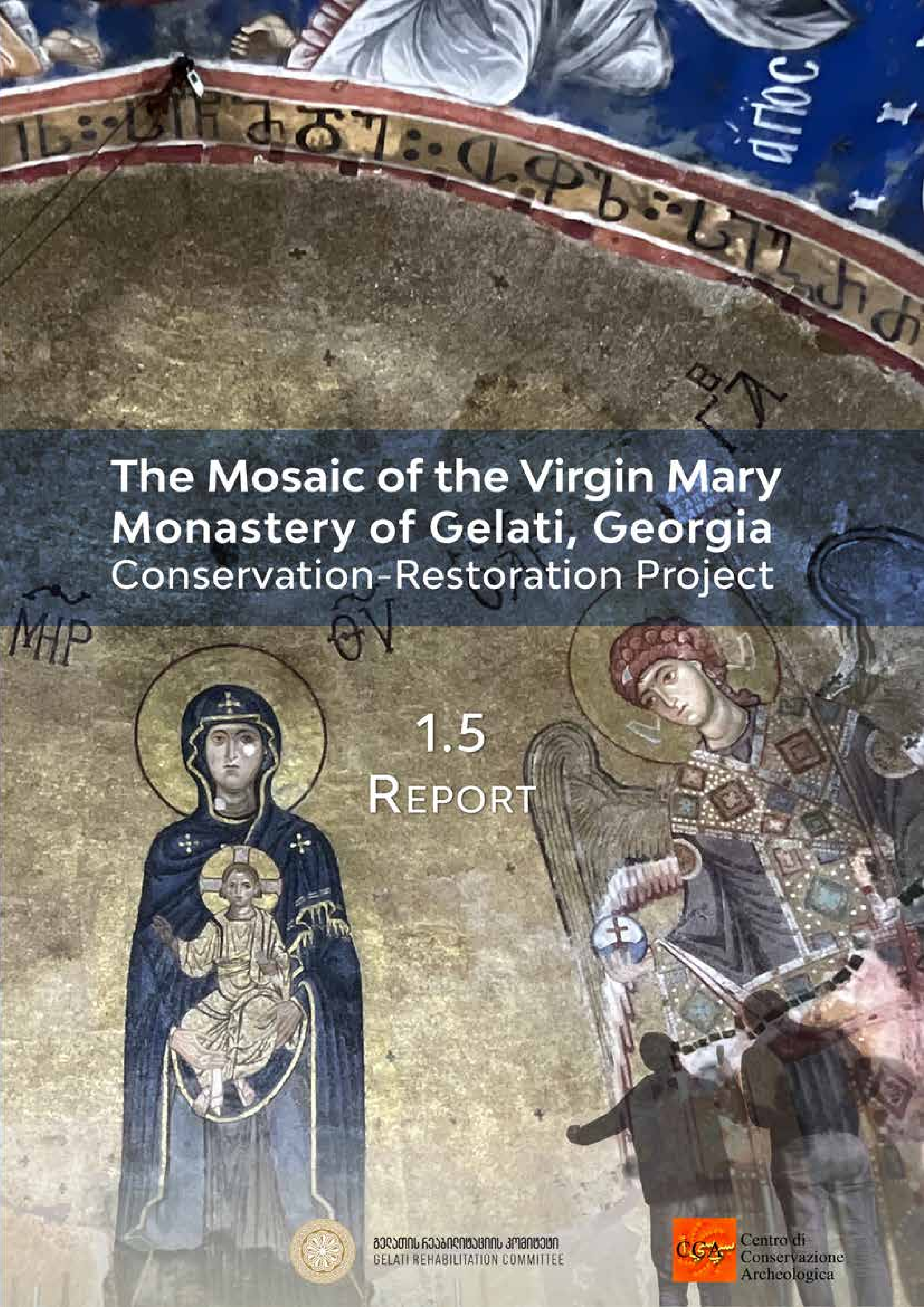


The Mosaic of the Virgin Mary Monastery of Gelati, Georgia
Conservation-Restoration Project

1.5
REPORT

გელათის რეაბილიტაციის კომიტეტი
GELATI REHABILITATION COMMITTEE

Centro di Conservazione Archeologica

The Mosaic of the Virgin Mary
Monastery of Gelati, Georgia
Conservation-Restoration Project

1.5

REPORT

Roberto Nardi
Centro di Conservazione Archeologica – Roma

March, 15th 2025

The Conservation-Restoration Project of the mosaic of the Virgin Mary in the Monastery of Gelati, Georgia, is made of a main text, that is the present volume, of a booklet that collects a selection of graphic tables reporting the state of conservation of the surfaces of the mosaic and of 2 appendices, which collect the study materials and the reports produced by the consultants who contributed to the definition of the project.

A list of the documents that make up the project as a whole follows:

1. The Conservation-Restoration Project Report;
2. The graphic documentation;
3. Appendix A:
    - Laser scanner and photogrammetric survey.
    - Thermovision and georadar investigation.
    - Conservation-restoration treatment tests
    - Experimental program to study mortars for injection and filling
4. Appendix B:
    - Limestone and pigments scientific analysis.
    - Glass tesserae scientific analysis.
5. Cost Estimate

The documents included in the Appendices have been originally delivered in Italian. A google translation into English was applied automatically.

Acknowledgements

Perhaps as never before, this study is the fruit of a multidisciplinary interaction that has brought together actors with humanistic, scientific, technical and religious backgrounds. This is a project that has been able to involve and enthuse colleagues and friends who have allowed themselves to be transported with generosity and pleasure in a multifaceted collaboration that we have enjoyed first in terms of an efficient, fruitful and above all very satisfying collaboration.

The list of people we sincerely want to thank is very long. We want to do it spontaneously, just as it comes to mind thinking of the help they have provided us, without hierarchies. Thanks to Pater Kirion, tireless guide and driving force of this entire operation, and to Davit Lortkipanidze for having been able to be present even those few times he was elsewhere. Thanks to Misha Gaprindashvili, who assisted us with an efficiency and kindness that we are not used to and to Manana Vardzelashvili for all the support work carried out. Infinite thanks to Ekaterine Gedevanishvili for opening up the world of the ancient history of mosaics and to Leila Khuskivadze for the current history. A special thought goes to Lado Gurgenadze, who recently passed away, who opened up not only his memory of the restoration work of the 80s but also provided us with invaluable photographic documentation. Thank you to Ketevan Asatiani for helping us identifying the days of the fires that damaged Gelati in the past centuries and Asmat Okropiridze for help finding the drawings reporting the restoration of the '80s. Thanks go to Vato Zesashvili for the help and the logistical assistance he provided to the project.

Thanks to the members of the Centro di Conservazione Archeologica who have taken up with great passion the responsibility of saving such an important and endangered work.

In order to make this document as accessible as possible, we decided to use images that illustrate the technical operations described in the text. To do this we used photos taken in Gelati during the treatment tests carried out in 2024. Where this was not possible because the planned processes were not contemplated in the tests, we used images taken during the conservation intervention of the mosaic of the Transfiguration in the Monastery of Saint Catherine in Sinai (2005-2015) and in the Baptistery of San Giovanni in Florence (intervention in progress). Both interventions, and the related images, are by the Centro di Conservazione Archeologica.

Summary

Introduction

This document contains the results of a study carried out in 2024 by a team of specialists coordinated by the Centro di Conservazione Archeologica of Rome, to produce a Conservation Project for the mosaic of the Virgin Mary in the Monastery of Gelati, Georgia, UNESCO World Heritage List since 1994.
It is based on a preliminary survey carried out by Roberto Nardi and Andreina Costanzi Cobau during their visit on July 14 and 15, 2023, followed by four additional surveys conducted on subsequent days when the Gelati Rehabilitation International Committee met on-site. The actual work program began on January 15, 2024, with activities carried out at CCA's headquarters in Rome and at the Convento di San Nicola in Belmonte in Sabina, in the consultants' institutes, and in Gelati. Four work campaigns were carried out in Gelati in March, May, July, and November 2024.
The institutions involved are: the University of Rome La Sapienza, Department of Physics; University of Venice IUAV, Laboratory of Analysis of Ancient Materials LAMA; University of Pisa, Department of Civil and Industrial Engineering; University of Bergamo, Service Center of the University Engineering Laboratories; Stazione Sperimentale del Vetro in Venice; Metis, Civil Engineering, Rome.
The total number of specialists who took part in the research is 27:

Anna Bottigliero, Centro di Conservazione Archeologica di Roma, conservator;
Massimo Canale, Centro di Conservazione Archeologica di Roma, metalwork;
Emanuele Canale, Centro di Conservazione Archeologica di Roma, metalwork;
Maria Elisa Cappelletto, Centro di Conservazione Archeologica di Roma, conservator;
Federico Capriuoli, University of Pisa, ACAS 3D Pisa, Digital Documentation and Solutions;
Miriam Cinelli, Centro di Conservazione Archeologica di Roma, conservator;
Guia Cocito, Metis engineering, Rome;
Denny Coffetty, Università degli Studi di Bergamo Laboratori di Ingegneria;
Luigi Coppola, Università degli Studi di Bergamo Laboratori di Ingegneria;
Luca Coscarelli, University of Pisa, ACAS 3D Pisa, Digital Documentation and Solutions;
Andreina Costanzi Cobau, Centro di Conservazione Archeologica di Roma, senior conservator;
Francesco D'Angelo, Metis engineering, Rome;
Andrea di Meo, University of Pisa, ACAS 3D Pisa, Digital Documentation and Solutions;
Roberto Falcone, Stazione Sperimentale del Vetro, Venice, Scientific Analysis;
Michele Musano, Metis engineering, Rome;
Roberto Nardi, Centro di Conservazione Archeologica di Roma, project director;
Fabrizio Noto, Metis engineering, Rome;
Andrea Piemonte, University of Pisa, ACAS 3D Pisa, Digital Documentation and Solutions;
Giovanni Pietropapa, Centro di Conservazione Archeologica di Roma, conservator;
Gian Mario Porcheddu, Centro di Conservazione Archeologica di Roma, senior conservator;
Stefano Ridolfi, University of Rome La Sapienza, Department of Physics;
Luca Romaniello, University of Pisa, ACAS 3D Pisa, Digital Documentation and Solutions;
Pierluigi Siena, freelance, videomaker and photo documentation;
Marta Vallotto, Stazione Sperimentale del Vetro, Venice, Scientific Analysis;
Marco Verità, Università Iuav di Venezia, Laboratorio di Analisi Materiali Antichi LAMA
Benedetta Visconti, Centro di Conservazione Archeologica di Roma, conservator;
Chiara Zizola, Centro di Conservazione Archeologica di Roma, senior conservator.

The study refers to the apse of the Church of the Nativity of the Virgin, both the mosaic part and the part reconstructed in painting. The objective of the study was to design a conservation plan that could dictate the guidelines and operational details for a conservative intervention capable of removing the source of the actual deterioration problems and restoring materials and structures.
In July 2023, during the first inspection in Gelati, the conditions of the mosaic appeared severe but not dramatic. Some detachments were evident but what appeared to be a protective net made of brass pins applied by Karlo Bakuradze during the restoration work in the 1980s was equally evident. The salt efflorescence, the areas of superficial condensation, the superficial deterioration of some tesserae, the falls of the *cartelline* were evident.
What was not evident in July was the seriousness of the situation that all the components just listed had determined.

As our familiarity with the mosaic grew stronger after four inspections and twelve months of study, through the study of the surface, through instrumental investigations, through the drafting of thematic tables on the reading of the forms of degradation, through the study of photographs and historical information, we became convinced that the mosaic is in a condition of progressive and rapid degradation and presents a high level of risk of collapse.

After the first two survey campaigns in Gelati we had a hard time believing the verdict of the engineers who quantified the mosaic surfaces detached from the wall support at 89% of the entire surface. According to the engineers' belief, numbers are numbers and therefore they are not up for discussion. But it was not this that convinced us of the validity of the estimate, but rather what Karlo Bakuradze reported in his technical report in which he quantifies the surfaces detached in 1985 at 80%. Therefore, a coincidence that erases any doubts about the current evaluation.

Despite these numbers, those who deal with mosaic conservation know well that it is not only the extent of a detachment that qualifies the seriousness of the problem, it is also the type of damage and the position of the detachments. In the case of Gelati, the panorama is the worst that can be imagined under all the aspects just mentioned. In more than 35% of that 89% of detached areas, the volume between the mosaic and the wall structure is practically empty for more than 22 millimeters of thickness. To the point that it was possible to investigate the interior of the structure with an endoscopic probe 5.5 mm thick and 2 meters long and identify, inside the mosaic, areas of strong air circulation, water passage and the presence of insects and biological attacks. Another 35% of detached areas is located in the upper section of the vault which means in the area of maximum physical stress. The picture is even more dangerous due to the presence of longitudinal fractures that did not exist at the time of Karlo Bakuradze.

As a result of the actual study, the preliminary observations were all confirmed. Therefore, the recommendation is not to take any risks regarding the stresses to which the mosaic may be subjected. This is to say that the structure of the apse and the mosaic cannot, or better say, must not, receive any static or vibrational stresses until an integrated mosaic-structure safeguarding system independent of the scaffold is put in place. This system should be put in place with a urgent preventive conservation program, organized in its own and which will be independent from the actual omni comprehensive conservation-restoration program that will be implemented in the future following immediately afterwards. It will consist of direct protection interventions on the mosaic surfaces that will ensure the stability of the mosaic and the creation of an external exoskeleton independent of the scaffolding, specially made according to the critical points of the mosaic which will help implementing all the activities needed safely.

Until this **preventive conservation intervention** is complete, it is recommended to exclude any action on the structures of the apse, both internal and external, and any intervention on the mosaic itself. Only when the entire mosaic surface will be secured, conservation activities and intervention on the roof of the apse will start in condition of security. The original strategy that CCA suggested to the Gelati Rehabilitation Committee was to start by studying the mosaic and producing a conservation plan before any direct activity on it. Today we know that this was a correct strategy. A year has passed and we hope not in vain. Today we know the mosaic better and we are able to propose a conservation project that includes strategy and practice. A plan based on a better knowledge of the artifact, on scientific investigations, on laboratory tests and on experiences translated from other interventions carried out.

