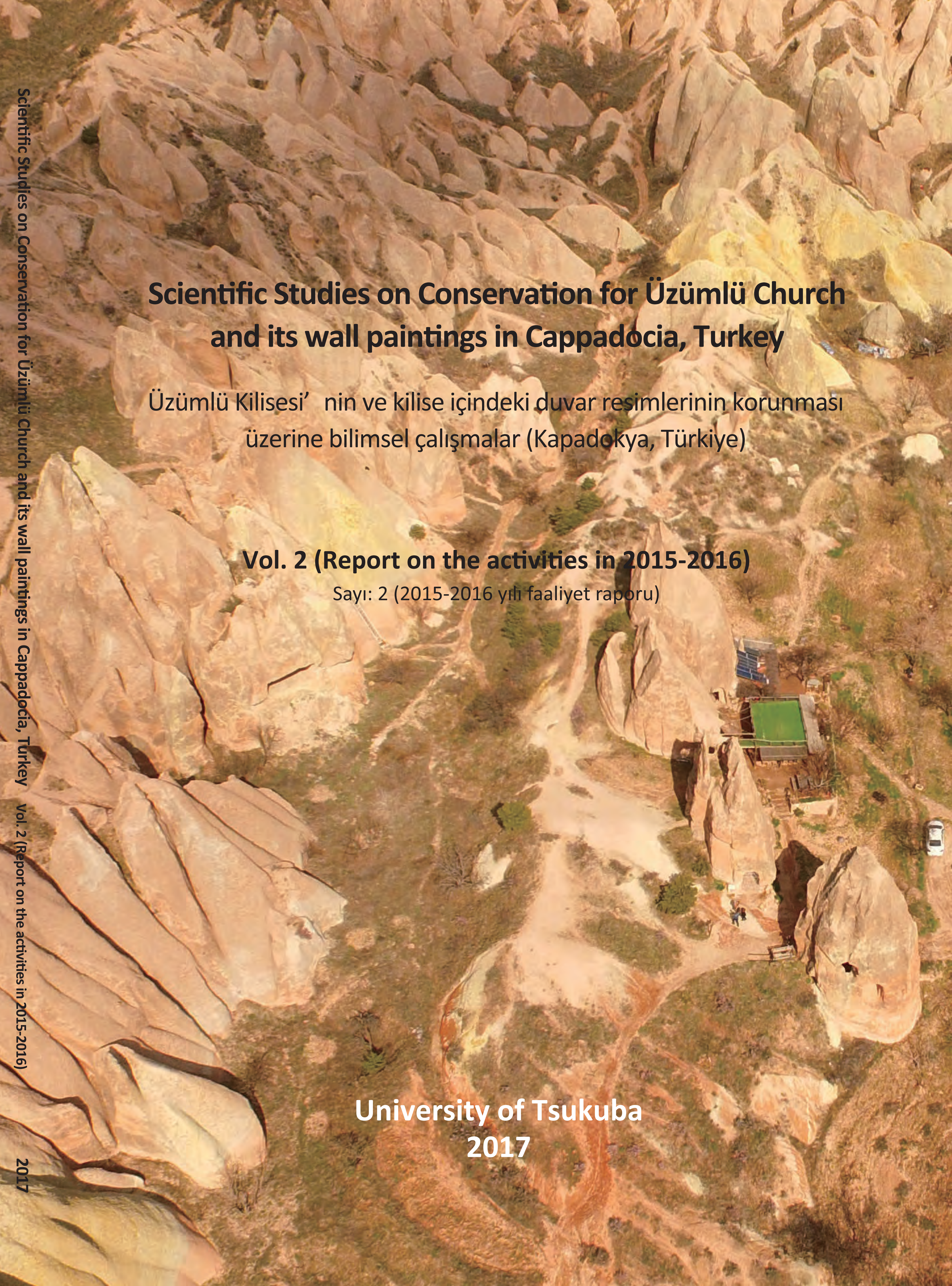


Scientific Studies on Conservation for Üzümlü Church and its wall paintings in Cappadocia, Turkey

Üzümlü Kilisesi' nin ve kilise içindeki duvar resimlerinin korunması üzerine bilimsel çalışmalar (Kapadokya, Türkiye)

Vol. 2 (Report on the activities in 2015-2016)

Sayı: 2 (2015-2016 yılı faaliyet raporu)

University of Tsukuba
2017

Scientific Studies on Conservation for Üzümlü Church and its wall paintings in Cappadocia, Turkey Vol. 2 (Report on the activities in 2015-2016) 2017

Published in March 2017

1-1-1 Tennodai, Tsukuba
Ibaraki, 305-8571, Japan

Scientific Studies on Conservation for Üzümlü Church and its wall paintings in Cappadocia, Turkey
Vol. 2: Annual report on the activities in 2015 and 2016

Printed in Japan at Maeda Printing co.
152-4 Yamanaka, Tsukuba
Ibaraki, Japan

Scientific Studies on Conservation for Üzümlü Church and its wall paintings in Cappadocia, Turkey

Vol. 2 (Report on the activities in 2015 – 2016)

Contents

I. Scientific Studies on Conservation for Üzümlü church and Its Wall Paintings

Ⅰ-1 Scientific Research and Conservation Intervention at Üzümlü Church 2016

Üzümlü Kilisede Yapilan Bilimsel Arastirmalarin Çalisma Raporu-2016

Yoko Taniguchi

Members　Üyeler
Japanese team　Japon ekibi
Yoko Taniguchi (University of Tsukuba)
Hisato Hashizume (Freelance conservator, Equilibrarte srl)

Turkish members　Türk Ekibi
Fazıl Açıkgöz (Director of Nigde Museum)
Hatice Temur (Director of Nevşehir Restorasyon ve Konservasyon Bölge Lab.)
Uğur Yalçınkaya (Restorer of Nevşehir Restorasyon ve Konservasyon Bölge Lab.)

Field work: 31 August – 11 September 2016

INTRODUCTION

The National Research Institute for Cultural Properties of Tokyo, the University of Tsukuba and Osaka University planned to initiate a research project in 2010 at the Üzümlü Church under the framework of UNESCO JFIT. Due to unforeseen circumstances, the project was not launched that year. However, with the permission of Turkey's Ministry of Tourism and Culture, a curtailed project for the Üzümlü Church was commenced in 2014 by the University of Tsukuba with participation from members of Japanese universities, Japanese companies in Kyoto, Osaka and Mie, and cooperative research teams from other countries. Funding for the project came from the Japanese government and the Kajima Foundation.

Since 2015, heightened security risks have raised concern in Turkey. This has created difficulties for students from Japan and elsewhere outside Turkey to access opportunities for didactic research activities in the field. Although the first three years of the Üzümlü Church project are near completion at this stage, the main objective—to resolve problems in conserving fragile tuff rock—has not yet been achieved. Therefore, further monitoring of the status of deterioration, the micro-environment and post-intervention conditions shall be continued until the second phase of the project is launched.

GİRİŞ

Öncelikle 2010 yılında, UNESCO'nun JFIT projesi çerçevesinde Tokyo'da bulunan Kültür Varlıklarının Ulusal Araştırma Enstitüsü, Tsukuba Üniversitesi ve Osaka Üniversitesi tarafından Üzümlü Kilise'nin araştırma projesi olarak yürütülmesi amaçlanmıştır.Çeşitli umulmadık nedenlerden ötürü proje başlatılamadı.2014'de Türkiye Cumhuriyeti Turizm ve Kültür Bakanlığının izni ile Japon hükümetinin fonları ve Kajima vakfının mali desteği alınarak Tsukuba Üniversitesi ve Japonyadaki Kyoto,Osaka ve Mie şehirlerinde bulunan diğer üniversiteler ve şirketlerle ve işbirlikçi diğer ülkelerin araştırmacıları ile yine Üzümlü Kilise'de daha küçük ölçekli bir proje başlatıldı.

Çevresindeki şartlar ile ilişkili olarak 2015'ten bu yana Türkiye'nin güvenlik seviyesinin belirsiz durumu giderek artmıştır.Yabancı öğrenciler için bazı eğitici çalışmalarda alan fırsatlarını değerlendirme durumu zorluğu ile sonuçlandı.Bu ilk 3 yıllık proje aşamasında neredeyse sonuca varılmıştır, ancak, aşınan tüf kayalar üzerine koruma sorununun temel amacı henüz çözülmüş değildir.Bundan dolayı, bozulmaların daha fazla izlenmesi, mikro-çevre koşulların etkisi ve koruma amaçlı uygulama sonrası durum, proje başlanıldığı zamandan itibaren projenin ikinci aşamasına kadar devam edilecektir.

1.Permeate application: A new trial

By Yoko Taniguchi

In 2015, a small tuff rock mass was chosen for a consolidation test using Permeate HS-360. A nearby tuff rock was also left untreated as a control and both were monitored for 1 year. The permeate is based on alkoxysilane containing a methyl or phenyl group. An alkoxy group is polymerised by hydrolysis with atmospheric moisture. After polymerisation, the 3D Si–O–Si structure improves bulk strength by firmly hardening in the gaps within the object. Moreover, after polymerisation, a methyl or phenyl group remains. As these groups are hydrophobic, the substance becomes water-repellent after curing. This alkoxysilane based consolidant does not form a film on the porous surface but penetrates and hardens at a depth of a few millimetres. Vapour can permeate the consolidant layer, although liquid water cannot infiltrate the layer. In practice, hydrolysis takes over 24 hours.

To quantify the degree of weathering of the tuff masses, stainless steel nails were anchored to the rock surface in September 2015. Surfaces facing in each of the four directions (north, east, west, and south) were identified and two nails were set in each direction such that one nail was located in the upper region and one in the lower region of the surface. One nail was then located on the top, leaving a total of nine nails on each test rock. The length of the nail appearing outside of the rock was measured with a digital caliper on both right and left sides. The nail length was measured by local collaborators every few months. In the ‘control’ mass, weathered tuff powder accumulated below the rock, and four out of the nine nails fell within the first four months from anchoring. In contrast, in the ‘treated’ mass, weathered deposits were generally small and only one nail fell off (Figure 1.1). The treated surface darkened distinctly as time passed (Figures 1.2a and 1.2b). The north side of the Üzümlü Church was also tested with the same material (Figures 1.7 and 1.8). However, this area showed less darkening compared to that on the rock masses.

In order to improve protection and to minimize darkening, a modified type of Permeate HS-390 was applied to another rock mass and on the north side of the church, next to the HS-360 area. 10 stainless steel anchors were placed on the new mass (Figure. 1.8). Periodical monitoring shall be carried

1. Permeate Uygulamaları (Yeni Deneme)

Yoko Taniguchi tarafından yapıldı

2015’te seçilmiş küçük bir kaya kütlesi üzerinde permeate HS-360 kullanarak konsolidasyon testi yapıldı.Bir yıl boyunca yakındaki tüf kayaçlar izlendi ve aşınan kumları düzeltilmeden bırakıldı.Permeate bir metil veya fenil gurubu içeren alkoksisilan bazlı bir organik bileşiktir ve bir alkoksi grubu atmosferik nem ile hidroliz yoluyla polimerize olur. (atmosferdeki nemi bünyesine alarak polimerleşmeşir) Polimerizasyon sonrası, üç boyutlu Si-O-Si (silisyum-Oksijen-Silisyum) yapısı içindeki boşluklar oldukça sıkı bir şekilde sertleşerek hacimce kuvvetini arttırır. Ayrıca, polimerizasyon sonucu, bir metil veya bir fenil grubu kalır.Bu gruplar hidrofobik olduğu için, kür sonrası su itici hale gelir. Bu alkoksisilan bazlı konsolidatör madde, gözenekli yüzey üzerinde bir film tabakası oluşturmaz ancak birkaç millimetre derinliğe nüfus eder ve sertleşir. Sıvı su tabakaya nüfuz edemezken buhar konsolidatif tabaka boyunca nüfuz edebilir. Pratikte, hidroliz 24 saati aşar.

Tüf kütlelerinin hava koşullarının aşndırma miktarını ölçmek için Eylül 2015'te paslanmaz çelik çiviler kaya yüzeyine yerleştirildi.Her yönde (üst ve alt kısımlar) ve üstte iki olmak üzere çivi yerleştirildi; Yani her bir test kayasında 9 çivi bulunuyordu. Kaya dışından görülen çivinin uzunluğu hem sağ hem de sol tarafta dijital kaliper ile ölçülmüştür. Her ay Nevşehir Bölge Laboratuvar uzmanları tarafından çivi uzunluğu ölçüldü.'Kontrol' kayasında, kayanın altına biriken aşınan tüf tozu ve yerleştirilen dokuz çivinin dördü dört ay sonra kaya kütlesinden düştü. Buna karşılık, 'permeate kaplanan' kayasında, yıpranmış katmanlar genelde küçüktür ve sadece bir çivi düşmüştür (Şekil 1.1).Uygulama yapılan yüzey, zaman geçtikçe belirgin olarak koyulaşmıştır (Şekil 1.2a, b). Üzümlü kilisesinin kuzeyi de aynı malzeme ile test edildi (Şekil 1.7, 1.8) ancak bu alan, kaya kütlesine kıyasla daha az kararmıştır.

Bu algılanan koyluğu düzeltmek için, bir başka kaya kütlesi üzerinde ve kilisenin kuzey tarafında (HS-360'ın yanında) bir modifiye edilmiş Permeate HS-390 uygulanmıştır. Yeni kütlenin üzerine 10 paslanmaz çelik çivi yerleştirildi (Şekil 1.8). Nevşehir Bölge Laboratuvar Müdürlüğü ile işbirliği periyodik izleme ve control çalışması yapılacaktır.

out in cooperation with the regional conservation lab in Nevshehir.

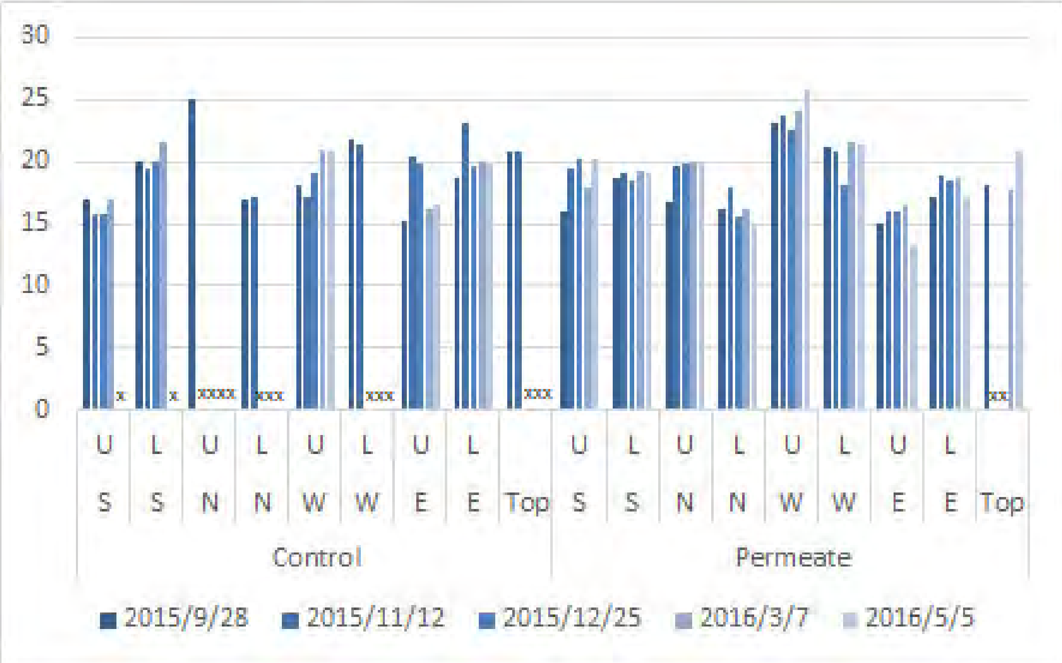


Figure. 1.1 Comparison of anchors (control and Permiate HS-360)
Şekil. 1.1 Çivilerin karşılaştırılması (kontrol ve permiate HS-360)

east ／Doğu

Figure. 1.2a Condition of area treated with Permeate HS-360 (Sep 2015)

Şekil. 1.2a Permeate HS-360 uygulanan alanın durumu (Eylül 2015)

east ／Doğu

Figure. 1.2b Condition of area treated with Permeate HS-360 (Sep 2016)

Şekil. 1.2a Permeate HS-360 uygulanan alanın durumu (Eylül 2015)

Figure. 1.3 Condition of area treated with Permeate HS-360. Some areas of the consolidated surface were detached (Sep 2016)
Şekil. 1.3 Permeate HS-360 uygulanan alanın durumu: Konsolide(kaplanan) yüzeyin bazı alanları ayrılmıştır (Eyl 2016)

Figure. 1.4 Condition of area treated with Permeate HS-360. The lower portion showed weathering under the consolidated layer (Sep 2016)
Şekil. 1.4 Permeate HS-360 uygulanan alanın durumu: alt bölüm, alt kısım konsolide (kaplanan) katmanın altında belirli hava şartlarına maruz kaldığı görülür (Eyl 2016)

Figure. 1.5 Application of HS-390 next to the HS-360 area (after 1 year) (north side of the church)

Şekil. 1.5 HS-390 uygulaması HS-360 alanının yanında (1 yıl sonra) (kilisenin kuzey tarafında)

Figure. 1.6 Application of HS-390 to a rock mass

Şekil. 1.6 Kaya kütlesi üzerinde HS-390 uygulaması

Figure. 1.7 Surfaces 24 hours from application (HS-390) and 1 year from application (HS-360)

Şekil. 1.7 Uygulamadan 24 saat sonra (HS-390) ve uygulamadan 1 yıl sonra (HS-360)

Figure. 1.8 Surface 24 hours from application

Şekil. 1.8 Uygulamadan 24 saat sonra

Figure. 1.9 Location of the tested masses (Permeate HS-360, 390 and control)

Şekil. 1.9 Test edilen kaya kütlelerin bulunduğu yer (Permeate HS-360, 390 ve kontrol)

Ⅰ -2 Evaluation on The Biodeterioration or Bioprotection Effect on The Rock by Lichens Species

Kaya Üzerinde Liken Türlerinin Biyolojik Koruma veya Biyolojik Bozunma Etkisine Göre Değerlendirme

Annalaura Casanova and Giulia Caneva
Department of Science, University Rome Tre 28/7/2016

Issue

The Uzumlu church, in Cappadocia, made by pink tuff substrata, appears significantly covered by a wide biological colonization, visually appearing as black-gray crusts and biofilms and mainly due to lichens growths. This colonization appears distributed over all the facades, which qualitative and quantitative changes depending on of their exposure (west, north, east and south) (Fig.1).

Durum

Kapadokya'daki Üzümlü Kilise, pembe tüf tabakalıdır, geniş bir biyolojik kolonizasyonla önemli ölçüde örtülüdür, görünüş olarak siyah-gri kabuklu olarak algılanır ve biyofilm (biyolojik tabaka) temelde likenlerin büyümesine bağlıdır. Bu kolonizasyon, niteliksel ve niceliksel değişikliklere bağlı olarak ortaya çıkar (batı, kuzey, doğu ve güney), tüm cephelere dağılmış görünmektedir.(Şekil 2.1).

Aim

The aim of this work is to identify the lichen species growing into the rocks and to investigate the biodeterioration or bioprotection effect on the stone. This information is fundamental for establishing if a biocide treatment of the rock could worsen or improve the state of conservation of the church.

Amaç

Bu çalışmanın amacı kayada gelişen liken türlerini saptamak-tanımlamak ve kaya üzerindeki biyolojik bozulmayı veya biyolojik koruma etkisini araştırmaktır. Bu bilgi, kayaların biyolojik oluşumlarının kilisenin korunma durumunu olumlu yönde etkilediği veya koruyamayacağı olumsuz etki sini belirlemek için temel bir gerekliliktir.

Materials and Methods

In situ observation and sampling

In the western façade, we have observed a very intense biological patina, which appears distributed mainly in the upper and middle areas (Fig. 1). The lower area next to the entrance looks rather not colonized. In this exposure, where the biological patina looked different we have collected two samples (W1 and W2). The northern surface is characterized by a sub-vertical inclination and seems mainly eroded. Here, the biological patina appears very compact and looks to be mainly composed of lichens and mosses. In this area, we took four samples in the lower zone (N1, N2, N3, and N4). The eastern exposure is sub-vertical and it is suffering from a strong colonization consisting of lichens. In the upper and lower area, we have collected two fragments (E1, E2). In the southern exposure, the surface appears widespread colonized, and we have taken two samples from the lower zone (S1, S2).

Malzemeler ve Yöntemler

Yerinde inceleme ve örnekleme

Kilisenin batı cephesinde özellikle üst ve orta bölümlerinde dağılmış olarak ortaya çıkan oldukça yoğun biyolojik patina gözlemlendi (Şekil 2.1). Kilise girişinin yanındaki alanda çok fazla biyolojik kolonileşmenin olmadığı görüldü. Biyolojik patinanın farklı göründüğü bu cepheden iki örnek alındı (W1 ve W2). Kilisenin kuzey yüzeyi alt-dikey eğimle karakterize edilmiş ve aslında aşındığı gözlemlenmiştir. Burada, biyolojik patina çok yoğun görünmekte ve çoğunlukla likenler ve yosunlardan oluştuğu gözlemlenmektedir. Bu alanda, alt kısımlardan 4 adet örnek alındı (Ö1, Ö2, Ö3 ve Ö4). Kilisenin doğusunda dikey-alt kısımlarında ortaya çıkan güçlü bir liken kolonizasyonu bulunmaktadır. Üst ve alt bölümlerden iki örnek alınmıştır (E1, E2). Kilisenin güney cephesinde, yüzeyde yaygın kolonize olduğu görünmektedir ve alt bölümlerden iki örnek alınmıştır (S1, S2).

Figure. 2.1 Distribution of biological colonization in different exposures
Şekil 2.1 Kilisenin farklı cephelerindeki biyolojik kolonizasyon dağılımı

Laboratory observations

The identification of the species was carried out partially in the field in the laboratory using specific keys of determination for each sampled biological group. We also thanks Dr. P. Giordani for the check of Lichens, and the identification work to arrive the species level will be completed at soon.

The rock is a dirty white to pink tuff rock, and contains minerals as plagioclase, quartz, biotite. The porosity is very high with an effective porosity of 38 % (Topal & Doyuran, 1998).

Analysis has been directly performed both on the samples without any preparation and on the polished cross-sections in order to investigate the fragment in depth. Sample preparation involved embedding the sample in a polyester resin prior to polishing according to UNI 10922. Pictures of all samples have been taken by an Olympus SZX16 stereomicroscope, digital pictures have been taken with a Color View II (Soft Imaging System GmbH, Münster, Germany) digital camera coupled to Cell^B software. In addition, the cross-sections were observed with a NIKON Eclipse ME600, SMZ 800, EPIPHOT 300 microscope and digital photographs were taken with a Nikon Digital Sight DS-Fi1 Digital Camera.

SEM analyses were performed on the fractured rock

Laboratuvar İncelemeleri

Örneklenen her bir biyolojik grup için türlerinin tanımlanlası; kısmen çalışma sahasında ve belirli tanımlama metotları kullanılarak laboratuvarda gerçekleştirildi. Ayrıca likenlerin kontrolü için Dr. P. Giordani'ye teşekkür ediyoruz ve yakında türlerin tanımlama çalışması tamamlanacaktır.

Tüf kaya, kirli beyaz-pembe tüf ve kuvars, biyotit, plajiyoklas gibi mineralleri içermektedir.Kayanın gözenekli yapısı, %38 oranında etkin bir gözeneklilik ile oldukça yüksektir (Topal &Doyurgan, 1998).

Hem herhangi bir hazırlık yapılmayan numunenin hemde parlatılmış parça-kesiti alınan numunenin derinlemesine araştırılması amacıyla analiz işlemleri doğrudan gerçekleştirilmiştir. Numune hazırlama işlemi, UNI 10922'ye gore parlatılmadan once numune bir polyester reçineye gömülmesini içerir.Tüm numunelerin resimleri OLYMPUS SZX16 streomikroskop ile, dijital resimler Renkli Görünüm II (Soft Görüntülemi Sistemi GmbH,Münster, Almanya) Cell^B yazılım programına bağlı dijital fotoğraf makinasıyla çekildi. Buna ek olarak, enine-kesitleri NİKON Eclipse ME600,SMZ 800, EPİPHOT 300 mikroskobu ile incelendi ve fotoğraflar Nikon Dijital Sight DS-Fi1 Dijital fotoğraf makinası ile çekildi.

Kırık kaya örnekler üzerinde SEM analizleri yapıldı (herhangi samples (without any preparation). All the samples were spurred with gold under vacuum using K550 unit (Emitech Technologies Ltd., Kent, England) and were then observed with a XL30 SEM microscope (FEI Company, Eindhoven, The Netherlands. Samples were inserted into the vacuum and secondary electron (SE) images was done at an accelerating voltage of 5 kV and a working distance of 8 mm in order to obtain a recognition of the morphological structure of the lichens species.

Results and discussion

West exposure

In both samples W1 and W2 has been observed the presence of the crustose lichen Acarospora sp., characterized by a red-brown thallus with small areoles firmly attached to the substrate (Fig 2 a, d).

In the W1 fragment SEM analysis showed a dense networks of fungal hyphae under the surface and in the lower part of the sample. On the other hand, in sample W2 fungal hyphae appear lesser dense but is clear the penetration inside the

hazırlık işlemi yapılmaksızın) Tüm numunelere K550 ünitesi (Emitech Tekonolojisi Ltd., Kent, İngiltere) kullanılarak vakum altında altın püskürtüldü ve daha sonar bir XL30 SEM mikroskopu (FEI Şirketi,Eindhoven,Hollanda) ile incelendi. Numuneler vakumun içine yerleşrildi ve ikincil electron (SE) görüntüleri 5kV'lık bir hızlandırma voltajıyla yapıldı ve liken türlerinin morfolojik yapısının belirlenmesi amacıyla 8mm'lik mesafede çalışıldı.

Sonuçlar ve tartışmalar

Batı cephe

Her iki örnekte W1 ve W2'de alt katmana sıkıca tutunmuş kırmızı-kahverengi küçük lekeler içeren bir talus ile belirlenen, krustoz liken Acarospora sp. gözlenmiştir (Şekil 2.2 a.d).

W1 parçasında yapılan SEM analizi, yüzeyin altında ve örneğin alt tarafında yoğun mantar hife ağlarının olduğunu gösterdi. Öte yandan, W2 örneğinde mantar hifelerinin yoğunluğunun daha az görülmesine ragmen kaya

Figure. 2.2 Biological colonization in west exposures a), d) Sampling points and pictures under the stereomicroscope; b), c) Microphotograph of the sample in polished cross sections; c), d) SEM image in false colour of the fragments.

Şekil 2.2 Kilisenin batı cephesinde biyolojik kolonizasyon a), d) Alınan örneklerin kilise yüzeyinde seçilen noktalar ve stereomikroskop altındaki resimleri ; c) Parlatılan kesitlerde örneklerin misroskopografisi ; c), d) Örnek parçaların renkli SEM görüntüsü stone between the rock grains.

taneciklerinin arasındaki taş içerisine nüfuz etmeye açıktır.

North exposure

N1

In the fragment N1 has been observed the crustose lichen Aspicilia; the thallus is whitish- to leaden grey and appear cracked-areolate with the surface of each areole warted (Fig 3 a). In addition, the OM and SEM observation (Fig. b, c) showed the presence of black meristematic fungi over the surface.

The SEM observation of the entire fractured sample highlights the dense networks of fungal hyphae inside the rock. The images also indicate that a relatively greater portion of the rock shows evidence of fragmentation and crumbling. In fact, as shown by Figs. 3 I and II, mineral grains are completely embedded in the interior of the hyphae networks. The abundance of hyphae decreases with the depth, and only a few hyphae can be seen in the bottom part.

North exposure

N1

In the fragment N1 has been observed the crustose lichen Aspicilia; the thallus is whitish- to leaden grey and appear cracked-areolate with the surface of each areole warted (Fig 3 a). In addition, the OM and SEM observation (Fig. b, c) showed the presence of black meristematic fungi over the surface.

The SEM observation of the entire fractured sample highlights the dense networks of fungal hyphae inside the rock. The images also indicate that a relatively greater portion of the rock shows evidence of fragmentation and crumbling. In fact, as shown by Figs. 3 I and II, mineral grains are completely embedded in the interior of the hyphae networks. The abundance of hyphae decreases with the depth, and only a few hyphae can be seen in the bottom part.

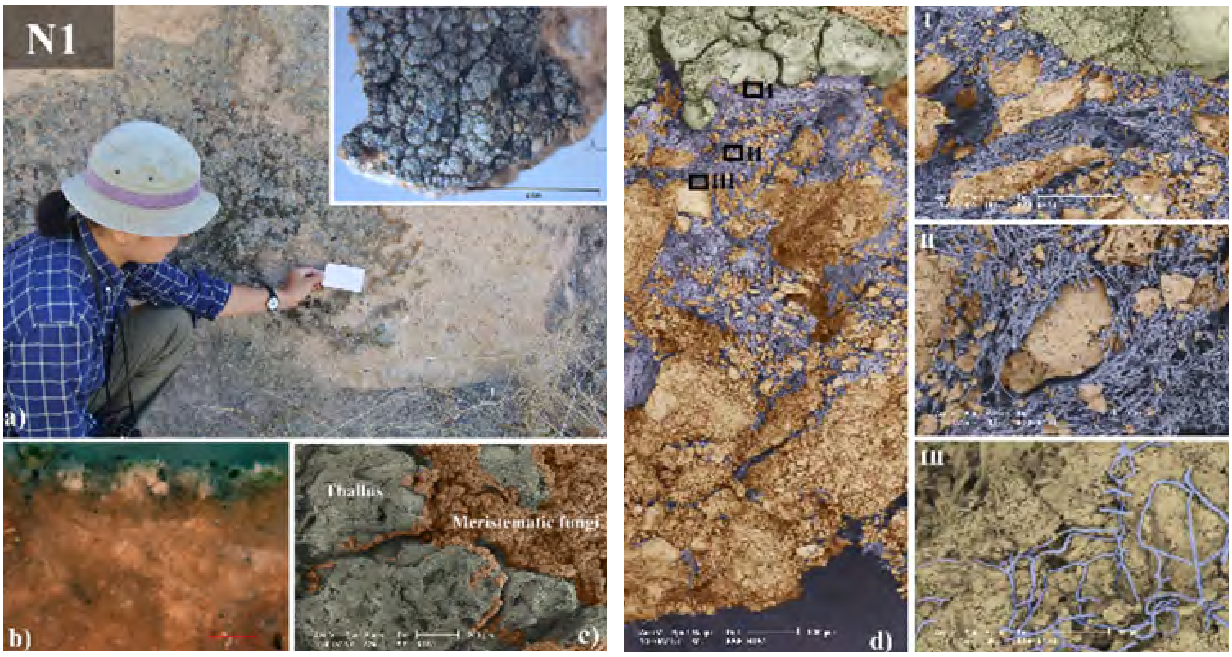


Figure. 2.3 Biological colonization in north exposures a) Sampling point (N1) and picture under the stereomicroscope; b) Microphotograph of the sample in polished cross sections; c) SEM image in false colour of the fragment surface; d) SEM image in false colour of the fragment.

Şekil 2.3 Kilisenin batı cephesinde biyolojik kolonizasyon a) Alınan örneğin (N1) kilise yüzeyinde seçilen noktası ve stereomikroskop altındaki resimi ; b) Parlatılan kesitlerde örneğin misroskopografisi; c) Örnek parça yüzeyinin renkli SEM görüntüsü, d) Örnek parçanın renkli SEM görüntüsü

N2

In the fragment N2 have been observed the crustose lichens Caloplaca and Lecanora cfr. crenularia, characterized by orange and brown apothecia without a thalline margin (Fig. 4 a). Meristematic fungi were also observed by OM in the polished cross-section (Fig. 4b, c).

The SEM details of the entire fractured sample show several spherical bore-holes arising from fungal hyphae and the reproductive fungi structures that actively penetrate inside the grains leaving tunnels and bore-holes on the surface (Fig. 4 d).

N2

N2 parçasında, turuncu ve kahverengi apotekiya ile çok büyük mesafe gerekmeksizin krustoz liken Caloplaca ve Lecanora cfr. Crenularia gözlenmiştir (Şekil 2.4 a). Cilalı kesitte OM analizi ile meristematik mantarlar gözlenmiştir (Şekil 2.4 b, c).

Kırık örneğin tamamının SEM analiz detayları, mantar hiflerden ve üreyen mantar yapılarından kaynaklanan çeşitli küresel delikleri göstermektedir; bu yapılar, yüzeyde boşluk ve delikler oluşturarak taneciklerin içine aktif şekilde nüfuz etmektedir (Şekil 2.4 d).

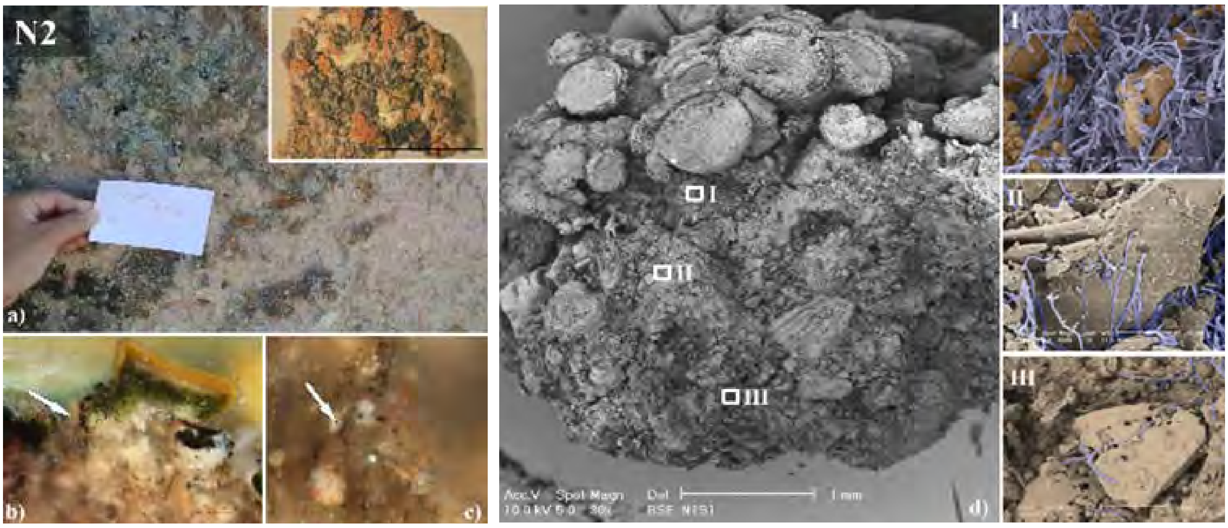


Figure. 2.4 Biological colonization in north exposures a) Sampling point (N2) and picture under the stereomicroscope; b) ,c) Microphotograph of the sample in polished cross section; d) SEM image of the entire fragment with detail in false colour.

Şekil 2.4 Kilisenin kuzey cephesinde biyolojik kolonizasyon a) Alınan örneğin (N2) kilise yüzeyinde seçilen noktası ve stereomikroskop altındaki resimi ; b) ,c)Parlatılan kesitlerde örneğin misroskopografisi; d) Örnek parçanın tamamının detaylı olduğu renkli SEM görüntüsü

N3 and N4

In the fragment N3 has been observed a crustose lichen Xanthoparmelia group Neofuscelia, the thallus is areolate and verrucose; the surface appear ash gray, globular, and epruinose. In addition, the OM observation (Fig. b, c) showed a dense presence of black meristematic fungi.

The SEM observation of the entire fractured sample shows the striking density and penetration of the networks of fungal hyphae inside the rock. In detail, the Fig. 6 I and II show the photobiontic layer in the thallus structure, while Fig. 6 III and IV underline as the mineral grains are completely embedded in the hyphae networks.

On the other hand, sample N4 appear colonized by a lichen with thallus foliose, the long upper surface is brown with some blackened areas. Due to the limited substrate attached to the lichen has not been possible to do observations by SEM.

N3 ve N4

N3 parçasında, talus ayrı ve yumrudur, yüzeyi kül grisi küresel ve epruizoz gibi görünen krustoz liken Xanthoparmelia sınıfından Neofuscelia gözlenmiştir. Bununla birlikte, OM gözleminde (Şekil b, c) siyah meristemik mantarların varlığı yoğun şekilde görülmektedir.

Kırık örneğin tamamının SEM analiz gözleminde, kayada bulunan mantar hifeleri ağlarının dikkat çeken yoğunluğu ve penetrasyonunu gösterir.Ayrıntıları şekildedir. Şekil, 6 I ve II, talus yapısındaki fotobiyotik tabakadır. Şekil 6 III ve IV, mineral taneleri hif ağlarına tamamen gömülmesini vurgular.

Öte yandan N4 örneği, talus foliozlu bir liken tarafından kolonize edilmiş gibi görünen uzun üst yüzeyi kahverengi ve bazı bölümleri kararmıştır. Substrat yüzeye bağlı likenlerin yüzünden SEM analizi ile gözlem yapmak mümkün olmadı.

Doğu cephesi

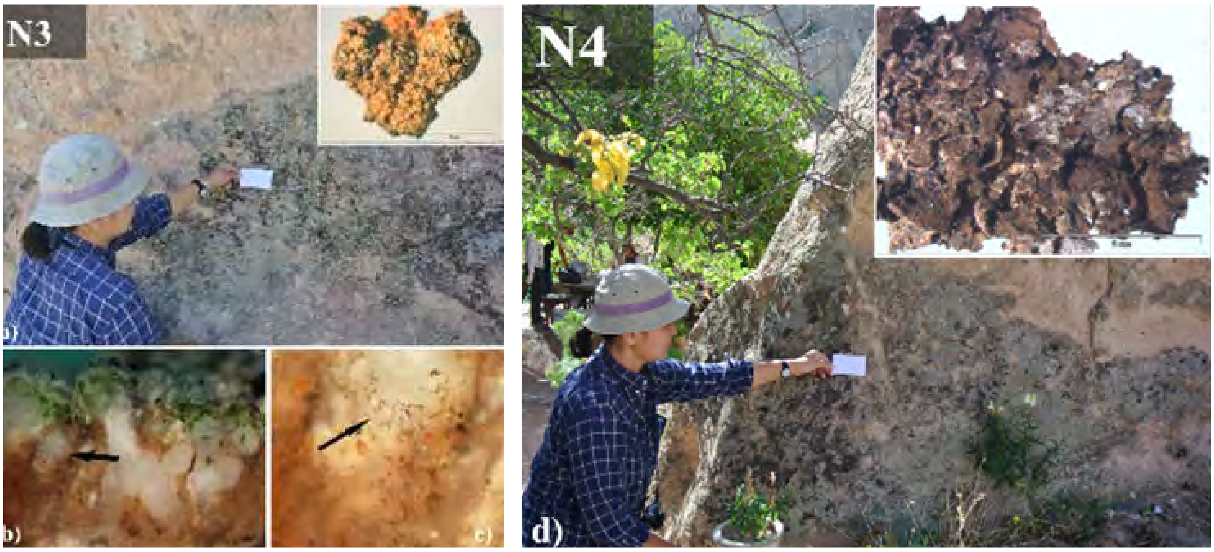


Figure. 2.5 Biological colonization in north exposures a), d) Sampling points (N3, N4) and pictures under the stereomicroscope; b), c) Microphotograph of the sample in polished cross section, the arrows underline the meristematic fungi presence.

Şekil 2.5 Kilisenin kuzey cephesinde biyolojik kolonizasyon a) Alınan örneklerin (N3,N4) kilise yüzeyinde seçilen noktalar ve stereomikroskop altındaki resimleri ; b), c) Parlatılan kesitlerde örneklerin misroskopografisi ve oklar meristematik mantarların varlığını vurgulamakta

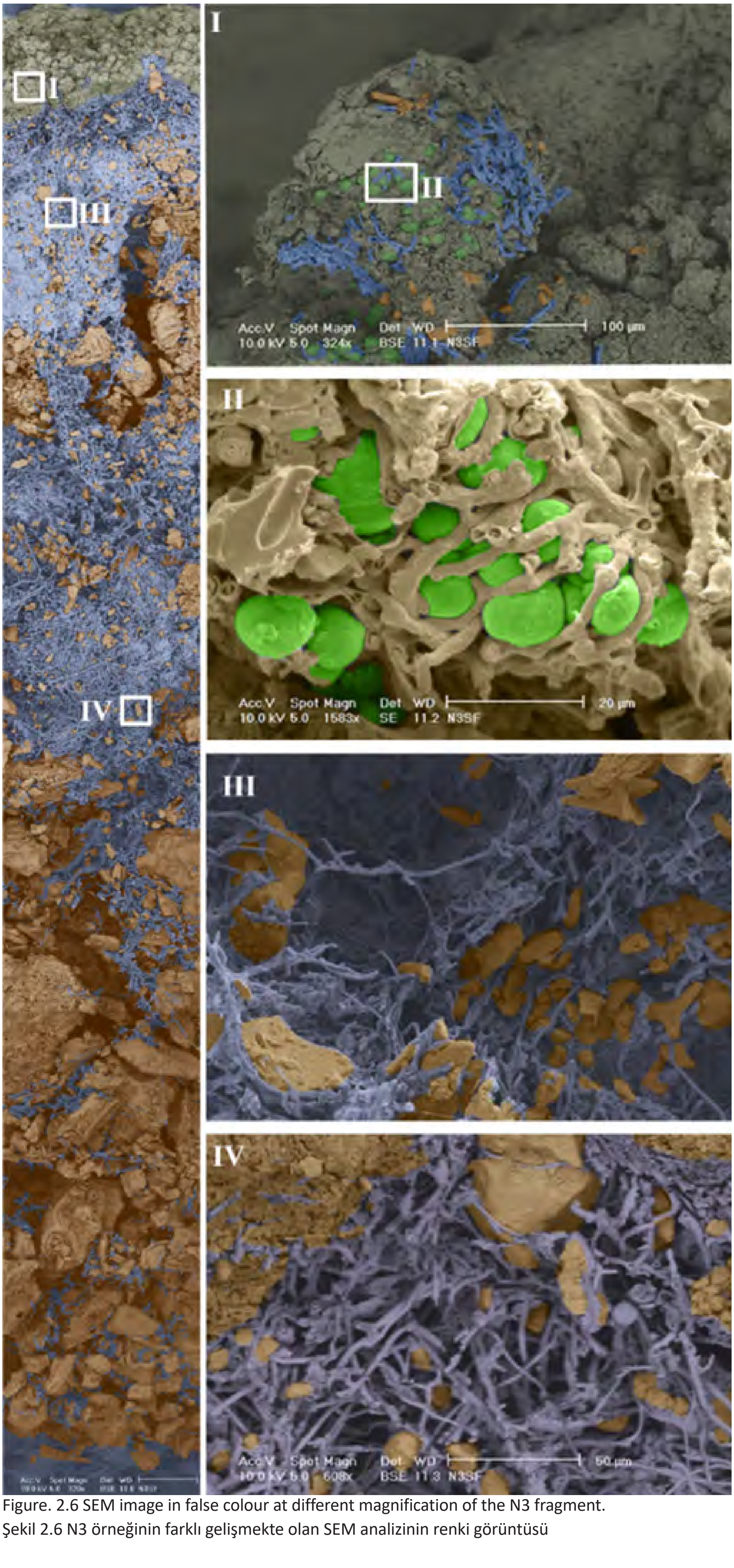


Figure. 2.6 SEM image in false colour at different magnification of the N3 fragment.
Şekil 2.6 N3 örneğinin farklı gelişmekte olan SEM analizinin renki görüntüsü

East exposure

E1

In the fragment E1 has been observed the crustose lichen Aspicilia; the thallus is grayish-white and appear cracked-areolate, with the surface of each areole irregular (Fig 7 a). Under the thallus area is evident a bright orange coloration (Figs. b, c).

SEM observations of the fragment showed a strong loss of the rock matrix and a dense network of fungal hyphae that penetrates into the substrate to a depth of several millimeters. In detail, the figures 8 II and III underline that mineral grains are completely embedded in the interior of the hyphae networks.

E2

In the fragment E2 has been observed the crustose lichen Caloplaca, characterized by orange and white apothecia without a thalline margin (Figs. 7 d). Meristematic fungi were also observed inside the rock by OM in the polished cross-section (Fig. 7 f).

SEM observations of the fragment showed a strong network of fungal hyphae under the surface where few rock grains have been observed (Fig. 9). The abundance of hyphae decreases with the depth, and only a few hyphae can be seen in the bottom part. Interesting, in an area of sample figures 9

Doğu cephesi

E1

E1 parçasında, talus griyimsi-beyazdır ve kırık görünümlü, her oyuğun yüzeyinde düzensiz olarak bulanan krustoz liken Aspicilia gözlenmiştir (Şekil 2.7 a). Talus bölgesinin altında açık turuncu renktedir (Şekil 2.7 b, c).

Parçanın SEM gözlemlerinde, kaya kaidesinin güçlü bir şekilde kaybedildiği ve birkaç millimetre derinliğe kadar subsrat içine nüfuz eden yoğun bir mantar hifesi ağı tespit edildi. Şekil 2.8 II ve III'de detaylı olarak mineral tanelerin hif ağlarının içine tamamen gömüldüğünü vurgular.

E2

E2 parçasında, turuncu ve beyaz apotekiya ile çok büyük mesafe olmaksızın krustoz liken Caloplaca gözlenmiştir (Şekil 2.7 d). Cilalı kesitte OM analiziyle kayalarda meristematik mantarlar gözlenmiştir (Şekil 2.7 f).

Örneğin SEM gözlemlerinde, birkaç kaya tanesinin bulunduğu yüzeyde mantar hiflerinin güçlü bağı olduğunu göstermektedir (Şekil 9). Hiflerin yoğunluğu derinleştikçe azalır ve alt kısımda sadece birkaç hif görünmektedir.Farklı olarak, Şekil 2.9 II ve III örneklerinin bir kısmının boyutu 5 µm'lik dairesel yapıların ayrıntını gösterir fakat yapılarının

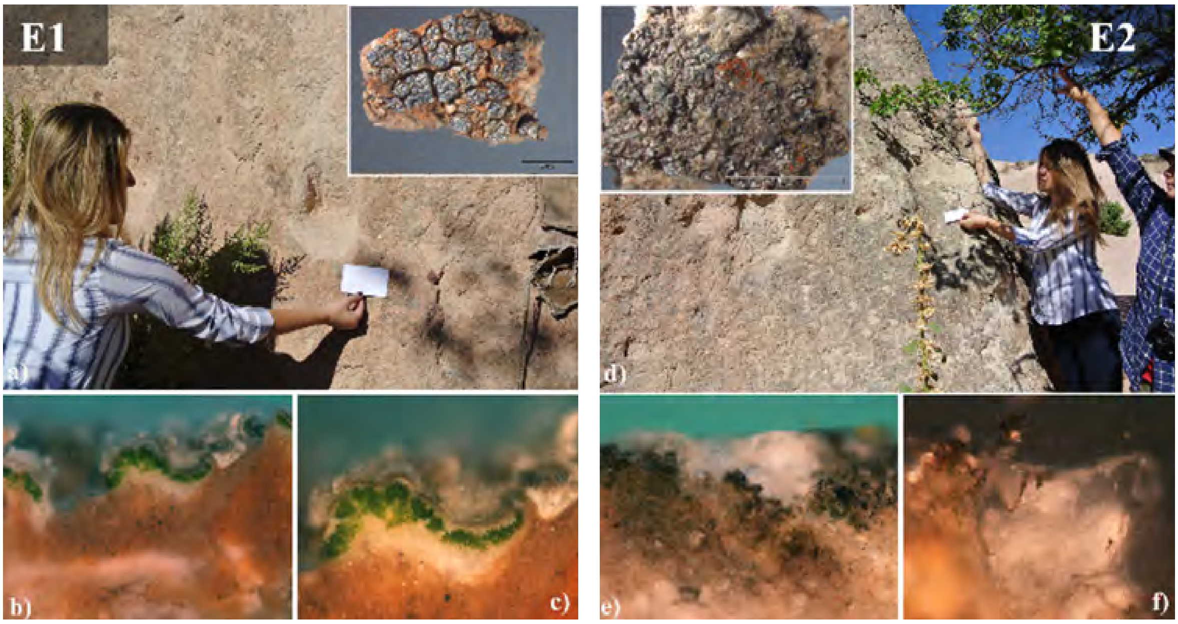


Figure. 2.7 Biological colonization in east exposures a), d) Sampling points (E1, E2) and pictures under the stereomicroscope; b), c), e), f) Microphotograph of the sample in polished cross sections.

Şekil 2.7 Kilisenin doğu cephesinde biyolojik kolonizasyon a), d) Alınan örneklerin (E1,E2) kilise yüzeyinde seçilen noktalar ve stereomikroskop altındaki resimleri ; b), c), e), f) Cilalı kesitlerde örneklerin misroskopografisi

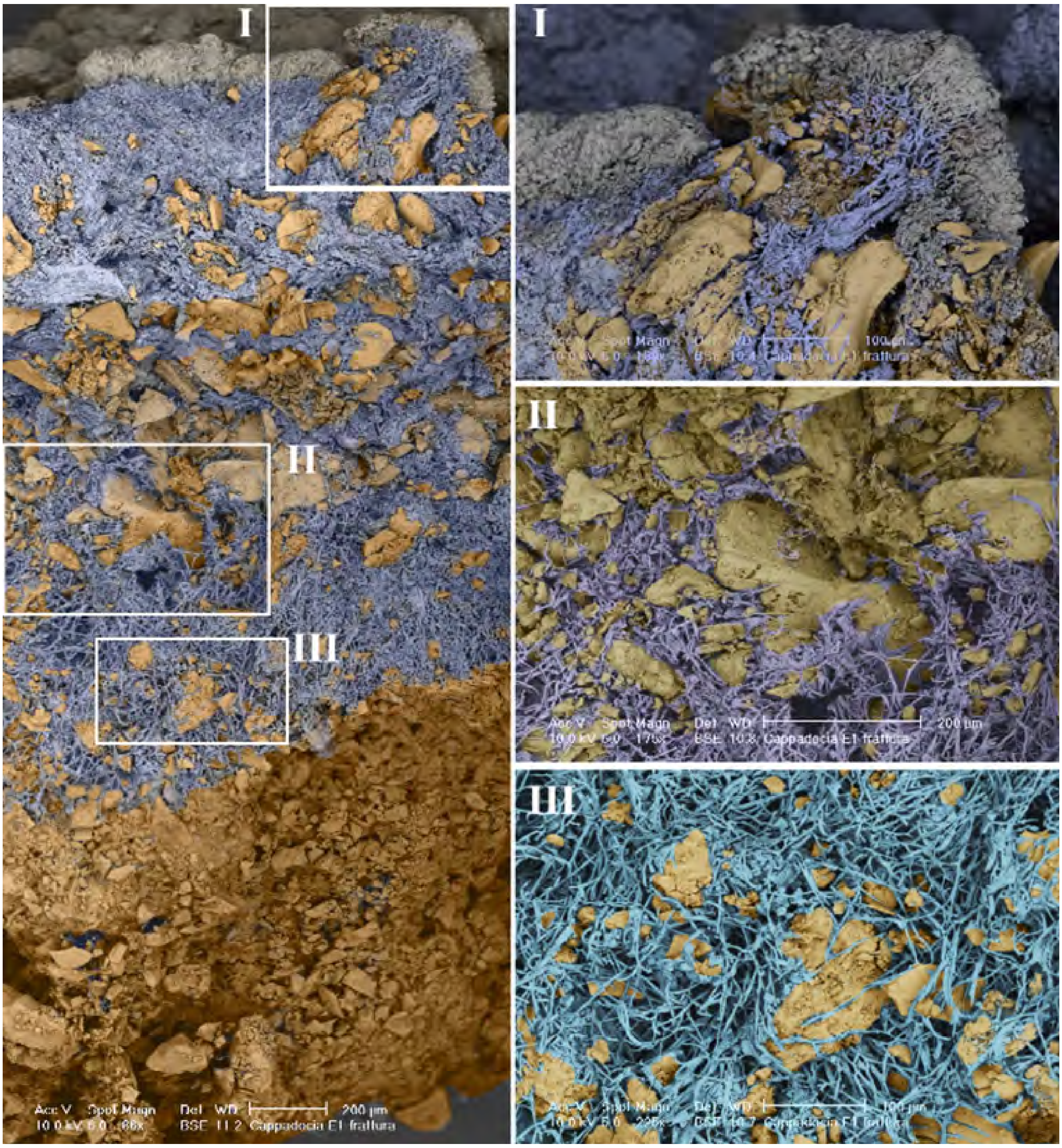


Figure. 2.8 SEM image in false colour at different magnification of the E1 fragment.

Şekil 2.8 E1 örneğinin farklı gelişmekte olan SEM analizinin renki görüntüsü

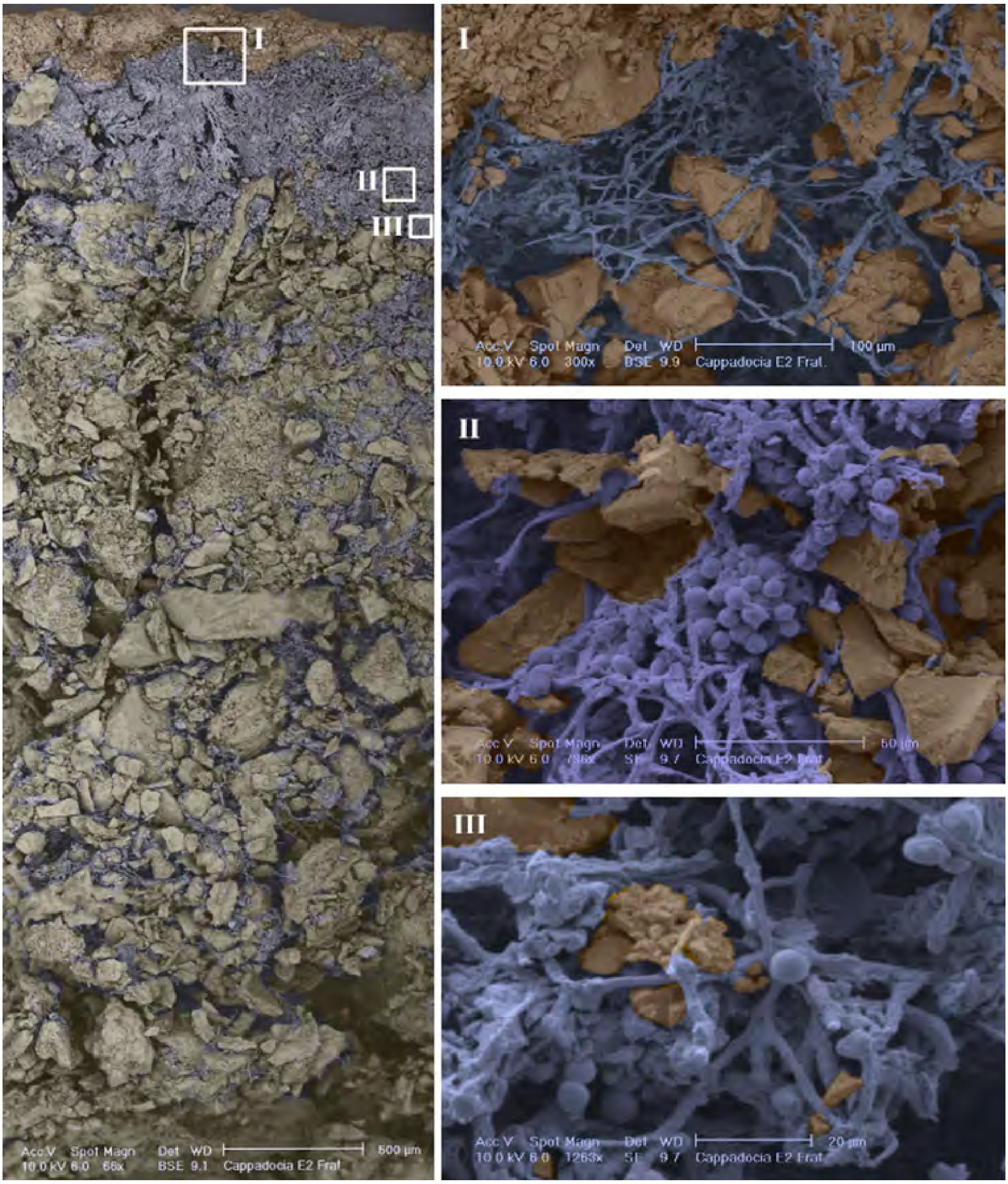


Figure. 2.9 SEM image in false colour at different magnification of the E2 fragment.
Şekil 2.9 E2 örneğinin farklı gelişmekte olan SEM analizinin renki görüntüsü

II and III shown a detail of circular structures of size of about 5 µm, but their nature is still to be investigated.

özelliği hala araştırılmaktadır.

South exposure

S1

In the fragment S1 has been observed a crustose lichen Acarospora; the thallus appears with angular areoles and the upper surface is reddish brown (Fig 10 a). In addition, the OM observation (Fig. 10 c) showed the presence of black meristematic fungi over the surface.

The SEM details of the fractured sample show mineral grains completely embedded in the hyphae networks and fragmentation of portion of the rock (Figs. 10 d, e, f, g).

Güney Cephe

S1

S1 örneğinde; üst yüzeyi kızıl kahve renkli ve açısal izlerle tallus, krustoz liken Acarospora gözlenmiştir. (Şekil 2.10 a).Buna ek olarak, OM gözleminde (Şekil 2.10 c) yüzey üzerinde siyah meristematik mantar gözlenmiştir.

Kırık örneğin SEM analiz detayları, hif ağlarında tamamen gömülü halde olan mineral taneleri ve kaya kısmının parçalanmasını göstermektedir (Şekil 2.10 d, e, f, g).

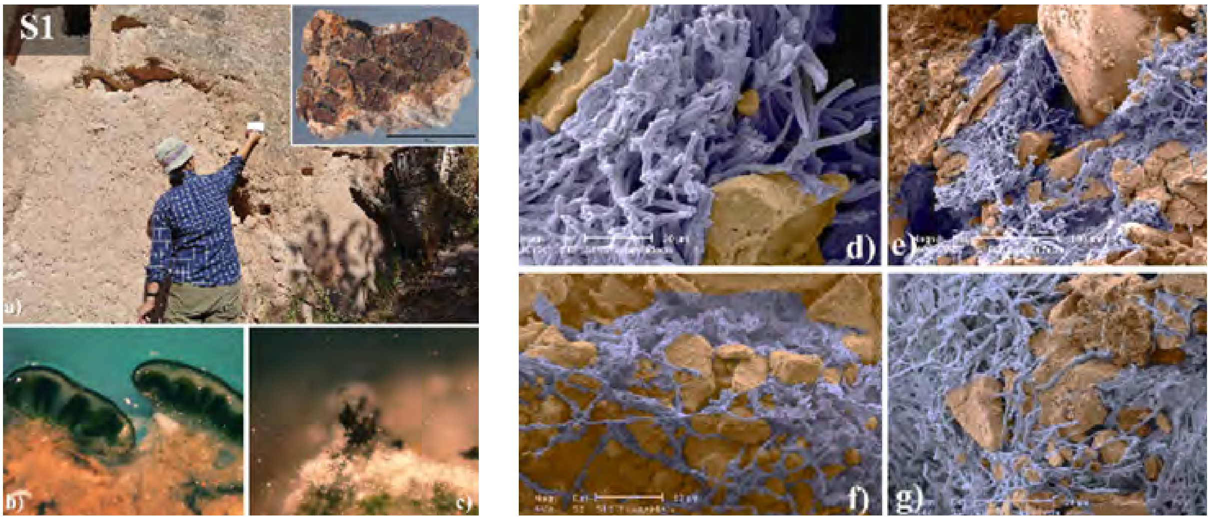


Figure. 2.10 Biological colonization in south exposures a) Sampling point (S1) and picture under the stereomicroscope; b), c) Microphotograph of the sample in polished cross section; d), e), f), g) SEM image in false colour of details observed in the sample

Şekil 2.10 Kilisenin güney cephesinde biyolojik kolonizasyon a) Alınan örneğin (S1) kilise yüzeyinde seçilen noktası ve stereomikroskop altındaki resmi ; b), c) Cilalı kesitte alınan örneğin misroskopografisi ; d), e), f), g) Örnek parçanın tamamının detaylı olduğu renkli SEM görüntüsü

S2

In the fragment S2 has been observed the crustose lichen Acarospora; the thallus is white and appear with the areoles more rounded (Fig. 11 a). The SEM details of the fractured sample show mineral grains completely embedded in the hyphae networks (Figs. 11 d, e).

S2

S2 parçasında, talusu beyaz renkli ve areoles daha yuvarlak görünen krustoz liken Acarospora gözlenmiştir (Şekil 2.7 d). Kırık numunenin SEM analizi detaylarında, hif ağlarına tamamen gömülü olan mineral taneleri görülmektedir (Şekil 2.11 d, e).

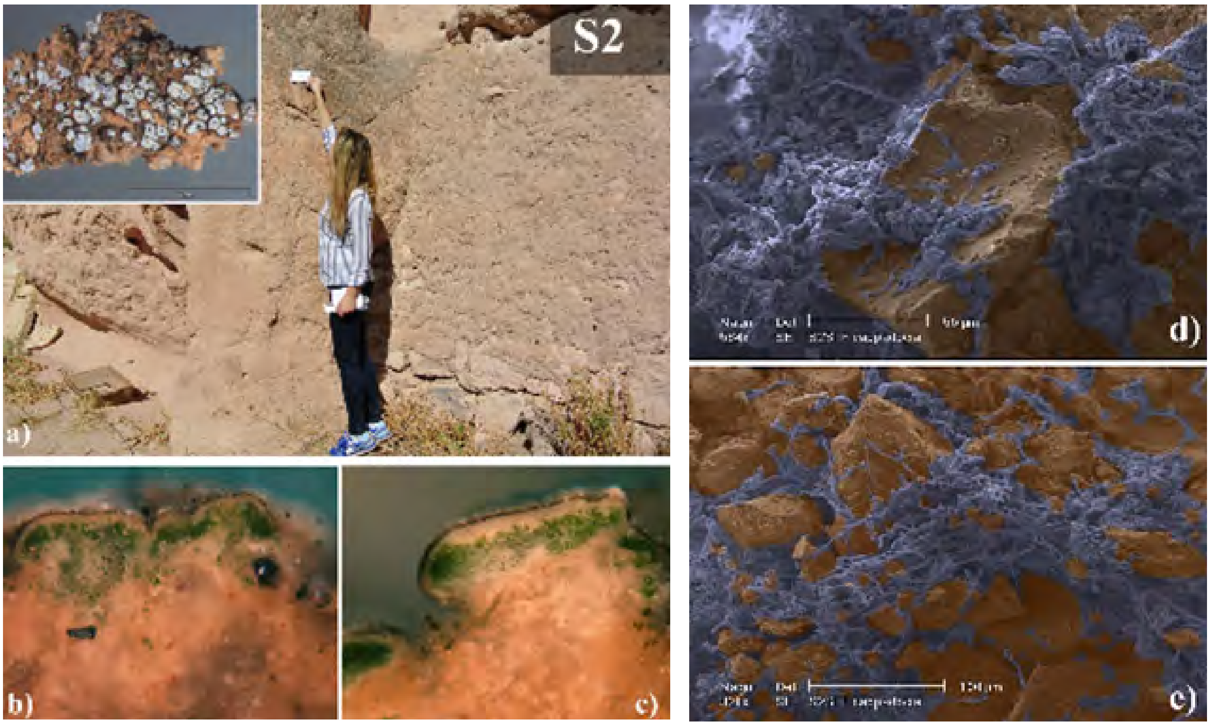


Figure. 2.11 Biological colonization in south exposures a) Sampling point (S2) and picture under the stereomicroscope; b), c) Microphotograph of the sample in polished cross section; d), e), SEM image in false colour of details observed in the sample

Şekil 2.11 Kilisenin güney cephesinde biyolojik kolonizasyon a) Alınan örneğin (S2) kilise yüzeyinde seçilen noktası ve stereomikroskop altındaki resmi ; b), c) Cilalı kesitte alınan örneğin misroskopografisi ; d), e) Örnek parçanın tamamının detaylı olduğu renkli SEM görüntüsü

Discussion and Conclusion

Results show the rock substrate, in all exposures, but highly in N, suffers of a more or less intense disaggregation and fragmentation of the stone. Moreover, the surfaces immediately below the lichens are interested by surface adhesion and in depth penetration of fungal hyphae. In fact, SEM analysis of the all fragments showed a dramatic loss of the stone matrix and a dense network of fungal hyphae penetrating into the substrate to a depth several millimetres (1.5 -5.5 mm). This may indicate an effective biodeterioration processes caused by the large concentration of fungal hyphae within the rock through the dissolution of minerals along grain boundaries, cleavages, and cracks, which increase porosity and permeability. Since these weathering processes interact and enhance each other effects.

On the other hand, lichens may perform a certain protection against other abiotic degradation factors even though they have deteriorative effects. In fact, lichens could have a protective role on porous stone reducing the action of weathering agents such as wind, water exchange, marine aerosols and pollution, giving rise to a protective effect against deterioration phenomena [Salvadori & Casanova Municchia, 2016; Concha-Lozano et al., 2011; Caneva et al., 2008), Carter & Viles, 2004; Ariño et al., 1995]. Previous studies regarding the case of the lichen covered tuff of Cappadocian monuments showed a higher vapor diffusion resistance and slower penetration of water if compared with no-colonized one [Garcia-Valles et al., 2003]. Nevertheless, usually it is a challenge establish if a species possess a biodeteriorative or bioprotective effect, because it is also highly influenced by stone and environmental characteristics.

In our case a such high penetration and colonization of the stone, the already loss of the stone matrix, such as the protective action of the superficial crusts reducing the weathering velocity by limiting the penetration of water into the rock, advise against the removal of such biological cover.

Tartışma ve Sonuç

Sonuçlar kaya yüzeylerin tümünde biyolojik kolonilere maruz kaldığını göstermektedir ancak N'de oldukça yüksek olduğu saptanmış ve taşı aşağı-yukarı parçalamış ve parçalamaya çalışmaktadır.Dahası, likenlerin hemen altındaki yüzeyler, yüzeye tutunma ve mantar hifeler derinlere ilerlemekle meşguldur. Aslında, tüm parçaların SEM analizi, taş yapısında şaşırtıcı bir kayıp olduğu ve birkaç millimetre (1,5 -5,5 mm) derinliğe kadar yüzey içine nüfuz eden mantar hifelerin yoğun bir ağı görülmektedir. Bu gözenekliliği ve geçirgenliği arttıran çatlaklar, çatlaklar ve granül sınırları boyunca minerallerin çözünmesiyle kaya içerisinde mantar hifelerinin yoğun konsantasyonunun neden olduğu etkili bir biyolojik bozunma süreci gösterebilir.

Bu süreçte hava koşullarının etkileşime girer ve birbirlerinin etkilerinin arttırırlar. Öte yandan, likenlerin bozucu etkisi olmasına ragmen diğer abiyotik (fiziksel-mikroorganizma dışındaki) bozunma faktörlerine karşın belirli bir koruma sağlayabilir.

Aslında, likenler, gözenekli taş üzerinde, hava koşullarının rüzgar, nem (su) değişimi, deniz aresolleri ve kirlilik gibi etkisini azaltarak koruyucu bir rol oynayabilirler ve bozulma olaylarına karşı koruyucu bir etki oluşturabilirler. [Salvadori & Casanova Municchia, 2016; Concha-Lozano vs., 2011; Caneva vs., 2008), Carter & Viles, 2004; Ariño vs., 1995]. Kapadokya tüf anıtların üzerini kaplayan likenlerle ilgili eski çalışmalarda, kolonize olamayan kısımla kıyaslandığında yüksek nem direnci ve suyun daha yavaş nüfuz ettiği görüldü. [Garcia-Valles vs., 2003]. Bununla birlikte, genellikle, bir türün biyolojik bozucu beya biyo koruyucu etkiye sahip olup olmadığını belirlemek zordur çünkü taş ve çevre koşullarından çok fazla etkilenmektedir.

Bizim durumumuzda likenlerin taş kolonizasyonu ve bu kadar nüfuz etmesi, taş yapısının çoktan kaybolması, suyun kayaya erişmesini sınırlayarak tahribat hızını düşürücü etkisi gibi yüzeysel koruyucu tabaka oluşturarak bu tür maddelerin uzaklaştırılmasına karşı biyolojik örtü olarak taviye edilir.

References

Ariño, X.; Ortega-Calvo, J.J.; Gomez-Bolea, A.; Saiz-Jimenez, C. Lichen colonization of the Roman pavement at Baelo Claudia (Cadiz, Spain): biodeterioration vs. bioprotection. *Sci. Total Environ.*, 1995, **67**, 353-363.

Caneva G., Nugari M.P, Salvadori O, 2008. *Plant Biology for cultural heritage*. Getty Conservation Institute. Los Angeles: 1-408.

Carter, N.E.; Viles, H.A. Lichen hotspots: raised rock temperatures beneath Verrucaria nigrescens on limestone. *Geomorphol. J.*, 2004, **62**, 1-16.

Concha-Lozano, N.; Gaudon, P.; Pages, J.; de Billerbick, G.; Lafon, D.; Eterradossi, O. Protective effect of endolithic fungal hyphae on oolithic limestone buildings. *J. Cult. Herit.*, 2012, **13(2)**, 120-127.

Garcia-Valles, M.; Topal, T.; Vendrell-Saz, M. Lichenic growth as a factor in the physical deterioration or protection of Cappadocian monuments. *Environ. Geol.,* 2003, **43**, 776-781.

Topal, T; Doyuran,V.; Analyses of deterioration of the Cappadocian tuff, Turkey. *Environ. Geol.,* **34**, 1998, 5–20.

Salvadori, O. Casanova Municchia, A.; The role of fungi and lichens. *Open Conf. Proc. J.*, 2016, 29–38.

I −3 Conservation intervention: Wall paintings at the Üzümlü Church

Üzümlü Kilisesi'nin duvar resimlerinde yapılan konservasyon müdehaleleri

By Yoko Taniguchi

Introduction

One main cause of serious ongoing damage to wall paintings at the Üzümlü church is extensive graffiti by tourists, most likely local tourists (Taniguchi, et.al 2016). However, there also exists areas where slight detachment along rock cracks requires proper stabilization.

Paintings at the Üzümlü Church consist of a relatively pure gypsum ground, various iron oxides (red ochre, yellow ochre), green earth and some lead oxides (Taniguchi, et.al 2016). No apparent organic binder has been detected so far (Takashima 2015). This means that the paintings are water sensitive, and break easily upon physical impact. Their properties restrict any watery intervention.

The origin of gypsum-based wall paintings goes back to Neolithic Anatolia such as Çatalhöyük (BC 7,500)(De Brito and Flores-Colen 2014). The method spread widely, known as the stucco technique in ancient West Asia and Central Asia (such as in Samarra, Iraq and the Egyptian Dynastic period), and reached the African and American continents (Burgio et.al 2007). Compared with lime plaster, which requires 900-1000°C temperatures to produce quick lime from limestone/ corals, gypsum (hemihydrate Plaster of Paris: $CaSO_4.\frac{1}{2}H_2O$) requires only 120-150°C from raw gypsum ($CaSO_4.2H_2O$). The reaction to convert it to its $CaSO_4.2H_2O$ form occurs as a simple hydration process (setting) that requires only water.

Our interventions were minimal and aimed only to stabilize the current state of materials, rather than enhance aesthetic appearances, which would require reintegration and reconstruction of images. Toning was carried out only in cases of obviously recent (with indication of years) -incised graffiti and carbon- and paint-based surface graffiti. Materials and methods were chosen as retreatable and compatible with original gypsum plasters. Intervention materials must be of a weaker substance and lighter weight than original materials.

Giriş

Üzümlü Kilise'nin duvar resimlerinin üzerinde devam eden ciddi zararların temel nedenlerinden biri, muhtemelen yerel turistlerce yapılan yoğun grafitiler, graffiti içeriğidir [Taniguchi, vs.2016]. Bununla birlikte, kaya çatlakları boyunca bazı alanlarda iyi bir stabilizasyon gerektiren ayrılmalar görülmektedir.

Üzümlü Kilise'nin duvar resimleri, yüksek oranda saf alçı bir zemin ile çeşitli demir oksitler (kırmızı aşıboya, sarı toprakboyası), yeşil toprak ve bazı kurşun oksitlerden meydana gelmektedir [Taniguchi,vs. 2016 yayını] Bu zamana kadar yapılan araştırmalarda hiçbir organic bağlayıcı tespit edilmedi [Takashima 2015] Bu da duvar resimlerinin suya karşı duyarlı ve herhangi bir fiziksel etkiye maruz kaldığında bozunabilir olduğu anlamına gelmektedir. Bu özellikler, sulu herhangi bir müdahele yapmayı kısıtlamaktadır.

Alçı bazlı duvar resimlerinin kökeni, Netolitik Çağ'a kadar Çatalhöyük (M.Ö. 7500) gibi [De Britoa ve Flores-Colen 2014] uzanır ve antik Batı Asya ve Orta Asya'da (Samara: Irak,Mısır'daki Hanedan dönemi vs) bilinen sıva tekniği, Afrika ve Amerika kıtalarına da yayılmıştır [Burgio, vs. 2007] Kireçtaşı/mercanlardan sıcak kireç elde etmek için 900-1000 °C sıcaklığa ihtiyaç kireç sıva ile karıştırılır, alçıdan (hemihidrat alçı sıva: $CaSO_4.\frac{1}{2}H_2O$) saf alçıdan ($CaSO_4.2H_2O$) için 120-150 °C sıcaklık gereklidir. $CaSO_4.2H_2O$ yapısını tekrar oluşturmak için verilen reaksiyon sadece su gerektiren basit hidrasyon işlemi (ayarlama) olarak gerçekleşir.

Müdahalelerimize ilişkin prensiplerimiz asgari düzeydeydi ve estetik görünüş için değil mevcut durumun stabile edip korunmasını amaçlamaktaydı, bu da görünümün yeniden bütünleşmesini ve yeniden oluşturulmasını gerektirmekteydi. Sadece grünür graffitide tonlama yapıldı, graffiti yüzeyine karbon/boya uygulandı. Malzemeler ve yöntemler geri weaker substance and lighter weight than original materials.

Materials to satisfy the above principles for gypsum plaster were basically gypsum-based mortars with compatible fillers and fluidizer, although they could be much more complicated than lime-based plaster, which has been the subject of much study and explanation. Testing for materials was conducted in Japan and Cappadocia prior to in-situ intervention in 2015 and 2016. No synthetic resin was applied in any case, because it would change the permeability of original walls.

A good injecting mortar (for grouting) for the Üzümlü wall paintings had to meet the following conditions.

-Fluid
-Chemically stable
-Lightweight
-Injectable through narrow needles
-Natural texture and colour to fit with tuff rocks
-Longer working time
-Limited water release ratio
-No shrinkage (volume loss) during setting
-Viscosity
-Weak in shear strength
-Enough cohesion
-Enough adhesion but mechanically removable between rock and gypsum surfaces

Gypsum

$CaSO_4.\frac{1}{2}H_2O$ is known as Plaster of Paris, and hardens due to a hydration process setting as $CaSO_4.2H_2O$ (gypsum) when it mixes with water. This reaction is exothermic and responsible for the ease with which gypsum can be cast into various forms and shapes.

The fast gypsum (alpha-shape) sets quickly. On the other hand, the slow gypsum (beta-shape) sets in about 10 minutes. Gypsum is slightly soluble in water which may cause fatal problems such as detachment and cracking if a grouting mortar with a high water release ratio comes into contact with

dönüşümlü olarak seçildi ve orjinal alçı sıvası uygun hale getirildi.Müdahale orjinal malzemelerden daha zayıf ve daha hafif olmalıdır.

Alçı sıva için yukarda bahsedilen prensipleri karşılayan malzemeler, temel olarak alçı bazlı uygun ve akışkan dolgu bağlayıcı harçları, alçıdan çok daha zor hazırlanmasına ragmen kireç bazlı çok fazla denemeler ve ilgili çalışmalarda bulunuldu. Malzemelerin testi, 2015 ve 2016 yıllarında yerinde müdaheleden once Japaonya'da deneyleri yapıldı ve daha sonra Kapadokya'da uygulandı. Durumu ne olursa olsun orjinal duvarların geçirgenliğini değiştiren bir sentetik reçine uygulanmamıştır.

Üzümlü Kilisesi duvar resimleri konservasyonunda kullanmak üzere iyi bir enjeksiyon harcı elde etmek için (dolgu için) özelllikle aşağıdaki koşulların sağlanması gerekir.

-Akışkan (sıvı)
-Kimyasal olarak kararlı yapıda
-Hafif ağırlıkta
-İnce uçla enjekte edilebilir
-Doğal yapı ve mevcut tüf kayanın rengine uygun
-Uzun sure çalışılabilir
-Ortama sınırlı oranda su bırakan
-Sertleşme sırasında daralmayan (hacim kaybı olmayan)
-Viskoz (yarı sıvı)
-Kayma kuvveti düşük
-Uygun tutunucu kuvvette
-Kaya ile alçı yüzey arasında mekanik olarak uygun yapışma kuvveti

Alçı

$CaSO_4.\frac{1}{2}H_2O$ hemihidrat alçı sıva olarak bilinen malzeme su ile karıştırıldığında hidrasyon işlemi (sertleşme) nedeniyle $CaSO_4.2H_2O$ (alçı) olarak sertleşir.Bu reaksiyon ekzotermiktir ve alçı çeşitli formlara ve şekillere dökülebilir kolaylıkta olmalıdır.

Hızlı alçı (alfa şekli) hızlı bir şekilde sertleşirken diğeri yavaş alçı (beta-şekli) 10 dakika da sertleşir.Alçı suda az çözünür, yüksek su salınım oranı olan bir enjeksiyon harcı, tarihi (orjinal) sıva ile temas ederse ayrılma ve çatlama gibi geri dönüşü olmayan kayıplara neden olabilir.Sentetik the traditional gypsum plaster. Some uses of synthetic resins may not be compatible with the original gypsum plaster, which is highly porous and permeable. Overall, the use of gypsum as a conservation material has various disadvantages, such as its heavy weight, short working time, low fluidity, and high water release ratio. To facilitate its use in conservation, gypsum must be modified using light weight fillers, retarders, and thickeners.

Citric and malic acids (and their sodium neutral salts) are traditionally used as retarders (Ersen, et.al 2006; Lanzon, et.al 2012; Fukui, et.al 1984). For example, sodium citrate functions to slow the crystalisation process, since it creates a thin layer of calcium citrate on the surface of $CaSO_4.2H_2O$. Although citric and malic acids work as retarders, their acidity accelerates crystalisation; therefore, organic salts are more effective as retarders than organic acids themselves.

Fillers

Shirasu microballoon (Shirafine®) is a product made from 30,000 year-old natural volcanic sediment from the Aira volcano in south Kyushu, mainly in the Kagoshima region (Nomoto 1967). Shirasu volcanic ash accumulates at a thickness of 10 – 200 meters in the region and creates a broad pyroclastic plateau, which manifests poor concreteness and high permeability. Shirasu ash is non-glutinous and appears as a white cream colour. The shirasu balloon is made by boiling shirasu in kilns. It consists of hemispherical micro particles of around 20 – 1400 μm φ of a rather small gravity [0.4-0.6 (bulk specific gravity) / α-gypsum: 2.76, β-gypsum:2.64]. The microballoons are flame-retardant, possess a high melting point, and are relatively cheap. They also have less water absorbency compared to glass microspheres, which results in better fluidity for a longer time (Isayama et.al 1976).

The advantages inherent to this natural volcanic microballoon as a filler relative to synthetic glass microspheres are the: (1) irregular, angular particle shape, (2) less sheer strength, which eases shaping work, (3) broader particle size distribution, and (4) natural ivory-white colour. Often glass-microspheres of homogeneous particles have a dilatancy effect, which make injection through a narrow syringe very difficult. Perhaps owing to the broad particle size distribution of the shirasu microballoon, fluidity is not disturbed in the syringes.

reçinelerin kullanıldığı yerlerde; son derece gözenekli ve geçirgen orjinal sıva ile uyumlu olmayabilir.Bununla birlikte, alçının bir koruma malzemesi olarak kullanılması ağırlığının yüksek olması, çalışma süresinin kısalığı, akıcılığının düşük oluşu ve yüksek su salınım oranı olması gibi çeşitli dezavantajları vardır. Koruyucu malzeme olarak kullanılması için hafif ağırlıkta dolgu maddeleri,donmayı geciktiriciler ve koyulaştırıcılar katmak gibi bazı değişiklikler yapılması gerekir.

