there are some studies about the geology of the study area (e.g., Akarsu, 1960; Bilgiç, 2009; Blumenthal, 1956; Demirtaşlı, 1976; Demirtaşlı et al., 1973; Gökten, 1976; Koçyiğit, 1976; Pampal, 1987) there is no study that was carried on the geotechnical features of the Taşkale granaries and rock structures in the area. The historical rural landscape of Taşkale village studied by Asrav (2015). The study area is located in the Karaman region in south-central Anatolia region. In the Taşkale granary area, three lithological levels that represent different colours and engineering characteristics were investigated. Our study represents that the lower, middle and upper levels of the rock unit where the granaries carved show markedly different lithological facies. Especially the lower and middle levels of fossiliferous reefal limestone in the region represent weak engineering properties. As a result of these structural discontinuities and lithological variations, it is expected that rockfalls will threat these ancient granaries if the necessary measures not taken to understand the stability problems in such areas (Fig. 1). It is worth mentioning the earlier (3rd millennium BC) granary facilities which appeared in abundance in the early stage of the Ninevite 5 period. These storage facilities were of grid structure with reed mat floors used as grain silos (Badra, 2015).

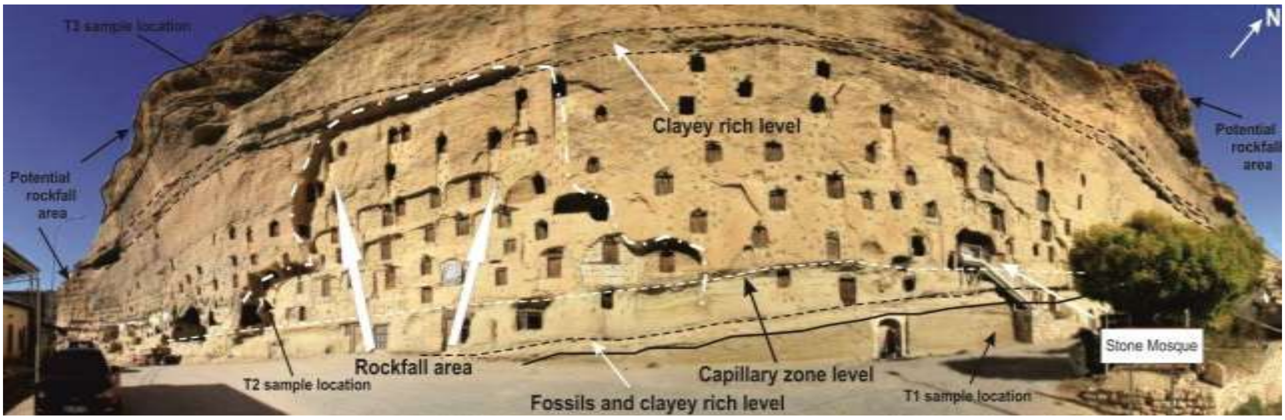

Figure 1. Panoramic view of the granaries carved in limestone and rockfalls area.

2. MATERIALS AND METHODS

2.1. The characteristics of Taşkale granaries

The surface of the rock formation was used also for the living environment as rock-cut houses. In order to build them, the surface was carved living place-sized and the front facade was closed by the masonry wall. These rock-cut houses were built attached to each other. They had flat roof, thus a circulation pattern on the roof was created. Some of the houses had their own granary carved on the top of their houses. They could reach these granaries by passing among the roofs (Asrav, 2015; Tapur, 2009).

In the Taşkale region, a part of the rock formations has been used through centuries as granaries with the aim of storing the cereal products. The main rock formation containing these granaries is 40 m in height and 165 m in width. There are 251 stone granaries. The depth of them changes from 5 to 10 meters and the storage capacity changes from 5 to 60 tons (Fig. 2) (Tapur, 2009).

Grains must be kept away from moisture as long as possible to preserve it in good conditions and prevent mold growth. Newly harvested grains brought into a granary tend to contain excess moisture, which encourages mold growth leading to fermentation and heating, both of which are undesirable and affect the quality. Fermentation generally spoils grain and may cause chemical changes that create poisonous mycotoxins (Kuijt and Finlayson, 2009). The cereal products can be stored in these rooms for many years and according to the statistics of Soil Products Office in Turkey, the wheat is being floured in the amount of 5% in 50 years (Asrav, 2015; Tapur, 2009).