The Research

The work program started on January 15th, 2024 with activities carried out in CCA's headquarter, in the consultants institutes and in Gelati. Nota 1 (1. Contract N 03-12-23 dated December 15, 2023, signed by the Gelati Provisional Restoration Committee and the Centro di Conservazione Archeologica, Rome.)
Four work campaigns have been carried out in Gelati, in March, in May, in July and November 2024. The objective of this research is to produce a Conservation Program for the mosaic. In order to do this, we first needed to realize a photorealistic three-dimensional survay of the mosaic to be used as the basis for further investigation and documentation. Second we needed to carry out the complete documentation of the state of conservation of surfaces and structure. Third a multifaceted instrumental investigation was planned in order to verify and support the visual anamnesis and diagnosis produced by the conservators. Forth, we proceeded with the collection of historical information and, finally, we carried out a study and interpretation of all data collected. All this is synthetized in the present document: the Executive Conservation Plan.
The study focused on the nature of the mosaic, on the manufacturing techniques, on the historical events, on past and ongoing processes of degradation and risk assessment, the structural and environmental context within which the mosaic, church, and monastery are located.
The study aims to collect all the information required to create a "point zero" where the actual status of the mosaic is recorded and crystallized in an intelligible and shareable form for the use of specialists, with multiple purposes, from the fundamental record for future memory for scholars and researchers, to the design of the executive conservation program.
It is structured in stages, which we can summarize:
preparation of the survey instruments;
documentation and diagnostics;
study;
editing of the executive conservation plan. (Plate 1)

Preparation of Survey Tools

In order to proceed with the documentation and study process, it was necessary to produce tools that would allow recording data in a logical and topographical format, acting at the same time as a database and management tools. For this, it was necessary to proceed preliminarily with instrumental survey campaigns to produce the final drawings used as bases for documentation.
We therefore proceeded with the realization of a photorealistic three-dimensional survey of the mosaic apparatus. The methodology used for the survey was an integrated laser scanner and photogrammetric type to provide a product optimized from both a geometric and colorimetric point of view.
Having the very high-resolution digital copy, it was therefore possible to extract a whole series of tools and documents useful for the creation, visualization, and interrogation of the mapping for the entire apparatus and for the individual tesserae.
The management of the survey occurs both through direct use of the three-dimensional model and through two-dimensional documents derived from projections on the plane of the curved surface.

Activity	State of advancement			
	25%	50%	75%	100%
1 Full terrestrial laser scanner survey;				
2 Ultra-high-resolution photogrammetric survey;				
3 Metric Computation of the Mapping on the Model				
4 Integrated 3D Model Processing				
5 Creating the Graphic and Photographic for Documentation				
6 Plates of documentation reporting the actual state of the mosaic;				
7 Flexible Video Endoscope survey (new activity);				
8 Dino-lite magnified observation of mosaic surface (new activity);				
9 GeoRadar survey;				
10 Not-visible metal elements detection with a Pacometer (new activity);				
11 Surface survey by Thermo-vision;				
12 Scientific analysis of materials and deterioration forms;				
13 Historical research;				
14 In situ and Laboratory tests				
15 Conservation treatment tests				
16 Video documentation of the mosaic and of the study and documentation process;				
16 Executive Conservation Plan				

Laser Scanner Survey

The laser scanner survey allowed the rigorous acquisition of the geometry of the structure, the definition of the reference system on which to place the other surveys, and the continuity of the survey between the different parts visible from the different levels of the scaffolding leaning against the structure. The instrumentation used for the survey is the Leica RTC360 laser scanner (Photo 1), the technical data sheet of which is reported in Appendix 1. This laser allows a three-dimensional coordinate precision of 1.9mm at 10 meters and acquires for each scan a 360°x300° calibrated spherical image of 432MP in HDR (High Dynamic Range) mode.

The acquisition was performed at very high resolution with a scanning step of 3mm at 10m and with dense stations in order to avoid any shadow cone deriving from elements projecting from the structure. Furthermore, the stations were created in order to avoid the shadow areas of the scaffolding and return a point cloud model that allows for a complete 3D overall view of the surface freed from the scaffolding.

1. Photogrammetric survey carried out with a Nikon D850 reflex camera.

Photogrammetric Survey

The detailed photogrammetric survey was carried out with a Nikon D850 reflex camera (technical data sheet in Appendix 2) equipped with fixed focal length lenses of 60mm and 105mm macro (technical data sheets in Appendix 3). The camera is equipped with a 45.4MP full-frame sensor (8256x5504), which at an average shooting distance of 150cm guarantees a GSD (Ground Sampling Distance) of 0.11mm and 0.06mm respectively with the two lenses used. Thanks to these characteristics, photogrammetric documents can be produced with a very high level of resolution, allowing a detailed representation with enlargements up to 2:1 scale.

To maintain rigor in the geometry and radiometric response of the surface to illumination, the frames are always acquired with the capture axis orthogonal to the surface. However, frames were also acquired with the capture axis inclined with respect to the surface to vary the reflection of the light on the tesserae, particularly on the gold ones. With this measure, it was possible to eliminate the reflections in the post-production phase.

The frames were acquired ensuring correct lighting using the Godox Witstro+ 400AR ring flash (technical sheet in Appendix 4) integral with the optics. The advantages of using this type of flash are many: the colorimetric differences on the detected object are minimized already in the acquisition phase, and it is possible to maintain very fast exposure times in order to avoid micro-blur effects due to the natural oscillations of the scaffolding.

Finally, to allow the color calibration of the frames in post-production, a color checker was inserted into the scene. All the processing was then conducted on a calibrated IPS LED panel.

Integrated 3D Model Processing

Data processing is divided into two macro phases. The first concerns the processing of the raw laser scanner data. The laser scanner instrument used allows, already during the campaign phase, to perform an initial pre-alignment of the individual scans.

This pre-alignment is possible thanks to the inertial systems integrated into the instrument and to the VIS (Visual Inertial System) technology, which, by carrying out real-time photogrammetric processing of the images acquired by a series of integrated cameras, is able to estimate the position and attitude of the instrument.

In the post-processing phase, the pre-alignment is refined by inserting cloud-to-cloud constraints and executing ICP (Iterative Closest Point) algorithms.

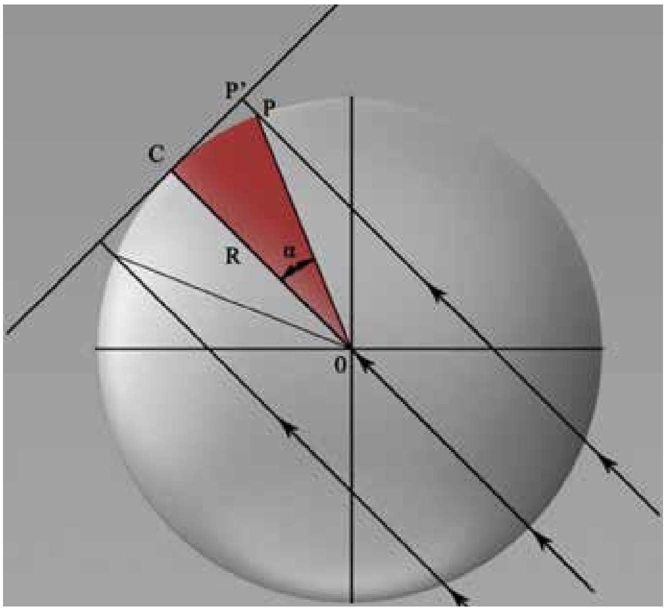
Once the overall point cloud is obtained, it acts as a geometric constraint for photogrammetry.

The frames acquired through the photogrammetric survey are recorded on the laser scanner through automatic recognition of homologous points identified on the frames themselves and on the individual colored scans transformed into cubic images. In order to have a verification of the automatic alignment, a series of targets were provided, coded and acquired specifically by the laser survey and identifiable with high precision on the frames. These targets were materialized on the structure in the area of the edge stucco.

After aligning the frames on the laser scanner (Photo 2) and checking the error, we proceed to create the reference surface (High Poly mesh) with high definition (Photo 3).

2. Aligning the frames on the laser scanner and checking the error.

3. The reference surface (High Poly mesh) created during the integrated 3D model processing.

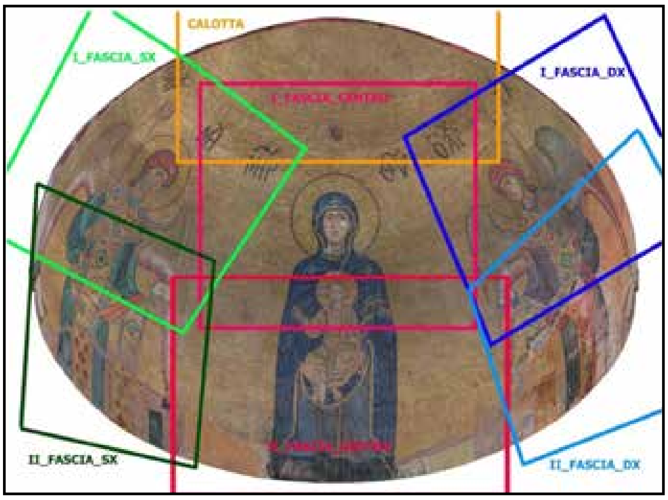


$$|\widehat{CP}| = R \cdot \sin\alpha \qquad (1)$$

$$|\acute{C}P'| = R \cdot \sin\alpha \cdot \cos\alpha \qquad (2)$$

$$\Delta_L = R \cdot \sin\alpha \cdot (1 - \cos\alpha) \qquad (3)$$

4. The orthographic azimuthal projection adopted for the planar representation of the dome.



5. Seven photogrammetric bases uploaded onto IPads for documentation.

This surface, characterized by a very high number of polygons (1.4 billion polygons), describes the mosaic surface with millimetric precision. The gaps, fractures, deformations, and all the discontinuities of the surface are visible on the 3D model.
The very high-resolution model (High Poly) is then textured. Through this process, the colorimetric information of the individual photogrammetric shots is transferred onto the surface in order to obtain a very high detail in terms of resolution and a homogeneous mapping at a colorimetric level (each shot is color corrected individually).

The final textured 3D model has the following characteristics:
- 1.4 billion polygons
- 128 textures of 16384 x 16384 pixels
- 280 GB of computing weight.

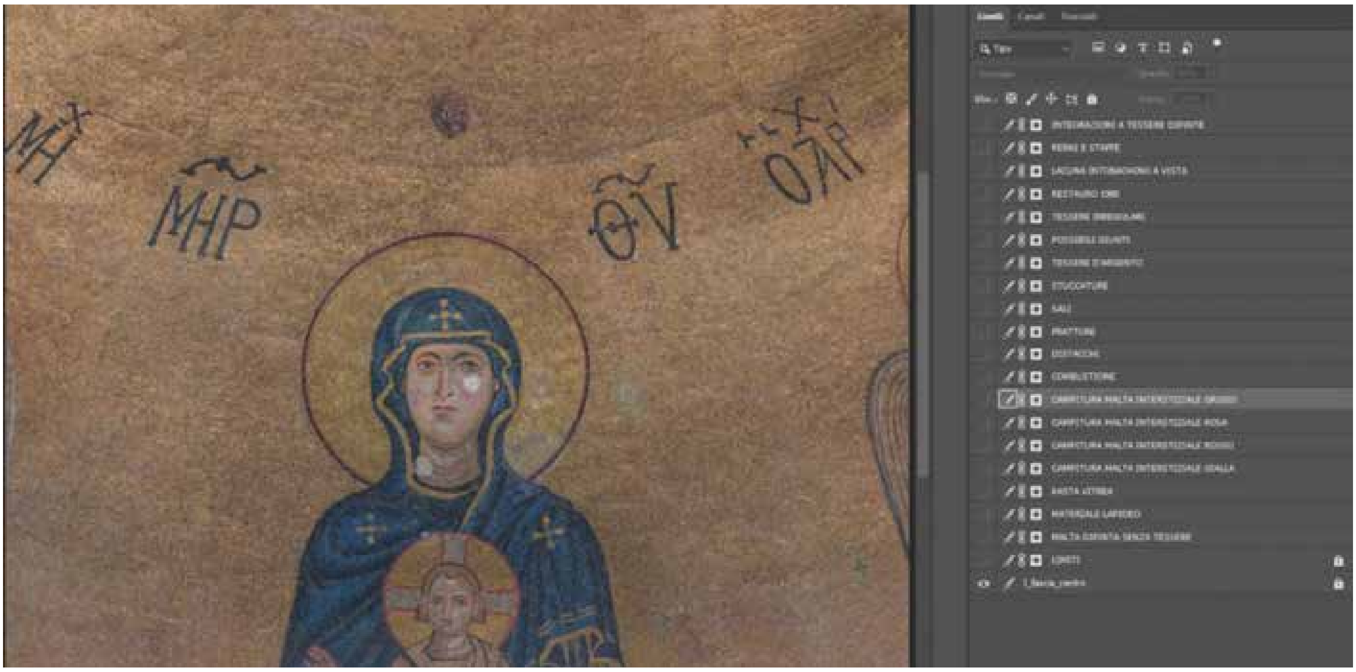
This model forms the basis for the next phase consisting of dividing the surface into portions and projecting them onto the plane.
In parallel with the processing of the 3D model at the highest possible resolution, a lightened 3D model (Low Poly) is created, built on the base model to minimize precision errors. This model will form the basis for the 3D visualization part of the mappings and for the calculation of the mapped surfaces.

Projection of the Model on the Plane

As is known, any representation of a semi-dome on a plane is characterized by a linear deformation due to the non-developability of the curved surface.
The methodology adopted for the planar representation of the dome can be described as an orthographic azimuthal projection. In this kind of projection, for a given curvature radius, linear deformation is directly linked to the distance of the projected point relative to the tangency point of the plane and therefore to the angle, according to Photo 4.
Taking into account the need to maintain deformations compatible with the potential representation scale given by the GSD and the operational needs of the restorers, who carried out the mapping, the subdivisions of the surface in the projections schematized in Photo 5 were agreed upon (Photo 5).