Donma geciktiricilerinde geleneksel olarak sitrik ve malik asitler (ve bunların nötr sodium tuzları) yaygın şekilde kullanılırlar [Ersen, vs 2016; Lanzon, vs. 2012; Fukui, vs 1984]. Örneğin, sodyum sitrat, $CaSO_4.2H_2O2$ (alçı)'nın yüzeyinde ince bir kalsiyum sitrat tabakası oluşturduğu için kristalleşme sürecini yavaşlatır. Sitrik/Malik asitler hem alçının sertleşme sürecini geciktirirler hem de asidik özellikleri kristalleşmenin hızlanmasında katkıda bulunurlar bu nedenle organik tuzların geciktirci etkisi organik asitlerden daha iyi etkisi vardır.

Dolgu Harcı

Shirasu mikrobalonu (Shirafine® markalı), esas olarak Kagoshima bölgesinde bulunan Aira yanardağının 30.000 yıl önceki patlaması sonucu doğal volkanik tortudan elde edilen üründür[Nomoto 1967]. Shirasu volkanik külü, bölgede 10-200 m kalınlıkta birikir ve geniş piroklastik plato oluşturur ve bu da düşük yoğunlukta ve yüksek gerçirgenlikte olduğunu gösterir. Shirasu külü yapışkan değildir ve beyaz krem renklidir.Shirasu balonu fırınlarda ısı ile kabaran shirasudur. Boyutu 20-1400 μm φ arasında yarı küre mikro parçacıklardan oluşur.Özgül ağırlık oldukça küçüktür (shirasu mikro balonu: 0.4-0.6 (birim hacim ağırlığı)/ α-alçı: 2.76, β-alçı:2.64), ve alev-geciktirme, erimenoktası yüksek ve olduça ucuz olması gibi özellikleri vardır. Shirasu mikronalonunun cam mikroküreciklerle kıyasla daha az su geçirgenliği olması ve bu yüzden uzun süre daha akışkan kalmasına neden olur [Isayama, vs. 1976].

Dolgu maddesi olarak kullanılan sentetik cam mikroküreciklerle bu doğal mikro balonu kıyaslarsak, doğal mikrobalonun avantajları bunlardır; (1) düzensiz/açısal parçacık şekli , (2) şekillendirme işini kolaylaştıran daha az etkin çekim kuvveti , (3) daha geniş parçacık boyutu dağılımı, (4) doğal fildişi beyaz rengi. Genellikle homojen parçacıkların cam mikrokürecikler, dilatansite basınç etkisi gösterir ve bundan dolayı dar bir enjektör içinde enjeksiyon yapılmasını zorlaştırır. Muhtemelen shirasu mikrobalonunun geniş parçacık boyutu dağılımı olduğundan, akışkanlk şırangalarda engellenmemiştir.

Table 3.1 Semi-quantitative data of Shirasu microballoon using XRF (Kagoshima prefectural Institute of Industrial Technology) [mass %]
Tablo 3.1 XRF'yi kullanarak bulunan Shirasu mikrobalonunun yarı kantitatif verileri (Kagoshima İli Endüstriyel Teknoloji Enstitüsü) [kütlece %]

Shirasu	K_2O	CaO	TiO_2	Na_2O	Fe_2O_3	MgO	Al_2O_3	SiO_2
	3.83	1.13	0.15	4.12	1.46	0.23	12.10	75.00

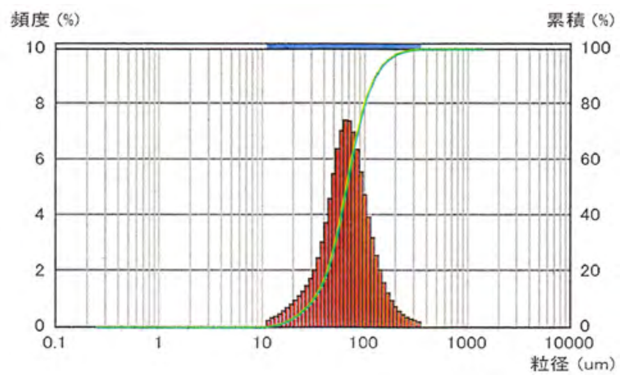


Figure 3.1 Particle distribution of Shirasu microballoon, ISM-065
Şekil 3.1 Shirasu mikrobalonunun parçacık dağılımı, ISM-065

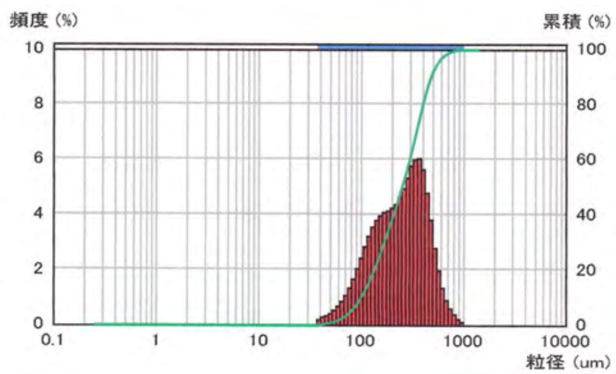


Figure 3.2 Particle distribution of Shirasu microballoon, ISM-250
Şekil 3.2 Shirasu mikrobalonunun parçacık dağılımı, ISM-250

Gums

Acrylic emersions are commonly used as fluidisers or plasticisers in conservation and industry, together with gypsum mortar. However, because acrylic resins tend to interfere with the original permeability of the gypsum mortar, or tuff rock fabric, other materials were tested. Initially, cellulose derivatives such as methyl cellulose were considered. However, these were ultimately difficult to separate from tuff rock and gypsum surfaces, likely due to their micro-fibrous characteristics.

Then, natural gums were tested, concentrating on diutan (Kelco-Crete DG®: CP Kelco.) and xanthan gums (KELZAN®: Sansyo Co.Ltd.). Both gums are known as polysaccharide biopolymers, which are used for the stabilization of

Reçineler

Akışkanlaştırıcı/plastikleştirici olarak genellikle akrilik emülsiyonlar konservasyonda ve alçı harcı ile birlikte endüstide kullanılır. Bununla birlikte, yine, akrilik reçineler alçı harcı/tüf kaya yapısının orjinal geçirgenlğini etkilemektedir, başka maddeler üzerinde test edilmiştir. İlk olarak, metil selüloz gibi selülozik malzemeler düşünüldü fakat tüf kayalar/alçı yüzeyler muhtemelen mikro-lif özelliğinden dolayı ayrılması zorlaştı.

Daha sonra, doğal reçineler test edildi, diutanın amaçlı (Kelco-Crete DG®: CP Kelco.) ve ksantan reçineleri (KELZAN®: Sansyo Co.Ltd.).Her iki reçinede, polisakkarit biyopolimerler olarak bilinen, semestasyon ve alçı gibi duvar malzemelerinde emulsions, foams and suspensions such as in masonry materials like cementations and gypsum. Both gums are of high molecular weight, produced by aerobic fermentation. An aqueous solution of diutan gum was infested with mould after 1-2 days, and was therefore excluded from the test.

Xanthan gum is produced from corn starch fermented by Xanthomonas campestris. It has a high molecular weight between 2,000,000 and 50,000,000. It is soluble in water and ethanol and stable in both acidic and basic conditions. In order to prevent excess water from reaching the grouting mortar, ethanol was first added to the gum before more water was added. After 6 months of observation in the lab at room temperature, the xanthan gum solution in water/ethanol was not infested by any mould.

Injectability through syringe needles was also evaluated. After some laboratory and in-situ tests and trials, the following compositions (Table 3.2) were selected as edging and grouting mortars. For convenience, all solutions were made in the Nevshehir laboratory prior to field work, and all powder was measured by volume instead of by weight.

emülsiyonların, köpüklerin ve süspansiyonların stabilize edilmesi için kullanılır. Aerobik fermantasyon(mikrobiyolojik türlerin oksijensiz solunumu) ile üretilen yüksek molekül ağırlığına sahip reçinelerdir. Diutan reçinesinin sulu çözeltisinde 1-2 gün sonunda küf oluşumu gözlendi bu nedenşe testten çıkarıldı.

Ksantan reçinesi, Xanthomonas kampestrisi tarafından mısır nişastasından fermente edilmiştir. 2.000.000 ila 50.000.000 arasında yüksek molekül ağırlığına sahiptir. Suda ve etanolde çözünür, asit veya baz koşullarında kararlıdır.Dolgu harcından fazla suyu uzaklaştırmak için, reçinenin içine su ilavesinden önce etanol eklendi.Laboratuvar ortamında oda sıcaklığında 6 ay gözlemlendikten sonar, su/etanol içindeki ksantan reçinesi çözeltisi herhangi bir küfün oluşumu görülmedi.

Şırıngalara takılı iğneler ile enjekte edilebilirlik değerlendirildi. Bazı laboratuvar, yerinde test ve denemelerden sonra, aşağıdaki karışımlar dolgu ve enjeksiyon harçları olarak seçildi. Yerinde yapılacak çalışmaların kolaylaştırmak amacıyla, tüm malzemelerin ağırlkları hacimsel ve kütlesel olarak ölçülerek, sahada kullanılmak üzere tüm çözeltilerin hazırlanması Nevşehir Restorasyon ve Konservasyon Bölge Laboratuvarı Müdürlüğü'nde yapıldı.

Table 3.2 Composition of edging/grouting gypsum mortar (by volume: ml)
Tablo 3.2 Dolgu/enjeksiyon alçı harç karışımı (hacim olarak: mL)

Mortar for	Gypsum	Filler (shirasu microballoon): Shirafine®		Water	Ethanol	Citric acid	Xanthan gum	Application
Edging	Natural gypsum (local) ($CaSO_4.1/2H_2O$)	ISM-M065	ISM-M250					
	60	30	30	50		0.025g		Spatula
Grouting	Artificial gypsum (dental grade: San Esu) (α-$CaSO_4.1/2H_2O$)	ISM-M065		105	45	0.075g	0.15g	Syringe >18G (ϕ 0.92mm)
	150	150						

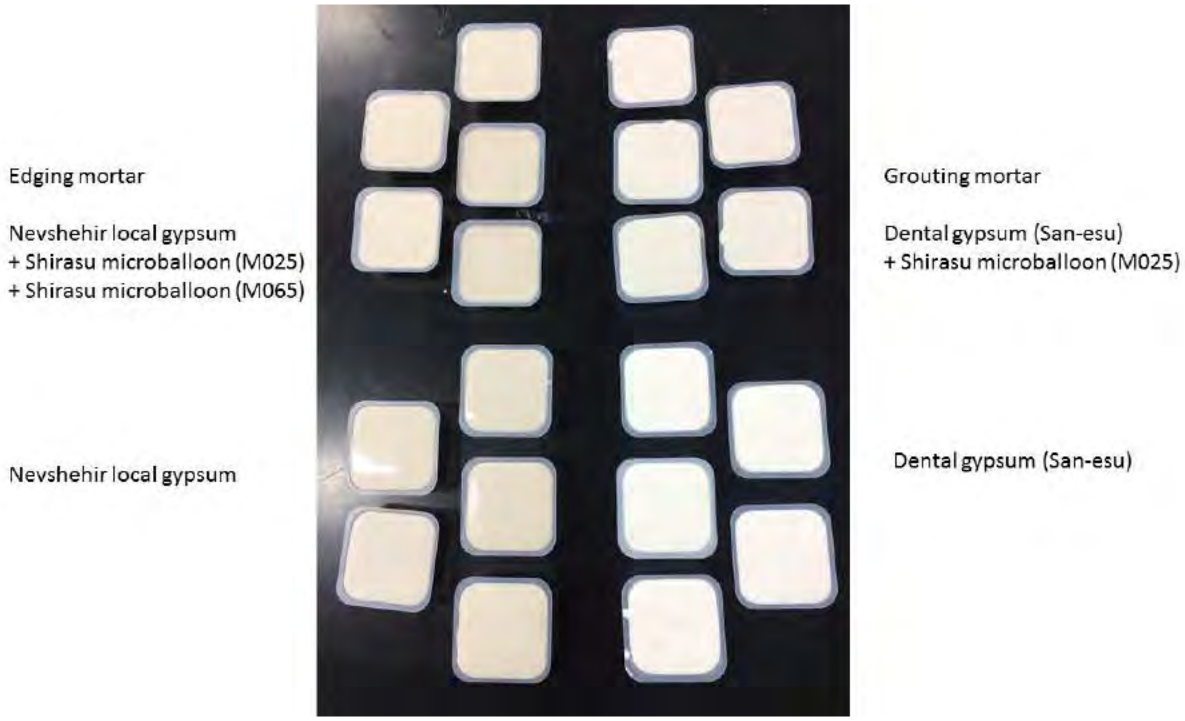


Figure 3.3 Edging/grouting mortars and gypsum
Şekil 3.3 Dolgu/enjeksiyon harcı ve alçısı

Table 3.3 Bulk specific gravities of mortars (after 1 week)
Tablo 3.3

	Fast gypsum (local)	**San-esu dental gypsum**	**Edging mortar** (fast local gypsum, citric acid, shirasu S, L)	**Grouting motar** (San-esu dental gypsum, shirasu S, citric acid, xanthan gum)
numbers (n)	**5**	**5**	**5**	**5**
bulk specific gravity (g/cm³)	**0.69**	**0.90**	**0.67**	**0.71**
volume (cm³)	**17**	**17**	**17**	**17**
average (g)	**11.67**	**15.36**	**11.39**	**12.12**

Table 3.3 indicates that the grouting mortar was of a lighter weight owing to the shirasu microballoon fillers, and both edging and grouting mortars possessed similar gravities owing to the original local gypsum. No obvious cracks were observed during the setting process of any gypsum pieces.

Tablo 3.3 Dolgu malzemesi (shirasu mikrobalon) sayesinde enjeksyon harcının daha hafif olduğunu, ve hem dolgu hemde enjeksiyon harcı orjinal yerel alçı ile benzer özellik kazandı. Herhangi bir alçı parçasının sertleşme işlemi sırasında belirgin bir çatlak oluşumu gözlemlenmedi.

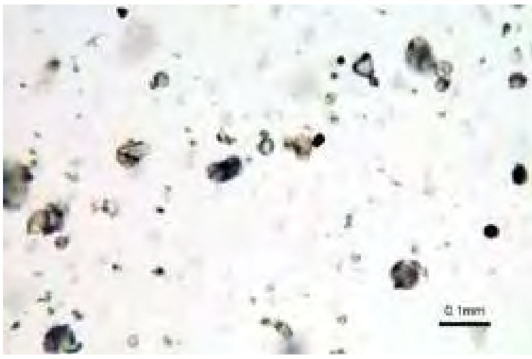


Figure 3.4 Microphotograph of ISM-065
(transmitted microscope, Olympus BH-2)
Şekil 3.4 ISM-065'in mikrofotoğrafı
(Geçirimli mikroskop, Olympus BH-2)

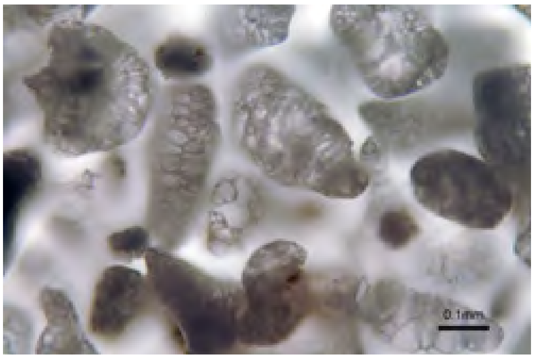


Figure 3.5 Microphotograph of ISM-250 (transmitted microscope, Olympus BH-2)
Şekil 3.5 ISM-250'in mikrofotoğrafı
(Geçirimli mikroskop, Olympus BH-2)

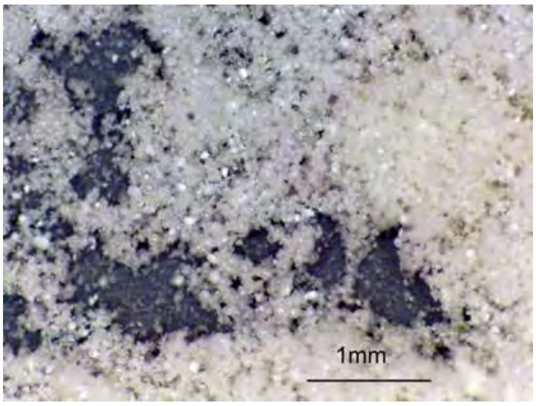


Figure 3.6 Microphotograph of ISM-065
(stereo microscope, LEICA DMS-300)
Şekil 3.6 ISM-0652in mikrofotoğrafı
(Stereomikroskop, LEICA DMS300)

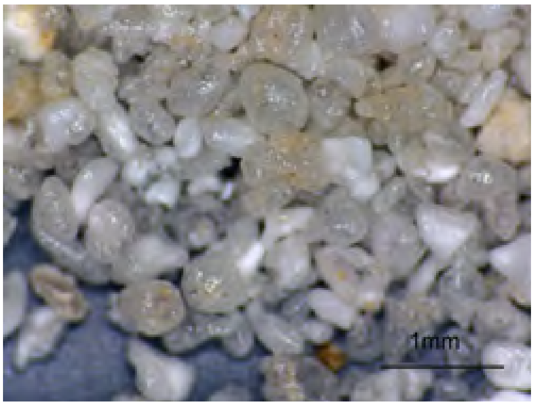


Figure 3.7 Microphotograph of ISM-250 (stereo microscope, LEICA DMS-300)
Şekil 3.7 ISM-250in mikrofotoğrafı
(Stereomikroskop, LEICA DMS300)

Figure 3.8 Laboratory preparation (31 August 2016)
Şekil 3.8 Laboratuvar hazırlığı (31 Ağustos 2016)

Figure 3.9 On site mortar preparation
Şekil 3.9 Yerinde harç hazırlığı

Figure 3.10 On-site mortar preparation
Şekil 3.10 Yerinde harç hazırlığı

Figure 3.11 Edging work at the nave
Şekil 3.11 Kilise ortasındaki dolgu harç çalışması

Figure 3.12 Grouting work at the altar
Şekil 3.12 Mihrap'ta yaplan enjeksiyon çalışması

Figure 3.13 Grouting work at the nartex
Şekil 3.13 Narktekste yapılan enjeksiyon çalışması

Figure 3.14 After intervention (altar)
Şekil 3.14 müdahale sonrası (mihrap)

Figure 3.15 After intervention (nave)
Şekil 3.15 müdahale sonrası (kilise ortası)

Figure 3.16 After intervention (nave, vault)
Şekil 3.16 müdahale sonrası (kilise ortası, tonoz)

Figure 3.17 After intervention (nave, vault)
Şekil 3.17 müdahale sonrası (kilise ortası, tonoz)

Conservation intervention

Stabilisation

Wall paintings were stabilized once more following the 2015 interventions. Although most areas were relatively stable at the time of our second intervention, some particular areas along the rock cracks were detached and delaminated. Those voids were filled with grouting mortar using needles to increase cohesion. Some areas were pre-wetted with an ethanol and water mixture before injection. Edging mortar was used to stabilise wall paintings that showed delamination and lacuna (Figures 3.8 – 3.17).

Toning

Areas marred by harsh white colouring due to scratches and incisions were toned with natural ochre powder and water. The pigments used were all natural iron oxides, from yellow to deep red [Italian/Japanese ochre (product name/company): terra rossa 0270/CTS; ocra rossa 4068/Roma Restauro, Tuscan red (Pompeii red)/Kremer; yellow ochre/Hojo, Tsukuba] without any organic binder.

Ivory black was selected for the black pigment due to its relatively heavier gravity than carbon black powder. Only areas that included recent graffiti (identified by Turkish rather than Latin, Greek, or Arabic text, as well as any dates given) were toned. Üzümlü wall paintings are one of the more important historical witnesses of historical graffiti. Several types of Greek inscriptions appear on the walls, some dating back to the 8th – 9th century AD, as do figures of horses and saints and Arabic graffiti. Also, religious vandalism on the hands and faces of saints could be of historical significance and, therefore, we established specific criteria for determining which shall be toned: only recent touristic graffiti and lines were toned, while we determined that others should remain as they are.

Documentation

All intervention was documented on transparent polyester sheets. Same base photographs were used as the first year’s documentation. Data was transferred to illustrator format (appendix III).

Konservasyon müdahalesi

Stabilizasyon

2015’ten itibaren devam eden duvar resimlerinin stabilizasyonu gerçekleştirildi.Duvar resimlerinin çoğunun nispeten stabil olmasına ragmen, bazı belirli alanlarda kaya çatlakları boyunca kopmalar ve tabakalar ayrılmaları vardır. Bu boşluklar, iğneler vasıtasıyla enjeksiyon harcı ile doldurur ve bağlantıları arttırılır. Bazı alanlar enjeksiyon yapılmadan önce etanol/su karışımı ile ıslatıldı. Ayrılan tabakalar ve aralıklar gözlemlenen duvar resmi boyunca, stabil durum sağlanması için dolgu harcı kullanılmıştır (Şekil 3.8-3.17).

Tonlama

Çizik ve kesiklerden dolayı belirgin beyaz renk gösteren alanlar doğal kum pulsu-su karışımı ile tonlandırılmştır. Pigmentlerin hepsi doğaldır demir oksit sarıdan koyu kırmızı renk skalasında (İtalyan/Japon aşıboyası: terra rossa 0270, CTS; ocra rossa. 4068, Roma Restauro, Toskana kırmızısı (Pompeii kırmızısı), Kremer; Tsukuba-Hojo’dan elde edilen sarı aşıboyası) ve herhangi bir organic bağlayıcı içermez.

Siyah pigmente gelince, fildişi siyahı karbon siyahına göre daha yüksek özgül ağrılığı olduğu için seçildi.Tonlanma yapılmış alanlar, son yapılan grafitiler olarak sınırlandı. (Muhtemelen yakın tarihte yapılmış türkçe grafitilere uygulandı, Latin/Yunan/Arap karakterler bırakıldı).Üzümlü duvar resimlerinin tarihsel grafitilerinden önemli bir tarihe tanıklık ettiği görülmektedir. M. S. 8.-9. Yüzyıl’a ait birkaç Yunan yazı türleri ve bunun yanısıra at figürü, azizler vb. ve bazı arapça grafitiler vardır. Aynı zamanda azizlerin elleri ve yüzlerinde yapılan dini vandalizmşer tarihsel delil oluşturabilir, bu nedenle tonlama işlemi yapılacak veya yapılmayacaklar için bir kriter oluşturuldu. Yalnızca son turistik graffiti ve çiziklerde tonlama işlemi yapılmalı diğerleri olduğu gibi bırakılmalıdır.

Dökumantasyon

Yapılan tüm konservasyon müdahaleleri şeffaf polyester plakalar üzerinde belgelendi.
Aynı temel fotoğraflar, ilk yılın belgelemesinde kullanıldı.
Veriler, resimsel (illustrator) biçiminde aktarıldı.

Figure 3.18 As of September 2013.
Şekil 3.18 2013 itibariyle

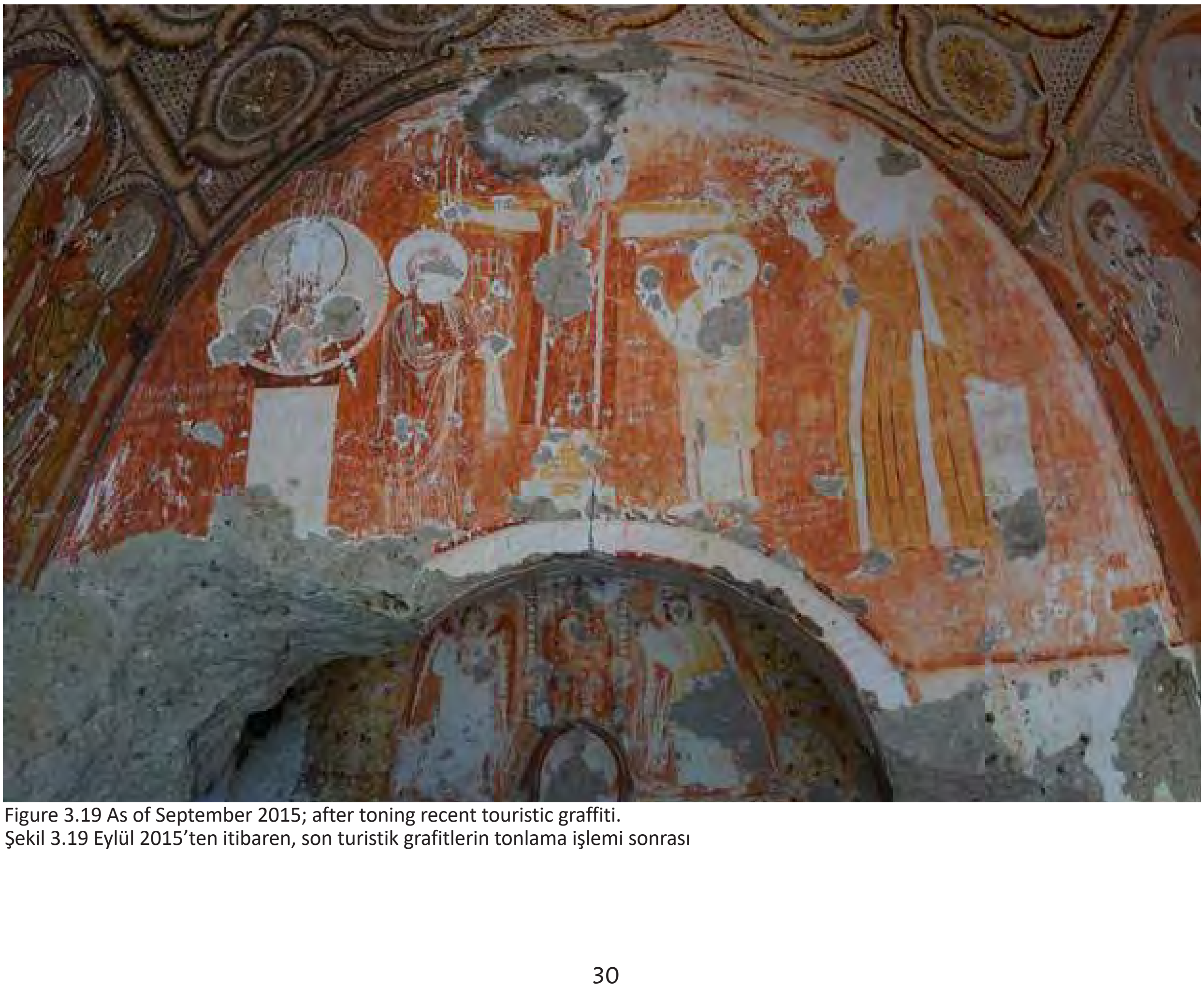


Figure 3.19 As of September 2015; after toning recent touristic graffiti.
Şekil 3.19 Eylül 2015'ten itibaren, son turistik grafitlerin tonlama işlemi sonrası

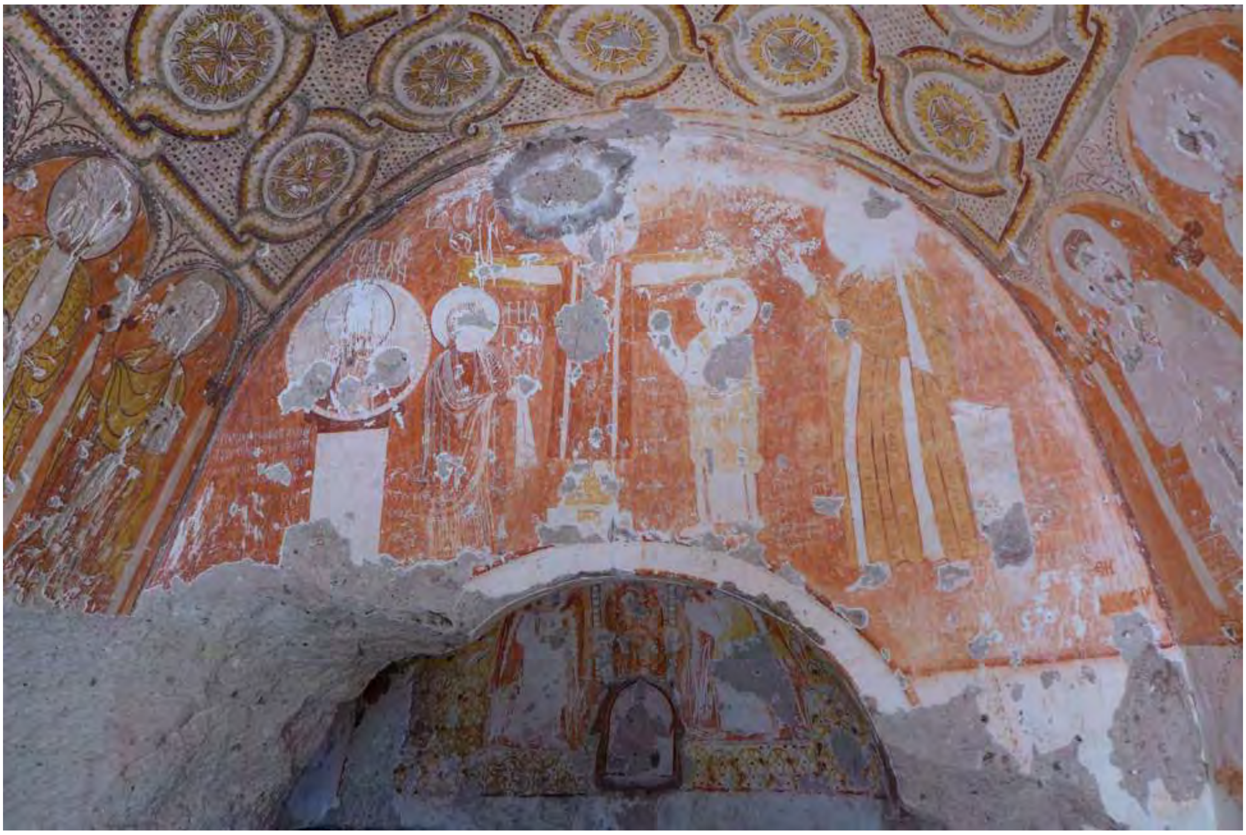


Figure 3.20 After intervention in September 2016
Şekil 3.20 Eylül 2016 müdahale sonrası


Figure 3.21 After intervention in September 2016 (altar)
Şekil 3.21 Eylül 2016 müdahale sonrası (mihrap)


Figure 3.22 After intervention in September 2016 (altar/nave)
Şekil 3.22 Eylül 2016 müdahale sonrası (mihrap/kilise ortası)

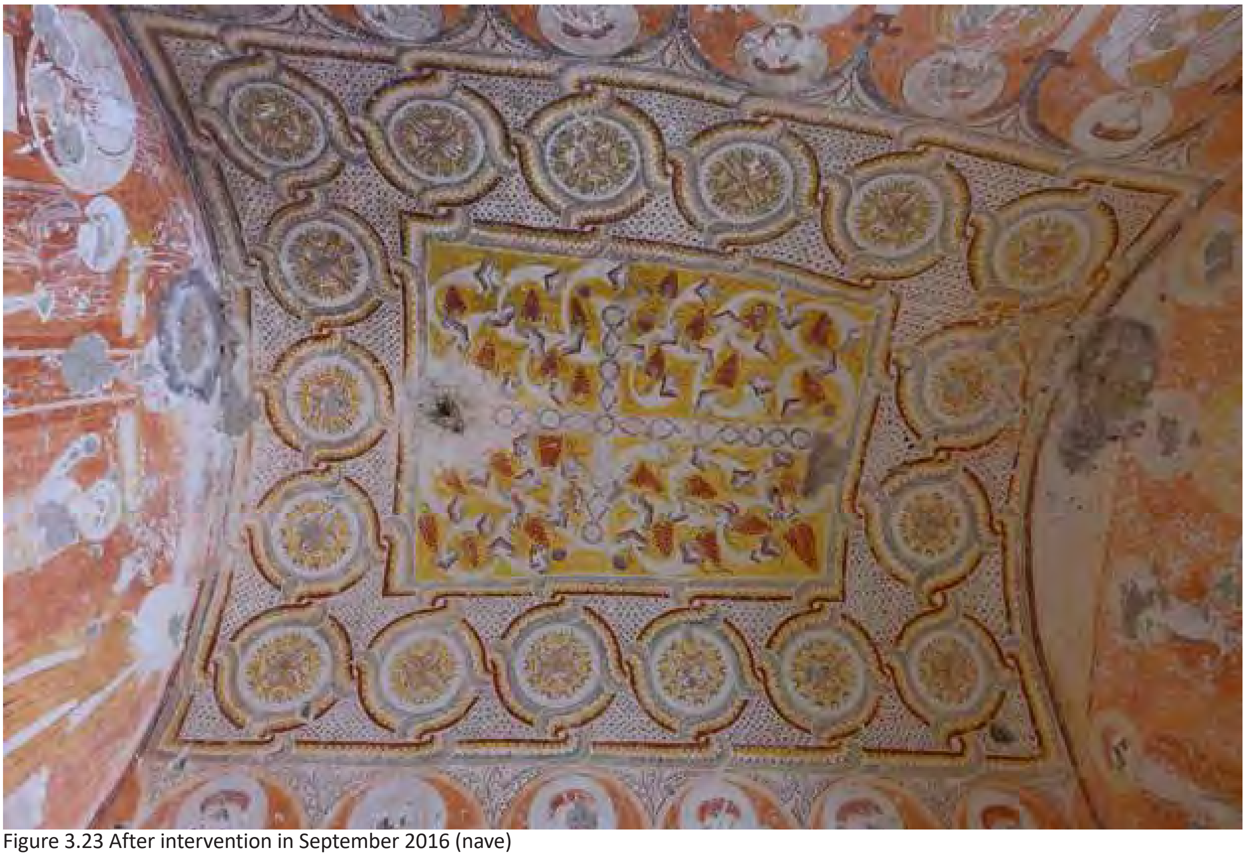


Figure 3.23 After intervention in September 2016 (nave)
Şekil 3.23 Eylül 2016 müdahale sonrası (Kilise ortası)

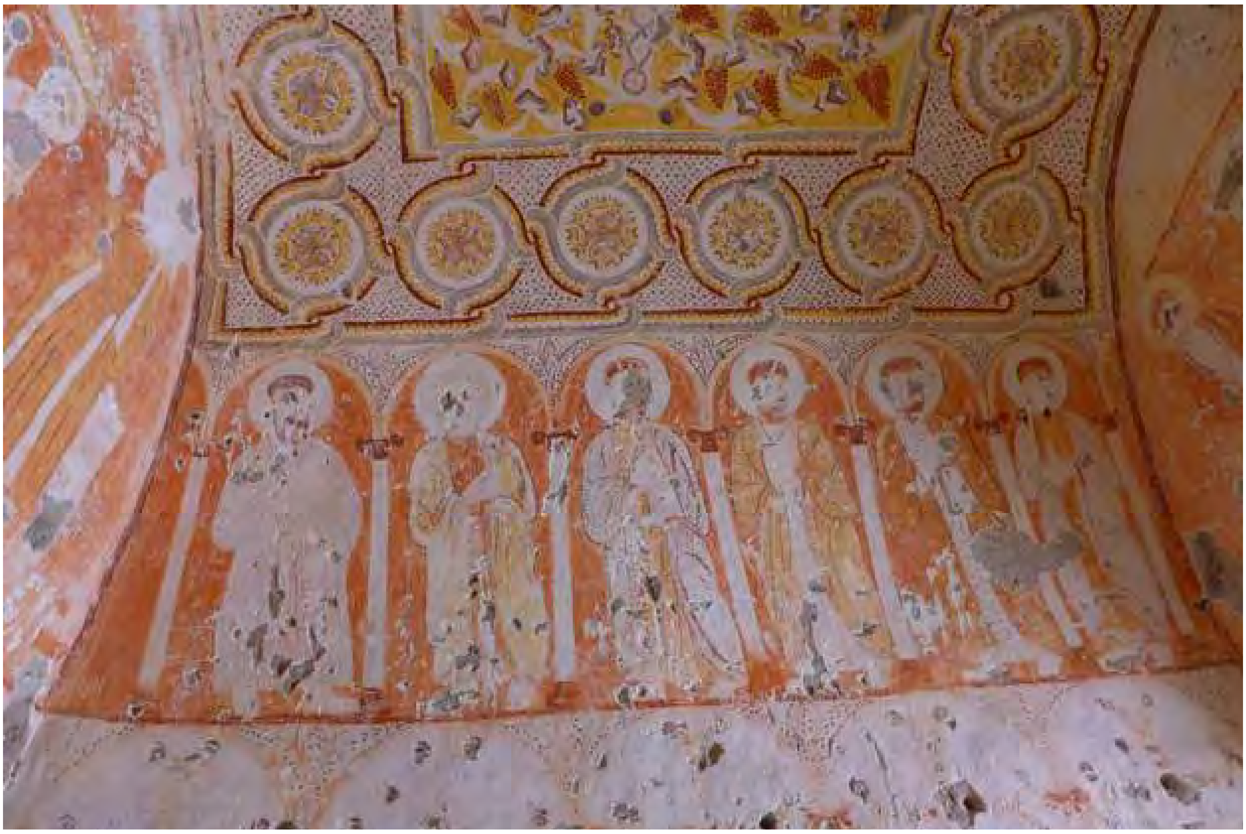


Figure 3.24 After intervention in September 2016 (nave, south wall)
Şekil 3.24 Eylül 2016 müdahale sonrası (kilise ortası, güney duvar)


Figure 3.25 After intervention in September 2016 (nave, south wall)
Şekil 3.25 Eylül 2016 müdahale sonrası (Kilise ortası, güney dıvar)

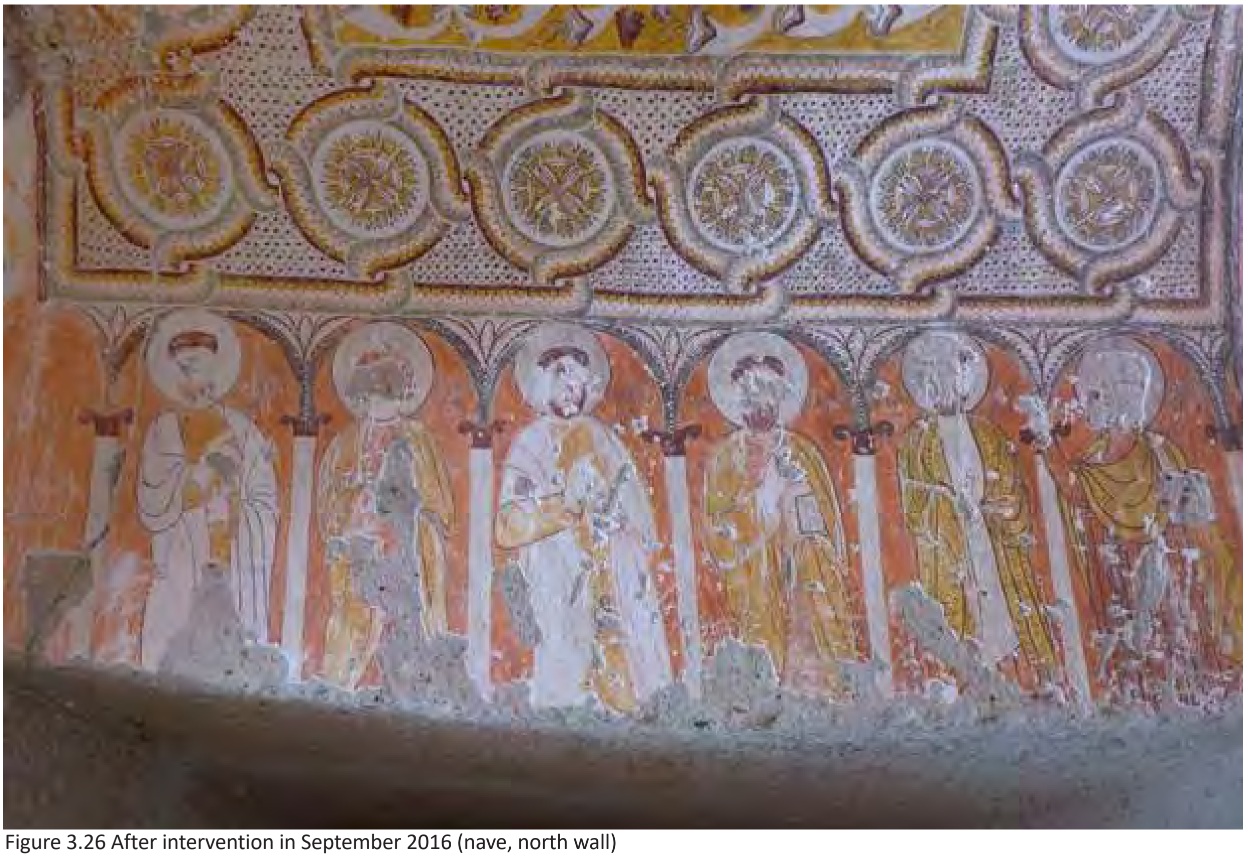


Figure 3.26 After intervention in September 2016 (nave, north wall)
Şekil 3.26 Eylül 2016 müdahele sonrası (Kilise ortası, kuzey duvar)


Figure 3.27 After intervention in September 2016 (nave, south wall)
Şekil 3.27 Eylül 2016 müdahale sonrası (Kilise ortası, güney duvar)

Figure 3.28 After intervention in September 2016 (narthex, north wall)
Şekil 3.28 Eylül 2016 müdahale sonrası (narteks, kuzey duvar)

Figure 3.29 After intervention in September 2016 (narthex
Şekil 3.29 Eylül 2016 müdahale sonrası (narteks)


Figure 3.30 After intervention in September 2016 (west)
Şekil 3.30 Eylül 2016 müdahale sonrası (batı)


Figure 3.31 After intervention in September 2016 (entrance)
Şekil 3.31 Eylül 2016 müdahale sonrası (giriş)

Figure 3.32 After intervention in September 2016 (narthex, north)
Şekil 3.32 Eylül 2016 müdahale sonrası (nartex, kuzey)

Figure 3.33 After toning in September 2016 (nave)
Şekil 3.33 Eylül 2016 tonlama sonrası (Kilise ortası)

Figure 3.34 After toning in September 2016 (nave)
Şekil 3.34 Eylül 2016 tonlama sonrası (Kilise Ortası)

Figure 3.35 After intervention in September 2016 (altar)
Şekil 3.35 Eylül 2016 müdahale sonrası (mihrap)

Figure 3.36 After intervention in September 2016 (nave)
Şekil 3.36 Eylül 2016 müdahale sonrası (Klise ortası)

Figure 3.37 After intervention in September 2016 (nave, altar)
Şekil 3.37 Eylül 2016 müdahale sonrası (Kilise ortası,mihrap)

Figure 3.38 Conservation members, 2016
Şekil 3.38 2016 yılının konservasyon üyeleri

The Üzümlü Church is not the most magnificent example of a Byzantine church in Cappadocia. However, it certainly is endowed with unique character owing to its surrounding landscape and historical settings. It is not the same without a well-preserved environment and beautifully maintained yards. There are numerous precious gypsum-based wall paintings in the valleys, which require careful protection. This project was designed to serve as a model for bringing locals and stakeholders together for the purpose of prolonging cultural heritage in the context of its original local settings. Rather than any drastic intervention, modest continuous treatment would be a wiser choice in conservation.

Numerous issues must yet be tackled in the conservation field in Cappadocia. We look forward to continuing long-term study and monitoring of post-intervention conditions.

I would like to express appreciation to MEXT/JSPS KAKENHI (24101014) and the Kajima Foundation for their financial support on this project. The Üzümlü project has

Üzümü Kilisesi, Kapadokya'da yer alan Bizans kilisesinin en önemli örneği değildir ancak çevresindeki coğrafi manzara ve tarihi süreç ile birlikte eşsiz tonlamasyla şüphesiz mirastır. İyi korunmuş doğa ve güzelce muhafaza edilmiş mabet aynı değildir.Vadi içinde çeşitli değerli gerektiren alçı bazlı korunması gereken duvar resimleri var. Bu proje orjinal yerel koşullara ayarlama çerçevesinde kültürel mirasın ömrünün uzatılması ve korunması için tüm yerli ve yabancı görevlileri bir araya getiren küçük bir örnek olmayı hedeflemiştir. Büyük bir müdahalenin yerine, bir dizi hafif, kontrollü olarak devam eden iyileştirici müdahaleler muhtemelen daha uygun bir tercih olabilir.

Kapadokya'daki korunması gereken alanlarda üzerinde durulacak çok fazla konu bulunmaktadır ve yapılan müdahaleler sonrası uzun vadede gözlemleme ve daha detaylı araştırma çalışmalarımızı sürdürmeyi planlamaktayız.

been supported by numerous individuals in both Turkey and Japan, especially the Turkish government and staff at the Nevşehir Restoration and Conservation Regional Laboratory Directorate. Special appreciation is extended to: the director of the Nevşehir Museum, Murat Ertuğrul Gülyaz; the director of the Niğde Museum, Fazıl Açıkgöz; Ibrahim & Hamidiye Sakınan and children; and Tolga Uyar, Zuhal Coçyğit, Giulia Caneva, Piao Chunzu, Shunsuke Fukasawa, Hisato Hashizume, Ryo Higuchi, Chiemi Iba, Kazuki Kawahara, Keigo Koizumi, Shigekazu Mizukoshi, Takeshi Nakazawa, Jennifer Porter, Katsuhiko Sano, Juni Sasaki, Mina Shibata, Yoshiko Shimadzu, Tamaki Suzuki, Miho Takashima, Mizuho Yoshioka, Kunio Watanabe and Rayna Rusenko.

Bu projeyle ilgili maddi desteklerinden dolayı Kajima Vakfı'na ve MEXT/JSPS KAKENHI (24101014) Merkezi'ne minnettar olduğumuzu belirtmek isterim.Üzümlü projesi hem Türkiye hemde Japonya'daki pek çok kişi tarafından, özelliklede Türkiye Cumhuriyeti Kültür ve Turizm Bakanlığı ve Nevşehir Restorasyon ve Konservasyon Bölge Laboratuvarı Müdürlüğü personeli tarafından desteklenmiştir.

Nevşehir Restorasyon ve Konservasyon Bölge Laboratuvarı Müdür V. Hatice TEMUR'a ve uzmanları Uğur YALÇINKAYA'ya, Ayça BAŞTÜRKMEN'e, Mustafa TOPTEPE'ye, Merve Azize IŞIN'a;Müze Müdürü E. Murat GÜLYAZ'a, Niğde Müze Müdürü Fazlı AÇIKGÖZ'e; İbrahim-Hamdiye Sakınan ve çocuklarına ve Tolga Uyar'a, Zuhal Koçyiğit'e, Giulia Caneva'ya, Piao Chunzu'ya, Shunsuke Fukasawa'ya, Hisato Hashizume'ye, Ryo Higuchi'ye, Chiemi Iba'ya, Kazuki Kawahara'ya, Keigo Koizumi'ye, Shigekazu Mizukoshi'ye, Takeshi Nakazawa'ya, Jennifer Porter'ya, Katsuhiko Sano'ya, Juni Sasaki'ye, Mina Shibata'ya, Yoshiko Shimadzu'ya, Tamaki Suzuki'ye, Miho Takashima'ya, Mizuho Yoshioka'ya, Kunio Watanabe'ye and Rayna Rusenko'ya katkılarından dolayı özellikle teşekkür ederim.

References

Burgio, L., et.al. (2007) Raman analysis of ninth-century Iraqi stuccoes from Samarra, *Journal of Archaeological Science*, **34** (2007) pp 756-762.

De Brito, J., Flores-Colen, I. (2014)3. *Gypsum plaster, Materials for Construction and Civil Engineering*, pp 123-184, Springer.

Ersen, A., et.al.(2006) Effect of malic and citric acid on the crystallisation of gypsum investigated by coupled acoustic emission and electrical conductivity techniques, *Journal of Material Science* **41**: 7210. doi:10.1007/s10853-006-0918-6

Fukui, H., Kito, H., Hisada, K., Kitaoka, T., Hasegawa, J., (1984) Effect of Sodium Citrate on Expansion Reversal of Gypsum-Bonded Investments (in Japanese), *Journal of the Japanese Society for Dental Materials and Devices*, **3**, pp.303-309.

Garland, K., Rogers, J. (2006) Review of Some Past Conservation Approaches for the Treatment of Clay-Based Chinese Wall Paintings and a Set of Seventeenth-Century Chinese Gate. In L. Rainer & A. Bass Rivera (Eds.),*the Conservation of Decorated Surfaces on Earthen Architecture: Proceedings from the International Colloquium*. pp 66–77, Los Angeles: The Getty Conservation Institute.

Lanzon, M. and Garcia-Ruiz, P. A.,(2012) Effect of citric acid on setting inhibition and mechanical properties of gypsum building plasters, *Construction and Building Materials*; **28**, 1; 506-511.

Lucas, JC. (1990) Synthetic binders' coatings for walls interior surfaces. Buildings technical information, ITE 27. National Laboratory of Civil Engineering, Lisbon.

Isayama, Y., et.al. (1976) On the Preparation and Utilization of the "Shirasu" Producing the hollow glass micro-sphere (Shirasu-balloons), *FLOTATION*, **23**, 144-157. (in Japanese)

Pasian, C, et.al.(2016) Non-structural injection grouts with reduced water content: Changes induced by the partial substitution of water with alcohol, *Studies in Conservation*. http://dx.doi.org/10.1179/2047058415Y.0000000022

Silveira, P. (2000) *Ancient gypsum plasters: building characterization and pathological analysis*. MSc Dissertation in Construction, Instituto Superior Te'cnico, Lisbon

Takashima, M. (2015) ELISA (Enzyme-linked immunosorbent assay) testing for organic binding media of Üzümlü wall paintings, in Taniguchi, Y. (ed.) (2015) *Scientific Studies on Conservation for Üzümlü Church and Its Wall Paintings in Cappadocia, Turkey: vol. 1 Annual report on the activities in 2014*, 96-102. University of Tsukuba

Taniguchi, Y. (ed.) (2015) *Scientific Studies on Conservation for Üzümlü Church and Its Wall Paintings in Cappadocia, Turkey: vol. 1 Annual report on the activities in 2014*, University of Tsukuba

Taniguchi, Y., et.al (2016) Scientific research for conservation of the rock hewn church of Uzumlu, Cappadocia, *37. International Symposium of Excavations, Surveys and Archaeometry, Erzurum 11-15 May 2015*, 361-378, Ministry of Culture and Tourism, Turkey.

谷口陽子（2004）シュウ酸アンモニウムによるグロビジェリーナ石灰岩製石造文化財の表面処理：処理後の評価『文化財保存修復学会第 26 回大会研究発表要旨集』、254-255.

野元堅一郎(1967)“未開発資源としての“シラス”について”, 九州鉱山学会誌第 35 巻第 1 号別冊, 85-99.

I -4 Assessmenr of Micro-Environment around Üzümlü Churech

Chiemi Iba, Kyoto University
Kunio Watanabe, Mie University

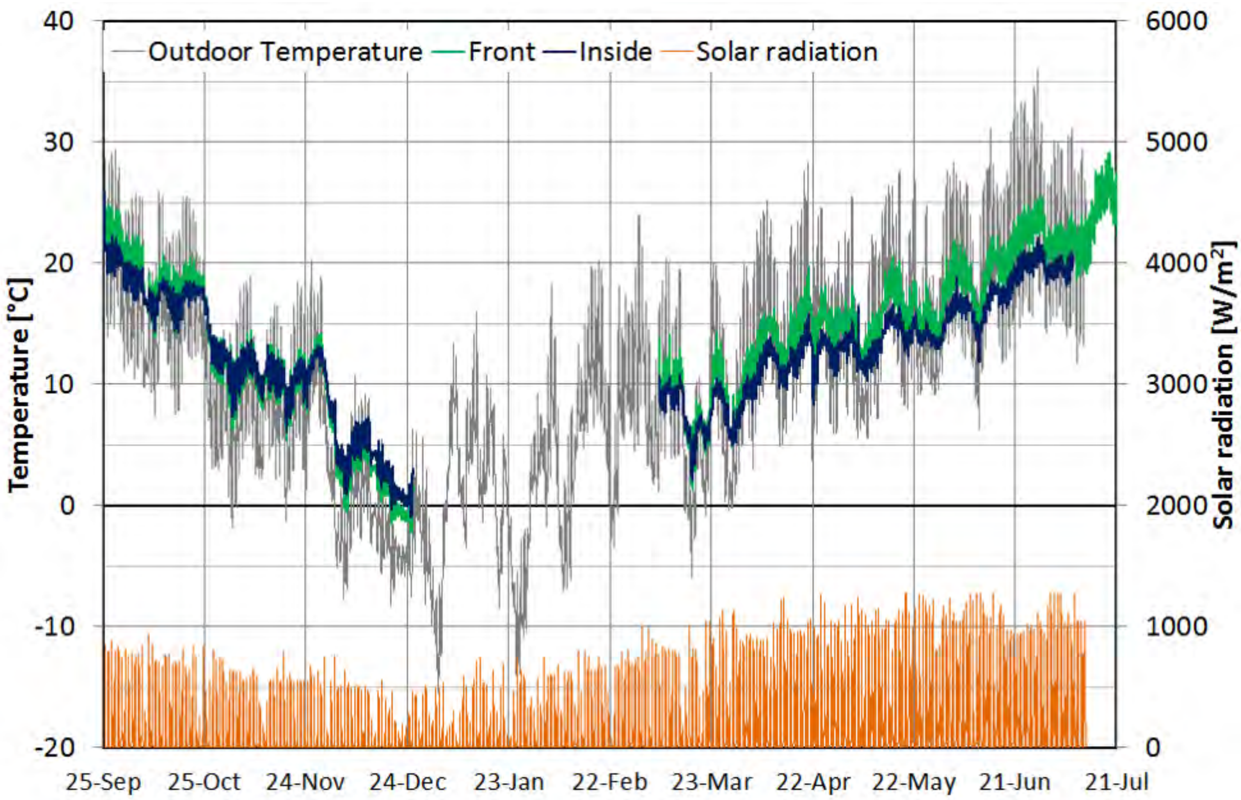


Figure 4.1. From Sep. 25, 2015 to Jul. 21, 2016 (300 days) Environmental data near Üzümlü Church

The diurnal temperature variation of outdoor air ranged over 10 degrees. The variation was 3 degrees at the entrance, and 2 degrees deep inside the church. Temperature at the entrance was susceptible to greater shifts than that inside due to airflow and solar radiation. The temperature profile is similar to that of last season.

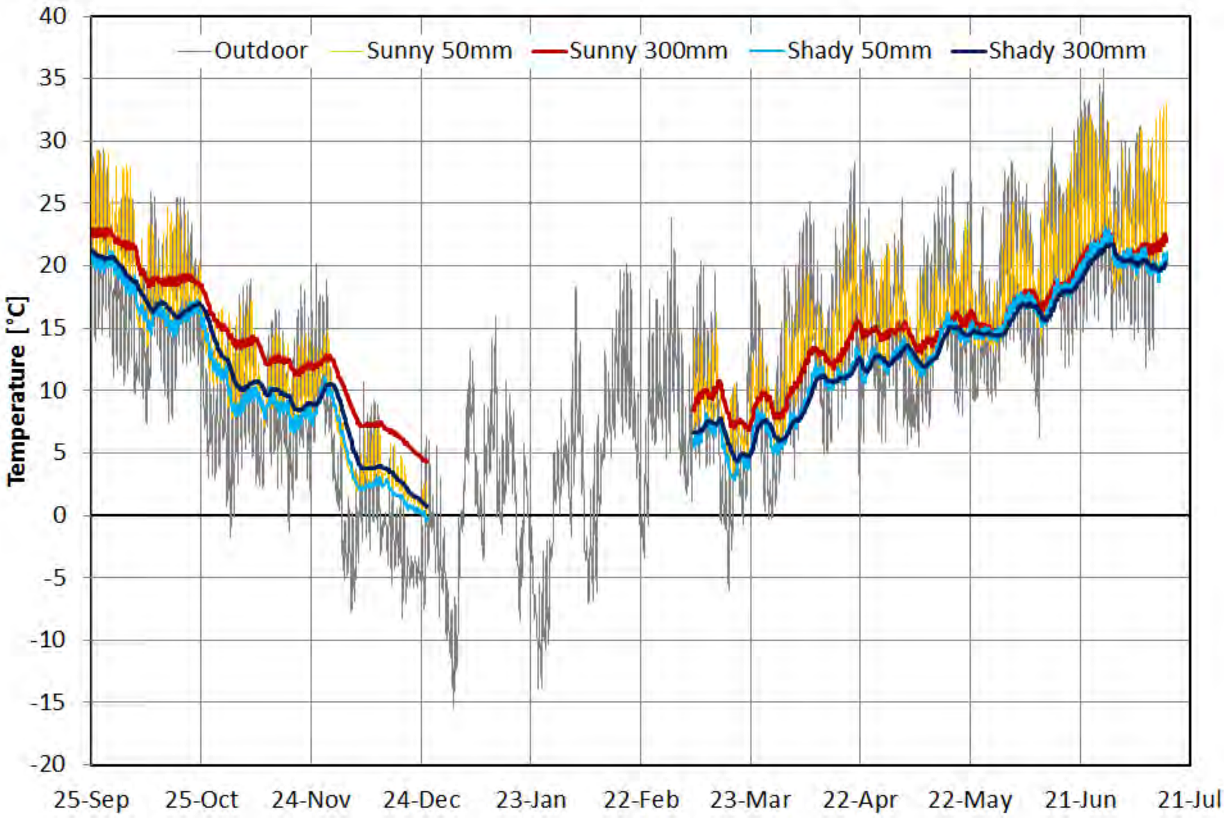


Figure 4.2. From Sep. 25, 2015 to Jul. 21, 2016 (300 days) Ground temperature at Üzümlü Church

In the shady area, ground temperatures measured deeper than 50 mm below the surface remained uniform. On the other hand, the ground temperature measured at a depth of 50mm in the sunny area fluctuated greatly due to solar radiation, while the temperature measured at a 300 mm depth remained 1-3 degrees higher than that in the shady area.

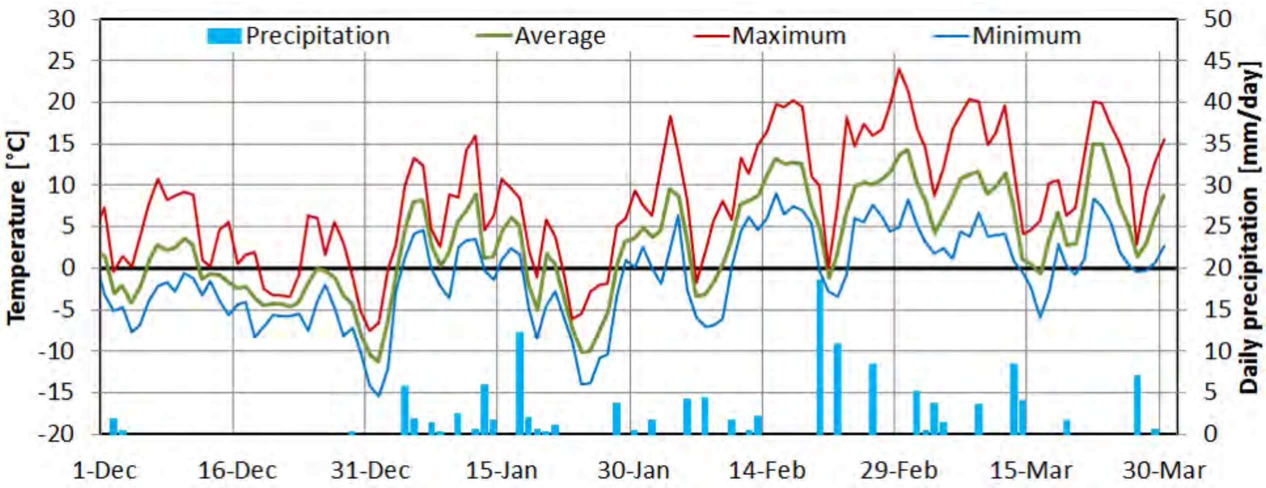
	2015-16 Winter	2014-15 Winter
Average temp. during winter months	3.1 °C	4.0°C
Minimum temp. during winter months (date and time of occurrence)	-15.5 °C	-16.4 °C
Number of frost days (min. temperature below 0° C)	**66**	**47**
Freeze-thaw cycle (Outdoor temp. -4 °C to +4 °C)	**10**	**6**
Number of days with precipitation (daily integrated value ⩾0.2mm)	37	52
Total precipitation	130.6	128.0

Figure 4.3. Meteorological features at red valley over two winter seasons

The weather seemed slightly colder In the 2015-16 season than the previous. The number of frost days (where minimum temperature dropped below 0 degrees) increased relative to 2014-15. There were 10 freeze-thaw cycle s in 2015-16, assuming that the cycle corresponds to outdoor temperature changes between -4 and +4 degrees. However, because rock surface temperatures tend to be higher than outdoor temperatures in the daytime, considering the influence of solar radiation, the actual number of freeze-thaw cycles is estimated to be higher. The total amount of precipitation in winter was very small and almost the same as that in the previous season.

Winter 2015-2016

2015-2016



Winter 2014-2015

2014-2015

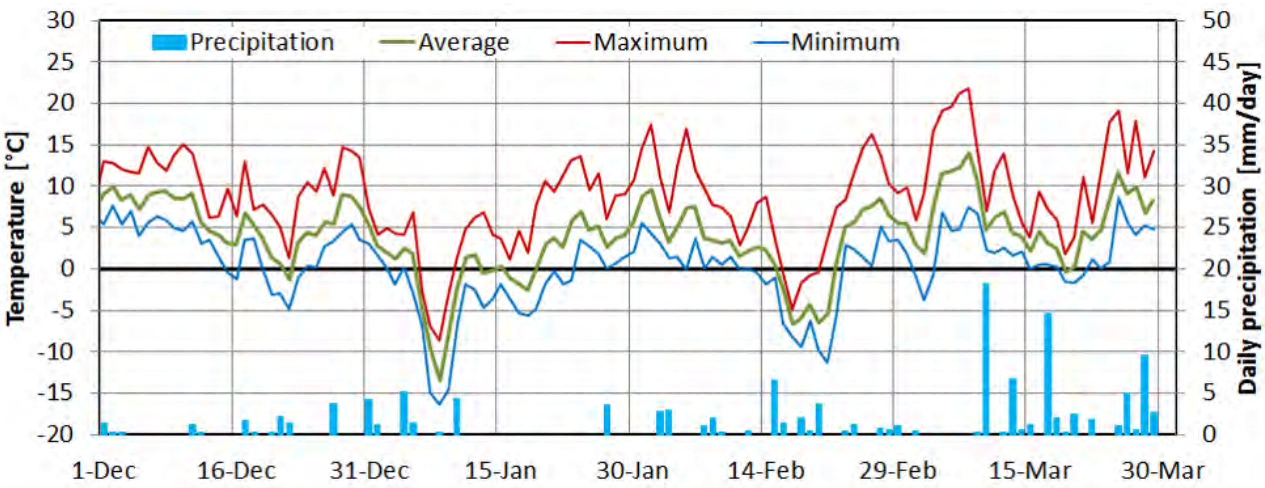
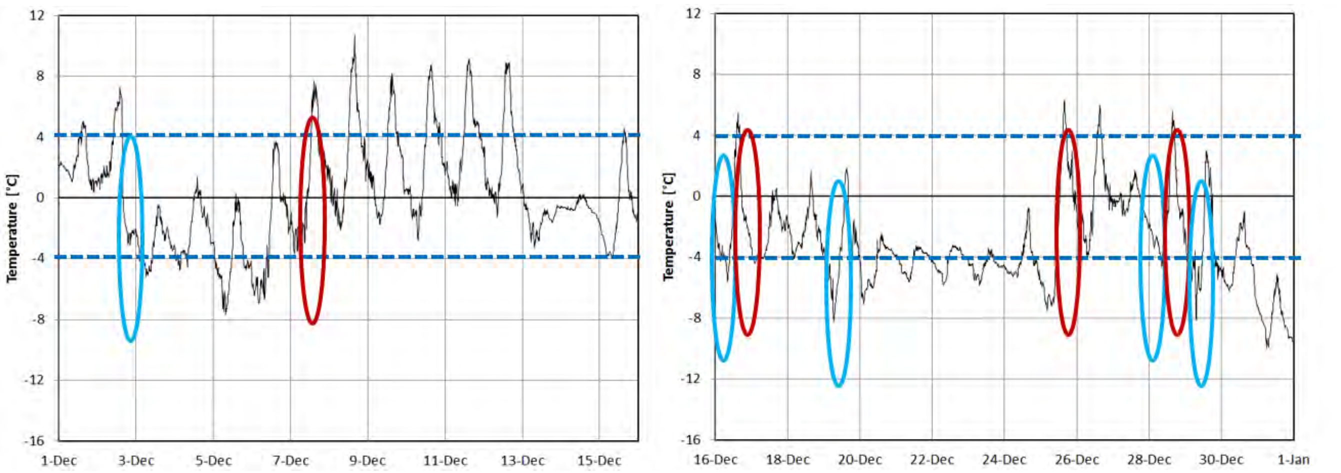


Figure 4.4. Daily average/maximum/minimum outdoor temperature and daily cumulative precipitation

December



January

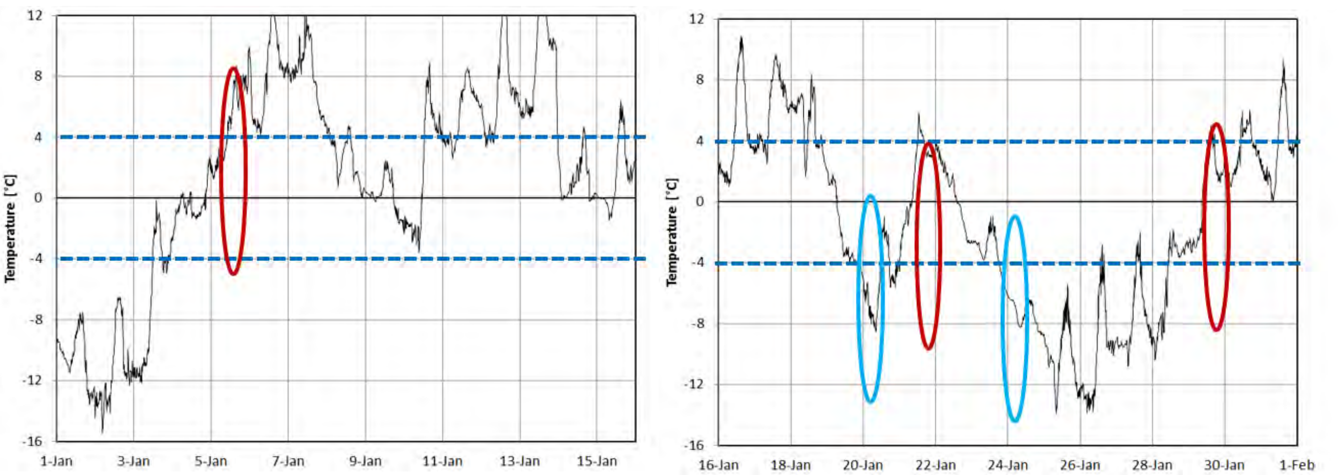
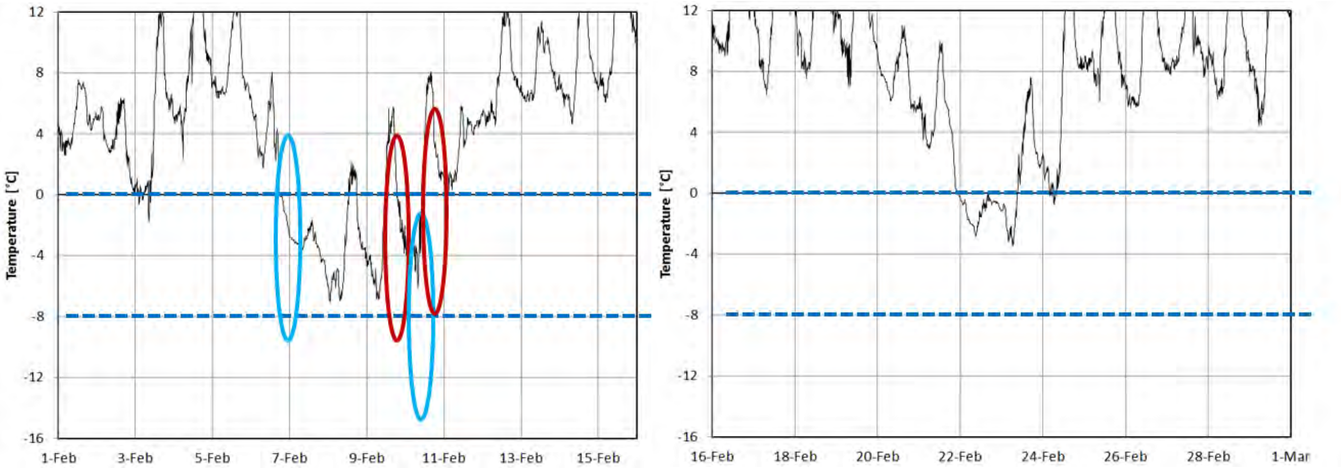


Figure 4.5. Outdoor temperature in Winter 2015-2016

February



March

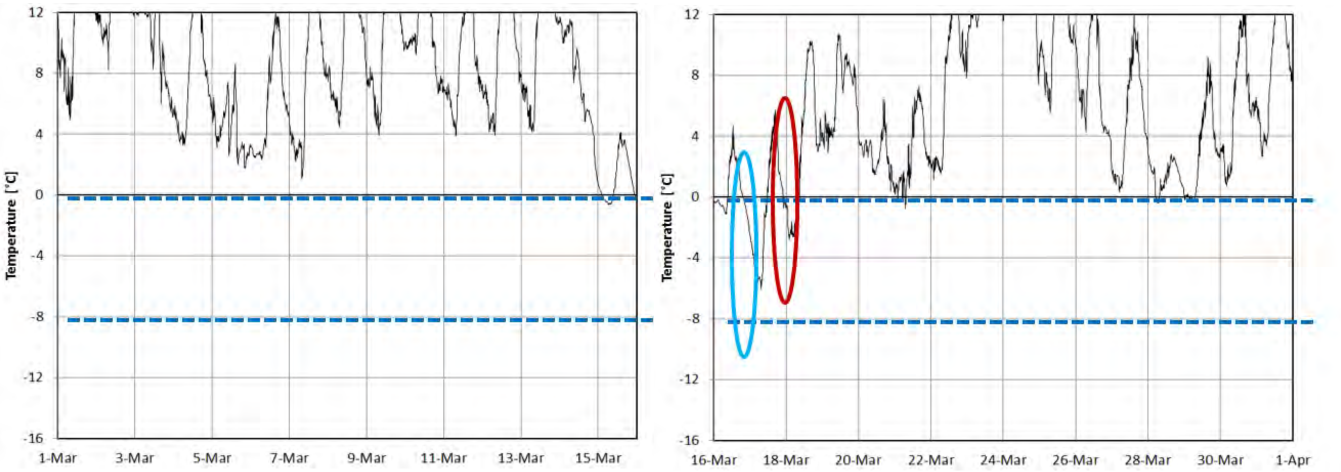


Figure 4.6. Outdoor temperature in Winter 2015-2016

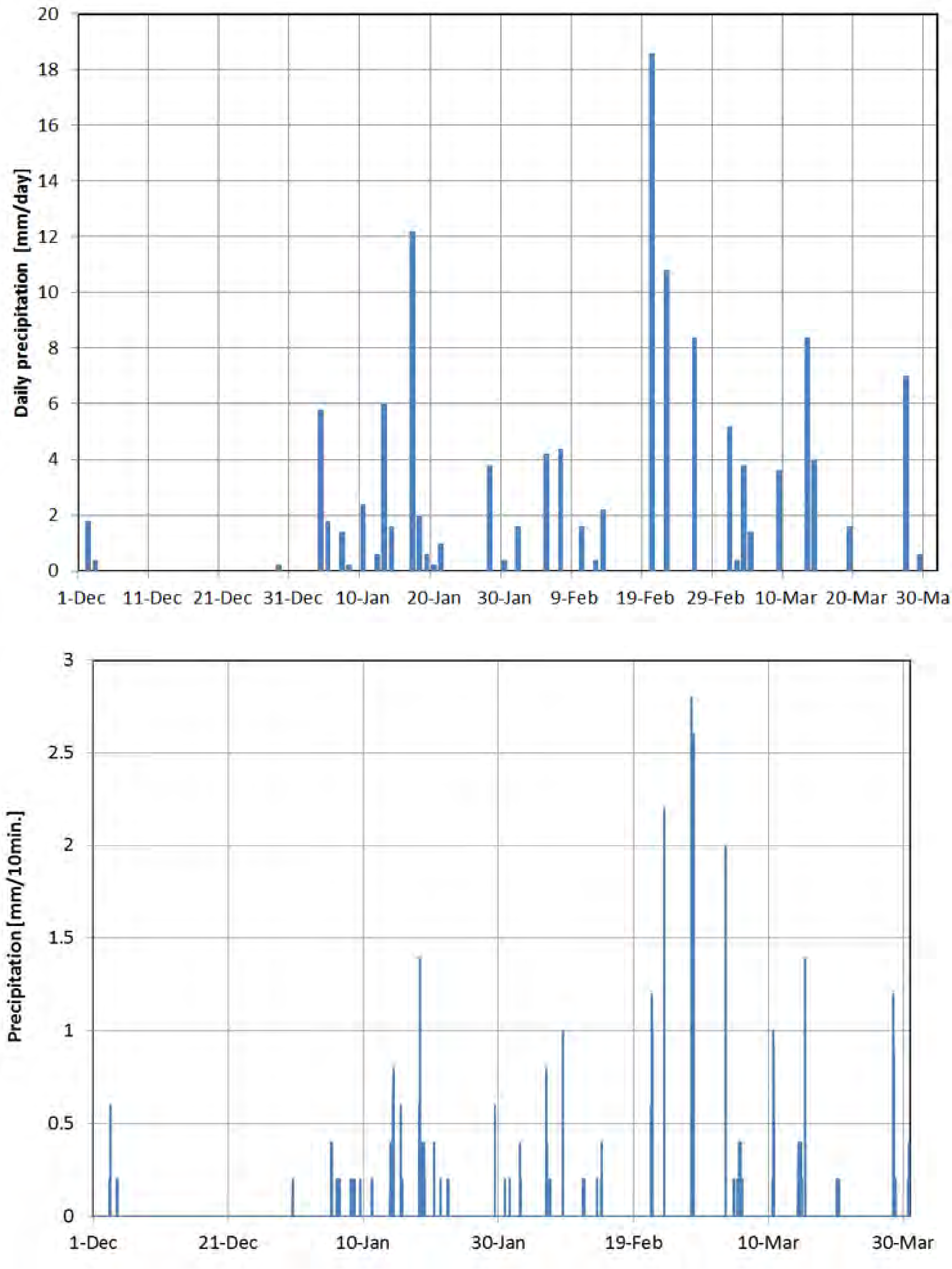


Figure 4.7. Daily cumulative precipitation and precipitation intensity (10min.)

Daily precipitation did not reach 20 mm. In the winter season, the rainfall intensity was relatively low, whereas the frequency was rather high.

*note that precipitation measurements might be uncertain in the case of snow.

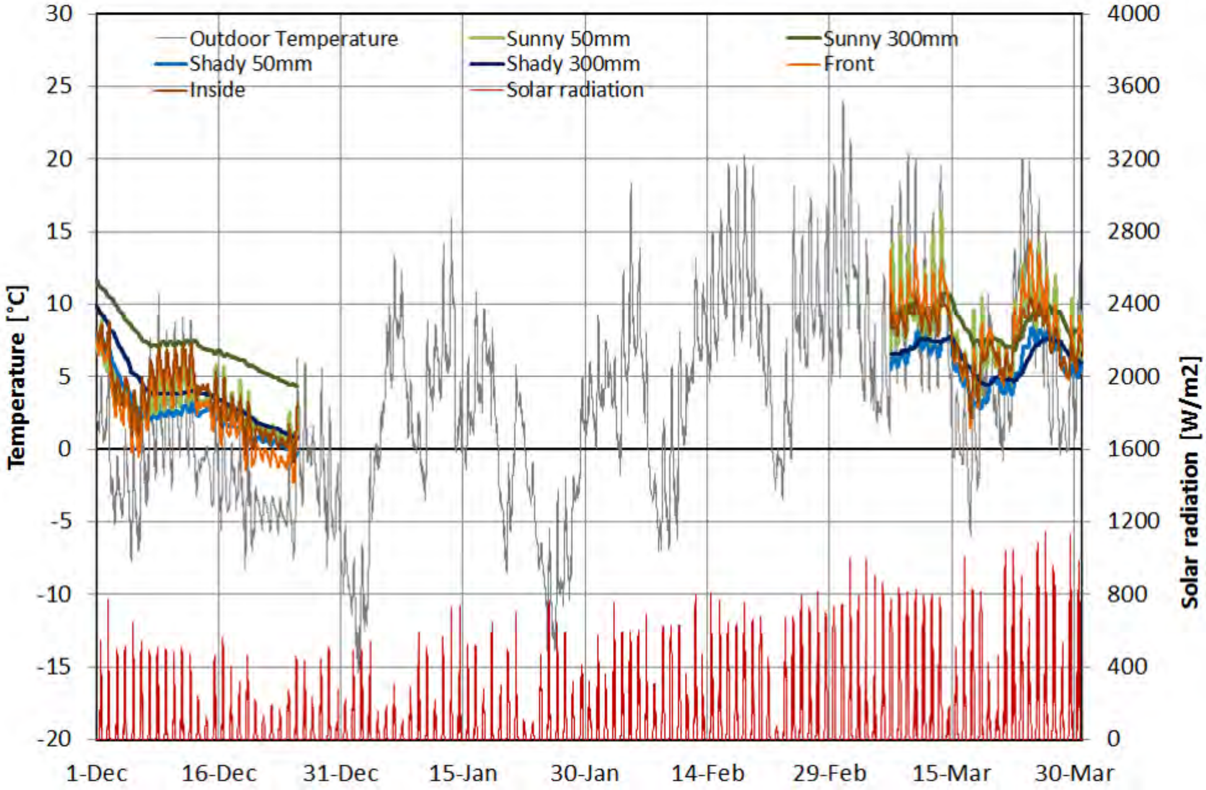


Figure 4.8. 2015-16 Environmental data near Üzümlü Church in Winter

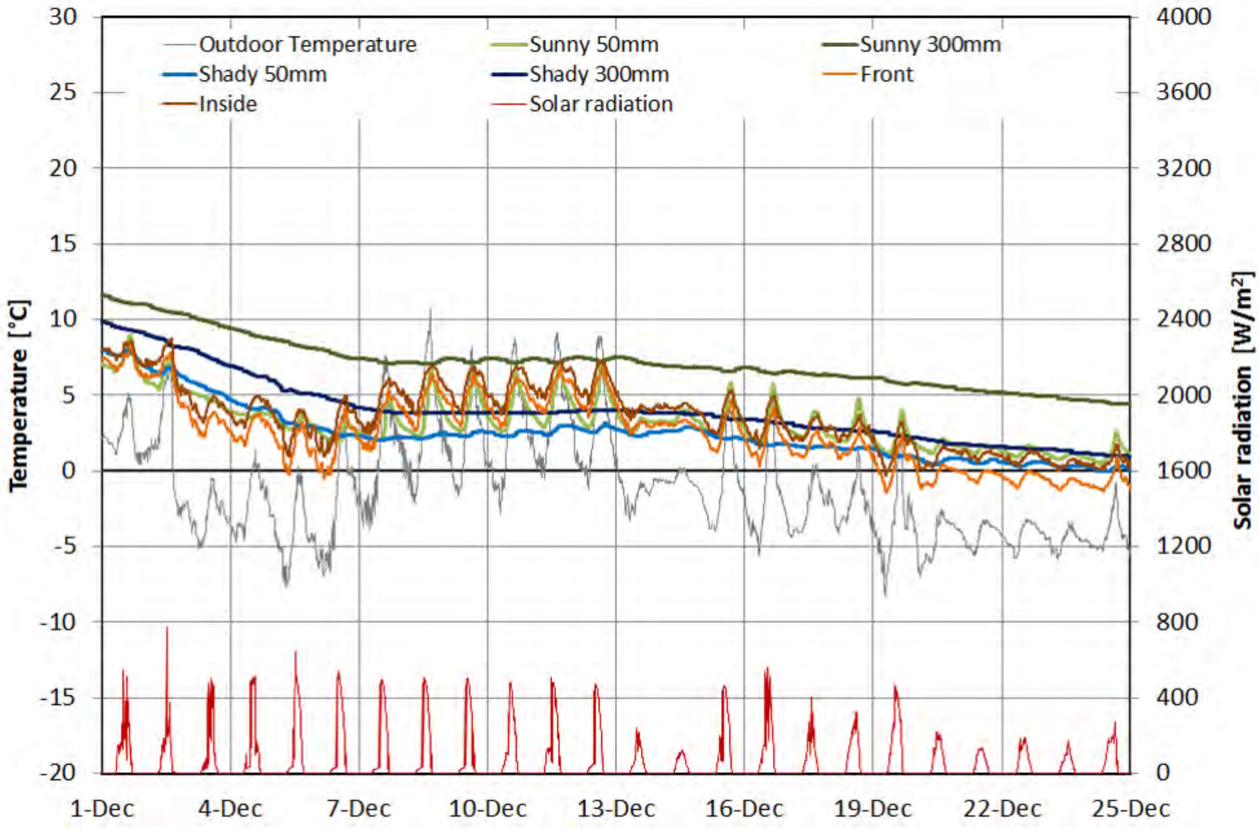


Figure 4.9. December 2015 Environmental data near Üzümlü Church in Winter

A focus on December reveals that ground temperatures around the surface in the sunny area were similar to those inside the church.