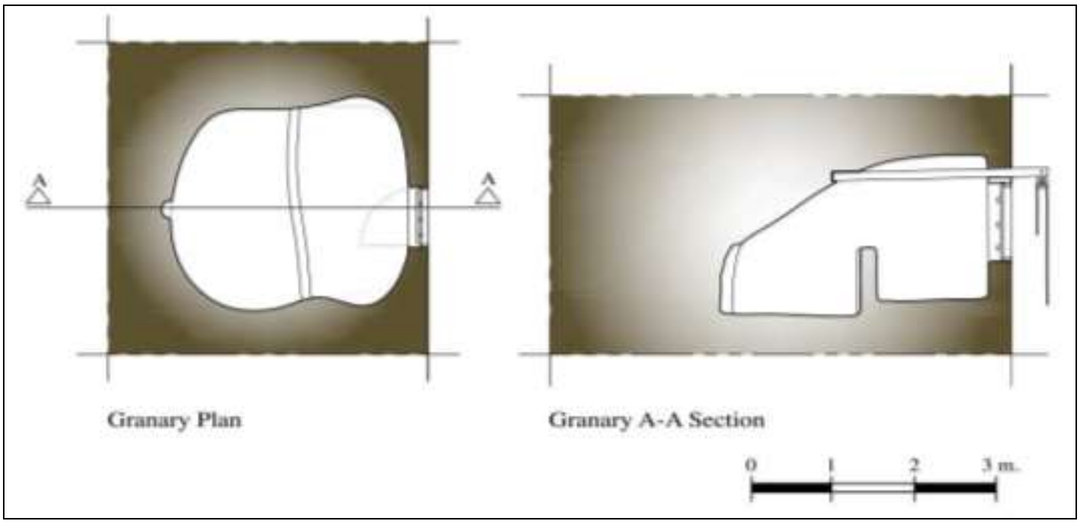

Figure 2. View of granary plan and granary cross section view.

2.2. *In situ and laboratory studies*

This study was conducted in two stages, namely in-situ and laboratory studies. In this study, infrared thermography study, surface moisture measurement and Schmidt rebound number measurements were taken from non-destructive (NDT) experiments in the granaries and stone mosque areas. Then 3 representative blocks were sampled according to the lithological change in the area where the granaries were opened (Fig. 3). To determine the mineralogical, petrographic chemical and geomechanical properties of the samples, thin sections, and powder, core and piece samples were prepared in the laboratory.

The rock mass where the Taşkale granaries area was carved in consists of fossiliferous reefal limestone and clayey-sandy limestone. Younger travertines are found on the limestones with an unconformity. The reefal and clayey-sandy limestones are light yellow in color and the nearby areas were investigated in three different facies separated in terms of texture, composition and lithology (Table 1). The rock mass of the granaries have weak rock properties and contains fossils fragments (0.5 to 4.5 cm in diameter).

Table 1. Sample location and remarks of studied samples.

Sample code	Sample location	Sample type	Remarks
T1	The bottom of the granaries	Fresh	Massive, coarse rock and fossil fragments, soft, weak and fractured
T2	Upper parts of the T1 level	Fresh	Yellow, high porous and soft, coarse rock fragments
T3	Upper levels of the granaries region	Fresh	Light gray, with small cavity melting, fine-grained massive and voids are filled with coarse secondary calcite

Figure 3. View of granaries area and lithological boundary.

In this study, detailed observations and measurements were conducted for determining the discontinuity effects of the joints according to the line survey method (ISRM, 2007) in granaries, stone mosque walls and other underground rock structures are placed. During the studies made for this scope, the orientation, number of sets, spacing, continuity, aperture, filling, roughness of the joints and the weathering effects on joint surfaces have been described in some detail.

Preservation of stone structure material is a sensitive and complex problem (Pinto and Rodrigues, 2008). Detecting the damaged sections of the structures (internal voids, joint, heat leaks, etc.) is critical for the sustainable preservation of the monuments (Binda et al., 2007; Grinzato et al., 2004; Martinho et al., 2014). Problems in determining the damages in the stones of the monuments are the preservation requirements, and the lack of samples to be used in the laboratory studies (Jo and Lee, 2014; Martinho et al., 2014). Non destrcustive techniques (NDT) are applicable in the rapid determination of the structural status of the structural elements without taking samples from the respective structure. Through these mapping of the areas of degradation in the respective structure becomes possible (Pinto and Rodrigues 2008; Martinho et al. 2014). A single analytic method often remains inadequate for the preservation studies. Assessment of the monuments by way of joint assessment of different test methods increases the reliability of the test techniques (Lim and Cao, 2013; Svahn, 2006). Therefore, in situ measurements were performed by non-destructive methods by making use of infrared thermography, surface humidity meter, and Schmidt hammer. Schmidt hammer type-L was used for the determination of rock hardness in the study area and laboratory. The Schmidt hammer test was performed according to ISRM (2007). The relative moisture values were determined using a Trotec T660 device.

NDT data have been obtained from the area of investigation divided into grids of 100×100 cm at the location of granaries and the stone mosque, and where 49 measurement stations were established at the specified spots at these grids. These measurements were performed under the weather conditions of 21.1 °C temperature, and 33.2% relative humidity.

Major element contents were determined by chemical analysis using XRF method on the same samples. As a result of the investigation of these prepared thin sections with the use of point counter in polarizing microscope, petrographic properties of the samples were determined. The main mineralogical composition, texture, void and crystal size, and the secondary mineral contents of the samples have been identified.

In order to determine the geomechanical properties of the stones, core samples (samples diameter=5.47 mm) were prepared from block samples with a laboratory core drilling machine. Samples length is 13.5-14.0 cm. Most of the specimens had length to diameter ratios of 2.5. On the samples taken from various levels of the granaries area, were taken based on the suggested methods by the International Society for Rock Mechanics (ISRM, 2007) and Turkish Standards TS 699 (2009), dry and saturated unit weight, water absorption, effective porosity, capillary water absorption, slake durability index, and uniaxial compressive strength values, the P-wave velocity and in-situ Schmidt rebound number measurements.