Graphic and Photographic Documentation

The monument was divided, during the acquisition phase, into 3 zones, marked by the geometry of the object but above all tied to the scaffolding.
The areas were then subjected to orth-projection and at the end of the operation, we obtained seven photogrammetric bases which, converted into PSD format, were uploaded onto iPad Pro 2023/2024.



6. An example of the maps used to document the mosaic.

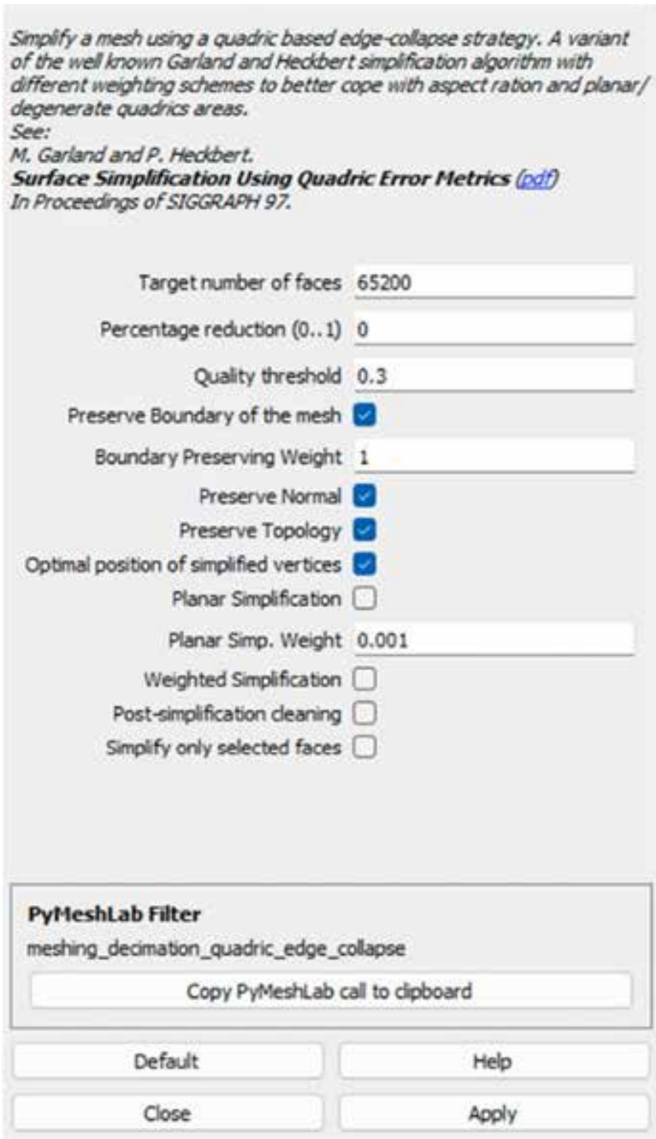
The color profile chosen for the PSD bases is sRGB. Using Adobe Photoshop iPad software and the Apple Pencil Pro, the restorers were able to map directly on-site using the iPad as a writing pad (Photo 6).

3D Mapping View

This section describes the process of creating the lightened 3D model (Low Poly), creating the UV mapping, and transferring the mapping from the ortho-projected bases to the single UV.

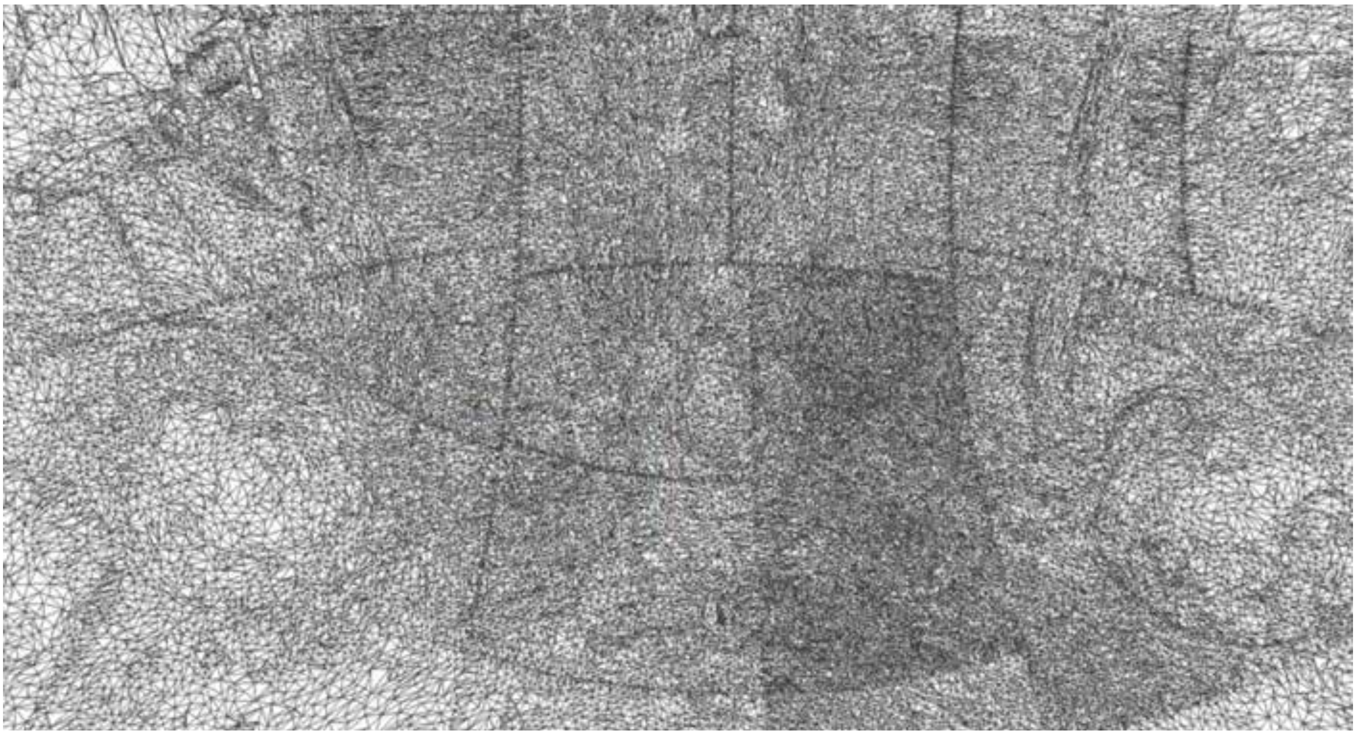
Creating the Low Poly 3D Model

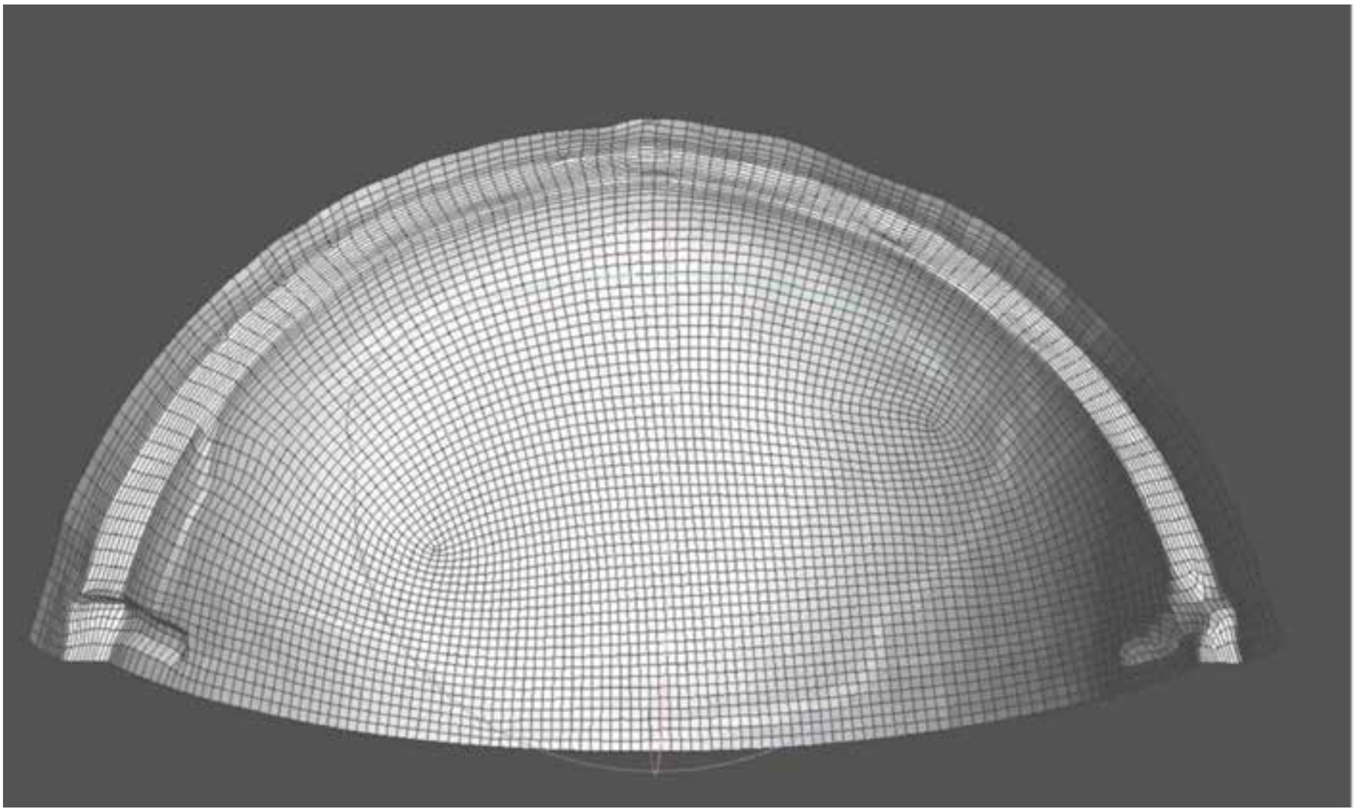
The very high-detail model, created by laser scanner and photogrammetric technique, is lightened through an iterative process with control of the geometric error due to the elimination of polygons. This process, performed in the MESHLAB software environment, allows reducing the number of polygons through the use of an algorithm that controls both the topological distribution of the faces and the deviation error with the reference model (Photo 7).



7. An algorithm that controls both the topological distribution of the faces and the deviation error with the reference model

By repeating this process iteratively, we arrive at a reference 3D model that is light and manageable (Photo 8-9).
Once the light model is obtained, we proceed to the re-topologization. That is, the model is reorganized so that the single element becomes quadrangular (previously the basic element was the triangle). In this way, the total model is easily manageable by an operator, who manually proceeds to the creation of the UV mapping.





8-9. The reference 3D model.

UV Mapping

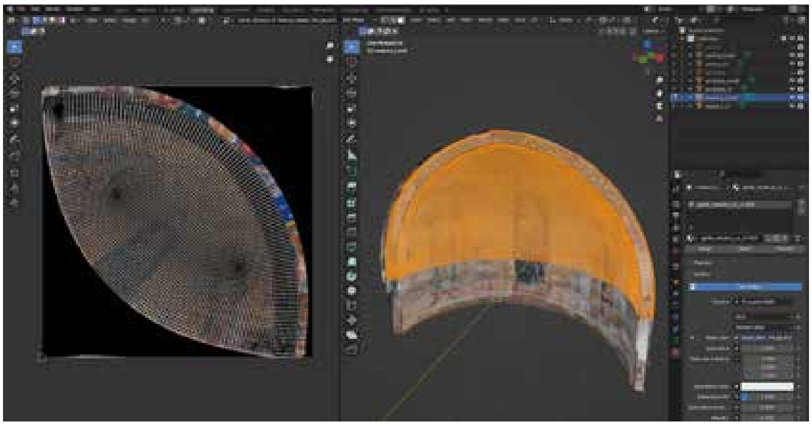
The UV mapping process on the lightened quadrangular model is used to obtain a distribution of the given color (texture) on the surface while maintaining adjacent elements on the UV that are also adjacent in the 3D model. Furthermore, thanks to the fact that the three-dimensional surface of the semi-dome is smooth and without protruding elements, the flat representation given by the UV is not excessively distorted and allows a direct connection with the flat projections, which formed the basis of the mapping (Photo 10).

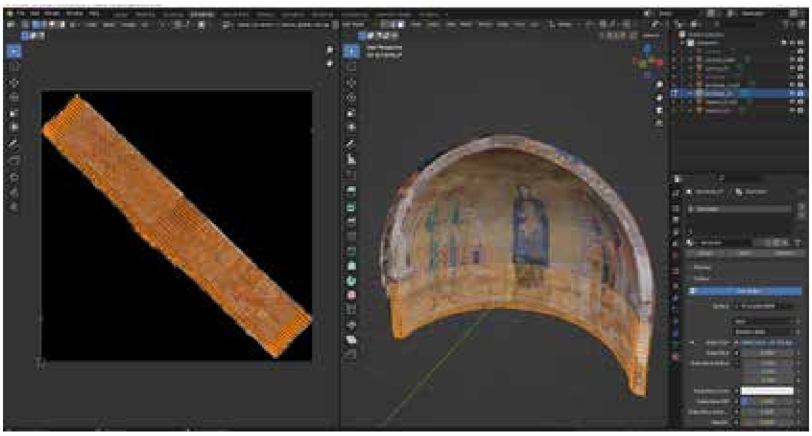
The described process, which can also be performed in fully automatic mode, was carried out in assisted mode (Photo 11) to allow an expert operator to guide the process and optimize the representation.

Together with the semi-dome, the underlying painted drum was also surveyed. For this portion of the surface, the flat representation was simpler since it is in fact made similar to a cylindrical surface, which can be developed without deformations (Photo 12).

