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FIRST INVESTIGATIONS OF THE WEATHERING AND DETERIORATION OF ROCK CUT MONUMENTS IN MYRA, LYCIA (TURKEY)

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Abstract

The rock cut architecture of the Lycian culture in Turkey, created from around 500 BC to 400 AC, is one of the most fascinating remains of humanity's ancient building heritage. The Lycian builders created monumental sarcophagi and tomb facades with unique forms and aesthetic styles which are never found twice in the Mediterranean world. Most of these magnificent monuments are cut into different limestone formations located in the area along the southern coast of Turkey, known as Lycia after its creators. The rocks as well as the monuments are affected by weathering and disasters, such as the dissolution and precipitation of calcite, biological growth and cracks due to earthquakes. To characterise the weathering forms and processes onsite investigations were done on rock cut monuments at the outstanding site known as Myra. Field investigations included quantitative mapping of damage phenomena, pointing surface hardness measurements utilizing a Schmidt pendulum hammer, water absorption using Karsten test pipes and closer surface observations using a digital microscope. The limestone varieties were characterised by petrophysical measurements and mineralogical analysis of thin sections.

Keywords: rock cut architecture, limestone, weathering, micro-climate, microbiology

1. Introduction

The historical landscape of Lycia lies on the Teke Peninsula in southwestern Anatolia in Turkey (Fig. 1a). Traveling overland to Lycia was difficult because of it being surrounded by massive mountain ranges rising over 3000 meters. The Lycian culture began around 3000 BC and lasted until 400 AC and was dominated by warfare. Lycian warriors were known all over the Mediterranean world. Homer (8^{th} or 7^{th} BC) described the Lycians as heroic warriors fighting for their allies the Trojans (between 1334 and 1135 BC). Lycian warriors armed with shields and lances as well as battle scenes are often depicted in the

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tombs and monuments (Fig. 2d). The Lycians were not only famous for their skills in battle, but also had a highly developed navy because they were masters in wooden ship construction (Kolb, Kalke 1992). They traveled in wooden ships and lived in wooden structures. The typical Lycian tomb copies the principles they used in their wooden architecture and transformed them into monuments that would last forever by carving them into the bedrock (Mühlbauer 2001, Fig. 1d and Fig.1e).

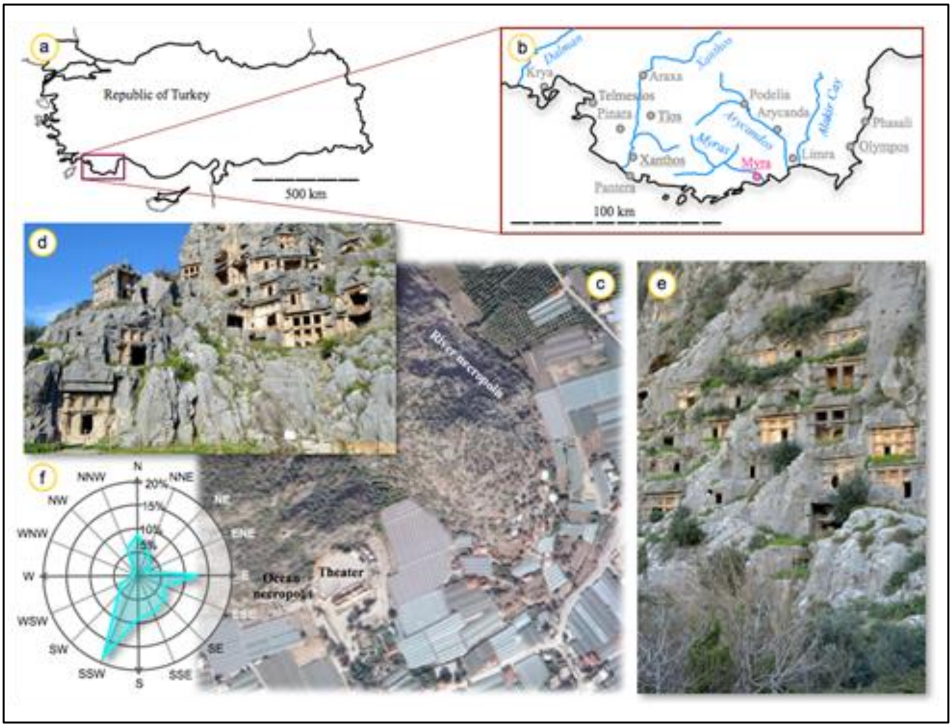

Fig. 1: a) Location of Lycia in the Republic of Turkey. b) Important Lycian cities. c) The ancient site of Myra (source: Google Earth). d) The ocean necropolis and e) the river necropolis. f) Annual wind and rain direction (source: www.windfinder.com).