3. RESULTS

3.1. Climate and common weathering processes in the Taşkale region

The study area has an average elevation of 998 m above sea level. The Taşkale region has a continental climate, where summers are hot and dry while winters are cold with moderate snowfalls and springs are rainy. The meteorological records of the Karaman station for the period 1950 and 2015 are given in Table 2. The maximum rain is recorded May and January, and the minimum rain in September (Table 2). The use of the meteorological records of Karaman region on the temperature-precipitation graph recommended by Fookes et al. (1971) reveals that very slight weathering (both physical and chemical) is expected in the study area (Fig. 4). This is in good agreement with the field observations. No air pollution problem exists around the granary area because it is located in a rural region.

Table 2. Sample location and remarks of studied samples.

Month	Temperature (°C)			Precipitation (average, mm)	Rainy days (average)	Average sunrise time (h)
	Average	Maximum	Minimum			
January	0.5	5.5	-3.8	42.2	10.2	3.3
February	1.8	7.1	-2.8	35.9	9.6	4.4
March	6.1	12.4	0.4	36.3	9.3	6.3
April	11.4	18.0	4.9	36.9	8.2	8.6
May	16.2	23.1	8.7	44.8	8.4	10.0
June	20.4	27.7	12.3	36.4	5.0	12.6
July	23.6	31.1	15.0	21.3	1.5	12.5
August	23.0	31.0	14.4	4.4	1.0	12.1
September	18.6	27.1	10.2	4.1	1.9	10.2
October	12.7	20.5	5.6	7.3	6.1	7.6
November	6.7	13.6	1. 1	28.3	6.7	5.3
December	2.6	7.6	-1.8	33.0	9.9	3.3
Annual	12.0	18.8	5.4	330.9	5.8	8.0

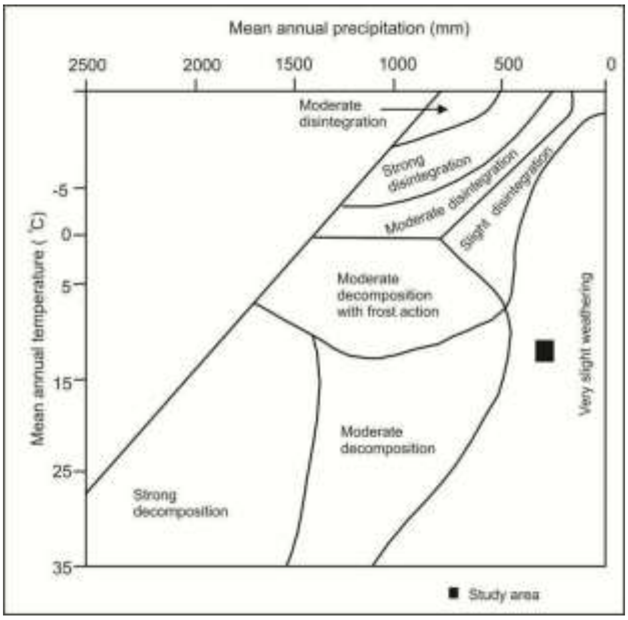

Figure 4. Relationship between climate and type of weathering for the Karaman region (modified from Fookes et al., 1971).

3.2. Geological setting of the study area

The middle-upper Miocene Kıraman Formation in the study area unconformably overlies pre-Miocene basement rocks and consists of alternating beds of yellow, brown mudstone, light grey marl, grey-grizzly, thickly bedded limestone and conglomerate (Bilgiç, 2009). The Kıraman Formation is gradationally conformable with the middle-upper Miocene Mut Formation. The Mut Formation is composed of yellow, light grey, cream, thickly bedded or massive, abundant fossiliferous reefal limestone and clayey-sandy limestone (Demirtaşlı et al., 1973; Gökten, 1976; Pampal, 1987). The Taşkale granaries were opened in this formation. The upper Miocene-Pliocene İnsuyu Formation consists of lacustrine clastic and carbonates and unconformably rests on the Mut Formation (Bilgiç, 2009). Quaternary aged alluvium and alluvial fan deposits comprise the upper part of the units and unconformably overlie the previous formations (Figure 5).