The model is divided into 3 portions: The quarter sphere, relating to the mosaic; the cylinder in the lower fresco portion; the frame, in the upper area.

Once these high-resolution 3D maps (32,768 x 32,768 pixels) have been obtained, the individual layers of the mappings coming from the graphic bases that the restorers used on the iPad are transferred onto them.





10. The UV mapping process on the lightened quadrangular model is used to obtain a distribution of the given color (texture)

11. The UV mapping process was carried out in assisted mode.

12. The survey of the underlying painted drum was simpler since it is in fact made similar to a cylindrical surface

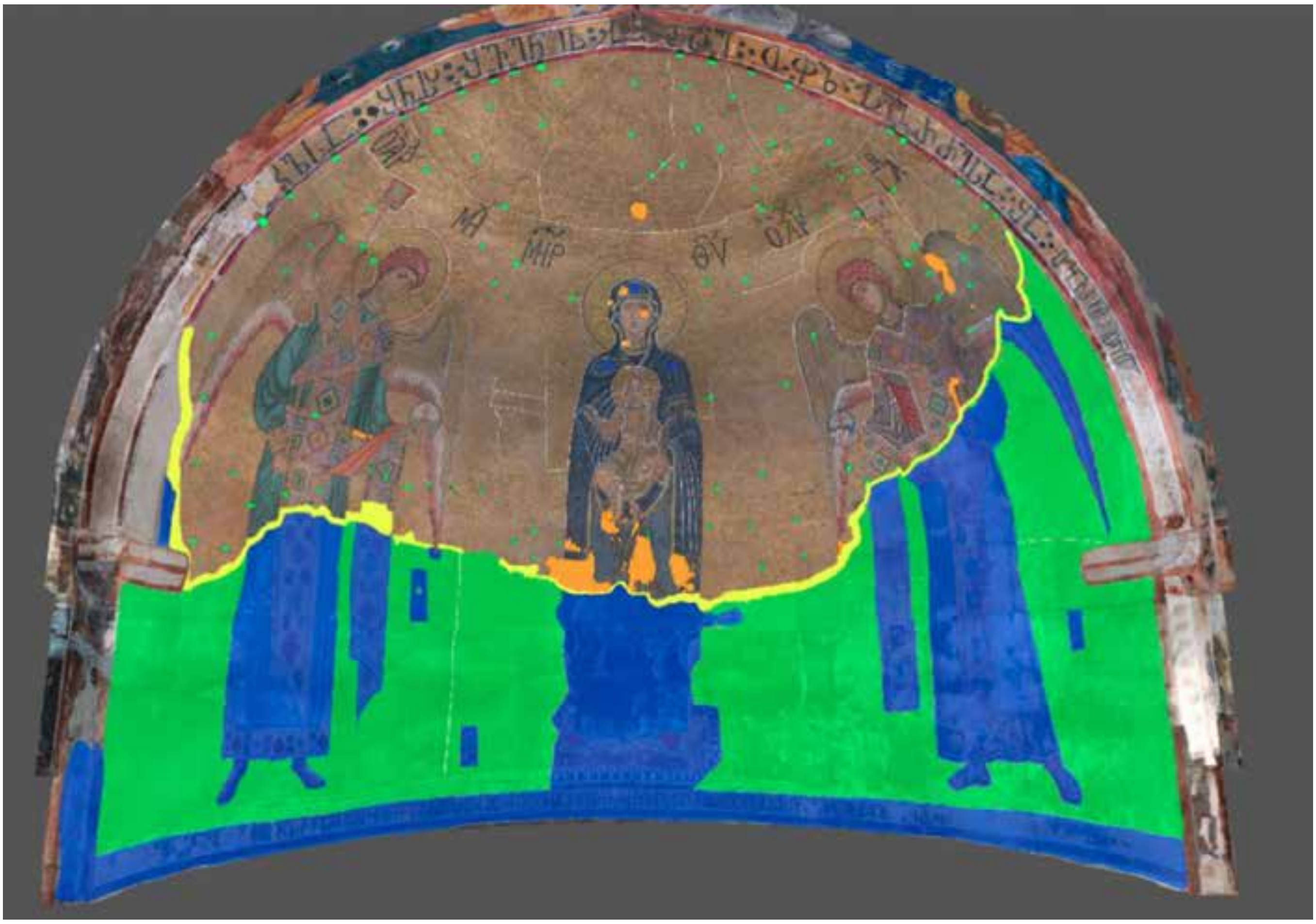
The mapping transfer process is automatic and controlled by the operator. For each transferred layer, a check was performed to ensure that the individual mapped tesserae correspond to the corresponding tesserae on the UV. Photos 13 to 16 show examples of mappings reported on the UV (Photo 13-16).

13-14. Examples of mappings reported on the UV. Here we have the map of detached areas and soluble salt efflorescence

Metric Computation of the Mapping on the Model

Once the 3D model with all the transferred mappings is obtained, in the JRC Reconstructor environment we proceed to calculate the individual areas. The areal measurement is therefore not approximated on a flat surface but calculated by directly following the curvature of the mosaic.
The process is automated; however, for greater control, it was preferred to manually define the area to be calculated each time.

15. A detail of the map of metal pins



16. A detail pf the map of the drum under the mosaic area

Documentation

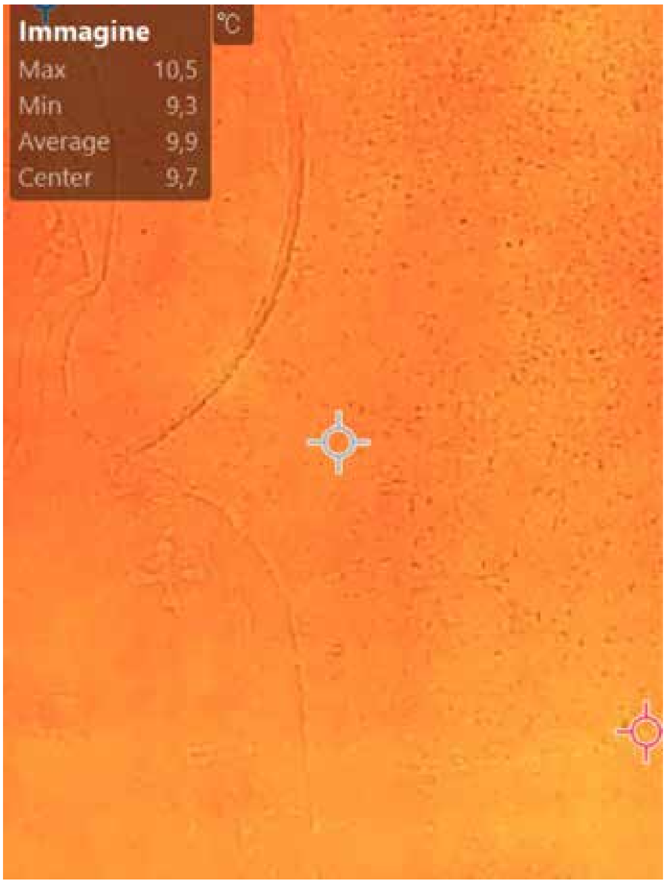
The activities just described were necessary to produce the graphic and photographic bases on which the conservators were able to create the documentation in all the descriptive components that we deemed necessary for the Gelati mosaic.
The photographic bases (which thanks to photogrammetry have a spatial numerical reference) were transferred to two iPads on which the legends for the documentation were prepared.
The goals of documentation are many and well-known. Perhaps it is useful to point out some of them, just because they well apply to Gelati.
The first, obvious one, is to crystallize the current state of the surfaces and structure of the mosaic in order to set "a zero point" that will serve as a reference for what will be done in the future and possibly interpret what happened in the past.
Another objective is to identify the distinctive elements present on the surfaces and within the mosaic in order to break down and classify what today seems to be a set of problems that are more or less difficult to understand.
A further possible goal of this operation is to bring out anomalies that may prove useful in identifying unexpected or new information.
In the case of Gelati, the documentation needed to be twofold: to be done manually, on a digital basis, by conservators with experience in this specific field, because a professional's ability to analyze and synthesize is not replicable instrumentally nor automatically.
Contextually, we decided to resort to instrumental means both to reach all the information not visible to the naked eye and to collect as much information as possible with an objective system, independent of the operator's critical judgment.
Following the experience carried out by the Centro di Conservazione Archeologica on the mosaic of the Transfiguration in the Monastery of Saint Catherine in Sinai and the work in progress on the mosaic at the Baptistry of Saint John in Florence, a legend was created taking care of the specific features of the mosaic of the Virgin in Gelati. After completing the analysis of the surfaces relying on the skills and experience of the conservators, we proceeded with some instrumental surveys with the objective of verifying and supporting on a scientific basis the results obtained with the direct observation. This kind of documentation will also serve as an "objective" archive based on numerical information.

Thermographic Investigation

The first of this technical survey was the thermal investigation which allows, through the use of a thermal camera, to detect thermal discontinuities on the investigated surface. Specifically, this non-invasive diagnostic investigation allows the detection of thermal energy emitted by an object and its conversion into a visible image, called a thermogram.
The aim of the investigation is to verify, through the processing of infrared (IR) data, the presence of structural discontinuities beneath the mosaic surface (Photo 17).

Type of Investigation: the mosaic surface was acquired in two different ways, the first one called "passive" consists in acquiring the thermograms with the environmental conditions, without thermal stimulation.
The second method, "active," involved the use of a heating source (convection) to amplify the response below the mosaic surface. In fact, there is a gap on the edge that allows hot air to be introduced.

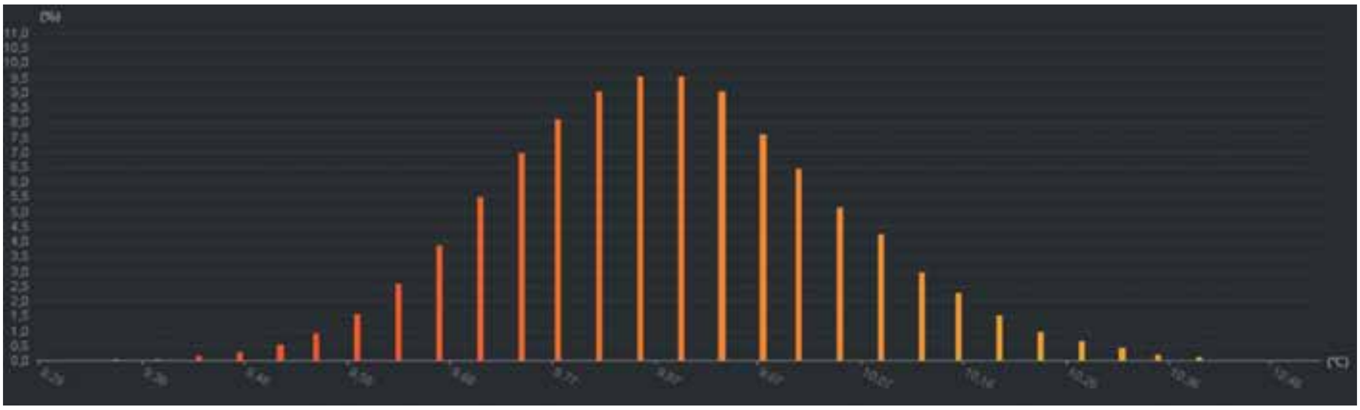
The thermal investigation of the apse area is made complex by some of the factors listed below.
The position of the vertical elements of the scaffolding makes the acquisition operation complex. In fact, some of them, entering the field of view of the instrument, alter the acquisition.
Thermographic investigation on a mosaic surface with a



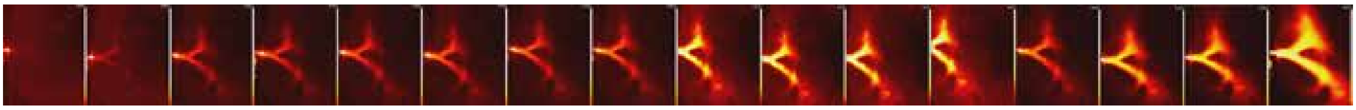
17. The presence of structural discontinuities beneath the mosaic surface detected through the processing of infrared (IR) data.

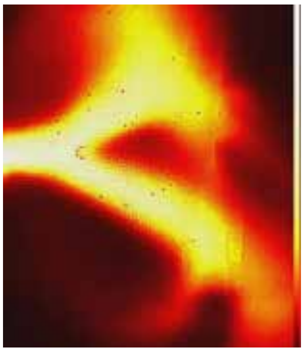
prevalence of gold tesserae is very complex. The emissivity (ε = capacity of a material to emit radiation with respect to an ideal black body) of gold is very low (0.02), which means that the material can reflect the surrounding environment generating incorrect measurements.
To overcome this problem, the measurement was prepared by turning off all the lights in the apse, allowing the surface to "cool down." Several test measurements were taken throughout the day, considering the mid-day sample as the reliable average.
Another precaution taken during the acquisition phase concerned the taking technique. To minimize reflections, shots were taken perpendicular to the area at different heights and using a scaffold for the higher parts.
Environmental Acquisition without Induced Variations: for the first acquisition, it was decided to analyze the semi-dome in its current state, with the environmental temperature and humidity conditions unchanged.
An average acquisition distance of 100cm was chosen. 360 thermal shots were taken over a period of about 1h. The individual shots were acquired in both IR (infrared) and RGB modes. Each RGB shot was mapped onto the surface already scanned by laser scanner. In this way, the entire thermal investigation used the 3D scan as a reference surface, avoiding manually mapping each image onto the surface. The mapping operation of the RGB image of the thermal camera on the laser survey occurred automatically, with the software search for homologous points.
Ambient Temperature = 20.3 degrees Celsius
Humidity = 19%
(Photo 18)
The overall picture generated shows that the surface of the mosaic has a temperature constant average of about 8 degrees. However, colder areas are identified near the right and left angles, in the upper area of the dome, and in the lower central part (Photo 19).