The Lycian people had their own language, writing and from the 6th century to the 3th century BC different Lycian dynasties existed. Sometimes they were in conflict with each other and at other times they formed alliances. Due to its geographical location Lycia was politically and militarily vulnerable when confronted with the Persians and the Greeks. From 168 BC – 43 AD several Lycian cities created an alliance of independent dynastic city republics. In these city alliances, six major cities were established with the right to vote in the Lycian League based on their number of inhabitants: Tlos, Pinara, Xanthus and Pantara in western Lycia, Myra in central Lycia, and Olympos at the border to the east (Fig. 1b underlined). Only limited authentic written sources are known that talk about the Lycians. Most of their settlements are still awaiting excavation, investigation and conservation.

2. The site of Myra and its necropolis

The ancient town of Myra in Lycia is located where the small town of Kale (Demre) is situated today in the present day Antalya Province of Turkey. The ancient settlement was located on the river Myras near the Aegean Sea. There is no substantiated written reference for Myra before it was listed as a member of the Lycian alliance (168 BC – AD 43); according to the Greek chronicler Strabo (around 63 BC – 23 AC) it was one of the largest towns in the alliance.

There are two necropolises of rock-cut tombs in the form of house and temple fronts carved into the natural rocks at Myra: the ocean necropolis (Fig. 1c), which faces due south/south-south-east (168°) just northwest of the theatre and the river necropolis that faces north-east (45°) parallel to the river Myras (Fig. 1e). The remains of the Lycian and Roman town are mostly covered by alluvial silts. Only the acropolis, the Roman theatre and the Roman baths have been partly excavated. The semi-circular theatre and the necropolis were partly destroyed in an earthquake in 141 AC.

2.1. Geological setting

The study area is located in the Taurus Belt in southern Turkey. The Taurus Belt is separated into three different tectono-stratigraphic formations from north to south called Lycian Nappes in the north, Beydaglari Autochthonous in the middle and Antalya Nappes in the south (Özgül, 1976). The Lycian Nappes mainly represent Mesozoic platform carbonate sequences, which consist of dolomites, oncoidal limestones, intraformational limestone conglomerates, and cherty limestones. In recent studies, the Lycian Nappes are also named the Kütahya-Bolkardagi Belt (Göncüoglu, 2011).

2.2. Environmental and climatic conditions

The Myra region nowadays is dominated by agricultural production of vegetables (Fig. 1c). The Mediterranean Sea is located around 8 km southwards. The climate is warm and temperate and is classified as Csa according to the Köppen-Geiger climate classification system. Winter months are much rainier than the summer months. The average annual temperature is 18.4°C. In a year, the average rainfall is 920 mm. The driest month is August with only 2 mm of precipitation. Most of the precipitation falls in December and January, averaging 210 and 226 mm (www.clima-data.org). In November and February precipitation averages reach 110 and 145 mm. The three dominant average annual wind and rain directions are SSW with 17.2 %, N with 8.9 % and E with 12.5 % (Fig. 1f). During the month with much rainfall a different wind and rain direction occurs as well as in August (Tab. 1):

Tab. 1: The three main wind and rain directions related to different months.

Monthly Period	North	East	South-South-West
November & February	11.6%	13.6%	12.7%
December & January	17.6%	14.4%	7.8%
August	4.5%	10.2%	26.0%

2.3. Weathering forms

Deterioration of the tomb facades is due to tectonic movements (earthquakes) and to weathering. The damages due to the earthquakes in 141 AC are characterised by broken areas with a total loss of the decorated surface as well as fractures and cracks. Weathering phenomena in this case can be divided into different forms, colors and intensities. In contact with drainage rainwater the stone shows a gray to bluish color and two main forms of weathering intensities:

1.) A grayish discolouration forming a rough but closed surface (Fig. 2c);

2.) A gray to blue disintegrated surface by forming a visible relief (Fig. 3b and Fig. 3c). Different kinds of amorphous deposits white in color and sometimes also reddish, probably due to iron oxides precipitate on the surface.