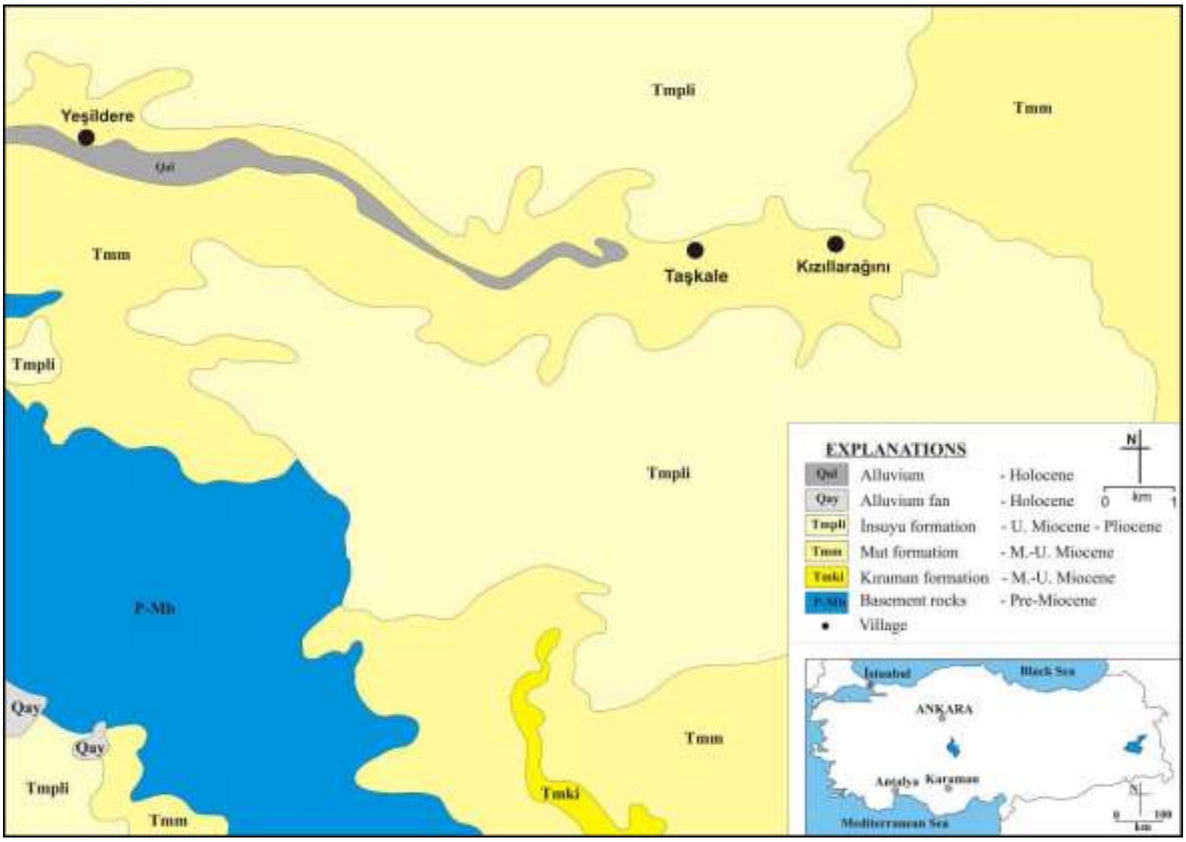

Figure 5. Geological map of the study area (modified from Bilgiç, 2009).

3.3. Mineralogical characteristics

XRF analysis showed partly differentiation in three distinct groups. First group contain T1 samples taken from at the bottom of the sample, and second group contain T2 sample that were taken from the granaries areas. T3 sample were taken from at the top of the granaries area. In the field, samples T1 and T2 located in the lower levels where the rock structures were found have relatively close in composition. SiO_2 contents of the T1 and T2 samples are higher; MgO and Fe_2O_3 are higher from T2 and T3 samples. CaO and LOI contents of the T2 and T3 samples are same and higher than T1 samples (Table 3).

Table 3. Chemical composition of the samples.

Major element Oxide (%)	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K2O	TiO_2	P_2O_5	MnO	Cr_2O_3	LOI	Sum
T1	9.37	1.94	1.41	2.98	41.89	0.10	0.39	0.89	0.06	<0.01	0.025	41.0	100.05
T2	1.91	0.43	0.56	0.91	55.57	<0.01	0.08	<0.01	0.07	<0.01	<0.002	40.0	99.53
T3	0.34	0.06	0.08	0.24	57.65	<0.01	<0.01	<0.01	0.02	<0.01	<0.002	41.2	99,59

3.4. Petrographical characteristics of samples

According to the polarizing microscopic investigation of the sample-T1, it contains 40% fossils, 27% micrite, 27% clay, 4% iron oxide and 2% void (Figure 6- a, d). This sample was termed as biomicrite based on Folk (1962) classification. Clasts range in size from 0.1-10 mm. As seen in thin section, framework grains in the sample-T2 compose about 50% of the total rock with a grain size of 0.05-0.25 mm (Figure 6- e). The composition of the sample-T2 is made up of fossils (50%), micrite (21%), clay (19%), intraclast (4%), iron oxide (4%) and void (2%) (Figure 6- b, e). The rock was defined as biomicrite according to the classification of Folk (1962). T3 samples were completely composed of calcite. The void ratio of the stone is 5%. Pores T3 samples showed fine grained micritic characteristics, in most of the samples pores are filled with coarse grained secondary calcites. The rock smaple-T3 has 5% of void and it was petrographically named as biolithite (Folk, 1962) (Figs 6- c, f).