18. The mapping operation of the RGB image of the thermal camera

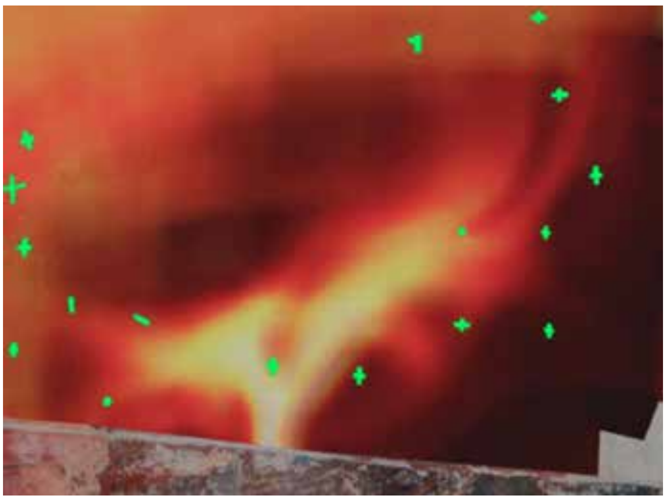


19. Colder areas are identified near the right and left angles, in the upper area of the dome, and in the lower central part





20-24. Acquisition with Thermal Stimulation



Acquisition with Thermal Stimulation

On the left half of the mosaic, in correspondence with the connection between the frame and the mortar, there is a hole into which hot air has been introduced. The introduction took place in a slow, gradual, and controlled manner.

Thermal investigation took place throughout the process, allowing us to visualize in real-time the trend of the hot air flow.

Real-time monitoring of the flow has allowed us to observe that there are some voids between the mosaic and masonry and that these voids are minimized in proximity to the pins (in the direct investigation area).

In fact, we observe the fluid bifurcating and filling another empty area to then have the same behavior near a pivot (Photo 21-24).

The investigation with thermal stimulation gave clear results that allow us to read the behavior of the layers below the mosaic.

However, this investigation was intentionally carried out for a limited time, to avoid any type of risk associated with the introduction of hot air into the mosaic cavity/underlying structure.

Pachometric Survey

The pacometer is a digital instrument that allows the non-destructive detection of the presence and direction of iron elements within a masonry structure.

It falls under the so-called magnetic methods, as it exploits the magnetic properties of iron for the localization of iron presences within a masonry. Its operation is based on the principle of electromagnetic induction.

The instrument consists of a magnetic field-emitting probe connected to a digital and acoustic processing unit. The probe is made to slide along the surface of the masonry, and from the absorption of the magnetic field, it is possible to determine the position of the metallic elements.

The instrument is composed of: a unit for the emission and reading of the electromagnetic field, and an emitting-receiving probe for the magnetic field.

The pacometer was used to detect the non-visible metallic components present inside the mosaic. We started with the intention of cross-referencing the data we received thanks to the images of the restoration by Karlo Bakuradze to verify their accuracy and/or consistency. Given the positive results of the detection, we decided to extend the investigation over the entire surface. This allowed us to identify a series of non-visible metallic presences from the outside and not signaled in the documents of the intervention of the '80s.

This allowed us to draw up a plate that we consider complete of the metallic presences inside the structure of the mosaic with important benefits in the subsequent development of the conservation intervention
(Photo 25-28).

25- 28. The pacometric process allows the non-destructive detection of the presence and direction of iron elements within a masonry structure.

Endoscopy

In order to investigate the hollow spaces where the mosaic is detached from the wall, a video borescope was purchased.
Featuring a weight of just 960 g, including image, video, and zoom function, display with a resolution of 1024 x 768 pixels, integrated LED illumination, and storage batteries with a service life of up to 4 hours, it was ideal to carry out virtual non-destructive investigations.
Thanks to a 5-stage LED light source, the light could always be adjusted to the appropriate ambient conditions. Image and video storage at the push of a button directly on the video borescope, it was possible to record images and videos on an SD card.

It was also possible to enlarge images with the zoom function 3 times (digital), so that even the smallest details could become visible.
The viewing direction was transmitted quickly and directly to the borescope tip by means of a joystick so that a 360-degree all-round view was possible.
The transmission of movement from the joystick to the borescope tip was ensured by servomotors – this has the advantage that you get a smooth and very easy control of the borescope tip even through narrow holes, channels, and complex components. As for the technical description, see Appendix.
The instrument was inserted into a cavity which gives access into the detached areas, allowing a deep investigation of the phenomenon.
Particularly important was the discovery of unexpected materials inserted during the restoration of the '80s to sustain the freshly inserted metal pins, biological presences, metal elements, and traces of the deteriorated mortar setting bed of the tesserae.

29-30. In order to investigate the hollow spaces behind the mosaic, a video borescope was used.

Very important was also to detect the positive/negative imprinting of the irregularity of the stone walls against the mortar attached to the mosaic, explaining that in these areas there was not a loss of material but (and more worryingly) severe distancing of the mosaic from the wall (Photo 29-30).

Dino-lite magnified observation

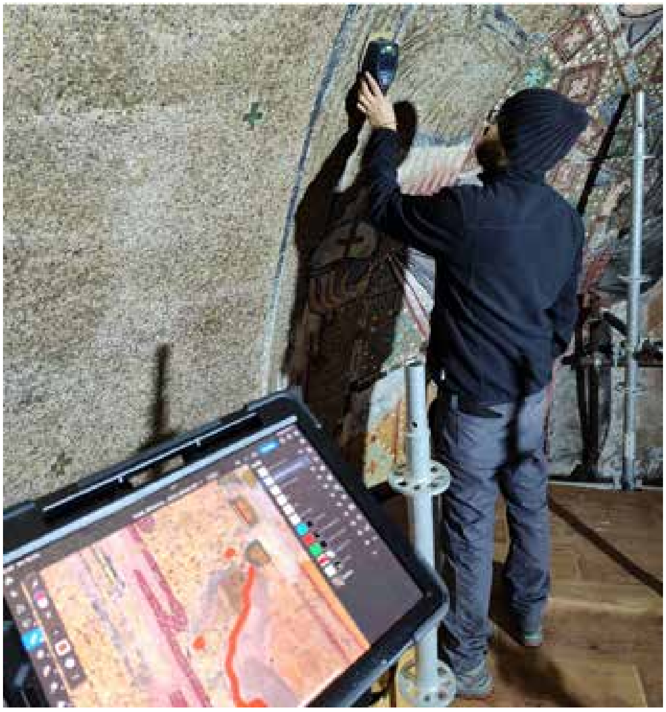
This simple but efficient technology was applied to investigate technical details of the mosaic.
Thanks to the magnification (Mag) ranges from 10x – 200x and to the possibility of shooting high resolution pictures, this observation techniques turns to be very useful. For instances, we detected the origin of the terracotta tesserae by identifying the presence of invetriatura in the section of the tesserae telling us the origin of them: glazed ceramic for domestic with parallels exposed in the Museum of Kutaisi. (Photos 31-32).

Geo-Radar Investigation

From November 17 to 20, 2024, a Geo-Radar survey was conducted. The purpose was to identify any metallic structures or supports of the 12th-century mosaic of the Virgin, not visible on the surfaces. (Photo 33)
The scan was performed using a Bosch D-tect 200 radar, which allowed the identification of areas where the mosaic was anchored to the underlying wall by metallic elements. The instrument detects metallic objects, wooden elements, lines, and electrical cables. The measuring tool examines the substrate beneath the sensor field (approximately 20 cm) by detecting objects that differ from the surface material.
The instrument is moved by exerting slight pressure on the substrate without lifting or changing the pressure exerted. When an object is detected, the light signal turns red; if the signal strength is adequate, the measurement display pulses, and an acoustic signal is emitted.
If no object is detected, the display indicates to proceed, and the light signal turns yellow.

31-32. Dino-lite magnified observation

33. The geo-radar survey carried out to identify internal metal elements

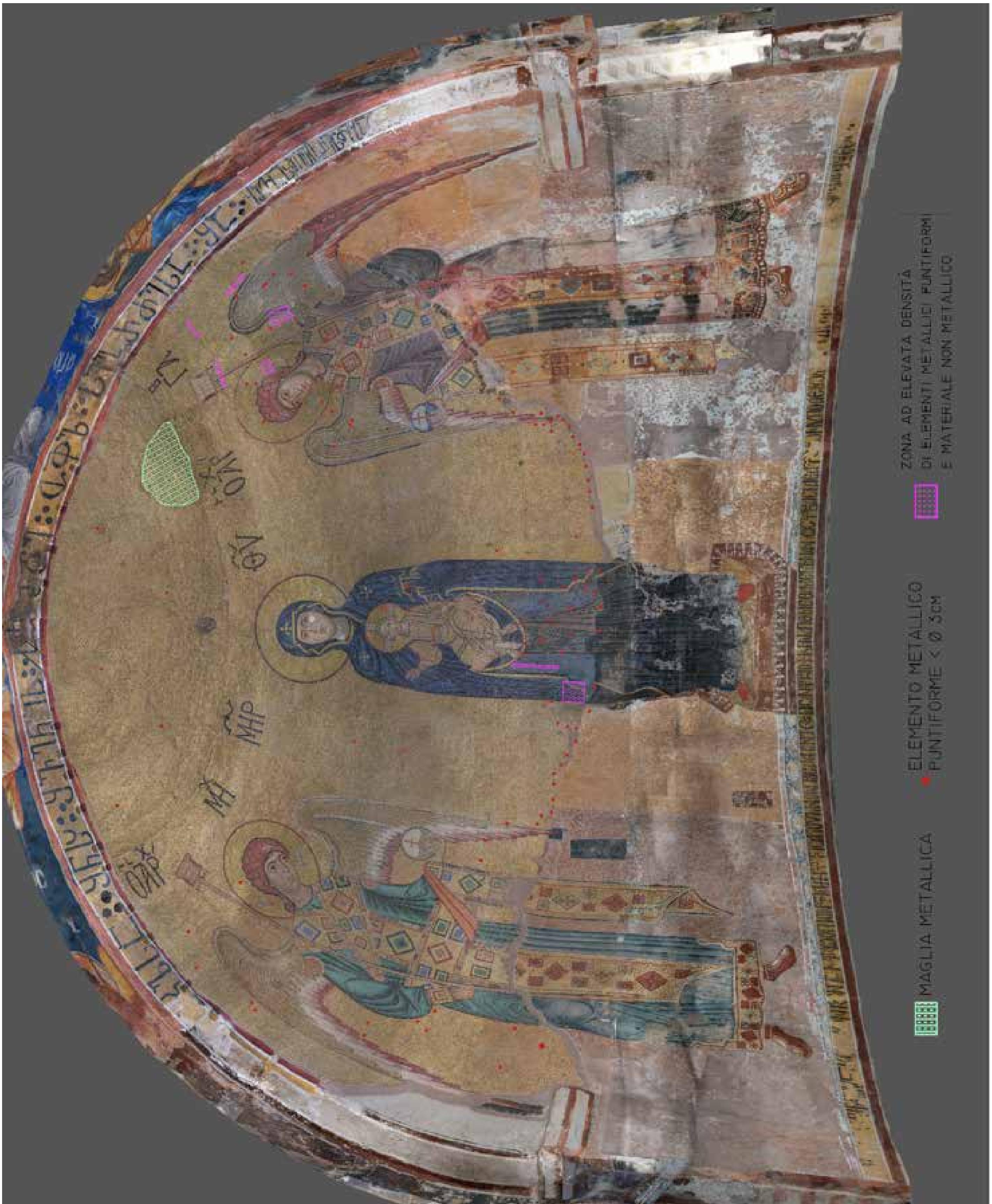


34-35. The geo-radar investigation caried out in a "targeted" way, instead of an extensive way.

If, while moving the instrument without lifting it from the surface, the indication to proceed turns off, the light signal turns green, indicating the complete absence of objects. If the measuring tool approaches an object, the pulsation in the measurement display increases, the light signal turns red, and an acoustic signal is emitted. Moving away from the object decreases the pulsation in the measurement display. In the case of small or deeply located objects, the light signal may turn yellow, but no acoustic signal is emitted. Larger detected objects are signaled by a high and continuous pulsation of the measurement display, and the light signal remains fixed in red. Each signal corresponds to a graph, which, when interpreted, allows the determination of the type of analyzed element.
(Photo 34)

Based on these principles, the entire surface of the mosaic was scanned, starting from the highest points with the aid of a mobile scaffold, down to the lowest part, where the mosaic ends and is replaced by a frescoed restoration. Concurrently with the scanning, using tablets, all identified anomalies were marked and mapped on the available photogrammetric bases, differentiating between point and areal anomalies. This was done using coded markers materialized on the surface.
The analysis was frequently interrupted due to the fact that during the scanning process, we realized that the *cartelline* were to unstable. It was therefore agreed to proceed with a targeted analysis rather than using the instrument in continuous mode.
(Photo 35)

During the scanning and subsequent data interpretation, three main categories were identified beneath the mosaic surface:
1. Point-like metallic elements, presumably nails with heads smaller than 3 cm in diameter.
2. Areas with the presence of many closely spaced metallic elements. Unfortunately, these areas are accompanied by significant background noise. Point-like analysis does not aid in characterizing these areas.
3. Areas characterized by grids or filiform metallic elements. These areas exhibit typical traits of grids or structures formed by filiform elements in a "pattern."
A graphic legend is attached, reported on the 3D photogrammetric mapping.
(Photo 36)
This investigation is a preliminary analysis conducted with a basic instrument. The investigation is only partially completed because it is necessary to first consolidate the *cartelline* of the golden and silver tesserae, too fragile to support the contact with the instrument. The investigation will be completed using a higher-frequency instrument after the surface of the mosaic will be secured and the cartelline consolidated during the preventive protection phase .



36 The map of metal internal elements identified by the geo-radar

Diagnostic analysis

A robust support of scientific analysis was necessary to provide answers to some questions related to the nature of materials and on their state of conservation. Mortars, tesserae, pigments and salts were analyzed and observed instrumentally.

The tesserae samples were observed and photographed under an optical microscope stereoscopic (MO).