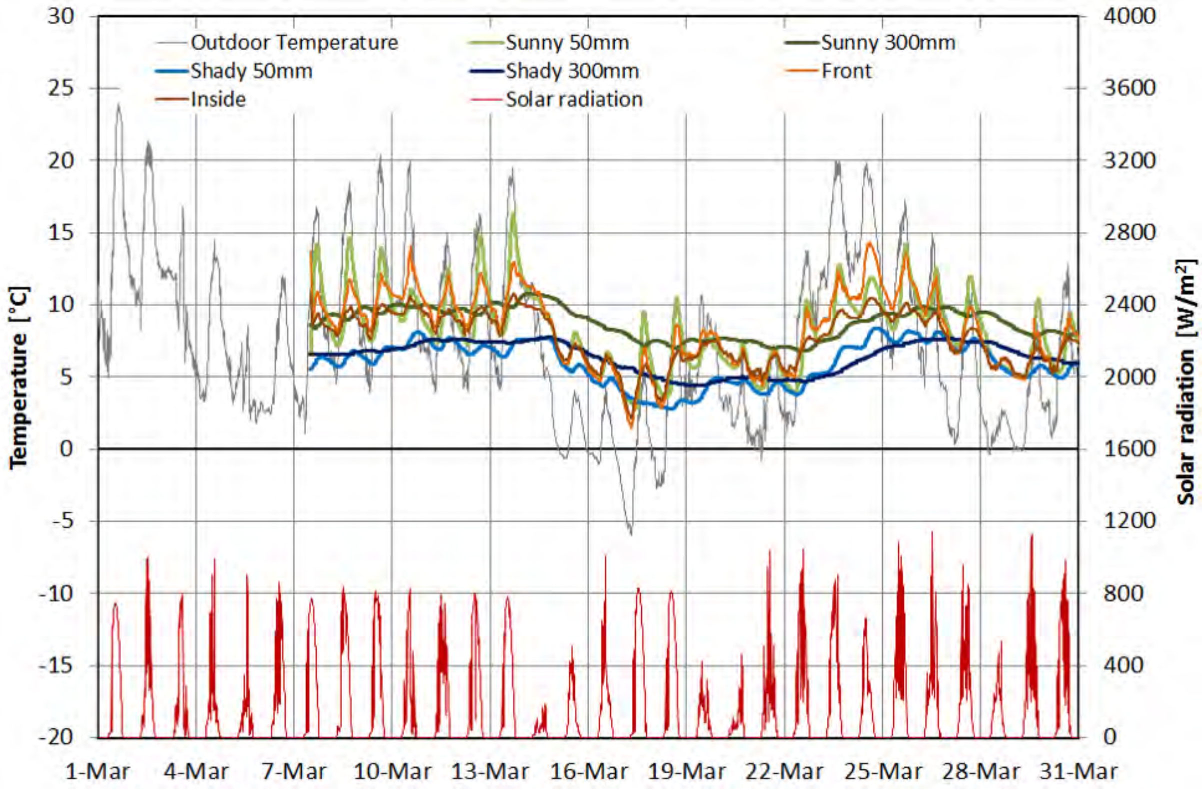


Figure 4.10. March 2016 Environmental data near Üzümlü Church in Winter

A focus on March reveals that ground temperatures around the surface (at a 50mm depth) in the sunny area fluctuate more than indoor temperatures owing to the solar heat.

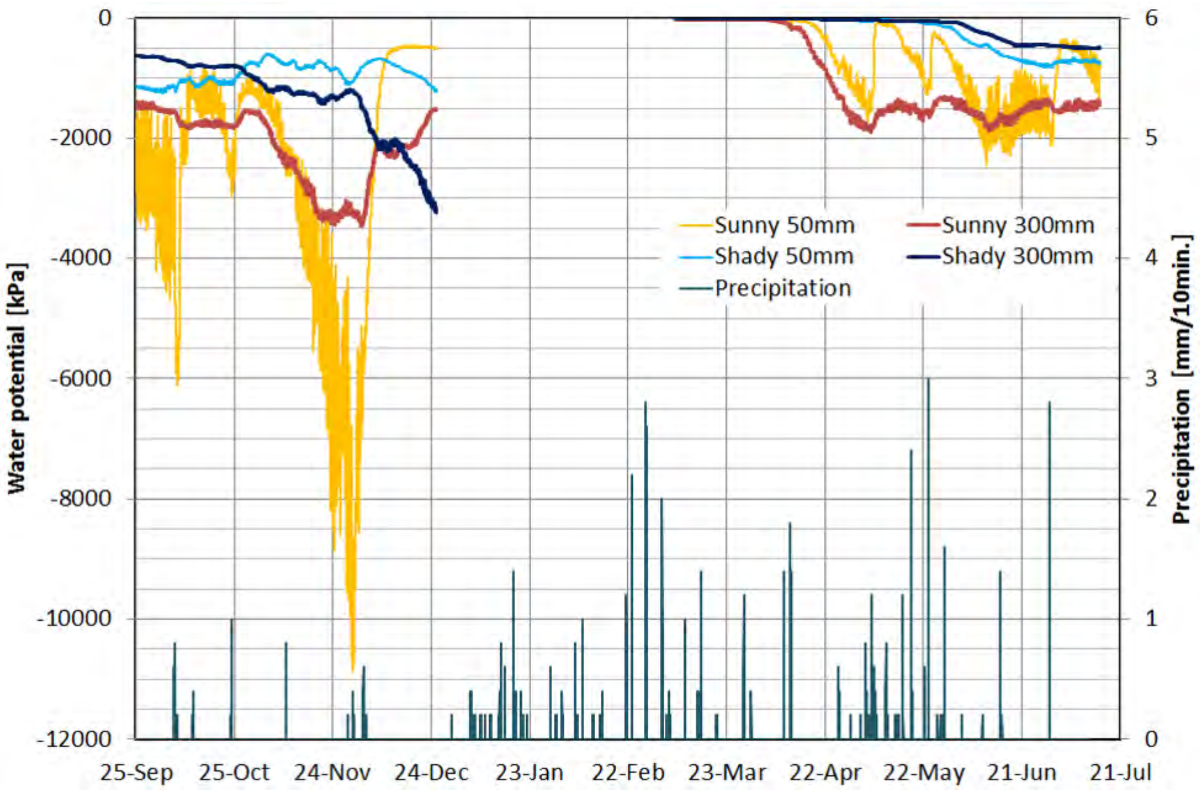


Figure 4.11. From Sep. 25, 2015 to Jul. 21, 2016 (300 days) Ground soil moisture data near Üzümlü Church

After rainfall in early December, underground water potential near the surface was higher than that in deeper zones. Therefore, the rock structure did not absorb significant amounts of groundwater. This tendency was same as that of the previous season. A few intervals of rainfall were observed in this area. The ground water potential seemed close to saturation until the end of March.

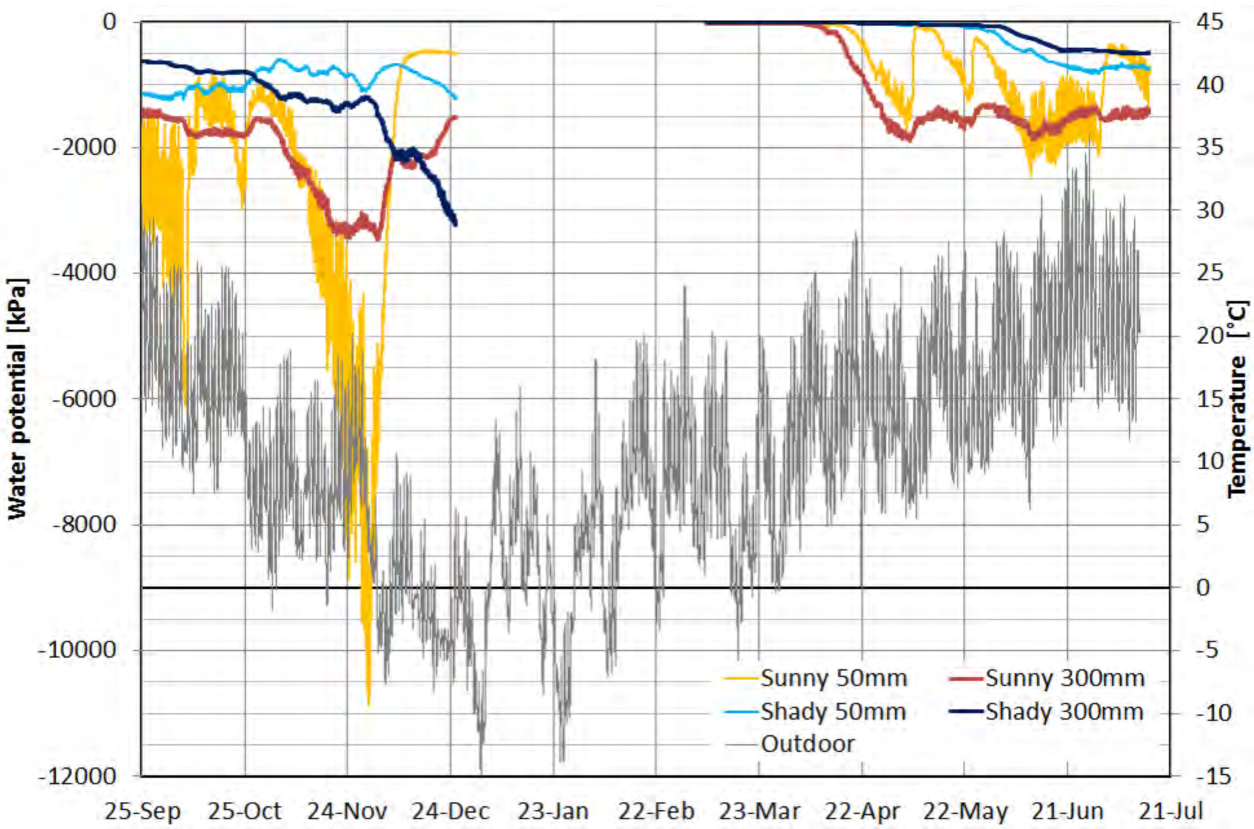


Figure 4.12. From Sep. 25, 2015 to Jul. 21, 2016 (300days) Ground soil moisture data near Üzümlü Church

It is likely that the freeze-thaw cycle will occur frequently in the immediate vicinity of the ground surface when the ground water potential remains high, because the ground surface temperature tends to drop lower than that of the outdoor air due to nocturnal radiation.

II. Published Articles on Scientific Studies for Üzümlü Church

Ryo Higuchi, Tamaki Suzuki, Mina Shibata, Yoko Taniguchi, "Methodology of High-resolution Photography for Mural Condition Database," in ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, II-5/W3 (2015), pp. 105-110 (offprint)

ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume II-5/W3, 2015
25th International CIPA Symposium 2015, 31 August – 04 September 2015, Taipei, Taiwan

METHODOLOGY OF HIGH-RESOLUTION PHOTOGRAPHY FOR MURAL CONDITION DATABESE

R. Higuchi [a,] *, T. Suzuki [b], M. Shibata [c], Y. Taniguchi [d]

[a] Dept. of Built Environment, Tokyo Institute of Technology, Japan - higuchi.r.ab@m.titech.ac.jp
[b] Asia-Japan Research Center, Kokushikan University, Japan - suzuki.tamaki0316@gmail.com
[c] National Research Institute for Cultural Properties, Japan - mina.shibata@gmail.com
[d] Graduate School of Humanities and Social Sciences, University of Tsukuba, Japan - taniguchi.yoko.fu@u.tsukuba.ac.jp

Symposium Topic D, D-4 Technologies aimed at preventive maintenance and monitoring of sites

KEY WORDS: Photography, documentation, high-resolution image, mural painting, rock-hewn church, Cappadocia

ABSTRACT:

Digital documentation is one of the most useful techniques to record the condition of cultural heritage. Recently, high-resolution images become increasingly useful because it is possible to show general views of mural paintings and also detailed mural conditions in a single image. As mural paintings are damaged by environmental stresses, it is necessary to record the details of painting condition on high-resolution base maps. Unfortunately, the cost of high-resolution photography and the difficulty of operating its instruments and software have commonly been an impediment for researchers and conservators. However, the recent development of graphic software makes its operation simpler and less expensive. In this paper, we suggest a new approach to make digital heritage inventories without special instruments, based on our recent our research project in Üzümlü church in Cappadocia, Turkey. This method enables us to achieve a high-resolution image database with low costs, short time, and limited human resources.

1. INTRODUCTION

Digital documentation, such as high-resolution photography, is one of the cutting-edge techniques and most useful methods to record the condition of cultural heritage. Especially, in recent mural painting conservation projects, high-resolution images become useful because it is possible to show both general view of mural painting and detailed mural condition in a single image. Such digital archiving is necessary because the mural paintings are damaged by diverse mechanisms, such as physical, environmental and biological effects. Therefore, it is necessary to record the details of painting condition on high-resolution base maps.

On the other hand, the cost of high-resolution photography and the difficulty of operating its instruments and software have commonly been an impediment for researchers and conservators. However, the recent development of graphic software makes its operation simpler and less expensive. In this paper, we suggest a new approach to develop a mural painting database, which is based on our recent our research project in Üzümlü church in Cappadocia, Turkey.

2. GENERAL INFORMATION OF ÜZÜMLÜ CHURCH

2.1 Location of the Site and its Architectural Style

The rock-hewn church of Üzümlü (Üzümlü means grape in Turkish) is located in the Red Valley in the Cappadocia in Turkey (Fig. 1). It is close to the west of Ortahisar village. The church shows obvious deterioration phenomena caused by environment, rock composition and seismic activity, biological and human activities including vandalism.

Figure 1. Map of Turkey and around the site

The Üzümlü church is identified as the chapel of Niketas the Stylite (Rodley 1963). Little is known about the history of the church since little documentation exists. However, because the mural paintings are similar to those found in Pantokrator Monastery (Zeyreki Kilise Camii, 1120 - 1136), Istanbul, the mural paintings in the Üzümlü church may date between the periods of the Komnenos dynasty (1081-1185). On the other hand, it is very difficult to determine the exact period when this church was built or when the murals were painted because the cave church was extended by excavating the rock gradually. The mural paintings do not contain any botanical materials such as thatch; therefore, a precise dating is very difficult.

The Üzümlü church is about 12 m in an east-west direction, and about 8 m in a north-south direction. The church is composed of five chambers (Fig. 2). Although it is unknown how these chambers were used originally, we assume that the three ordered chambers from western entrance to eastwards are "*narthex*", "*nave*" and "*apse*". The two other chambers attaching the north side of *nave* and *apse* may be extra ones, as the ceiling height of these chambers are shorter than the other three

* Corresponding author

chambers and these two are not covered with mural paintings. The plans of *narthex* and *nave* are imperfect rectangles, and the plan of *apse* is an ellipse. The ceiling of the *narthex* and *nave* are barrel vault and that of *apse* is dome. The two chambers on the north side of *nave* and *apse* are cuboid and were never covered with paintings. Compared with the exposed rock surface of the main chambers, the surfaces of the two chambers are roughly excavated. This obviously may indicate that the main chambers and other combers were made by different techniques. Therefore, it would seem that the latter two chambers were never painted. Also, these seem to be excavated in a later period.

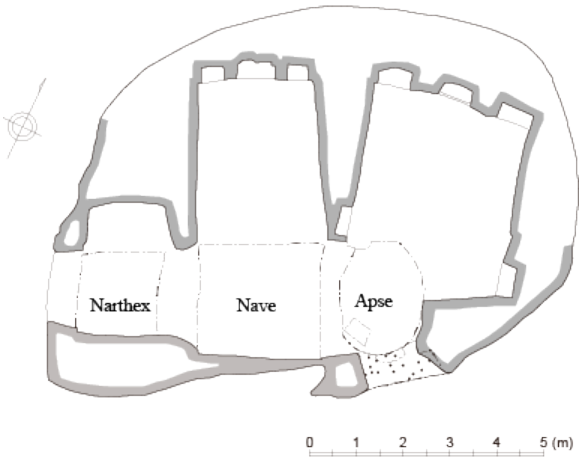


Figure 2. Plan of the Üzümlü church

2.2 Former documentation project

The comprehensive documentation of the rock-hewn churches in Cappadocia was first undertaken by Dr. Nicole Thierry, from the University of Paris-Sorbonne, France, in the 1960s (Thierry, 1963). Her research focused on recording the iconographic scheme. Preliminary measurement of the rock-hewn churches around Cappadocia valley was also done by a research team led by Dr. Masaru Maeno, Professor of Tokyo University of the Arts in the early 1970s, during which the architectural drawings of Üzümlü church were made (unpublished). However, since the 1970s, no further documentation has been undertaken, and the paintings have been gradually damaged by physical, environmental and biological effects.

2.3 Location of mural painting

The mural paintings that were depicted in the 12th century survive on the following surfaces of the church: intrados of the arched entrance, west-wall, south-wall, east-wall, north arch and barrel vaulted ceiling in the *narthex*, west-wall, south-wall, east-wall and barrel vaulted ceiling in the *nave*, southeast-wall and domed ceiling in the *apse*, and transverse arch between *narthex* and *apse*. Although we assume that the intrados of transverse arch between *narthex* and *nave* may be covered with paintings, we cannot identify any remnants of the mural paintings because the lower part of this transverse arch is collapsed.

3. DOCUMENTATION METHODOLOGY

Since the paintings are depicted on the large surface of the walls, vaulted ceiling and dome, it was impossible to capture whole images in a single shot. Therefore, the wall was photographed in several pieces both vertically and horizontally, and the pieces were merged digitally into a single high-resolution image using Adobe Photoshop® software. After the images were rectified by measurement data, each image piece of wall or ceiling was used as base map. The conditions of the mural paintings were recorded on the OHP films on the printed base map. After digitalising the OHP films, the condition of the mural paintings were drawn on the high-resolution base map used by Adobe Illustrator®. Consequently, the process of documentation generally followed these four steps:

1) Photography of the paintings
2) Measurement of the cave and location of paintings
3) Image processing: Merging photographs into a single high-resolution photograph, rectification of the images and creation of the base map.
4) Condition assessment and recording

3.1 Instrument

The instruments we used in our study are listed below:

・Digital Camera (Canon EOS 60D)
・Wide-angle Lens (Canon EF-S10-22mm F 3.5-4.5 USM)
・Tripod (Manfrotto 055 CXPRO3JP)
・Laser digital distance meter (Leica Disto D210)
・Measuring Tape
・Software: Adobe Photoshop CS6, Adobe Illustrator CS6

3.2 Photography of mural painting

Photography was conducted by setting the camera on a tripod horizontally and parallel to the mural painting. Then, the distance between the lens and the mural painting was measured by a digital distance meter. Depending on the dimensions of the mural paintings, the paintings were taken in several shots. When the camera was moved horizontally or vertically, the distance between the lens and the paintings was kept constant, and each shot should contain enough overlap with photographs of adjacent areas, so that the digital merge could be processed successfully. Figure 3 is an example of a merged photograph. In this example, four photos (two rows of two shots) were taken of the wall paining on the south-wall in the *nave*.

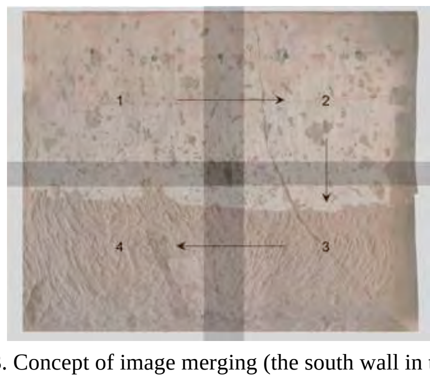


Figure 3. Concept of image merging (the south wall in the *nave*)

3.3 Measurement

The measurement of the cave was based on the architectural plan created by Prof. Maeno in 1970s, since there is no digital measurement data about this church. Further measurements were taken in this research in order to record the exact dimension of the paintings and distance between some important figures and features, which were necessary for image processing. First, the height and width of the mural paintings were measured using a digital distance meter or the measuring tape. Additionally, the distance between distinctive figures in the mural paintings, such as saints, was measured. When we measured curved surfaces, such as barrel vault or dome, we also measured the inner radial of these in order to make a planar image from the curved surface (Fig. 4).

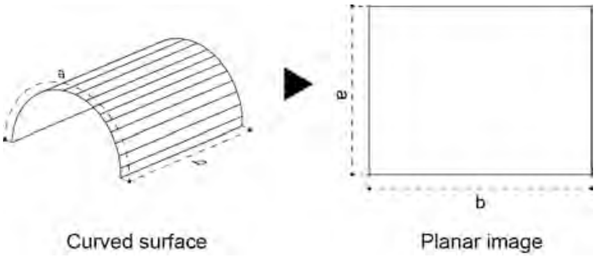


Figure 4. Diagram of conversion from curved surface to planar image

3.4 Image Processing

The photographs were merged into a single high-resolution image using the "photo merge" function of Adobe Photoshop CS6. The merged image was manually rectified based on the measurement data, and resized to the exact scale. Then, these images were imported into Adobe Illustrator CS6 to record the mural condition. The process of merge and rectification using Adobe Photoshop CS6 is as follows:

[Procedure of Photomerge]

1) Read files (Fig. 5): read the files to merge. Then select [Automate] in the [File] menu. Then click [Photomerge] and Select [Add Open Files].

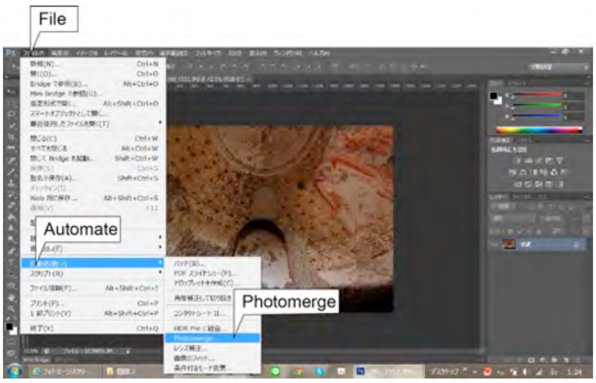


Figure 5. Image merging process 1: "Photomerge" on the menu

2) Merge files (Fig. 6): check [Blend Images Together], [Vignette Removal] and [Geometric Distortion Correction]. Then click [OK].

3) Check the edge of each of the images (Fig. 7): if the processes above were done correctly, we then check each end of the reading photographs.

4) Combine the layers: select [Layer] menu and click [Merge Visible].

5) Set the guidelines for revision: select [View] menu and click [New Guide...]. Then move the guides based on the measured places such as Figure 8.

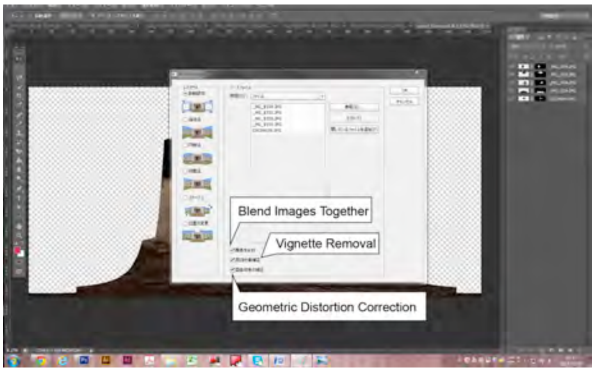


Figure 6. Image merging process 2: Choose the files to combine

Figure 7. Image merging process 3: Example of succeeded (left) and failed (right) combining photos

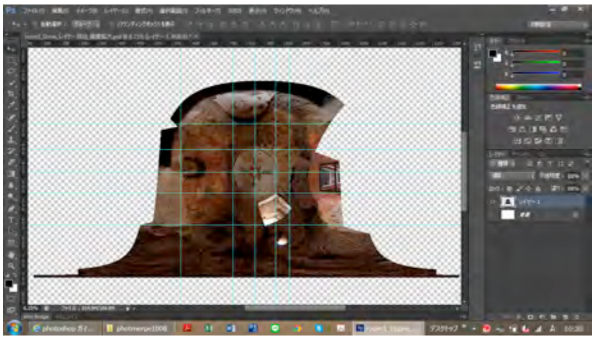


Figure 8. Image merging process 5: Set the guildelines

6) Revise the photograph (Fig. 9): select [Edit] menu and click [Warp] from the [Transform] menu, and revise the distorted areas of the merged photographs and adjust them to fit the exact scale.

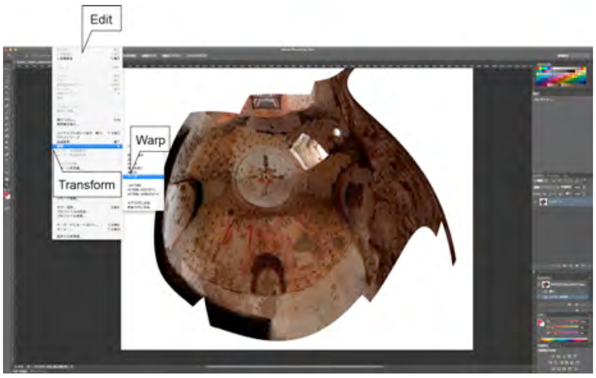


Figure 9. Image merging process 6: Chose "Warp" tool

7) Apply the transform (Fig. 10): after finishing transform, click [Apply] in the window "Apply the transform?"

Figure 11 is an example of the photograph of the dome, which was merged from five images.

Following this method, we created thirteen base maps.

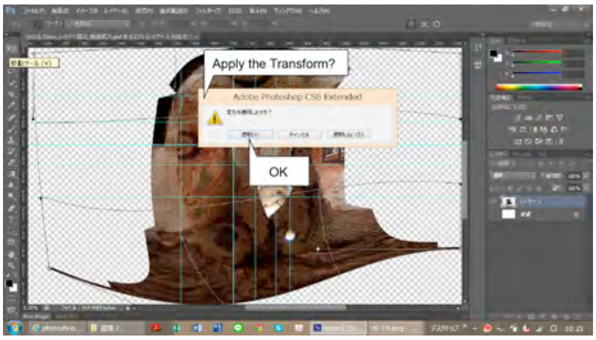


Figure 10. Image merging process 7: Applying the "Warp" tool

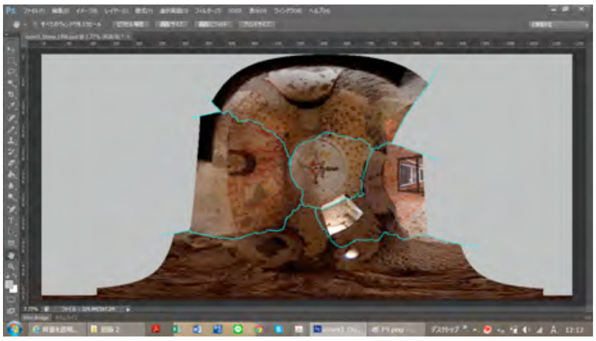


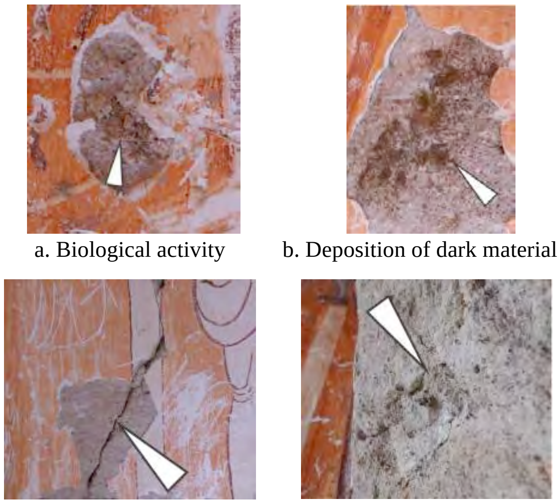
Figure 11. Finished photograph merged five images

3.5 Condition assessment and recording of mural paintings

After creating the base maps, the conditions of the mural paintings were recorded on the OHP sheets on the printed base maps. The mural paintings in the Üzümlü church are composed of three layers: rock layer, plaster layer and paint layer. Therefore, we recorded the condition of each layer of a mural painting as separated mural condition sheets. The identified deterioration items in each layer are as follows.

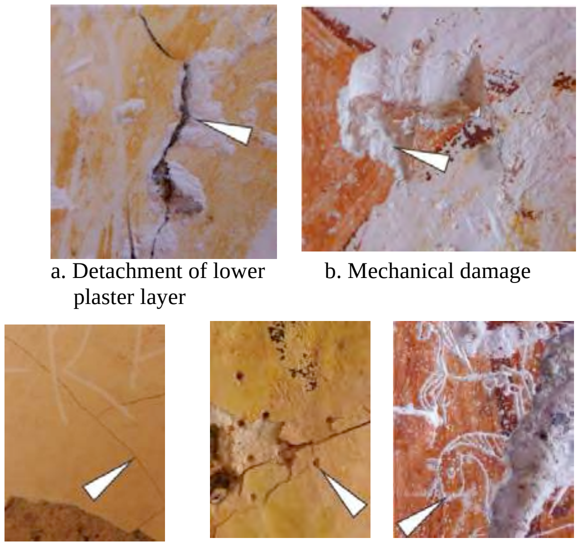
a) Rock layer deterioration is identified by four items: biological activity (Fig. 12-a), deposition of dark material (Fig. 12-b), structural cracks (Fig. 12-c) and spalling (Fig. 12-d). Biological activity is evidence of animal inhabitation on rock, such as insects or spiders. Deposition of dark material is deposit of dark brown or blockish material on the surface of the rock. Structural cracks are large cracks that run through the body of the rock, caused by faulting. Spalling is detachment of the rock on a small scale, in parallel to the surface of the rock.

b) Plaster layer deterioration is identified by five items: detachment of lower plaster layer (Fig. 13-a), mechanical damage (Fig. 13-b), cracking (Fig. 13-c), holes (Fig. 13-d) and incised graffiti (Fig. 13-e). Detachment of lower plaster layer is loss of adhesion between the lower plaster layer and rock substrate, as assessed by visual evidence alone. Mechanical damage is rupture of the painting stratigraphy by human or animal action, causing a variety of damage types: loss of the entire stratigraphy, revealing the underlying rock substrate; loss of the paint layer, ground and part of the lower plaster layer, leaving the interior of the lower plaster layer exposed; loss of only the upper plaster ground, leaving the surface of the lower plaster layer intact; deformation of the painting stratigraphy, which otherwise remain intact. Cracking is that of plaster layer most often resulting from cracking of the rock structure and mechanical damage, though there may be other causes. Holes are very circular, small holes of approximately 5mm Ø, which enter into the plaster layer and generally do not reach the substrate. Incised graffiti is inscriptions and drawing incised into the surface of the painting, affecting the paint layer, ground and plaster layer.



a. Biological activity b. Deposition of dark material
c. Structural cracking d. Spalling

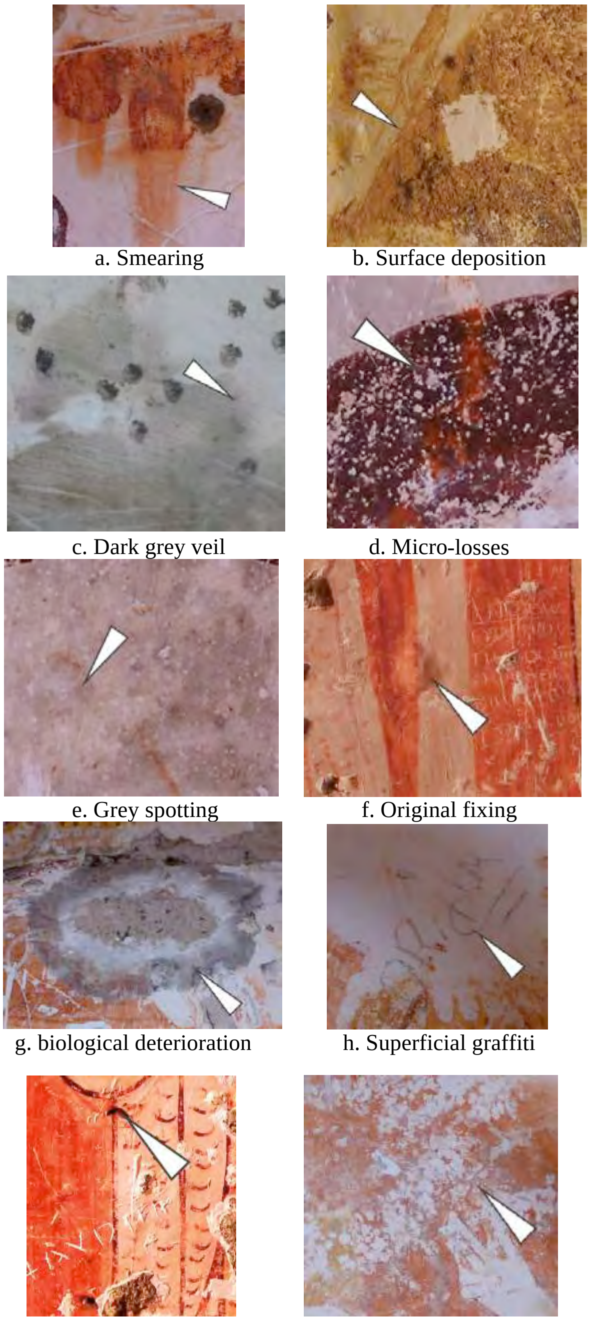
Figure 12. Photos of rock layer deterioration



a. Detachment of lower plaster layer b. Mechanical damage
c. Cracking d. Holes e. Incised graffiti

Figure 13. Photos of plaster layer deterioration

c) Paint layer deterioration is identified by ten items: smearing (Fig. 14-a), surface deposition (Fig. 14-b), dark grey veil (Fig. 14-c), micro-losses (Fig. 14-d), grey spotting (Fig. 14-e), original fixing (Fig. 14-f), biological deterioration (Fig. 14-g), superficial graffiti (Fig. 14-h), nail (Fig. 14-i) and paint loss due to biological activity (Fig. 14-j). Smearing is displacement of the paint layer by mechanical action beyond its original location, seen as a spreading of the paint across the surface of the plaster. Surface deposition is deposition of material on the surface of the painting, such as mud from birds' nests or from later construction in the church such as mud plaster. Dark gray veil is veil extending over the surface of the painting, dark gray in color, somewhat patchy, and of unclear origin. Micro losses are extremely small, rounded losses of the paint layer generally on the order of 0.5-1 mm Ø. Grey spotting is the faint, circular grey spots, 0.5-3 mm Ø, on the surface of the painting. Original fixing is the trace of fixing that may be carried out almost at the same period of mural painting depicted because the colors of this part and around area of that are almost the same. Biological deterioration is discoloration, generally dark gray, of certain areas of painting due to animal inhabitation. Superficial graffiti is the graffiti applied to the surface of the painting using a medium such as paint, ink or graphite. Nail is the part of nail on the paint layer. Paint layer loss due to biological activity is loss of the paint layer due to the former presence of birds' nests primarily which, when separated from the painting surface, removed part of the paint layer.



a. Smearing b. Surface deposition
c. Dark grey veil d. Micro-losses
e. Grey spotting f. Original fixing
g. biological deterioration h. Superficial graffiti
i. Nail j. Paint loss due to biological activity

Figure 14. Photos of paint layer deterioration

After recording the condition of deterioration of a layer, the OHP sheet was scanned in order to make digital mural condition sheets (Fig. 15). In the case that there were too many items to record an OHP sheet, we used more than two OHP sheets to record one layer. Using Adobe Illustrator, we traced the scanned data with a pen tool. The traced deterioration places were divided into different layers by each item of deterioration. Therefore, one mural condition sheet can show the deteriorated places of selected items in one layer. Then, the scale of mural condition sheets was adjusted to 1/10, 1/15, 1/20, 1/25. As we checked the deterioration of each layer of the mural paintings, we produced 39 mural condition sheets and 13 photographs of mural paintings for the digital heritage inventories. Figure 15 is one of the examples of digital heritage inventories, which is the paint layer deterioration of the ceiling in the *nave*.

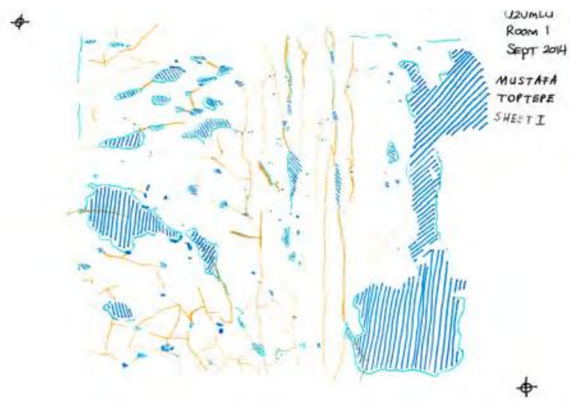


Figure 15. Scanned OHP sheet of plaster deterioration of the ceiling in the *narthex*

Figure 16. An example of digital heritage inventories: Paint layer deterioration of the ceiling in the *nave*.

4. CONCLUSION

In this paper, we suggested a new approach to develop a mural painting database, using normal digital single-lens reflex camera and tripod, measuring tools and standard digital image processing software. Compared with conventional digital documentation, our method can produce high-resolution images at low cost, and with limited time and human resources.

ACKNOWLEDGEMENTS

This work was supported by JSPS KAKENHI Grant-in-Aid for young Scientists (B) Number 24760528.

REFERENCES

Rodley, L., 1985, *Cave Monasteries of Byzantine Cappadocia,* Cambridge University Press, Cambridge: New York.

Thierry, N. et al., 1963. *Nouvelles églises rupestres de Cappadoce, région du Hasan Dagi : new rock-cut churches of Cappadocia,* Klincksieck, Paris.

Taniguchi, Y. (ed.), 2015, *Scientifics on Conservation for Üzümlü Church and its Wall Paintings in Cappadocia, Turkey,* Tsukuba, Japan.

Virtual Archaeology Review, **7**(14): 31-42, 2016
http://dx.doi.org/10.4995/var.2016.4241

Received: October 30, 2015
Accepted: March 7, 2016

DIGITAL NON-METRIC IMAGE-BASED DOCUMENTATION FOR THE PRESERVATION AND RESTORATION OF MURAL PAINTINGS: THE CASE OF THE ÜZÜMLÜ ROCK-HEWN CHURCH, TURKEY

Ryo Higuchi[a,*], Tamaki Suzuki[b], Mina Shibata[c], Yoko Taniguchi[d], Murat Gülyaz[e]

[a] Department of Built Environment, Tokyo Institute of Technology, 4259 Nagatsuta-cho, Midori-ward J3-28 Nasu Lab. in Tokyo Tech, Yokohama, 226-8503, Japan. higuchi.r.ab@m.titech.ac.jp

[b] Asia-Japan Research Center, Kokushikan University, Japan. suzuki.tamaki.0316@gmail.com

[c] National Research Institute for Cultural Properties, Tokyo, Japan. mina.shibata@gmail.com

[d] Faculty of Humanities and Social Sciences, University of Tsukuba, Japan. taniguchi.yoko.fu@u.tsukuba.ac.jp

[e] Nevşehir Museum, Turkey. murategulyaz@gmail.com

Abstract:

Digital photography is a valuable documentation technique for the preservation of a cultural heritage site because high-resolution photography presents both general and detailed views of mural paintings and mural condition in a single image. Advanced digital technology is particularly helpful for preserving and restoring mural paintings given that the painting condition is recorded on high-resolution base maps shows how mural paintings are damaged by environmental stresses, mechanical damages and inappropriate treatments, among others. In addition, photogrammetric software technology is rapidly advancing and being applied to the digital documentation of mural paintings or rock art. Nevertheless, human experience and investigation of mural paintings is indispensable for recording the condition of mural paintings, and this highlights that every step of documentation conducted in situ is desirable. However, images by photogrammetric software do not show sufficient resolution because most normal portable computers used on-site are not usually sufficient. Based on our experience at the Üzümlü Church in Cappadocia, Turkey, we propose a new approach to document mural conditions in situ for preservation and restoration. Our method is based on a comparison of a non-metric but approximate high-resolution image with the actual mural paintings. The method does not require special instruments and enables digital documentation of the mural condition in situ at a low cost, in a short time frame and using minimal human resources.

Key words: digital documentation, photography, image processing, mural painting, rock-hewn church, Cappadocia

1. Introduction

Documentation is one of the principal requirements for studies of mural paintings. The iconographic or stylistic analyses of mural paintings and the preservation and restoration of these are based on data derived from documentation. During the 20th century, the main methods of documentation were analogue photography and drawings. The former was disadvantageous due to the fact that only a limited number of shots could be captured because of the numerous heavy instruments used. Additionally, although some murals are painted over small areas, generally speaking photographing an entire painting is impossible with analogue technology. A typical solution is the mosaicking of photographic shots, but this approach presents high costs, entails long periods and requires many human resources. Depicting mural paintings as illustrations can overcome these problems, but such representations do not accurately reflect the actual work of art given that they are usually mediated by the interpretation of an illustrator.

The recent rapid development of digital photography has expanded the possibilities of documentation primarily through digital documentation. The digital camera has paralleled, and in some cases exceeded, the quality of an analogue camera because it produces detailed high-resolution images (Allen & Triantaphollodou, 2010, pp. 279–280). It is easier to manipulate images on a computer compared to photographs from an analogue camera. Moreover, images on the computer can display various kinds of data satisfying the user's needs, whereas analogue images cannot change their printed form. In addition, photogrammetric software is rapidly being introduced specifically for the documentation of

* Corresponding Author: Ryo Higuchi, higuchi.r.ab@m.titech.ac.jp
DOI: http://dx.doi.org/10.4995/var.2016.4241

mural paintings or rock art (Cerrillo-Cuenca et al., 2014; Cosentino et al., 2011; Domingo et al*.,* 2013; Ke et al*.,* 2008). As Doneus *et al.* (2011) clarifed, digital photogrammetry can provide an accuracy that is similar to mid-range laser scanning devices.

However, digital photogrammetry of mural paintings has an avoidable problem. Comprehensive documentation of the mural condition usually consists of two steps: making images of the mural paintings and depicting the condition of the mural paintings on the images by naked eye investigation, as done by Bayerova *et al.* (2011). Documentation of images is best done at the highest resolution possible, and every phase of digital documentation in situ is desirable. Although digital photography can be used with photographic apparatus, laptop and printer, a high-quality digital photogrammetry system still requires a high-performance computer (Koutsoudis et al*.,* 2014). To address this problem, the National Research Institute for Cultural Properties, Tokyo, implemented several missions for the mural conservation project of the Ajanta Buddhist caves (Yamauchi 2013, 2014).

An important feature of recording the mural condition is the high resolution of the images and the comparability between the image and the actual mural paintings. Metric data are not essential, and we therefore tried to make the entire process of digital documentation based on a non-metric approximate image in situ. We used our recent research project, the Üzümlü Church in Cappadocia, Turkey (a UNESCO World Heritage site since 1985), as an example. This method enabled us to make a high-resolution image that is comparable to or surpasses one taken by a multi-shot camera and in addition has a low cost and uses limited human resources. The digital documentation project was conducted in cooperation with Nevşehir Museum, which manages the cultural heritage sites in Cappadocia. More than 400 rock-hewn churches (Turkish Ministry of Culture and Tourism, 1985, p. 22), including the Üzümlü Church, can be found in Cappadocia (Fig. 1).

Figure 1: West façade of the Üzümlü Church

2. Overview of the Üzümlü Church

2.1. Location and architectural style

On the southern side of Aktepe, which is a rock mountain in the northern part of Cappadocia, are two tourist routes from Ortahisar Village: Red Valley and Rose Valley. The rock-hewn church of Üzümlü (üzümlü is Turkish for 'grape') is located west of the middle cross-point of Red Valley and Rose Valley (Fig. 2). We chose this church as our first target for the preservation and restoration of mural paintings in rock-hewn churches because it exhibits typical Cappadocian deterioration caused by environmental factors, rock composition, seismic activity, and biological and human activities, including vandalism.

The structure of the Üzümlü Church is a solitary cone that is approximately 12 m in the east–west direction and approximately 8 m in the north–south direction. The entrance to the church is a cut on the western façade of the rock. In the past, another entrance was on the southern side; however, this entrance is now filled. Although the church comprises two stories, the upper floor was already inaccessible in the 1960s (Schiemenz, 1969, p. 241). The lower story was composed of five chambers (Fig. 3). It is unknown how these chambers were originally used, but we labelled the three consecutive chambers (from west to east) as 'Narthex', 'Nave' and 'Apse', following the method adopted in previous studies (Rodley, 1985, p.184). Two other chambers on the north side of nave and apse were referred to simply as 'Chamber 1' and 'Chamber 2' (from west to east) because these are extra chambers that may have been carved at a later period. The ceiling heights of these chambers were shorter than those of the other three, and no murals were painted on their walls.

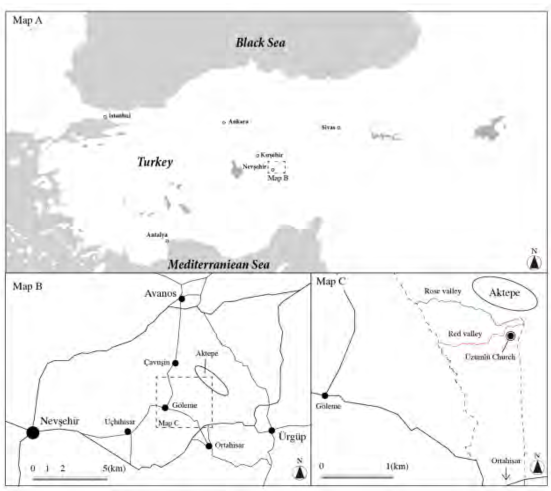


Figure 2: Map of Turkey (A) and the study site (B & C).

The structures of the three main chambers are as follows: Narthex is an imperfect rectangle that spans 1.7 m in the east–west direction and 1.8 m in the north–south direction; Nave is an imperfect rectangle that spans 2.6 m in the east–west direction and 2.4 m in the north–south direction; and Apse is an ellipse with a minor axis of 1.8 m in the east–west direction and a major axis of 2.4 m in the north–south direction. Narthex and Nave are covered by a barrel vault, whereas Apse is covered by a dome. Chamber 1 and Chamber 2 are cuboid structures. Compared with the exposed rock surface of the main chambers, those of Chamber 1 and Chamber 2 are roughly excavated. This suggests that the former three chambers and the latter two were constructed using different techniques. Given that different excavation techniques were used for the main and extra chambers and only the main chambers have mural paintings, Chamber 1 and Chamber 2 appear to have never been painted.

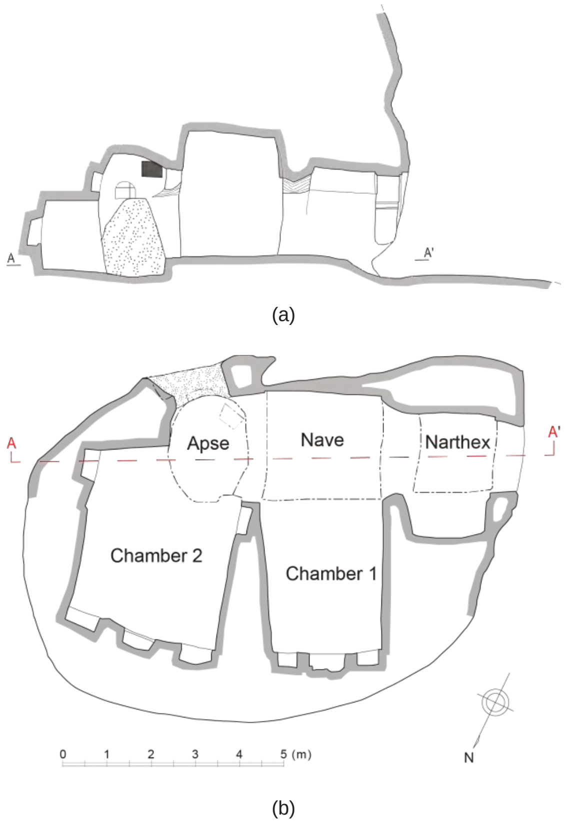


Figure 3: The drawings of the Üzümlü Church: a) East-west (AA') section; b) Ground floor plan.

2.2. Dating of mural paintings

Although the Üzümlü Church was known at the time of Jerphanion (1942), who first systematically studied the mural paintings in Cappadocia, he paid minimal attention to this church. Schiemenz (1969) then identified the Üzümlü Church as the chapel of Niketas the Stylite, who is depicted in the mural painting on the east wall of Nave. Little information is available and known about the history of the church due to lack of historical records that can sufficiently shed light on this issue have been found. Absolute dating methods, such as radiocarbon dating, are ineffective because mural paintings do not contain botanical materials, such as thatch. Previous absolute dating is therefore based on iconographic characteristics.

Jerphanion dated the church as going back to the iconoclast period, that is, the 8th to 9th centuries (Jerphanion, 1942, p.404). Schiemenz (1969), who was the first scholar to treat the Üzümlü Church as a primary research object, dated the church's construction to be in the 9th century after 863 A.D. His dating of the church was based on his deduction that the saint painted on the east wall of Narthex, which has now collapsed and is nearly invisible but was visible at that time, is Euthymios the Younger, who died in 863. He interpreted a three-line inscription 'ΠΘ/ΥΜ/ΗΟC', which is on the east side of the saint, as ΕΥΘΥΜΙΟC (this is Euthymios in Greek orthography) based on contemporary Byzantine Greek writing and phonetic manners; he did not discuss which Euthymios this referred to (Schiemenz, 1969, p. 242). Conversely, Thierry (1981, p. 507) dated the mural paintings to a slightly earlier period, specifically the late 7th century or early 8th century A.D., on the basis of iconographic details, style of ornamentation and epigraphy. This argument remains inconclusive to this day. For example, Alioglu *et al.* (2012) assumed the church to be from the 10th century by its decoration programme, but Pelosi *et al.* (2012) supposed 6–7th century by its stylistic and technical characteristics. We believe, similar to Rodley (1985: 189), that the saint on the east wall of Narthex is not Euthymios the Younger but possibly Euthymios the Great (ca. 377–473). Therefore, Schiemenz's dating, which did not consider the earlier Euthymios, cannot be validated, but the church seems to have been built at least during the 9th century A.D. This means it is one of the earliest phase churches in Cappadocia and one of the few representatives of the iconoclast period of Byzantine churches.

2.3. Previous documentation projects

The comprehensive documentation of the rock-hewn churches in Cappadocia was first undertaken by Jerphanion (1942) from the 1920s to the 1940s. However, he regarded the Üzümlü Church as having minimal importance. The first person to publish photographs on the mural paintings of the church was Budde (1958, fig 34), and a number of researchers, including Schiemenz (1969), Thierry (1963, 1981) and Rodley (1985), subsequently recorded and analysed the iconographic schemes of the paintings. The preliminary measurement of the rock-hewn churches around Cappadocia valley was conducted by a research team led by Dr. Masaru Maeno, a professor affiliated with the Tokyo University of the Arts in the early 1970s; during this period, (unpublished) architectural drawings of the Üzümlü Church were made. Since the 1980s, no further documentation has been undertaken, and the mural paintings have been gradually damaged by physical, environmental and biological elements.

2.4. Location of the mural paintings

The mural paintings that were depicted until the 9th century can be seen on the following surfaces of the church: the intrados of the arched entrance, the west, south and east walls and the north arch and barrel-vaulted ceiling in Narthex; the west, south and east walls and the barrel-vaulted ceiling in Nave; the southeast wall and the domed ceiling in Apse; and the transverse arch between Narthex and Apse. All those surfaces were depicted without flattening, i.e. murals are also on the concave point. Although we assume that the intrados of the transverse arch between Narthex and Nave may have been covered with paintings, we cannot identify any remnants of the murals because the lower part of this transverse arch collapsed, and its remains were removed.

3. Documentation methodology

In this project, our aim was to provide a continuous operation of digital documentation for preservation and restoration of mural paintings in situ. Even though we made inner and outer figures of the rock by three-dimensional (3D) laser scanner, the results showed that time and effort were needed for metric accuracy; in addition, the laser scanner was difficult to operate for the whole documentation process in situ. We therefore prioritised the high resolution imagery over metric accuracy because murals were depicted on a highly distorted surface. We used Adobe Photoshop® software due to its easeness for image processing and its availability. These are very important factors that efficiently and effectively advance the documentation of a large number of Cappadocian churches.

Since the murals were painted on large surfaces of the walls, the vaulted ceiling and dome and the small inner space, capturing entire images in a single shot was impossible. We solved this problem by photographing the surfaces in several vertical and horizontal shots and digitally merging the pieces into a single high-resolution image with Adobe Photoshop. Although morphing of the images was required in many cases, approximate images that were comparable to the actual mural paintings were sufficient as a base map, which was the photograph that depicted the current condition of the mural paintings. Details regarding mural condition were recorded on the overhead projector transparent sheets (hereinafter OHP sheet) on the printed base map. After the OHP sheets were digitalised, the condition of the mural paintings was illustrated on the high-resolution base map by Adobe Illustrator®. The documentation generally proceeded in four steps:

1) Taking the shots of the mural paintings;

2) Measurement of the cave and location of the paintings to transform those to be comparable to the actual mural paintings;

3) Image processing: merging photographs into a single high-resolution image, warping the images and creating the base map;

4) Condition assessment and recording.

3.1. Instruments/programmes

We used the following instruments/programmes in our research:

- Digital single-lens reflex (SLR) camera (Canon EOS 60D).
- Wide-angle lens (Canon EF-S10-22mm F 3.5-4.5 USM).
- Tripod (Manfrotto 055 CXPRO3JP).
- Laptop computer (Mac OS 10.9, 4-core Intel i7 processor at 2.30 Ghz, 8 GB of RAM and AMD Radeon HD 6750M 1 GB GDDR5 SDRAM).
- Laser digital distance meter (Leica Disto D210).
- Measuring tape.
- Adobe Photoshop CS6 and Adobe Illustrator CS6.

3.2. Photography of the mural paintings

The mural paintings were photographed by mounting the camera on a tripod horizontally and almost parallel to each mural; then, the distance between the lens and a mural painting was measured by the digital distance meter. As this method was not intended to take metric data, the distance did not require strict accuracy and permited errors. Depending on the dimensions of the mural painting, several shots were taken. Even when the camera was moved horizontally or vertically, the distance between the lens and the painting was kept constant, and we ensured that each shot overlapped with the photographs of adjacent areas. Although it depends on the surroundings, a 10% overlap was usually enough. This approach was designed to guarantee successful digital merging. Figure 4 is an example of a merged photograph. In this example, four photos (two rows of two shots) were taken of the wall painting on the south wall in Nave.

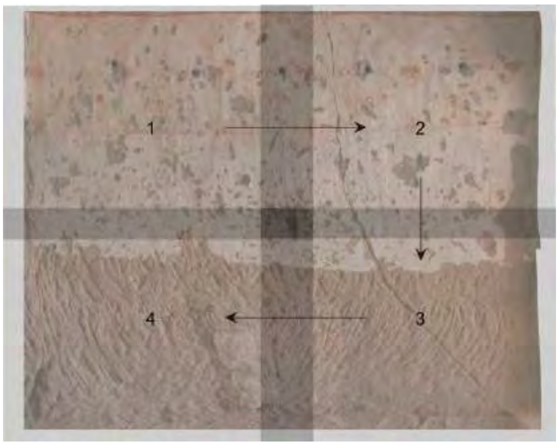


Figure 4: Concept of image merging (south wall in Nave).

3.3. Measurement

The measurement of the cave was based on the architectural plan created by Prof. Maeno in the 1970s because no digital measurement data on this church exist. Additional measurements of the distance between some important figures and features were conducted to morph the merged image being compared to the actual mural painting. First, the heights and widths of the mural paintings were measured using either a digital distance meter or a measuring tape. The distance between distinctive figures, such as saints, was also measured. When we measured curved surfaces, such as the barrel vault or dome, we also measured the inner radius of these to create an approximate planar image from the curved surfaces (Fig. 5).

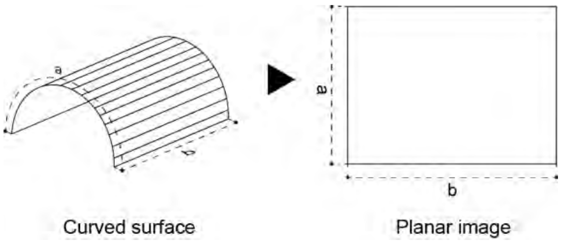


Figure 5: Conversion from curved surface to planar image.

3.4. Image processing

The photographs were merged into a single high-resolution image using the 'photomerge' function of Adobe Photoshop CS6. The merged image was manually morphed using the 'warp' function on the basis of the measurement data and resized to an approximate scale. These images were then imported into Adobe Illustrator CS6 to document the mural condition. We used the following merging and morphing (photomerging) procedure within Adobe Photoshop CS6:

1) Read files (Fig. 6): Read the files to merge. Then select <Automate> in the <File> menu. Click <Photomerge> and select <Add Open Files>.

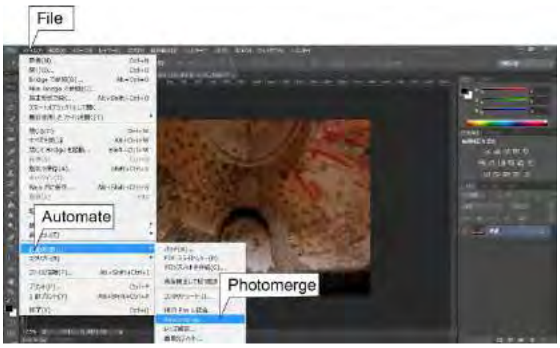


Figure 6: 'Photomerge' on the menu.

2) Merge files (Fig. 7): Check <Blend Images Together>. Also check <Vignette Removal> and <Geometric Distortion Correction> to reduce morphing time after merging as we do not intend to make a metric image. Click <OK>.

3) Check the edge of each of the images (Fig. 8): Upon correct execution of the preceding steps, we checked each end of the reading photographs.If it was wrong, morphed images would not fit each other (such as in Fig 8b). Lack of overlapping images usually induced this error.

4) Combine the layers: Select <Layer> menu and click <Merge Visible>.

Figure 7: Choosing files to combine.

(a) (b)

Figure 8: Photomerge examples: a) Successful implementation; b) failed photo combination.

5) Set the guidelines for revision: Select <View> menu and click <New Guide...>. Move the guides on the basis of the measured sites, as in Figure 9.

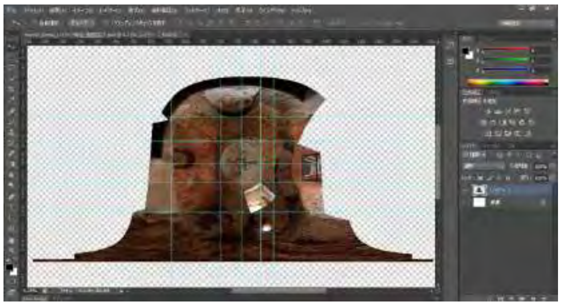


Figure 9: Setting the guidelines.

6) Revise the photograph (Fig. 10): Select <Edit> menu and click <Warp> from the <Transform> menu. Revise the distorted areas of the merged photographs and adjust them to fit the approximate scale.

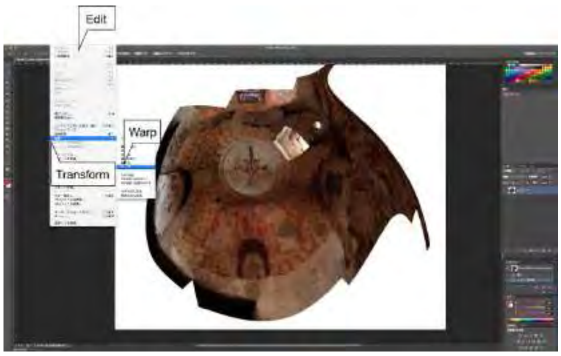


Figure 10: Choosing the 'Warp' tool.

7) Apply the transformation (Fig. 11): After completing the transformation, click <Apply> in the window <'Apply the transform?'>

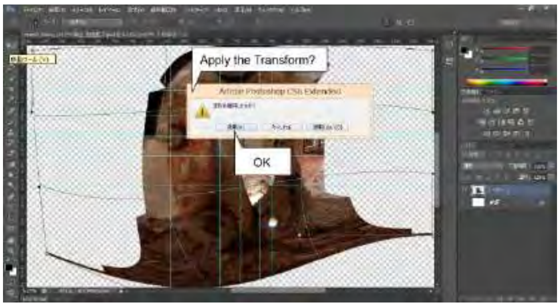


Figure 11: Applying the 'warp' tool.

Figure 12 is an example of the image mosaic of the dome, which was merged from five images. Following this method, we created 13 base maps with resolutions of at least 300 ppi.

3.5. Assessment and documentation of the mural condition

After creating the base maps, the condition of the mural paintings was documented on OHP sheets on the printed base maps. As every site has a different component, specific conditions and unique problems with the mural paintings, naked eye investigation was necessary to preserve and restore the art effectively.

The mural paintings in the Üzümlü Church are composed of three layers: rock, plaster and paint. We recorded the condition of each layer of the mural painting as a separate mural condition sheet. We identified deteriorating items in each layer by naked eye investigation. The following sections present detailed explanations of this process.

3.5.1. Rock layer deterioration

Rock layer deterioration was identified on the basis of four factors: biological activity (Fig. 13a), deposition of dark material (Fig. 13b), structural cracks (Fig. 13c) and spalling (Fig. 13d). Biological activity was evident by animal (e.g. spiders, other insects) inhabitation on a rock. Deposition of dark material pertains to a deposit of dark brown or blackish material on the surface of a rock. Structural cracks are large cracks that run through the body of a rock and are caused by faulting. Spalling refers to the small-scale detachment of a rock parallel to the surface of the rock.

3.5.2. Plaster layer deterioration

Plaster layer deterioration was identified on the basis of five factors: detachment of the lower plaster layer (Fig. 13a), mechanical damage (Fig. 13b), cracking (Fig. 13c), holes (Fig. 13d) and incised graffiti (Fig. 13e). Detachment of the lower plaster layer is the loss of adhesion between the lower plaster layer and a rock substrate, as assessed by visual evidence alone. Mechanical damage refers to the rupture in painting stratigraphy caused by human or animal activity. This type of damage causes a variety of other harmful effects, such as loss of entire stratigraphy; revealing an underlying rock substrate; loss of the paint layer, ground and part of the lower plaster layer, thus leaving the interior of the lower plaster layer exposed; loss of only the upper plaster ground, which leaves the surface of the lower plaster layer intact; and deformation of painting stratigraphy, which otherwise remains intact. Cracking occurs on a plaster layer most often because of the cracking of the rock structure and mechanical damage, although other factors may cause such damage. Holes are small highly circular holes of approximately 5 mm in diameter; these penetrate into a plaster layer but generally do not reach a substrate. Incised graffiti are inscriptions and drawings inscribed onto the surface of a painting, thus affecting the paint, ground and plaster layers.

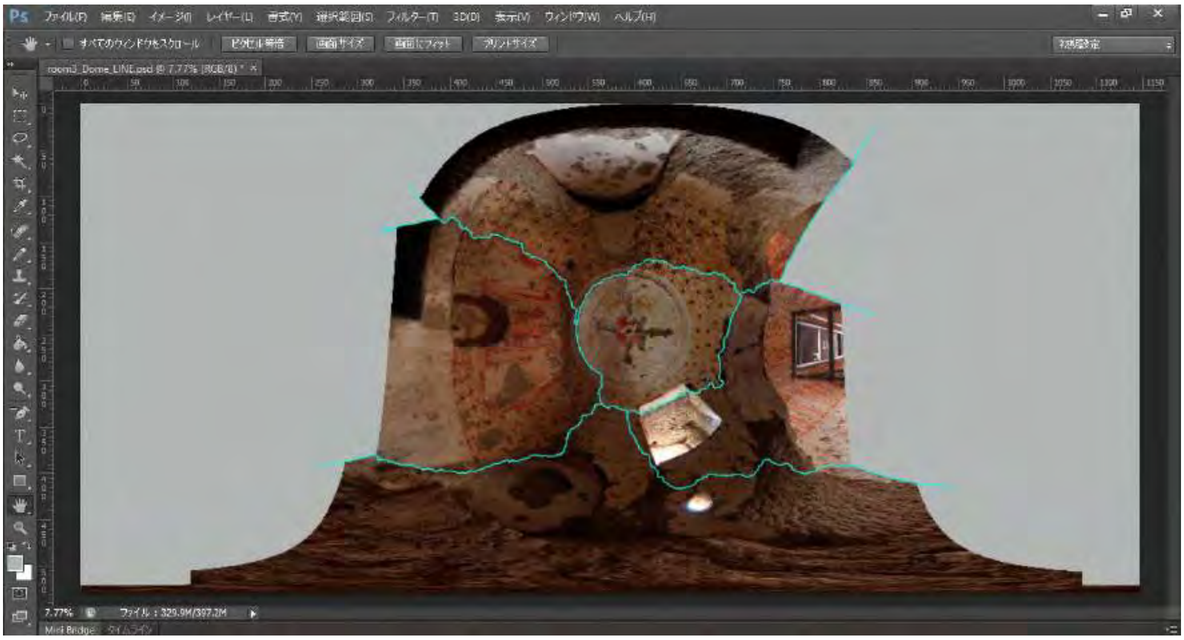
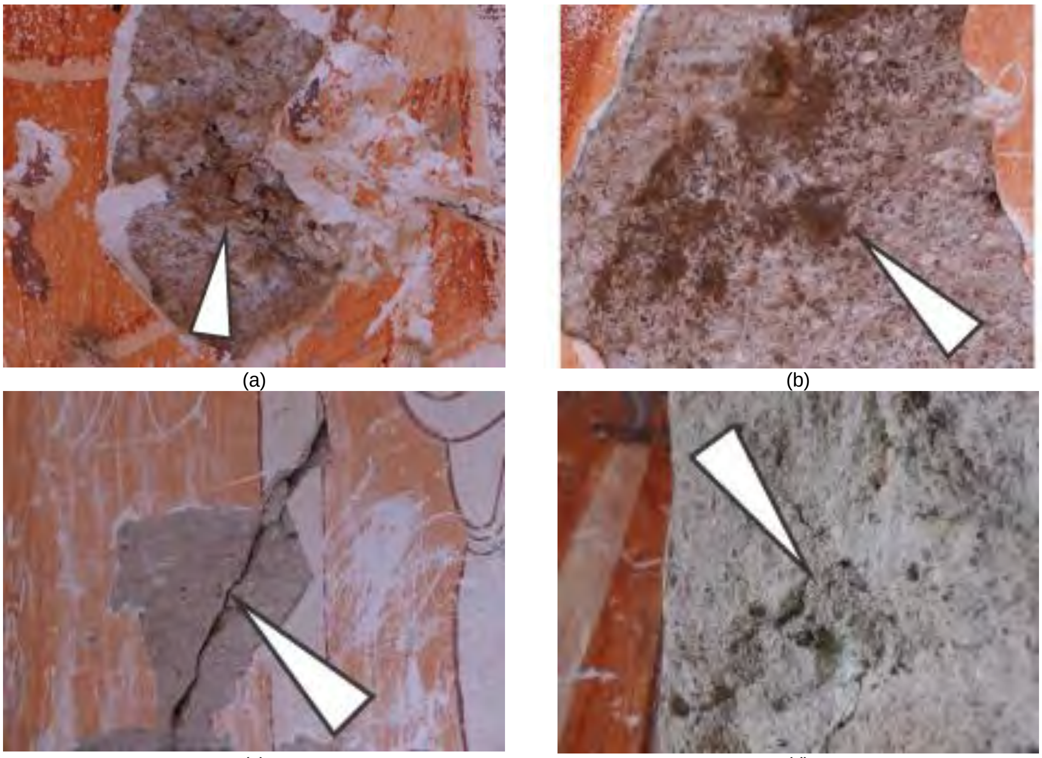
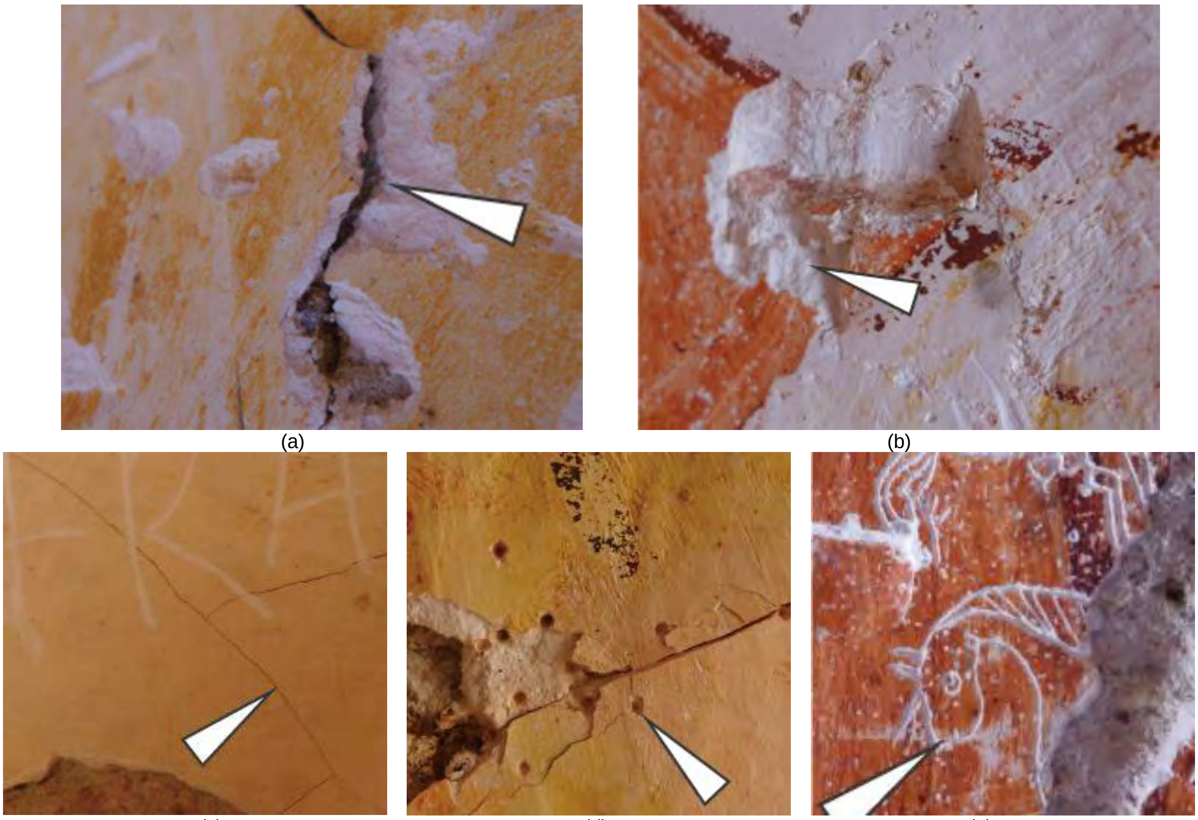


Figure 12: Completed image mosaic from five merged images



(a) (b) (c) (d)

Figure 13: Photos of rock layer deterioration: a) Biological activity; b) Deposition of dark material; c) Structural cracks; d) Spalling.



(a) (b) (c) (d) (e)

Figure 14: Photos of plaster layer deterioration: a) Detachment of lower plaster layer; b) Mechanical damage; c) Cracking; d) Holes; e) Incised graffiti.

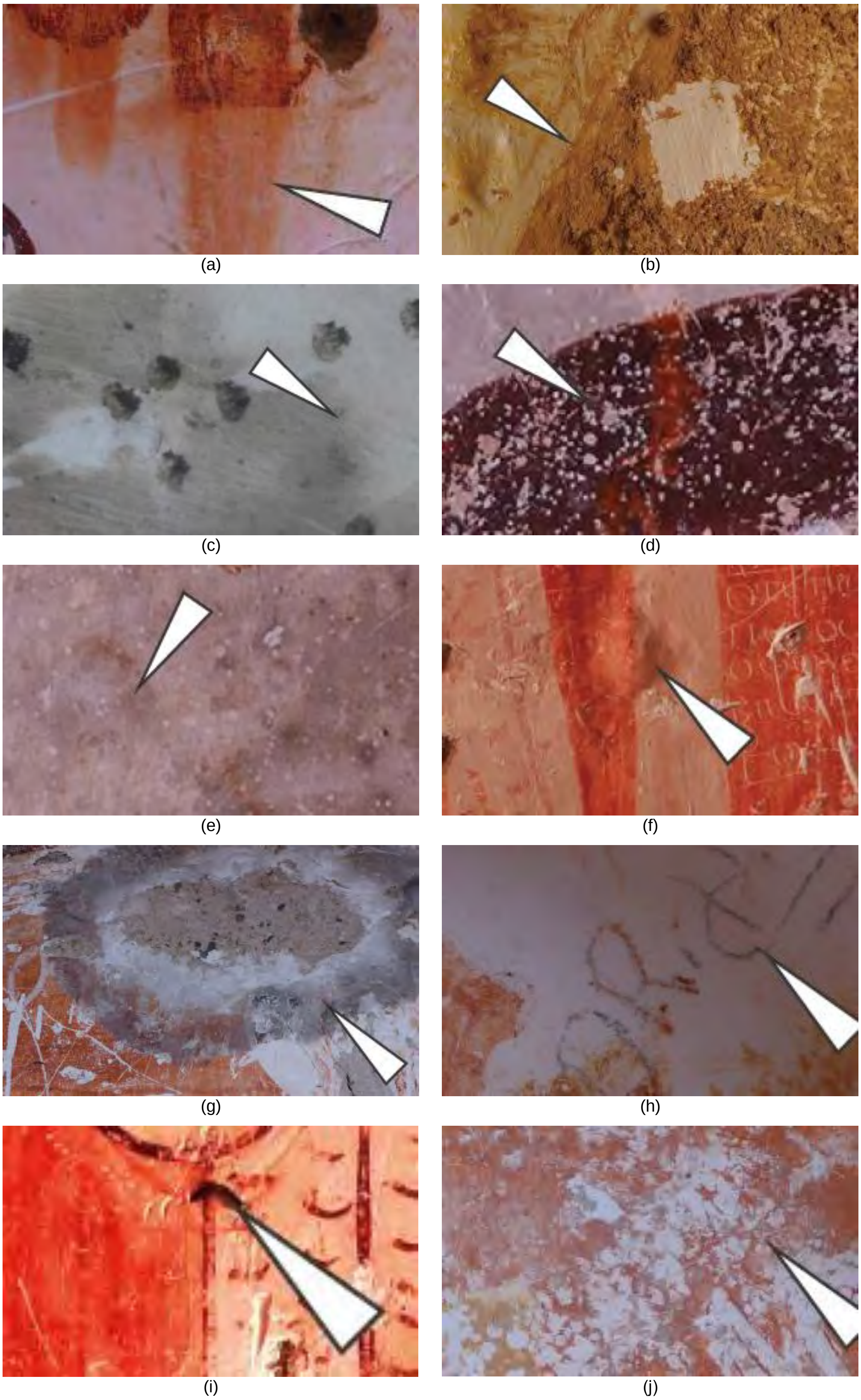


Figure 15: Photographs of paint layer deterioration: a) Smearing; b) Surface deposition; c) Dark grey veiling; d) Micro-losses; e) Grey spotting; f) Original fixing; g) Biological deterioration; h) Superficial graffiti; i) Nail; j) Paint loss due to biological activity.

3.5.3. Paint layer deterioration

Paint layer deterioration was identified on the basis of 10 factors: smearing (Fig. 14a), surface deposition (Fig. 14b), dark grey veiling (Fig. 14c), micro-losses (Fig. 14d), grey spotting (Fig. 14e), original fixing (Fig. 14f), biological deterioration (Fig. 14g), superficial graffiti (Fig. 14h), nail (Fig. 14i) and paint loss due to biological activity (Fig. 14j). Smearing is the mechanically induced displacement of a paint layer beyond its original location, seen as a spreading of paint across a plaster surface. Surface deposition pertains to the deposition of material on the surface of a painting; examples of materials are mud from birds' nests or from later construction in churches (mud plaster). Dark grey veiling is the appearance of a veil that extends over the surface of a painting. The veil is dark grey, somewhat patchy and of unclear origin. Micro-losses are the extremely small rounded losses of a paint layer generally on the order of 0.5–1 mm diameter. Grey spotting is the occurrence of faint circular grey spots (0.5–3 mm diameter) on the surface of a painting. Original fixing refers to traces of fixing that may have been carried out almost at the same period of mural painting depiction because the colours characterising this section and its surrounding area are almost the same. Biological deterioration is the dark grey discoloration of certain areas of a painting and is caused by animal inhabitation. Superficial graffiti refers to graffiti applied to the surface of a painting using a medium, such as paint, ink or graphite. A nail is the part of a nail on a paint layer. Paint layer loss due to biological activity is the loss of a paint layer because of the presence of birds' nests. When materials from the nests are separated from a painting surface, part of the paint layer is removed.

After the state of layer deterioration was documented, an OHP sheet was scanned to create a digital mural condition sheet (Fig. 16). In cases where the number of items was too large for these to be recorded on an OHP sheet, we used more than two OHP sheets to document one layer. Using Adobe Illustrator, we traced the scanned data with a pen tool. The traced deterioration sites were divided into different layers according to each item of deterioration. Therefore, each mural condition sheet can show the deterioration sites of selected items when a pdf file is created and viewed via pdf viewer software. The approximate scale of the mural condition sheets was then adjusted to 1/10, 1/15, 1/20 and 1/25. As we checked the deterioration of each layer of the mural paintings, we produced 39 mural condition sheets and 13 image mosaics of the mural paintings for the digital heritage inventories. An example is Fig. 17, which shows the paint layer deterioration of the ceiling in nave. All the digital inventories of the printed versions (Taniguchi 2015) that we created are available for viewing in Appendix 3 at the following webpage address: http://rcwasia.hass.tsukuba.ac.jp/kaken/contents/content%20images/0_20150723_uzumlu_2014_final_s.pdf.

4. Comparison to previous methods

With the above-described method, we successfully documented the condition of the mural paintings in Üzümlü Church with non-metric images. Although conducting all steps of documentation in situ is desirable for efficient documentation of the mural condition, it is still impossible to create high-resolution images by photogrammetry without high-performance computers,

Figure 16: Scanned OHP sheet of plaster deterioration on the ceiling in narthex.

which are impossible to bring in situ. For instance, Koutsoudis *et al*. (2014) used a computer system equipped with an 8-core Intel i7 processor at 3.50 Ghz, 32 GB of RAM and a NVidia Geforce GTX580 3 GB RAM graphics card running Microsoft Windows 7 64-bit for making a 3D model by Agisoft PhotoScan (Koutsoudis et al., 2014), which is one of the major commercial photogrammetric software. This 3D model would be possible to use as a base map due to its high level of detail; however, the process requires specifications that are too high for laptop computers (PhotoScan Agisoft, 2016). For example, the mural conservation project by the National Research Institute for Cultural Properties, Tokyo, divided the documentation process into work in situ and tasks that require high-performance computers in Japan and conducted each work and task alternately. They required several missions on site (Yamauchi 2013, 2014). Additionally, they used orthoprojection images for recording, which are difficult to use in Cappadocian churches, including Üzümlü Church, because usually murals are depicted on distorted and sometimes concave surfaces.

We do not deny the importance and effectiveness of using photogrammetry in the preservation and restoration of mural paintings. However, taking into account that naked eye investigation is indispensable for the preservation and restoration of mural paintings, this paper reports on a coherent operation of documenting mural paintings in situ. We agree existing problems can be solved by developing specific computers and photogrammetric software. However, we show the usefulness of digital documentation based on non-metric images at the present time.

In addition to our project objective carried out in the Üzümlü Church, the Nevşehir Museum is responsible for managing cultural heritage sites in Cappadocia. However, the large number of these sites is beyond the current management system's capability. Meanwhile, the tourist volume continues to increase, exerting progressive stress on each site. In such situations, as Tsumura (2006) pointed out, the idea is to transform the concept of mural painting preservation from stopping deterioration regardless of how unreasonable this may be to recording the deterioration itself. Our method may facilitate future preservation and restoration projects in the region given that it enables the documentation of the site conditions and requires limited human resources and instruments.