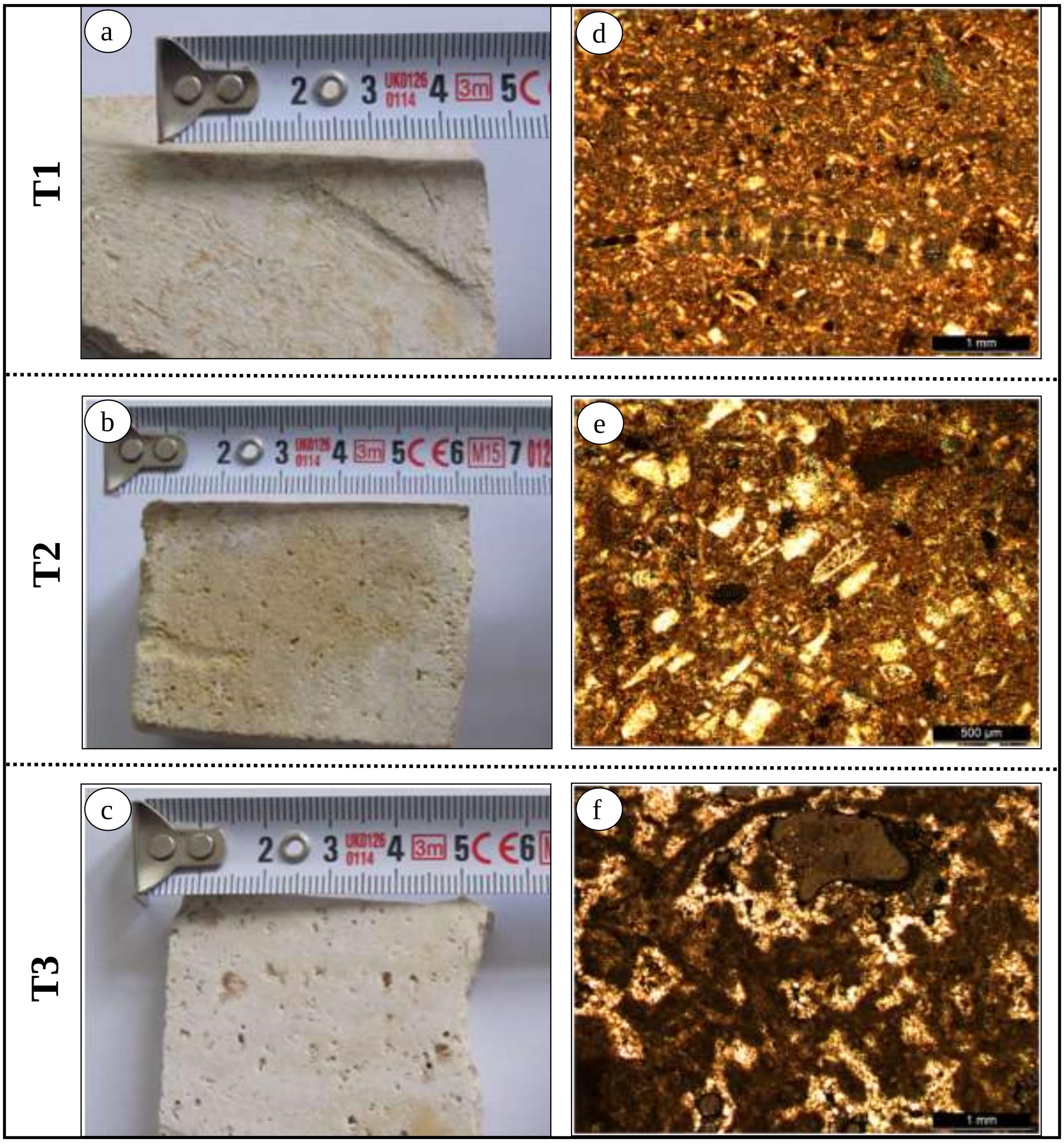

Figure 6. Macroscopic (a-c) and microscopic (d-f, cross nicols) images of the rock samples

3.5. Structural characteristics of the Taşkale granaries

Starting from the south granaries section, walls opened to the granary were examined individually in detail, in terms of joint system and the surficial decomposition. Vertical joint surfaces developed in the walls have coarse roughness, very wide aperture and joints were often observed to be unfilled (Fig. 7) (Table 4). As seen in the basis of measurements taken from the granaries areas of fracture-joints are not very regular and approximately E-W direction compression is observed. Stability problems in these fractures were observed (Fig. 7).

Table 4. Discontinuity properties of the granary walls according to ISRM 2007 (*Values in the parentheses obtained from the study area).

Properties	T1 section	T2 section	T3 section
Number of sets	2 and more joints	2 and more joints	3 and more joints
Spacing	(2.5-7.2 m) Very-extremely wide	(3.0-8 m) Very-extremely wide	(3.80-8.20 m) Very-extremely wide
Continuity	(> 12 m) High-very high	(> 15 m) High-very high	(> 16 m) High-very high
Aperture	(1-3 cm) Very wide	(1.2-3.2 cm) Very wide	(2.5-4.3 cm) Very wide
Filling	Unfilled	Unfilled	Unfilled
Roughness	(IV) Rough, undulating	(IV) Rough, undulating	(IV) Rough, undulating
Weathering	(II) Slightly	(II) Slightly	(I) Fresh
Orientation	N45E/20SE, N75E/15SE, N30E/80SW, N50E/32SE	N70E/45SW, N45E/55SE, N40W/36SW, N60E/47NW	N85E/40NW, N35W/45NE, N60W/21NE, N52W/32NE