The chemical compositions of tesserae have been determined by x-ray microanalysis using an x-ray micro fluorescence spectrometer EDXRF energy dispersive. Four tesserae were subjected to morphological characterization investigations and compositional by scanning electron microscopy (SEM) and X-ray microanalysis in energy dispersion (EDS microanalysis).

A microscope was used for the analyses field emission electron microscope (FEG-SEM ApreoS LoVac ThermoFisher) equipped with an energy dispersive x-ray microanalysis system (Quantax 200 System, EDS Detector). Pigments were investigated with micro-FTIR SEM/EDS. Calcareous tesserae were investgated with Mineralogical-petrographic analysis and Diffractometric analysis. (Photo 37-38)

37. The map locating the areas of tests

38. A general view of the apse before 1984

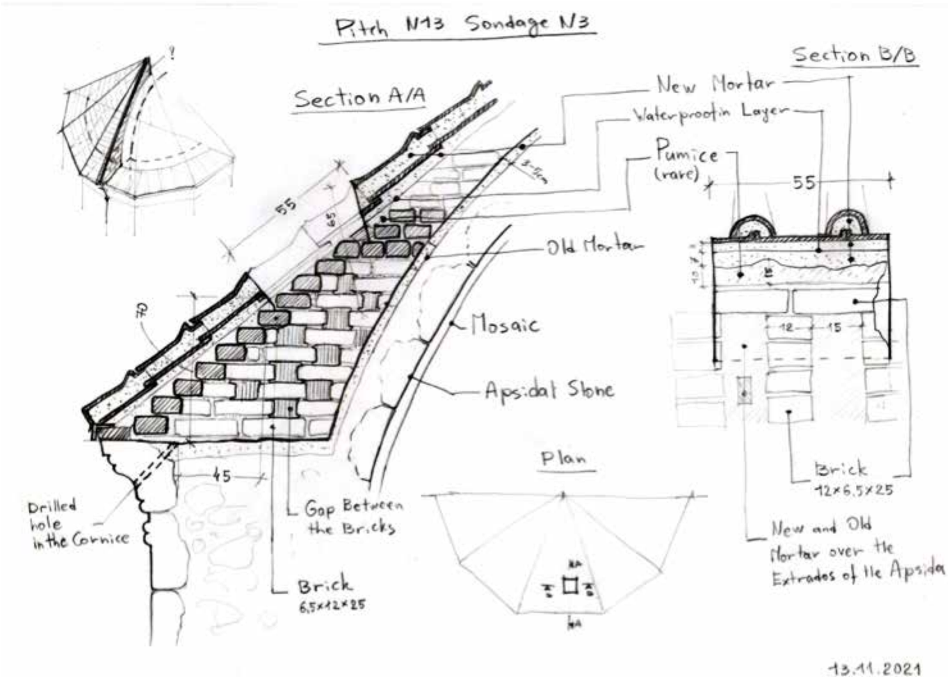
Original Materials and Execution Technique

The mosaic of the Virgin was created in the upper part of the circular apse of the church. The base of the area, which was once entirely decorated with mosaic, starts at a height of 11 meters from the church floor and reaches its highest point at 18.17 meters. Starting from the base with the inscription, the decorated field rises vertically for about 290 cm. and enters the apse's dome, which has a radius of approximately 420 cm.

This results in a total field, originally entirely decorated with mosaic, measuring 710 cm in height with a radius of 420 cm, corresponding to a total of 94 square meters. (Photo 1)

Of the original mosaic layout, only the upper part of the dome remains today, from a height of 13.77 meters from the church floor to the top at 18.17 meters, equivalent to 46.5 m^2 (with a tolerance of 0.3 m^2). The part restored in fresco during now-historicized interventions covers 47.40 m^2 (with a tolerance of 0.3 m^2).

1. The lower part of the mosaic, damaged during the fires was restored with a painted reconstruction.



2. A sketch representing a section of the vault.

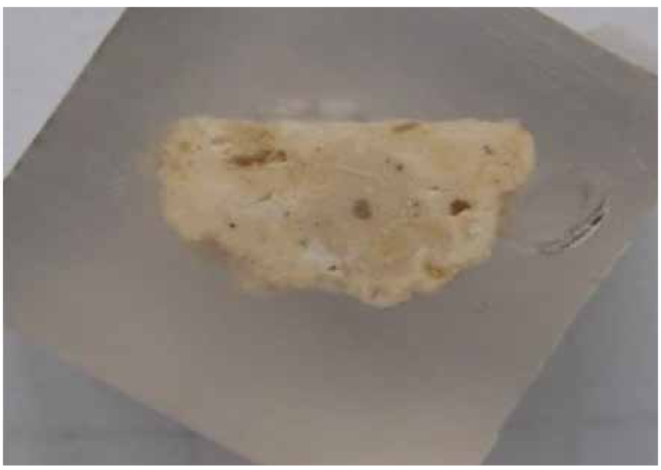
The mosaic is set within a vault structure made of dolomitic stone blocks, as deduced from the study by Tariel Kiparoidze and Lasha Shartava (2022)[1]. (Photo 2)

3. A detail showing two preparation layers plus the line of the tesserae

Preparation Layers

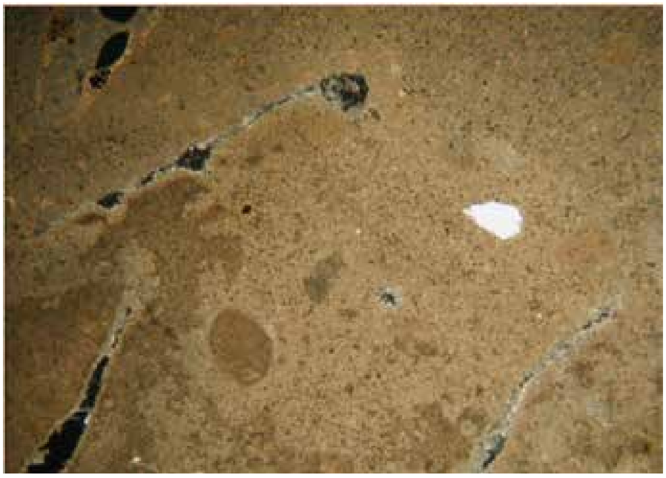
Given the relatively regular finish of the sandstone block structure, the mosaic was applied on a rather thin preparation base, with a total thickness of 20 mm. According to analyses conducted as part of the present project on a residue of mortar present on one of the removed tesserae, and thus very limited in quantity, the mosaic's base mortar appears to be composed of two layers, each approximately 10 mm thick. Both layers are characterized by the predominant presence of aerial lime binder with very little aggregate, predominantly siliceous[2]. (See Appendix Ridolfi). (Photos 3-4)

According to Karlo Bukuradze's report on the restoration intervention, the mosaic was applied in three layers: "The first layer spread on the stone wall is thicker and composed of lime and straw. The thickness of this layer is 8-10 mm; the second layer, according to chemical analysis, is 8-10 mm thick and is pure lime; the third layer represents a thin layer of lime applied over the second layer, 2-3 mm thick (in scientific literature, the second and third layers are considered as one layer.[3]
Given Karlo Bakuradze's extensive experience and the opportunity he had to make deep and extensive observations on the mosaic and its preparation layers during the restoration intervention, we are more inclined to believe his interpretation rather than our own.



4. Photo of the embedded section.

1. T. Kiparoidze, L. Shartava, "Technical report with photo and graphic documentation regarding the new sondages", Tiblisi 2022
2. S. Ridolfi, "Petrographic thin-section and XRF investigations Second report," Rome, 2025, pp. 3-6
3. L. Khuskivadze, "The mosaic of Gelati", Tbilisi, 2005



5 Lime lumps and very rare aggregates with porosity

6. Photo of the embedded section.

This information seems to be confirmed by two images that we have received by the endoscope during the investigation of the inner part of the detached mortar.
In the images we see inclusions that recall the presence of straw. (Photos 5-9)
Naturally, a definitive answer will be provided during a possible future intervention when it will be possible to access the mosaic's preparation layers.

Karlo Bakuradze's description of the preparation layers concludes with the words: "A thin layer of lime is colored with ochre, brick red, and white. These colors, which we sometimes see among the tesserae, create the overall color palette of the mosaic." This is the colored base layer, executed with red and yellow ochre and gray color, which we can still see shining through the gaps between the tesserae. As we have observed in the mosaic of the Transfiguration in the Church of the Monastery of Saint Catherine in Sinai[4], the practice of preparing the tesserae bedding layer with a monochromatic base applied fresh to guide the mosaicist and enhance the final chromatic effect of the mosaic is not new.
In the case of Gelati we have three tonalities of colored base layer: red, yellow and grey. In order to understand the nature of these pigments, three samples were analyzed with optical microscopy, XRF and SEM/EDS.
(See Appendix)

7. Lime lumps and very rare aggregates with porosity in photo. MPOM photomicrograph in transmitted light, thin section, 80 x N+.

8-9. Details of straw elements embedded into the mortar

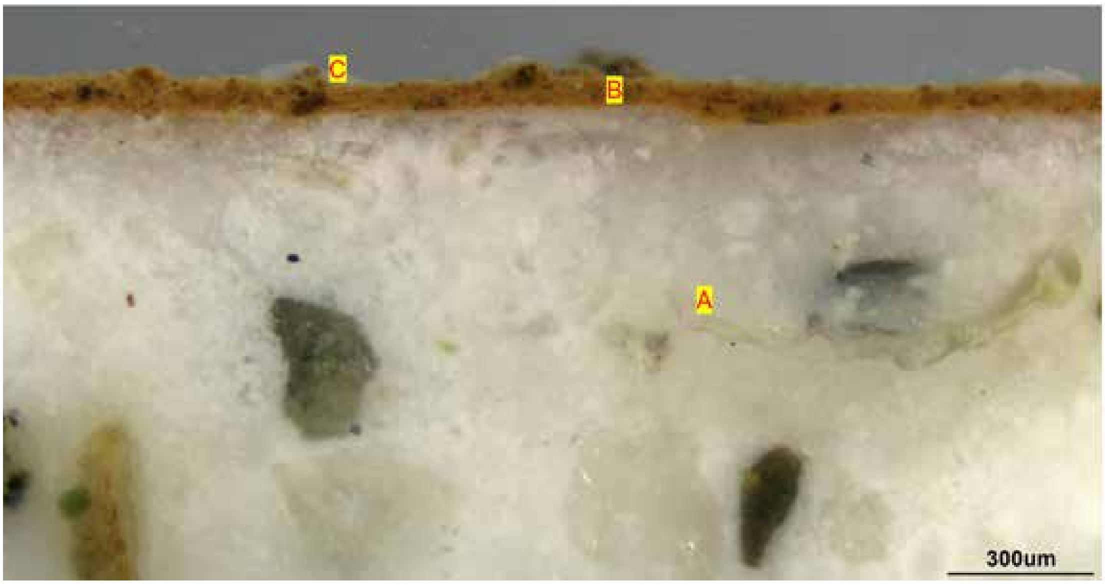
4. Roberto Nardi, Internal technical report, Monastery of Saint Catherine, 2015

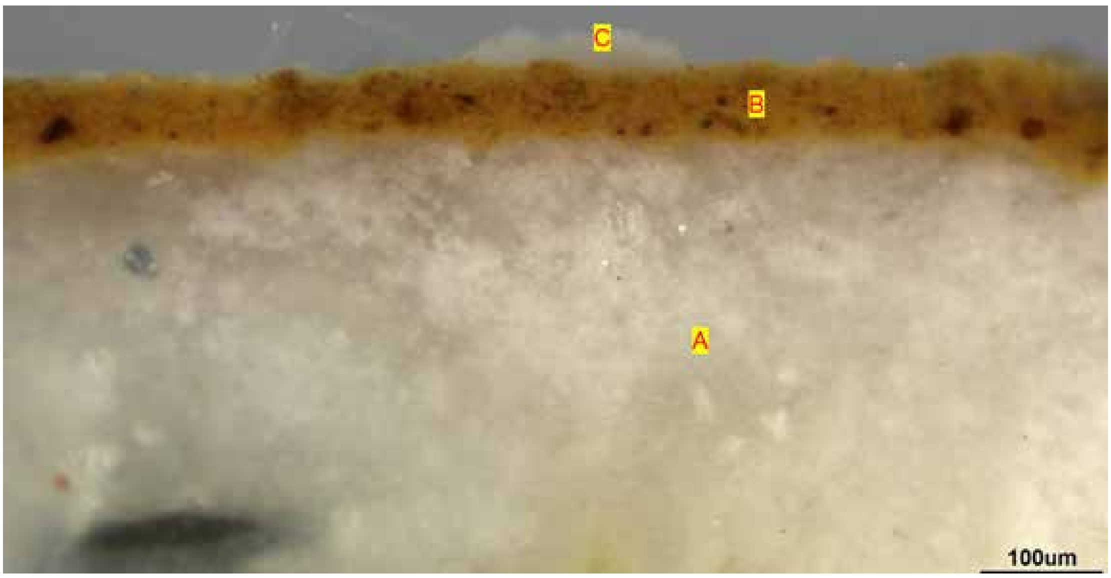
In sample 1, a brown pictorial finish based on ochres and iron oxides of a blackish-brown colour was applied dry (with a carbonation line) over the plaster.