Figure 17: Example of digital image-based documentation of paint layer deterioration on the ceiling in nave

5. Conclusion

This paper summarises the procedure of digital non-metric image-based documentation of mural paintings in Üzümlü Church as a demonstration of our proposed approach. Each of the processes, the photographing of the mural paintings, the image processing of the shots and the description of mural condition was accomplished with the help of simple tools, such as a typical digital SLR camera, tripod, measuring tools, standard laptop computer and Adobe software. The images are non-metric and approximate but can be compared with actual mural paintings; therefore, the approach enables digital documentation for preservation and restoration of mural paintings in situ. This approach is expected to contribute to further documenting preservation and restoration projects in Cappadocia and elsewhere. Compared with conventional digital documentation and despite being non-metric, our method can produce high-resolution images at low cost, in short time frames and with limited human resources.

It is worth noticing that our method is an approximate one and does not address the metric accuracy problem. As we stated, we regard this method as a transitional one until laptop computers can run the photogrammetric software in situ. However, in a next step we should compare our images with accurate metric images undertaken by photogrammetry and clarify their accuracy for effective transitioning from ours to a forthcoming method.

Acknowledgement

This work was supported by the JSPS KAKENHI Grant-in-Aid for young Scientists (B) under Grant Number 24760528; and the JSPS KAKENHI Grant-in-Aid for Scientific Research on Innovative Areas under Grant Number 24101014.

References

Alioglu, E. F., Erkan, Y. K., Alper, M. & Alper, B. (2012). Rock Carved Spaces of Ortahisar. In Crescenzi, C., & Caprara, R. (Eds.) *The Rupestrian Settlements in the Circum-Mediterranean Area* (pp.233–244). Retrieved from https://flore.unifi.it/retrieve/handle/2158/781838/24752/volumeRicerca%202012-11-15.pdf

Allen, E. & Triantaphillidou, S. (Eds.). (2010). *The Manual of Photography,* 10th ed., Oxford: Focal Press.

Bayerova, C. & Gruber, M. (2011). Graphic documentation: a cool presentation tool or a helpful assistant? Case study Nako, North India. In. Pavelka, K. (Ed.), *Proceedings of the XXIIIrd CIPA Symposium*, Prague, Czech Republic: CIPA, ISPRS, Czech Technical University in Prague and Czech Society for Photogrammetry and Remote Sensing. Retrieved from http://cipa.icomos.org/fileadmin/template/doc/PRAGUE/019.pdf

Budde, L. (1958). *Göreme, Höhlenkirchen in Kappadokien,* Düsseldolf: Schwann.

Cerrillo-Cuenca, E., Ortiz-Coder, P. & Martínez-del-Pozo, J.Á. (2014). Computer vision methods and rock art: towards a digital detection of pigments. *Archaeological and Anthropological Sciences*, *6*(3), 227–239. doi:10.1007/s12520-013-0147-2

Cosentino, A., Stout, S., & Scandurra, C. (2015). Innovative Imaging Techniques for Examination and Documentation of Mural Paintings and Historical Graffiti in the Catacombs of San Giovanni, Syracuse. *International Journal of Conservation Science*, *6*(1). 23–34. Retrieved from http://www.ijcs.uaic.ro/public/IJCS-15-03_Cosentino.pdf

Domingo, I., Villaverde, V., López-Montalvo, E., Lerma, J. L., & Cabrelles, M. (2013). Latest Developments in Rock Art Recording: Towards an Integral Documentation of Levantine Rock Art Sites Combining 2D and 3D Recording Techniques. *Journal of Archaeological Science*, *40*(4), 1879–1889. doi:10.1016/j.jas.2012.11.024

Doneus, M., Verhoeven, G., Fera, M., Briese, C., Kucera, M., & Neubauer, W. (2011). From Deposit to Point Cloud – A Study of Low-cost Computer Vision Approaches for the Straightforward Documentation of Archaeological Excavations. *Geoinformatics FCE CTU*, *6*, 81–88. doi:10.14311/gi.6.11

Jerphanion, G. D. (1942). *Une nouvelle province de l'art byzantin: les églises rupestres de Cappadoce, II*, Paris: P. Geuthner.

Ke, C.Q., Feng, .X.Z., Du, J. K., and Tang, G.D. (2008). 3D Information Restoration of the Digital Images of Dunhuang Mural Paintings. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXVII*(B5), 987–992. Retrieved from http://www.isprs.org/proceedings/XXXVII/congress/5_pdf/171.pdf

Koutsoudis, A., Vidmar, B., Ioannakis, G., Arnaoutoglou, F., Pavlidis, G. & Chamzas, C. (2014). Multi-image 3D reconstruction data evaluation. *Journal of Cultural Heritage*, *15*(1), 73–79. doi:10.1016/j.culher.2012.12.003

Pelosi, C., Agresti, G., Andaloro, M., Baraldi, P., Pogliani, P. & Santamaria, U. (2012). The rock hewn wall paintings in Cappadocia (Turkey). Characterization of the constituent materials and a chronological overview. *e-Preservation Science,* 10, 99–108.

PhotoScan Agisoft, 2016, http://www.agisoft.com/, (accessed 7 January 2016).

Rodley, L. (1985) *Cave Monasteries of Byzantine Cappadocia,* New York: Cambridge University Press.

Schiemenz, G. P. (1969). Die Kapelle des Styliten Niketas in den Weinbergen von Ortahisar, *Jahrbuch der Österreichischen Byzantinistik, 18*, 239–258.

Thierry, N., & Thierry, M. (1963). *Nouvelles églises rupestres de Cappadoce: région du Hasan Dağı: new rock-cut churches of Cappadocia*, Paris: Klincksieck.

Thierry, N. (1981). Les enseignements historiques de l'archéologie cappadocienne, *Travaux et Mémoires,* **8**, 501–519.

Taniguchi, Y. (ed.). (2015). *Scientifics on Conservation for Üzümlü Church and its Wall Paintings in Cappadocia, Turkey,* Tsukuba: University of Tsukuba.

Turkish Ministry of Culture and Tourism (1983). *Structural Conservation of Göreme: Göreme Land of Fairy Chimneys,* Ankara: UNESCO.

Tsumura, M. (2006). DCM Archiving of Cultural Properties for Assessment of the Collapsing - Perspective from Digitizing with CAD to Archiving with 4D-GIS - *The Computers and the Humanities Symposium 2006,* 95–100.

Yamauchi, K. (ed.). (2013). *Japanese Research for the Conservation of Ajanta Paintings: Conservation of the mural paintings of the Bamiyan Buddhist caves*, Tokyo: National Research Institute for Cultural Properties, Tokyo.

Yamauchi, K. (ed.). (2014). *Japanese Research for the Conservation of Ajanta Paintings: Conservation and Scientific Investigation of the Paintings of Ajanta Caves 2 and 9*, Tokyo: National Research Institute for Cultural Properties, Tokyo.

吉岡瑞穂, 伊庭千恵美, 谷口陽子, 小泉圭吾, 渡辺晋生, 朴春澤, 佐野勝彦：カッパドキア岩窟教会外壁の劣化抑制に関する研究－現地の環境計測による劣化要因の推定－, 日本文化財科学会第33回大会研究発表要旨集, pp.260-261, 2016.6（転載）

カッパドキア岩窟教会外壁の劣化抑制に関する研究
－現地の環境計測による劣化要因の推定－
Environmental monitoring for suppression of deterioration of a rock-hewn church, Cappadocia

吉岡瑞穂（京都大学）、◯伊庭千恵美（同左）、谷口陽子（筑波大学）、小泉圭吾（大阪大学）、
渡辺晋生（三重大学）、朴春澤（ハイテック(株)）、佐野勝彦（(株)ディアンドディ）
Mizuho YOSHIOKA, ◯Chiemi IBA (Kyoto Univ.), Yoko TANIGUCHI (Univ. of Tsukuba),
Keigo KOIZUMI (Osaka Univ.), Kunio WARANABE (Mie Univ.), Chunze PIAO (Hytec Inc.),
Katsuhiko SANO (D&D Corp.)

1. 背景・目的

カッパドキアはトルコ中央部に位置する奇岩地帯であり、凝灰岩を掘削して造られた岩窟教会が多数現存する。本研究で対象としているウズムル教会（聖ニキタス教会、7 世紀末に造成と推定）もその岩窟教会の 1 つであり、内面に壁画を有している。図 1 に教会外観を示す。同教会においては、表面の剥離・粉化や亀裂などといった凝灰岩壁体の劣化が顕著であり、また壁画にも亀裂や剥離などの損傷が及んでいる。教会外壁に関しては凍害などの水分による劣化が激しいと考えられており、その抑制策として壁体外気側表面に撥水剤を塗布する手法が検討されている。しかし、地下水の吸い上げなど表面以外から壁体へ浸入した水分が撥水剤により移動を阻害され、壁体内部に蓄積しその場で凍結するなど、現在とは異なる場所での劣化を誘発するおそれがある。そのため壁体への水分供給経路を十分に検討する必要がある。

本報では、現地周辺の気象環境と土壌水分量のモニタリング、および現地の気象データを用いた熱水分移動解析を行い、壁体への水分供給源と外壁の水分劣化の主要因の推定を行った。

2. 計測概要

周辺環境から壁体へと供給される水分の経路としては、地下水の吸い上げ、降雨、そして壁体表面での結露が考えられる。これらを検討するため、教会周辺の気象と教会壁体の地下部分の水分状態を測定した。図 2、3 に気象ステーションと温湿度ロガー、および土壌ポテンシャル計、土壌含水率計の設置個所を示す。

図 1　教会外観

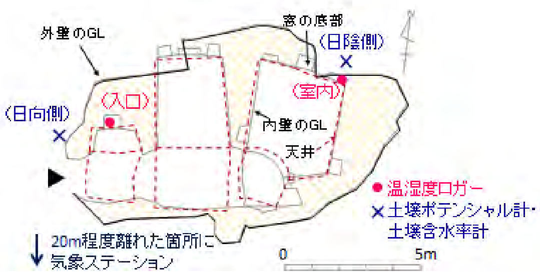


図 2　教会平面図と機器設置個所

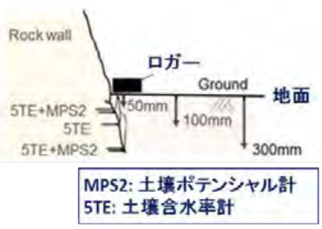


図 3　機器設置深さ

3. 計測結果

i) 地下水の吸い上げ

図 4 に 2014 年 9 月から 2015 年 4 月における日向・日陰両側の教会壁体地下 50mm、300mm 地点の水分ポテンシャルを示す。9 月は両側で 50mm の方が 300mm よりも水分ポテンシャルが低い。その後 11 月には 50mm の方が高くなり、12 月を過ぎると深さ方向での違いはほぼ見られない。この結果より、地中の水分は秋冬期にかけて、気温が高い9月を除き概ね下方に移動すると考えられる。また壁体の不飽和透水係数[1]を考慮して 9 月の吸い上げ量を求めると、その値は最大でも 2.0×10^{-16} kg/m^{2}s 程度の非常に小さな値となる。よって地盤から壁体への水分供給は非常に小さく、外壁撥水処理を行った場合でも壁体内に水分が蓄積することはほぼないと考えられる。

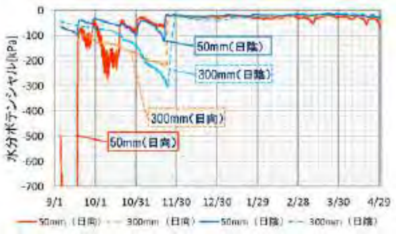


図 4　水分ポテンシャル変動

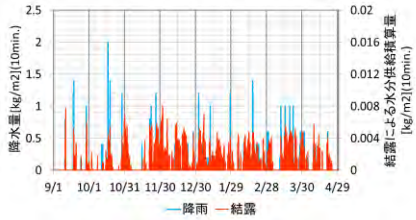


図 5　降雨・結露による水分供給量

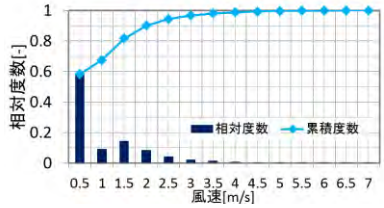


図 6　降雨時の風速の相対度数分布

ii) 降雨・結露

教会外壁の表面温度は機器による測定を行っていない。そこで日射を考慮した外壁の三相系一次元熱水分解析[2]を行い、北向き垂直外壁の表面温度および表面飽和絶対湿度から結露による水分供給量を求めた。結露水の流下は考慮していない。図 5 に外気側表面での結露による水分供給量（解析値）と降雨量（実測値）の 10 分積算値の経時変化を示す。期間中の積算供給水分量では降雨が結露による供給の約 9.8 倍であったが、供給時間を比較すると結露による供給が降雨の約 14 倍となった。また結露による供給は夜間（特に日の出前）において顕著であった。これは日没後から日の出前においては壁体の夜間放射によって壁体表面温度が外気温を下回るためである。室内側では結露による水分供給は見られなかった。

i) ii)より、壁体への水分供給経路は主に外気側表面を通じたものであることがわかる。これは壁体の外気側表面において剥離･粉化などの劣化が激しいという現地での観察結果と矛盾しない。供給量のみを見れば降雨が水分の主供給源であると考えられるが､結露による供給は期間が長く、また凍害が生じやすい夜間に発生するため、壁体の劣化を考えるうえで無視できない。

また図 6 に降雨時の風速の相対度数分布、累積度数分布を示す。降雨時の 90%の時間で風速はほぼ 2m/s 以下と小さいことから､雨滴が壁体に衝突する際の風の影響は小さいと考えられる。

以上の結果をもとに、外気側表面への撥水剤処理が有効であると判断し、現地で試験的な塗布処置を開始した。

4. まとめ

本報では現地周辺の気象環境のモニタリングおよび土壌水分量の計測と､その結果を用いた壁体の一次元熱水分解析を行い､壁体への水分供給源および外壁の水分劣化の主要因の推定を行った。その結果、地下水の吸い上げは少なく、壁体への主な水分供給源は外気側での表面結露および雨水であることが推定された｡今後は気象と土壌水分量に加えて､塗布処置の経過を観察する。

＜謝辞＞本研究の一部は JSPS 科学研究費補助金（24101014 及び 15K21092）の助成を受けたものです。ここに記して謝意を表します。

＜参考文献＞

[1] 吉岡瑞穂、伊庭千恵美、渡辺晋生、鉾井修一：カッパドキア岩窟教会外壁での表面処理による劣化抑制に関する研究－現地凝灰岩の熱水分物性と秋冬期における表面処理の影響―、日本建築学会近畿支部.2016

[2] 松本衛，馬沙：地盤の凍結と融解過程の解析に関する研究，日本建築学会論文集，第 482 号，pp.25-34，1996.4

吉岡瑞穂, 伊庭千恵美, 渡辺晋生, 鉾井修一：カッパドキア岩窟教会外壁での表面処理による劣化抑制に関する研究－現地凝灰岩の熱水分物性と秋冬期における表面処理の影響－, 日本建築学会近畿支部研究報告集, 第56 号・環境系, pp.237-240, 2016.6（転載）

平成28 年度日本建築学会
近 畿 支 部 研 究 発 表 会

カッパドキア岩窟教会外壁での表面処理による劣化抑制に関する研究
－現地凝灰岩の熱水分物性と秋冬期における表面処理の影響―

正会員 ○吉岡瑞穂*1　同 伊庭千恵美*2　非会員　渡辺晋生*3　正会員　鉾井修一*4

4. 環境工学―9. 湿気―ｆ. 熱水分移動解析
凍結破砕，文化財保存，表面処理，熱水分同時移動

1.　本研究の目的及び概要

カッパドキアはトルコ中央部に位置する奇岩地帯であり、初期キリスト教徒によって凝灰岩を掘削して造られた岩窟教会が多数現存する。この保存に関して壁体や内部壁画の劣化が深刻な問題である[1]。

岩窟教会外壁の劣化要因として、凝灰岩内部での凍結破砕などの水分による劣化が挙げられる。この抑制策として、水分浸入の防止を主眼に置いた表面処理剤の塗布が検討されている[2]。しかし既報[3]で述べた通り、外壁内部の熱水分移動性状の変化や塗布が不十分な箇所からの水分の浸入によって、新たな箇所での劣化の発生や進行が懸念される。

本研究はカッパドキアのレッドバレーに位置するウズムル教会を対象として、表面処理剤の塗布が教会外壁内部の熱水分移動と分布性状に与える影響の解明を目的とする。本報では現地凝灰岩の熱水分に関する移動係数の実測結果から各移動係数の水分依存性を推定し、それらを用いて現地気象下における教会外壁の水分移動・蓄積の性状を検討した。

2.　現地凝灰岩の熱水分物性の推定

検討対象を構成する凝灰岩の熱水分移動に関する物性値として、実験室で平衡含水率関係を、現地で飽和透水係数と熱伝導率の測定を行った。また測定結果に基づき、不飽和時の液相水分伝導率と、熱伝導率の水分依存性を推定した。

2.1.　平衡含水率

多孔質材料はおよそ95%以上の高湿度域において平衡含水率の変化が著しく大きくなる。本報では相対湿度が95%以下の低湿度域ではデシケータ法[4]を、95%以上の高湿度域では砂柱法[5]および水分ポテンシャル測定装置 WP4 を用いて測定した。デシケータ法では一定温度(23℃)のもとで、相対湿度 11.3%、33%、53%、75%、85%、94%における容積基準の平衡含水率ψ_lを測定した。測定結果をもとに、相対湿度と温度によって定まる水分化学ポテンシャルμと平衡含水率の関係を式(1)で近似した。測定結果と式(1)のグラフを次頁図 1、2 に示す。なお本報では吸放湿履歴は考慮していない。

$$\psi_l(m) = \frac{0.6936}{2.9856 + e^{1.0703(m-1.793)}} + \frac{0.2316}{1.0 + e^{3(m-1.793)}} \qquad (1)$$

ただし$m = \log_{10}(-\mu)$

2.2.　液相水分伝導率

検討対象である教会の西壁を構成する凝灰岩を対象として、ディスク浸潤計を用いて飽和透水係数K_{sat}を測定した[6]。測定は異なる水圧条件で 3 回実施し、平均値から K_{sat}=1.037×10^{-4} [m/s] を得た。この結果を用いて液相水分伝導率の推定を行った。

水分化学ポテンシャル勾配に対する不飽和液相水分伝導率$\lambda'_l(\mu)$については、Van Genuchten の作成した土壌の不飽和透水係数を推定するモデル[7]を参考に、飽和にごく近い領域で急激に値が増加するという多孔質材料の性質を考慮して液水の飽和度 S を変数とする式(2)で与えた。次頁図 3 、4 に式(2)で与えられた不飽和液相水分伝導率と水分量との関係を示す。ただし式(2)の適用範囲は$\mu < -1.0 \times 10^{-4}$ [J/kg]であり、μがそれより大きい場合は式(3)で表される飽和液相水分伝導率$\lambda'_{l_{sat}}$を用いる。

$$\lambda'_l(\mu) = K_{sat}\,S^{15}\left[1-\left(1-S^{\frac{1}{0.03595}}\right)^{0.03595}\right]^2\left(\frac{1}{g}\right) \qquad (2)$$

$$\lambda'_{l_{sat}} = K_{sat}/g \qquad (\mu \geq -1.0 \times 10^{-4}\ \text{[J/kg]のとき}) \qquad (3)$$

2.3.　熱伝導率

熱伝導率の測定は現地にて行った。試験体として教

Prevention against deterioration by water using surface finishing to Rock-hewn Churches in Cappadocia
YOSHIOKA Mizuho, IBA Chiemi, WATANABE Kunio and HOKOI Shuichi

会近傍の凝灰岩体と教会の床、西側壁体、北東側壁体の 4 つを選定し、各々自然乾燥状態と液水をかけて比較的含水率を高くした状態の 2 条件下で、熱特性計（DECAGON 社　KD2 PRO）を用いて測定した。

測定結果を表 1 に示す。試験体ごとのばらつきが大きいが、いずれの試験体についても自然乾燥状態よりも高含水状態において熱伝導率が大きくなる。これは水分の浸入によって空隙内の空気の一部がより熱伝導率の大きい水に置き換わったこと、また水分が岩石粒子間に架橋を形成することで熱が伝わりやすくなったことが原因であると考えられる。

表 1　熱伝導率測定結果

熱伝導率　[W/mK]	岩体	床	西壁	北東壁
自然乾燥	0.246	0.263	0.197	0.139
高含水	0.488	0.535	0.509	0.55

土壌物理学の分野では、多孔質材料である土壌の熱伝導率の水分依存性を示す式として、Campbell の式が提案されている[8]。Hannson ら（2004）はこれを凍土に拡張した式を与えている[9][10]。本報はこの拡張モデル[9]を用いて熱伝導率の水分依存性を推定した。実測値は自然乾燥状態と高含水状態を各々平衡含水率 0.004、0.2（飽和度 0.008、0.43）にあたる状態とみなし、4 か所の平均値を推定に用いた。空隙内に氷と液水が共存している場合の実測値は得られていないため、空隙が氷で飽和している場合の熱伝導率を氷と固体実質部の熱伝導率を各体積率で重みづけした加重平均に等しいと仮定して求め、この値を推定に用いた。

熱伝導率の推定式を式(4)に、図 5 と 6 に実測値と式（4）のグラフを示す。ψ_wは水蒸気を含めた水分量で、$\psi_w \simeq \psi_l$である。また F は水と氷の熱伝導率の違いに基づく係数である。図 5 は凍結が生じていないときの液水の含水率と熱伝導率の関係を、図 6 は空隙内に含まれる水分が全て凍結したときの含氷率と熱伝導率の関係を表す。

$$\lambda = 0.472 + 0.241(\psi_w + F\psi_i) \\ -(0.472 - 0.198)exp\{-[8.495(\psi_w + F\psi_i)^4\} \tag{4}$$

ただし　$F = 1 + 13.05\psi_i^{1.06}$

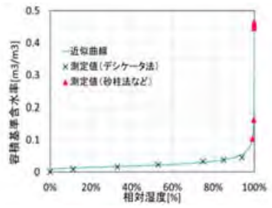


図 1　相対湿度と容積基準含水率の関係

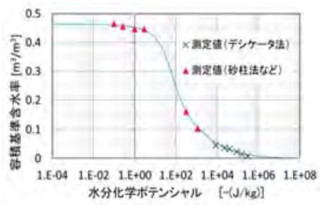


図 2　水分化学ポテンシャルと容積基準含水率の関係

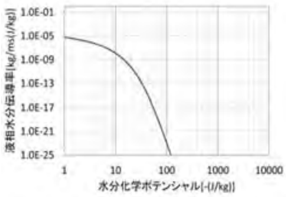


図 3　水分化学ポテンシャルと液相水分伝導率の関係

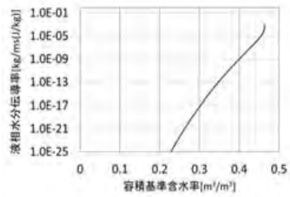


図 4　容積基準含水率と液相水分伝導率の関係

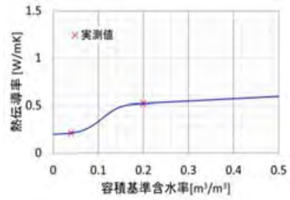


図 5　容積基準含水率と熱伝導率の関係（凍結が生じていない場合）

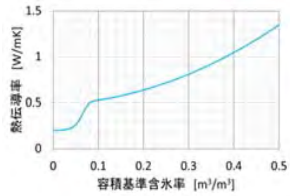


図 6　容積基準含氷率と熱伝導率の関係（空隙内水分がすべて凍結時）

3.　表面処理剤の材料内凍結性状への影響の解析

3.1.　計算モデル

計算モデルの概要を図 7 に示す。厚さ 1000mm の凝灰岩単一層からなる垂直外壁を検討対象とし、一次元の熱水分同時移動解析を行う。現地気象条件下において外気側での表面処理が壁体外気側表面近傍の水分分布性状に与える影響に着目して検討する。

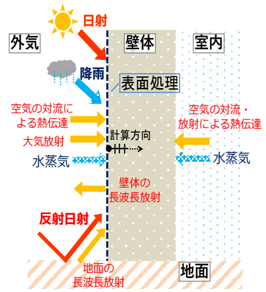


図 7 現地環境を想定した計算モデル

3.2.　基礎方程式[11]

壁体内部の熱水分移動は、各相の水分状態を考慮した式(5)から(7)に示す三相系の熱水分同時移動方程式を用いて計算する。水分移動の駆動力は水分化学ポテンシャルμを用いる。本報では重力を考慮しない。

【水分収支式】

$$\frac{\partial \rho_l \psi_l}{\partial \mu}\frac{\partial \mu}{\partial t} = \frac{\partial}{\partial x}\left(\lambda'_{Tg}\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial x}\left((\lambda'_{\mu g} + \lambda'_{\mu l})\frac{\partial \mu}{\partial x}\right) - \frac{\partial \rho_i \psi_i}{\partial t} \tag{5}$$

【エネルギー収支式】

$$c\rho\psi\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(\lambda\frac{\partial T}{\partial x}\right)$$
$$+H_{gl}\left\{\frac{\partial}{\partial x}\left(\lambda'_{Tg}\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial x}\left(\lambda'_{\mu g}\frac{\partial \mu}{\partial x}\right)\right\}+H_{li}\frac{\partial \rho_i\psi_i}{\partial t} \tag{6}$$

ただし$c\rho\psi=c_i\rho_i\psi_i+c_l\rho_l\psi_l+c_b\rho_b\psi_b$

【結氷条件式】

$$\mu=H_{li}\log(\frac{T}{T_k}) \tag{7}$$

3.3. 計算条件

外気側と室内側の境界条件は、ウズムル教会近傍の外気と室内空気の温度と相対湿度、日射量、降水量の測定結果を使用した。壁体内部の初期条件は、温度と相対湿度ともに各表面はそれぞれ外気、室内空気の初期値と等しいとし、内部を直線分布とした。現地凝灰岩の熱水分物性値と移動係数は実測結果および **2.**で推定した式を使用した。表 2 に本解析で使用した現地凝灰岩の物性値を示す。また境界面での熱水分流の計算に用いた係数は表 3 の通りである。

表 2　現地凝灰岩の物性値と移動係数

物性値	値	移動係数	値
乾燥密度 [kg/m^3]	1400	湿気伝導率 [kg/msPa]	3.38×10^{-11}
空隙率 [m^3/m^3]	0.47	液相水分伝導率[kg/ms(J/kg)]	式(2)(3)
比熱 [J/kgK]	1200	熱伝導率 [W/mK]	式(4)
平衡含水率[m^3/m^3]	式(1)		

表 3　境界面での計算に用いた係数

	対流熱伝達率	放射熱伝達率	湿気伝達率
外気	8.6 [W/m^{2}K]	-	0.0184
室内空気	4.1 [W/m^{2}K]	4.65 [W/m^{2}K]	[kg/m2s(kg/kg')]
	日射反射率	日射吸収率	放射係数
壁体	-	0.8	0.9
地面	0.4	0.6	0.9

3.4. 計算 Case

表面処理を行わない北向き垂直壁を基準（Case1）とし、現地での使用が検討されている含浸封孔剤の塗布を想定した場合を Case2 とした。含浸封孔剤は、多孔質材料表面の微細孔に含浸して硬化し、塗布面の透湿性は損なわずに撥水性を高めるとされる。本報では別途行われた推定から得られた、塗布表面から 1.5mm までの透水抵抗を 3.3 倍、1.5mm から 3.5mm までの透水抵抗を 125 倍にするモデルを用いた[12]。

3.5. 計算結果

各 Case について、2014 年 9 月 4 日から 2015 年 1 月 1 日まで数値解析を行った。図 8 に計算期間の外気・室内温度を、図 9 に外気と室内の相対湿度と 10 分間降水量を示す。

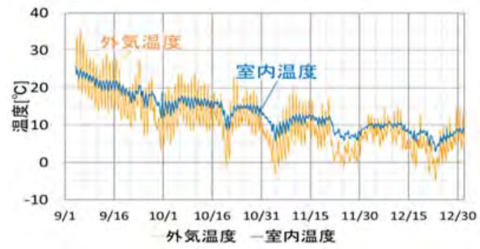


図 8　2014 年 9 月-12 月　外気・室内温度

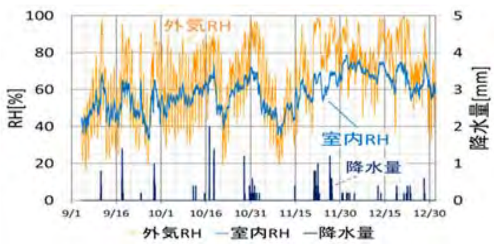


図 9　2014 年 9 月-12 月　外気・室内相対湿度(RH)と降水量

図 10 に Case1 での外気側表面温度と外気温、図 11 から 13 に外気側表面、表面から 1mm、2mm、10mm における含水率、含氷率の計算結果を示す。図 11、12 は各々Case1 での含水率と含氷率の変動、図 13 は Case2 での含水率変動である。

まず Case1 に関して検討する。温度（図 10）は、夜明け前等に外気側表面温度が外気温を下回るため、表面結露の発生が懸念される。また含水率（図 11）と含氷率（図 12）は表面での変動が顕著である。凍結が生じる範囲は表面から 2mm までのごく浅い領域のみであった。含水率、含氷率のいずれも 11/25 午前の外気側表面で期間中最大となる。これは 24 日の日没後より外気側表面の温度が低下して凍結が発生・進行し、25 日の日の出後に日射を受けて表面温度が上昇し氷が融解したためである（図 14 参照）。

次に表面処理の影響について検討する。壁体内の含水率・含氷率の変動に関して、Case1 と Case2 で変化は見られない（図 11 と 13）。これは計算を行った秋期は現地環境下において外気や室内空気からの水分供給が少ないことと、そのために壁体が常に比較的乾燥していることが原因であると考えられる。外気と室内からの壁体に浸入する水分は空気中の水蒸

気と降雨、壁体表面での結露である。このうち表面処理剤が対象としているのは液水で浸入する降雨と結露であり、いずれも量・供給時間が小さい。乾燥した壁体内部の水分量が増加し液相による水分移動が支配的となる前に、供給された水分が表面で蒸発したため、含浸部分の撥水処理が内部の水分分布性状に影響を与えなかったと考えられる。

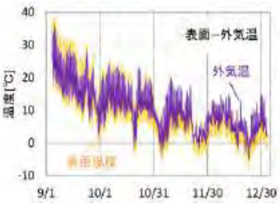


図 10　Case1 外気・表面温度

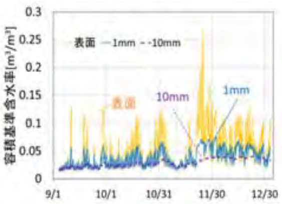


図 11　Case1 含水率変動

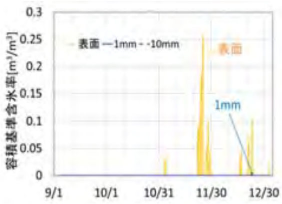


図 12　Case1 含氷率変動

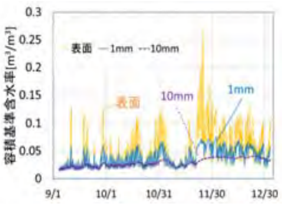


図 13　Case2 含水率変動

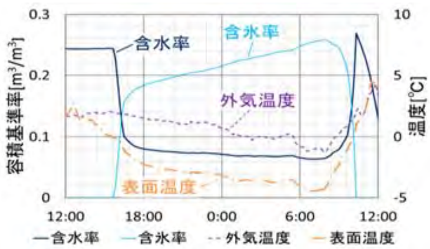


図 14　Case1　11/24 12:00 から 11/25 12:00 の外気温度と外気側表面の温度・含水率・含氷率

4.　結論

本報では表面処理剤の塗布が教会外壁内部の水分分布性状に与える影響の解明を目的として、現地凝灰岩の熱水分に関する移動係数を推定した。そしてそれらを用いた現地気象下における教会外壁内部の1次元熱水分同時移動解析を行い、以下の結論を得た。

1) 熱水分物性　平衡含水率、飽和透水係数と熱伝導率の測定を行った。その結果から平衡含水率曲線、不飽和時の液相水分伝導率と、熱伝導率の水分依存性を推定した。

2) 数値解析　1)の結果をもとに、検討対象の教会外壁を想定した単一層垂直外壁モデルを作成し、現地気象下における9月から12月にかけての壁体内水分移動・蓄積の性状を検討した。その結果、以下の事項が明らかになった。

- 現地において秋期は乾燥しており、大気中の水分や降雨による外壁への液水供給が少ない。
- 壁体は表面を除いてほぼ常に乾燥した状態であるため、壁体内の液水移動は非常に小さい。
- 含浸封孔剤による表面処理は液水浸入の抑制が対象であるため、水蒸気での移動が主である期間では壁体内の水分分布性状に影響を与えない。

今後は融雪時期など湿潤な気候下における表面処理の影響を検討する。

記号　μ : 自由水基準の水分化学ポテンシャル(=$RvTlog(h)$)　[J/kg], T : 絶対温度 [K], h : 相対湿度 [-], t : 時間 [s], Rv : 水蒸気の気体定数 (=461.643) [Pam^3/(kgK)], T_k : 自由水の結氷温度(=273.16) [K], g: 重力加速度 [m^2/s] c : 比熱 [J/kgK], ρ : 密度 [kg/m^3], ψ : 容積基準体積率 [m^3/m^3], S : 液水の飽和度 [m^3/m^3], λ : 熱伝導率 [W/mK], λ' : 水蒸気圧勾配に対する湿気伝導率 [kg/msPa] , λ'_{Tg},$\lambda'_{\mu g}$: 温度勾配, 水分化学ポテンシャル勾配に対する気相水分伝導率 [kg/msK], [kg/ms(J/kg)], $\lambda'_{\mu l}$: 水分化学ポテンシャル勾配に対する液相水分伝導率[kg/ms(J/kg)], H_{ls} : 水の融解潜熱 [J/kg],　H_{gl} : 水の蒸発潜熱 [J/kg]

添え字　g:水蒸気　l:液水　i:氷　b:材料実質部 w: 水分 sat: 飽和

謝辞

三重大学（当時）三輪睦実さんには凝灰岩物性値の測定に関して多大なご協力を頂きました。筑波大学　谷口陽子准教授、大阪大学　小泉圭吾助教、ハイテック㈱　朴春澤氏、㈱ディ・アンド・ディ　佐野勝彦氏には、岩窟教会や含浸封孔剤について、貴重な助言を頂きました。また、本研究の一部は JSPS 科学研究費補助金（24101014 及び 15K21092）の助成を受けたものです。ここに記して謝意を表します。

参考文献

[1] Topal, T.; V. Doyuran. Analyses of deterioration of the Cappadocian tuff, Turkey. : Environmental geology, 1998, vol.34(1) p.5-20.

[2] La Russa, Mauro Francesco, et al. Cappadocian ignimbrite cave churches: stone degradation and conservation strategies. Periodico di Mineralogia. 2014, vol. 83(2), p.187-206.

[3] 吉岡瑞穂; 伊庭千恵美；鉾井修一. カッパドキア岩窟教会外壁での表面処理による凍結破砕防止に関する研究―表面処理剤が壁体内部の含水率分布に与える影響の検討―.日本建築学会近畿支部.2015

[4] 日本建築学会. 日本建築学会環境基準　AIJES-H001-2006　湿気物性に関する測定基準・同解説. 丸善, 2006, p.12-14.; p.38-44.

[5] Dane J.H. and J.W. Hopmans, 2002. Water retention and storage. In Methods of Soil Analysis. Part 4. Physical Methods. (J.H. Dane and G.C. Topp, Eds.) SSSA Book Series No.5. pp. 675-690.

[6] Kirkham, M.B. 2005. Principles of soil and plant water relations. Elsevier Academic Press, Burlington, MA.

[7] Van Genuchten, M. Th. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Science Society of America Journal .1980, vol.44 (5), p.892-898.

[8] Campbell, Gaylon S. Soil physics with BASIC: transport models for soil-plant systems. 1985. Vol. 14, Elsevier,

[9] Hansson, Klas, et al. Water flow and heat transport in frozen soil. Vadose Zone Journal. 2004. vol. 3(2), p. 693-704.

[10] 渡辺晋生; 取出伸夫; 坂井勝. 凍結をともなう土中の水分・熱・溶質移動モデル (特集　水分・溶質移動モデル). 土壌の物理性. 2007. 106, p.21-32.

[11] 松本衛, 馬沙. 地盤の凍結と融解過程の解析に関する研究. 日本建築学会論文集. 1996, 第 482 号, p.25-34.

[12] 福井一真；伊庭千恵美；鉾井修一.　防水・撥水剤の水分移動特性と建造物への適用可能性に関する研究.京都大学卒業論文.2015

＊1 京都大学大学院工学研究科　修士課程　Student, Graduate School of Engineering, Kyoto University

＊2 京都大学大学院工学研究科　助教・博士(工学)　Asst. Prof., Graduate School of Engineering, Kyoto University, Dr.Eng.

＊3 三重大学大学院生物資源学研究科 准教授・博士(学術)　Assoc. Prof.., Graduate School of Bioresources, Mie University, Ph.D.

＊4 京都大学大学院工学研究科　教授・工博　Prof., Graduate School of Engineering, Kyoto University, Dr.Eng

吉岡瑞穂, 伊庭千恵美, 鉾井修一：カッパドキア岩窟教会外壁での表面処理による劣化防止に関する研究－現地凝灰岩の熱水分物性と雨水浸入に対する表面処理の影響－, 日本建築学会学術講演梗概集 D- Ⅱ, pp. 411-412, 2016.8（転載）

カッパドキア岩窟教会外壁での表面処理による劣化防止に関する研究
―現地凝灰岩の熱水分物性と雨水浸入に対する表面処理の影響―

正会員　○吉岡　瑞穂 1*　　正会員　伊庭　千恵美 2**　正会員　鉾井　修一 3***

熱水分同時移動　　文化財保存　　表面処理
雨水　　多孔質材料

1.本研究の背景と目的

カッパドキアはトルコ中央部に位置する奇岩地帯であり、初期キリスト教徒によって凝灰岩を掘削して造られた岩窟教会が多数現存する。この保存に関して壁体や内部壁画の劣化が深刻な問題である[1]。

岩窟教会外壁の劣化要因として、凍害などの凝灰岩内部での水分による劣化が挙げられる。この抑制策として、水分浸入の防止を主眼に置いた表面処理剤の塗布が検討されている[2]。しかし既報[3]で述べた通り、外壁内部の熱水分移動性状の変化や未塗布箇所からの水分の浸入によって、新たな箇所での劣化の発生や進行が懸念される。

本研究はカッパドキアのレッドバレーに位置するウズムル教会を対象として、表面処理剤の塗布が教会外壁内部の熱水分移動と分布性状に与える影響の解明を目的とする。本報では現地凝灰岩の熱水分に関する移動係数の実測結果から各移動係数の水分依存性を推定した。またそれらを用いて教会外壁の計算モデルを作成し、現地気象下での教会外壁の水分移動・蓄積の性状を検討した。

2.現地凝灰岩の熱水分物性の推定

検討対象を構成する凝灰岩の平衡含水率・液水水分伝導率・熱伝導率を測定した。

平衡含水率ψ_lは実験室において測定した。測定に関しては、相対湿度が 95%以下の領域ではデシケータ法[4]を、95%以上の領域では砂柱法[5]および水分ポテンシャル測定装置 WP4 を用いた。測定結果をもとに相対湿度と温度によって定まる水分化学ポテンシャルμと平衡含水率の関係を近似した。結果を図 1 に示す。本報では吸放湿履歴を考慮していない。

飽和液相水分伝導率λ'_{lsat}は、現地でディスク浸潤計を用いて測定[6]した飽和透水係数 K_{sat}=1.037×10^{-4} [m/s]　を用いて求めた。不飽和液相水分伝導率λ'_lについては、Van Genuchten の作成した土壌の不飽和透水係数を推定するモデル[7]を参考に、飽和にごく近い領域で急激に値が増加するという多孔質材料の性質を考慮して液水の飽和度 S を変数とする式で与えた。液相水分伝導率と水分化学ポテンシャルの関係を図 2 に示す。

熱伝導率λの測定は現地教会にて行われた。教会近傍の凝灰岩体と教会の床、西側壁体、北東側壁体の 4 つを試験体として選定し、自然乾燥状態と液水をかけて比較的含水率を高くした状態の 2 条件下で、熱特性計（DECAGON 社　KD2 PRO）を用いて測定した。その結果、いずれの試験体についても高含水状態の方が値が大きくなった。これらの実測値から、凍土を含めた土壌の熱伝導率の水分依存性を示す Hannson らのモデル[8]を用いて、現地凝灰岩の熱伝導率の水分依存性を推定した。実測値は自然乾燥状態と高含水状態を各々飽和度 0.008、0.43 にあたる状態とみなし、4 か所の平均値を推定に用いた。空隙内に氷と液水が共存している場合の実測値は得られていないため、空隙が氷で飽和している場合の熱伝導率を氷と固体実質部の熱伝導率を各体積率で重みづけした加重平均に等しいと仮定して求め、この値を推定に用いた。熱伝導率の推定式を式(1)に示す。ψ_wは水蒸気を含めた水分量で$\psi_w \simeq \psi_l$である。図 3 は凍結が生じていないときの含水率と熱伝導率の関係を、図 4 は空隙内の水分が全て凍結したときの含氷率と熱伝導率の関係を表す。

$$\lambda = 0.472 + 0.241(\psi_w + F\psi_i) \\ -(0.472 - 0.198)exp\{-[8.495(\psi_w + F\psi_i)^4\} \quad (1)$$

ただし　$F = 1 + 13.05\psi_i^{1.06}$

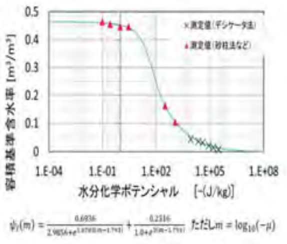


図 1　容積基準の平衡含水率曲線

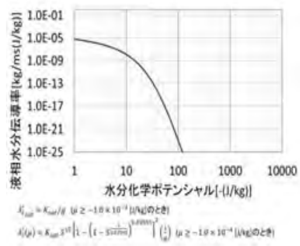


図 2　液相水分伝導率

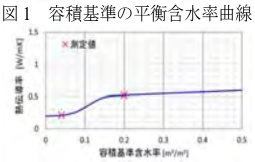


図 3　熱伝導率（凍結なし）

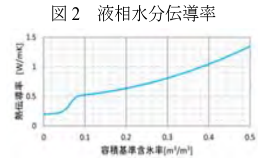


図 4　熱伝導率（すべて凍結）

3.表面処理が壁体内部の熱水分移動に与える影響の検討

計算モデルの概要を図 5 に示す。厚さ 1000mm の凝灰岩単一層からなる北向き垂直外壁を計算対象とし、二次元の熱水分同時移動解析を行った。壁体内部の熱水分移動の計算は、各相の水分状態を考慮した式(2)から(4)に示す三相系の熱水分同時移動方程式[9]を用いた。本解析では重力を考慮していない。

$$\frac{\partial \rho_l \psi_l}{\partial \mu}\frac{\partial \mu}{\partial t}=\frac{\partial}{\partial x}\left(\lambda'_{Tg}\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial x}\left((\lambda'_{\mu g}+\lambda'_{\mu l})\frac{\partial \mu}{\partial x}\right)-\frac{\partial \rho_i \psi_i}{\partial t} \tag{2}$$

$$c\rho\psi\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(\lambda\frac{\partial T}{\partial x}\right)+H_{gl}\left\{\frac{\partial}{\partial x}\left(\lambda'_{Tg}\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial x}\left(\lambda'_{\mu g}\frac{\partial \mu}{\partial x}\right)\right\}+H_{li}\frac{\partial \rho_i \psi_i}{\partial t} \tag{3}$$

$$\mu = H_{li}\log\left({}^{T}/_{T_k}\right) \tag{4}$$

計算期間は 2015 年 1 月 1 日で、外気側と室内側の境界条件は対象教会近傍の測定結果を使用した（図 6）。壁体内部の初期条件は一次元の予備解析（計算期間：2014 年 9 月 4 日－2015 年 1 月 30 日）により得られた温度分布と相対湿度分布を用いた。現地凝灰岩の移動係数は 2.で推定した値を用いた。また境界面での熱水分流の計算に用いた係数を表 1 に示す。

計算 Case は、表面処理を行わない場合を基準（Case1）とし、現地での使用が検討されている含浸封孔剤を一様に塗布した状況を想定した場合を Case2、一部表面に塗り残しがある場合を Case3 とした（図 7）。含浸封孔剤は塗布表面から 1.5mm までの透水抵抗を岩体の 3.3 倍、1.5mm から 3.5mm の透水抵抗を 125 倍にするモデルを用いた[10]。

図 8 に 2015 年 1 月 1 日の 13:00 と 15:00 における壁体内の含水率分布を示す。現地気象条件下において外気側での表面処理が壁体外気側表面近傍の水分分布性状に与える影響に着目し、外気側表面から 5mm 深さまでの領域の水分分布を検討する。この日は 12 時から 20 時頃まで断続的に降雨があった。いずれの Case においても 1mm 以深では含水率がほぼ変化していない。これは壁体内部が初期的に乾燥しており液相水分伝導率が小さかったためであると考えられる。Case1 では雨水が内部に徐々に浸透して、表面および 1mm 深さでの含水率が時間の経過とともに増加している。Case2 においても同様の傾向が見られるが、その変化は Case1 と比較して穏やかである。また Case3 では未塗布箇所から液水が浸透しその部分の含水率が増加しているが、15:00 における表面全体での含水率は全 Case 中最も低い。この場合では、塗り残し部分が局所的に劣化する恐れがある。

4. まとめ

本報では実測より現地凝灰岩の熱水分に関する移動係数を推定した。またそれらを用いて教会外壁の計算モデルを作成し、現地気象下での教会外壁の水分移動・蓄積の性状を検討した。その結果、含浸封孔剤による表面処理は雨水の浸透抑制に効果的であるが、その範囲を検討する必要があることが示唆された。

記号　μ：自由水基準の水分化学ポテンシャル(=$RvTlog(h)$)　[J/kg], T：絶対温度 [K], h：相対湿度 [-], t：時間 [s], Rv：水蒸気の気体定数(=461.643) [Pam³/(kgK)], T_k：自由水の結氷温度(=273.16) [K], g: 重力加速度 [m²/s] c：比熱 [J/kgK], ρ：密度 [kg/m³], ψ：容積基準体積率 [－], S：液水の飽和度 [m³/m³], λ：熱伝導率 [W/mK], λ'：水蒸気圧勾配に対する湿気伝導率 [kg/msPa], λ'_{Tg},$\lambda'_{\mu g}$：温度勾配, 水分化学ポテンシャル勾配に対する気相水分伝導率 [kg/msK], [kg/ms(J/kg)], $\lambda'_{\mu l}$：水分化学ポテンシャル勾配に対する液相水分伝導率[kg/ms(J/kg)], H_{li}：水の融解潜熱 [J/kg],　H_{gl}：水の蒸発潜熱 [J/kg]

添え字　g:水蒸気　l:液水　i:氷　b:材料実質部　w: 水分　sat: 飽和

謝辞　三重大学　渡辺晋生准教授、三輪睦実さん（当時）には凝灰岩物性値の測定と推定に関して多大なご協力を頂きました。筑波大学　谷口陽子准教授、大阪大学　小泉圭吾助教、ハイテック㈱　朴春澤氏、㈱ディ・アンド・ディ佐野勝彦氏には、岩窟教会や含浸封孔剤について、貴重な助言を頂きました。また、本研究の一部は JSPS 科学研究費補助金（24101014 及び 15K21092）の助成を受けたものです。ここに記して謝意を表します。

参考文献

[1] Topal, T.; V. Doyuran. Analyses of deterioration of the Cappadocian tuff, Turkey.　Environmental Geology, 1998, vol.34(1), pp.5-20.

[2] La Russa, Mauro Francesco, et al. Cappadocian ignimbrite cave churches: stone degradation and conservation strategies. Periodico di Mineralogia. 2014, vol. 83(2), pp.187-206.

[3] 吉岡瑞穂; 伊庭千恵美；鉾井修一. カッパドキア岩窟教会外壁での表面処理による凍結破砕防止に関する研究―表面処理剤が壁体内部の含水率分布に与える影響の検討―. 日本建築学会近畿支部研究報告集　第 55 号　環境系、pp. 289-292, 2015

[4] 日本建築学会. 日本建築学会環境基準　AIJES-H001-2006　湿気物性に関する測定基準・同解説. 丸善, 2006, pp.12-14.; pp.38-44.

[5] Dane J.H. and J.W. Hopmans, 2002. Water retention and storage. In Methods of Soil Analysis. Part 4. Physical Methods. (J.H. Dane and G.C. Topp, Eds.) SSSA Book Series No.5. pp. 675-690.

[6] Kirkham, M.B. 2005. Principles of soil and plant water relations. Elsevier Academic Press, Burlington, MA.

[7] Van Genuchten, M. Th. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Science Society of America Journal .1980, vol.44 (5), pp.892-898.

[8] Hansson, Klas, et al. Water flow and heat transport in frozen soil. Vadose Zone Journal. 2004. vol. 3(2), pp. 693-704.

[9] 松本衛, 馬沙. 地盤の凍結と融解過程の解析に関する研究. 日本建築学会論文集. 1996, 第 482 号, pp.25-34.

[10] 福井一真、伊庭千恵美、吉岡瑞穂、鉾井修一：防水・撥水剤が建築材料内の水分移動・蓄積に与える影響　（その 1）―浸透系撥水剤の液相水分伝導率―、日本建築学会近畿支部研究報告集　第 56 号　環境系、2016

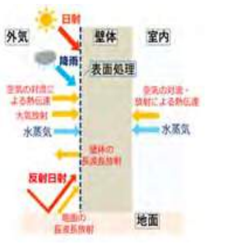


図 5　計算モデル

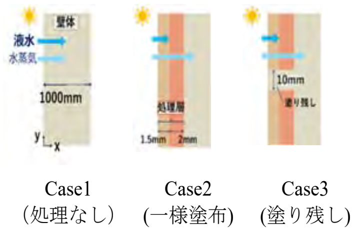


図 7　計算 Case

表 1　境界面での計算に用いた係数

	対流熱伝達率	放射熱伝達率	湿気伝達率
外気	8.6 [W/m²K]	-	0.0184 [kg/m2s(kg/kg')]
室内空気	4.1 [W/m²K]	4.65 [W/m²K]	
	日射反射率	日射吸収率	放射係数
壁体	-	0.8	0.9
地面	0.4	0.6	0.9

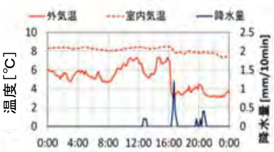


図 6　1 月 1 日の気温・降水量

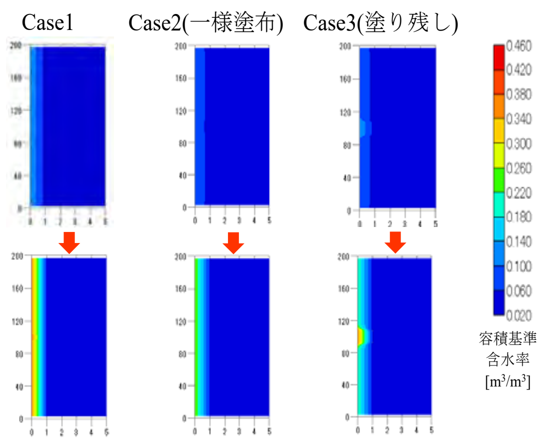


図 8　1 月 1 日の壁体内含水率分布（上が 13:00, 下が 15:00）

*1 京都大学大学院工学研究科建築学専攻　修士課程

**2 京都大学大学院工学研究科 助教・博士（工学）

***3 京都大学大学院工学研究科 名誉教授・工博

* Graduate Student, Graduate School of Engineering, Kyoto University

**Asst. Prof., Graduate School of Engineering, Kyoto University, Dr. Eng.

*** Prof.Emeritus, Graduate School of Engineering, Kyoto University, Dr. Eng.

EFFECTS OF WATER REPELLENT ON FROST DAMAGE IN OUTER WALLS OF ROCK-HEWN CHURCHES IN CAPPADOCIA, TURKEY

M. Yoshioka[1], C. Iba[1], K. Watanabe[2], Y. Taniguchi[3], Dr. K. Koizumi[4], K. Sano[5], C. Piao[6]

[1] Graduate School of Engineering, Kyoto university, Kyoto, Japan

[2] Graduate School of Bioresources, Mie university, Tsu, Japan

[3] Faculty of Humanities and Social Sciences, University of Tsukuba, Tsukuba, Japan

[4] Graduate School of Engineering, Osaka University, Osaka, Japan

[5]D&D CORPORATION, Yokkaichi, Japan

[6]HYTEC Inc., Osaka, Japan

ABSTRACT

Rock-hewn churches are common in Cappadocia, many of which contain culturally valuable reliefs or wall paintings. However, their tuff structures easily deteriorate, partly because of water infiltration and freezing. Thus, application of water repellent consolidant as a surface treatment is considered effective for preserving such structures. This study examines the effectiveness of water repellent on the water/ice distribution on the walls of a rock-hewn church. After the heat and moisture properties of the tuff were surveyed, the heat and moisture transfer in the walls were analyzed, with the results showing that the moisture distribution in the walls depended on the treated-area distribution.

INTRODUCTION

Cappadocia in Turkey has a famous heritage of unique landscapes, a historic past, and man-made rock structures. The region comprises extraordinarily soft and fragile tuff, and erosion and weathering by wind, rain, and snow have produced this unique landscape. In addition, many rock-hewn churches, which were originally carved by Christians there who had escaped from the Roman Empire, contain historically and culturally valuable reliefs or wall paintings on their interior surfaces. These rocky sites have been registered as a UNESCO World Natural and Cultural Heritage site under the name Göreme Natural and Historical National Park (UNESCO 1985).

To preserve these rock-hewn churches, it is an urgent importance to prevent deterioration of both the interior wall paintings and their tuff structures. One of the main factors contributing to deterioration of these structures seems to be water infiltration and the accompanying frost damage.

We recently launched a research project at Üzümlü Kilise (St. Nichlitas Church) in the Red Valley, Cappadocia. The primary objective of the project is to find a suitable method for prolonging the life of tuff structures using water-repellent consolidant as a surface-finishing material. This method is expected to delay the deterioration of tuff structures because it controls moisture infiltration into the tuff envelopes and improves the strength of the tuff. Surface treatment as a method for preservation has been tried in other tuff constructions in Cappadocia. However, most of the trials were not effective in reducing the rate of tuff erosion. In some cases, it has even promoted deterioration of the tuff (La Russa, 2014).

This study aims to evaluate the effects of water-repellent surface treatment on ice and moisture distribution in tuff structures in the actual environment. To achieve this, the following procedures were conducted in this study and are discussed here:

- Measurements and estimates of the heat and moisture properties of Cappadocian tuff
- Modeling and simulation of heat and moisture transfer in the tuff wall of the church

THE CHURCH AND ENVIRONMENT

Üzümlü Church

Üzümlü Church (Fig. 1) is located in the Red Valley, Cappadocia. It is estimated to have been originally constructed at the end of the seventh century. It has retained the wall paintings in its rooms. Both the tuff structure and paintings in this church exhibit various deterioration phenomena such as severe cracking, wall embrittlement, and fading. In particular, the progress of surface exfoliation or powdering is strikingly advanced. This deterioration has been caused by the environment, tectonic activity, and biological and human activities, including vandalism. The church has not been treated in the past; therefore, it was selected for this case study (Taniguchi et al. 2015).

In this project, several types of alkoxysilane-based water repellent with consolidation properties (Permeate® HS-360) were selected as the treatment substance. When the surfaces of base materials are treated, they attain the unique property that liquid water is prevented from infiltrating the treated area while vapor penetration is still allowed (Iba et al. 2016).

Local Climate

To clarify the environment around the church, meteorological data, indoor temperature, and relative humidity were monitored near the church. Figure 2 shows the outdoor and indoor temperatures and precipitation at 10 minutes intervals from September 2014 to March 2015.

In September, the outdoor temperature was relatively high, although it sometimes dropped below 0°C during winter. However, based on previous studies, we considered the critical temperature at which frost damage is induced in soil or rock to be approximately −4°C. Such conditions were observed only four times during the period under consideration, which was less often than we had anticipated (Iba et al. 2016).

Figure 1. Exterior of Üzümlü Church

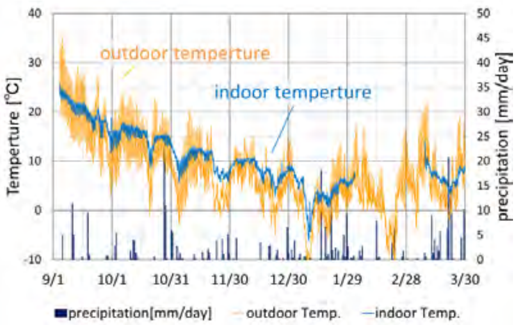


Figure 2. Outdoor/indoor temperatures and precipitation (September 2014–March 2015)

MEASUREMENT OF MATERIALPROPERTIES

To numerically analyze the characteristics of heat and moisture transfer in the tuff walls of the church, it was essential to clarify the heat and moisture properties of Cappadocian tuff.

In this paper, adsorption isotherms, liquid water conductivity, and thermal conductivity of the tuff were measured.

Adsorption Isotherms

The adsorption isotherms of many porous media used for building material drastically increase in areas where the relative humidity is fairly high. In consideration of this, the adsorption isotherm of Cappadocian tuff (ψ_l) was measured using different methods and devices. At lower humidity levels (below 95% RH), seven specimens were placed into individual desiccators in which different relative humidity conditions were created. After the specimens reached an equilibrium state, the weight water content of each specimen was measured and its mass water content was calculated (ψ_l) [m^3/m^3]. In this measurement, $\psi_l$was measured at seven different relative humidity values (11.3%, 33%, 53%, 75%, 85%, and 94%) at a constant temperature of 23°C.

At higher humidity levels (above 95% RH), the sand-pillar method (Dane & Hopmans 2002) and a water potential measuring device (WP4, Decagon) were adapted to measure the water content.

Based on the results, the adsorption isotherm of Cappadocian tuff was estimated using Equation (1). The water chemical potential is represented by μ [J/kg], and the values of μ and m are given by Equations (2) and (3), respectively. Hysteresis is not taken into account in this paper.

$$\psi_l(m) = \frac{0.6936}{2.9856 + e^{1.0703(m-1.793)}} + \frac{0.2316}{1.0 + e^{3(m-1.793)}} \quad (1)$$

$$\mu = R_v T ln(h) \quad (2)$$

$$m = \log_{10}(-\mu) \quad (3)$$

where

R_v: vapor content of air (= 461.643) [Pa·m^3/(kg·K)],
T: absolute temperature [K],
h: relative humidity [-]

The relationship between the relative humidity and moisture content is shown in Figure 3. In addition, the relationship between the water chemical potential and moisture content is shown in Figure 4.

Liquid Water Conductivity

The saturated coefficient of permeability K_{sat} was measured in situ using a disk infiltrometer (Kirkham 2005). The tuff forming the west wall of Üzümlü Church was used for the measurement. The permeability K_{sat} was measured at different water pressure conditions. As a result, a K_{sat} value of approximately 1.037 × 10^{-4} [m/s] was obtained.

In estimating the relationship between the water chemical potential μ and unsaturated liquid water conductivity $\lambda'_l(\mu)$[kg/ms (J/kg)], it was assumed that in porous media $\lambda'_l(\mu)$ sharply increases when it is nearly saturated. The relationship between the water chemical potential μ and liquid water conductivity $\lambda'_l(\mu)$ is shown in Equation 4, referring to the Van Genuchten model (Van Genuchten 1980). When μ is above -1.0×10^{-4} [J/kg], the tuff is treated as saturated and $\lambda'_l(\mu) = \lambda'_{l sat}$, as given by Equation 5.

Here S represents the degree of saturation of the tuff, as given by Equation 6.

$$\lambda_l'(\mu) = K_{sat}\, S^{15} \left[1-\left(1-S^{\frac{1}{0.03595}}\right)^{0.03595}\right]^2 \left(\frac{1}{g}\right) \quad (4)$$

$$\lambda_{l\,sat}' = K_{sat}/g \quad (\mu \geq -1.0\times10^{-4}\ \text{[J/kg]}) \quad (5)$$

$$S = \psi_l/\psi_0 \quad (6)$$

where g is the acceleration of gravity [m/s^2] and ψ_0 is the porosity of the tuff [m^3/m^3].

The relationship between the relative humidity and liquid water conductivity $\lambda_l'(\mu)$ is shown in Figure 5. The relationship between the water chemical potential μ and liquid water conductivity $\lambda_l'(\mu)$ is shown in Figure 6.

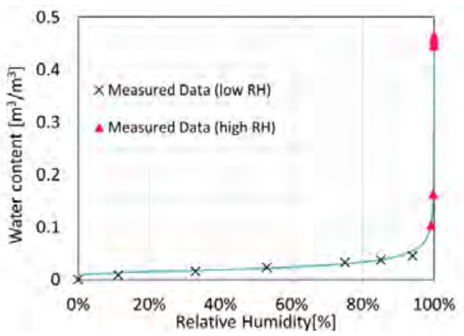


Figure 3. Relative humidity and adsorption isotherm

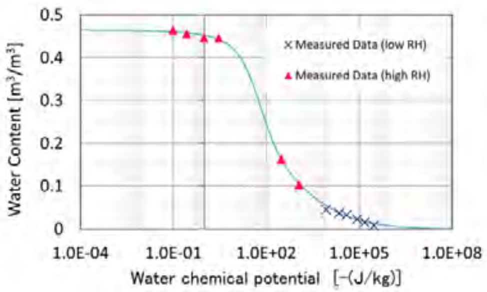


Figure 4.Water chemical potential and adsorption isotherm

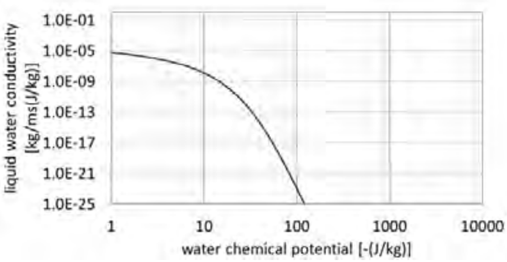


Figure 5. Water chemical potential and liquid water conductivity

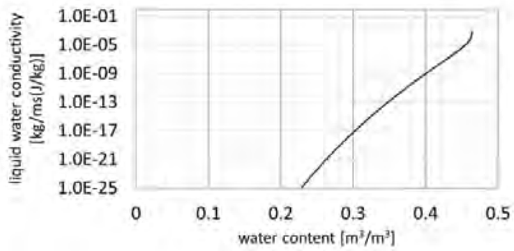


Figure 6. Water content and liquid water conductivity

Thermal Conductivity

The thermal conductivity of the tuff λ [W/mK] was also measured in situ. For this measurement, four samples were selected: weathered tuff rock near the church and in the floor, west wall, and northeast wall of the church. Each sample was measured using a thermal properties meter (KD2 Pro, Decagon) under two moisture conditions: naturally dry, and wet owing to pouring water. This measurement was performed for the purpose of estimating the relationship between the thermal conductivity and water content of the tuff.

The results of the measurement are listed in Table 1. Although the measured values varied widely among samples, the thermal conductivity increased when they were wet partly because air in the pores of the tuff was replaced by infiltrated moisture, whose thermal conductivity is higher than that of air. Moreover, it might be also considered that moisture in the pores formed a water film on the rock particles and behaved as a thermal bridge. The tuff is so fragile that it has difficulty forming in lab tests; therefore, these results were used for estimation.

Table 1
Measured thermal conductivity

Thermal conductivity [W/mK]	Rock	Floor	West wall	Northeast wall
dry	0.246	0.263	0.197	0.139
wet	0.488	0.535	0.509	0.55

In the field of soil physics, Campbell (1985) proposed an equation that estimates the relationship between the water content and thermal conductivity of soil, which, like rock, is porous. Hannson et al. (2004) then extended the equation to apply to frozen soil. In this paper, Hannson's model was adopted with the measured data, shown in Table 1, used for curve fitting. In this case, the dry and wet conditions were considered to correspond to water contents of $\psi_l = 0.004$ and 0.2 [m^3/m^3], respectively. As there were no data available for frozen rock, the average of the thermal conductivities of ice and tuff, which was weighted by the porosity and volume content of the solid part of the tuff, was calculated. Subsequently, and the obtained value was used for fitting as the thermal conductivity at a time when the tuff is saturated with ice.

Finally, the relationship between the thermal conductivity and water content of the tuff is given by Equation 7. In this equation, F is a constant given by Equation 8.

$$\lambda = 0.472 + 0.241(\psi_w + F\psi_i) \\ -(0.472 - 0.198)exp\{-[8.495(\psi_w + F\psi_i)^4\} \quad (7)$$

$$F = 1 + 13.05\psi_i^{1.06} \quad (8)$$

where ψ_w is the moisture content including vapor [m^3/m^3] (approximately equal to the water content ($\psi_w \simeq \psi_l$), and ψ_i is the ice content [m^3/m^3].

Figure 7 represents the relationship between the water content and thermal conductivity in the unfrozen condition. Figure 8 shows the relationship between the ice content and thermal conductivity when the water in the tuff completely freezes.

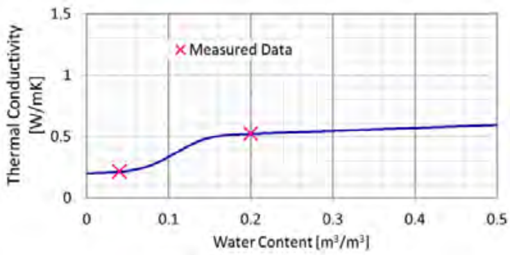


Figure 7.Water content and thermal conductivity (unfrozen condition)

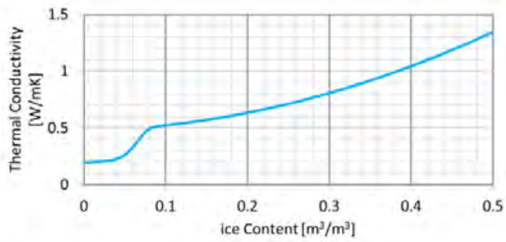


Figure 8. Ice content and thermal conductivity (fully frozen condition)

NUMERICAL ANALYSIS

Modeling

In this paper, we focused on the effects of surface treatment using a water-repellent consolidant on the ice and moisture distribution in a tuff wall, especially in the area close to its outer surface. To simulate heat and moisture transfer in the wall in its actual environment, a simple two-dimensional wall model was proposed, as shown in Figure 9. In the numerical calculation, these differential equations were discretized using a central difference method in space and a forward difference method in time. The time increment was set at 0.0001 s during freezing and at 0.05 s otherwise.

Fundamental Equations

The simultaneous heat and moisture transport equations proposed by Matsumoto (1993) were used in the following analysis. The heat and moisture balance equations are shown as Equations 9–10. Equation 11 presents the freezing condition. In this calculation, the effect of gravity on moisture transfer was ignored.

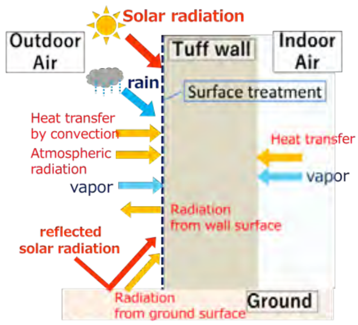


Figure 9. Simulation model of wall

$$c\rho\psi\frac{\partial\psi}{\partial t} = \frac{\partial}{\partial x}\left(\lambda\frac{\partial T}{\partial x}\right) + H_{li}\frac{\partial\rho_i\psi_i}{\partial t} \\ +H_{gl}\left\{\frac{\partial}{\partial x}\left(\lambda'_{Tg}\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial x}\left(\lambda'_{\mu g}\frac{\partial\mu}{\partial x}\right)\right\} \quad (9)$$

$$\frac{\partial\rho_l\psi_l}{\partial\mu}\frac{\partial\mu}{\partial t} = \frac{\partial}{\partial x}\left(\lambda'_{Tg}\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial x}\left((\lambda'_{\mu g} + \lambda'_{\mu l})\frac{\partial\mu}{\partial x}\right) - \frac{\partial\rho_i\psi_i}{\partial t} \quad (10)$$

$$\mu = H_{li}\ln(\frac{T}{T_k}) \quad (11)$$

where

$c\rho\psi = c_i\rho_i\psi_i + c_l\rho_l\psi_l + c_b\rho_b\psi_b$

and c is the specific heat [J/kgK], ρ is the density [kg/m^3], ψ is the volume content [m^3/m^3], μ is the water chemical potential [J/kg], T is the absolute temperature [K], T_k is the freezing temperature of free water (=273.16) [K], t is time [s], H is the latent heat of moisture [J/kg], λ is the thermal conductivity [W/mK], λ'_{Tg} is the vapor conductivity caused by the temperature gradient [kg/msK], $\lambda'_{\mu g}$ is the vapor conductivity caused by the water chemical potential gradient [kg/ms(J/kg)], and $\lambda'_{\mu l}$ is the liquid water conductivity caused by the water chemical potential gradient [kg/ms(J/kg)].

Subscripts:

i = ice, l = liquid water, g = vapor, b = body part

Calculation Conditions and Material Properties

The measured outdoor/indoor temperatures and relative humidity, precipitation, and solar radiation were used as boundary conditions. To obtain the initial conditions of the wall, we calculated beforehand the one-dimensional heat and moisture transfer in the walls from September 2014 to March 2015. The results were used as the initial temperature and relative humidity conditions of the wall in the 2-D calculation. The 2-D model was calculated using January 1, 2015 as a target.

The measured material properties of tuff mentioned in the previous section were used for this calculation. The other properties are shown in Table 2. The heat and moisture coefficients are listed in Table 3, and the values in Table 4 were used in calculating the solar heat gain and long-wave radiation on the wall surface.

Table 2

Properties of the tuff

Properties		Value
Density	[kg/m^3]	1400
Porosity	[m^3/m^3]	0.47
Specific heat	[J/kgK]	1200
Vapor conductivity	[kg/msPa]	3.38×10^{11}

Table 3

Heat and moisture transfer coefficients

	Heat [W/m^{2}K]		Moisture [kg/m^{2}s(kg/kg')]
	Convection	Radiation	Vapor
Outdoor	8.6	-	0.0184
Indoor	4.1	4.65	

Table 4

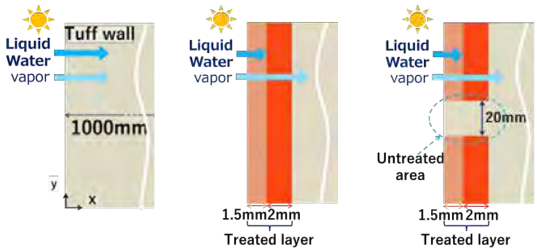
Coefficients of radiation

	Solar reflection	Solar absorption	Long-wave radiation
Wall	-	0.8	0.9
Ground	0.4	0.6	0.9

Simulation Cases

In this calculation, a vertical north-facing wall was analyzed. Three cases were compared: with/without water-repellent treatment, and with differences of distribution on the treated surface area. Figure 10 shows models of the three cases. Case 1 shows the present wall of the church, which has no surface treatment applied. Case 2 depicts the wall with the water-repellent uniformly applied on the outer surface. Case 3 assumes that a spot without surface treatment lies on the treated layer of Case 2.

The water-repellent consolidant, which is expected to be applied on the outer wall of Üzümlü Church, penetrated through the applied surface into the base material. After it reached a certain depth, it hardened to increase the water resistance of the infiltrated area. The water resistance of the water-repellent layer was estimated to have been increased by a factor of 3.3 from the surface to a depth of 1.5 mm and by a factor of 125 from a depth of 1.5 mm to a depth of 3.5 mm, based on a separately conducted experiment (Fukui.K, 2016).



Case 1 (present) Case 2 (uniform treatment) Case 3 (untreated spot)

Figure 10. Simulation case

Results and Discussion

Figure 11 shows the outdoor/indoor temperature, relative humidity, and precipitation on January 1, 2015, the calculation period. Figures 12–14 represent the fluctuation of temperature, volume water content, and volume ice content, respectively, in Case 1 (present wall). As mentioned above, we focused on an area close to the outer surface. Therefore, the values of the outer surface, at depths of 1 and 10 mm, are illustrated in Figures 12–14.

With respect to temperature, there was little difference between the three points. The wall temperature was about 4°C below the outdoor temperature before sunrise (0:00–7:00). During the day (7:00–17:00), the wall temperature rose owing to solar radiation, long-wavelength radiation in the air, and solar radiation reflected by the ground. After sunset (17:00–onward), the wall temperature was once again below the outdoor temperature. Furthermore, it soon dropped below 0°C. The temperature difference between the outdoor air and wall produced condensation dew on the surface of the wall.

As Figure 13 indicates, from afternoon to night the water content at the wall surface exceeded 0.3 [m^3/m^3], which is relatively high, and sometimes reached saturation (16:00–18:00). This was the result of intermittent rain in the afternoon, temperature descent after sunset, and condensation in the evening. After 18:00, the water content declined because the water partly turned into ice. In contrast to the wet surface, the water content at the inside of the wall was low. Although the water content of the inside of the wall increased with that of the outer surface, the fluctuation was not sharp. One reason for the mild fluctuation can be attributed to the initially dry condition on the inside of the wall. As shown in Figure 6 and Table 2, the liquid water conductivity of Cappadocian tuff is assumed to be much less than its vapor conductivity when the water content is comparatively low (<0.3 [m^3/m^3]). Therefore, the rain or condensation might not have infiltrated into the dry tuff wall and remained instead on the surface.

According to Figure 14, freezing occurred on the surface after 18:00, as the temperature dropped. In this calculation period, wall had not frozen except its surface. The results in Figures 13–14 suggest that liquid water supplied from outdoors might have been retained on the surface for a certain time. This assumption supports the fact that the actual wall surface suffers embrittlement, whereas the inside of the wall structure is relatively tough.

Considering both the metrological data and outcomes of Case 1, we focused on the following two periods: (i) 12:00–15:00 and (ii) 18:00–20:00. In period (i), we examined the difference in liquid water infiltration for the three cases. Also, period (ii) was selected to analyze and compare the freezing characteristics of each case. Figures 15–17 show the water content distribution for each case in period (i) ((a) 12:00 and (b) 15:00).The wall depth from the surface to 5 mm is represented in Figures 15–17. In the same way, Figures 18–20 illustrate the ice content distribution in period (ii) ((a) 18:00 and (b) 20:00).

In Figures 15–17, all cases show that the water content at the surface and at a depth of 1 mm gradually increased with time. However, the moisture condition at depths of more than 1 mm hardly changed.

Compared with Case 1, Case 2 (uniform treatment) displays lower water content on the surface at 15:00. This is attributed to the restriction on liquid water infiltration due to the water repellent. For Case 3, Figure 17(b) indicates that liquid water penetrated the inside of the wall through an untreated area. By contrast, the surface water content in the treated area was as low as that in Case 2 at 15:00. An untreated area can cause local deterioration.

In Figures 18–20, each case illustrates ice content distribution similar to the water content distribution. The wall surface of Case 1 froze uniformly. Case 2 showed the lowest ice content of all cases. In Case 3, ice content in the area surrounding the untreated spot was highest, whereas that at the treated surface was as low as that in Case 2.

As mentioned, the ice content of each case fluctuated in the same way as its water content. In other words, freezing occurred in the areas with higher water content. This outcome suggests that the ice distribution is highly related to water-infiltration control. Based on this numerical analysis, we can conclude that uniform water-repellent treatment (Case 2) is successful for the preservation of the wall surface, given the low water/ice content in the case. However, water/ice distribution is deeply affected by environmental condition, and therefore uniform treatment might not always be suitable.

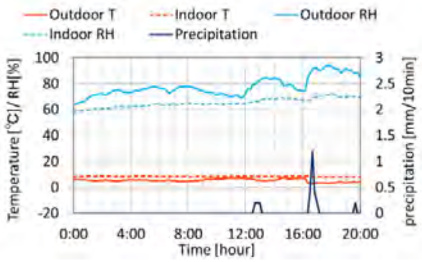


Figure 11. Outdoor/Indoor boundary conditions

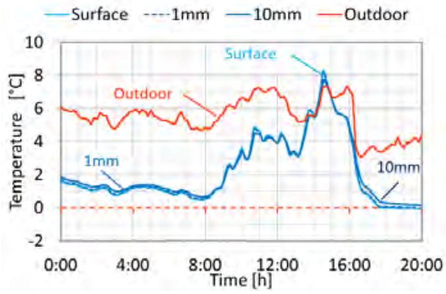


Figure 12. Temperature fluctuations (Case 1)

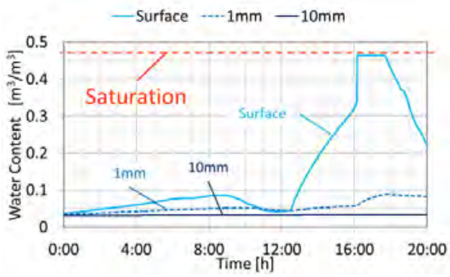


Figure 13. Water content fluctuations (Case 1)

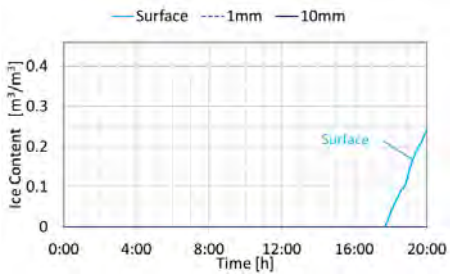
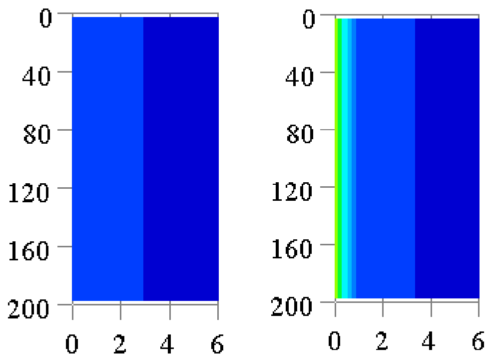
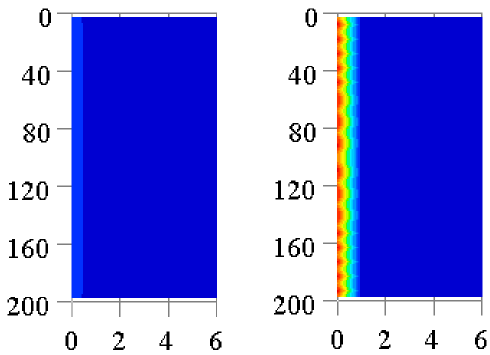


Figure 14. Ice content fluctuations (Case 1)



(a) 12:00 (b) 15:00

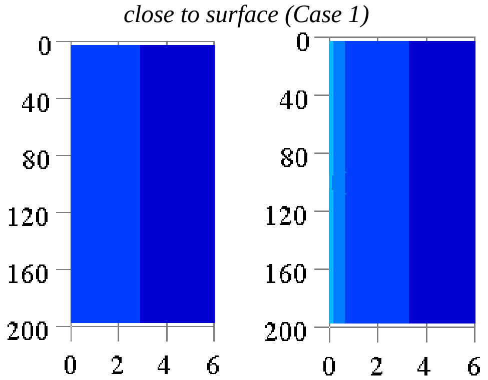
Figure 15. Water content distributions in area close to surface (Case 1)



(a) 18:00 (b) 20:00

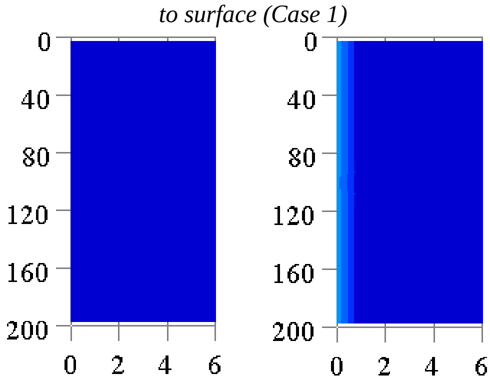
Figure 18. Ice content distributions in area close to surface (Case 1)

Water content [m^3/m^3]



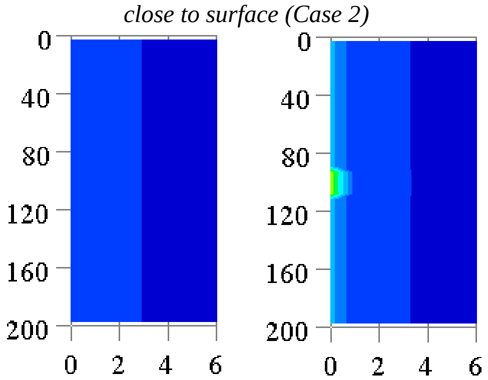
(a) 12:00 (b) 15:00

Figure 16. Water content distributions in area close to surface (Case 2)



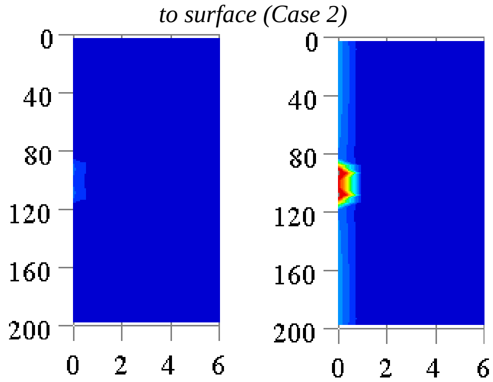
(a) 18:00 (b) 20:00

Figure 19. Ice content distributions in area close to surface (Case 2)



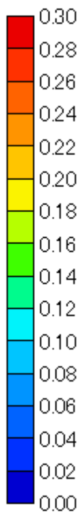
(a) 12:00 (b) 15:00

Figure 17. Water content distributions in area close to surface (Case 3)



(a) 18:00 (b) 20:00

Figure 20. Ice content distributions in area close to surface (Case 3)



Ice content [m^3/m^3]

CONCLUSION

This study was conducted to examine and evaluate the effects of water-repellent surface treatment on ice and moisture distribution in the tuff walls of Üzümlü Church in their actual environment. First, the adsorption isotherm, liquid water conductivity, and thermal conductivity of the tuff were estimated from measured data. Subsequently, a numerical model of the tuff wall was developed. Using this model, simultaneous heat and moisture transport in the wall were numerically analyzed. From the results, the following were revealed:

- The arid environmental conditions desiccate the inside of the church walls. Therefore, liquid water infiltration of the wall through the outer surface will take certain time.
- Uniform treatment with water-repellent consolidant, a practically feasible procedure, reduces water infiltration, thereby reducing the

occurrence of freezing. Therefore, such a treatment will be effective in preventing deterioration caused by water, including frost damage.