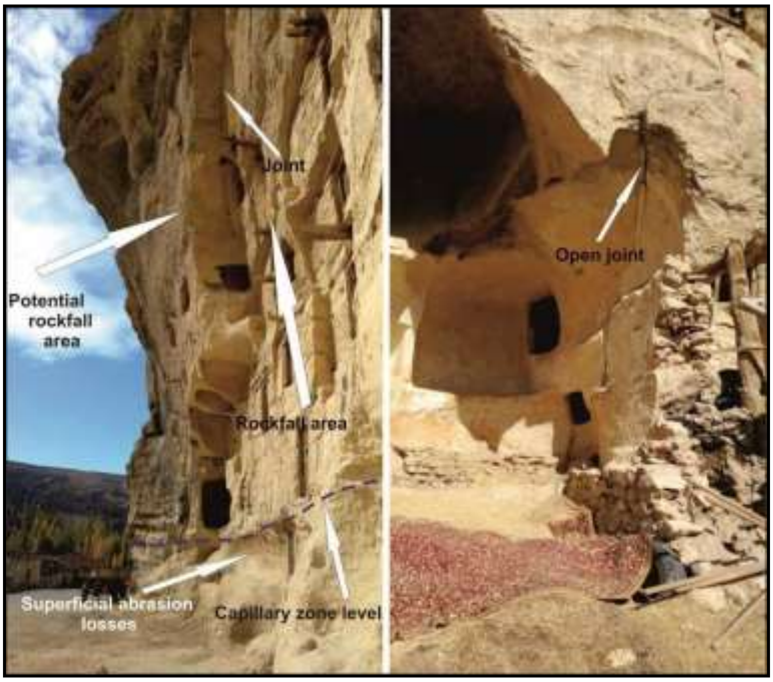

Figure 7. View of rockfall and potential rockfall area and open joint.

3.6. Physico-mechanical properties

Physico-mechanical properties data obtained from the experiments are shown in Table 5. The average lowest values with respect to the representative samples having relatively different textural features taken from the segment where the granaries was opened level from T1 and T2 samples taken from the levels showing the void, clay and fossils content is relatively high (Table 5).

The highest values of the effective porosity were obtained from the samples T1 and T2, the lowest values were obtained from the samples T3 (Table 5). Changes in the values of the rock porosity significantly effect their mechanical properties in addition to physical properties of the rock. Increased porosity also provides a low intensity to the rock, and be effective on the rock's sound and heat conductivity (Goodman, 1989). Porosity values of the samples having high clay and fossils content are relatively high values (Table 5).

Table 5. Some physico-mechanical properties of the studied samples (S.D. = Standard deviation).

Physicomechanical properties	Test number	T1 (mean ±S.D.)	T2 (mean ±S.D.)	T3 (mean ±S.D.)
Dry unit weight (kN/m^3)	5	17.59±0.34	16.33±0.71	24.15±0.18
Saturated unit weight (kN/m^3)	5	20.40±0.13	18.92±0.46	24.56±0.14
Water absorption (%)	5	15.99±0.40	15.92±2.45	1.72±0.13
Effective porosity (%)	5	28.65±0.62	26.36±2.93	4.23±0.33
Uniaxial comp. strength (MPa)	5	5.88±0.06	8.37±0.06	30.81±1.51
Sonic velocity (m/s)	3	1770±21.62	2507±42.43	2913±44.45
Slake durability-4 cycle (%)	2	78.55±0.28	86.90±0.26	98.96±0.02
Capillary water absorption (kg/m^{2}h$^{0.5}$)	3	3.35±0.33	7.72±0.53	0.31±0.04
Schmidt rebound number	10	18.8±3.20	22.5±3.23	38.6±1.82

The highest values of the average capillary water absorption (C) were obtained from the same sample T1 and T2, the lowest values were obtained from the sample T3 (Table 5). The higher the capillary water absorption and porosity, the worse are the negative consequences. Petrographic features, such as type, size, distribution and position of mineral components, homogeneity, and the size, shape and system of interconnected pores in the stone are also important (Tomašić et al., 2011). T1 and T2 samples are "highly absorbing", T3 samples are "slightly absorbing" rock class according to Snethlage (2005).

Particularly to determine the resistance against fragmentation and weakening as a result of wetting and drying of the tuff, marl and clay bearing weak rocks, the dispersion in water against the slake durability index test has been performed using two cycles with the methods proposed by Franklin and Chandra (1972) and ISRM (2007). Some studies (Campos et al., 1983; Dick et al., 1994; Gökceoğlu et al., 2000) were conducted based on number of cycles greater than 2 (3 or 4) in the slake durability test and researchers recommended that 4-cycle slake durability test would be suitable particularly for clay-bearing rocks, such as mudstone, shale, marl, claystone etc. Similarly, in this study 4-cycle slake durability test were performed. Investigated samples are located in the class of "medium (T1, T2) -very high (T3) degree of stable" rock in terms of slake durability index as a result of 4-cycles, according to Gamble (1971).