Sample 1, Photo 11-13

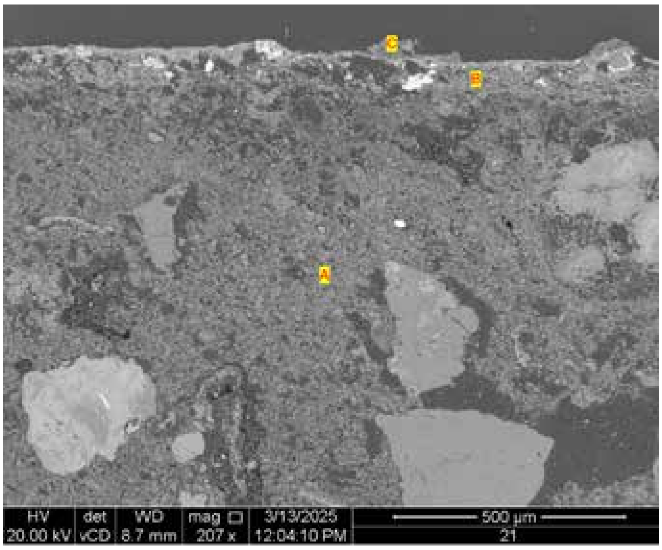
Stratum	Layer nature for correlation between optical microscopy and ESEM-EDS analysis
A	White plaster with scattered aggregates of various shapes and colors.
B	Brown painted finish with a thickness of 45-55 μm characterised by the presence of calcium carbonate and pigmented with ochres (yellow, red and a few brown ochres with manganese) and iron oxides, also of a dark colour.
C	White residues of calcium and magnesium carbonate. Thickness 0-30 μm.

11. A photo of the sample as is at the optical microscope.





12-13. MPOM photomicrograph in reflected light, transverse polished section

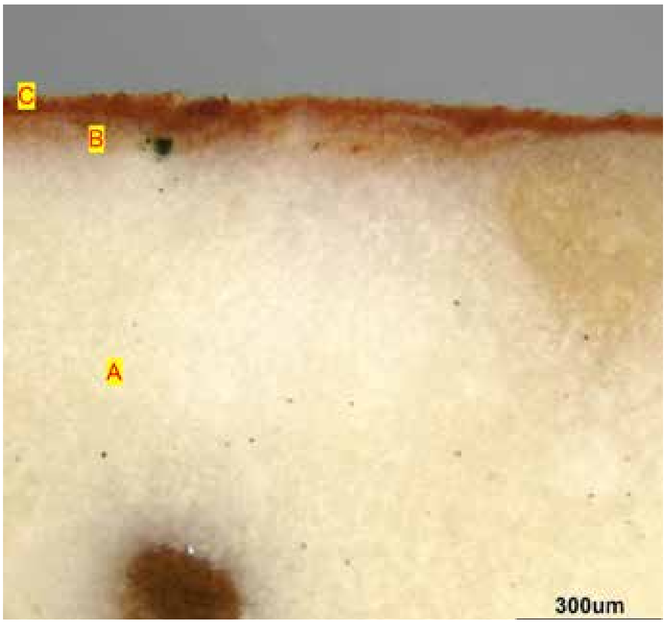


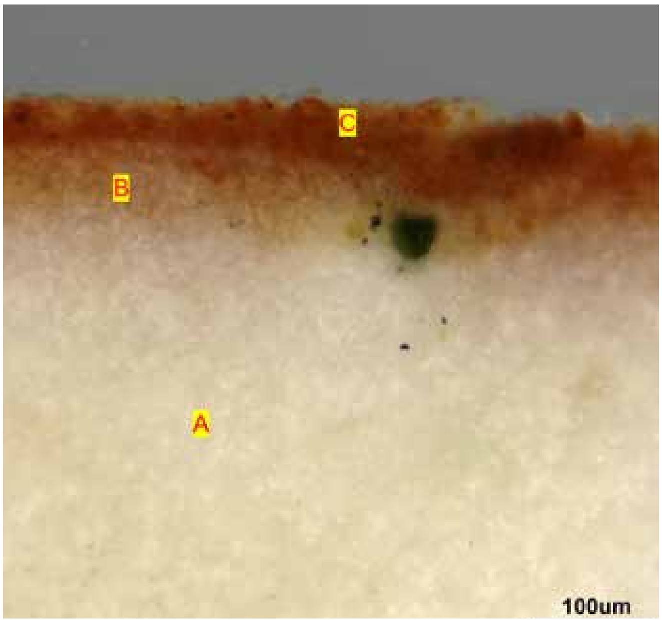
14. *ESEM image with backscattered electrons in Low Vacuum (LV) mode*

In sample 2, a fresh application can be observed over the plaster (absence of a carbonation line) with a few dispersed ochre particles and a sporadic particle of green earth. The surface pictorial finish was pigmented with red ochres with a high iron oxide content.

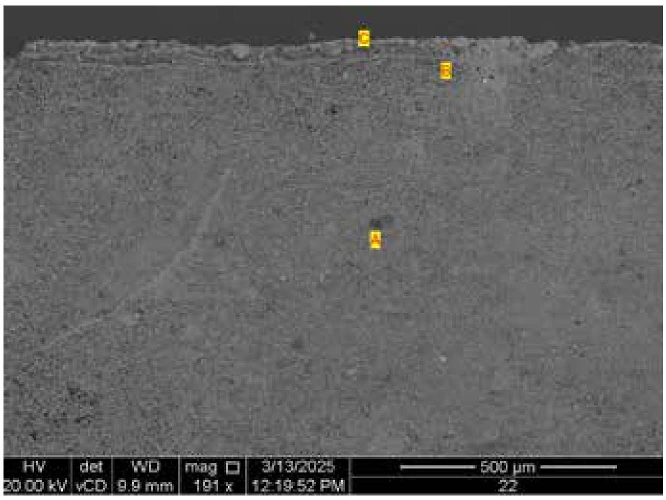
Sample 2, Photo 14-18

Stratum	Layer nature for correlation between optical microscopy and ESEM-EDS analysis
A	White layer of calcium carbonate.
B	Slightly orange layer with scattered particles of ochre and a particle of green earth. The layer may have been applied freshly because no carbonation lines are visible. Thickness 25-35 µm.
C	Red pictorial finish based on calcium carbonate and red ochre with a high content of iron oxides. Thickness 15-25 µm.





15-16. *MPOM photomicrograph in reflected light, transverse polished section.*

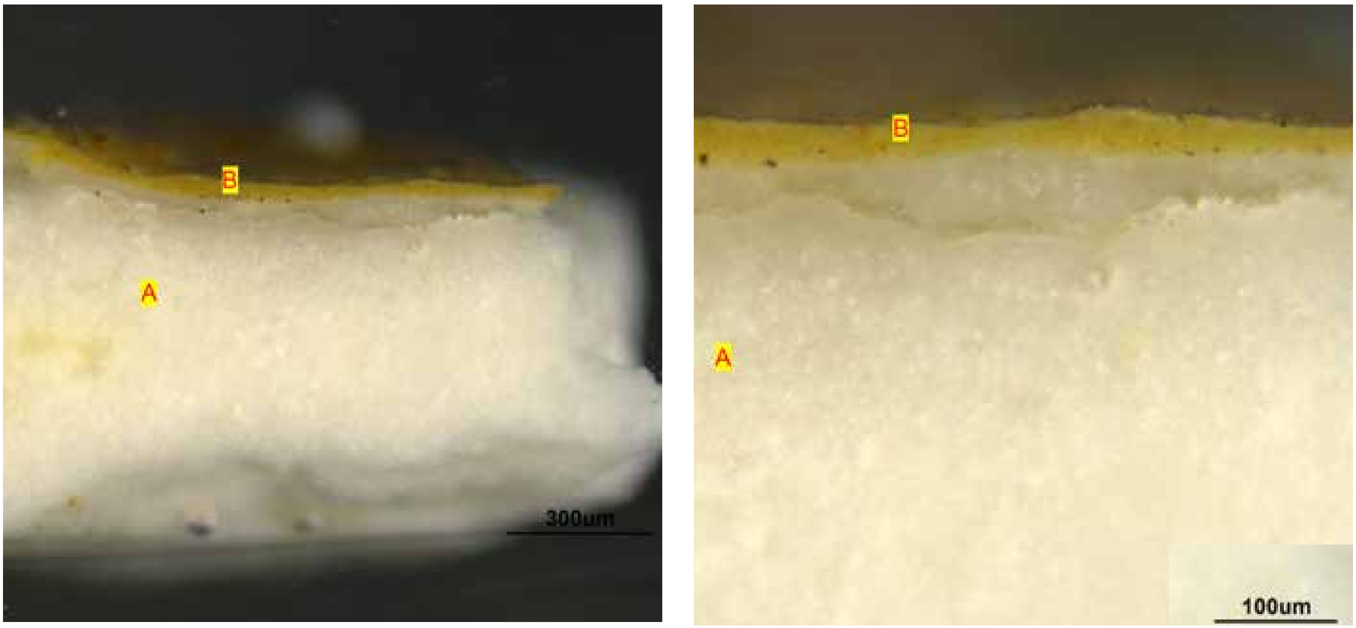


17. *(above) Photo of the sample as is at MPOM.*
18. *(right) ESEM image with backscattered electrons in Low Vacuum (LV) mode*

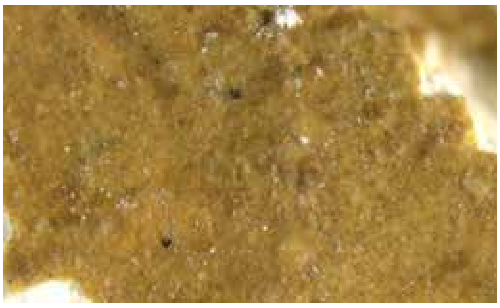
The yellow pictorial finish of sample 3 was created with yellow ochres with a high iron oxide content.
The scenario that we can interpretate from the analysis is that an original pigmentation in red, yellow and grey was applied when the intonaco was still fresh, at the same time of the application of the tesserae. After this, other color was applied when the intonaco was dry, which means, most probably, during the 1984-90 restoration program or even during older interventions.

Sample 3, Photo 19-22

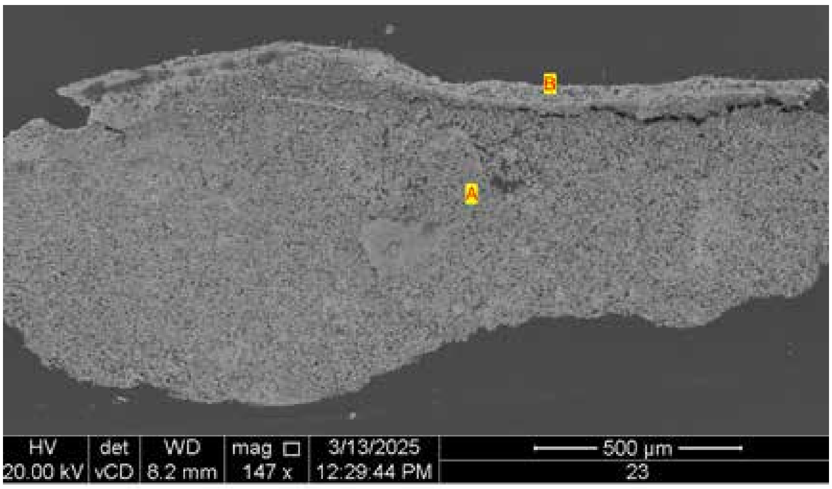
Stratum	Layer nature for correlation between optical microscopy and ESEM-EDS analysis
A	White layer of calcium carbonate.
B	Yellow pictorial finish based on calcium carbonate and yellow ochre with a hight iron oxide content. Thickness 20-30 μm.



19-20. MPOM photomicrograph in reflected light, transverse polished section.



21. Photo of the sample as is at MPOM.



22. ESEM image with backscattered electrons in Low Vacuum (LV) mode.

A unique feature of this mosaic is the intentional presence of some points left free from the tesserae, where the red background color shines through, such as at the sides of the figures' eyes. This seems to be due to the artist's desire to enrich the final composition of the mosaic by adding a pictorial effect to the bed of the tesserae's glass, confirming what Leila Khuskivadze suggested in her descriptive text of the mosaic.[5] (Photo 23, red arrows)

Tesserae

The tesserae were applied to the bedding layer while it was still fresh. The analysis of the surfaces with raking light and photogrammetry allowed us to identify a series of linear irregularities on the surface of the mosaic and overlaps of the background mortar: these are due to the so-called "giornate," or the perimeter lines relative to the areas into which the work was divided based on the setting time of the bedding layer's mortar.

These areas are called "giornate," which in Italian means "day," perhaps using an improper and misleading term: their actual size was dictated by the setting time of the bedding layer's mortar, which could vary depending on the climate and season in which the work was carried out. For example, with a hot and dry climate (not ideal for creating a mosaic), the mortar's setting time was much faster than in a cold and humid climate. The fact that Karlo Bakuradze found straw in the mortar composition could be linked to the need to retain water in the mixture and slow down the mortar's setting time, thus giving the mosaicist more time to complete their work.[6]

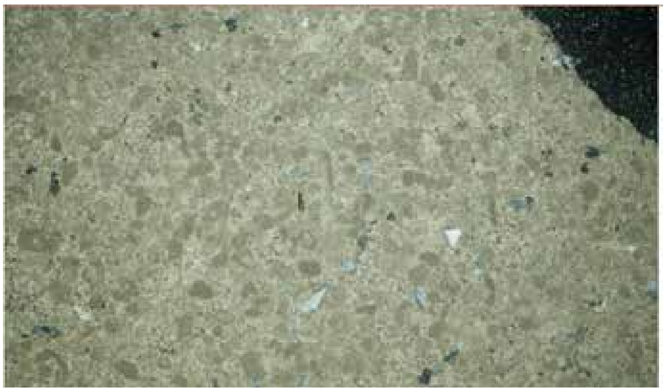
Thus, the table of "giornate" provides us with a series of interesting information about the technique and progression of the work, but it does not tell us the number of working days. The cleaning will allow us to read the distribution of the "giornate" with greater accuracy. (Photo 24)

23. As example, we can see the area of the face of Christ with edges of the "pizza" (green arrow); tesserae with round shape (white arrow); areas intentionally left without tesserae and painted with red ocher (red arrow)

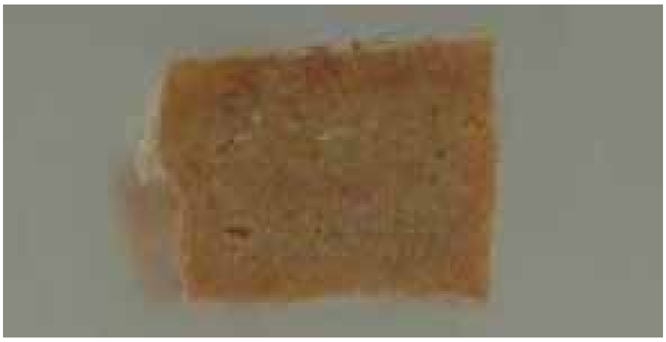
24. (next page) Plate with the giornate

5. *Ibidem*
6. K. Bakuradze, L. Khuskivadze, "Restoration of the Gelati mosaic", Tiblisi 1990

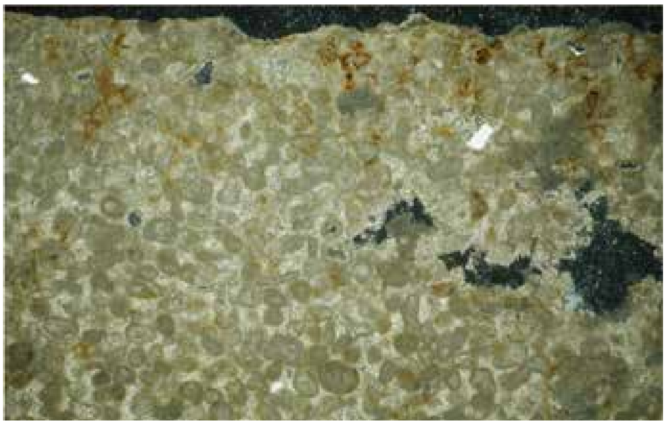
25 Photo of the embedded section.