- Untreated spots in the treated surface allow water to penetrate into the wall, and thereby cause topical freezing.
  Thus, untreated areas promote direct or proximate local deterioration.

Summarizing these results, we conclude that surface treatment involving application of a water-repellent consolidant is thought to be effective for preventing deterioration caused by water. However, as shown in Cases 2 and 3, the treatment of an area may be responsible for a change in the water distribution in the wall. A further study of the relationship between the treated area and deterioration must be conducted.

This study also suggests that surface treatment with water repellent can effectively delay deterioration speed. Such treatments may be applicable to other historical heritage sites and buildings constructed from porous materials such as stone, provided that the environmental conditions, deterioration mechanisms, and material properties are carefully considered.

ACKNOWLEDGMENTS

The authors would like to thank MEXT/JSPS KAKENHI(24101014) and the Kajima Foundation for their financial support on this project. The Üzümlü Church project has been supported by numerous individuals in both Turkey and Japan, especially staff members of the Nevşehir Restoration and Conservation Regional Laboratory Directorate.

REFERENCES

Campbell, G.S. 1985. Soil physics with BASIC: transport models for soil-plant systems, Elsevier, vol. 14,.

Dane, J.H. and Hopmans, J.W. 2002. Water retention and storage, In Methods of Soil Analysis, Part 4. Physical Methods. (J.H. Dane and G.C. Topp, Eds.) SSSA Book Series No.5. 675-690.

Erguler, Z.A. 2009. Field-based experimental deterioration of the weathering rates of the Cappadocian tuffs, Engineering Geology, vol. 105, 186-199.

Fukui, K., et al. 2016. Effects of waterproof or repelling agent on water transfer and accumulation of building materials (part1) Liquid moisture conductivity of water repellent, Proceedings of Annual Meeting of Architectural Institute of Japan Kinki Branch, No.56, 165 - 168, (In Japanese)

Hansson, K. et al. 2004. Water flow and heat transport in frozen soil, Vadose Zone Journal, vol. 3(2), 693-704.

Iba, C. et al. 2016. Environmental monitoring and surface treatment tests for conservation of the rock-hewn church of Üzümlü, Cappadocia, 13th International Congress on the Deterioration and Conservation of Stone (to be published)

Kirkham, M.B. 2005. Principles of soil and plant water relations, Elsevier Academic Press, Burlington, MA.

La Russa, M. F. et al. 2014. Cappadocian ignimbrite cave churches, stone degradation and conservation strategies. Periodico di Mineralogia, vol. 83(2), 187-206.

Matsumoto, M., Gao, Y., Hokoi, S. 1993. Simultaneous heat and moisture transfer during freesing-melting in building materials, CIB/W40 meeting, Budapest

Taniguchi, Y. et al. 2015. Scientific research for conservation of the rock hewn church of Üzümlü, Cappadocia, International Symposium of Excavations, Surveys and Archaeometry.

UNESCO, 1985. Structural conservation of Göreme. Göreme, land of fairy chimneys. Ministry of Culture and Tourism, Turkey. General Directorate of Antiquities and Museums. Author, A., 2010, Boulder, gravel and sand consist of stone, Ph.D. thesis, University of Hopes and Dreams, Country.

Van Genuchten, M. Th. 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils, Soil Science Society of America Journal, vol.44 (5), 892-898.

C. Iba, Y. Taniguchi, K. Koizumi, K. Watanabe, K. Sano C. Piao and M. Yoshioka: Enviromental Monitoring and Surface Treatment Tests for Conservation of the Rock-Hewn Church of Üzümlü, Cappadocia, Proceedings of the 13th International Congress on the Deterioration and Conservation of Stone, vol. 2, pp.1145-1152, 2016.9 (offprinting)

ENVIROMENTAL MONITORING AND SURFACE TREATMENT TESTS FOR CONSERVATION OF THE ROCK-HEWN CHURCH OF ÜZÜMLÜ, CAPPADOCIA

C. Iba[1*], Y. Taniguchi[2], K. Koizumi[3], K. Watanabe[4], K. Sano[5,] C. Piao[6] and M. Yoshioka[1]

Abstract

A project at Üzümlü Church (St. Nichita's church: the end of the seventh century AD) in the Red Valley in Cappadocia, Turkey, has been launched to establish a suitable method for conservation of the extremely soft and fragile tuff structure of the church through geo- and environmental-engineering techniques. This project aims to find a method for prolonging the life of the tuff structures of Cappadocia using material that allows retreatment and is chemically compatible with the original tuff. To understand the cause and factors of rock weathering, *in situ* environmental monitoring was conducted, particularly focusing on heat and moisture flow in the rock structure and underground. From the results, it seemed that freeze–thaw cycles would not occur frequently and would not severely damage the structure. Erosion by water infiltration derived from rain or melting snow appeared to be more harmful to the rock structure; therefore, prevention of infiltration by liquid water is emphasised in our project. An outdoor exposure test was launched to evaluate the effectiveness and aging characteristics of a water-repellent consolidant. To quantify the degree of weathering, stainless steel nails were anchored to the rock surface and their lengths were measured by local collaborators every few months using a digital calliper. The water repellents had the effect of at least delaying deterioration. This case in Üzümlü is certainly a most technically difficult challenge and could serve as a model case for new approaches to integrating, presenting and advancing ethical conservation in Cappadocia.

Keywords: rock weathering, fragile tuff, environmental monitoring, surface treatment, water repellent

[1] C. Iba* and M. Yoshioka
Department of Architecture and Architectural Engineering, Kyoto University, Japan
iba@archi.kyoto-u.ac.jp

[2] Y. Taniguchi
Faculty of Humanities and Social Sciences, University of Tsukuba, Japan

[3] K. Koizumi
Department of Global Architecture, Graduate School of Engineering, Osaka University, Japan

[4] K. Watanabe
Department of Environmental Science and Technology, Mie University, Japan

[5] K. Sano
D&D Corporation, Japan

[6] C. Piao
Hytec Inc., Japan

*corresponding author

1. Introduction

In 1985, Cappadocia was selected as a UNESCO World Natural and Cultural Heritage Site under the name 'Göreme Natural and Historical National Park' (UNESCO 1985). In this region, there are many rock-hewn churches, which often contain reliefs and wall paintings dating from Byzantine and later periods that constitute part of their historical value. However, the fabric of these churches, which acts as bodies and supports of wall paintings, is severely damaged and collapses occur due to weathering and seismic activity every year. The unique landscape of Cappadocia is composed of soft, fragile tuff. The structure of this rock suffers from stone powdering, spalling and other types of deterioration caused or exacerbated by wind and rain erosion and insolation stresses. Particularly during winter, the region receives fairly high levels of rainfall and snowfall, which may cause freezing and thawing and other severe surface problems, resulting in rapid weathering at a rate of 0.4–2.5 mm/a (Erguler 2009).

Earlier, the problems of acute cracking and erosion were commonly addressed by applying a lime-cement-based render over the tuff surface as a tentative measure, since no proposed water repellents seemed to be convincing for realistic application (Idil 1995). Although trials were conducted using an iron mesh at the capping-tuff rock interface, detachment between them always occurs because of possible water infiltration and thermal impact by intense solar radiation (Yorulmaz et.al 1995). None of the surface treatment and capping have not been effective at reducing the rate of tuff erosion. Often, intense intervention does not allow future treatments and fails to provide continuous preservation.

This project aims to find a suitable method for prolonging the life of Cappadocia's fragile tuff structures to preserve these valuable sites. This method is expected to slow the speed of erosion by application of material that is chemically compatible with the original tuff and does not involve covering the tuff with foreign material. We also aim to allow 'retreatability' in at least 10-yr intervals.

The Üzümlü Church (Fig. 1) in the Red Valley, a stand-alone rock-hewn church, was selected for this case study. The church shows deterioration phenomena such as severe cracking, surface disintegration and exfoliation caused by the environment, rock composition and tectonic activity as well as biological and human activities including continuous vandalism. The church structures have not been treated in the past, providing a unique opportunity for this type of study.

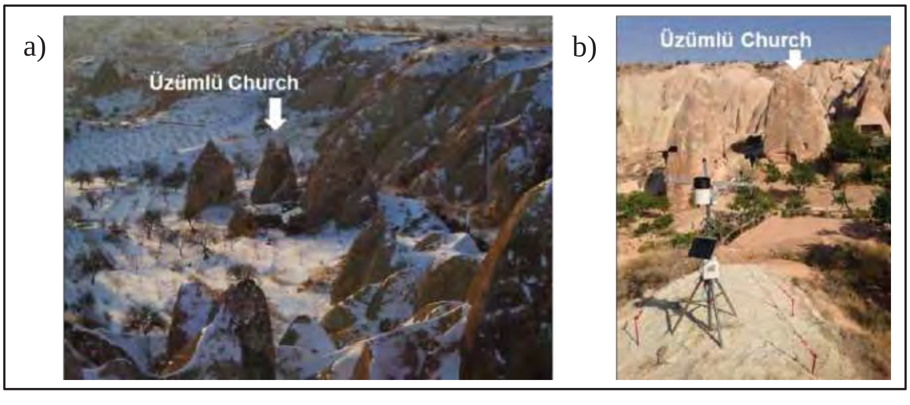


Fig. 1: Üzümlü Church (a) Appearance in winter (b) Environmental monitoring stations.

To consider the mechanism of rock weathering and preservation of rock structures, water and heat flows in the rock should be measured. Temperature and moisture behaviour in the soil and rocks were monitored at the base of Üzümlü Church. The micro-environment of the church interior and surroundings was also monitored. Based on the monitoring data obtained over 12 months, some types of alkoxysilane-based water repellents with consolidation properties (Permeate® HS-360) were selected for *in situ* tests to evaluate their effectiveness and aging characteristics.

2. Environmental monitoring

To understand the environment around the church, meteorological data, indoor temperature and humidity, soil water content, soil water potential and temperature were measured throughout the year.

2.1. Measurement outline

A set of environmental monitoring stations (Onset HOBO U30-NRC) for monitoring air temperature (*T*), relative humidity (*RH*), rainfall, wind speed/direction and solar radiation were installed near Üzümlü Church (Fig. 1b). Additionally, two sets of data loggers, HOBO U23 for RH/T, were placed in the church to monitor the indoor thermal environment. One logger was placed in the alcove near the entrance (Fig. 2 (Entrance)), and the other was set in Room 3 (Fig. 2 (Interior)). Two small pits (15 × 15 cm^2) were trenched on the south (sunny) and north (shady) sides of Üzümlü Church. As shown in Fig. 2, soil water (5TE) and potential (MPS2) sensors were horizontally inserted into the rock wall at three different depths (50, 100 and 300 mm) in each pit. The pits were refilled with the original soil. All data were recorded every 10 min.

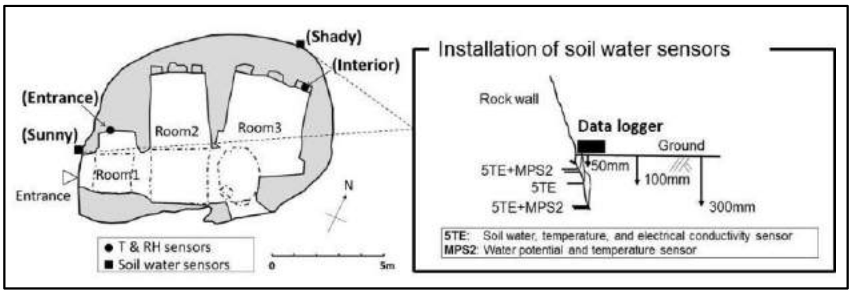


Fig. 2: Installation of environmental sensors.

2.2. Outdoor/Indoor/Ground temperatures

Fig. 3 shows the outdoor and indoor temperatures and global solar radiation (including direct and diffuse sky radiation) and the underground temperature (shady side, 300 mm depth). There are large diurnal temperature variations in the outdoor air. The temperature fluctuations in the church are smaller than those outside. The temperature near the entrance is notably affected by the outdoor air due to ventilation, whereas in Room 3, it slightly fluctuates owing to the heat capacity of the thick rock. Furthermore, the outer wall in Room 1, located on the southwest side of the church, is exposed to more solar radiation than Room 3, located on the northern side. We considered that the critical temperature associated with frost damage to soil or rock is approximately -4°C based on previous studies (Fukuda 1974, 1983). Such situations were observed only four times in the 2014–2015 season, significantly less often than that assumed.

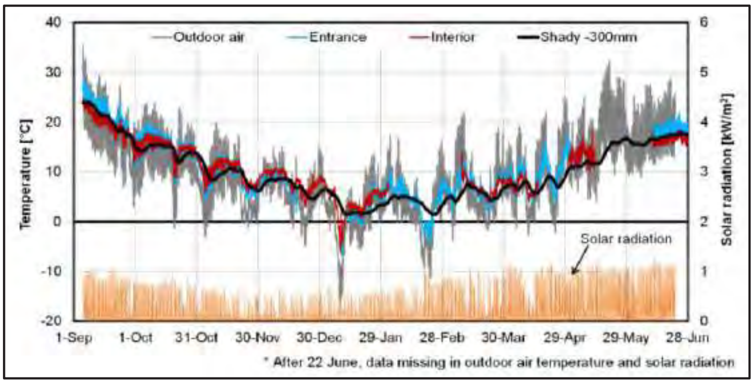


Fig. 3: Outdoor/indoor temperatures and solar radiation (September 2014–June 2015).

The underground temperatures on both the sunny and shady sides of the church are shown in Fig. 4, focusing on the winter season (December–February 2014). On the sunny side, diurnal temperature fluctuations were observed in the soil near the ground surface (50 and 100 mm depth), which may result from the effect of direct solar radiation. The temperature at 300 mm depth on the sunny side was on average a few degrees centigrade higher than that on the shady side. The underground temperature deeper than 50 mm below the ground surface did not fall below zero even in the coldest season. From these results, freezing appears to not penetrate the ground.

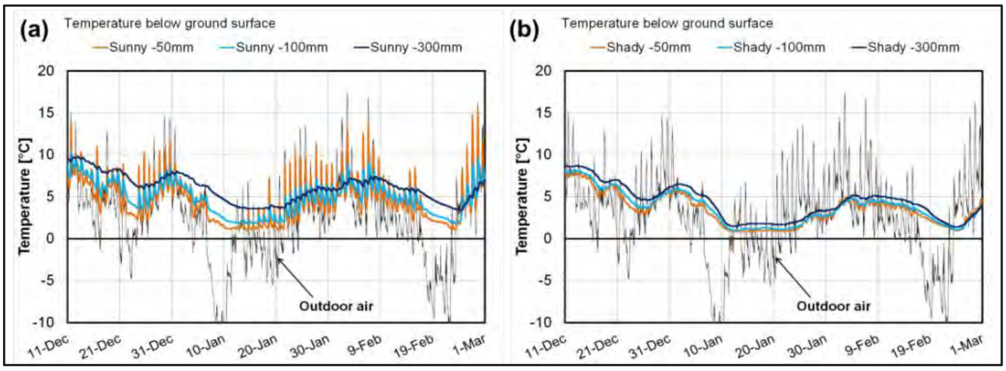


Fig. 4: Underground temperature during winter (December 2014–February 2015) (a) Sunny side (b) Shady side.

2.3. Wind speed and direction

The upper part of Fig. 5 shows wind roses, which indicate the wind direction frequency in each direction in each season (except for summer) for both daytime and night time. Particularly in autumn and spring, there is a clear difference in the wind rose between daytime and night time. Interestingly, since its installation, the weather station has consistently shown the prevailing wind direction to be north–south around Üzümlü Church (September 2014–May 2015) probably owing to the geological setting of the Red Valley. One of the reasons for the daily wind direction change might be caused by the surface temperature change of the slope behind (north of) the church. An updraft can occur near the back slope, producing a south wind. The lower part of Fig. 5 shows the cumulative frequencies of wind speeds for daytime and night time. In this area, moderate wind speeds were usually recorded, although relatively strong winds blew, mainly in the daytime, from the south. When there was slightly heavy rain (over 2.0 mm/10 min.), the wind speed was generally less than 1.5 m/s from autumn to spring. Therefore, apparently, the influence of wind direction and speed on moisture transfer in the soil or rock can be ignored in the analysis of erosion and frost damage.

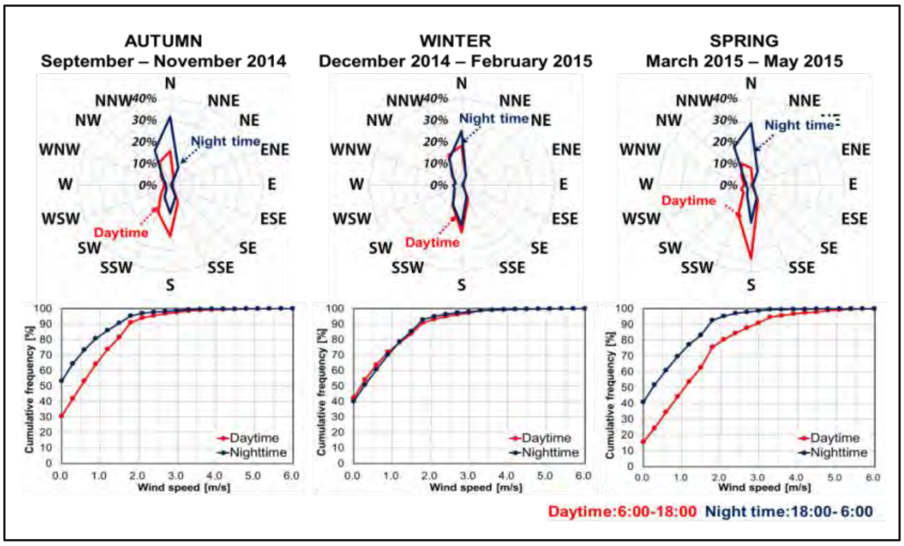


Fig. 5: Wind direction and speed near Üzümlü Church (September 2014–May 2015).

2.4. Soil water content, potential and temperature

Fig. 6a shows the soil water potential (depth: 50 and 300 mm) at the sunny and shady sides of the church and the precipitation measured at the weather station. When the soil is dry, the water potential has a large negative value. Soil water flows because of a potential gradient (Fig. 6b); therefore, the direction of water flow under the ground surface can be determined from the potential difference between depths of 50 and 300 mm.

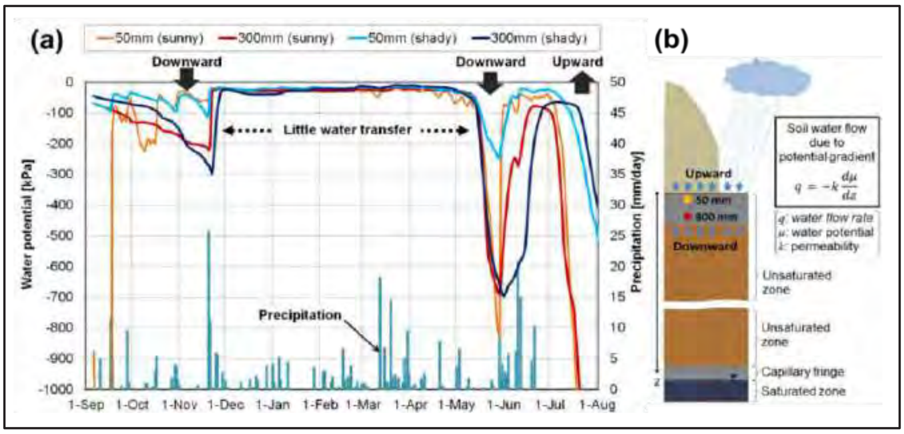


Fig. 6: Underground water potential (a) Time profile from September 2014 to July 2015 (b) Schematic of moisture flow due to water potential gradient.

Until the end of November 2014, water appeared to flow downward on both the sunny and shady sides. After heavy rain at the end of November, the water potential at all measured points rapidly increased. During winter (December–April), the water potential at each depth remained high due to periodic small precipitation, and the potential gradient became nearly zero. After April, the potential in the deeper area decreased, leading to downward water flow. In June, heavy rain appeared to occur and the potential at 50 mm depth steeply increased, then gradually increased at 300 mm depth. During summer, the moisture in the area near the ground surface was prone to evaporate and upward water flow was observed. Similar tendencies were observed in both sunny and shady sides. Based on these conditions, we can infer that the church structure did not continuously suck up significant amounts of groundwater in this area regardless of the solar radiation intensity.

In contrast, a few intervals of heavy rainfall were observed in this area, which could cause severe erosion of the fragile tuff structure. Therefore, coating with a consolidant/water repellent and reducing water infiltration to the structure are considered to be very effective for preventing degradation.

3. Rock consolidation/water repellent test on small rock masses

Based on the environmental monitoring results, an outdoor exposure test was launched to evaluate the effectiveness and durability of consolidation by surface treatment agents for tuff rocks.

3.1. Characteristics of water repellent/consolidant

In this trial, Permeate® HS-360 (D&D Corp.) was selected as a surface treatment agent after laboratory tests to identify possible consolidants and protective materials for tuff substrates (Sano and Mizukoshi 2015).

Permeate® is based on alkoxysilane containing a methyl or phenyl group, and an alkoxy group is polymerised by hydrolysis with atmospheric moisture. After polymerisation, the 3D Si–O–Si structure improves bulk strength by firmly hardening in the gaps within the object. Moreover, after polymerisation, a methyl or phenyl group is left. As these groups are hydrophobic, the substance becomes water-repellent after curing. This alkoxysilane-based consolidant does not form a film on the porous surface but penetrates and hardens at a few millimetres depth. Vapour can permeate through the consolidant layer although liquid water cannot infiltrate the layer. In practice, hydrolysis takes over 24 h.

3.2. Test rocks and testing method

Two small-scale tuff masses near Üzümlü Church were chosen for the test. Fig. 7 shows the one (b) that was splayed with the Permeate® HS-360 and the other (a) that was left untreated as a control. To quantify the degree of weathering of the tuff masses, stainless steel nails were anchored to the rock surface (Fig. 8a). Two nails were set in each direction (upper and lower parts) and on the top; i.e. each test rock contained nine nails. The nail length appearing outside the rock was measured with a digital calliper (Fig. 8b) on both right and left sides. After anchoring, the measurement error of four different measurements was checked because the rock surface was considerably uneven. The relative error for the average value was mostly within 10%. The nail length was measured by local collaborators every few months. In the 'control' mass, weathered tuff powder accumulated below the rock, and four out of the nine nails fell off the mass in the four months after anchoring. In contrast, in the 'treated' mass, the weathered deposits were generally small and only one nail fell off. As flakes of a particular suitable thickness appeared to exfoliate in some places in the 'treated 'mass in winter, deterioration might occur if moisture could accumulate in local areas of the mass. A follow-up examination will consider the possibility of frost damage.

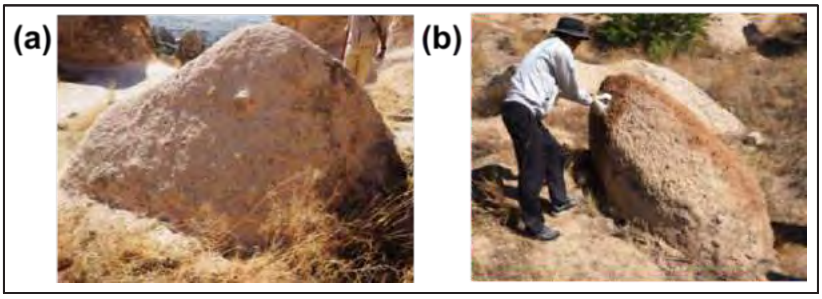


Fig. 7: Outdoor exposure test rocks: (a) Control (b) Treated mass.

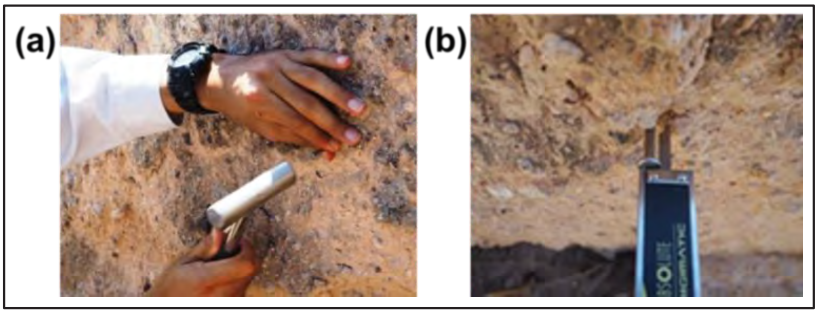


Fig. 8: Quantification of the degree of weathering
(a) Anchoring of a nail (b) Measurement of nail length.

4. Conclusions

To understand the causes and factors of rapid weathering of extremely friable tuff rock structures in Cappadocia, *in situ* environmental monitoring has been ongoing since 2014, focusing particularly on heat and moisture flow in the rock structure and underground. Freeze–thaw cycles occur infrequently and do not appear to cause severe damage to the structure. Furthermore, upward moisture flow from underground to the above-ground rock structure scarcely appeared in winter, i.e. groundwater would not be sucked up and supplied to the structure. From the results, we concluded that prevention of rainwater and infiltration water from melting snow from outside are the most appropriate measures to be taken in the project.

For that purpose, some outdoor exposure tests were carried out beforehand in Japan to assess the efficiency of the water repellent/consolidant. The test sample without water repellent broke in two weeks and collapsed in four weeks, whereas the sample with water repellent retained its shape for three months (Sano and Mizukoshi 2015). Following the results, an outdoor exposure test has been started in Cappadocia to evaluate the effectiveness and aging characteristics of the consolidant. The water repellents had the effect of at least delaying deterioration. The degree of weathering will be quantitatively evaluated through the project.

Both method and materials must be compatible with the original materials and implemented on a minimal scale to avoid excess and unnecessary treatments. Moreover, it is necessary to carefully verify whether a surface treatment might cause different damage or exacerbate deterioration of the rock structure. Although infrequent, frost damage could occur in this region. Detailed investigation of heat and moisture flow will be performed using computational analysis in future.

Due to similarities in the original technique and deterioration with other sites in Cappadocia, this study will have relevance for a wider region. The case in Üzümlü is certainly a technically difficult challenge and could serve as a model for new approaches to integrating, presenting and advancing ethical conservation in the Cappadocia region.

Acknowledgements

The authors would like to express their appreciation to MEXT/JSPS KAKENHI (24101014) and the Kajima Foundation for their financial support on this project. The Üzümlü project has been supported by numerous individuals in both Turkey and Japan, especially staff members of the Nevşehir Restoration and Conservation Regional Laboratory Directorate: Hatice Temur, Ayça Baştürkmen, Uğur Yalçınkaya, Alev Elçin Cankur, Merve Aziz Işın, Mustafa Toptepe, Tuğba Eryaşar. Director of the Nevşehir Museum: Murat Ertuğrul Gülyaz. Director of the Niğde Museum: Fazıl Açıkgöz and Ibrahim Sakınan and family.

References

Erguler, Z.A., 2009, Field-based experimental determination of the weathering rates of the Cappadocian tuffs, Engineering Geology, 105, 186-199.

Fukuda, M., 1974, Rock weathering by freezing-thawing cycles, low temperature science (in Japanese), Low temperature science. Series A, Physical Sciences, 32, 243-249.

Fukuda, M. 1983, An experiment of freeze-thaw cycles of rock specimens (in Japanese), Low temperature science. Series A, Physical Sciences, 42, 163-169.

Sano, K. and Mizukoshi, S., 2015, II-5 Preliminary aging tests (outdoor environment) of consolidants for tuff rock samples, in Scientific Studies on Conservation for Üzümlü Church and its Wall Paintings in Cappadocia, Turkey, Taniguchi, (ed.), Annual report on the activities in 2014, University of Tsukuba, 37-41.

UNESCO, 1985, Structural conservation of Göreme. Göreme, land of fairy chimneys. Ministry of Culture and Tourism, Turkey. General Directorate of Antiquities and Museums.

Yorulmaz, M., Ahunbay, Z. 1995, Structural Consolidation of El Nazar Church, In The Safeguard of the Rock-Hewn Churches of the Göreme Valley (Proceedings of an International Seminar, Ürgüp, Cappadocia,Turkey, 5–10 September 1993), 135–142. Rome: ICCROM, 1995.

Idil, A, Ç., 1995, Testing three products in Göreme valley, Cappadocia, In The Safeguard of the Rock-Hewn Churches of the Göreme Valley (Proceedings of an International Seminar, Ürgüp, Cappadocia,Turkey, 5–10 September 1993), 143–149. Rome: ICCROM, 1995.

K.Koizumi, K.Watanabe,C.Iba,C.Piao, K.Sano, Y.Taniguchi、Field Research for understanding the weathering process of rock-hewn church in Cappadocia –First report of the field survey-、第50 回地盤工学研究発表会梗概集、2015 年9 月、地盤工学会、pp.27-28（転載）

カッパドキア岩窟教会の風化メカニズムに関する調査研究 －初回調査報告－

世界遺産　割れ目　水分浸透

大阪大学　国際会員　○小泉　圭吾
ハイテック　非会員　朴　春澤
三重大学　正会員　渡辺　晋生
京都大学　非会員　伊庭千恵美
筑波大学　非会員　谷口　陽子
ディ・アンド・ディ　非会員　佐野　勝彦

1.はじめに

トルコの中央アナトリアに位置するカッパドキアは 6000 万年前の火山噴火で堆積して形成された凝灰岩の地盤が浸食を受け，キノコや煙突のような奇岩として存在すること，またこの奇岩が 4 世紀頃からキリスト教徒の教会洞窟として用いられたことから，自然遺産，文化遺産としての価値が高く，1985 年に複合遺産として世界遺産に登録された。一方，これらの岩窟は雨水による乾湿の繰返し，冬場の積雪による凍結破砕や浸食を受け，年々風化，劣化が進み，その保存に対する対策が喫緊の課題となっている。そこで本研究は，カッパドキア，Red Valley にある岩窟教会(ウズムル教会)を対象に，上述した風化・劣化現象の発生メカニズムとその特性を理解し，最終的には現地の管理者自らがこの劣化現象を抑制，緩和することができる対策手法を提案することを目的に研究を開始した。本報告では，2014 年 9 月に行った地質調査と観測機器設置に関する概要を報告する。

2.対象地の地質概況

2.1 周辺地質

中央アナトリアの大部分が海抜 1,000m ほどの高地になっている。トロス山脈と平行して，エルジェス山とハッサン山など大きな火山が存在する。これらの火山の噴火により，中央アナトリアに渡って，新第三紀～第四紀の火山岩が東西方向に広く分布している。

また，北アナトリア断層と東アナトリア断層に制御され，カッパドキア周囲（**図 1**）には，NW-SE，EN-WS 方向の断層（赤破線）が多く存在する。これらの断層の影響を受け，地域内の地盤，同方向を示すリニアメントが多く確認できる。

2.2 対象岩窟の風化状況

ウズムル教会（**図 2**）は観光名所ギョレメの東北に位置する Red Valley にある。このエリアも同様，NW-SE，EN-WS 方向のリニアメントが発達している。また Red Valley 自体は東部の隆起に伴う表流水の浸食によって形成された谷筋である。周辺の地質踏査では，両岸と斜交あるいは平行する割れ目（**写真 1**）が多く確認された。これらの割れ目付近は，岩盤崩落の発生及び浸食を受けやすい箇所になる。教会を挟んで，すぐ上流側に売店岩窟，下流側にワイナリーがある。隣接するこの３つの岩窟は元々岩盤として一体だったものが，割れ目に沿った浸食作用で，分断されたものと考えられる。

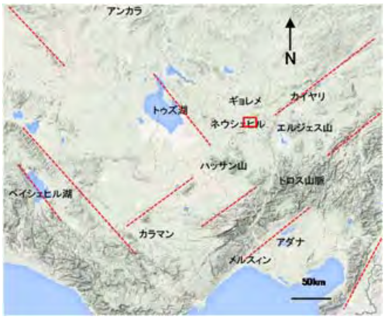


図 1 中央アナトリア地形概況

図 2 ウズムル教会周辺地形状況

写真 1　ウズムル教会周辺地形状況

また，教会岩窟の外壁には割れ目に起因する崩落跡が多数残っている。崩落の発生原因については，割れ目に沿った降雨，降雪による水の浸透・浸食，あるいは凍結融解の繰り返しによる要因が考えられる。特に北西面に走っている割れ目（**写真 2-左側**）が谷筋とほぼ平行，N50° E の角度で教会に貫通していることが内部からも確認できる（**写真 2-右側**）。さらに，内部天井部の割れ目に水分の移動によるものと考え

Field Research for understanding the weathering process of rock-hewn church in Cappadocia –First report of the field survey-

K.Koizumi(Osaka University), K.Watanabe(Mie University), C.Iba(Kyoto University),C.Piao(Hytec), K.Sano(D&D) and Y.Taniguchi(Tsukuba University)

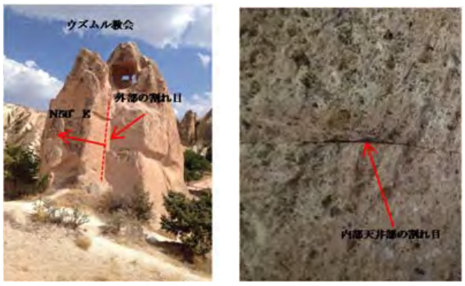


写真 2　ウズムル教会割れ目状況

られる石灰質の堆積物が確認された。このことから，外部からの水の浸入が教会内部の環境に影響を与えている可能性が示唆された。

教会岩窟の外壁は表層風化が進んでおり，簡易針貫入試験で 4～6kN/m^2 程度であった。日照時間の短い北側では若干高い値を示したが，全体的に風化が進行していることが確認された。以上のことから，対象岩窟の安定性を維持するためには，割れ目とともに，表層風化に対する対策が必要である。

3.観測システムの構築

3.1 観測手法

本調査では，対象岩窟の乾湿繰返し，および凍結融解に伴う風化，劣化のメカニズム解明を最終目的とし，**図 3** に示す観測機器を設置した。まず，岩窟教会周辺の気象環境を把握するためのウェザーステーション，対象岩窟と表層地盤間の水分移動を観測するための土壌水分計，水分ポテンシャル計および，岩窟教会内部の温湿度変化，地盤内部の地温変化を把握するための温湿度計および地温計をそれぞれ設置し，2014 年 9 月末より観測を開始した。土壌水分計，水分ポテンシャル計および地温計は，日射の影響を考慮し対象岩窟の北側と南側に，温湿度計は入口付近と奥側にそれぞれ設置した。計測は 10 分間隔とし，データは各計器に接続されたロガーに記録される。記録されたデータはトルコ側の共同研究者によって定期的に収集され，日本側の研究者と共有する体制を構築した。

3.2 観測結果

(1) 冬期の外気，窟内，地中温度

図 4 は観測期間中の外気温が最低気温を示した 2015 年 1 月 9 日を中心に，前後約 1 週間の外気，窟内および地中内の温度変化を示した図である。この内，窟入口についてはデータロガー不良のため，1 月 10 日以降のデータのみを表示している。1 月 6 日夜間から外気温が 0℃を下回り，1 月 9 日には観測期間中最低となる約-16℃を示した。これに対し，窟奥の 1 月 6 日夜間の温度は 4℃程度であり，1 月 9 日には最低温度となる-6℃を示し，この時点での外気との差は約-10℃であった。窟入口に設置した温度計は窟奥よりも若干低い温度変化を示しており，窟奥と比較して外気の影響を受けていることがわかる。一方この間，地中深度 5cm，10cm，30cm の地温が 0℃を下回ることは無かった。

(2)冬期の体積含水率，サクション

図 5 は観測期間である冬期の降雨（降雪を含む）と**図 3** に

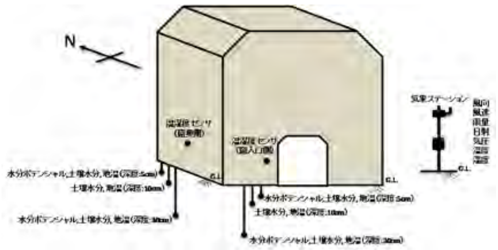


図 3　気象観測機器の設置概要

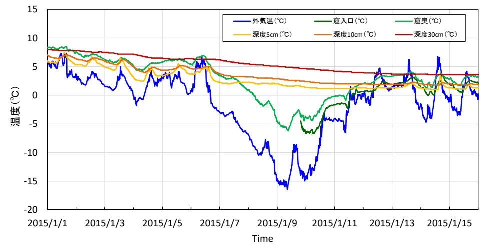


図 4　冬期の外気，窟内，地中温度の関係

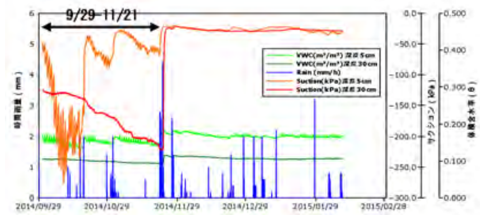


図 5　冬期の降雨（降雪）と土壌水分，水分ポテンシャル

示す窟南側深度 5cm および 30cm に埋設した体積含水率，サクションの関係を示した図である。この図より，9 月 29 日から 11 月 21 日の期間において，深度 5cm では降雨に伴う体積含水率，サクションの変動がみられるものの，深度 30cm においては単調に減少しており，緩やかな重力排水が生じている。一方，11 月 21 日の降雨により，深度 5cm と同様，深度 30cm においても体積含水率，サクションの反応がみられ，その後，特にサクションの値がほぼ一定に推移していることがわかる。この原因は 11 月 21 日以降の断続的な降雨あるいは降雪による影響であるものと推測されるが，詳細な考察は今後の課題である。

4.まとめ

本報告では，対象となるカッパドキア岩窟教会周辺の地質と観測機器設置に関する初回調査概要を纏めた。その結果，岩窟教会は周辺岩盤と同様，割れ目の発達，風化の進行が進んでいることが確認された。また，今回設置した観測システムより，冬期の一部限定された結果ではあるが，外気，窟内および地中温度の関係，降雨（降雪）と地中内の体積含水率およびサクションの関係を把握することができた。今後は，観測を継続すると共に，現地試料を用いた乾湿繰返し，凍結破砕に関する室内実験と窟周辺地盤をモデル化することで，対象岩窟の劣化メカニズムに関する研究を進める予定である。

謝辞：共同研究先であるトルコ・ネブシェヒール博物館のムラート氏，修復研究所のファージル氏らには多大なる協力を賜った。また，本研究は JSPS 科研費（24101014）の助成を受けたものです。またここに記して謝意を表します。

Ⅱ –9 Scientific Research for Conservation of Rock Hewn Church, Üzümlü(Cappadocia) in 2015: Chapel of Niketas The Stylite in Red Valley

Üzümlü(Kapadokya)'da Bulunan Kaya Oyma Kilisenin Korunmasi İcin 2015'de Yürütülen Bilimsel ÇaliŞmasi : KizilÇukur Vadisindeki Stilit NiketsS Şapeli

Yoko Taniguchi
Keigo Koizumi
Chiemi Iba
Kunio Watanabe
Katsuhiko Sano
Piao Chunze
Hatice Temur
Ayça Baştürkmen
Uğur Yalçınkaya
Mustafa Toptepe

1. INTRODUCTION

A project at Üzümlü Church in the Red Valley of Cappadocia, Turkey was launched in 2014 with two primary objectives: conserving the soft, fragile tuff structure of the church through geo- and environmental-engineering methods, and conserving interior wall paintings while conducting a scientific study of their technology. The church structure and wall paintings had not been treated in the past, presenting a unique opportunity for this type of study. The project aims to find a suitable method for prolonging the life of Cappadocia's fragile tuff structures and the paintings they shelter, through the use of 'retreatable' conservation materials. Often, intense intervention does not allow for future treatment, and fails to allow for continuous preservation. Due to similarities in the techniques and deterioration of structures and paintings across Cappadocia's sites, this study will have relevance for the greater region.

1. GİRİŞ

2014 yılında, Kapadokya'nın Kızılçukur Vadisi'nde bulunan Üzümlü Kilisesi'nde iki temel amacı gerçekleştirmek üzere bir proje başlatıldı. Bu amaçların ilki jeoloji mühendisliği ve çevre mühendisliği teknikleri kullanılarak kilisenin yumuşak ve kırılgan tüf yapısını korumak. İkinci amaçsa kilisenin iç duvarlarındaki duvar resimlerini korumak ve bu resimlerin yapımında kullanılan teknoloji üzerine bilimsel bir çalışma gerçekleştirmek. Kilisenin yapısı ve duvar resimleri geçmişte onarılmamış olduğu için bu tarz bir çalışma için eşsiz bir fırsat sunmaktadır. Bu proje, "tekrar onarılabilen" koruma materyallerinin kullanımıyla Kapadokya'nın kırılgan tüf yapıları ve içlerinde barındırdıkları duvar resimlerinin ömrünü uzatmak için uygun bir yöntem bulmayı hedeflemektedir. Koruma amacıyla gerçekleştirilen yoğun müdahaleler çoğu zaman gelecek onarım işlemlerine izin vermemekte ve sürekli bir korumayı mümkün kılmamaktadır. Kapadokya'nın farklı bölgelerindeki yapıların ve duvar resimlerinin yapım teknikleri ve bozulma biçimleri benzerlik gösterdiğinden dolayı bu çalışma tüm bölge için önemli olacaktır.

2. A comparative look at documentation from 1968–1970 and the present

2. 1968–1970 yılları arasındaki ve günümüzdeki belgeleme işlemlerine karşılaştırmalı bir bakış

A team from Tokyo National University of Fine Arts and Music (currently, Tokyo National University of the Arts) conducted research surveys in Cappadocia in 1968 and 1970. The team consisted of young architectural historians, art historians and artists such as Masaru Maeno and Yasushi Nagatsuka. They successfully measured and photographed hundreds of caves using tools and methods that were traditional or unique, such as a fishing rod. A comparison of photographs from 1968/70 and 2015 (Figure 1a, b) shows minimal to no change in the wall paintings other than recent graffiti. This means that the wall paintings are quite stable and intact.

Tokyo Devlet Güzel Sanatlar ve Müzik Üniversitesi'den (Günümüzdeki adıyla Tokyo Devlet Sanat Üniversitesi) bir ekip Kapadokya bölgesinde 1968-1970 yılları arasında bir takım araştırmalar yapmıştır. Bu ekip, Masaru Meno ve Yasushi Nagatsuka gibi genç sanatçılar, mimari ve sanat tarihçilerinden oluşmaktaydı. Ekip geleneksel yöntemlerle birlikte bir olta kullanmak gibi bazı sıra dışı yöntem ve araçlar da kullanarak yüzlerce mağarada ölçüm yapıp bu mağaraları fotoğraflamıştır. 1968-1970 arasında ve 2015'te (1a ve b görselleri) çekilmiş fotoğraflar kıyaslandığında, yakın zamanda yapılmış duvar yazısı örnekleri dışında duvar resimlerinde ya hiç değişiklik olmamış ya da gerçekleşen değişimler asgari düzeydedir. Bu da duvar resimlerinin dayanıklı ve sağlam olduğunu göstermektedir.

Figure 1a. Inside of Üzümlü church in 2015 (left) and 1968/70 (right)
Görsel 1a. Üzümlü Kilisesinin içi, 2015 yılı(sol) 1968/70(sağ)

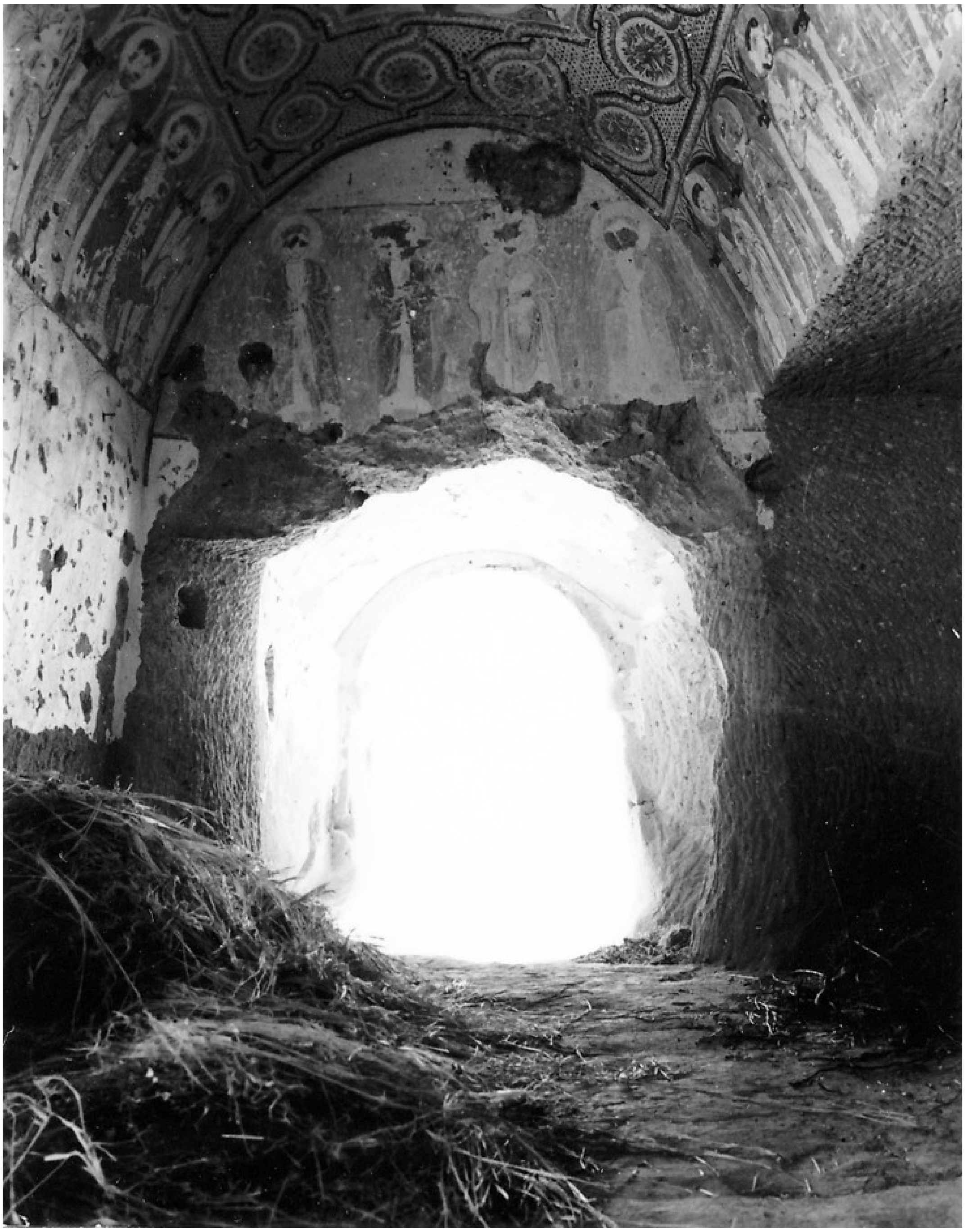


Figure 1b. Transformation from a monastery to a stable for animals was already done by 1970. A pile of hay is seen in the Nave. Interior condition seems to be unchanged.
Görsel 1b. Kilise 1970 yılında çoktan bir manastırdan ahıra dönüştürülmüştü. Nef kısmında saman yığını görülebiliyor. İçerisinin durumu değişmemiş görünüyor.

In 2015, a 3D land survey was carried out in and around the Üzümlü Church. The narthex (Ch1), nave (Ch2), altar (Ch3) and two extended rooms are located in the lower part of the rock mass (Figure 2).

Figure 3 shows two surveys, one from 1968/70 (right) and one from 2015 (left). Together these indicate that the north-eastern side of the exterior surface has been eroded to a great degree.

2015 yılında Üzümlü Kilisesi ve çevresinde üç boyutlu arazi taraması yapıldı. Narteks (Ch1), Nef (Ch2), sunak (Ch3) ve iki tane uzatılmış oda kaya kütlesinin alt kısmında bulunmaktadır (Görsel 2). 3. Görselde biri 1968/70 (sağdaki) diğeri 2015 (soldaki) yıllarında yapılmış iki tarama görülebiliyor. İki tarama beraber incelendiğinde dış yüzeyin kuzeydoğu yönünün büyük ölçüde aşınmış olduğu görülüyor.

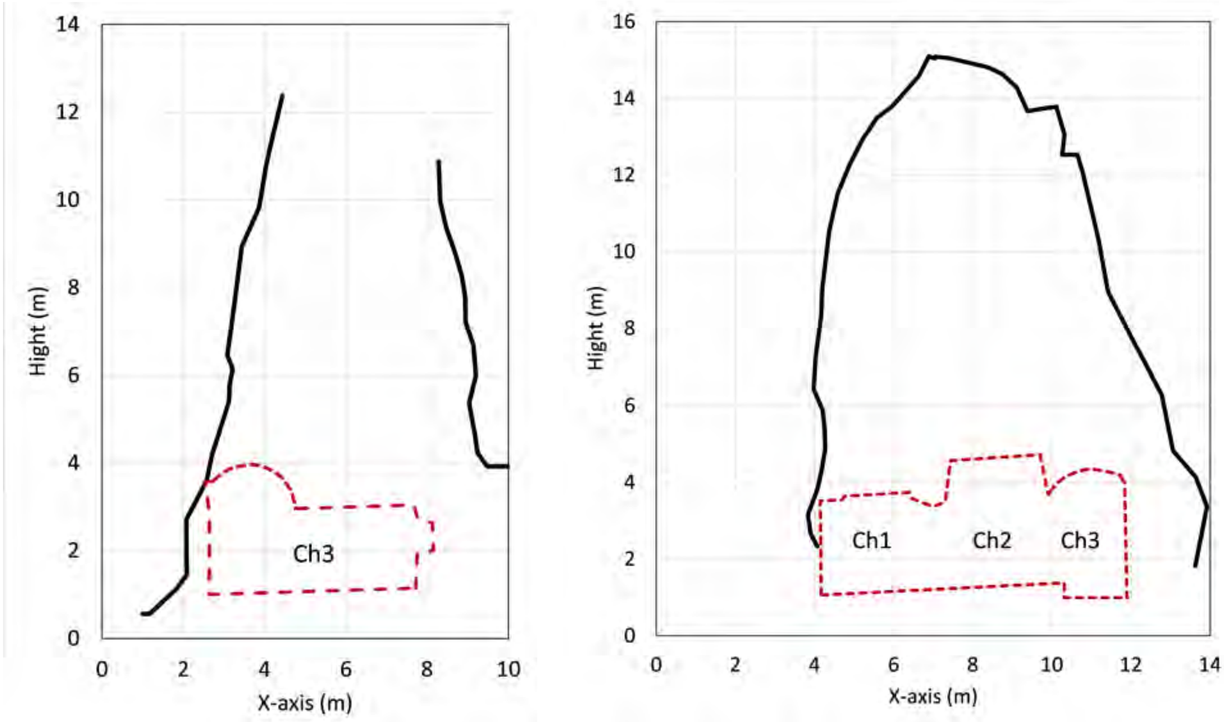


Figure 2. Cross-section view N-S (left) and E-W (right).
Görsel 2. Enine kesit. Kuzey-Güney (soldaki) ve Doğu-Batı (sağdaki).

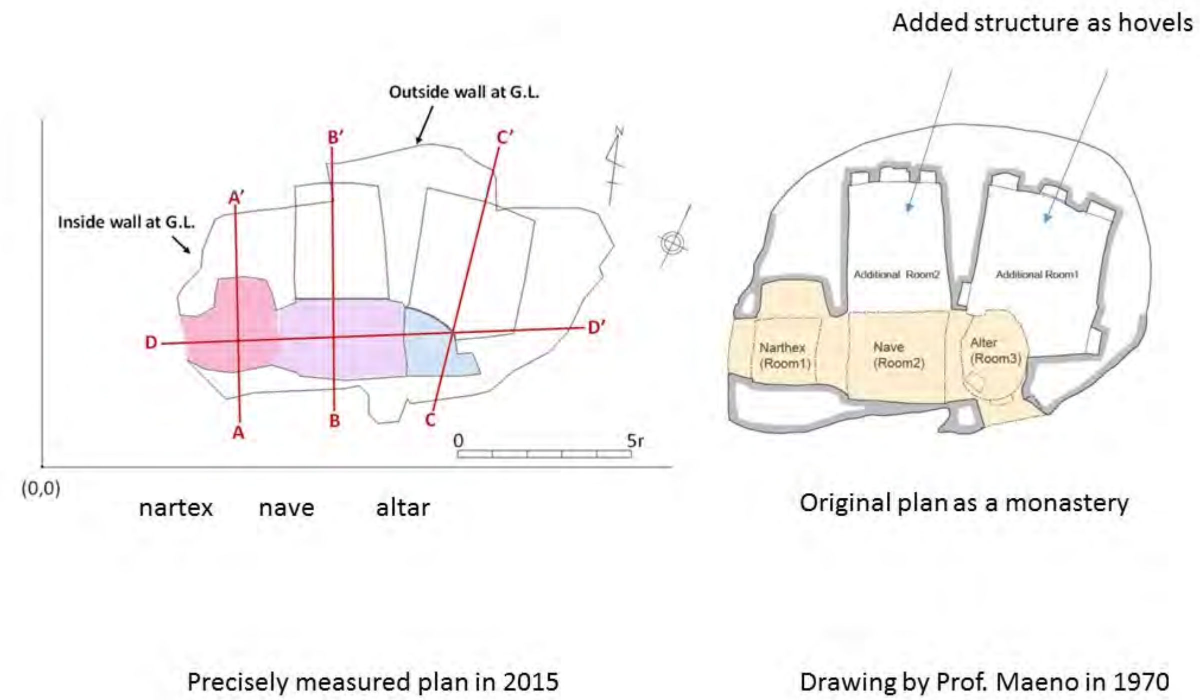


Figure 3a. Comparison of measurements between 2015 (left) and 1968/70 (right)
Görsel 3a. 2015 (soldaki) ve 1968/70 (sağdaki) yıllarında yapılmış ölçümlerin karşılaştırması.

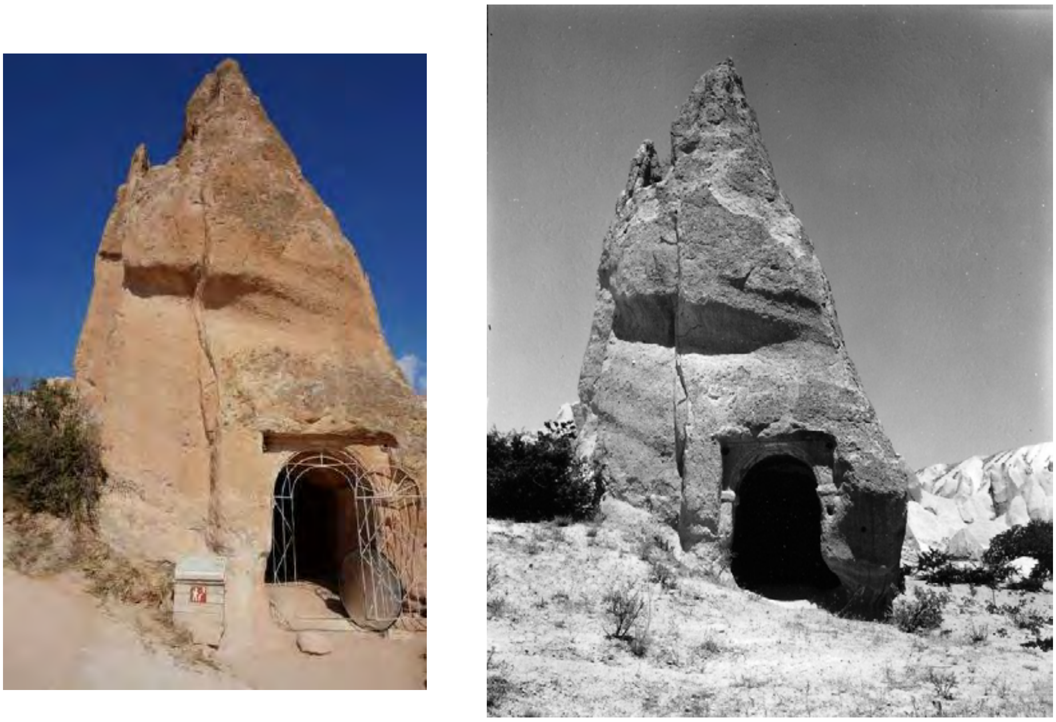


Figure 3b. Comparison of the exterior between 2015 (left) and 1968/70 (right)
Görsel 3b. 2015 (soldaki) ve 1968/70 (sağdaki) yıllarında dış yapının karşılaştırması.

Figure 3c. Condition of the top part of the church in 2015.
Görsel 3c. 2015 yılında kilisenin üst kısmının durumu.

3. ENVIRONMENTAL STUDIES INSIDE AND OUTSIDE OF THE CHURCH

3.1 Maintenance

First, the weather station and all measurement data both inside and outside the church were carefully checked. Unfortunately, the data logger ceased functioning on 21 June, 2015 for reasons unknown. Waterproof casing on devices seemed to retain moisture internally, and therefore evidenced a risk of damage; in their place, umbrella-shaped rain covers were installed around the devices to protect them. Then, all batteries were checked and replaced to ensure proper procurement of data.

3.2 Survey of indoor environment

The temperature of the indoor wall surface was measured at 8 different points in the church and the airflow was checked in order to examine the risk of surface condensation. Surface condensation would cause pigment loss in the wall paintings due to an apparent lack of binding media. Furthermore, it would trigger soluble salt problems in the wall paintings. Therefore, accurate assessment of any possibility of condensation on wall surfaces was essential.

Dew condensation would occur whenever indoor surface temperatures fall lower than the dew point temperature of indoor or incoming outdoor air. Therefore, temperatures at the floor corner and ceiling were measured for comparison.

Figures 4a-4c show the time profile of the measured temperatures at each point. The amplitude of the air temperature was lowest in Chamber 3 (Inside). The floor temperatures (2FR, 2FL, 3FR, 3FL) were generally lower than the air (room) temperature by 1-3°C in the daytime, whereas the ceiling temperatures (2C, 3C, 3CL) were higher. In chamber 1, the wall surface temperature was very close to the room temperature.

In 2015, the relative humidity inside the church remained in the range of 30-55%. Figure 4d shows a comparison of the floor temperature (the lowest in the church) and the dew point temperature of the outdoor air. The graph indicates that condensation would not occur if outdoor air entered the church. As the inner surface temperature is not expected to differ much from the indoor air temperature, it is permissible

3. KİLİSENİN İÇİNDE VE DIŞINDA GERÇEKLEŞTİRİLEN ÇEVRE ÇALIŞMALARI

3.1 Bakım

İlk olarak hava istasyonunun ve kilisenin içindeki ve dışındaki ölçümlerin verileri dikkatlice incelenmiştir. Ne yazık ki veri toplayıcı bilinmeyen sebeplerden ötürü 21 Haziran 2015'te bozulmuştur. Cihazların su geçirmez kılıfları nemi içeride tuttuğu için cihazda hasar oluşturma riski olduğundan onların yerine cihazları korumak için üstlerine şemsiye şeklinde muhafazalar yerleştirildi. Sonrasında ise kesintisiz bilgi toplanmasını sağlamak için tüm piller kontrol edilip değiştirildi.

3.2 İç ortamın incelenmesi

Yüzey yoğuşması riskini belirlemek için kilisenin iç duvar yüzeylerinin sıcaklığı sekiz farklı noktada ölçüldü ve hava akışı incelendi. Görünür bir bağlayıcı malzeme eksikliğinden dolayı yüzey yoğuşması duvar resimlerinde pigment kaybına neden olabilir. Ayrıca çözülebilir tuzların çözülmesini tetikleyip sorunlar yaratabileceğinden duvar yüzeylerinde gerçekleşmesi olası bir yoğuşmanın doğru bir şekilde tayin edilmesi gerekmekteydi.

İç yüzey sıcaklığının içerideki ya da içeri giren dış havanın çiğ oluşma sıcaklığının altına düşmesi çiğ yoğuşmasına sebep olacağından zemin köşelerinin ve tavanın sıcaklıkları karşılaştırma yapmak amacıyla ölçüldü.

4a, 4b ve 4c görselleri her bir noktada yapılan sıcaklık ölçülerinin zamana bağlı grafiğini göstermektedir. Üçüncü odacık (içerisi) en düşük hava sıcaklığı genliğine sahipti. Zemin sıcaklıkları (2FR, 2FL, 3FR, 3FL) odaların hava sıcaklıklarından gündüz vaktinde genellikle 1-3°C düşükken tavan sıcaklıkları (2C, 3C, 3CL) daha yüksektir. Birinci odacıktaki duvar yüzeyi sıcaklıkları odanın sıcaklığına oldukça yakındır.

2015 yılı süresince kilisenin içindeki bağıl nem %30-%55 arasında seyretmiştir. 4d görseli zemin sıcaklıkları (kilise içindeki en düşük sıcaklık) ile dışarıdaki havanın yoğuşma noktası arasındaki karşılaştırmanın grafiğidir. Bu grafik dışarıdaki havanın kiliseye girmesi halinde yoğuşma gerçekleşmeyeceğini göstermektedir. İç yüzey sıcaklıklarının iç hava sıcaklığından çok farklı olması beklenmediğinden iç

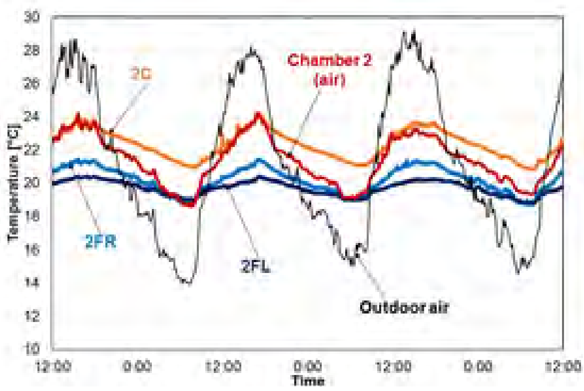


Figure 4a. Measured temperature in Chamber 2
Görsel 4a. 2. Odacıktaki ölçülen sıcaklık

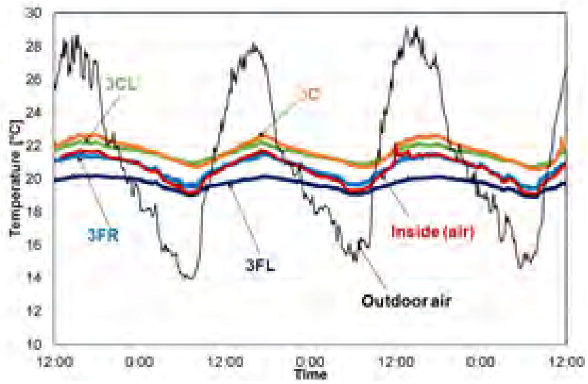


Figure 4b. Measured temperature in Chamber 3
Görsel 4b. 3. Odacıktaki ölçülen sıcaklık

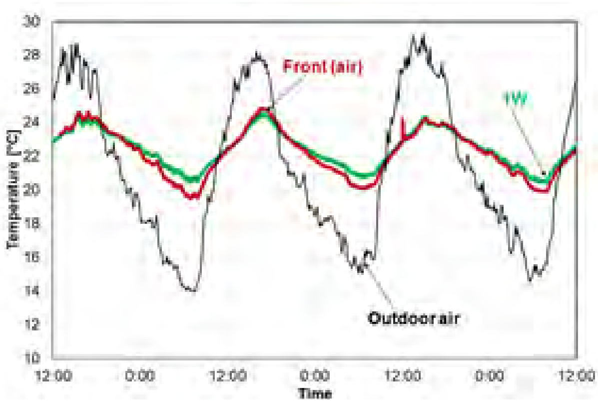


Figure 4c. Measured temperature in Chamber 1
Görsel 4c. 1. Odacıktaki ölçülen sıcaklık

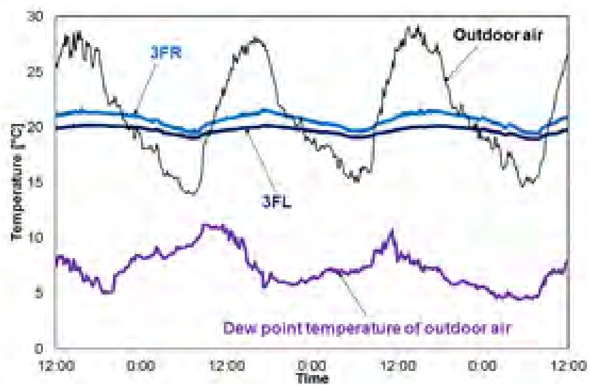


Figure 4d. Judgement of condensation
Görsel 4d. Yoğuşma Grafiği

to ascertain the likelihood of condensation based on the indoor air temperature.

Airflow speed and direction were checked at several points in the church to obtain basic data for estimating the ventilation rate between outdoor and indoor air. Wind speed near the entrance and the window were measured at 15 second intervals throughout the day and night.

Figure 5 shows the indoor wind speed (at 15 second intervals) and its moving average (per 5 minutes) during the daytime compared to the outdoor wind speed (10 minute average). Figure 6 shows the case of nighttime in chamber 3. In chamber 3, the average wind speed did not exceed 0.2 m/s even in the daytime. The wind speed near the entrance varied in accordance with the outdoor wind speed, and was greater than that in chamber 3. These results will be used to further investigate ventilation in the church.

hava sıcaklığına bakarak yoğuşma ihtimalini kesinleştirmek büyük oranda mümkündür.

İçerideki ve dışarıdaki hava arasındaki havalandırma hızını hesaplamak için hava akış yönü ve hızı kilisenin bazı noktalarında ölçülmüştür. Giriş ve pencere yakınındaki rüzgar hızı gündüz ve gece boyunca 15 saniyelik aralıklarla ölçülmüştür.

5. Görsel gündüz saatlerinde içerideki rüzgar hızının (15 saniyelik aralıklarla) ve bu hızın hareketli ortalamasının (5 dakikada bir) dışarıdaki rüzgar hızı (10 dakikalık ortalama) ile karşılaştırılmasını göstermektedir. 6. Görsel ise gece süresince 3. Odacıktaki durumu göstermektedir. 3. Odacıkta ortalama rüzgar hızı gündüz saatlerinde bile 0.2 m/s'yi geçmemiştir. Girişin yakınında ölçülen rüzgar hızı dışarıdaki rüzgar hızına bağlı olarak değişmekte olup 3. Odacıktaki rüzgar hızından yüksektir. Bu sonuçlar kilisenin içindeki hava akışını daha detaylı incelemek için kullanılacaktır.

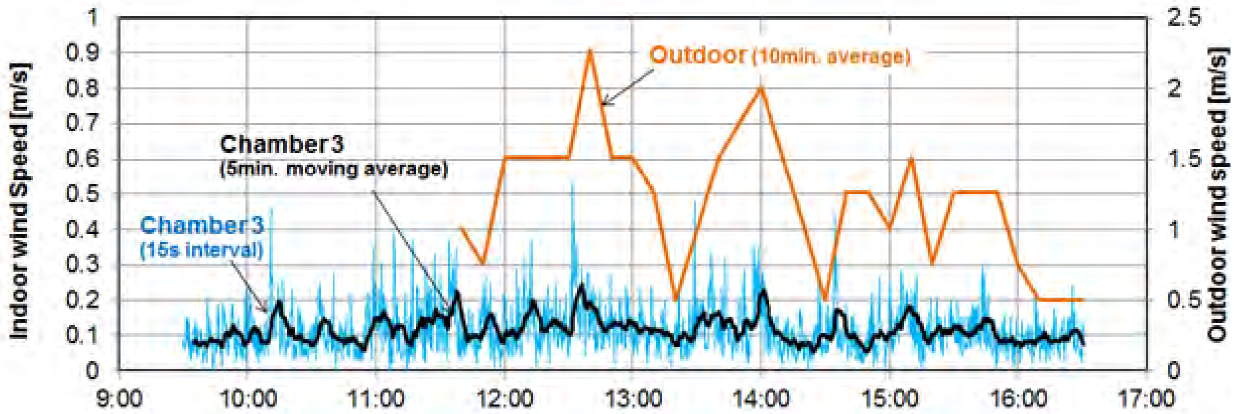


Figure 5. Wind speed in chamber 3 during the daytime (Sep. 25)

Görsel 5. Gündüz saatlerinde 3. Odacıktaki rüzgar hızı (25 Eylül)

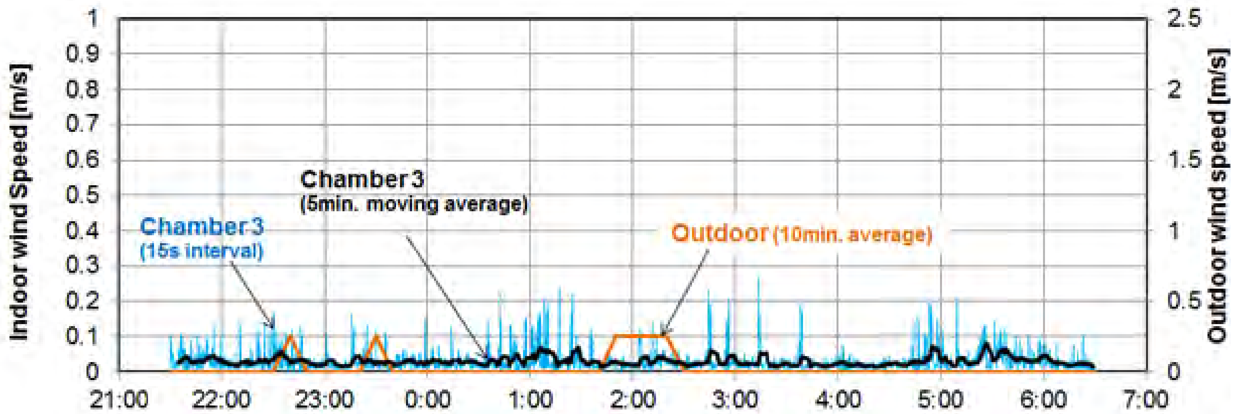


Figure 6. Wind speed in chamber 3 during the nighttime (from 25-26 September)

Görsel 6. Gece saatlerinde 3. Odacıktaki rüzgar hızı (25-26 Eylül)

3.3. Verification of potential evaporation estimated by metrological data

Knowing the rate of evaporation from ground surface is essential for simulating water and energy balance at the Üzümlü church. Although the evaporation rate could be estimated from metrological data using, for example, the Penman-Monteith equation (1) with some assumptions, verification of the equation is necessary to perform a realistic simulation. Therefore, we measured the evaporation rate and monitored metrological data.

Duration: 24-28 September, 2015

Location and procedure:

A plastic container (30 cm x 20 cm) was filled with water and set at near the weather station (Figure 7). The water level in the container was measured several times each day and the evaporation rate from the open water surface (potential evaporation, Ep, which corresponds to the maximum

3.3. Meteorolojik verilere göre hesaplanan potansiyel buharlaşmanın doğrulanması

Zemin yüzeyindeki buharlaşma hızını bilmek Üzümlü Kilisesi’nin su ve enerji dengesini simüle etmek için gereklidir. Bazı varsayımlarla yapıp Penman-Monteith denklemi kullanılarak meteoroloji verilerinden buharlaşma hızını hesaplamak mümkün olsa da gerçekçi bir simülasyon oluşturmak için denklemin doğrulanması gerekmektedir. Bu nedenle meteorolojik veriler gözlemlenip buharlaşma hızı hesaplanmıştır.

Süreç: 24-28 Eylül, 2015

Konum ve Yöntem:

30cm x 20cm ebatlarında plastik bir kap su ile doldurularak meteoroloji istasyonu yakınına bırakılmıştır (Görsel 7). Kaptaki su seviyesi gün içinde birkaç kez ölçülerek açık su yüzeyinde gerçekleşen buharlaşma oranı (Ep olarak gösterilen potansiyel buharlaşma, toprak yüzeyinde gerçekleşen

evaporation from soil surface) was evaluated.
Ep was also estimated from metrological data using equation (1) and compared to the measured Ep.

maksimum buharlaşma miktarına karşılık gelmektedir) değerlendirilmiştir.
Ep değeri aynı zamanda (1) numaralı denklem kullanılarak hesaplanmış ve ölçülen değerle kıyaslanmıştır.

$$E_p = \frac{0.408\Delta\left(R_n - G\right) + \gamma \dfrac{900}{T+273} u\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34u\right)} \qquad (1)$$

where Rn is net radiation, G is ground heat flux, T is average daily temperature, u is wind velocity at a height of 2 meters, es is saturated water vapor pressure, ea is vapor pressure at dew point, e_S is the gradient of saturated water vapor pressure curve, and e_a is the hygrometer constant.

Bu denklemde Rn net ışımaya, G yer ısı akışnaı, T ortalama günlük sıcaklığa, u 2 metre yükseklikteki rüzgar hızına, es doygun su buharı basıncına, D doygun su buharı basıncı eğrisinin eğimine, g ise higrometre sabitine karşılık gelmektedir.

Data:
Figure 8 shows the cumulative evaporation from 24 to 28 September. Water evaporated faster in the daytime and slower in the night. However, the evaporation rate was mostly constant during the observation period (Ep = 4.72 mm/d; about 4 mm in the daytime and 1 mm in the night).

On the other hand, the estimated Ep produced by Eq. (1) and metrological data from the weather station (Figure 9) was 4.89. 5.63, and 5.35 mm/d for Sep. 25, 26 and 27, respectively. The average Ep was 5.29 mm/d and is 0.57 mm larger than the observed Ep. The difference might come from condensation of water in the early morning. Overall, the equation seems useful for simulating the water balance at Üzümlü church, as long as a small correction is applied.

Veriler:
8. görsel 24 Eylülden 28 Eylül'e kadar gerçekleşen toplam buharlaşmayı göstermektedir. Su gündüz daha hızlı buharlaşıp gece daha yavaş buharlaşmış olmakla beraber gözlem süresi boyunca buharlaşma hızı çoğunlukla sabit kalmıştır. (Ep = 4.72 mm/g; gündüzleri yaklaşık 4mm geceleriyse yaklaşık 1 mm).

(1) Denklemi ve meteoroloji verileri (Görsel 9) kullanılarak yapılan hesaplamalar ise 25 Eylül için 4.89 mm/g, 26 Eylül için 5.63 mm/g ve 27 Eylül için 5.35 mm/g sonuçlarını vermiştir. Ortalama Ep 5.29 mm/g olup gözlemlenen Ep'den 0.57 mm/g daha fazladır. Bu fark sabah saatlerinde yoğuşan sudan kaynaklanıyor olabilir. Genel olarak bu denklem, küçük bir düzeltme yapıldığı takdirde Üzümlü Kilisesi'nin su dengesini simüle etmek için uygun gözükmektedir.

3.4. Verification of thermal properties estimated by soil monitoring data

To simulate temperature change in the rock wall of Üzümlü church, the thermal properties (thermal diffusivity, thermal conductivity, and heat capacity) of the rock must be known. Although the thermal diffusivity could be analytically estimated though use of soil monitoring data with some assumptions, a realistic simulation requires verification. Therefore, we measured the thermal diffusivity, thermal conductivity, and heat capacity of the rock around Üzümlü church.

3.4. Toprak gözlemleme verilerine göre hesaplanan termal özelliklerin doğrulanması

Üzümlü Kilisesi'nin taş duvarlarındaki ısı değişimini simüle etmek için taşın termal özellikleri (ısıl dağılım, ısı geçirgenliği ve ısı sığası) bilinmelidir. Isıl dağılma bazı varsayımlar yapılarak ve toprak gözlemleme verileri kullanarak analitik olarak hesaplanabilir, ancak gerçekçi bir simülasyon için doğrulama gereklidir. Bu nedenle Üzümlü Kilisesi'nin etrafındaki taş yapısının ısıl dağılımı, ısı geçirgenliği ve ısı sığası hesaplanmıştır.

Figure 7. Observation site
Görsel 7. Gözlem alanı

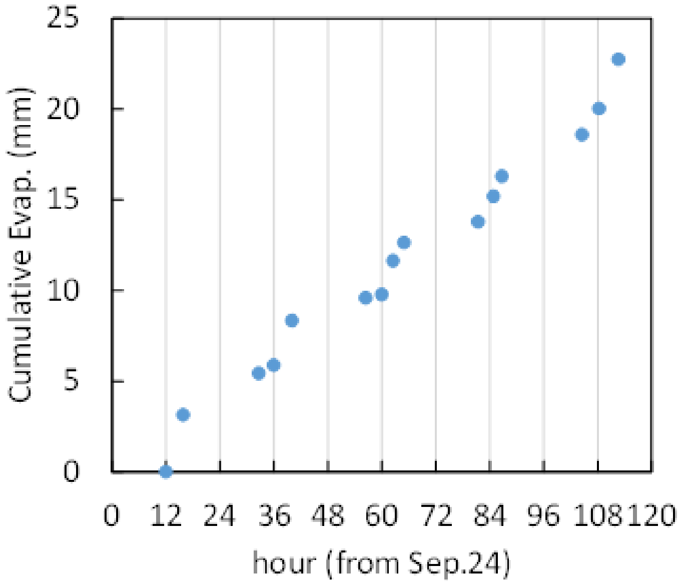


Figure 8. Cumulative evaporation from 24 to 28 Sep.
Görsel 8. 24-28 Eylül arasındaki toplam buharlaşma.

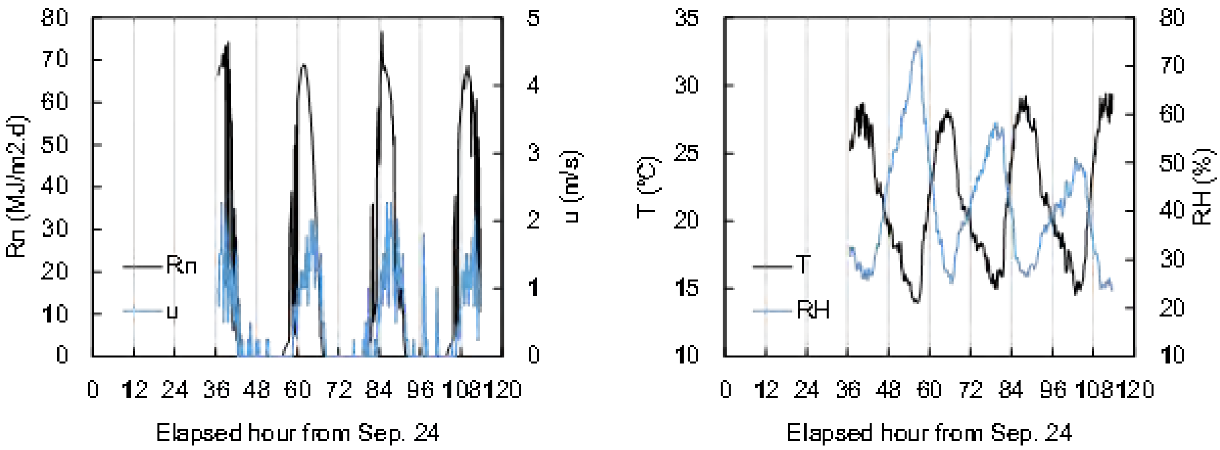


Figure 9. Metrological data for calculating Ep by Eq. (1)
Görsel 9. (1) denklemini kullanılarak Ep'yi hesaplamak için gerekli meteoroloji verileri

Duration: 24-27 September, 2015

Location and procedure:

Samples were taken from weathered rock (R) beside the church, the church floor (F), and the west (W) and north east (E) bases of the church where soil monitoring sensors are buried. The thermal diffusivity, κ; thermal conductivity, λ and heat capacity, C were measured according to the dual heat probe method using a KD2-pro (Decagon device). The thermal conductivity λ was fitted to the Campbell equation (2), which is useful for solving thermal conduction.