The average lowest P-wave velocity values were obtained from T1 samples having higher void and fossil content, the highest values were obtained from T2 and T3 samples having relatively higher geomechanical properties (Tablo 5). In terms of P-wave velocity, the samples are located at "rock having very low - low seismic velocity" group according to NBG (1985).

In-situ Schmidt rebound number measurements were made by using L-type hammer on the fresh and weathered smooth surfaces. Very low rebound values were obtained particularly in the lower parts of the underground rock structures where the humidity is high and in the upper parts (T1 and T2 sampling area) relatively higher rebound values were obtained (Table 5). The Schmidt rebound number values obtained as a result of the Schmidt rebound number measurements at different levels in the field, samples take place in "solid soil-soft-hard" rock class according to De Beer (1967).

Taşkale granaries structures were opened is quite low resistance (T1 and T2) level (Figure 1 and Figure 3). The highest average values were obtained from the samples T3 having low porosity, relatively high rate of unit weight (Table 5). Low resistance of the samples caused by, unit weight, and higher level of decomposition and porosity values is considered to be effective. Investigated samples are located in the "low- medium resistance" rock class according to ISRM (1981) "very low-low resistance" rock class according to Deer and Miller (1966).

3.7. *Assessment of the data obtained by NDT methods*

First of all, humidity and surface Schmidt rebound number measurements were taken from these stations via surface humidity meter and Schmidt hammer. As a consequence of the measurements, a significant correlation has been determined between the humidity found within the rock and the values of Schmidt rebound number (Figure 8). While the humidity values increase from stations M-1 up to M-18 Schmidt rebound number values decrease from stations S-1 up to S-18 (Figure 8). This situation is suggested to arise from the capillary water coming from the ground. While the humidity values between the stations M-19 and M-37 remain at average level, Schmidt rebound number values decrease from stations S-19 up to S-37 (Fig. 8). This situation is suggested to arise from the porous and weak endurance provided by the fossil limestone being observed at the region. It may be viewed also in the thermal image displaying the surface heat distribution. While the humidity values decrease between the stations M-38 and M-43, Schmidt rebound number reaches its peak values (Fig. 8). This situation is also suggested to arise due to the unit with less pores and high endurance. While the humidity values increase in between the stations M-44 and M-46 (Fig. 8), Schmidt rebound number decrease within the same range. This situation is suggested to arise not only due to the area in question is located inside the entrance groove, but also due to the lithologically lower endurance, clay content, lack of any porous section thereat. Since this area receives insufficient sunlight, and due to its clay content, humidity is kept within the area, and its Schmidt rebound number decreases accordingly. While the humidity values decrease between the stations M-47 and M-49 (Fig. 8), Schmidt rebound number increase from stations S-47 up to S-49. This situation is suggested to arise not only due to the direct sunshine received by the area in question, but also due to its composition of lithology with lithological higher endurance.