2.4. Rock material and case studies

In this study the original rock material of the necropolis (NL) and a so-called Myra limestone (ML) was investigated. The Myra limestone is quarried around 15 km to the north of the ancient site and is sold on the international market. This stone material is also used for restoration of the ancient site. For this study two comparable monuments were chosen: one from the ocean necropolis and one from the river necropolis. Both monuments are similar in size and form. They have a size of around 4 by 4 meters and show the typical Lycian-stepped rectangular decoration on the façades (Fig. 2d and 3d).

3. Methods

Field investigations were done by quantitative mapping of the visible damage phenomena, surface hardness measurements by a Schmidt or pointing pendulum hammer, water absorption by Karsten test pipes and closer surface observations by using a digital microscope. Surface hardness was done on representative areas based on the mapped conditions by taking no less than 10 single measurements. Water uptake tests were done on several representative areas under different conditions. Laboratory tests were done by measuring the porosity and density using hydrostatic weighting (DIN 52 102), ultrasonic wave velocities using the pulse transmission technique and analysing thin sections.

4. Results

4.1. Mapping

4.1.1. The soldier tomb of the ocean necropolis

The soldier tomb of the ocean necropolis shows different forms of weathering (Fig. 2e). Large amounts of broken areas (15 %) mostly cover moderately weathered areas and form a gray discoloration that covers 37 % of the surface. These gray surfaces are connected to water stains and show a roughened surface (Fig. 2c). Only 1 % of the surface shows strong weathering. Sintered areas are found at well conserved surfaces (29 %). However, 18 % are still in a very good state of conservation even showing tool marks and only small forms of sintering (Fig. 2a). Sintered areas show reddish discolorations and amorphous precipitations (Fig. 2b).

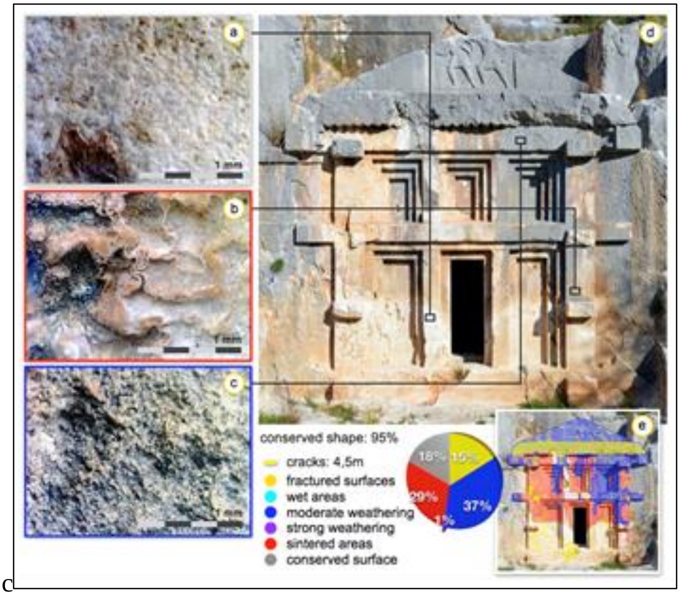

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Fig. 2: The monument of the ocean necropolis (d); a) Well-conserved surface showing only partial sintering; b) Amorphous forms of sintering and reddish discolorations; c) Roughened surface with grayish discolorations on a moderately weathered area. e) Quantified mapping and results.

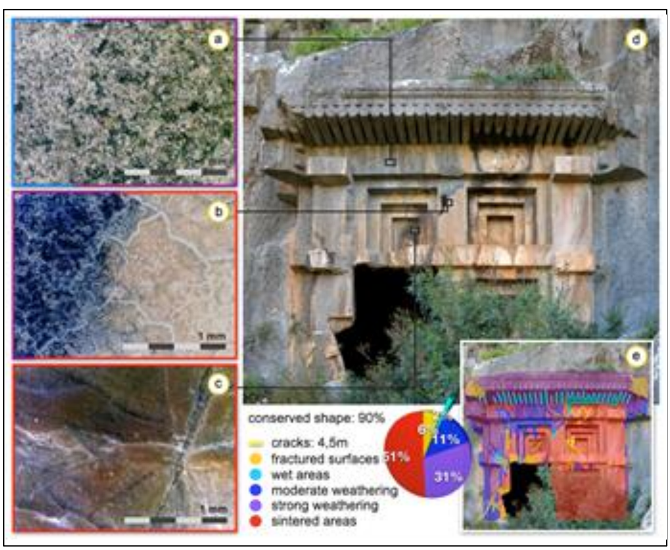

Fig. 3: The monument of the river necropolis (d); a) Moderate and strongly weathered surface; b) Strongly weathered and connected sintered area; c) Sintered area showing elephant skin-like forms, e) Quantified mapping and results.