Süreç: 24-27 Eylül, 2015

Konum ve yöntem:

Kilise zemininden (F), toprak gözlem sensörlerinin gömülü olduğu kilisenin batı (W) ve kuzey-doğu (E) temelinden ve kilisenin yanındaki aşınmış kayadan (R) örnekler alınmıştır. k ile gösterilen ısıl dağılım, 1 ile gösterilen ısı geçirgenliği ve C ile gösterilen ısı sığası, bir KD2-pro(dekagon cihazı) kullanılarak çifte ısı sondası yöntemi kullanarak ölçülmüştür. Isı geçirgenliği (l), ısı geçirgenliğini hesaplamada kullanılan Campbell denklemine (2) eşitlenmiştir.

$$\lambda = A + B\theta + (A - D)\exp\left[-(C\theta)^4\right] \qquad (2)$$

where θ is water content, and A, B, C, and D are fitting parameters that relate to porosity, and the fraction of clay and

Bu denklemde q su miktarı; A,B,C ve D ise kil ve kuvarsın gözenekliliğine ve fraksiyonuna denk gelen değişkenlerdir.

quartz.

Thermal diffusivity κ of the rock was also estimated using fluctuations in temperature at the soil monitoring site, and compared to the observed κ. When the soil temperature fluctuation can be assumed to be a sine curve with no soil water flow, then the thermal diffusivity can be estimated as

Taş yapısının ısıl dağılımı (k) da toprak gözlemleme alanındaki sıcaklık değişiklikleri kullanılarak hesaplanmış ve gözlemlenen k karşılaştırılmıştır. Topraktaki sıcaklık değişimlerinin topraktaki su akışının ihmal edildiği bir sinüs eğrisi olduğu varsayılırsa ısıl dağılım aşağıdaki denkleme göre hesaplanabilir.

$$d = \frac{z_1 - z_2}{\ln\left[\dfrac{T_{\max} - T_{\min}\big|_{z=1}}{T_{\max} - T_{\min}\big|_{z=2}}\right]} = \sqrt{\frac{\kappa\tau}{\pi}} \qquad (3)$$

where d is damping depth, z is depth, Tmax and Tmin are maximum and minimum temperatures at z, τ is the rotation period, and π is circular constant.

Bu denklemde d ıslanma derinliğine, z derinliğe, Tmax ve Tmin değerleri z derinliğindeki maksimum ve minimum sıcaklıklara, τ ise devir süresine karşılık gelmektedir.

Data:

First, the thermal properties of the rocks were measured in a naturally dried state. Then, the rock was saturated with water and the thermal properties measured again. Table 1 lists each rock’s thermal properties as measured by KD2-pro. Comparing to common rocks, the rocks around Üzümlü church had relatively low thermal diffusivity, thermal conductivity and heat capacity. The low heat capacity for W and E indicates low porosity in rocks on the surface of the church. The thermal conductivity was well fitted to equation (2) as shown in Figure 10.

Figure 11 shows the soil temperature change monitored at (E) from September 12 to 14, 2014. This temperature change was analyzed using equation (4) producing an estimated thermal diffusivity for wet rock of 0.43 mm^2/s. The measured κ slightly underestimated the analyzed κ. This may stem from poor contact between the KD2-pro sensor rod and the sample rocks. The analyzed κ seems sufficient for calculating the heat flow of the church wall.

Veriler:

Taşların ısıl özellikleri ilk önce doğal olarak kuru bir halde ölçülmüştür. Daha sonra su ile ıslatılıp tekrar ölçülmüştür. Tablo 1 her bir kayanın KD2-pro ölçülmüş ısıl değerlerini göstermektedir. Normal kayalarla kıyaslandığında Üzümlü Kilisesi’nin etrafındaki kayaların ısıl dağılım, ısı geçirgenliği ve ısı sığası daha düşük olarak ölçülmüştür. W ve E’nin düşük ısı sığası, kilise yüzeyindeki kayanın gözeneklilik değerinin düşük olduğunu göstermektedir. Görselde 10.’da görülebileceği gibi ısı geçirgenliği (2) denklemine uygun olarak belirlenmiştir.

Görsel 11 (E) noktasında 12 ile 14 Eylül, 2014 aralığında gözlemlenen sıcaklık değişimini göstermektedir. Bu sıcaklık değişimi (4) denklemi kullanılarak incelenmiş ve ıslak kayanın ısıl dağılımı yaklaşık 0.43 mm^2/s olarak hesaplanmıştır. Ölçülen k değeri, hesaplanan değerden düşük çıkmıştır. Bu fark KD2-pro’nun ölçüm çubuğunun örnek kayalarla olan temasının yeterince iyi olmamasından kaynaklanmış olabilir. Hesaplanan k değeri kilise duvarındaki ısı akışını hesaplamak için yeterli görünmektedir.

Table 1. Thermal properties of rocks measured by KD2-pro.
Tablo 1. Kayaların KD2-pro ile ölçülmüş termal özellikleri

Sample name		R		F		W		E	
Moisture condition		Dried	Wetted	Dried	Wetted	Dried	Wetted	Dried	Wetted
Thermal diffusivity	mm3/s	0.149	0.243	0.181	0.278	0.194	0.324	0.193	0.362
Thermal conductivity	W/m.K	0.246	0.488	0.263	0.535	0.197	0.509	0.139	0.55
Heat Capacity	MJ/m3.K	1.647	2.008	1.455	1.927	1.013	1.57	0.721	1.561

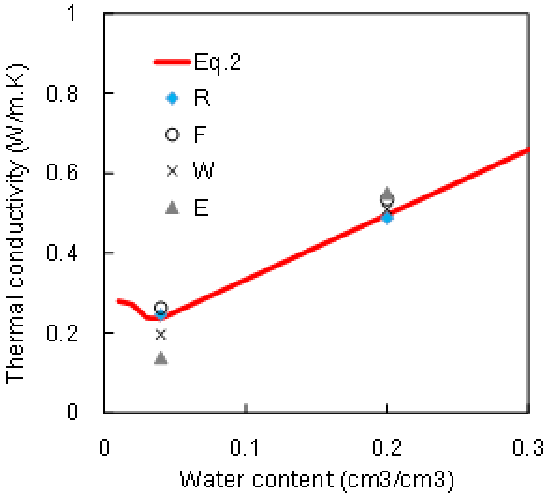


Figure 10. Thermal conductivity of rocks around Üzümlü church

Görsel 10. Thermal conductivity of rocks around Üzümlü Kilisesi etrafındaki kayaların ısı geçirgenliği

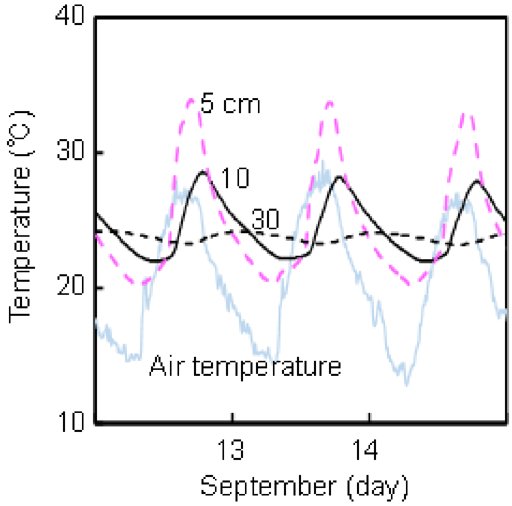


Figure 11. Temperature change at 5, 10 and 30 cm depth at site (E).

Görsel 11. (E) bölgesinde 5, 10ve 30(cm) derinliklerindeki sıcaklık değişimleri

4. LAB TESTING AND CONSERVATION OF THE ÜZÜMLÜ WALL PAINTINGS

One of the main causes of ongoing serious damage to the wall paintings at Üzümlü church is extensive graffiti by tourists, most likely local tourists. Figure 13 clearly shows large incisions in the wall presenting the Turkish mobile number “0532445033”, and the words “guide” and “Paul”, which appeared between 2010 and 2013. These are not related to acts of cultural genocide, which have increased recently in West Asian regions such as in the Mosul museum and Palmyra attacks.

Some other graffiti containing personal names includes dates such as 2014 and 2015, which indicates that these actions took place recently. Therefore, measures to prevent further damage should be taken as soon as possible; these may include posting signs at the site, setting up a proper platform along the church floor, or educating local tourist guides.

The Üzümlü wall paintings are an important site for historical graffiti. There are several types of Greek inscriptions that seem to date back to the 8th or 9th century AD, as well as figures of horses and saints, and some Arabic graffiti. Also, some evidence of religious vandalism on the hands and faces of saints could be historical; therefore, criteria for which graffiti shall and shall not be remedied has been established. Only recent touristic graffiti and lines shall be toned down;

4. LABORATUVAR TESTLERİ VE ÜZÜMLÜ DUVAR RESİMLERİNİN KONSERVASYONU

Üzümlü kilisesine verilen en büyük zarar, çoğunluğu yerel turistler olmak üzere turistler tarafından duvarlara yapılan çizimler olmuştur. 13. Görselin açıkça gösterdiği gibi duvarda Türkiye’ye ait bir telefon numarası “0532445033” ayrıca “guide” ve “Paul” kelimeleri 2010 ve 2013 yılları arasında görülmüş olan vandalizmlerdir. Bunların son zamanlarda Batı Asya bölgelerinde artmakta olan Musul Müzesi ve Palmyra’ya yapılan saldırılar gibi kültürel soykırımlarla bir ilgisi yoktur.

Kişisel isimler içeren diğer duvar yazıları 2014 ve 2015 yıllarında yapılmış, yani yakın zamanda meydana gelmiştir. Bu nedenle, gelecek zararları engelleyecek önlemler en kısa zamanda alınmalıdır. Bu önlemler uyarı tabelaları asmak, kilise zeminine uygun bir platform yerleştirmek ve yerel turist rehberlerini eğitmek şeklinde olabilir.

Üzümlü duvar resimleri tarihi duvar yazıları için önemli bir konumdadır. Üzümlü’de Sekizinci ve dokuzuncu (8. ve 9.) yüzyıldan kaldığı düşünülen birkaç farklı Yunan yazıtı, bunun yanı sıra at ve aziz tasvirleri ve bir takım Arap duvar yazıları bulunmaktadır. Ayrıca, aziz tasvirlerinin ellerine ve yüzlerine yapılmış dini Vandalizm örnekleri tarihi değer taşıyabilir; bu nedenle, hangi duvar çizimlerinin onarılıp hangilerinin onarılmayacağına dair bir kriter oluşturulmuştur. Sadece

Figure 12a. Wall painting in chamber 2, June 2010
Görsel 12b. Kilisenin nef kısmında bulunan duvar resmi, kuzey duvar, 1968 veya 1970

Figure 12b. Wall painting in the nave, north wall, 1968 or 1970.
Görsel 12b. Kilisenin nef kısmında bulunan duvar resmi, kuzey duvar, 1968 veya 1970

Figure 13. Modern incised graffiti by local visitors.
Görsel 13. Yerel ziyaretçiler tarafından yakın zamanda oyularak yapılmış duvar yazıları

others must remain as they are.

In order to provide a optically uniform effect, graffiti of apparently recent origin was partially toned using mineral-based pigments (red ochre, yellow ochre, green earth, ivory black, local earth) without any organic binder. The pigment particles were applied using only water since prior analysis indicated that the original wall paintings had no organic binding media. Some pencil based graffiti and crayons were removed using PVAC free eraser and hexane.

A series of material testing for grouting and edging mortar was carried out in the labs and on-site parallel to the toning trials. The main composition of the original plaster in the wall painting is gypsum, without any plant fibres, sand particles, etc. Some areas are cracked and detached due to long-term rock movement. Therefore, grouting and edging mortar was chosen based on gypsum. However, it should be modified to become weaker and lighter than the original plaster. Also, an excess amount of liquid water may damage the original plaster. Thus, a reduction of water would be ideal. For the sake of convenience in application, retarder additives were

yakın zamanda yapılmış duvar çizimleri onarılmalıdır, geri kalanlar olduğu gibi bırakılmalıdır.

Görsel bütünlük sağlayabilmek adına yakın zamanda yapıldığı düşünülen duvar yazılarının üzeri mineral bazlı pigmentler (kırmızı toprakboya, sarı toprakboya, yeşil toprak, fildişi siyahı, yerel toprak) ile organik bağlayıcı madde kullanılmadan boyanarak kısmen kapatılmıştır. Pigment tanecikleri, önceden yapılan incelemelerin gösterdiği üzere orijinal duvar resimleri organik bağlayıcı madde içermediğinden dolayı sadece su kullanarak uygulanmıştır. Bazı kurşun kalem tabanlı duvar çizimleri ve pastel boyalar PVAC içermeyen silgi ve heksan kullanılarak silinmiştir.

Derzleme, kenar düzeltme ve alçılama için laboratuvarda yapılan tonlama araştırmalarına paralel olarak birtakım malzeme test deneyleri yapılmıştır. Duvar boyasında bulunan orijinal alçıdaki ana karışım, içinde kum tanecikleri ve bitki lifleri vb. malzemeler bulunmayan jipstir. Bazı kısımlar uzun süreli kaya hareketleri nedeniyle çatlamış veya yerlerinden çıkmıştır. Bu nedenle, derzleme ve düzeltme sıvası jips temel alınarak seçilmiştir. Fakat bu karışım, orijinal sıvadan daha also tested to prolong the workability and setting time of gypsum binders to at least 30 minutes. In order to achieve such material properties, xanthan gums, volcanic glass-based microbaloon, and sodium citrate were used. Some scientific evaluation shall be carried out this year, and an actual intervention will be executed in 2016.

az yoğun ve hafif olacak şekilde değiştirilmelidir. Ayrıca, karışımda fazla miktarda su bulunması orijinal sıvaya zarar verebilir. Bu nedenle, su miktarını azaltmak ideal olacaktır. Uygulama kolaylığı adına, kimyasal tepkime önleyici olarak kullanılan katkı maddeleri jipsin kuruma süresini en az 30 dakika arttırmak ve böylece işlenebilirliğini artırmak için denenmiştir. Bu özelliklere sahip bir materyal elde edebilmek için ksantan sakızı, volkanik cam bazlı mikro balon ve sodyum sitrat kullanıldı. Bu yıl içinde bir takım bilimsel araştırmalar gerçekleştirilecek ve asıl müdahale 2016 yılında hayata geçirilecektir.

5. PRELIMINARY TESTING FOR PROTECTIVE COATING OF ROCKS

Two small rock masses with similar rock and weathering characteristics were chosen for testing (Figure 14). One rock was sprayed with an alkoxysilane based consolidate and water repellent agent (Permeate HS-360, 150g/m2), and the other was left as untreated as a control specimen. In order to compare the degree of weathering, 9 SUS anchors (nails) were set in each rock mass (North, East, South, West: lower and higher positions, and the top). The exposed length of each anchor was measured periodically using a digital caliper. Since the surface of the rocks is extremely friable, the measurement was not accurate enough (Figure 15). However, the number of remaining anchors demonstrated that surface treatment had a clear effect of (Table 2): after less than 8 months of exposure, 6 anchors of 9 were lost due to heavy weathering.

In-situ trials to stabilise wall paintings and further environmental studies shall be carried out in 2016. A comprehensive approach is required to achieve success in conservation of the whole site, especially as it must involve tourist management to reduce intentional vandalism to cultural materials.

5. KAYAÇLARIN KORUYUCU KAPLAMARI İÇİN ÖN TESTLER

Aşınma ve yapısal özellikleri benzer olan iki küçük kaya kütlesi test edilmek üzere seçilmiştir. (Görsel 14). Bir kayaya alkoxysilane tabanlı sağlamlaştırıcı ve su geçirmez bir madde (Permeate HS-360, 150g/ m2) püskürtülmüş, diğer kaya kütlesi ise kontrol grubu olarak kullanılmak için herhangi bir işlem yapılmamıştır. Aşınma miktarını ölçmek adına 9 SUS sabitleyici (çivi) kaya kütlelerine sabitlenmiştir. (Kuzey, Güney, Doğu, Batı: alçak ve yüksek noktalar ve tepe). Her sabitleyicinin açıkta kalan kısmı düzenli olarak dijital kalınlık ölçerlerle ölçülmüştür. Kaya yüzeyleri ufalanmaya oldukça müsait olduğundan hesaplamalar yeterli derecede doğru değildir (Görsel 15). Fakat, geriye kalan sabitleyici sayısı şunu gösteriyor ki yüzey koruması bariz bir etkiye sahiptir (Tablo 2): 8 aydan kısa bir süre boyunca açıkta bırakıldıktan sonra 9 sabitleyiciden 6'sı hava etkisiyle yoğun aşınma sonucu kaybolmuştur.

Duvar resimlerini konservasyonu içinse yerinde bakımlar ve başka çevresel çalışmalar 2016 yılında gerçekleştirilecektir. Tüm alanın korunabilmesi için bütünsel bir yaklaşım gerekmektedir. Bu çalışma özellikler bilinçli vandalismin kültürel mirasa verdiği zararı azaltmak için turist yönetimini de kapsamalıdır.

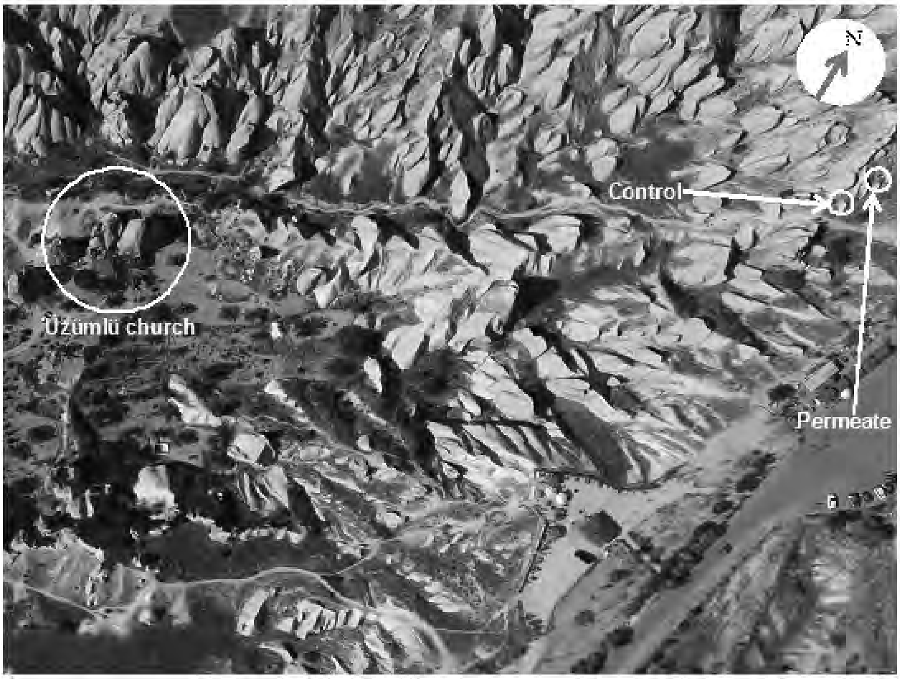


Figure 14. Locations of testing rock masses and Üzümlü church
Görsel 14. Üzümlü Kilisesi'ndeki kaya kütlelerinin test alanı

Table 2. Comparison of numbers of remained SUS anchors
Tablo 2. SUS sabitleyicilerinin açıkta kalan kısmının uzunluklarının düzenli ölçümü

	2015/9/28	2015/11/12	2015/12/25	2016/3/7	2016/5/5
Control	9/9	8/9	5/9	5/9	3/9
Permeate	9/9	9/9	9/9	9/9	9/9

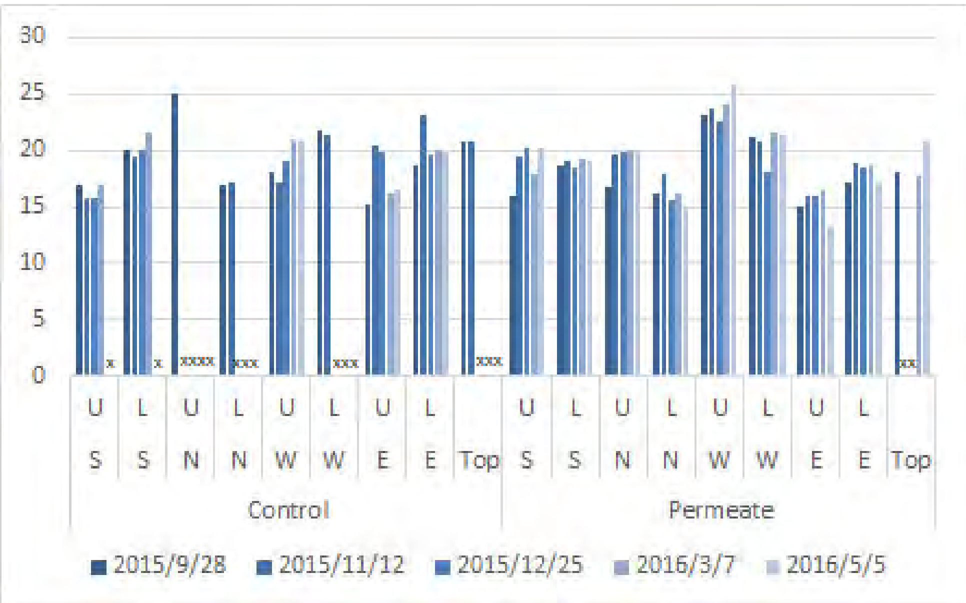


Figure 15. Periodical measurement of exposed length of SUS anchors
Görsel 15. SUS sabitleyicilerinin açıkta kalan kısmının uzunluklarının düzenli ölçümü

References

Erguler, Z.A., 2009, Field-based experimental determination of the weathering rates of the Cappadocian tuffs, *Engineering Geology*, **105**, pp.186-199.

Fukakusa, S., Kawahara, K., Nakazawa, T., 2015, III-4 Nano liquid chromatography-electrospray ionization tandem mass spectrometry (Nano-LC-ESI-MS/MS) analysis of the Üzümlü wall paintings, In Taniguchi, ed., *Scientific Studies on Conservation for Üzümlü Church and Its Wall Paintings in Cappadocia, Turkey., vol. 1. Annual report on the activities in 2014*, p.103-106.University of Tsukuba.

Higuchi, R., Suzuki, T., Shibata, M., Taniguchi, Y., Murat Gülyaz, M., 2016, Digital Non-Metric Image-Based Documentation for the Preservation and Restoration of Mural Paintings: the Case of the Üzümlü Rock-Hewn Church, Turkey, *Virtual Archaeology Review*, **7**, pp.31-42.

Pelosi, C., Agresti, G., Andaloro, M., Pogliani, P., Santamaria, U., 2013, 'The rock hewn wall paintings in Cappadocia (Turkey). Characterization of the constituent materials and a chronological overview', *e-Preservation Science,* **10**, pp.99-108.

Rovella, N., Andaloro, M., Crisci, G.M., La Russa, M.F., Pelosi, C., Pogliani, P., Ruffolo, S.A., 2014, Cappadocian rupestrian churches and conservative strategies: from the lab to the archeological site, *VIII Congresso Nazionale di Archeometria Scienze e Beni Culturali: stato dell'arte e prospettive, Bologna, Italy, 5-7 February 2014.*

Sano, K., Mizukoshi, S., 2015, II-5 Preliminary aging tests (outdoor environment) of consolidants for tuff rock samples, In Taniguchi, ed., *Scientific Studies on Conservation for Üzümlü Church and Its Wall Paintings in Cappadocia, Turkey, vol. 1. Annual report on the activities in 2014*, p.37-41.University of Tsukuba.

Taniguchi, Y., Koizumi, K., Iba, C., Porter, J., Açıkgöz, F., Gülyaz, M., 2016, Scientific Research for Conservation of the Rock Hewn Church of Üzümlü, Cappadocia, *37. International Symposium of Excavations, Surveys and Archaeometry, Erzurum 11-15 May 2015*, pp.361-378.

UNESCO, 1985, *Structural conservation of Göreme. Göreme, land of fairy chimneys*. Ministry of Culture and Tourism, Turkey. General Directorate of Antiquities and Museums.

Acknowledgements:

The authors would like to express their appreciation to MEXT/JSPS KAKENHI (24101014) and the Kajima Foundation for their financial support on this project. The Üzümlü project has been supported by numerous individuals in both Turkey and Japan, especially the Turkish government and staff at the Nevşehir Restoration and Conservation Regional Laboratory Directorate. Special appreciation is extended to: the director of the Nevşehir Museum, Murat Ertuğrul Gülyaz; the director of the Niğde Museum, Fazıl Açıkgöz; Ibrahim Sakınan and family; and Tolga Uyar, Zuhal Coçyğit, Shunsuke Fukasawa, Ryo Higuchi, Kazuki Kawahara, Shigekazu Mizukoshi, Takeshi Nakazawa, Jennifer Porter, Juni Sasaki, Mina Shibata, Tamaki Suzuki and Mizuho Yoshioka.

Note: this paper is a modified (some figures were added) version of forthcoming proceedings of 38th International Symposium of Excavations, Surveys and Archaeometry (38. Uluslararası Kazı, Araştırma ve Arkeometri Sempozyumu) in Trakya University, Edirne, 23-27 May 2016.

Yoko Taniguchi, Keigo Koizumi, Chiemi Iba, Jennifer Porter, Fazıl Açıkgöz, Murat Ertuğrul Gülyaz,
37. International Symposium of Excavations, Surveys and Archaeometry, Erzurum 11-15
May 2015, 361-378, Published in 2016

Ⅱ -10 Scientific Research for Conservation of The Rock Hewn Church of ÜZÜMLÜ, Cappadocia

Üzümlü(Kapadokya)'da Bulunan Kaya Oyma Kilisenin Korunmasi İcin 2015'de Yürütülen Bilimsel ÇaliŞmasi

* Yoko Taniguchi
Keigo Koizumi
Chiemi Iba
Jennifer Porter
Fazıl Açıkgöz
Murat Ertuğrul Gülyaz

1. INTRODUCTION

1.1 Outline and objectives of the project

A project at Üzümlü Church in the Red Valley in Cappadocia, Turkey, has recently been launched with two primary objectives: the conservation of the soft, fragile tuff structure of the church through geo- and environmental-engineering methods, and the conservation of the interior wall paintings, including a scientific study of their technology. The structure and wall paintings have not been treated in the past, presenting a unique opportunity for this type of study. The project aims to find a suitable method for prolonging the life of Cappadocia's fragile tuff structures and the paintings they shelter, through the use of 'retreatable' conservation materials. Often, intense intervention does not allow for future treatments, and fails to allow for continuous preservation. Due similarities in original technique and deterioration with other sites in Cappadocia, this study will have relevance for the greater region.

During an initial investigative campaign (September 2014), the structure and wall paintings were inspected to understand their technology and deterioration, and samples were taken as necessary. Documentation and a condition survey of the paintings on the interior of the church were carried out, and environmental monitoring of the church interior and surroundings was initiated in order to identify the primary agents of deterioration to the tuff rock structure, and to test the hypothesis that dew/frost cycles have the most significant impact during the early spring season, as has been noted in earlier studies (Erguler 2009). Micro-organisms such as lichens and algae have also often been observed on tuff rocks in Cappadocia, and therefore visible colonies of biological growth on the church's exterior surface were studied to determine whether they had positive (protective) or negative (deterioration accelerating) impacts on the tuff rock.

1.2 The church

Cappadocia's unique landscape results from the natural erosion of a soft and fragile tuff rock formed by volcanic accumulation. Hundreds of churches and dwellings were excavated within the tuff rock structures in valleys of the region, and many of them contain important historical and religious reliefs and paintings. The Üzümlü, meaning Grape, Church is located at the beginning of the Red Valley, to the west of the town of Ortahisar. A tuff formation or "fairy chimney" was hollowed out for use as a monastic complex and likely housed the church's monks. The church is cut into the lower level of the tuff formation, while the upper level contains a chamber that can be seen only from the outside due to the partial collapse of the walls. There is a cross relief on the ceiling. The church has a square plan with one apse and one nave and at the far end of the nave is a grave niche (Figure 1). This church is also called The Church of St. Nichitas due to the presence of a

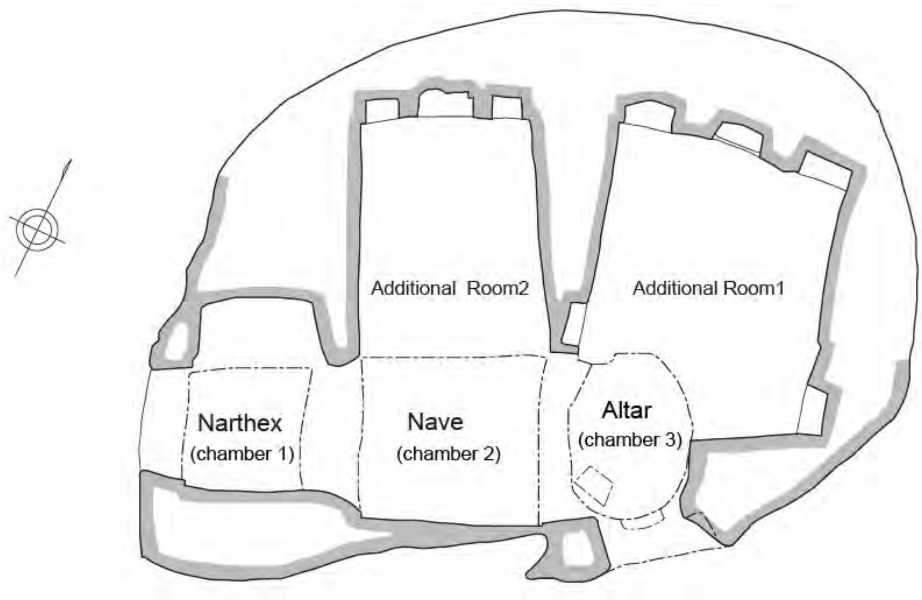


Figure 1. Structure of the Üzümlü Church

dedication inscription to St Nichitas inside the church. The nave ceiling is decorated with rich embellishments: its surface is orange in colour and adorned with a cross composed of circles and rectangles with bunches of grapes and geometrical motifs surrounding it. The border is embellished using medallions with Maltese crosses. Although not definite, it is common belief that the earliest structure of the church dates back to the 8th or 9th century AD, though the paintings are thought to be from a later date, probably related with the period of Komnenos dynasty (1081-1185), based on stylistic evaluation, such as similarities with the motifs in Pantokrator Monastery (Zeyrek Kilise Camii), Istanbul (1120-1185) (Suzuki et.al 2015: 107).

The Üzümlü church was selected for study because of the typical structural issues it presents, and due to its wall paintings, for their conservation and also due to significant scientific research interest in wall paintings in Eurasia, especially those from the medieval period.

2. ASSESSMENT OF UZUMLU TUFF STRUCTURE AND WALL PAINTINGS

The tuff structure of the Üzümlü church suffers from deterioration common to other rock-cut churches in the Cappadocia region: stone powdering and spalling, as well as structural cracking. While structural cracking originates from seismic activity, cracking and other types of deterioration are originated or exacerbated by wind and rain erosion, and insolation stresses. Environmental monitoring was therefore undertaken to understand the mechanisms of deterioration at Üzümlü, and seek to address them.

2.1 Environmental monitoring

A set of environmental monitoring stations (Onset HOBO U30-NRC) for monitoring RH, T, rainfall, wind speed/direction, and solar radiation were installed near the Üzümlü Church (photo 1). Loggers with sensors that measure water potential and water content were situated in the lower level of the church along the exterior wall (5TE, MPS2 and Em50: Decagon Device). Also 2 sets of datalogger, HOBO U23 for RH/T were placed in the church.

Photo 1. Installation of a weather station and Üzümlü church (centre)

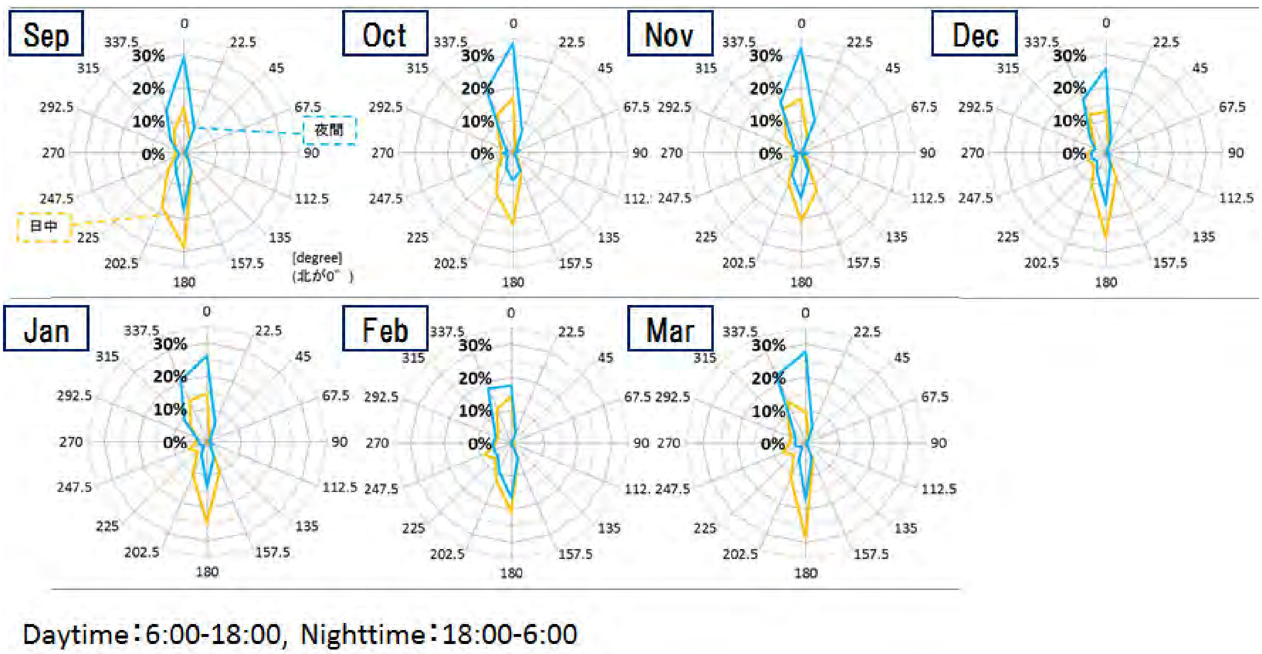


Figure 2. Wind direction near the Üzümlü Church (September 2014- March 2015)

Members of Nevşehir Restoration and Conservation Regional Laboratory Directorate (Nevşehir Restorasyon ve Konservasyon Bölge Laboratuvarı Müdürlüğü) have collected data periodically. The data shows that after October 2014 day temperatures dropped below 0 C. However, critical temperature fluctuations at around -4 C, as associated with the dew-frost phenomena, were only counted 4 times in this season. Such occurrence was significantly less than assumed. Precipitation such as rainfall increased from November to December, and again from February to March.

Interestingly, the weather station, since its installation, has consistently shown the prevailing wind direction to flow North-South around the Üzümlü church (September 2014 to March 2015) probably owing to the geological setting of the Red Valley. This may also affect erosion of the rock surface on the NS side (Figure 2). Further details on environmental factors shall be examined after a year of data has been obtained.

2.2 Conservation context

Erosion and deterioration in Cappadocia's tuff rocks have been studied and Erguler [2009] reported in a case study that erosion (0.4-2.5mm /yr) occurred due to frequent dew-frosts (37/yr). Tuff erosion remains the most critical and urgent conservation issue in Cappadocia.

In the past, the problems of acute cracking and erosion were commonly addressed by applying a lime-cement based render over the tuff surface, as is done in Göreme National Park.

Although trials were conducted with iron mesh at the interface between capping and tuff rock, detachment between the two always occurs due to possible water infiltration and thermal impact by intense solar radiation. Most of the surface treatment and capping has not been effective at reducing the rate of the tuff erosion, and in some cases has exacerbated its deterioration. Therefore, in this project, a different treatment approach is being explored: slower the speed of erosion with chemically compatible material with the original tuff, not to cover with a foreign material, and it will be retreatable in 10 years intervals.

2.3 Sampling for laboratory testing

Tuff rock pieces were sampled from the Red Valley near the Üzümlü Church for lab testing. Basic mechanical tests carried out included porosity measurement and chemical analysis such as mineralogical/XRD studies.

The same pieces were also used for some surface treatment tests in cooperation with D&D Co. Since frost-dew was initially assumed to be the main cause of deterioration. Some consolidants were chosen which is impermeable to liquid water but permeable to water vapour as testing materials first (i.e. 150g/m2 of Permeate® HS-360, Permeate® Prototypes 1401, 1402, 1403 and 1404). Exposure tests of these treated samples are still under way, and some select products shall be tested in Cappadocia after lab tests are complete (Sano and Mizukoshi, 2015).

3. STRUCTURE AND CONSTIUTENT MATERIALS OF ÜZÜMLÜ WALL PAINTINGS

Similar to other wall paintings in Cappadocia, the Üzümlü wall paintings are executed on a white plaster layer, which was directly applied onto the tuff rock substrate. The plaster layer is extremely thin (approx. 2-5 mm), and covered in a fine white ground (approx. 1-2 mm thick), both apparently composed of similar materials. The plaster and ground both appear to have been applied quite wet, since brush strokes and bubbles can be observed in both layers. They contain little aggregate, unlike some other paintings in the region, which often contain plant or animal fibres (Pelosi et al. 2013).

The painting palette initially appears to consist mainly of strong red, yellow and greyish colours. However, closer inspection reveals that a much wider range of tonal effects had originally been achieved, through the mixing of pigments, and the variations in the opacity with which paint layers were applied, as has also been noted in other paintings in the region (Pelosi et al. 2013): in some areas, paint appears to have been applied as thin washes in order to obtain different effects of tonality. Despite the presence of plant patterns such as vines and grapes, very little green pigment was observed, except for in certain sections of painting in the altar room.

Detailed examination of the paint layers was undertaken using a digital camera-attached microscope (®Microadvance), and micrographs were recorded. Infra-red and ultra-violet photographs (365nm excitement wavelength) were also taken to assess specific types of painting materials.

Following visual inspection, 13 small samples were taken from discreet but representative areas of the ground and paint layers, prepared as cross-sections, and/or analyzed for organic and inorganic constituents.

The cross-sections revealed that most of the plaster and ground layers were quite fine and homogeneous in composition without any particular inclusions. No visible varnish or glaze layers had been applied on top and painting layers were extremely thin.

Table 1 provides a summary of the results of analysis of the 13 samples taken from the wall painting. A sample of the lower white plaster layer (UZM_002) was identified as gypsum [JCPDS: (00-033-0311): $CaSO_4.2H_2O$] with the XRD (Figure 3) without any other inclusions. This technology has been used in other paintings (Pelosi et al. 2013, Schwartzbaum 1986). Red lead (minium) was used extensively, and its alteration products were also detected (ex. PbO) (Figure 4). Lead-based pigments were manmade, and of the kind commonly traded and used in the medieval world.

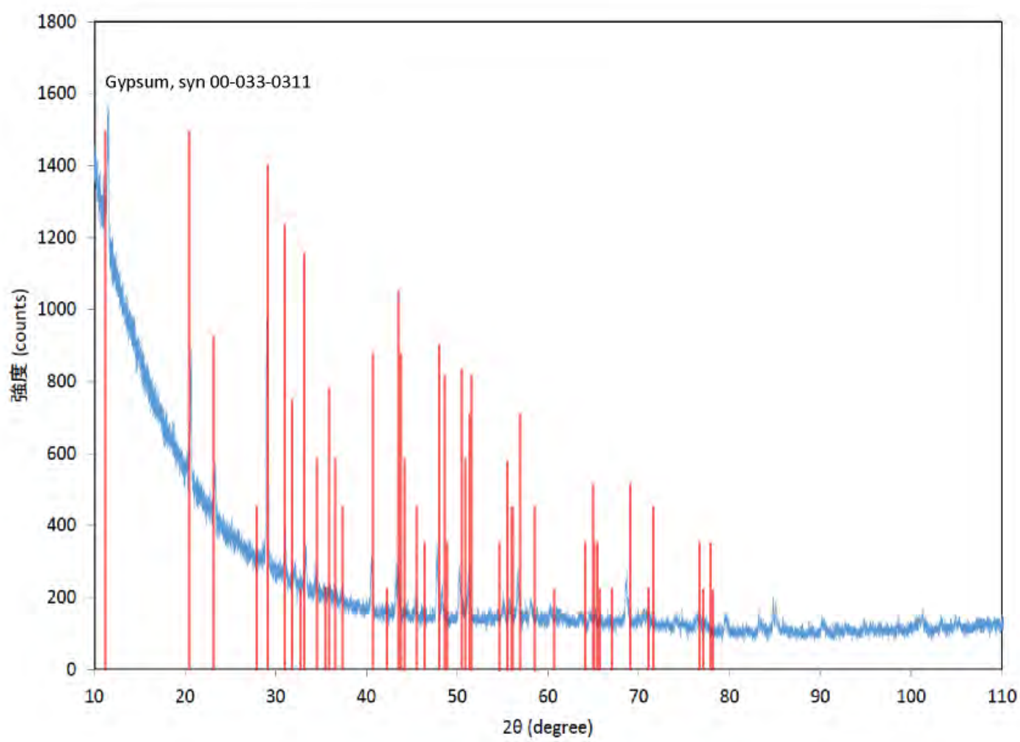


Figure 3. X-ray diffractogram of the white ground (UZM_002).

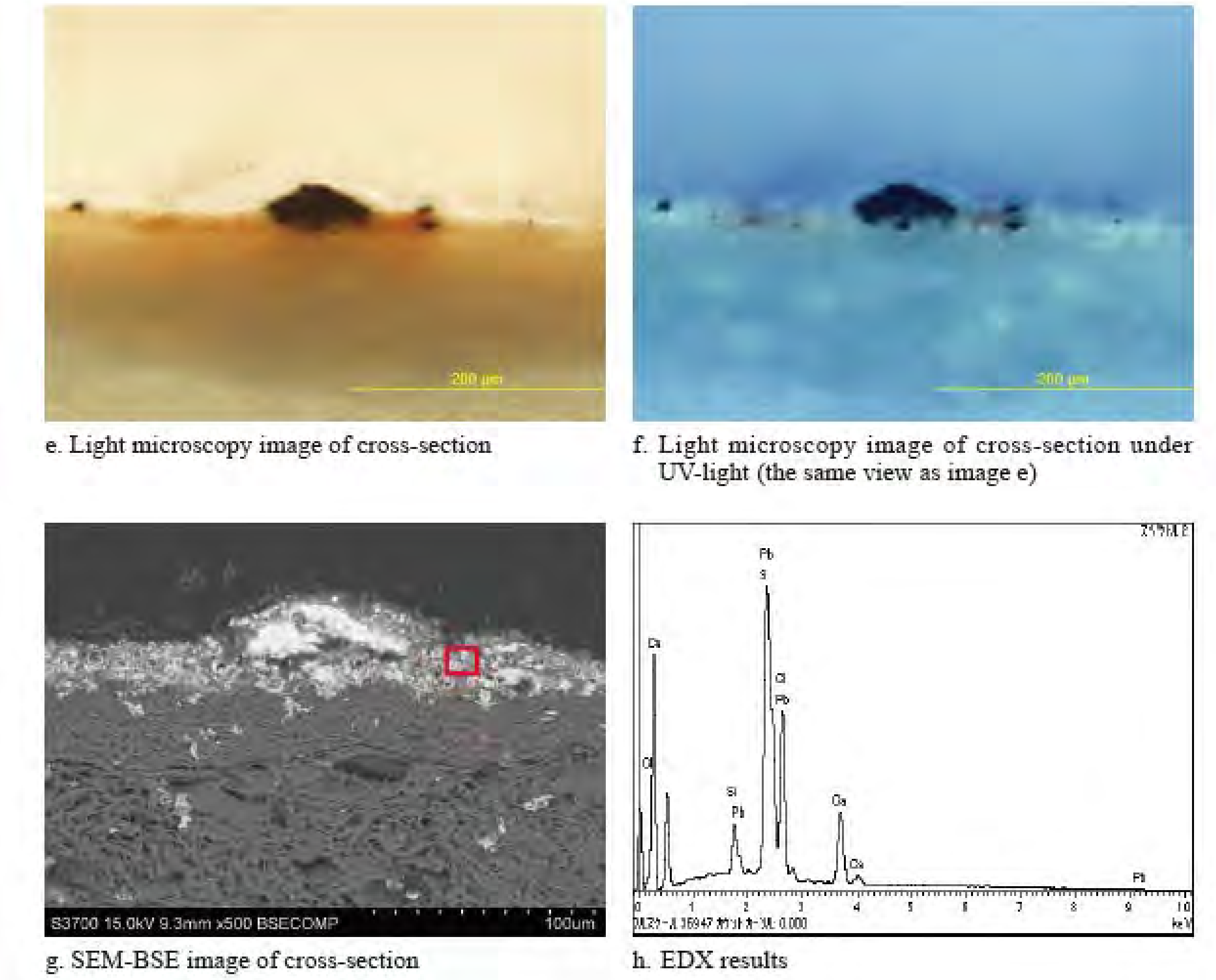


Figure 4. Analytic results of one cross section (UZM_004) using: (a) PLM, (b) PLM-UV, (c) SEM-BSE and (d) elemental analysis with EDS

Table 1. Summery of examinations

sample ID	surface color	states of surface (LM)	thickness of top layer (SEM-BSE)	EDS detected elements in the top layer	note
UZM_003	reddish	small number of red particles on pale reddish orange surface	very thin	Fe, Si, Al	similar to 010
UZM_004	pink	pink color and rough texture	10-20um	Pb, Cl, Ca, S	
UZM_005	dark red	red and black particles	20um	Pb	
UZM_007	red	reddish brown surface on bright red	20um	Fe, Si	
UZM_008	green	dull off-white (beige)	<10um	Si, Al, Mg, K, Fe	
UZM_009	gray	gray	(no layer recognised)	(not analysed)	
UZM_010	pale pink	small number of red particles on pale reddish orange surface	very thin	Fe, Si, Al	similar to 003
UZM_011	dark red	red and black particles, rough texture	15um	Pb	

As for the organic binder, surface observation leads one to exclude the likelihood that Üzümlü paintings were depicted using drying oils or wax. Major possible candidates include water-soluble binders (animal proteins, casein: milk/cheese, plant gums). Two different biochemical techniques were employed in order to detect very low concentrations of organic media. First, ELISA (Enzyme Linked Immunosorbent Assay) was applied for the protein including to materials such as animal glues, caseins and plant gums (Takashima 2015). There was no positive reaction from any of the tests. Secondly, a nano-LC-ESI-MS/MS was employed in order to accurately detect and identify collagen (Fukakusa et.al 2015). Again, no positive results were obtained. Such findings lead to the possibility that the Üzümlü wall paintings were depicted without any organic binder. Rather, it appears to have been set on the surface with gypsum, which worked naturally as a weak binder.

4. CONDITION SURVEY OF THE ÜZÜMLÜ WALL PAINTINGS

While the tuff structure of the Üzümlü church suffers from extensive environmental deterioration, the wall paintings are in relatively stable condition, and continue to be well-protected by the fabric. The paintings were therefore considered in parallel to the structure, but the investigative approach varied, as will any eventual treatment needs.

4.1 Documentation of the Üzümlü Church

In the 1970s, Prof. Masaru Maeno and a research team from the Tokyo National University of Fine Art and Music (Tokyo University of the Art) undertook the first architectural documentation of church structures in Cappadocia and Ihlara valley, inclusive of the Üzümlü Church (Figure 5). For the current project, a digital

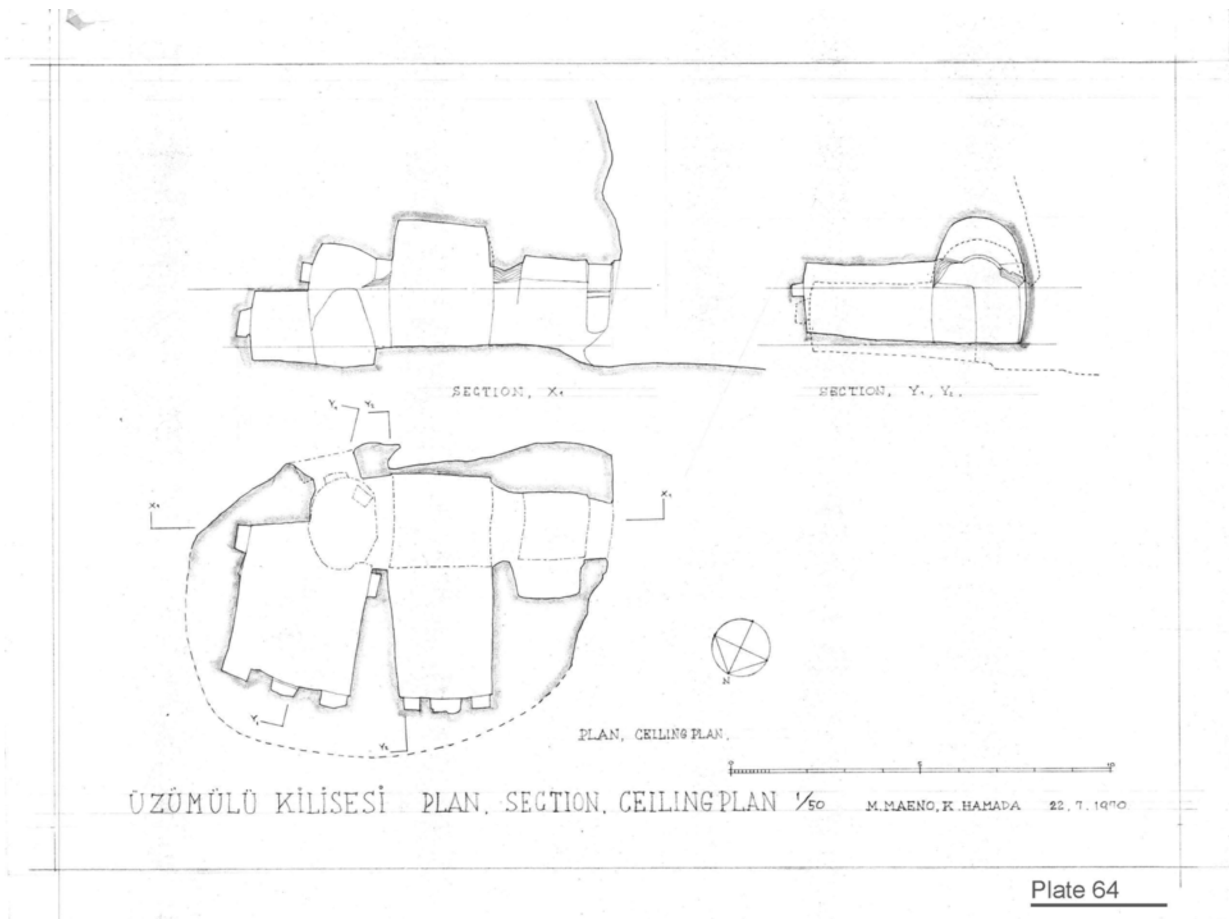


Figure 5. A plan of Üzümlü Church depicted by Prof. Maeno in 1970

Figure 6. A merged image of the dome of the altar

photographic technique was applied in order to create a base map of the Üzümlü wall paintings. In the Üzümlü Church, some wall paintings are applied on curved surfaces such as those in domes or vaults. Therefore, photographs produce representations that appear distorted and are not of sufficient quality for use. During the survey, images were processed using a specific method to create base photographs for mapping as well as for accurate assessment of conditions.

As some wall painting were captured in a sectional series of more than two photographs, it was necessary to later merge these images together using image processing software, Photoshop CS6 in this case. After combining the photographs through the add-in Photomerge tool, the edges of each section were checked. Distorted areas within combined photographs were revised by the add-in warp tool. Finally, all photographs were adjusted to fit to the exact scale (Figure 6).

4.2 Condition survey

Deterioration of the interior rock surfaces and wall painting was identified and mapped on transparent polyether sheets in order to record deterioration phenomenon and their distribution. Sheets were then transferred into a digital format in Japan using Illustrator files (Figure 7).

Structural cracking and external erosion, though indirect, can be considered the most significant ongoing threats to the wall paintings. Currently, cracking has not resulted in water infiltration to the interior, but this will inevitably become a problem if the structural issues are not addressed. In some areas, cracking does seem to have resulted in the detachment of the wall painting plaster from the tuff substrate, in which case some detachment can also be considered ongoing.

The most extensive direct damage to the wall paintings has been caused by humans and animals. Most was perpetrated mechanically through the use of sharp tools for creating graffiti, leaving scratches, and removing faces and hands from Saints. There is also significant impact damage, which has been another cause of cracking and detachment of the plaster layer.

Mechanical damage has often revealed the bright white gypsum ground and plaster beneath the paint layers. White areas are quite distinguishable and optically overshadow darker tones in paintings. Such vandalism may be classified and defined by period and purpose. First, there is iconographic vandalism during what could be characterized as an iconoclastic period. Second, there was graffiti applied as part of worshipping practices depicting saints, horses, and prayers in Greek letters both pre- and post-dating the iconoclastic period. Third, there is graffiti by tourists or locals with names and dates (Figures 8, 9). The second case in particular should be the subject of more careful study before any conservation intervention is initiated. This is necessary to achieve a balance between preserving the cultural importance of the work as a historical witness and upholding its original visual aesthetic toning.

Despite the extensive mechanical damage, much of the original paint layer appears to survive intact. However, detailed observation revealed that many pigments were actually discoloured, darkened, and lost. The vault of

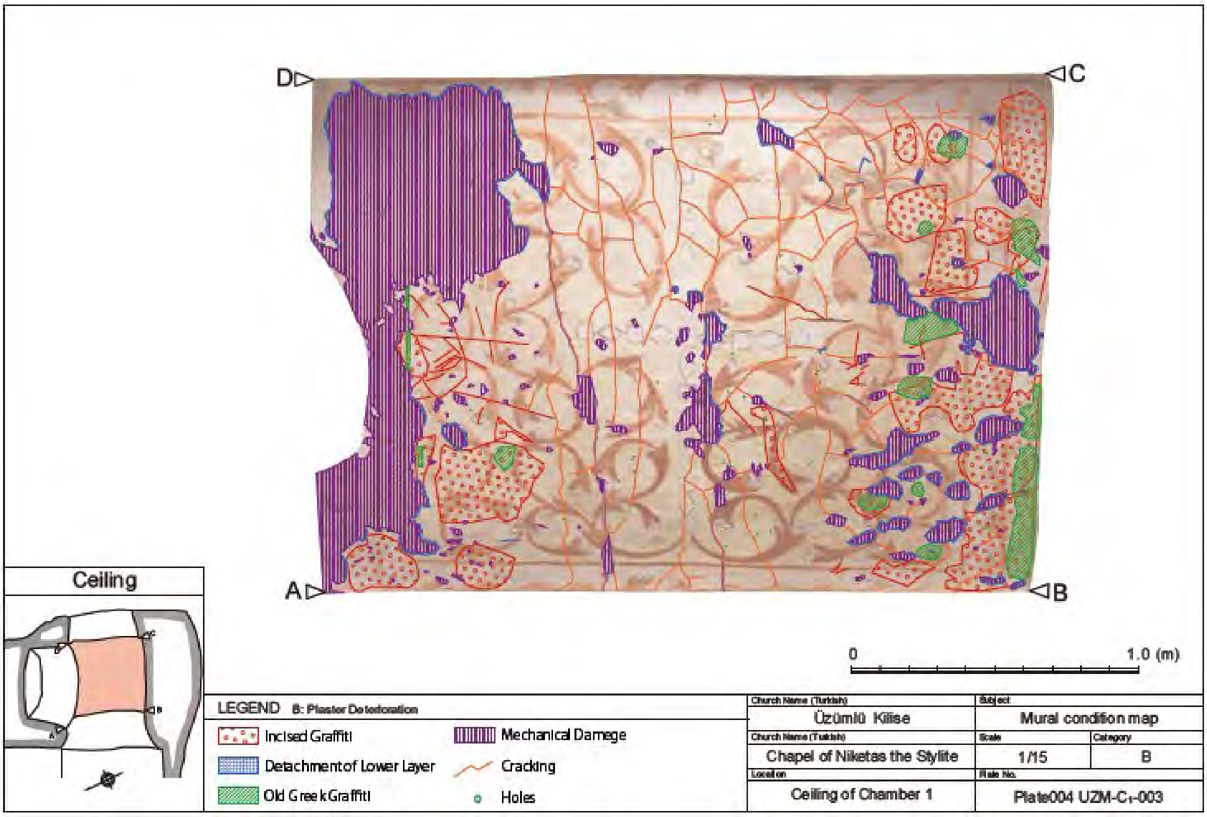


Figure 7. A complete example of condition assessment

Figure 8. Graffiti, possibly by tourists

Figure 9. Graffiti, possibly from the Christian period

Figure 10. A scene of vines without grapes

the Narthex in particular has inexplicably lost important grape motifs in the centre of its vine decorations (Figure 10). A similar motif of grapes and vines is visible in the vault of the Nave endured better. Particular metal-based pigment alterations, likely caused by exposure to the outdoor environment, were observed, including the alteration of lead-based pigments to PbO.

While the paint appears to have been applied as thin washes in many areas, paint loss seems to have occurred in some specific instances. The cause of this loss in not yet understood, however it could be due to water-related loss of paint materials. It may also be related to missing images by probably paint thinning and disappearing, such as the grapes in the first vault. Microscopic observation did also reveal microlosses from paint layers, in the form of small white spots, the cause of which also remains unclear for the moment.

Preferential loss of paint layers has also been observed in other sites, with particular note having been made of the loss of green pigment (Andaloro 2008), and this phenomenon will require further study and perhaps treatment.

Deterioration very similar to those affecting the church and paintings at Üzümlü have long been recognized as the main threats to sites throughout the Cappadocia region (UNESCO 1985), and many subsequent studies have confirmed and reiterated this finding (Schwartzbaum 1986; Andaloro 2008 & 2014; Rovella 2014). The study and treatment of these phenomena and their causes at Üzümlü will therefore be of great relevance to sites throughout the area.

5. TOWARDS ON-SITE CONSERVATION TRIALS

Environmental data and results from material analysis have provided information useful for planning a range of conservation tests and trials for the Üzümlü wall paintings and tuff rock substrate. In this regard, in-situ tests shall be indispensable for selecting suitable conservation materials and application methods, as well as for managing better indoor conditions. In 2015, further testing shall be carried out for identifying possible consolidants and protective materials for the tuff substrates, in addition to testing materials for the readhesion of the detached gypsum ground and friable paint layers. Measures will also be taken to better protect the site from future vandalism and animal inhabitation, thus reducing the risk of renewed mechanical damage to the paintings.

In each case, both method and materials must be compatible with the original materials, and implemented on a minimal scale, to avoid excess and unnecessary treatments. The case in Üzümlü is certainly a most technically difficult challenge, and could serve as a model case for new approaches to integrating, presenting, and advancing ethical conservation in the Cappadocia region.

References

Andaloro, M., 2008, Rock paintings of Cappadocia: images, materials and state of preservation, *25. Araştırma Sonuçları Toplantısı, 2. Cİlt, 28 Mayıs-01 Hazİran 2007 Kocaelİ*, pp.163-178.

Andaloro, M., Pignatale, T. and Verdiani, G., 2014, 'The Church of Meryem Ana in Göreme, Cappadocia: Correct documentation for a meaningful heritage at risk', Conference on Cultural Heritage and New Technologies, Vienna, Austria, November 1113, 2013.

Aydan, Ö., Ulusay, R. 2003, Geotechnical and geoenvironmental characteristics of man-made underground structures in Cappadocia, Turkey, *Engineering Geology*, **69**, pp.245-272.

Doğan, U., 2011, Climate-controlled river terrace formation in the Kizilimak Valley, Cappadocia section, Turkey: Inferred from Ar-Ar dating of Quatenary basalts and terraces stratigraphy, *Geomorphology*, **126**, pp.66-81.

Erguler, Z.A., 2009, Field-based experimental determination of the weathering rates of the Cappadocian tuffs, *Engineering Geology*, **105**, pp.186-199.

Fukakusa, S., Kawahara, K., Nakazawa, T., 2015, III-4 Nano liquid chromatography-electrospray ionization tandem mass spectrometry (Nano-LC-ESI-MS/MS) analysis of the Üzümlü wall paintings, In Taniguchi, ed., *Scientific Studies on Conservation for Üzümlü Church and Its Wall Paintings in Cappadocia, Turkey., vol. 1. Annual report on the activities in 2014*, p.103-106.University of Tsukuba.

McCrone, W. C. et al., 1979, *The Particle Atlas V, 2nd ed.*, Ann Arbor Science Publishers Inc., Ann Arbor, Michigan.

Plesters J., 1956, Cross-sections and chemical analysis of paint samples, *Studies in Conservation*, **2**, pp.110-157.

Pelosi, C., Agresti, G., Andaloro, M., Pogliani, P., Santamaria, U., 2013, 'The rock hewn wall paintings in Cappadocia (Turkey). Characterization of the constituent materials and a chronological overview', *e-Preservation Science*, **10**, pp.99-108.

Pelosi, C., Agresti, G., Andaloro, M., Baraldi, P., Pogliani, P., Santamaria, U., Russa, M.F., Ruffolo, S.A., Rovella, N., 2015, Micro-Raman and micro-stratigraphic analysis of the painting materials in the rock-hewn church of the Forty Martyrs in Şahinefendi, Cappadocia (Turkey), *Archaeometry*, forthcoming.

Rovella, N., Andaloro, M., Crisci, G.M., La Russa, M.F., Pelosi, C., Pogliani, P., Ruffolo, S.A., 2014, Cappadocian rupestrian churches and conservative strategies: from the lab to the archeological site, VIII *Congresso Nazionale di Archeometria Scienze e Beni Culturali: stato dell'arte e prospettive, Bologna, Italy, 5-7 February 2014.*

Sano, K., Mizukoshi, S., 2015, II-5 Preliminary aging tests (outdoor environment) of consolidants for tuff rock samples, In Taniguchi, ed., *Scientific Studies on Conservation for Üzümlü Church and Its Wall Paintings in Cappadocia, Turkey, vol. 1. Annual report on the activities in 2014*, p.37-41.University of Tsukuba.

Schwartzbaum, P., 1986, Conservation of the mural paintings in the rock cut churches of Göreme, In *Tokalı Kilise: 10th Century Metropolitan Art in Byzantine Cappadocia*, A. J. Wharton ed., Dumbarton Oaks, Appendix I.

Suzuki, T., Higuchi, R., Shibata, M., 2015, III-6 Documentation of Üzümlü Church: High-resolution database of the condition of paintings, In *Scientific Studies on Conservation for Üzümlü Church and Its Wall Paintings in Cappadocia, Turkey., vol. 1. Annual report on the activities in 2014*, Y. Taniguchi, ed., pp.107-117.University of Tsukuba.

Takashima, M., 2015, III-4 ELISA (Enzyme-linked immunosorbent assay) testing for organic binding media of Üzümlü wall paintings, In *Scientific Studies on Conservation for Üzümlü Church and Its Wall Paintings in Cappadocia, Turkey., vol. 1. Annual report on the activities in 2014*, Y. Taniguchi, ed., p.96-102.University of Tsukuba.

UNESCO, 1985, *Structural conservation of Göreme. Göreme, land of fairy chimneys*. Ministry of Culture and Tourism, Turkey. General Directorate of Antiquities and Museums.

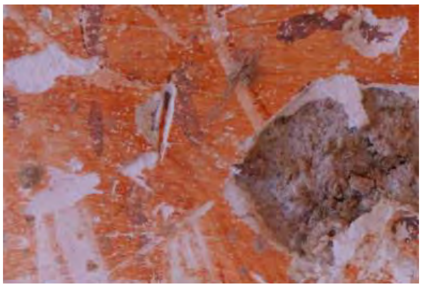
Acknowledgements

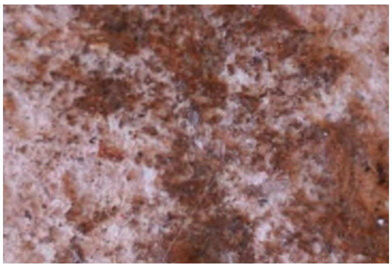
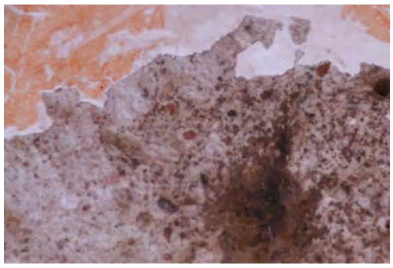
The authors would like to express their appreciation to MEXT/JSPS KAKENHI (24101014) and the Kajima Foundation for their financial support on this project. The Üzümlü project has been supported by numerous individuals in both Turkey and Japan, especially staff members of the Nevşehir Restoration and Conservation Regional Laboratory Directorate: Hatice Temur, Ayça Baştürkmen, Uğur Yalçınkaya, Alev Elçin Cankur, Merve Aziz Işın, Mustafa Toptepe, Tuğba Eryaşar. And Ibrahim Sakınan and family, Zuhal Coçyğit, Katsuhiko Sano, Shigekazu Mizukoshi, Piao Chunzu, Kunio Watanabe,

Tamaki Suzuki, Ryo Higuchi, Mina Shibata, Natsuko Kuguya, Ayako Ogawa, Yoshiko Shimadzu, Miho Takashima, Takeshi Nakazawa, Kazuki Kawahara, Shunsuke Fukasawa, Mizuho Yoshioka, Satsuki Shobo, Juni Sasaki and Kazuya Yamauchi.

III. Appendices

III-1 ÜZÜMLÜ CHURCH, CAPPADOCIA
Condition glossary
September 2014

<table>
<tr><td>ROCK DETERIORATION
KAYADA BOZULMA</td><td></td><td></td></tr>
<tr><td></td><td>BIYOLOJIC BOZULMA</td><td>BIOLOGIC ACTIVITY

Evidence of animal inhabitation (insects, spiders). Often, they appear to have inhabited pre-existing fractures in the rock, possibly exacerbating deterioration</td></tr>
<tr><td colspan="3">  </td></tr>
<tr><td>SIYAHLAŞMA</td><td colspan="2">DEPOSITION OF DARK MATERIAL

Deposits of dark brown or blackish material on the surface of the rock. Its origin is unclear, but it may be caused by biologic activity (ex. insects, bats). It appears to have been deposited on the stone after a loss of plaster, but this is uncertain – similar deposits do not appear on the surface of the plaster or paint layers. Could it have formed under the plaster and contributed to detachment? If of insect or animal origin, what caused the depopulation?</td></tr>
<tr><td colspan="2" rowspan="2"> </td><td>YAPISAL ÇATLAH</td></tr>
<tr><td>STRUCTURAL CRACKS

Large cracks which run through the body of the rock, caused by faulting</td></tr>
</table>

YÜZEYDE KÜÇÜK ÇATLAK

SPALLING

Detachment of the rock on a small scale, in parallel to the surface of the rock, probably more due to internal failure of the rock itself than macro-failure of the structure, though the two factors may be inter-related

PLASTER DETERIORATION

SIVADA BOZULMA

YAPISAL ÇATLAH

STRUCTURAL CRACKS

Large cracks which run through the body of the rock, caused by faulting

YÜZEYDE KÜÇÜK ÇATLAK

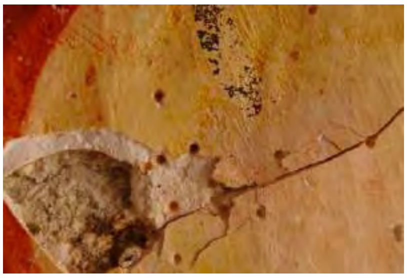
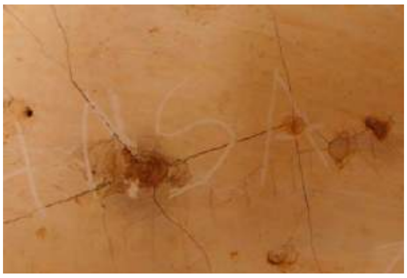
SPALLING

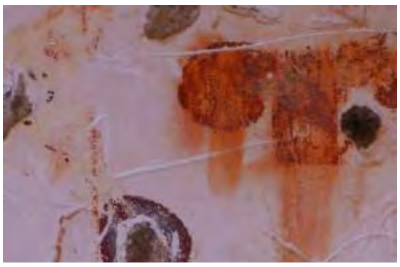
Detachment of the rock on a small scale, in parallel to the surface of the rock, probably more due to internal failure of the rock itself than macro-failure of the structure, though the two factors may be inter-related

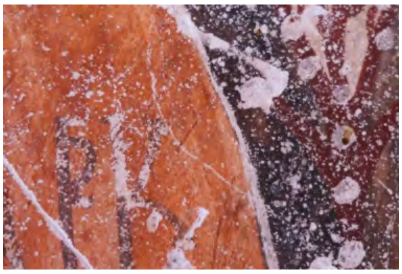
BÜTÜN ÇATLAKLAR

CRACKING

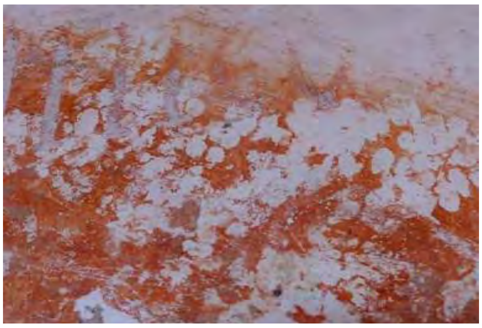
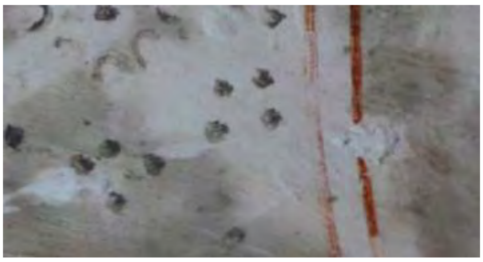
Cracking of the plaster layer most often resulting from cracking of the rock structure and mechanical damage, though there may be other causes

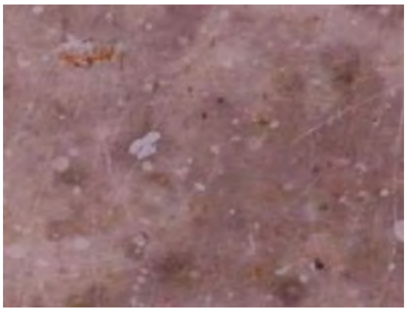
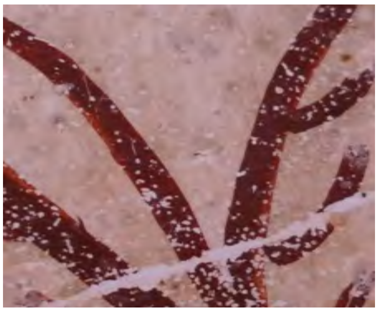
 	
DELIKLER (5mm ø)	OLES Very circular, small holes of approximately 5 mm Ø, which enter into the plaster layer and generally do not reach the substrate. Cause is unknown as of yet.
 	
GRAFİTİ	INCISED GRAFFITI Inscriptions and drawings incised into the surface of the painting, affecting the paint layer, ground and plaster layer. Some graffiti appears to be ancient (written in Greek; imagery of horses, monks etc), but a significant proportion is modern (based on writing, dates, phone numbers …).

PAINT LAYER DETERIORATION BOYA TABABASINDA BOZULMA		
	LEKELENMELER	SMEARING Displacement of the paint layer by mechanical action beyond its original location, seen as a spreading of the paint across the surface of the plaster. Generally appears to have been caused by contact with the paint layer, perhaps in combination with the presence of water



MIKRO KAYIPLAR	MICRO LOSSES Extremely small, rounded losses of the paint layer generally on the order of 0.5-1 mm Ø. Not always confined to specific paint layers, but does appears to be somewhat location-specific

	BİYOLOJIK NEDENLERLE BOYA TABAKASINDA KAYIP	PAINT LAYER LOSS DUE TO BIOLOGIC ACTIVITY Loss of the paint layer due to the former presence of birds' nests (primarily) which, when separated from the painting surface, removed part of the paint layer
	KOYU GRI LEKELENMELER	DARK GREY VEIL Veil extending over the surface of the painting, dark grey in color, somewhat patchy, and of unclear origin. Does not appear to be soot.