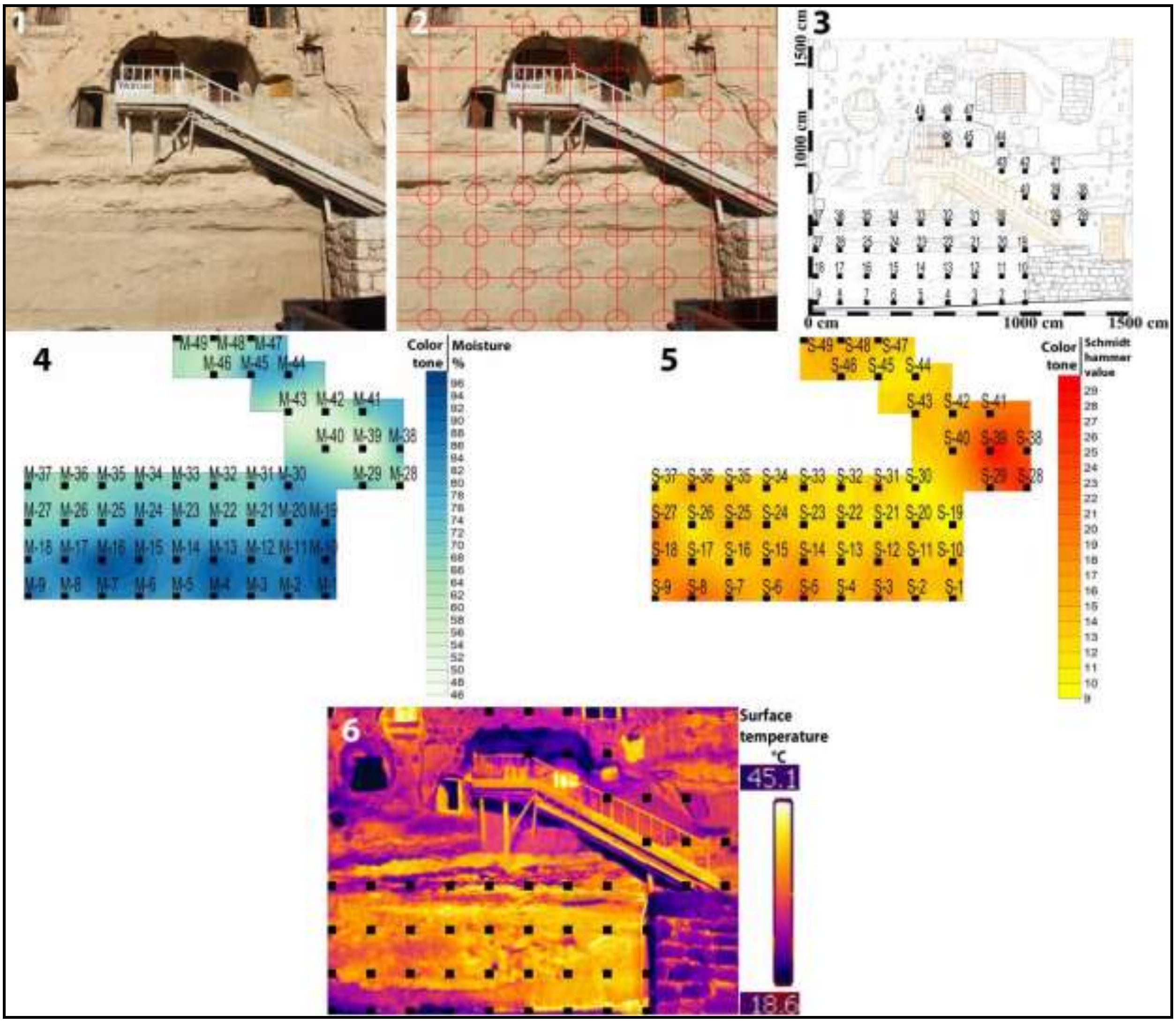

Figure 8. Non-destructive tests values of the granaries and the stone mosque area.

4. DISCUSSION: GEOLOGICAL HAZARDS AND SUGGESTIONS

Since the discontinuities can contribute to instability, an investigation is required for assessing the geological hazards around the Taşkale granaries to ensure both the stability of the stone monument and the safety of residence.

Some studies have been attempted to consider the protection and preservation of historic sites and monuments with regard to geological problems associated with the slope stability, and have been reported in the literature (Choi et al., 2009). Many researchers have studied on the rockfalls around historic sites (e.g., castles (Topal et al., 2007), towns (Sofianos et al., 1988), pedestrian roads built on subvertical cliff (Aversa et al., 1997).

A natural monument undergoes several decay processes due to the exposure to aggressive environmental conditions that threaten its durability and preservation (Charola, 2000; El-Gohary, 2012). Moisture, whose presence may be due to rain, condensation or capillary rise (Sandrolini and Franzoni, 2007; Snethlage, 2005), plays a key role in the degradation of porous materials (Korkanç, 2013; Korkanç et al., 2015; López-Doncel et al., 2013; Lourenço et al., 2006; Rirsch and Zhang, 2010; Vařilová et al., 2011; Wedekind et al., 2011), being directly or indirectly responsible for several decay processes Sandrolini and Franzoni (2006), such as freeze-thaw cycles, soluble salts crystallization cycles, biological growth, chemical attack by acid rain, wind erosion Nardi (1987), lithological properties and discontinuities (El-Gohary, 2017; Korkanç et al., 2015).

In the study area, the capillary water level is usually below the granaries level. According to the investigations in all the walls open to Taşkale granaries and other underground cavities, it is observed that the joints are open, superficial abrasion losses occurred on fracture surfaces are increasing as a result of the moisturizing effect, and the joint openings are also increasing with time (Fig. 9).

These kinds of studies are important for protection, stability of such historical places and for handing down them to the next generations. Alongside the expansion of current cracks, and the formation of new cracks are opened, particularly at levels in strength loss occurs due to capillary moistening and surface losses in the argillaceous limestone, which are found within the capillary zone under the section of the granaries. That is why rockfalls occurred in the crack positioned approximately parallel and vertical to the wall at the northeastern section of the granaries. Entrances of most of the granaries were damaged due to rockfalls. These entrances were then restored by making use of the fallen rocks. There are still risk of rockfalls at the southern section of this crack (Figs 1, 7 and 9). It is thought that, the weight of the huge travertine mass positioned approximately horizontal above this section may play a part in the activation of these cracks. Since there are settlements and roads in this section, a rockfall likely to happen in this section may cause losses of life and traffic problems, it is therefore suggested to have the settlements in this region evacuated (Fig. 9).

Figure 9. View of potential rockfall and residential area

5. CONCLUSIONS

In this study, the rocks where underground rock structures were placed show markedly different characteristics for their lower and upper levels in terms of color and textural properties. There are carved underground rock structures especially in the middle part of the region. Clayey-sandy limestones and fossiliferous reefal limestones in the lower part of the rock structures have high porosity, low unit weight and low strength values and are more sensitive than the travertines of the upper parts against atmospheric conditions. According to the NDT measurements, a significant correlation have been determined between the humidity and Schmidt rebound values.

On the walls of the northeastern parts of the granaries, rockfalls were observed due to the low strength rocks, due to the negative effects of atmospheric conditions on the joints on this side of granaries. The falling risk of large blocks that became free with discontinuities in the granaries, nearby parts must be determined, and studies must be carried out to support them before they create any life-threatening emergency.

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