4.1.2. The tomb of the river necropolis

The façade of the monument is protected by the still conserved stylized representation of the beam ceiling. Weathering phenomena are found all over the monument. Strongly weathered areas are connected with the water stains visible by the grayish discoloration**.** In contrast to the moderately weathered areas, they are showing the development of a micro-relief (Fig. 3a). Similar to the soldier monument different forms of sintered crusts are also found (Fig. 3b 6 c). Sintered areas (50%) and strong weathering (31 %) are the main forms of deterioration. In contrast to the tomb of the ocean necropolis wet areas could also be detected. These wet areas can be traced back to structural cracks and aquifer water transport mechanisms.

4.2. Surface hardness

Surface hardness measurements show that undamaged parts of the soldier monument (NL) reach the highest value with an averaged 90 pendulum surface hardness (Psh) (Fig. 4b). The moderately weathered area tested reached a value of 59 Psh by a clear spread of the single measurements. The monument of the river necropolis shows similar values in the non-weathered areas with an average value of 87 Psh (Fig. 4b). The moderate areas are also comparable with an average value of 61 Psh. The lowest values of all measurements are found in the strongly weathered areas. They reach an average value of 57.5 Psh and show the largest spreading (Fig. 4b). The rock material, according to Rilem (1997), can be defined as very hard, the weathered areas as hard.

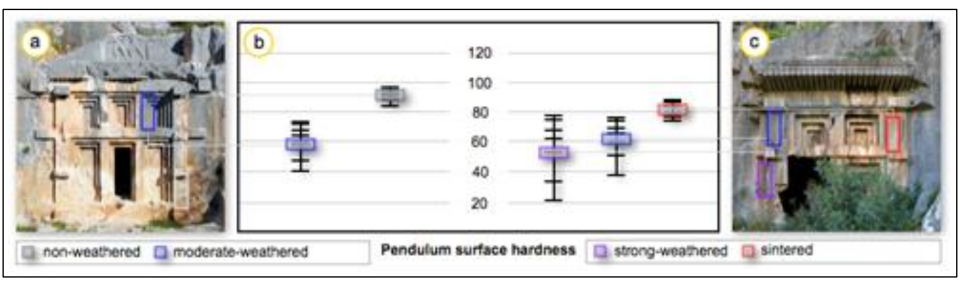

Fig. 4: a) Testing areas at the soldier monument of the ocean necropolis. b) Results of the measurements. c) Testing areas at the monument of the river necropolis.

4.3. Capillary water absorption

Capillary water absorption measured with Karsten test pipes show no water absorption at sintered surfaces and only a little water absorption at moderately weathered surfaces. This takes place only during the first minute of capillary suction. Strongly weathered areas clearly show water absorption with an A-value of around 0.4 $kg/m^2 \sqrt{1h}$. A nearly linear absorption is recognizable on freshly fractured surfaces with an A-value of around 1.4 $kg/m^2 \sqrt{1h}$ (Fig. 5b).

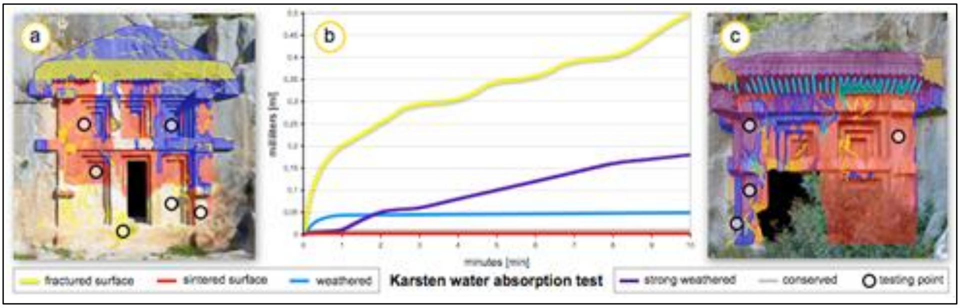

Fig. 5: a) The tomb of the ocean necropolis; b)Results of the Karsten absorption test; c) The tomb of the river necropolis.