GRİ LEKELENMELER	REY SPOTTING Faint, circular grey spots, 0.5-3 mm Ø, on the surface of the painting. Origin unclear, but often generally occurs in the same vicinity as the grey veil

YÜZEY BİRİKİNTİLERİ	SURFACE DEPOSITION Deposition of material on the surface of the painting, such as mud from birds' nests or from later construction in the church (ex. mud plaster)

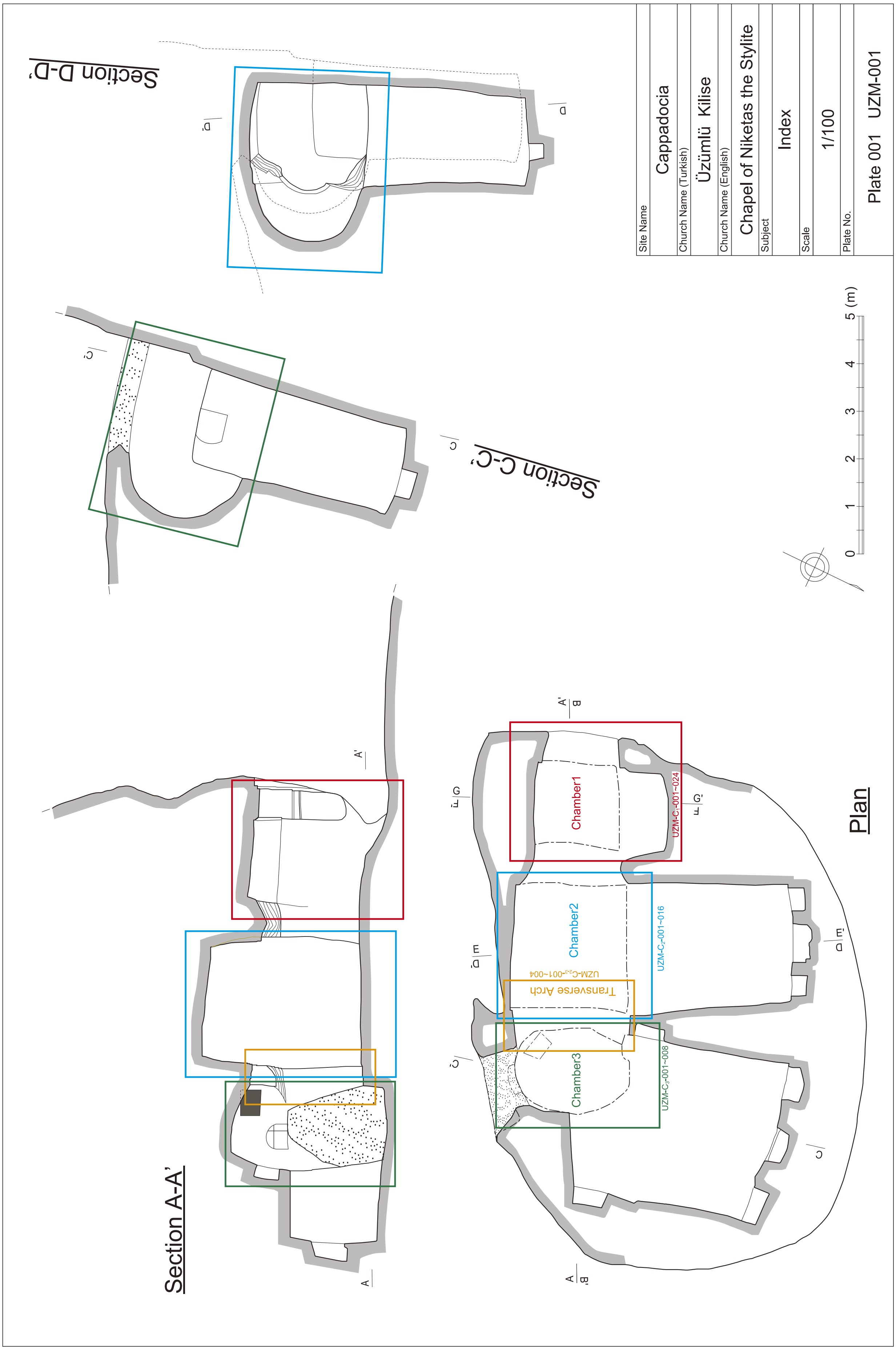
  

BİYOLOJİK BOZULMA	BIOLOGIC DETERIORATION Discoloration (generally dark grey) of certain areas of painting due to animal inhabitation. Has also resulted in the peeling and detachment of the plaster layer in certain areas

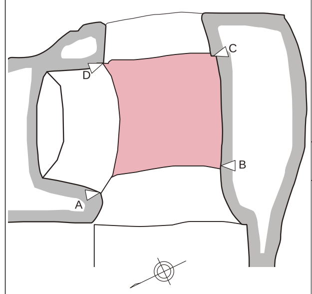
	YÜZEYSEL GRAFİTİ	SUPERFICIAL GRAFFITI Graffiti applied to the surface of the painting using a medium such as paint, ink, or graphite. At times the original paint layer used as a medium by taking advantage of its friability/ water sensitivity

III-2 Documentation of Wall Painting (2014) : Condition Survey

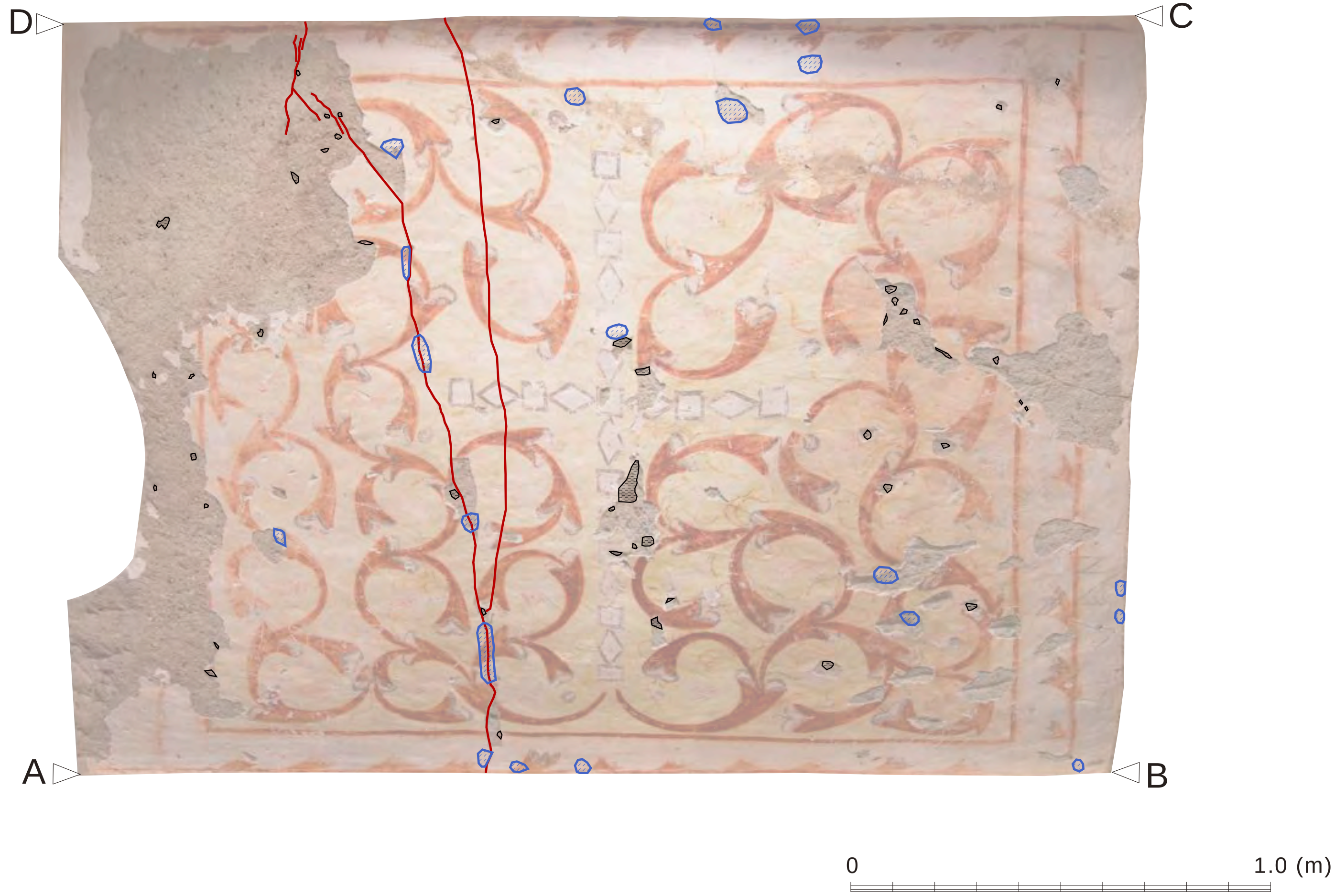
	No	Scale	Location	Category
Index	UZM-001	1/100		Plan and Section
Mural condition map of Chamber 1	UZM-C_1-001	1/15	Ceiling	Photograph
	UZM-C_1-002	1/15	Ceiling	Rock Deterioration
	UZM-C_1-003	1/15	Ceiling	Plaster Deterioration
	UZM-C_1-004	1/15	Ceiling	Paint Deterioration
	UZM-C_1-005	1/25	Intrados of Entrance Arch	Photograph
	UZM-C_1-006	1/25	Intrados of Entrance Arch	Rock Deterioration
	UZM-C_1-007	1/25	Intrados of Entrance Arch	Plaster Deterioration
	UZM-C_1-008	1/25	Intrados of Entrance Arch	Paint Deterioration
	UZM-C_1-009	1/15	North Arch	Photograph
	UZM-C_1-010	1/15	North Arch	Rock Deterioration
	UZM-C_1-011	1/15	North Arch	Plaster Deterioration
	UZM-C_1-012	1/15	North Arch	Paint Deterioration
	UZM-C_1-013	1/10	South Wall	Photograph
	UZM-C_1-014	1/10	South Wall	Rock Deterioration
	UZM-C_1-015	1/10	South Wall	Plaster Deterioration
	UZM-C_1-016	1/10	South Wall	Paint Deterioration
	UZM-C_1-017	1/10	West Wall	Photograph
	UZM-C_1-018	1/10	West Wall	Rock Deterioration
	UZM-C_1-019	1/10	West Wall	Plaster Deterioration
	UZM-C_1-020	1/10	West Wall	Paint Deterioration
	UZM-C_1-021	1/10	East Wall	Photograph
	UZM-C_1-022	1/10	East Wall	Rock Deterioration
	UZM-C_1-023	1/10	East Wall	Plaster Deterioration
	UZM-C_1-024	1/10	East Wall	Paint Deterioration
Mural condition map of Chamber 2	UZM-C_2-001	1/20	Ceiling	Photograph
	UZM-C_2-002	1/20	Ceiling	Rock Deterioration
	UZM-C_2-003	1/20	Ceiling	Plaster Deterioration
	UZM-C_2-004	1/20	Ceiling	Paint Deterioration
	UZM-C_2-005	1/15	South Wall	Photograph
	UZM-C_2-006	1/15	South Wall	Rock Deterioration
	UZM-C_2-007	1/15	South Wall	Plaster Deterioration
	UZM-C_2-008	1/15	South Wall	Paint Deterioration
	UZM-C_2-009	1/10	West Wall	Photograph
	UZM-C_2-010	1/10	West Wall	Rock Deterioration
	UZM-C_2-011	1/10	West Wall	Plaster Deterioration
	UZM-C_2-012	1/10	West Wall	Paint Deterioration
	UZM-C_2-013	1/10	East Wall	Photograph
	UZM-C_2-014	1/10	East Wall	Rock Deterioration
	UZM-C_2-015	1/10	East Wall	Plaster Deterioration
	UZM-C_2-016	1/10	East Wall	Paint Deterioration
Mural condition map of Transversal Arch	UZM-C_2-$_3$-001	1/10	Intrados of Transversal Arch	Photograph
	UZM-C_2-$_3$-002	1/10	Intrados of Transversal Arch	Rock Deterioration
	UZM-C_2-$_3$-003	1/10	Intrados of Transversal Arch	Plaster Deterioration
	UZM-C_2-$_3$-004	1/10	Intrados of Transversal Arch	Paint Deterioration
Mural condition map of Chamber 3	UZM-C_3-001	1/20	Ceiling	Photograph
	UZM-C_3-002	1/20	Ceiling	Rock Deterioration
	UZM-C_3-003	1/20	Ceiling	Plaster Deterioration
	UZM-C_3-004	1/20	Ceiling	Paint Deterioration
	UZM-C_3-005	1/10	South-eastern Wall	Photograph
	UZM-C_3-006	1/10	South-eastern Wall	Rock Deterioration
	UZM-C_3-007	1/10	South-eastern Wall	Plaster Deterioration
	UZM-C_3-008	1/10	South-eastern Wall	Paint Deterioration


Section D-D'
Section C-C'
Section A-A'
Plan
Chamber1
UZM-C1-001~024
Chamber2
UZM-C2-001~016
Transverse Arch
UZM-C2,3-001~004
Chamber3
UZM-C3-001~008
0 1 2 3 4 5 (m)
Site Name
Cappadocia
Church Name (Turkish)
Üzümlü Kilise
Church Name (English)
Chapel of Niketas the Stylite
Subject
Index
Scale
1/100
Plate No.
Plate 001 UZM-001

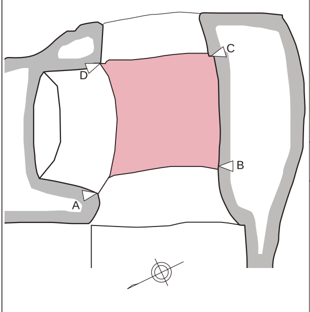
Ceiling



Church Name (Turkish): Üzümlü Kilise	Subject: Mural condition map
Church Name (Turkish): Chapel of Niketas the Stylite	Scale: 1/15 — Category: Photograph
Location: Ceiling of Chamber 1	Plate No.: Plate002 UZM-C_1-001



Ceiling



LEGEND A: Rock Deterioration

Deposition of Dark Material

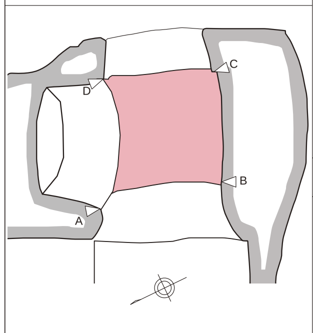
Structural Cracks

Biologic Activity

Church Name (Turkish) Üzümlü Kilise	Subject Mural condition map
Church Name (Turkish) Chapel of Niketas the Stylite	Scale: 1/15 / Category: A
Location Ceiling of Chamber 1	Plate No. Plate003 UZM-C_1-002

0 1.0 (m)

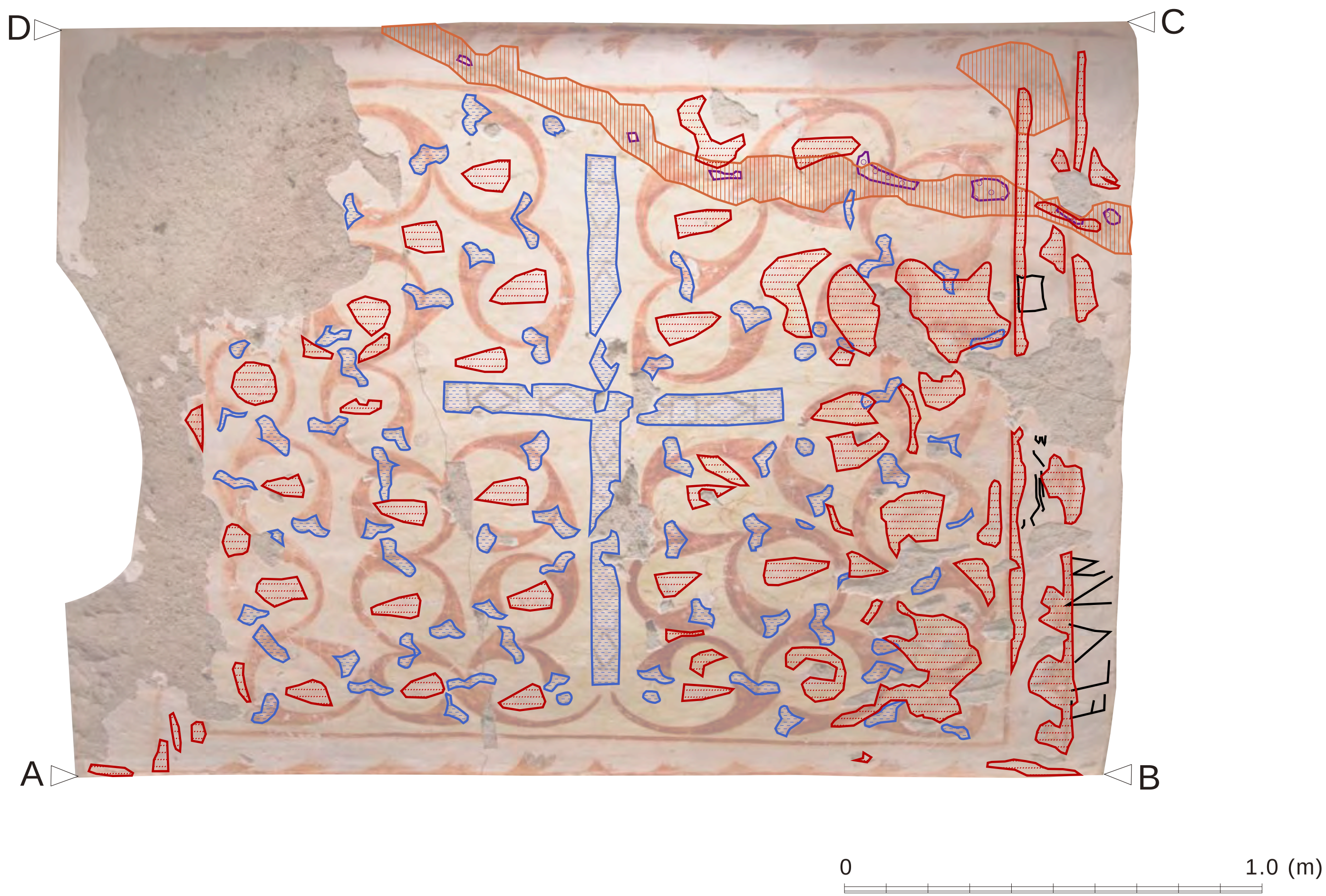
Ceiling



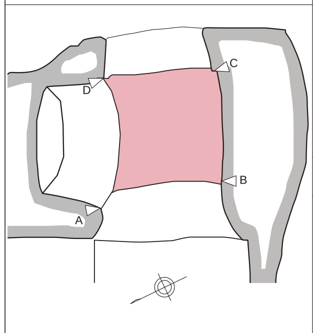
LEGEND B: Plaster Deterioration

Incised Graffiti	Mechanical Damege
Detachment of Lower Layer	Cracking
Old Greek Graffiti	Holes

Church Name (Turkish)	Subject	
Üzümlü Kilise	Mural condition map	
Church Name (Turkish)	Scale	Category
Chapel of Niketas the Stylite	1/15	B
Location	Plate No.	
Ceiling of Chamber 1	Plate004 UZM-C1-003	



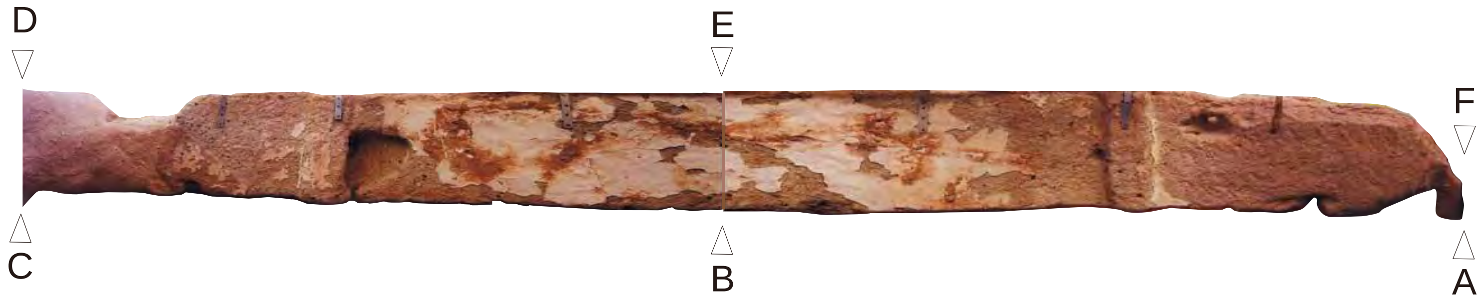
Ceiling



LEGEND C: Paint Deterioration

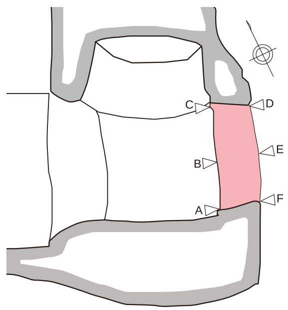
- Smearing
- Surface Deposition
- Superficial Graffiti
- Biological Deposition
- Micro Losses
- Paint Loss due to Biological Activity

Church Name (Turkish)	Subject	
Üzümlü Kilise	Mural condition map	
Church Name (Turkish)	Scale	Category
Chapel of Niketas the Stylite	1/15	C
Location	Plate No.	
Ceiling of Chamber 1	Plate005 UZM-C_1-004	

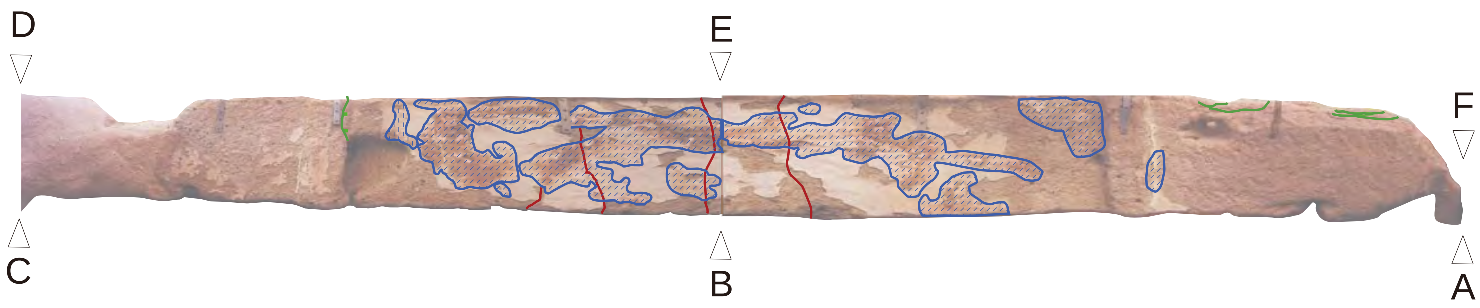


0 1.0 (m)

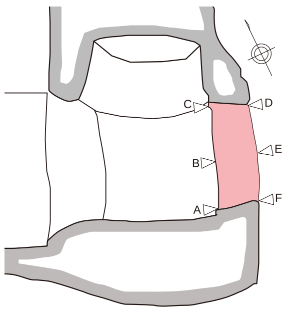
Ceiling



Church Name (Turkish)	Subject	
Üzümlü Kilise	Mural condition map	
Church Name (Turkish)	Scale	Category
Chapel of Niketas the Stylite	1/20	Photograph
Location	Plate No.	
Intrados of Entrance Arch	Plate006 UZM-R1-005	



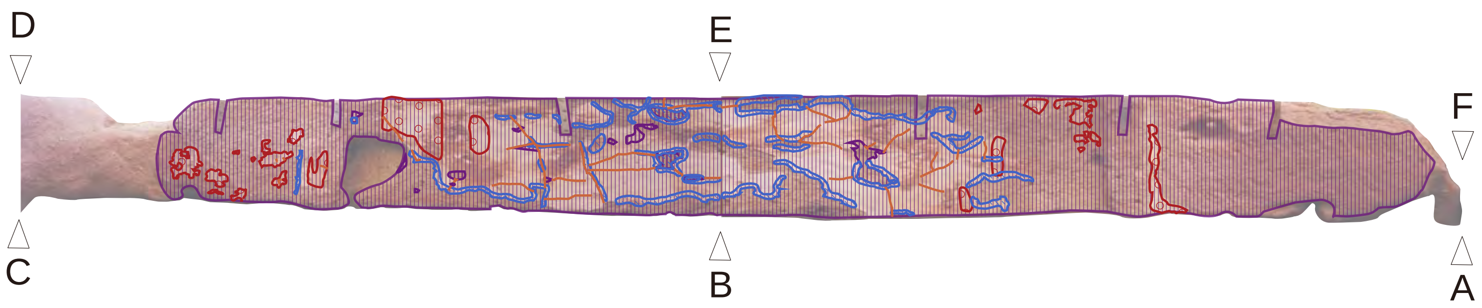
Ceiling



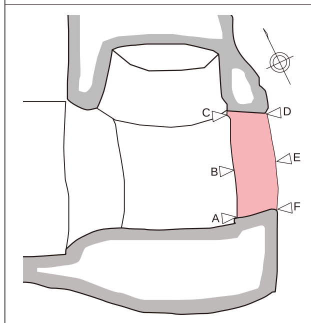
LEGEND A: Rock Deterioration

- Biologic Activity
- Spalling
- Structural Cracks

Church Name (Turkish)	Subject	
Üzümlü Kilise	Mural condition map	
Church Name (Turkish)	**Scale**	**Category**
Chapel of Niketas the Stylite	1/20	A
Location	**Plate No.**	
Intrados of Entrance Arch	Plate007 UZM-C_1-006	



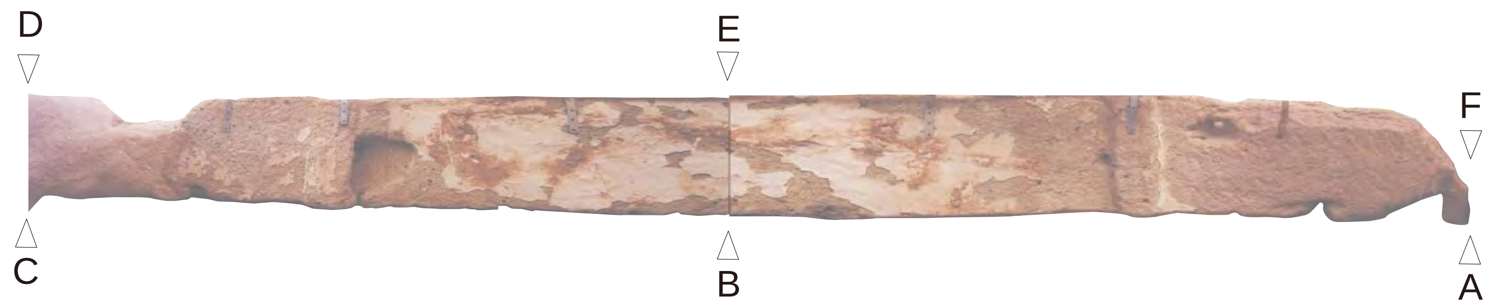
Ceiling



LEGEND B: Plaster Deterioration

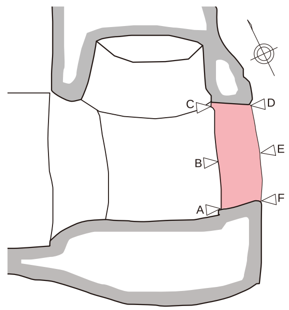
- Incised Graffiti
- Detachment of Lower Layer
- Mechanical Damege
- Cracking

Church Name (Turkish) Üzümlü Kilise	Subject Mural condition map
Church Name (Turkish) Chapel of Niketas the Stylite	Scale: 1/20 / Category: B
Location Intrados of Entrance Arch	Plate No. Plate008 UZM-C1-007



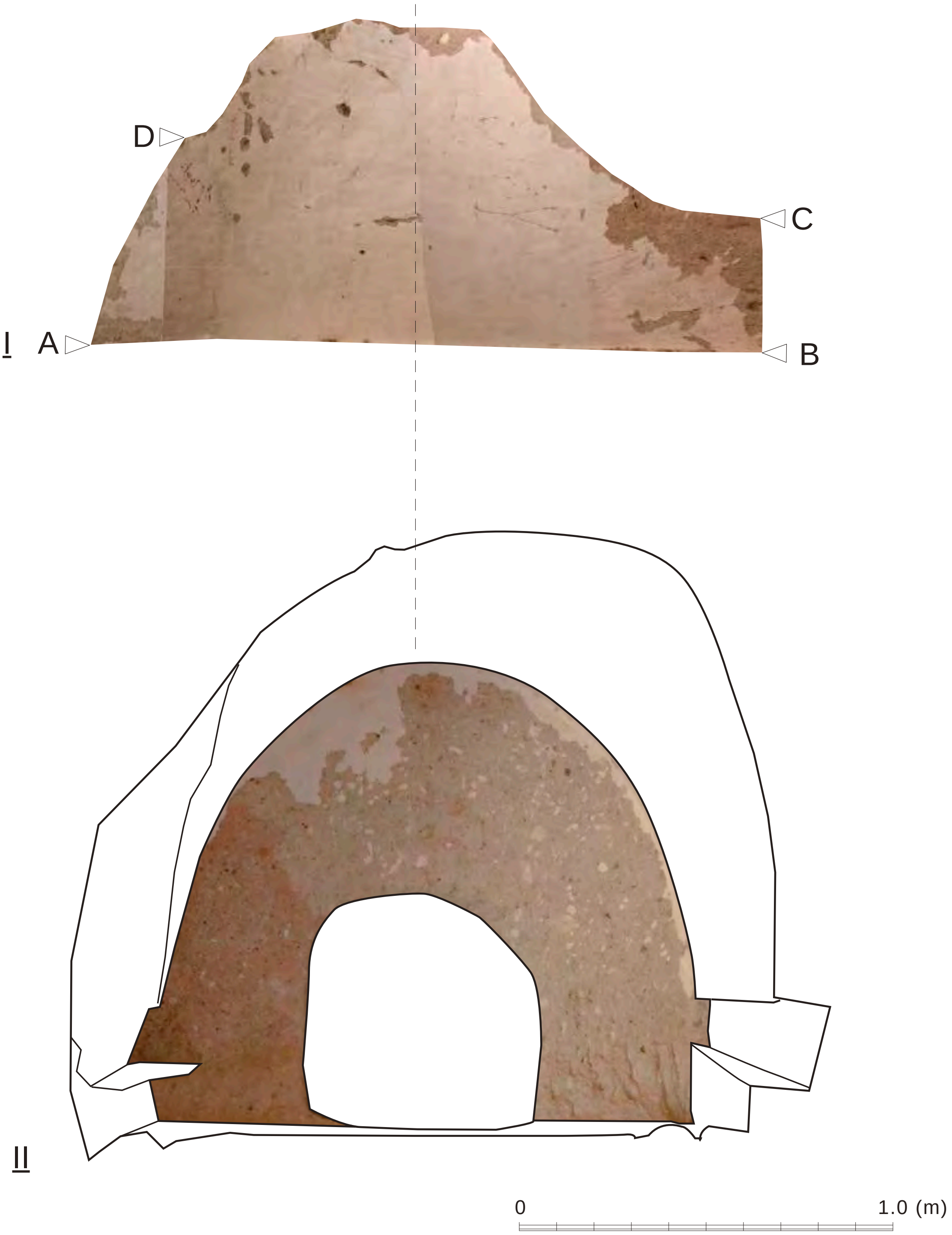
0 1.0 (m)

Ceiling

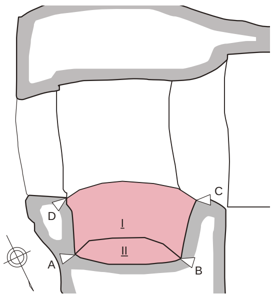


LEGEND C: Paint Deterioration

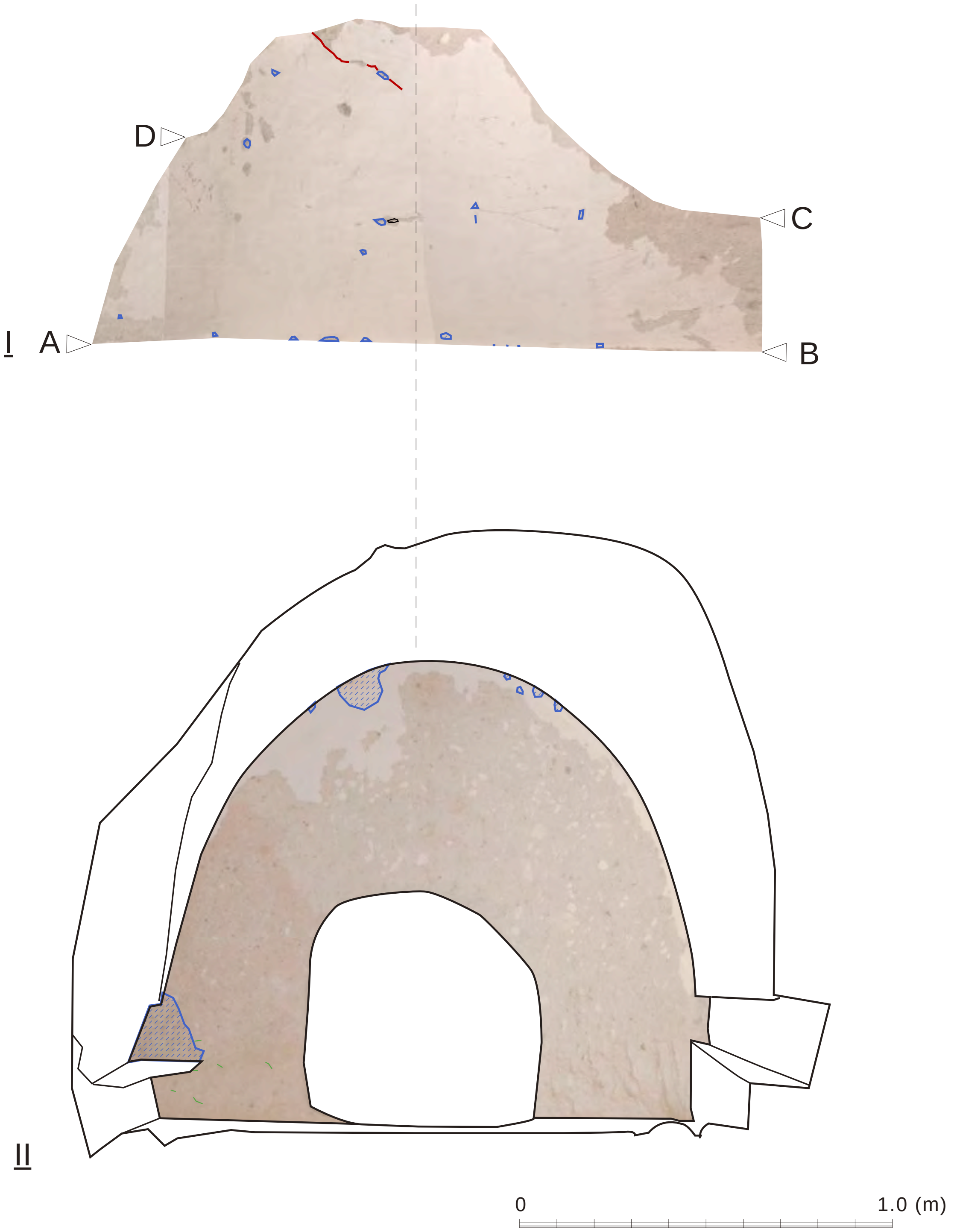
Church Name (Turkish)	Subject	
Üzümlü Kilise	Mural condition map	
Church Name (Turkish)	Scale	Category
Chapel of Niketas the Stylite	1/20	C
Location	Plate No.	
Intrados of Entrance Arch	Plate009 UZM-C_1-008	



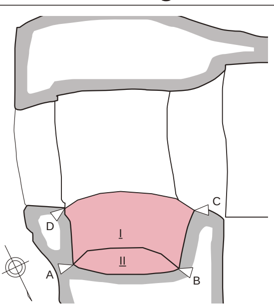
Ceiling



Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
North Arch of Chamber 1	
Subject	
Mural condition map	
Scale	Category
1/15	Photograph
Plate No.	
Plate 010 UZM-C1-009	



Ceiling



LEGEND A: Rock Deterioration

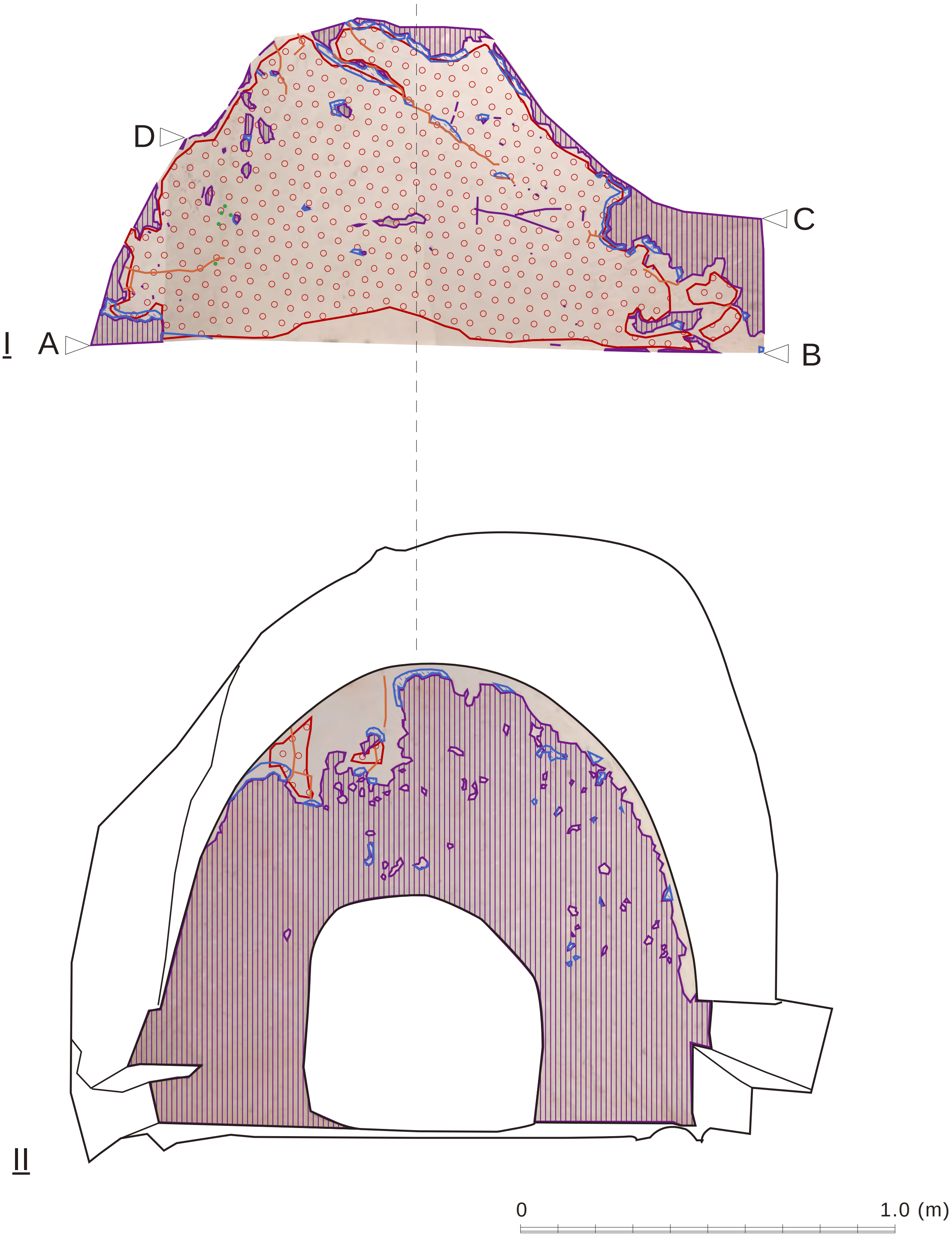
Deposition of Dark Material

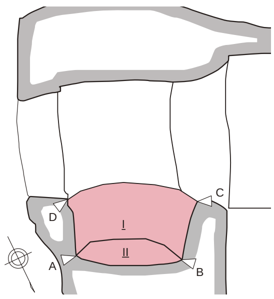
Spalling

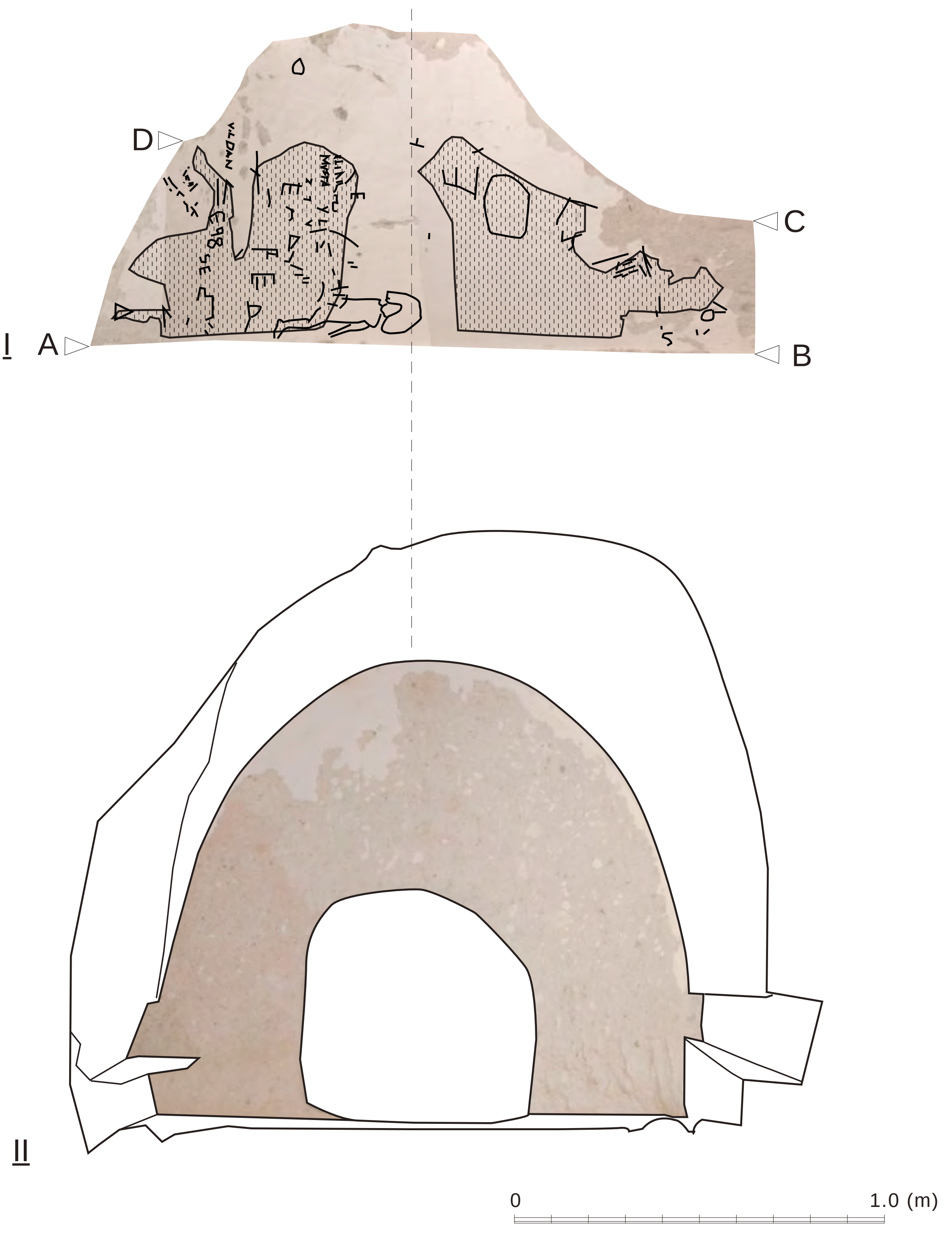
Biologic Activity

Structural Cracks

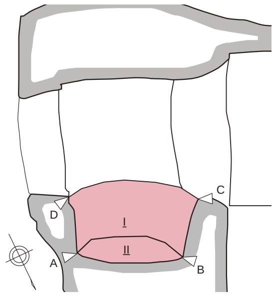
Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
North Arch of Chamber 1	
Subject	
Mural condition map	
Scale	Category
1/15	A
Plate No.	
Plate 011 UZM-C1-010	



Ceiling	LEGEND B: Plaster Deterioration	Church Name (Turkish): Üzümlü Kilise
	Incised Graffiti	Church Name (English): Chapel of Niketas the Stylite
	Detachment of Lower Layer	Location: North Arch of Chamber 1
	Mechanical Damege	Subject: Mural condition map
	Cracking	Scale: 1/15 / Category: B
	Holes	Plate No.: Plate 012 UZM-C1-011

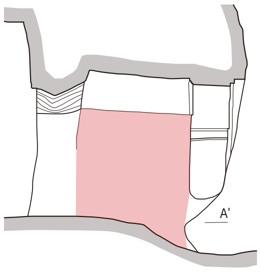


Ceiling	LEGEND C: Paint Deterioration	Church Name (Turkish): Üzümlü Kilise
	Dark Grey Veil; Superficial Graffiti	Church Name (English): Chapel of Niketas the Stylite
		Location: North Arch of Chamber 1
		Subject: Mural condition map
		Scale: 1/15 — Category: C
		Plate No.: Plate 013 UZM-C_1-012



0 0.5 (m)

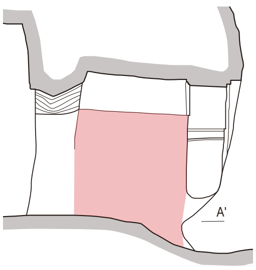
Section A-A’



Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
South Wall of Chamber 1	
Subject	
Mural condition map	
Scale	Category
1/10	Photograph
Plate No.	
Plate014 UZM-C_1-013	

0 0.5 (m)

Section A-A’



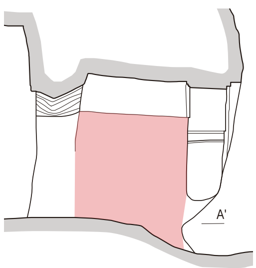
LEGEND A: Rock Deterioration

- Deposition of Dark Material
- Biologic Activity

Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
South Wall of Chamber 1	
Subject	
Mural condition map	
Scale	Category
1/10	A
Plate No.	
Plate015 UZM-C1-014	

0 0.5 (m)

Section A-A'	LEGEND B: Plaster Deterioration



Detachment of Lower Layer

Mechanical Damege

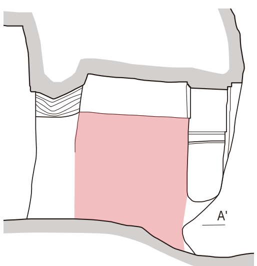
Cracking

Holes

Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
South Wall of Chamber 1	
Subject	
Mural condition map	
Scale	Category
1/10	B
Plate No.	
Plate016 UZM-C_1-015	

0 0.5 (m)

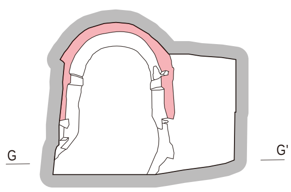
Section A-A'

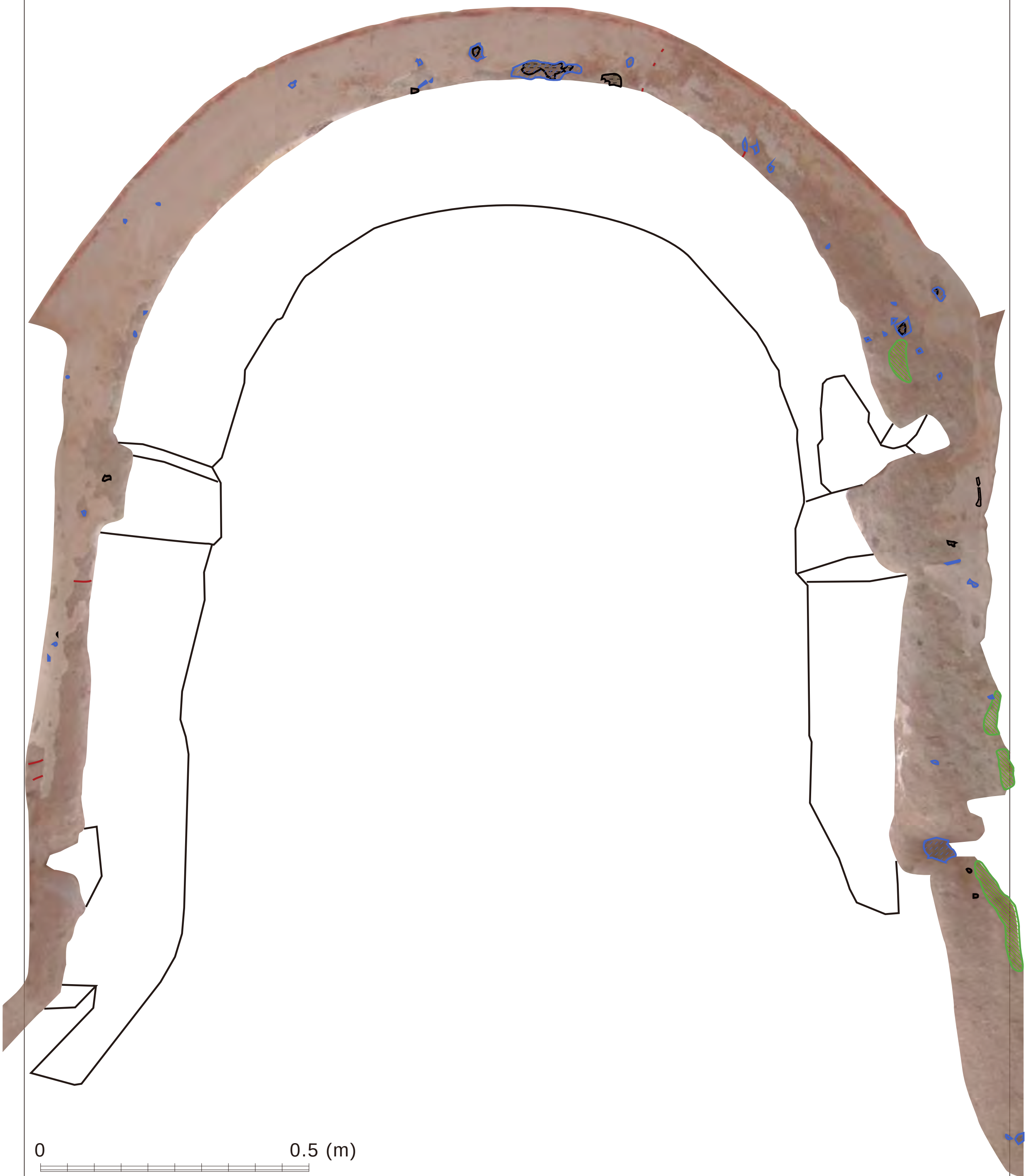


LEGEND C: Paint Deterioration

- Smearing
- Surface Deposition
- Superficial Graffiti

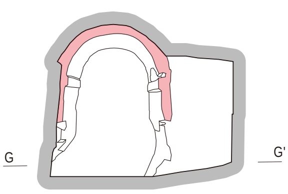
Church Name (Turkish)	Üzümlü Kilise
Church Name (English)	Chapel of Niketas the Stylite
Location	South Wall of Chamber 1
Subject	Mural condition map
Scale	1/10
Category	C
Plate No.	Plate017 UZM-C_1-016

Section G-G’		
		Church Name (Turkish) Üzümlü Kilise Church Name (English) Chapel of Niketas the Stylite Location West Wall of Chamber 1 Subject Mural condition map Scale: 1/10 Category: Photograph Plate No. Plate018 UZM-C_1-017



0 0.5 (m)

Section G-G’

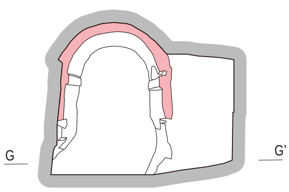


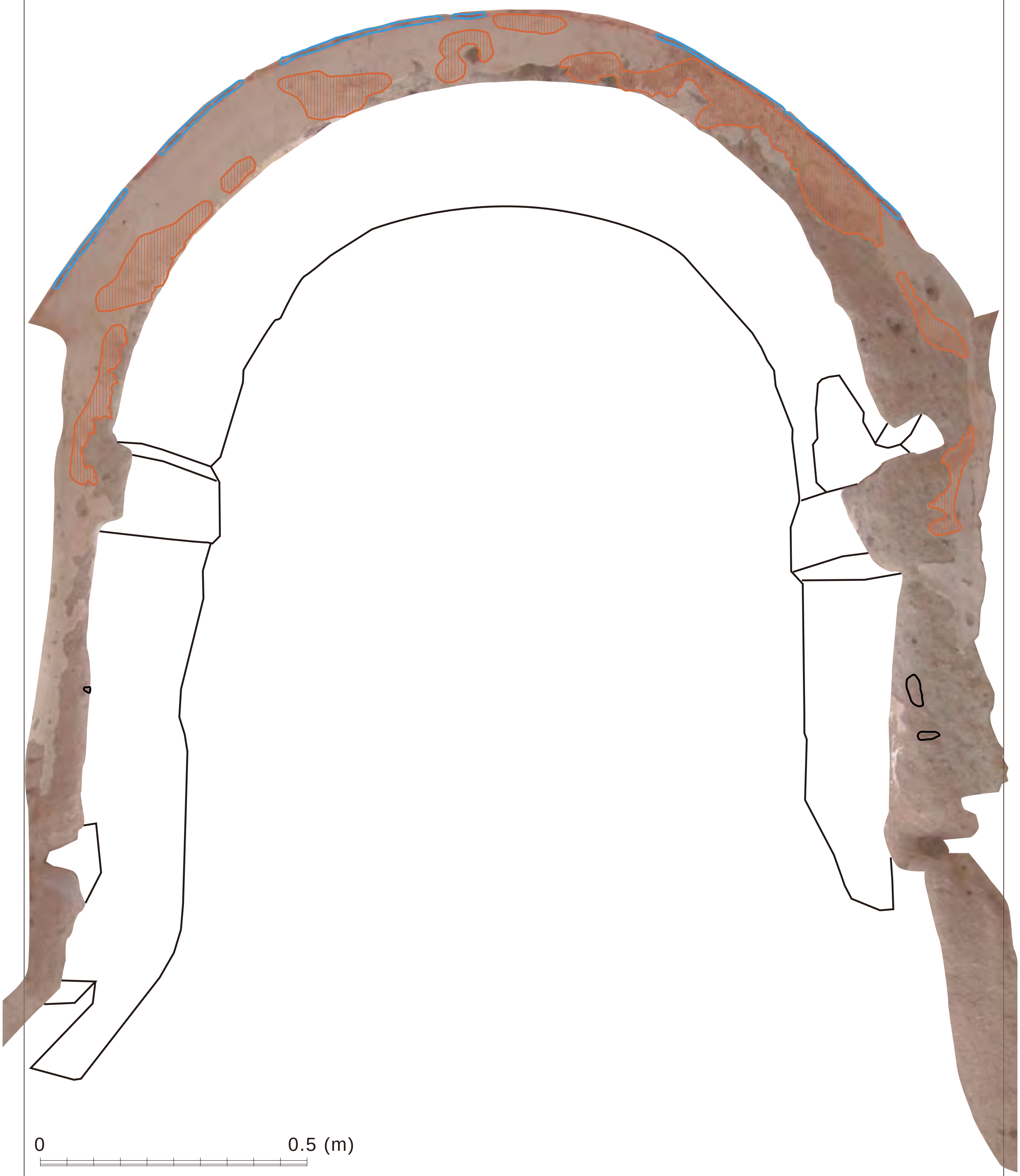
LEGEND A: Rock Deterioration

- Deposition of Dark Material
- Biologic Activity
- Spalling
- Structural Cracks

Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
West Wall of Chamber 1	
Subject	
Mural condition map	
Scale	Category
1/10	A
Plate No.	
Plate019 UZM-C1-018	

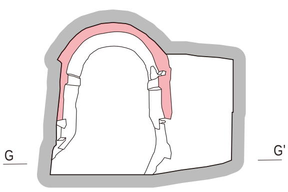
Section G-G'	LEGEND B: Plaster Deterioration	Church Name (Turkish): Üzümlü Kilise
	Incised Graffiti	Church Name (English): Chapel of Niketas the Stylite
	Detachment of Lower Layer	Location: West Wall of Chamber 1
	Mechanical Damege	Subject: Mural condition map
	Cracking	Scale: 1/10 / Category: B
	Holes	Plate No.: Plate020 UZM-C_1-019





0 0.5 (m)

Section G-G’

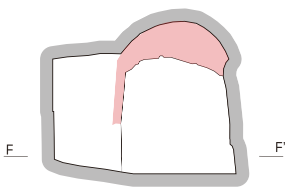


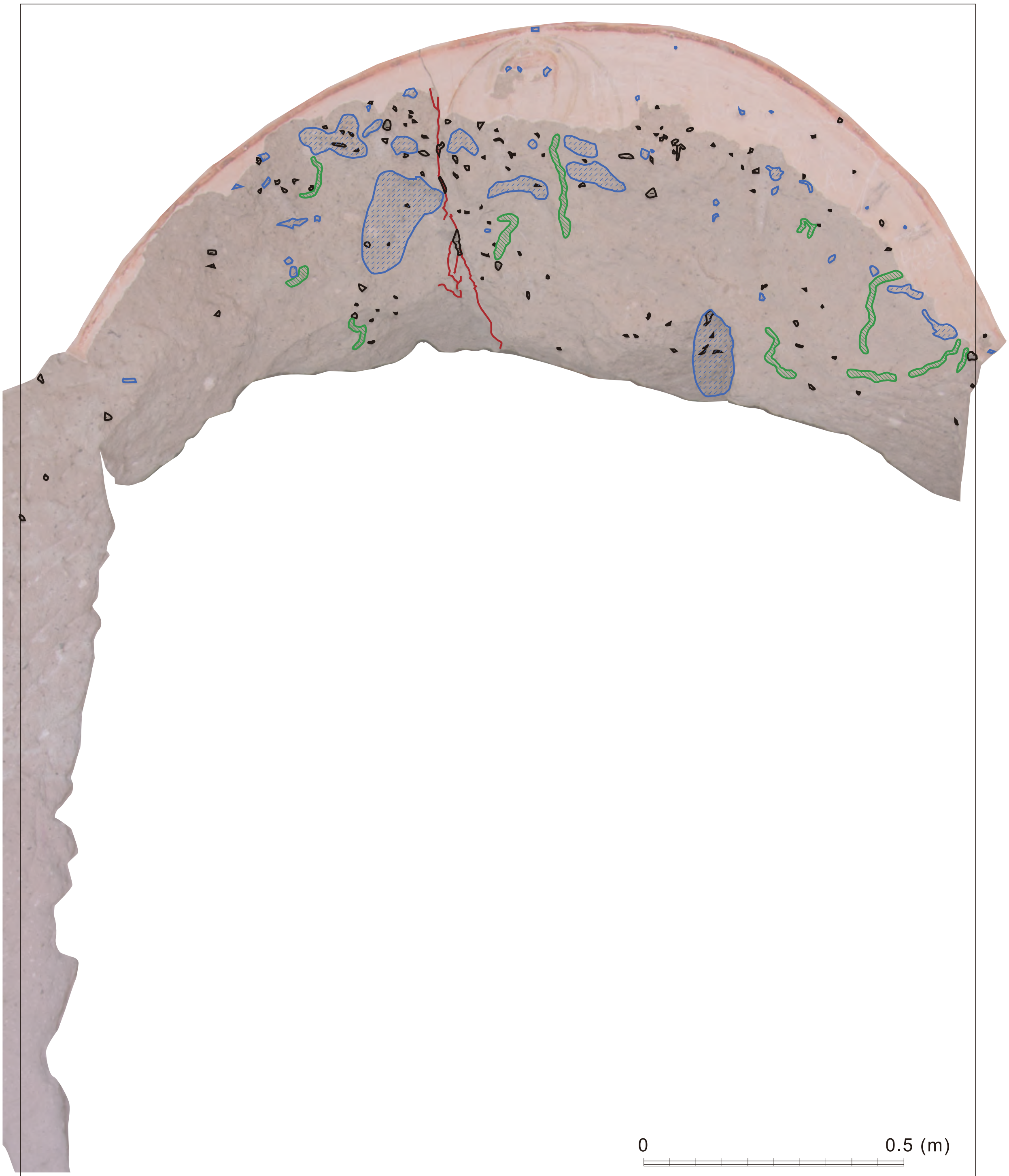
LEGEND C: Paint Deterioration

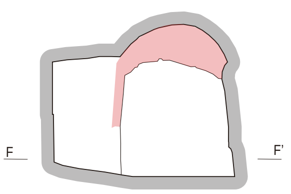
- Smearing
- Surface Deposition
- Superficial Graffiti
- Biological Deposition
- Paint Loss due to Biological Activity
- Micro Losses
- Grey Spotting
- Dark Grey Veil

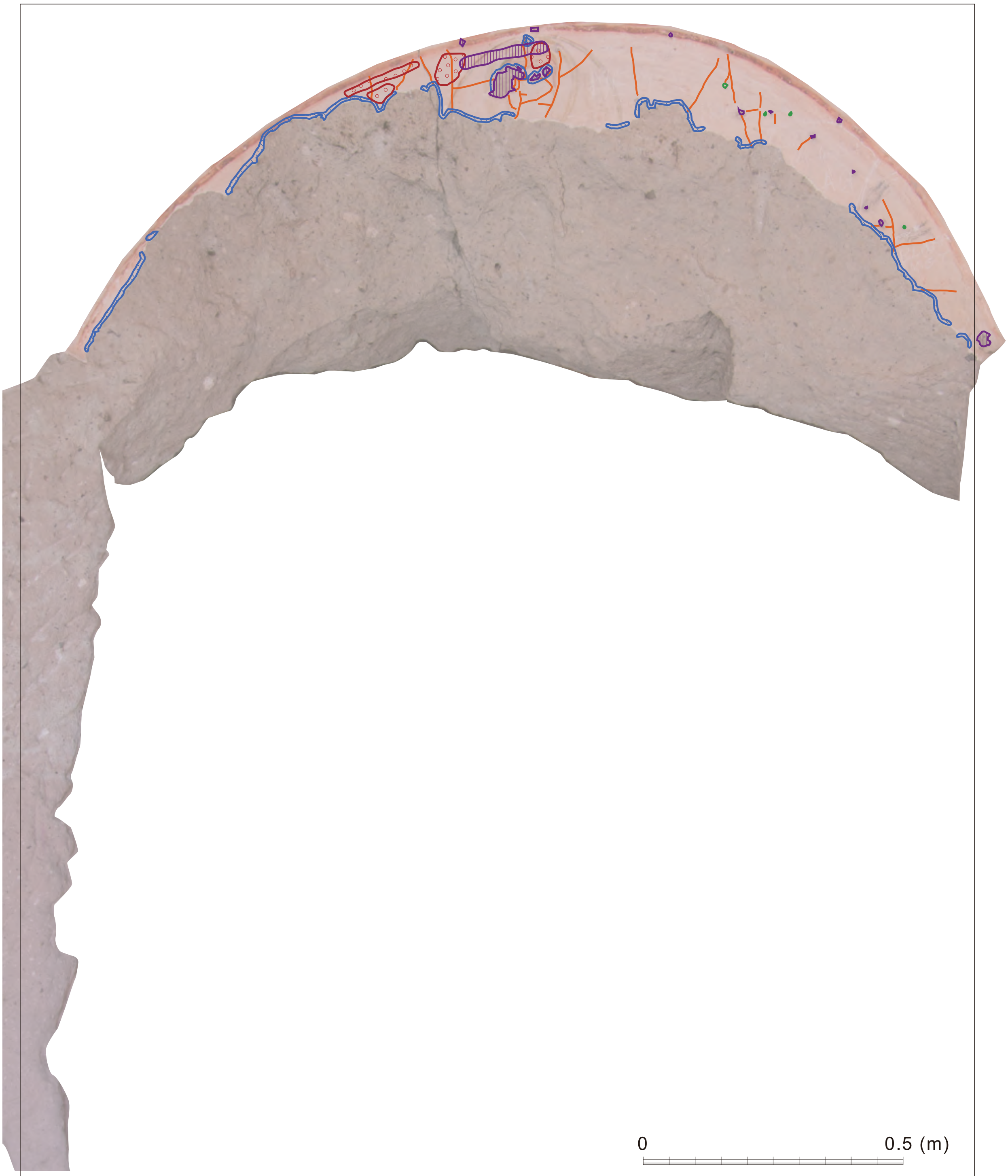
Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
West Wall of Chamber 1	
Subject	
Mural condition map	
Scale	Category
1/10	C
Plate No.	
Plate021 UZM-C_1-020	

0 0.5 (m)

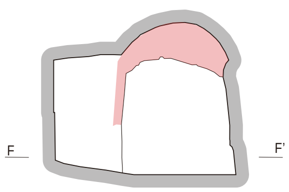
Section F-F’		Church Name (Turkish)
		Üzümlü Kilise
		Church Name (English)
		Chapel of Niketas the Stylite
		Location
		East Wall of Chamber 1
		Subject
		Mural condition map
		Scale: 1/10 / Category: Photograph
		Plate No.
		Plate022 UZM-C_1-021



Section F-F’	LEGEND A: Rock Deterioration	Church Name (Turkish): Üzümlü Kilise
	Deposition of Dark Material Biologic Activity Spalling Structural Cracks	Church Name (English): Chapel of Niketas the Stylite Location: East Wall of Chamber 1 Subject: Mural condition map Scale: 1/10 Category: A Plate No.: Plate023 UZM-C1-022



Section F-F'

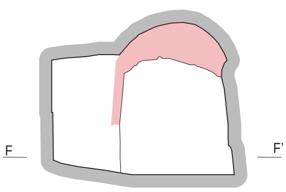


LEGEND B: Plaster Deterioration

- Detachment of Lower Layer
- Mechanical Damege
- Holes

Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
East Wall of Chamber 1	
Subject	
Mural condition map	
Scale	Category
1/10	B
Plate No.	
Plate024 UZM-C1-023	

Section F-F'



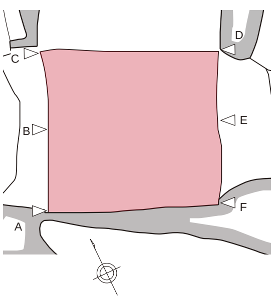
LEGEND C: Paint Deterioration

- Smearing
- Micro Losses
- Dark Grey Veil
- Biological Deposition

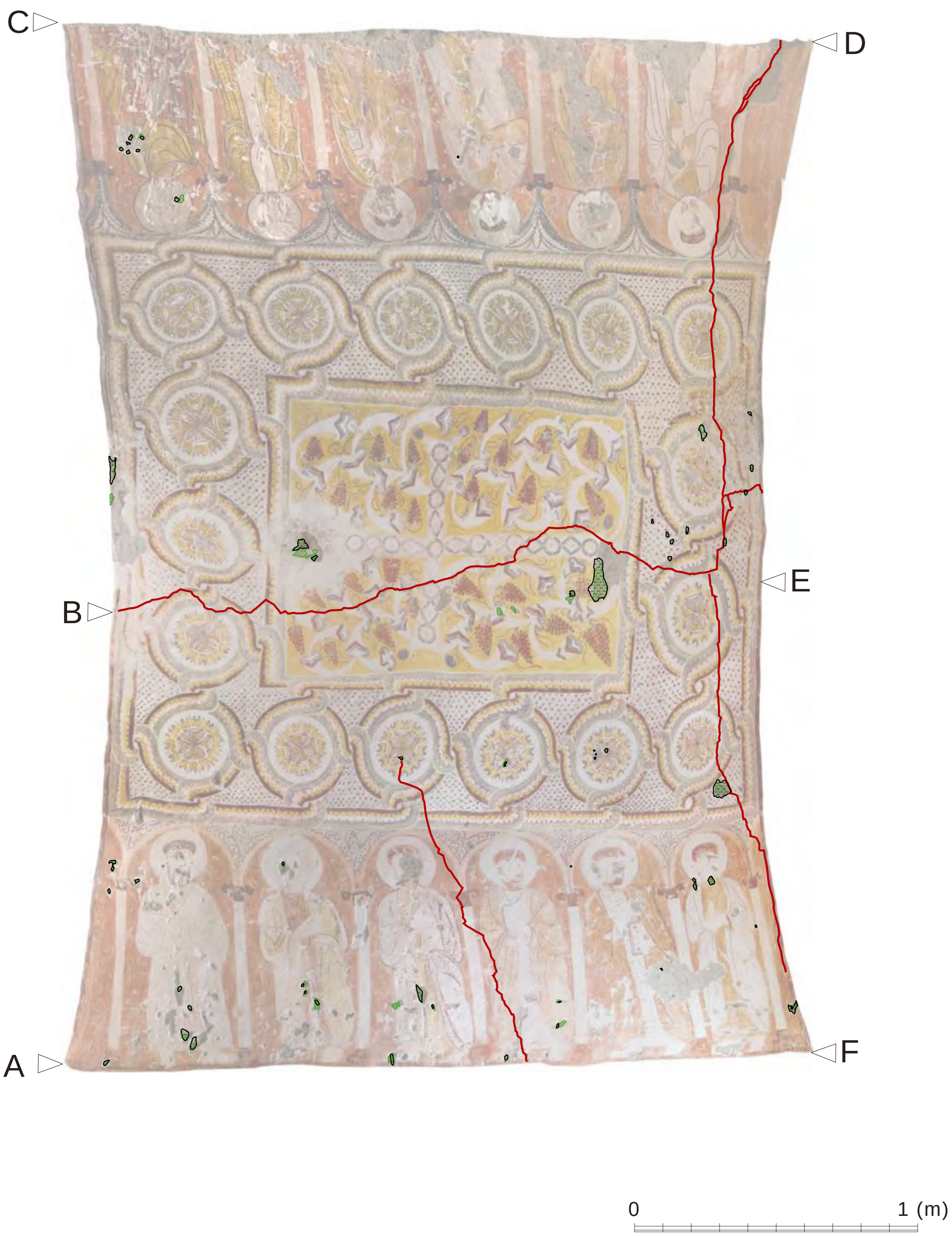
Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
East Wall of Chamber 1	
Subject	
Mural condition map	
Scale	Category
1/10	C
Plate No.	
Plate025 UZM-C_1-024	

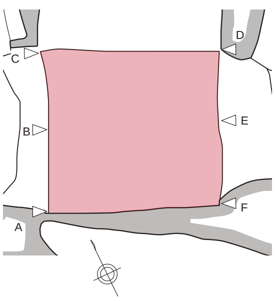
0 1 (m)

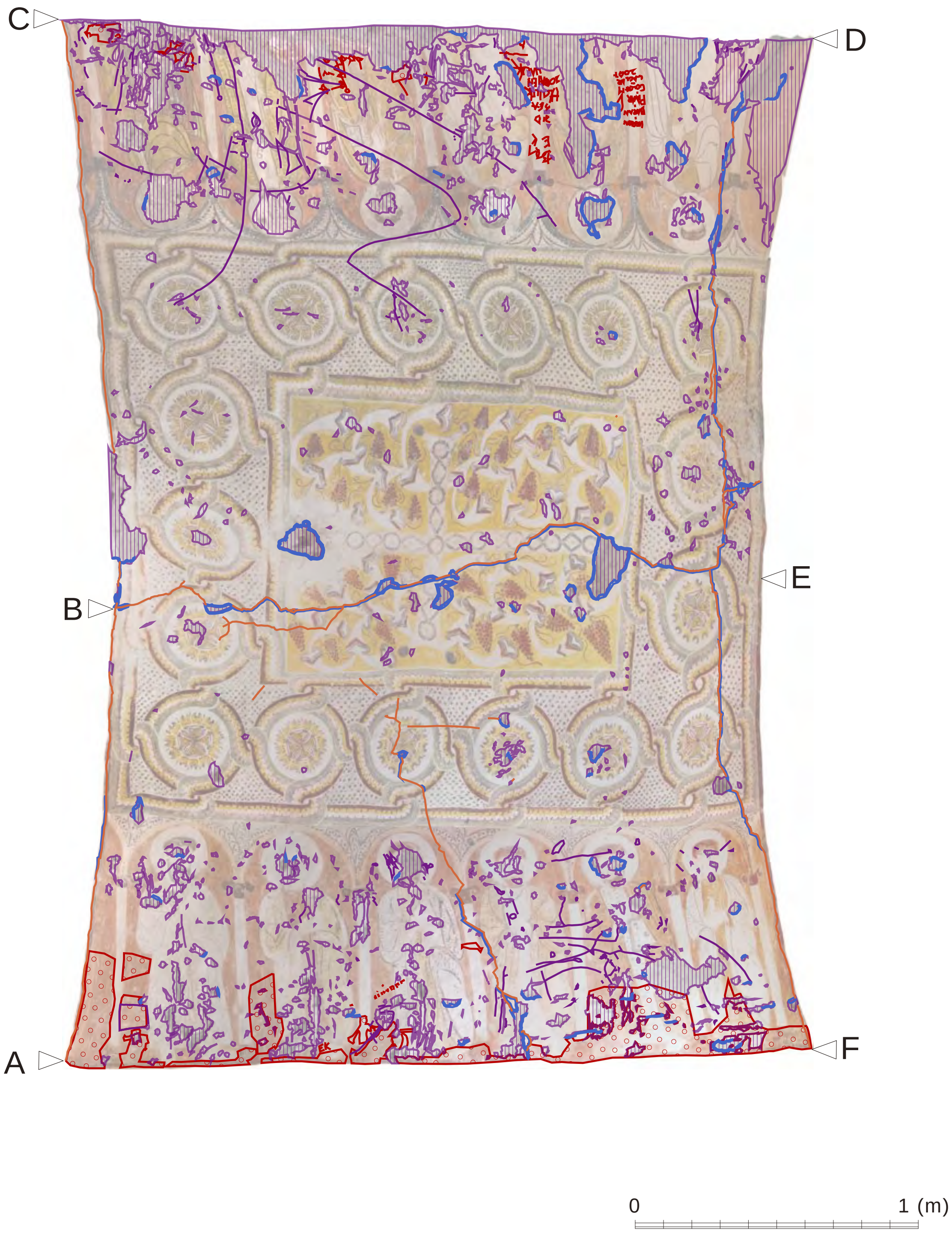
Ceiling



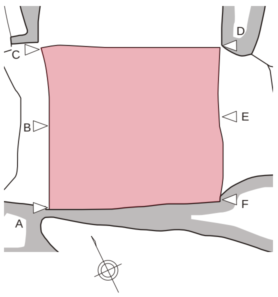
Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
Ceiling of Chamber 2	
Subject	
Mural condition map	
Scale	Category
1/20	Photograph
Plate No.	
Plate026 UZM-C_2-001	



Ceiling	LEGEND A: Rock Deterioration	Church Name (Turkish) Üzümlü Kilise
	Deposition of Dark Material	Church Name (English) Chapel of Niketas the Stylite
	Spalling / Biologic Activity	Location Ceiling of Chamber 2
	Structural Cracks	Subject Mural condition map
		Scale 1/20 / Category A
		Plate No. Plate027 UZM-C2-002



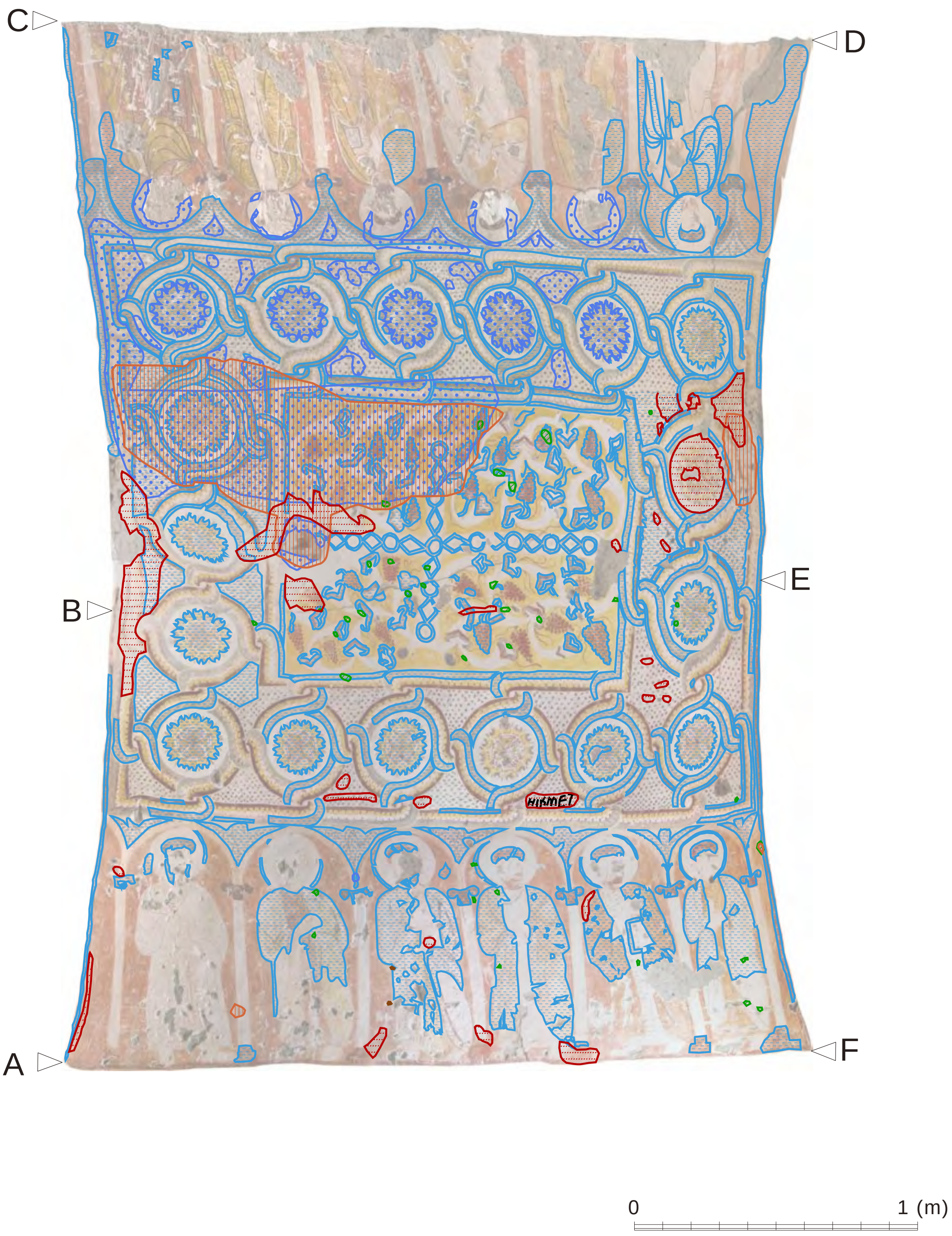
Ceiling



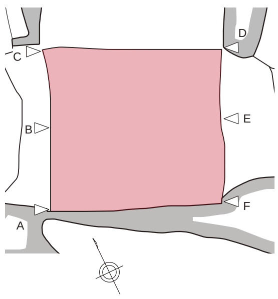
LEGEND B: Plaster Deterioration

- Incised Graffiti
- Detachment of Lower Layer
- Mechanical Damege
- Cracking
- Holes

Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
Ceiling of Chamber 2	
Subject	
Mural condition map	
Scale	Category
1/20	B
Plate No.	
Plate028 UZM-C_2-003	



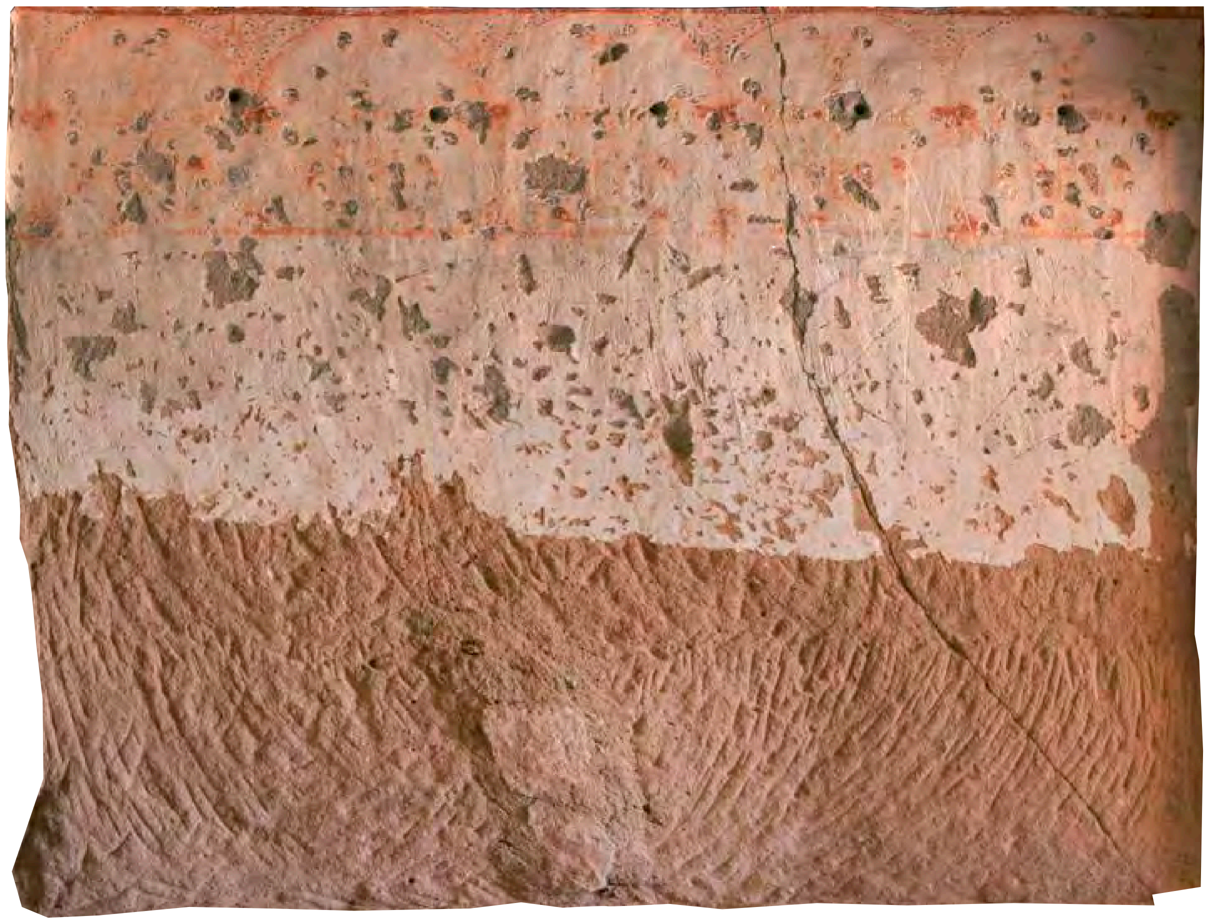
Ceiling



LEGEND C: Paint Deterioration

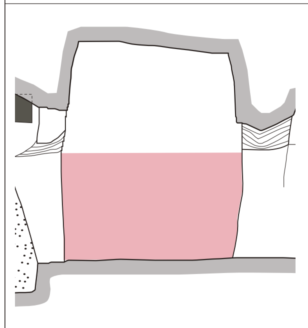
- Smearing
- Surface Deposition
- Dark Grey Veil
- Micro Losses
- Grey Spotting
- Original Fixing
- Biological Deposition
- Superficial Graffiti
- Nail
- Paint Loss due to Biological Activity

Church Name (Turkish)	Üzümlü Kilise
Church Name (English)	Chapel of Niketas the Stylite
Location	Ceiling of Chamber 2
Subject	Mural condition map
Scale	1/20
Category	C
Plate No.	Plate029 UZM-C_2-004



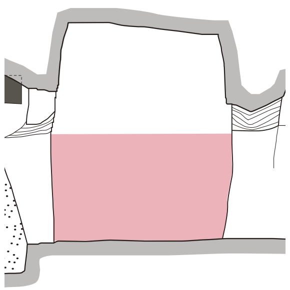
0 1.0 (m)

Section A-A’



Church Name (Turkish)	Subject	
Üzümlü Kilise	Mural condition map	
Church Name (Turkish)	Scale	Category
Chapel of Niketas the Stylite	1/15	Photograph
Location	Plate No.	
South Wall of Chamber 2	Plate030 UZM-C_2-005	

Section A-A’



LEGEND A: Rock Deterioration

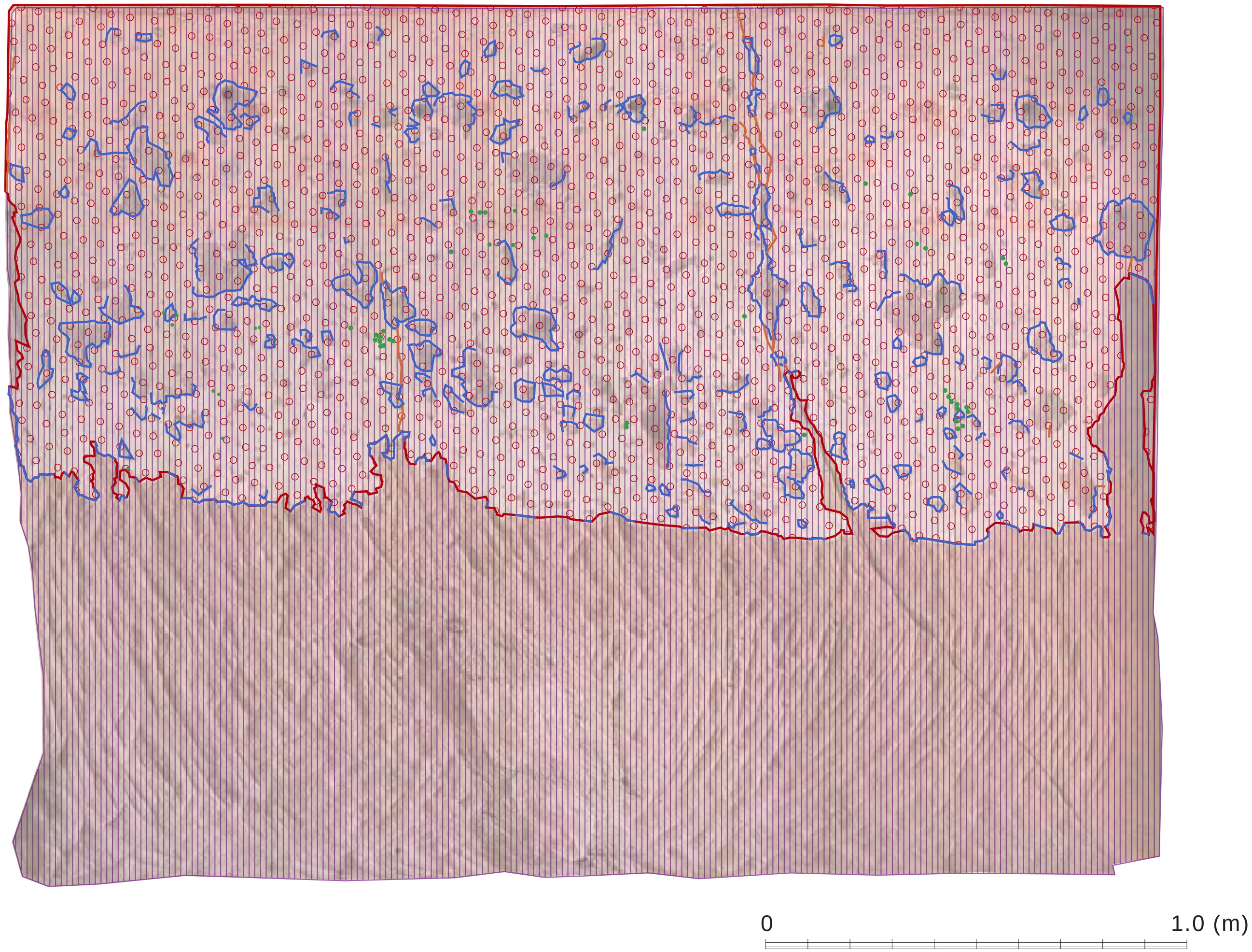
Deposition of Dark Material

Spalling

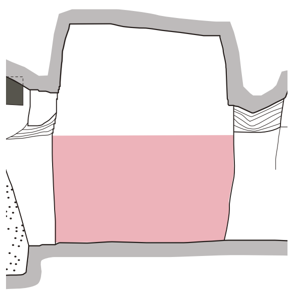
Biologic Activity

Structural Cracks

Church Name (Turkish)	Subject	
Üzümlü Kilise	Mural condition map	
Church Name (Turkish)	Scale	Category
Chapel of Niketas the Stylite	1/15	A
Location	Plate No.	
South Wall of Chamber 2	Plate031 UZM-C_2-006	