4.4. Petrophysics and mineralogy

The necropolis limestone shows a micritic oolitic matrix (Fig. 6a). The Myra limestone contains many components like bioclasts and rudists fossils (Fig. 6c). Cathodoluminescence shows that both stone varieties are a very pure calcitic (calcareous) composition (Fig. 6b and Fig. 6d).

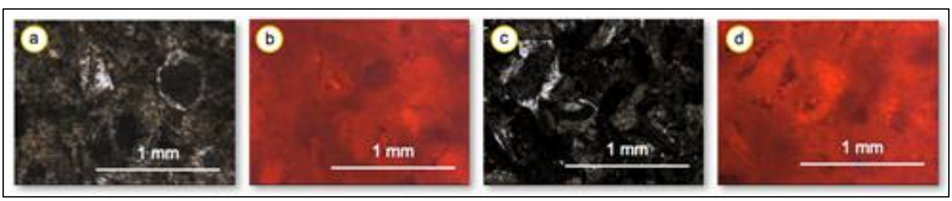

Fig. 6: a and b) Thin section of the necropolis limestone; c and d) Thin section of the Myra limestone; a and c) In transmitted light; b and d under cathodoluminescence.

Both stone varieties show a clear porosity, whereas the variety of the necropolis is less porous and also shows higher p-wave velocities (Tab. 2). In total the pendulum hammer hardness of the matrix in the necropolis limestone is harder, whereas rudists found in the Myra limestone show the highest values of all (Tab. 2).

Tab. 1: Summary of petrophysical results.

Specimen	**Porosity**	**Density**	**P-wave velocity**	**Pendulum hammer hardness**
	(%)	(kg/m³)	(km/s)	(-)
Necropolis Limestone (NL)	7.430	2.681	3.808 ± 33	75.5 - 83.7
Myra Limestone (ML)	10.832*	2.689*	3.524 ± 282*	76.77 / 105.8 (rudists)

*naturelmar madencilik company, www.naturelmer.com

5. Discussion and conclusions

Weathering mainly takes place due to chemical weathering by dissolution and precipitation. Relevant weathering only took place where the falling rainwater could reach the façade. Aquifer water leads to an intense form of damage because at affected parts of the facade infiltration takes place for a much longer time. Slightly dissolved and weathered areas develop a secondary porosity as was shown by surface hardness measurements and capillary water uptake. However, interaction with water and even light sintering effects leads to a protective sealing of the cut surface, where no water can penetrate. The investigations show that microclimatic conditions have a significant influence on the intensity of weathering of the limestone due to its exposition. After a rainfall the ocean necropolis exhibits a faster drying out, whereas the river necropolis, exposed to a north-easterly direction has a longer period of wetness. The most important factor for the different weathering intensities is the main wind and rain direction during periods with high precipitation rates in contrast to the dry summertime (Tab. 1). Based on the three annual main wind and rain directions, the river necropolis is confronted nearly two times stronger by direct rainfall than the ocean necropolis during February and November. In the months with the highest precipitation (December & January), the river necropolis is affected more than four times stronger than the ocean necropolis. In contrast drying winds in summer mainly affect the ocean necropolis. The presence of humidity is also a recognizable factor due to the settlement of higher plants. This is visible due to the growth of microbiology, which cannot be found in similar quantities at the ocean necropolis.

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References

Göncüoglu, M.C., 2011, Geology of Kütahya-Bolkardag Belt (in Turkish). In Ergun Gökten (ed.), The Journal of mineral research and exploration, Ankara, 142, 227-282.

Rilem TC 127-MS, 1997, Tests for masonry materials and structures, Materials and Structures, vol. 30, July 1997, 323-328

Kolb, F., Kupke, B., 1992, Lykien. Geschichte Lykiens im Altertum, Antike Welt, special issue, Zaberns Bildbände zur Archäologie, vol. 2

Huelden, O., 2006, Gräber und Grabtypen im Bergland von Yavu. Studien zur antiken Grabkultur in Lykien Antiquitas issue 3, vol. 45. Habelt.

Mühlbauer, L., 2001, Lykische Grabarchitektur. Vom Holz zum Stein? PhD thesis, Technical University of Munich, Germany.

Özgül, N., 1976, Toroslar'ın bazı temel jeoloji özellikleri : TJK Bull., 19, 65 - 78.