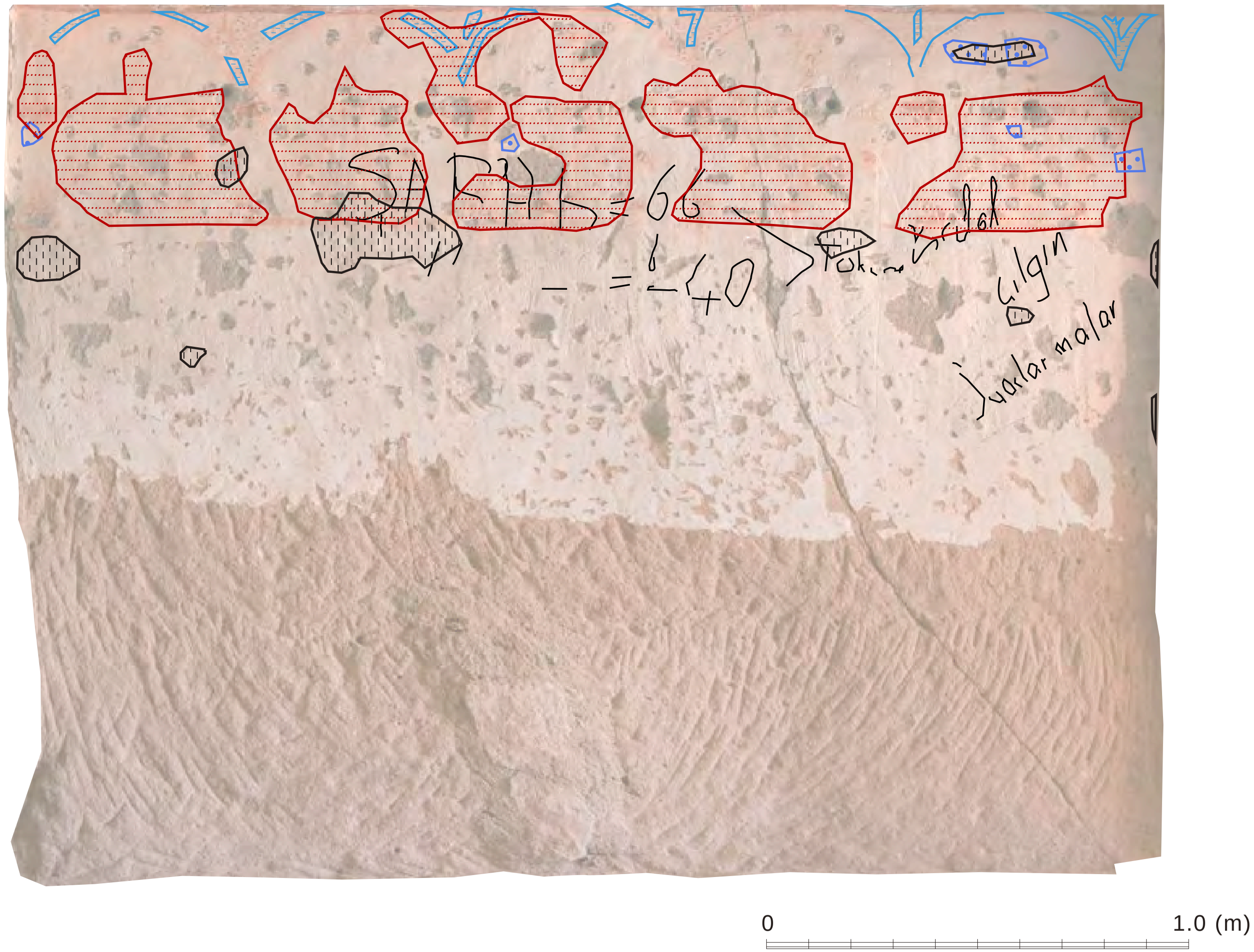
Section A-A’



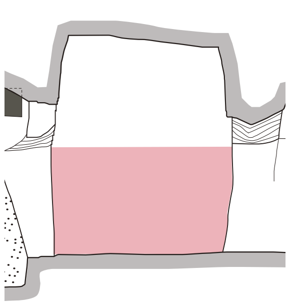
LEGEND B: Plaster Deterioration

Incised Graffiti | Detachment of Lower Layer
Cracking | Holes | Mechanical Damege

Church Name (Turkish)	Subject	
Üzümlü Kilise	Mural condition map	
Church Name (Turkish)	Scale	Category
Chapel of Niketas the Stylite	1/15	B
Location	Plate No.	
South Wall of Chamber 2	Plate032 UZM-C_2-007	



Section A-A'

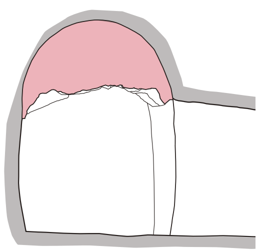


LEGEND C: Paint Deterioration

- Smearing
- Surface Deposition
- Dark Grey Veil
- Micro Losses
- Grey Spotting
- Superficial Graffiti

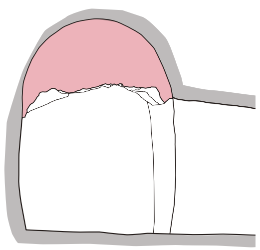
Church Name (Turkish): Üzümlü Kilise	Subject: Mural condition map
Church Name (Turkish): Chapel of Niketas the Stylite	Scale: 1/15 · Category: C
Location: South Wall of Chamber 2	Plate No.: Plate033 UZM-C2-008

Section D-D'



Church Name (Turkish)	Subject	
Üzümlü Kilise	Mural condition map	
Church Name (English)	Scale	Category
Chapel of Niketas the Stylite	1/10	Photograph
Location	Plate No.	
West Wall of Chamber 2	Plate034 UZM-C_2-009	

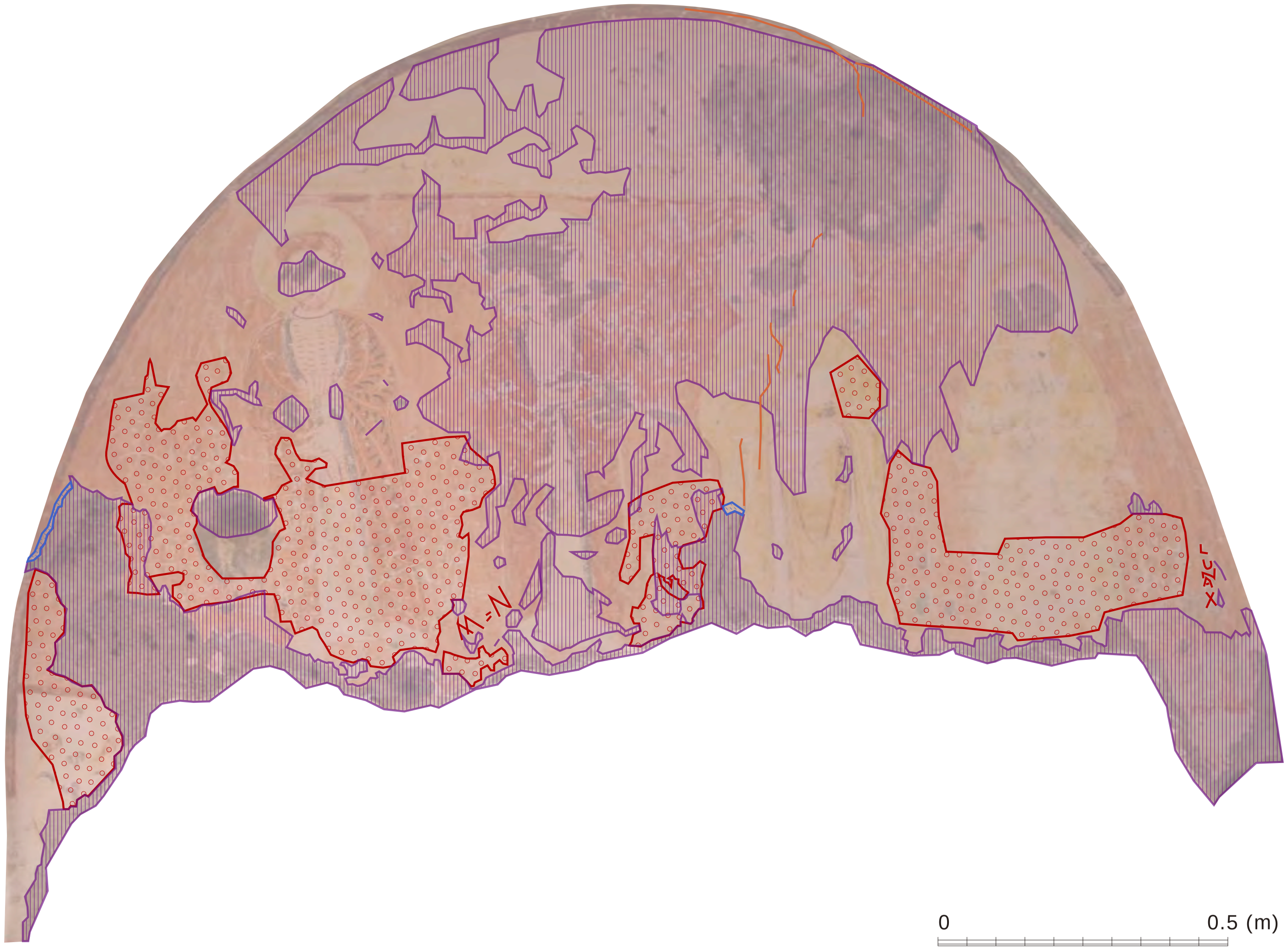
Section D-D’



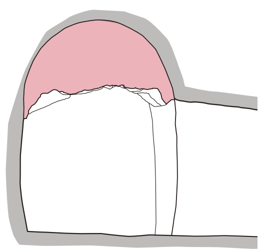
LEGEND A: Rock Deterioration

Deposition of Dark Material
Biologic Activity
Spalling
Structural Cracks

Church Name (Turkish)	Subject	
Üzümlü Kilise	Mural condition map	
Church Name (English)	Scale	Category
Chapel of Niketas the Stylite	1/10	A
Location	Plate No.	
West Wall of Chamber 2	Plate035 UZM-C_2-010	



Section D-D'

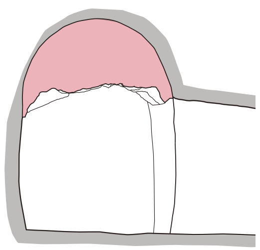


LEGEND B: Plaster Deterioration

- Incised Graffiti
- Detachment of Lower Layer
- Mechanical Damege
- Cracking
- Holes

Church Name (Turkish): Üzümlü Kilise	Subject: Mural condition map
Church Name (English): Chapel of Niketas the Stylite	Scale: 1/10 / Category: B
Location: West Wall of Chamber 2	Plate No.: Plate036 UZM-C2-011

Section D-D’

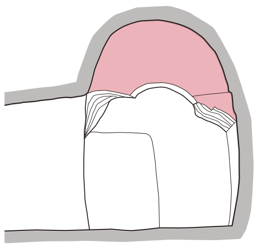


LEGEND	C: Paint Deterioration	
Micro Losses	Biological Deposition	Dark Grey Veil
Grey Spotting	Paint Loss due to Biological Activity	

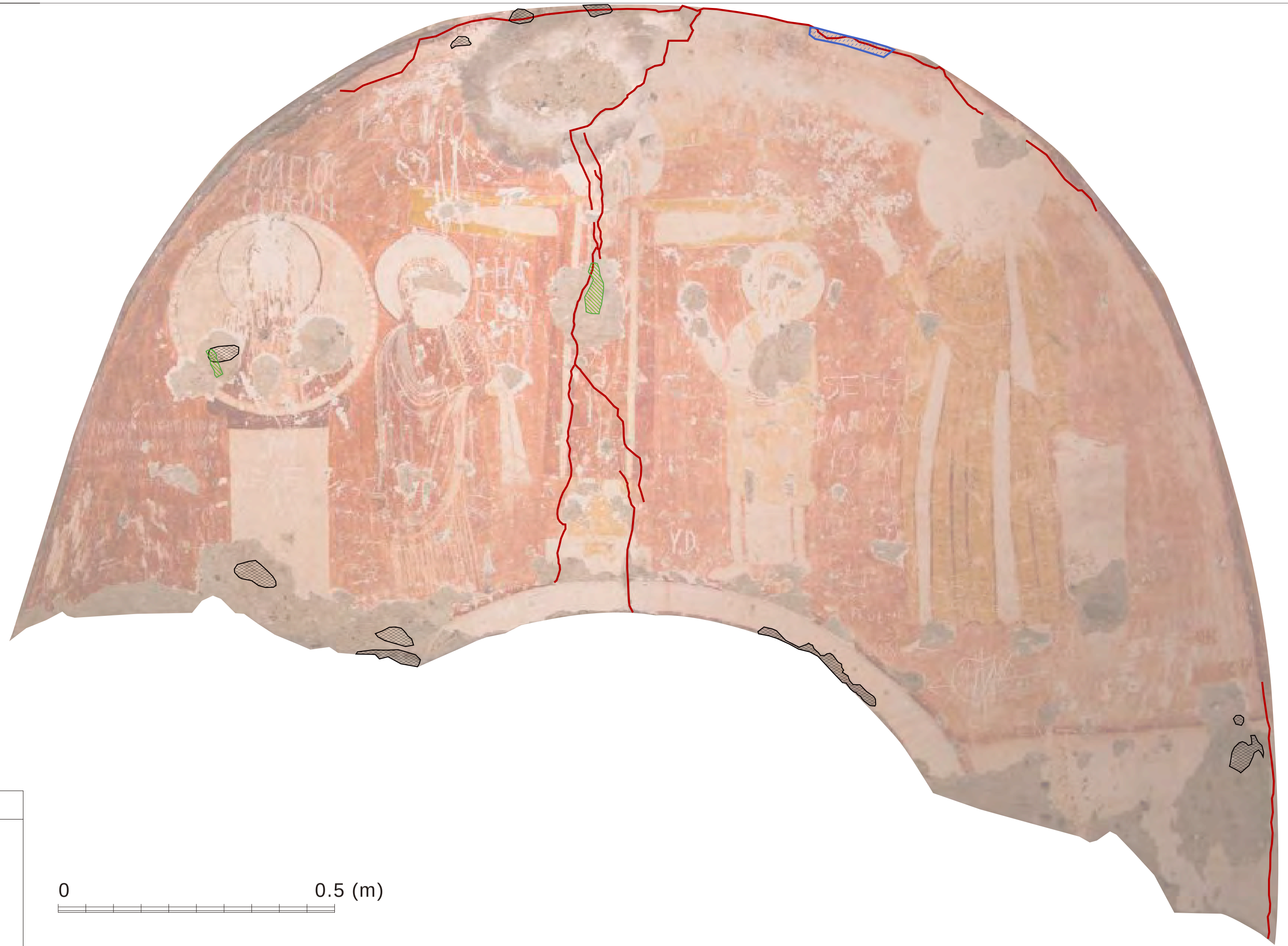
Church Name (Turkish)	Subject	
Üzümlü Kilise	Mural condition map	
Church Name (English)	Scale	Category
Chapel of Niketas the Stylite	1/10	C
Location	Plate No.	
West Wall of Chamber 2	Plate037 UZM-C$_2$-012	

0 0.5 (m)

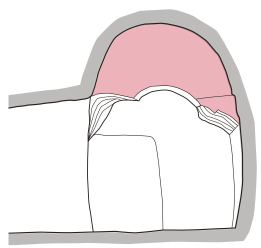
Section C-C'



Church Name (Turkish)	Subject	
Üzümlü Kilise	Mural condition map	
Church Name (English)	Scale	Category
Chapel of Niketas the Stylite	1/10	Photograph
Location	Plate No.	
East Wall of Chamber 2	Plate038 UZM-C_2-013	



Section C-C'



LEGEND A: Rock Deterioration

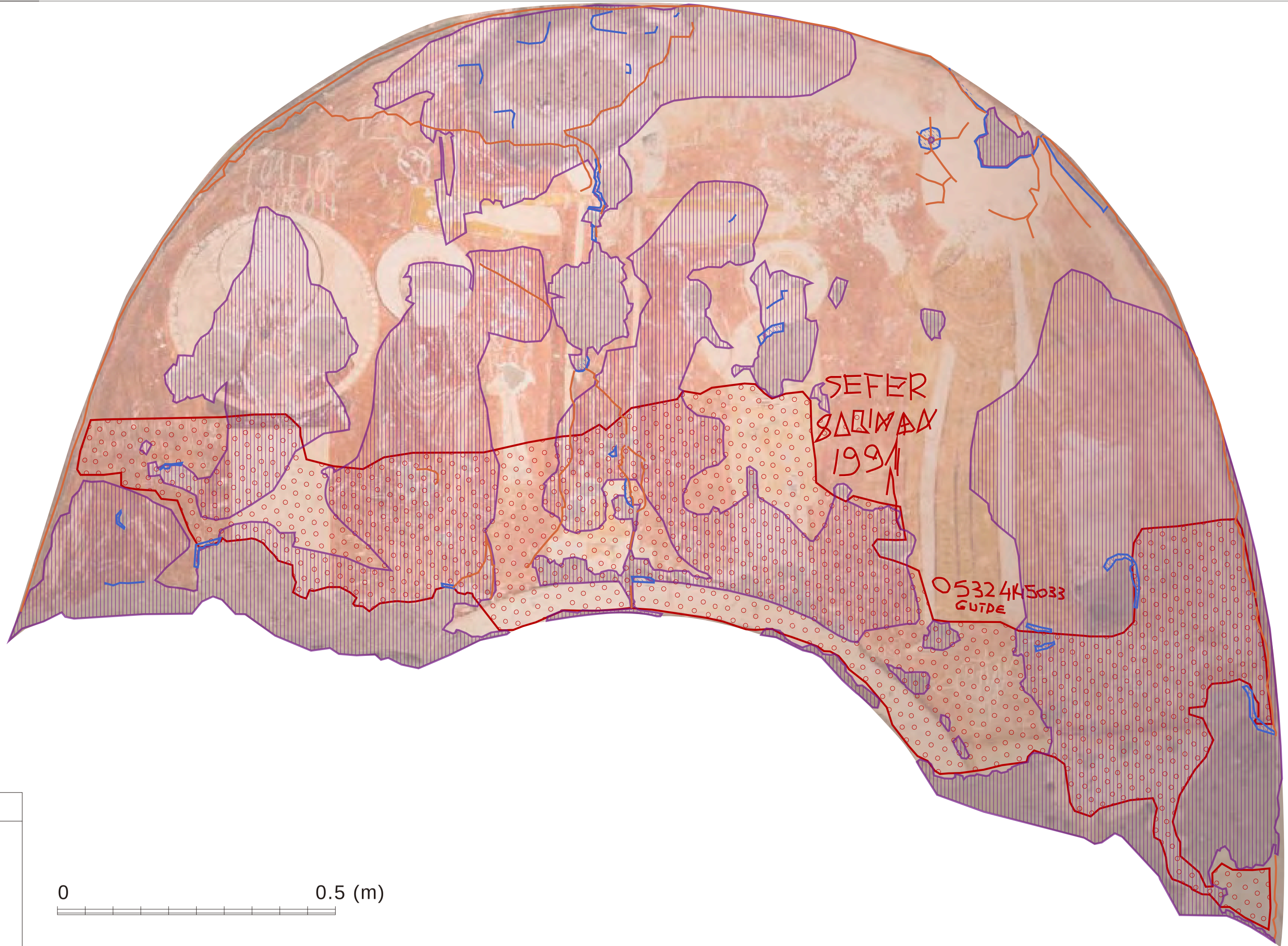
Deposition of Dark Material

Biologic Activity

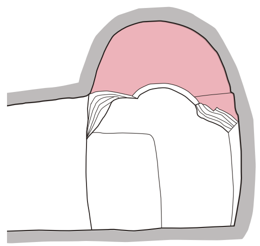
Spalling

Structural Cracks

Church Name (Turkish)	Subject	
Üzümlü Kilise	Mural condition map	
Church Name (English)	Scale	Category
Chapel of Niketas the Stylite	1/10	A
Location	Plate No.	
East Wall of Chamber 2	Plate039 UZM-C2-014	



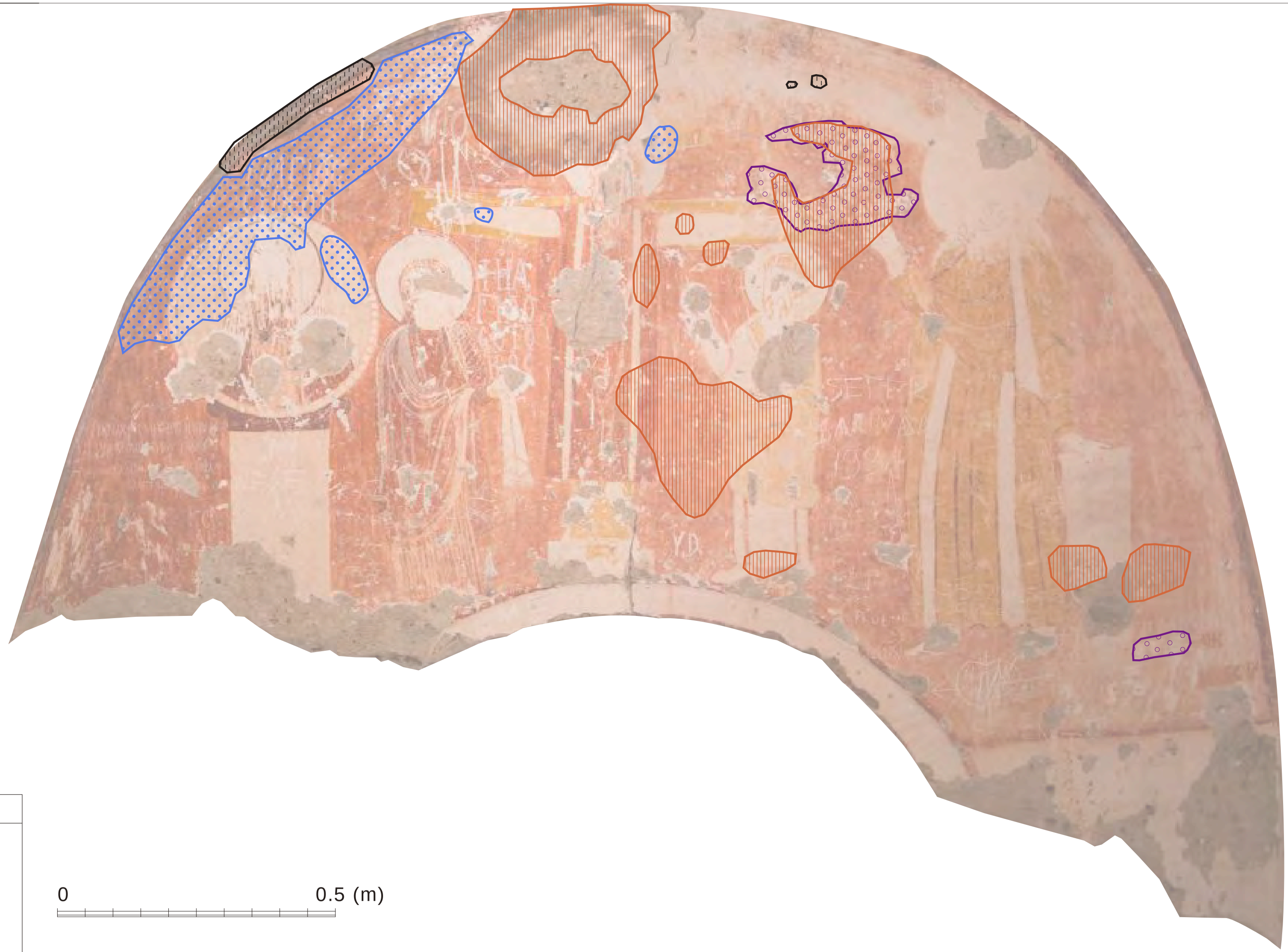
Section C-C'



LEGEND B: Plaster Deterioration

- Incised Graffiti
- Detachment of Lower Layer
- Mechanical Damege
- Cracking
- Holes

Church Name (Turkish)	Subject	
Üzümlü Kilise	Mural condition map	
Church Name (English)	Scale	Category
Chapel of Niketas the Stylite	1/10	B
Location	Plate No.	
East Wall of Chamber 2	Plate040 UZM-C2-015	

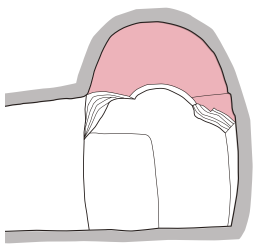


0 0.5 (m)

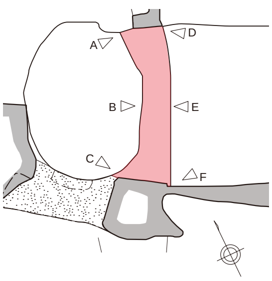
LEGEND C: Paint Deterioration

- Micro Losses
- Grey Spotting
- Biological Deposition
- Paint Loss due to Biological Activity
- Dark Grey Veil

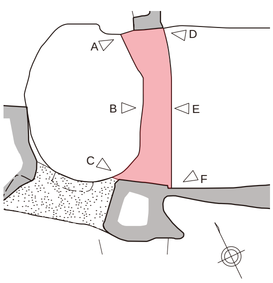
Section C-C’



Church Name (Turkish)	Subject	
Üzümlü Kilise	Mural condition map	
Church Name (English)	Scale	Category
Chapel of Niketas the Stylite	1/10	C
Location	Plate No.	
East Wall of Chamber 2	Plate041 UZM-C$_2$-016	

Ceiling		
		Church Name (Turkish): Üzümlü Kilise
		Church Name (English): Chapel of Niketas the Stylite
		Location: Transverse Arch between 2-3
		Subject: Mural condition map
		Scale: 1/10 — Category: Photograph
		Plate No.: Plate042 UZM-$C_{2\cdot3}$-001

Ceiling	LEGEND A: Rock Deterioration	Church Name (Turkish): Üzümlü Kilise



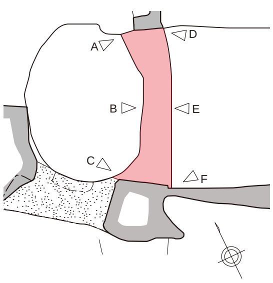
Deposition of Dark Material

Spalling

Structural Cracks

Church Name (Turkish)	Üzümlü Kilise
Church Name (English)	Chapel of Niketas the Stylite
Location	Transverse Arch between 2-3
Subject	Mural condition map
Scale	1/10
Category	A
Plate No.	Plate043 UZM-C2-3-002

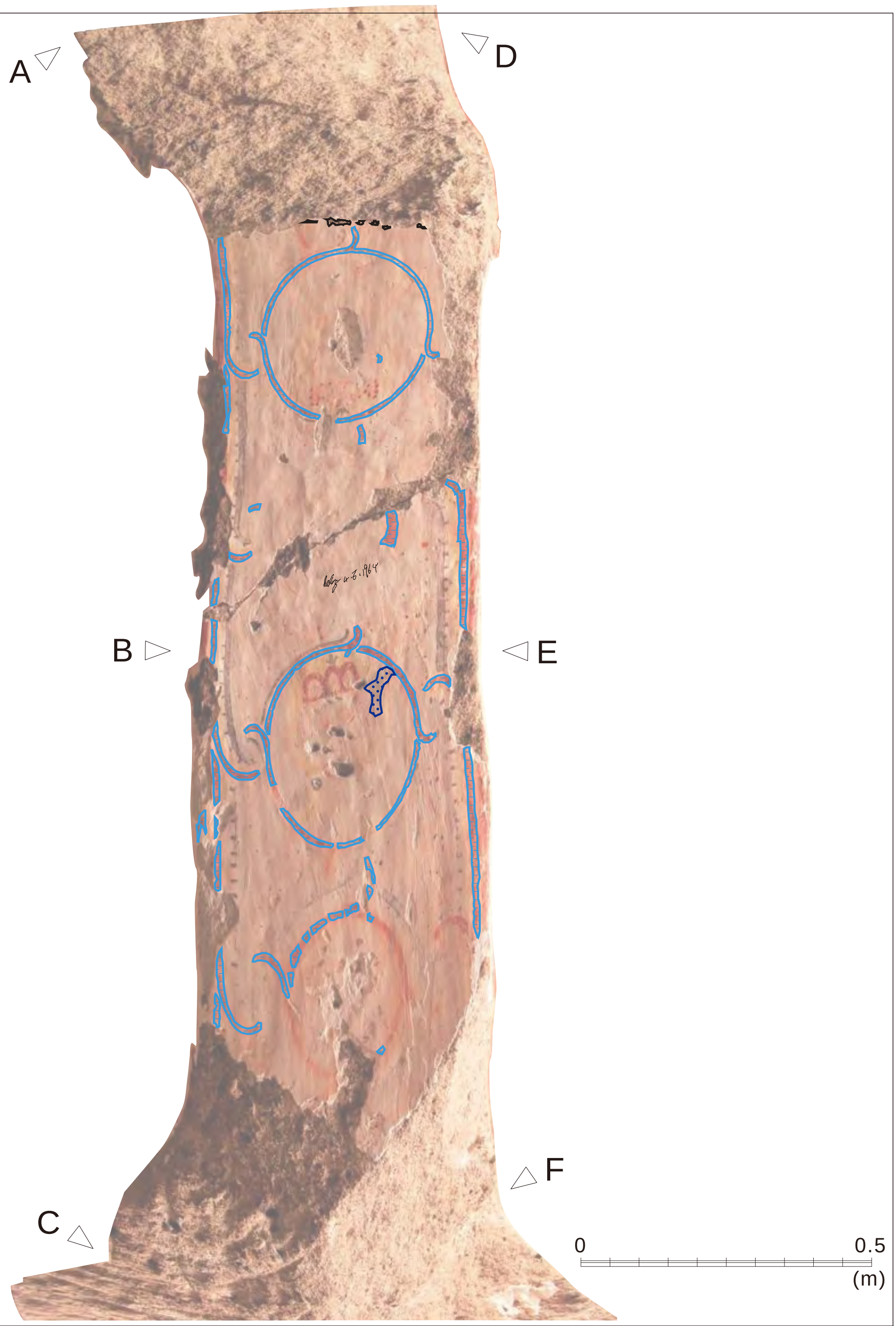
Ceiling



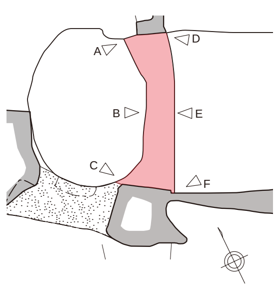
LEGEND B: Plaster Deterioration

- Incised Graffiti
- Detachment of Lower Layer
- Mechanical Damege
- Cracking

Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
Transverse Arch between 2-3	
Subject	
Mural condition map	
Scale	Category
1/10	B
Plate No.	
Plate044 UZM-$C_{2\cdot3}$-003	



Ceiling

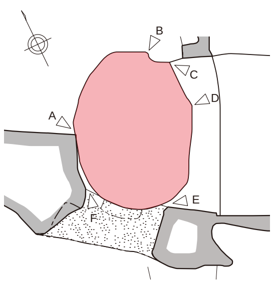


LEGEND C: Paint Deterioration

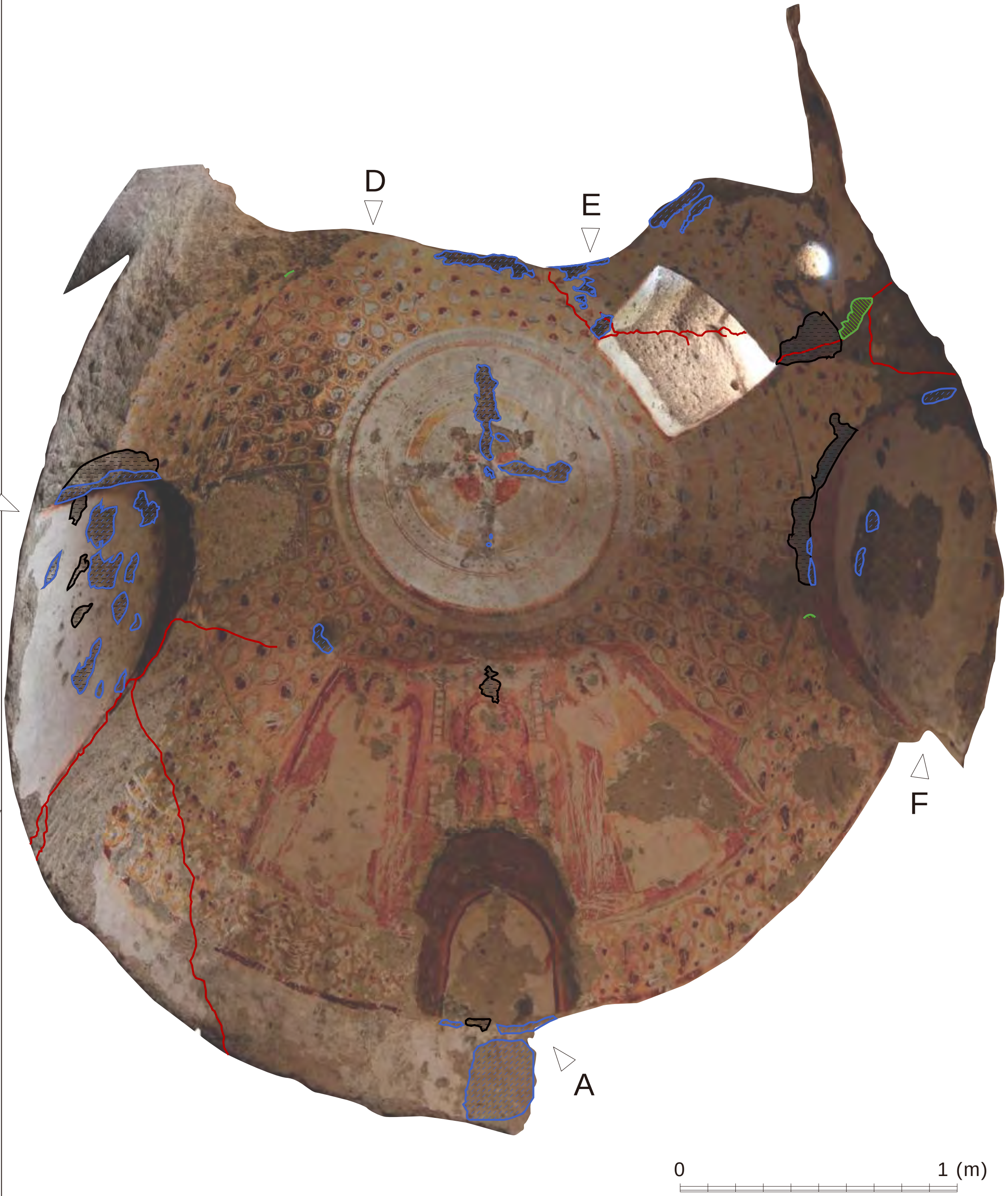
- Micro Losses
- Dark Grey Veil
- Grey Spotting
- Superficial Graffiti

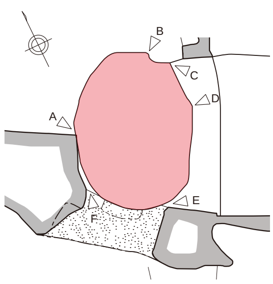
Church Name (Turkish)	Üzümlü Kilise
Church Name (English)	Chapel of Niketas the Stylite
Location	Transverse Arch between 2-3
Subject	Mural condition map
Scale	1/10
Category	C
Plate No.	Plate045 UZM-$C_{2\cdot3}$-004

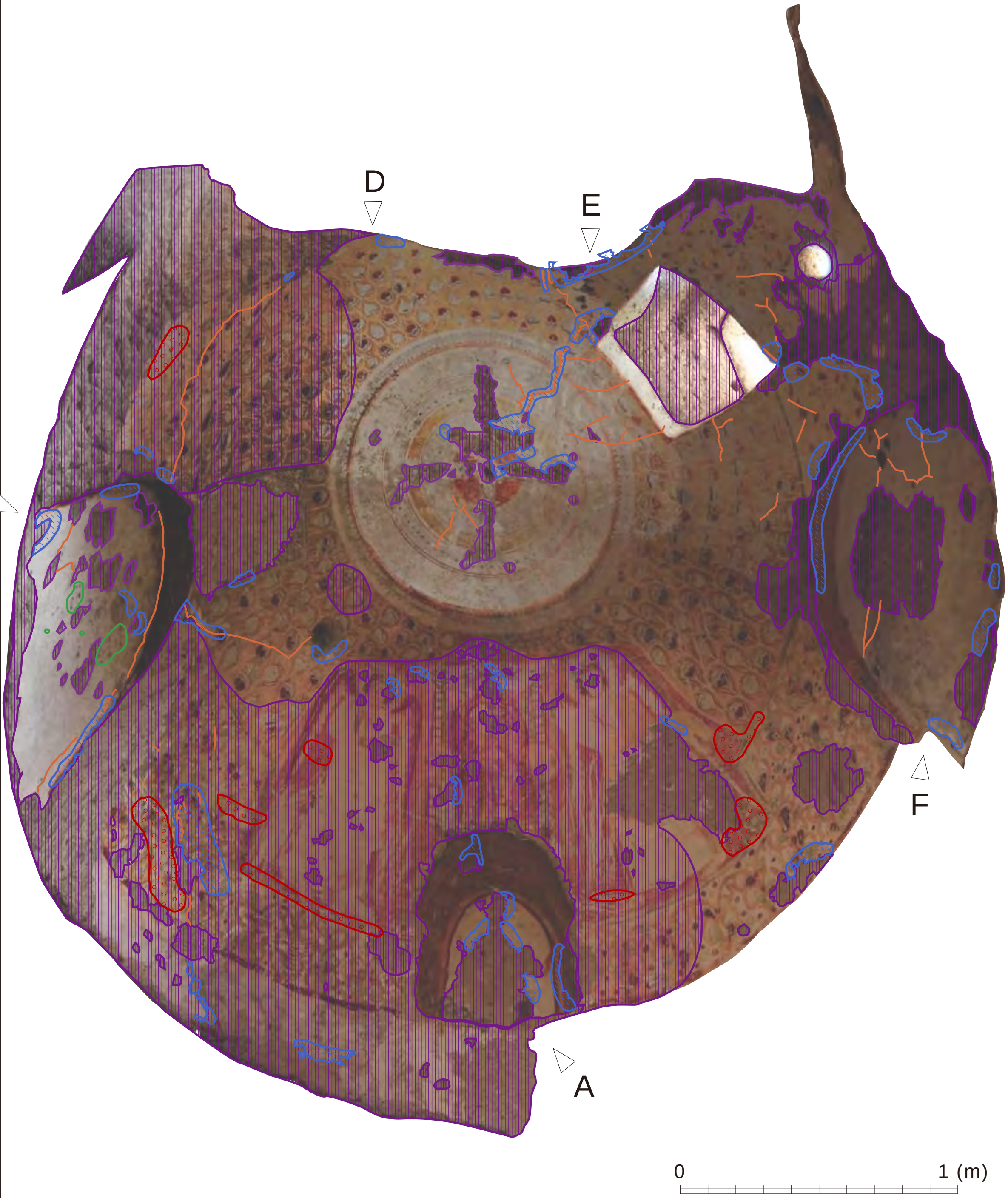
Ceiling



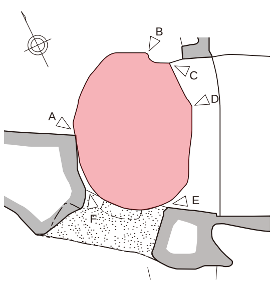
Church Name (Turkish)	Üzümlü Kilise
Church Name (English)	Chapel of Niketas the Stylite
Location	Ceiling of Chamber 3
Subject	Mural condition map
Scale	1/20
Category	Photograph
Plate No.	Plate046 UZM-C3-001



Ceiling	LEGEND A: Rock Deterioration	Church Name (Turkish): Üzümlü Kilise
	Deposition of Dark Material	Church Name (English): Chapel of Niketas the Stylite
	Biologic Activity	Location: Ceiling of Chamber 3
	Spalling	Subject: Mural condition map
	Structural Cracks	Scale: 1/20 — Category: A
		Plate No.: Plate047 UZM-C3-002

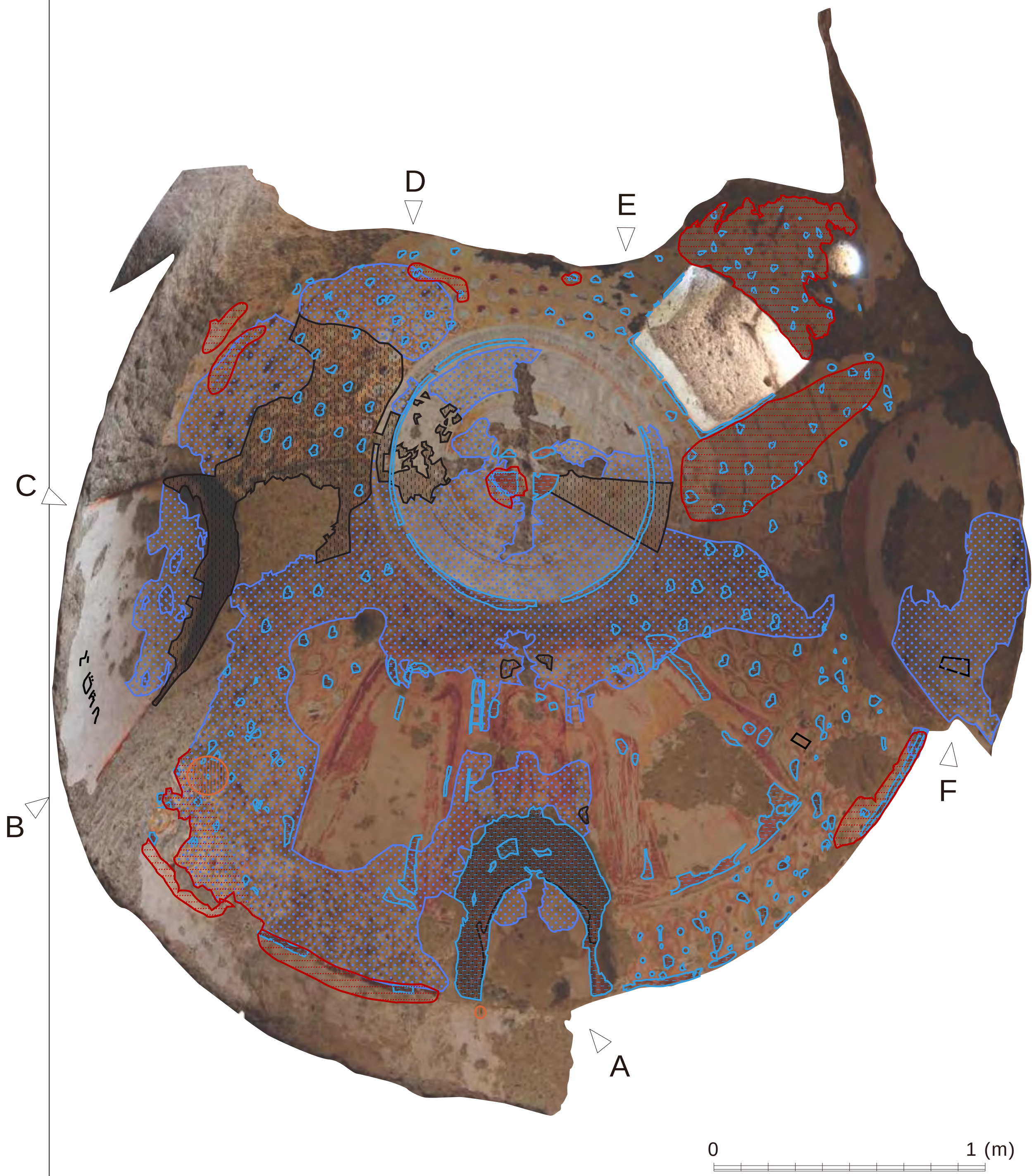


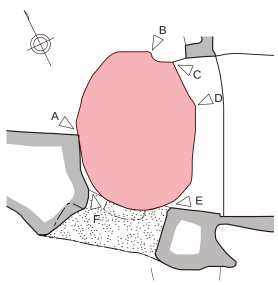
Ceiling	LEGEND B: Plaster Deterioration	Church Name (Turkish): Üzümlü Kilise



- Incised Graffiti
- Detachment of Lower Layer
- Mechanical Damege
- Cracking
- Holes

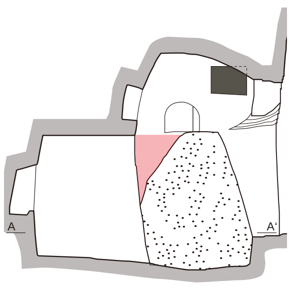
Church Name (Turkish)	Üzümlü Kilise
Church Name (English)	Chapel of Niketas the Stylite
Location	Ceiling of Chamber 3
Subject	Mural condition map
Scale	1/20
Category	B
Plate No.	Plate048 UZM-C3-003



Ceiling	LEGEND C: Paint Deterioration
	Smearing; Micro Losses; Biological Deposition; Grey Spotting; Superficial Graffiti; Dark Grey Veil

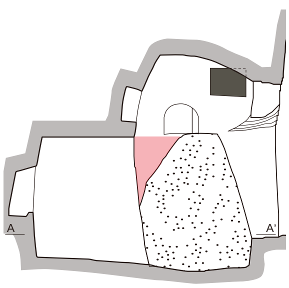
Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
Ceiling of Chamber 3	
Subject	
Mural condition map	
Scale	Category
1/20	C
Plate No.	
Plate049 UZM-C3-004	

0 0.5 (m)

Section A-A’		Church Name (Turkish)
		Üzümlü Kilise
		Church Name (English)
		Chapel of Niketas the Stylite
		Location
		South East Wall of Chamber 3
		Subject
		Mural condition map
		Scale: 1/10 · Category: Photograph
		Plate No.
		Plate050 UZM-C_3-005

0 0.5 (m)

Section A-A’

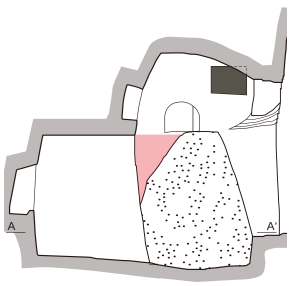


LEGEND A: Rock Deterioration

- Deposition of Dark Material
- Biologic Activity
- Spalling
- Structural Cracks

Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
South East Wall of Chamber 3	
Subject	
Mural condition map	
Scale	Category
1/10	A
Plate No.	
Plate051 UZM-C_3-006	

Section A-A’

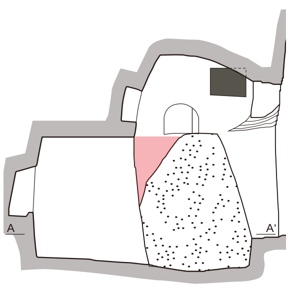


LEGEND B: Plaster Deterioration

- Incised Graffiti
- Detachment of Lower Layer
- Mechanical Damege

Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
South East Wall of Chamber 3	
Subject	
Mural condition map	
Scale	Category
1/10	B
Plate No.	
Plate052 UZM-C3-007	

Section A-A'



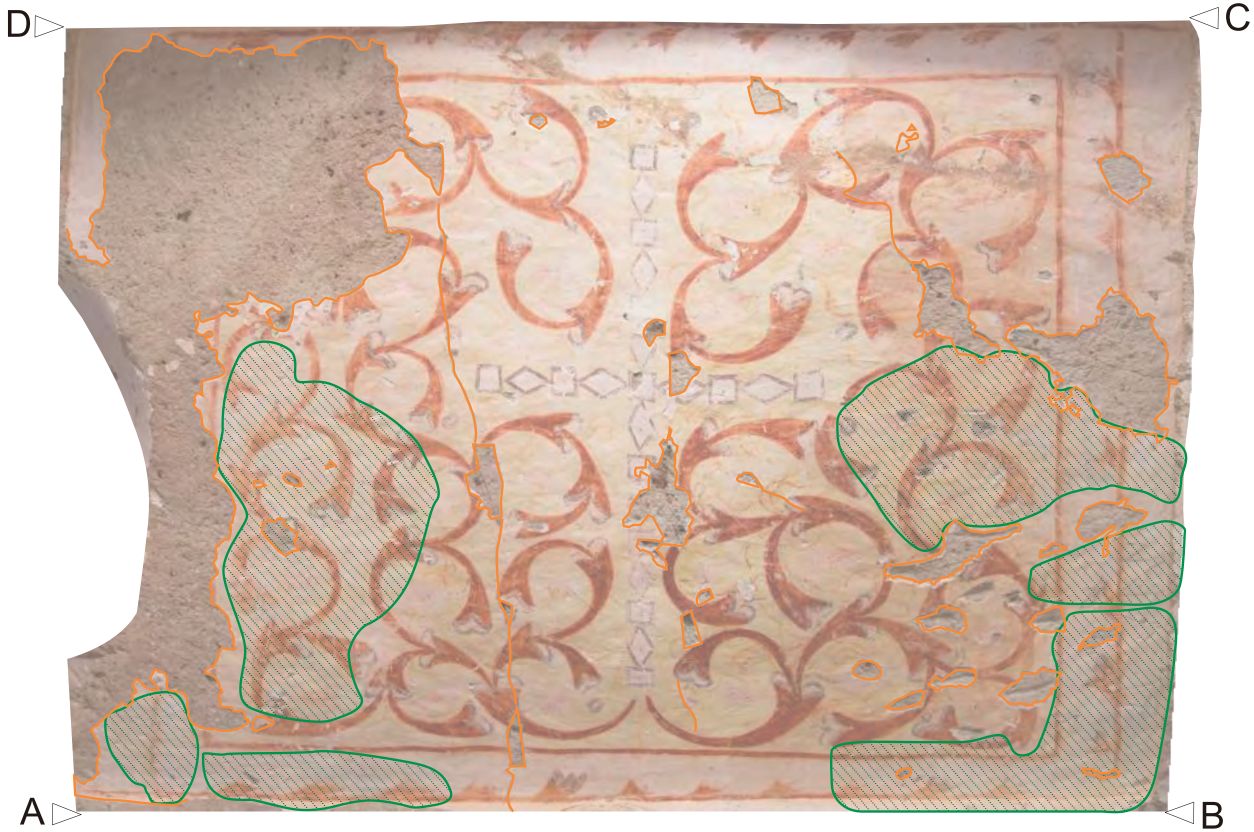
LEGEND C: Paint Deterioration

- Micro Losses
- Grey Spotting
- Superficial Graffiti

Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
South East Wall of Chamber 3	
Subject	
Mural condition map	
Scale	Category
1/10	C
Plate No.	
Plate053 UZM-C$_3$-008	

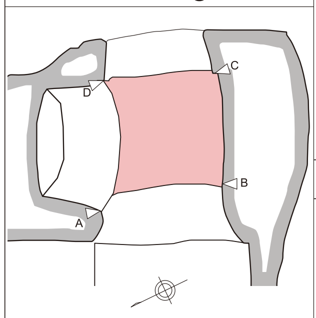
III-3 Documentation of Wall Painting (2016) : Conservation Intervation

No	Scale	Location	Category
Mural condition map of Chamber 1			
UZM-I_1-01	1/15	Ceiling	Coservation
UZM-I_1-02	1/25	Intrados of Entrance Arch	Coservation
UZM-I_1-03	1/15	North Arch	Coservation
UZM-I_1-04	1/10	South Wall	Coservation
UZM-I_1-05	1/10	West Wall	Coservation
UZM-I_1-06	1/10	East wall	Coservation
Mural condition map of Chamber 2			
UZM-I_2-07	1/20	Ceiling	Coservation
UZM-I_2-08	1/15	South Wall	Coservation
UZM-I_2-09	1/10	West Wall	Coservation
UZM-I_2-10	1/10	East Wall	Coservation
Mural condition map of Transversal Arch			
UZM-$I_{2\text{-}3}$-11	1/10	Intrados of Transversal Arch	Coservation
Mural condition map of Chamber 3			
UZM-I_3-12	1/20	Ceiling	Coservation
UZM-I_3-13	1/10	South-eastern Wall	Coservation



0 1.0 (m)

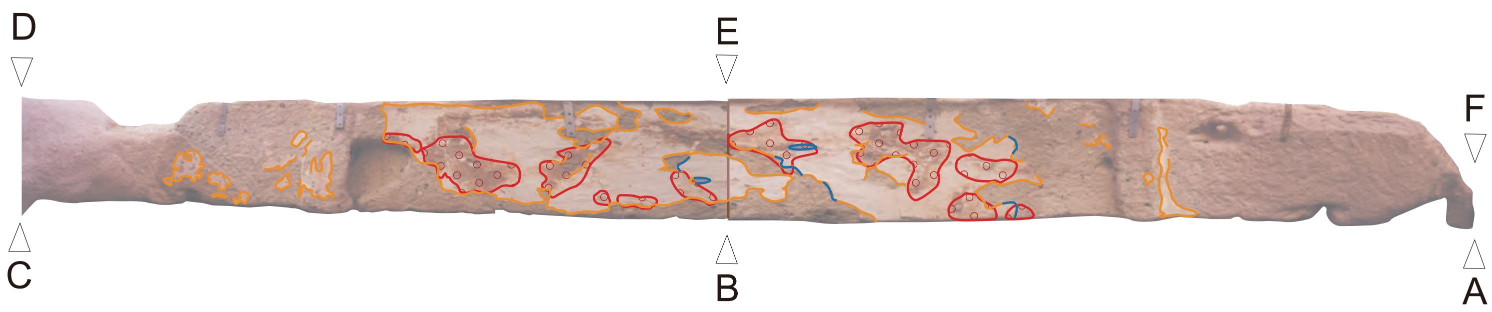
Ceiling



Edging

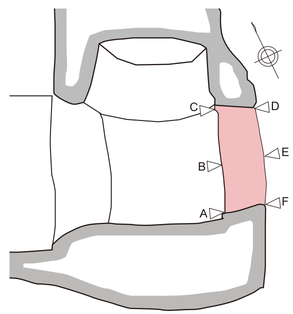
Toning

Church Name (Turkish) Üzümlü Kilise	Subject Conservation intervention
Church Name (Turkish) Chapel of Niketas the Stylite	Scale: 1/15 — Category: Conservation
Location Ceiling of Chamber 1	Plate No. UZM-I_1-01



0 1.0 (m)

Ceiling

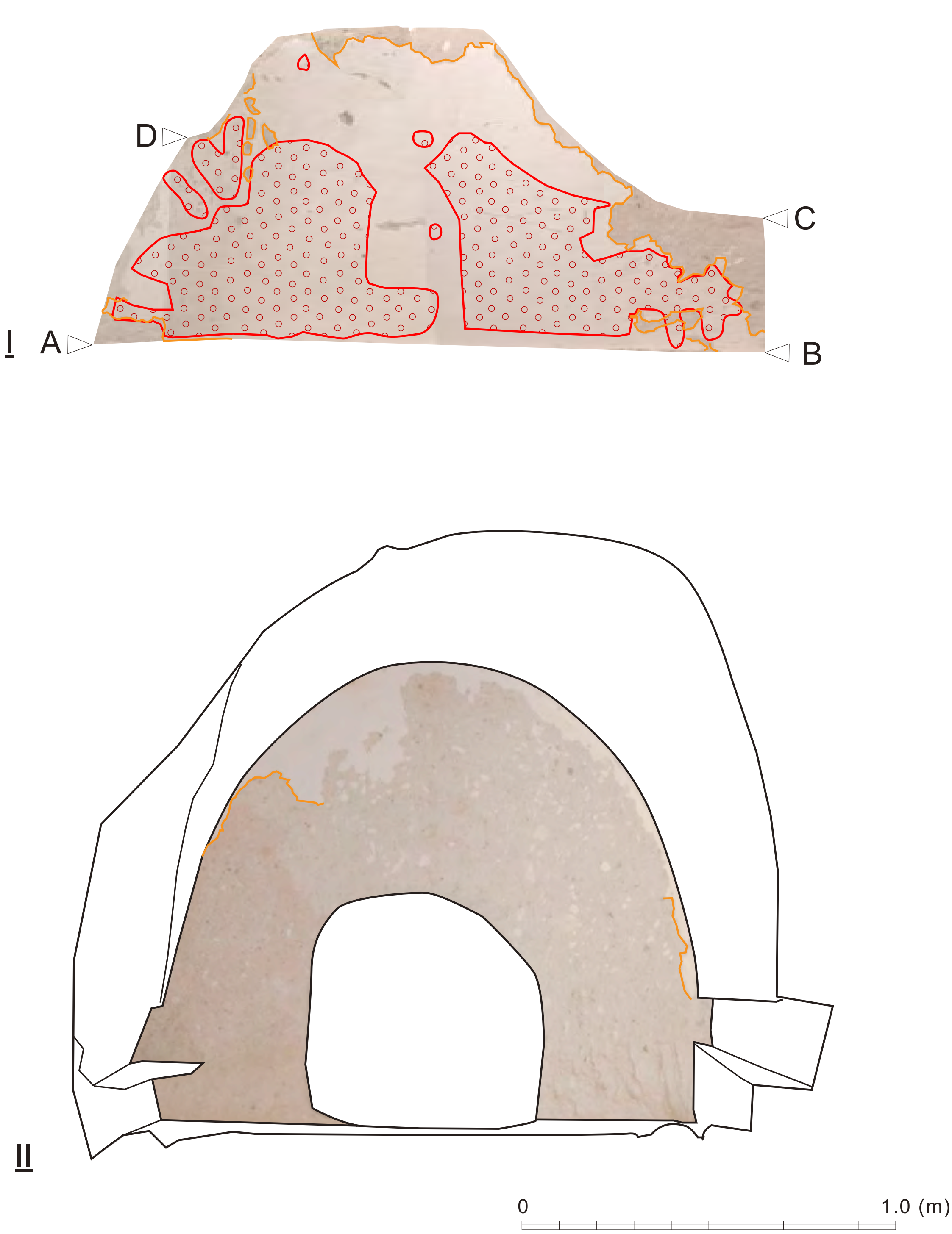


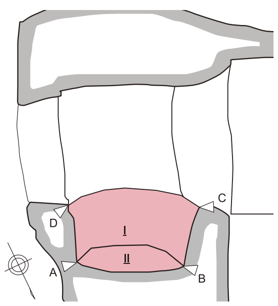
Edging

Grouting

Mechanical Cleaning

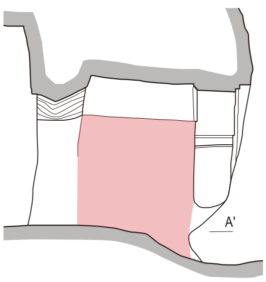
Church Name (Turkish)	Subject	
Üzümlü Kilise	Conservation intervention	
Church Name (Turkish)	Scale	Category
Chapel of Niketas the Stylite	1/20	Conservation
Location	Plate No.	
Intrados of Entrance Arch	UZM-I$_1$-02	



Ceiling		Church Name (Turkish)
	Edging Toning Mechanical Cleaning	Üzümlü Kilise
		Church Name (English)
		Chapel of Niketas the Stylite
		Location
		North Arch of Chamber 1
		Subject
		Conservation intervention
		Scale: 1/15 — Category: Conservation
		Plate No.
		UZM-I1-03

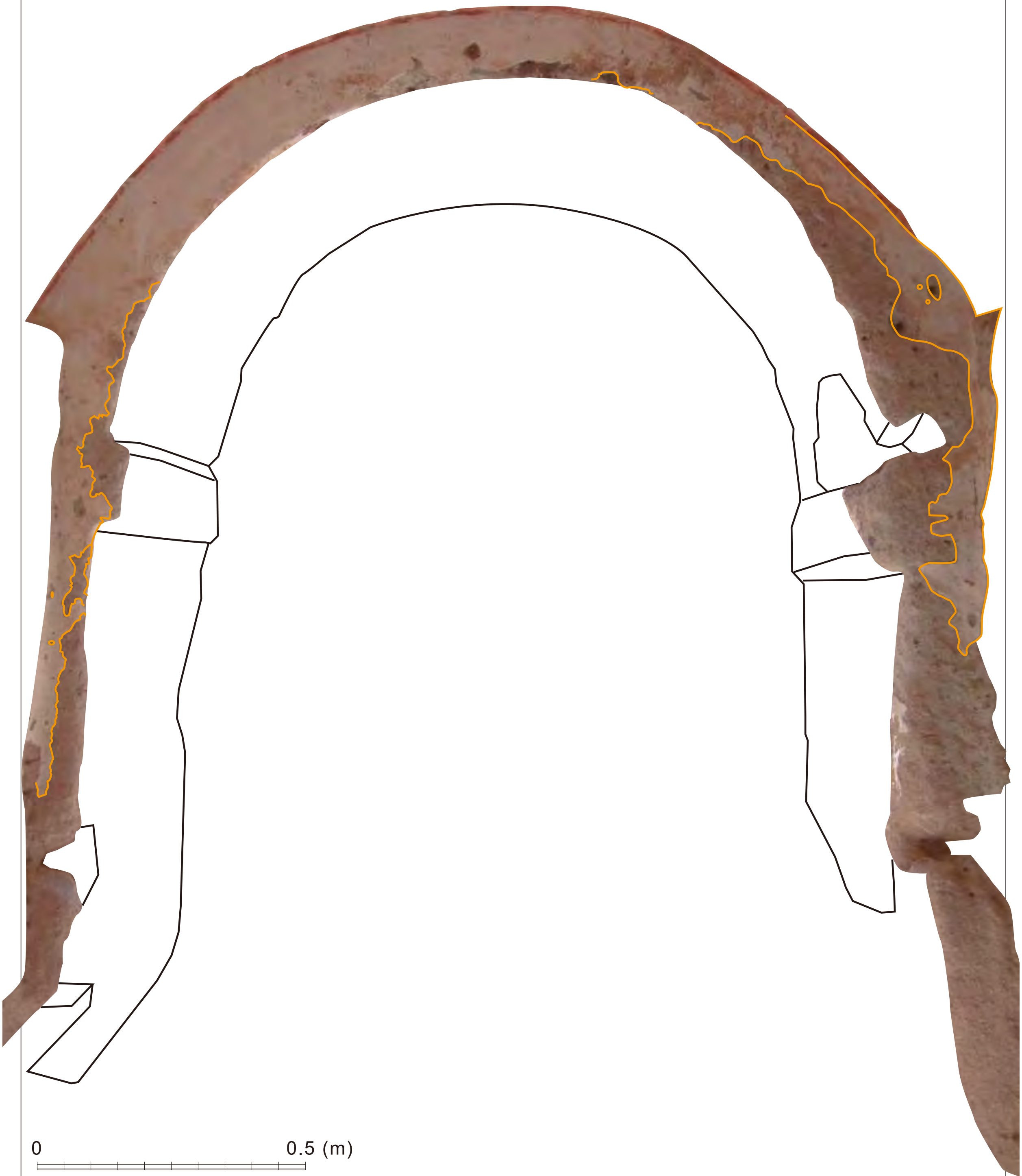
0 0.5 (m)

Section A-A’

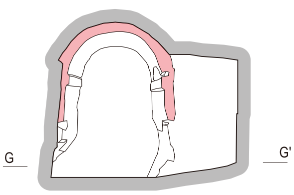


Edging

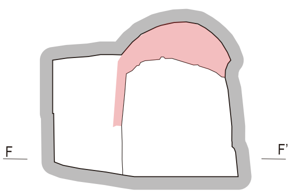
Church Name (Turkish)	Üzümlü Kilise
Church Name (English)	Chapel of Niketas the Stylite
Location	South Wall of Chamber 1
Subject	Conservation intervention
Scale	1/10
Category	Conservation
Plate No.	UZM-I$_1$-04



Section G-G’		Church Name (Turkish)
		Üzümlü Kilise
	Edging	Church Name (English)
		Chapel of Niketas the Stylite
		Location
		West Wall of Chamber 1
		Subject
		Conservation intervention
		Scale: 1/10 — Category: Conservation
		Plate No.
		UZM-I1-05



Section F-F’

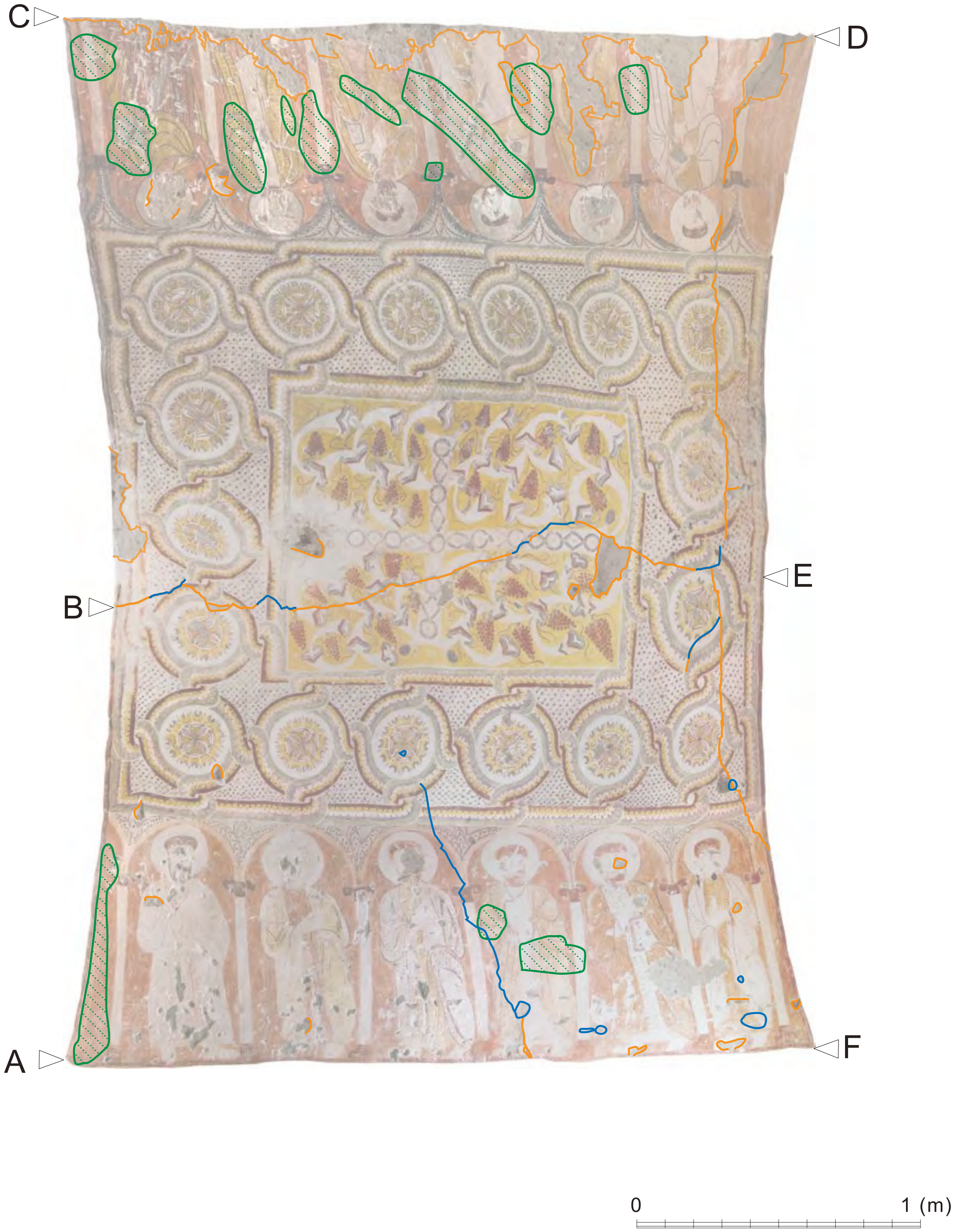


Edging

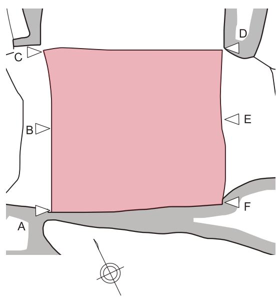
Toning

Mechanical Cleaning

Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
East Wall of Chamber 1	
Subject	
Conservation intervention	
Scale	Category
1/10	Conservation
Plate No.	
UZM-I1-06	



Ceiling

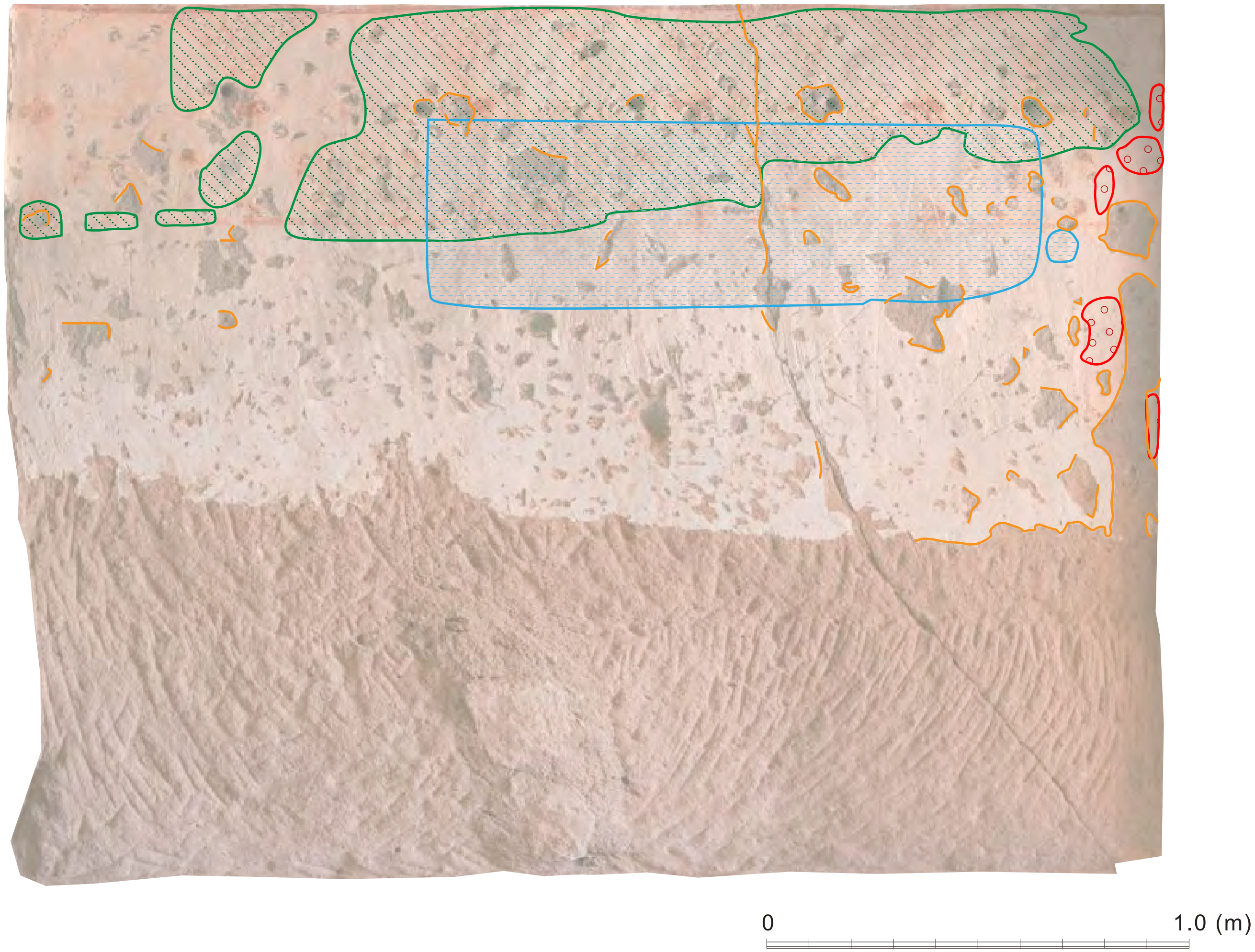


Edging

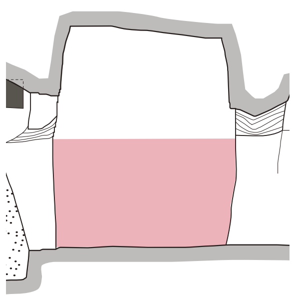
Grouting

Toning

Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
Ceiling of Chamber 2	
Subject	
Conservation intervention	
Scale	Category
1/20	Conservation
Plate No.	
UZM-I2-07	



Section A-A’



Edging

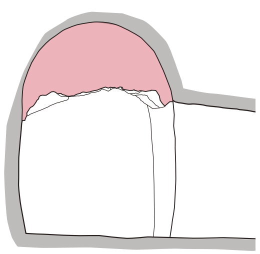
Toning

Mechanical Cleaning

Chemical Cleaning (hexane)

Church Name (Turkish)	Subject	
Üzümlü Kilise	Conservation intervention	
Church Name (Turkish)	Scale	Category
Chapel of Niketas the Stylite	1/15	Conservation
Location	Plate No.	
South Wall of Chamber 2	UZM-I$_2$-08	

Section D-D’



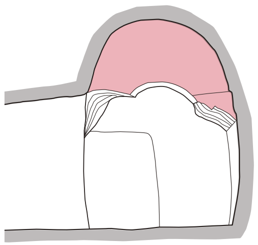
Edging

Toning

Mechanical Cleaning

Church Name (Turkish)	Subject	
Üzümlü Kilise	Conservation intervention	
Church Name (English)	Scale	Category
Chapel of Niketas the Stylite	1/10	Conservation
Location	Plate No.	
West Wall of Chamber 2	UZM-I$_2$-09	

Section C-C'



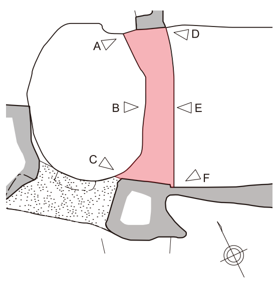
0 — 0.5 (m)

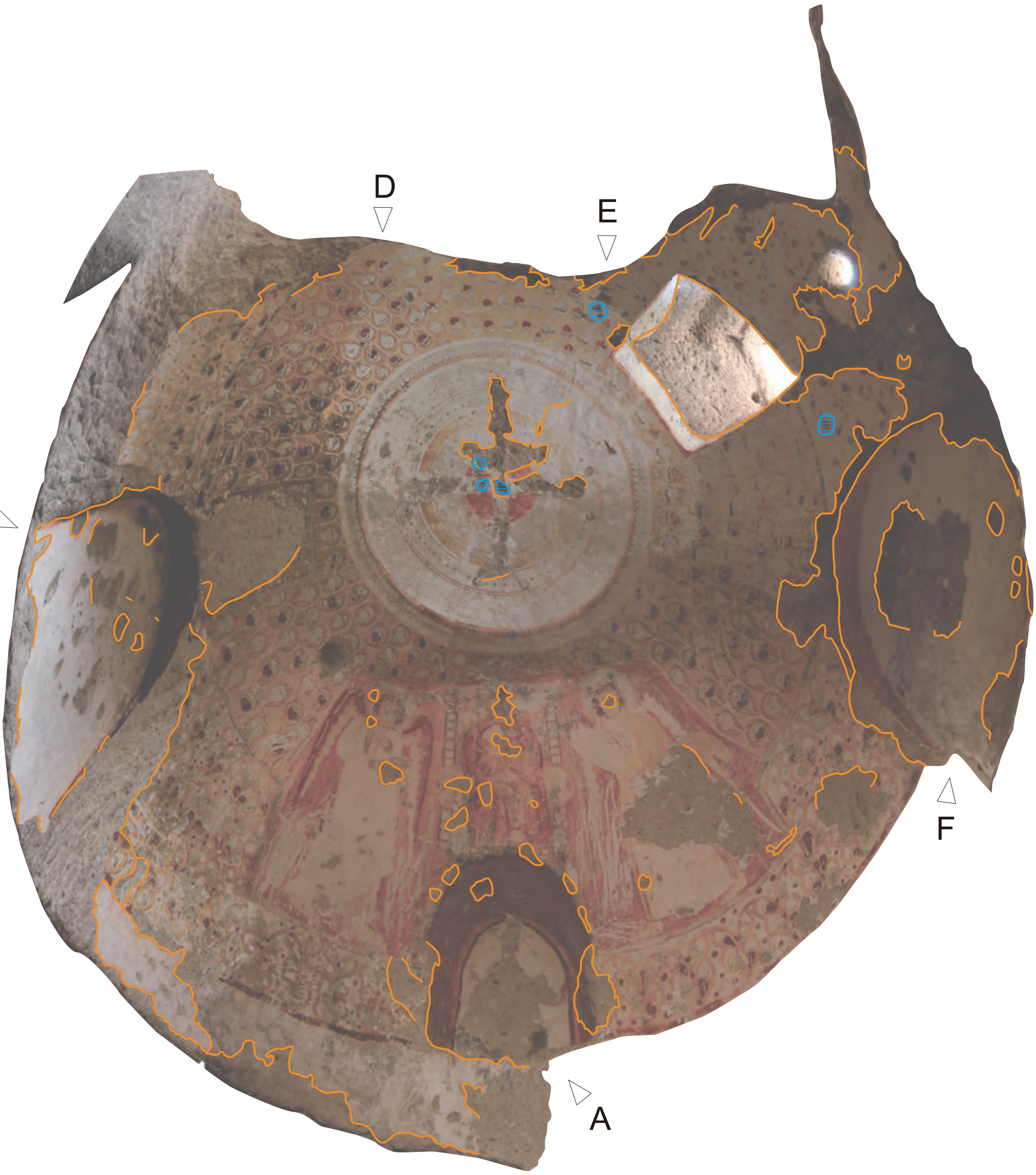
Edging

Toning

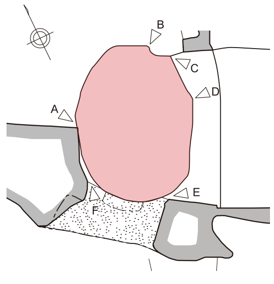
Mechanical Cleaning

Church Name (Turkish)	Subject	
Üzümlü Kilise	Conservation intervention	
Church Name (English)	Scale	Category
Chapel of Niketas the Stylite	1/10	Conservation
Location	Plate No.	
East Wall of Chamber 2	UZM-I$_2$-10	

Ceiling		Church Name (Turkish)
	Edging	Üzümlü Kilise
		Church Name (English)
		Chapel of Niketas the Stylite
		Location
		Transverse Arch between 2-3
		Subject
		Conservation intervention
		Scale: 1/10 — Category: Conservation
		Plate No.
		UZM-I2·3-11

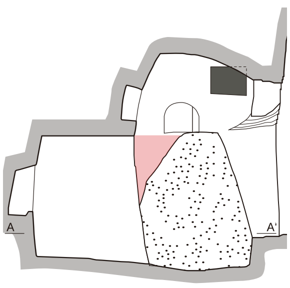


Ceiling		Church Name (Turkish)
		Üzümlü Kilise
	Edging	Church Name (English)
	Grouting	Chapel of Niketas the Stylite
		Location
		Ceiling of Chamber 3
		Subject
		Conservation intervention
		Scale: 1/20 — Category: Conservation
		Plate No.
		UZM-I3-12



0 0.5 (m)

Section A-A’



Edging

Church Name (Turkish)	
Üzümlü Kilise	
Church Name (English)	
Chapel of Niketas the Stylite	
Location	
South East Wall of Chamber 3	
Subject	
Conservation intervention	
Scale	Category
1/10	Conservation
Plate No.	
UZM-I3-13	

This project has been conducted under the agreement between University of Tsukuba, Nevşehir Museum, and Nevşehir Restoration and Conservation and Regional Laboratory as *Üzümlü Kilise Restorasyon-Konservasyon" Bilimsel Çalışmalarına İlişkin Protokol (Protocol on Restoration-Conservation Scientific Studies at Uzumlu Church)* since September 2014.

Editor

Yoko Taniguchi (University of Tsukuba)

Translation and Editorial assistance

Hatice Temur

Rayna Rusenko

Contributors for this volume

Fazıl Açıkgöz (Niğde Museum)

Giulia Caneva (University Roma Tre)

Piao Chunzu (Hytec co.)

Murat Ertuğrul Gülyaz (Nevşehir Museum)

Ryo Higuchi (Tokyo Institute of Technology)

Chiemi Iba (Kyoto University)

Keigo Koizumi (Osaka University)

Annalaura Casanova Municchia (University Roma Tre)

Jennifer Porter (University of Malta)

Katsuhiko Sano (D&D co.)

Mina Shibata (Assistant, National Research Institute for Cultural Properties, Tokyo)

Yoko Taniguchi (University of Tsukuba)

Kunio Watanabe (Mie University)

Mizuho Yoshioka (Kyoto University)

Front and back cover design

Mina Shibata

Scientific Studies on Conservation for Üzümlü Church and its wall paintings in Cappadocia, Turkey
Vol. 2 (Report on the activities in 2015 and 2016)

University of Tsukuba

This project was supported by Japan Society for the Promotion of Science (JSPS) Grant-in-Aid for Scientific Research, *Scientific studies on constituent materials and state of conservation for Cultural Heritage in West Asia* [24101014] by Yoko Taniguchi and Kajima Foundation (2015-2016)

Scientific Studies on Conservation for Üzümlü Church and its wall paintings in Cappadocia, Turkey Vol. 2 (Report on the activities in 2015-2016) 2017

公益財団法人
鹿島学術振興財団

RESEARCH CENTER FOR
WEST ASIAN CIVILIZATION

ICR 人文社会国際比較研究機構
Institute for Comparative Research in Human and Social Sciences