26. MPOM photomicrograph in transmitted light, thin section, 40 x N+



27. Photo of the embedded section.



28. MPOM photomicrograph in transmitted light, thin section, 40 x N+

The tesserae belong to two main families: stone and glass. The former were used for the flesh tones, while the latter were used for everything else, including the backgrounds. A third group, limited to a single red-orange color, consists of tesserae made from terracotta fragments used to render the inner lining of the archangels' stoles.

The tesserae sizes vary depending on their type:
1. Metal leaf tesserae (background and interior and wings of the angels), average size 8x8 mm;
2. Colored tesserae (drapery of the figures), average size 10x10 mm;
3. Flesh tones (faces, feet, hands), average size 5x5 mm.

The development of these sizes tells us that:
1. For the metal leaf backgrounds, an average of 15,610 tesserae per m^2 were used;
2. For the drapery of the figures, an average of 10,000 tesserae per m^2 were used;
3. For the flesh tones, an average of 40,000 tesserae per m^2 were used.

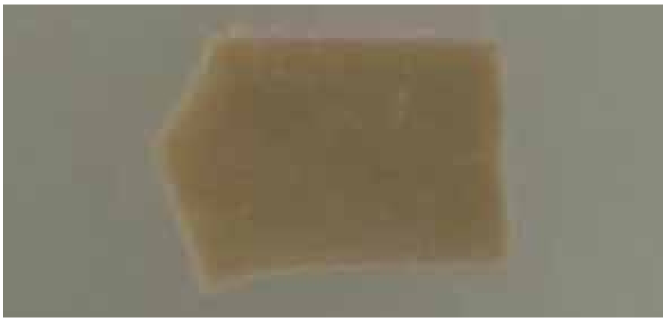
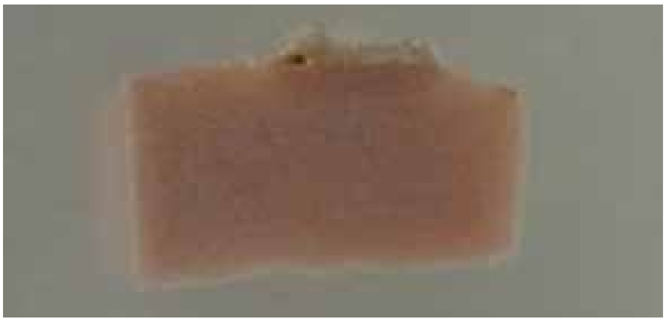
The total number of tesserae used is approximately 681,000 for the part existing today, divided into:
1. Gold and silver leaf tesserae: approximately 537,000;
2. Colored glass tesserae: approximately 108,000;
3. Limestone tesserae: 36,000.

Originally, following the current reconstruction in fresco, the total number of tesserae used was approximately 1,283,000 units, of which nearly 1,000,000 were gold and silver metal leaf tesserae, confirming the magnitude of the operation and the power of the commission.[7]

The stone tesserae, of which five colors have been identified, are divided into four marbles (A-D) with shades ranging from white to pink and a schistose stone (E) approaching black. These were analyzed by Prof. Stefano Ridolfi, University of Rome La Sapienza, Didactic Area of Sciences Applied to Cultural Heritage, (Appendix 1).[8] The first group (A-D) was essentially used for the flesh tones and is formed by sedimentary carbonate rocks, while the dark-colored tesserae (E), consisting of a silicate rock derived from regional metamorphism, were used within the figures to emphasize lines and profiles.

Of the four stone tesserae used for the flesh tones, two can be classified as oolitic limestones (tesserae A and tesserae B), both containing rare and fine quartz fragments and, in tesserae B, a fine dispersion of clay-ochre minerals that determine the stone's yellowish-pink hue. (Photos 25-28)

7. The tesserae count was performed manually on two 10x10 cm squares in the area of the drapery executed with colored tesserae, within which 100 tesserae were counted; on two 10x10 cm squares in two areas of the flesh tones realized with limestone tesserae, within which approximately 400 tesserae were counted; on two 10x10 cm squares in two background areas in which approximately 156 gold and silver tesserae were counted.
8. S. Ridolfi, "Petrographic thin-section and XRF investigations Second report," Rome, 2024

29-30. Photo of the embedded section.


31-32. MPOM photomicrograph in transmitted light, thin section, 40 x N+

The other two tesserae (C and D) are classifiable as micritic limestones, very fine, with some microfossils in tesserae C attributable to planktonic foraminifera, while no microfossils are observed in tesserae D. (Photos 29-32) Finally, the dark tesserae (E) is a metamorphic silicate rock that the composition would classify as a phyllite (or argillaceous schist). (Photos 33-34)

33. Photo of the embedded section.

34. MPOM photomicrograph in transmitted light, thin section, 40 x N+

Completing the list is a series of terracotta tesserae used to create the inner lining of the Archangels' stoles. (Photo 35-36)

The glass tesserae can be classified into the following types:
- Metal leaf tesserae, both gold and silver;
- Semi-opaque colored tesserae in blue, green, brown-purple (glass pastes);
- Opaque red and translucent black tesserae.

Given the particular nature of the glass tesserae and their special interest in the predominant role this category of materials plays in the mosaic composition of the Virgin at Gelati, it was decided to proceed with a laboratory study using non-destructive techniques to investigate their nature and state of conservation.

35. Terracotta tesserae

36. A detail with dinolite photograph of a terracotta tessera

This study was conducted by Prof. Marco Verità, Università IUAV of Venice, Laboratory of Analisys of Ancient Materials LAMA, (Appendix 2)[9] based on analytical data provided by the Venetian Glass Experimental Station (Appendix 3)[10], where the original samples taken from the mosaic were sent with authorization No. N22/1531 issued by the LLEP National Agency for Cultural Heritage Preservation of Georgia.[11]

The investigations were carried out following this procedure:
1. Observation of macro photos of the mosaic to identify glass tesserae of different types and states of conservation;
2. Identification of representative examples of the various types to be subjected to laboratory instrumental analysis;
3. Identification of the most appropriate laboratory to perform the analyses of the tesserae with non-destructive techniques to relocate the tesserae in situ in the mosaic at the end of the investigations;
4. Assistance to laboratory personnel to determine the chemical composition of the glass materials most accurately, identify the most significant component elements, and ascertain the forms of degradation;
5. Elaboration and interpretation of the results and drafting of the report.

The selection of tesserae to be sampled followed these criteria:
- Collection of the minimum number necessary to answer questions about the different types of glass materials and their state of conservation, avoiding sampling in particularly important parts of the mosaic;
- Sampling of at least one glass paste per color, except for opaque red and translucent black because the sampling, in the current state of processing, would have been potentially damaging to the original material;
- Sampling of blue glass pastes in various areas of the mosaic; these tesserae were chosen for a series of reasons explained later;
- Sampling of gold leaf tesserae of different color shades in various areas of the mosaic;
- Sampling of silver leaf tesserae with different degrees of deterioration.

All tesserae were observed and photographed under a stereoscopic optical microscope (MO). The chemical compositions of thirteen tesserae were determined using micro-X-ray analysis with a Bruker M4 TORNADO energy-dispersive micro-X-ray fluorescence spectrometer (µEDXRF) with a rhodium (Rh) tube with polycapillary optics (spot size ~ 25 µm) and a silicon energy-dispersive detector (SDD) with an active area of 30 mm^2. From three to five measurements were performed on a polished surface of each sample under the following analytical conditions: voltage 50 kV, current 200 µA, real time of the single measurement 600 s. The spectrometer was calibrated with certified standard glasses.

Four tesserae were subjected to morphological and compositional characterization investigations using scanning electron microscopy (SEM) and energy-dispersive X-ray microanalysis (EDS). For the analyses, a field emission scanning electron microscope (FEG-SEM ApreoS LoVac ThermoFisher) equipped with an energy-dispersive X-ray microanalysis system (Quantax 200 System, EDS Detector XFlash 6|60 Bruker) with an SDD detector with an active area of 60 mm^2 was used. To allow analysis under high vacuum conditions, it was necessary to make the sample surfaces conductive by depositing a carbon layer a few tens of nanometers thick under vacuum.

Below are some photos of the tesserae photographed under the MO as they are and polished and the chemical compositions determined by µEDXRF. Subsequently, the results of the SEM/EDS analyses are reported.

Appearance of the Tesserae

(Optical Microscope in Reflected/Transmitted Light)

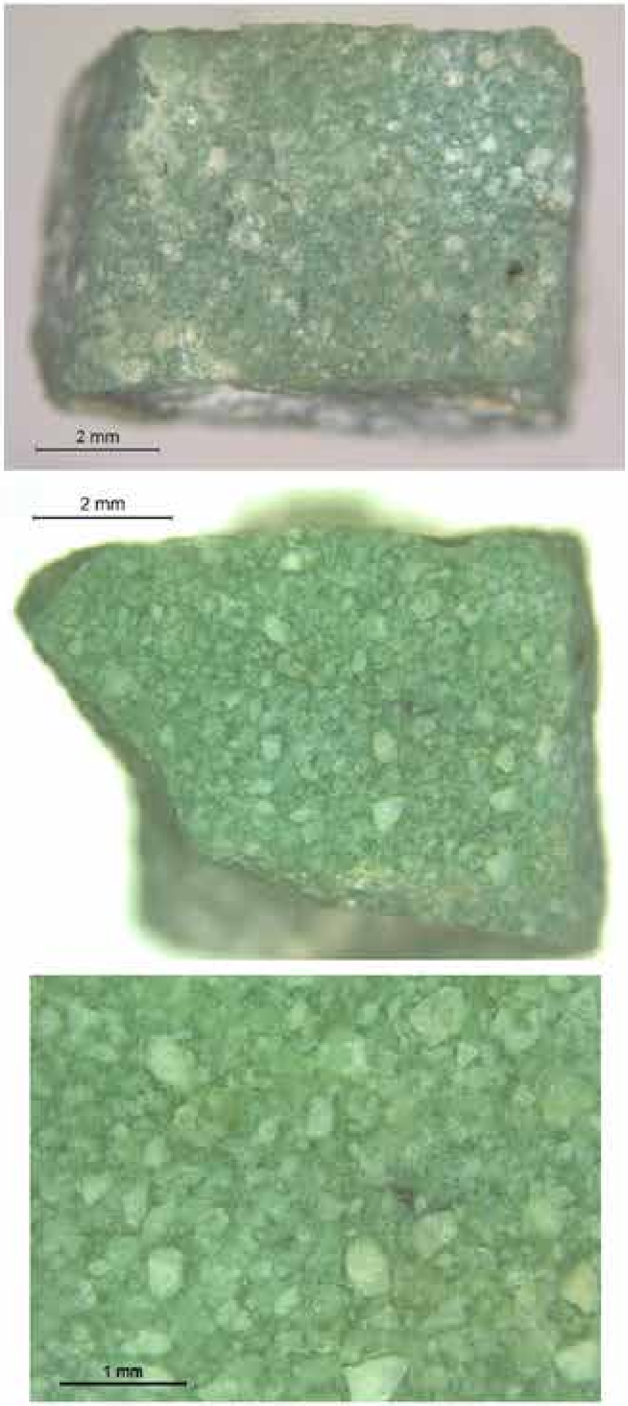
The glass pastes appear to be composed of a colored glassy phase and a translucent crystalline phase of variable grain size and numerous bubbles. The greatest quantity of crystalline phase is found in the lightest shades. The exposed surface of these tesserae is in a discreet state of conservation, with modest phenomena of whitening, iridescence, and flaking due to the formation of thin layers of altered glass, typical of the deterioration processes of glass mosaic tesserae.

9. M. Verità, Report of scientific investigations, Venice, 2024
10. R. Falcone, N. Favaro, M. Vallotto, Venetian Glass Experimental Station, REPORT NO. 000210569, Venice, 2024
11. The Authorisation Body for all the permissions is the "LLEP National Agency for Cultural Heritage Preservation of Georgia":
Permission for the taking of the samples of the tesserae from the mosaic compositions (permission for the intervention) with obligation to return the samples to their original places by December 13, 2024;
Permission for temporarily taking samples abroad from Georgia to Italy for laboratory investigations: N22/1531, issued on May 24, 2024, with the obligation to return them to Georgia no later than October 1, 2024;
Considering that the laboratory investigations in Italy took more time than planned, upon your updated application, the new permission was issued for the return of the samples to Georgia on October 2, 2024, N 22/2928—with a new date for returning the material to Georgia—no later than November 30, 2024.

Area 1 - Sample 1 Silver

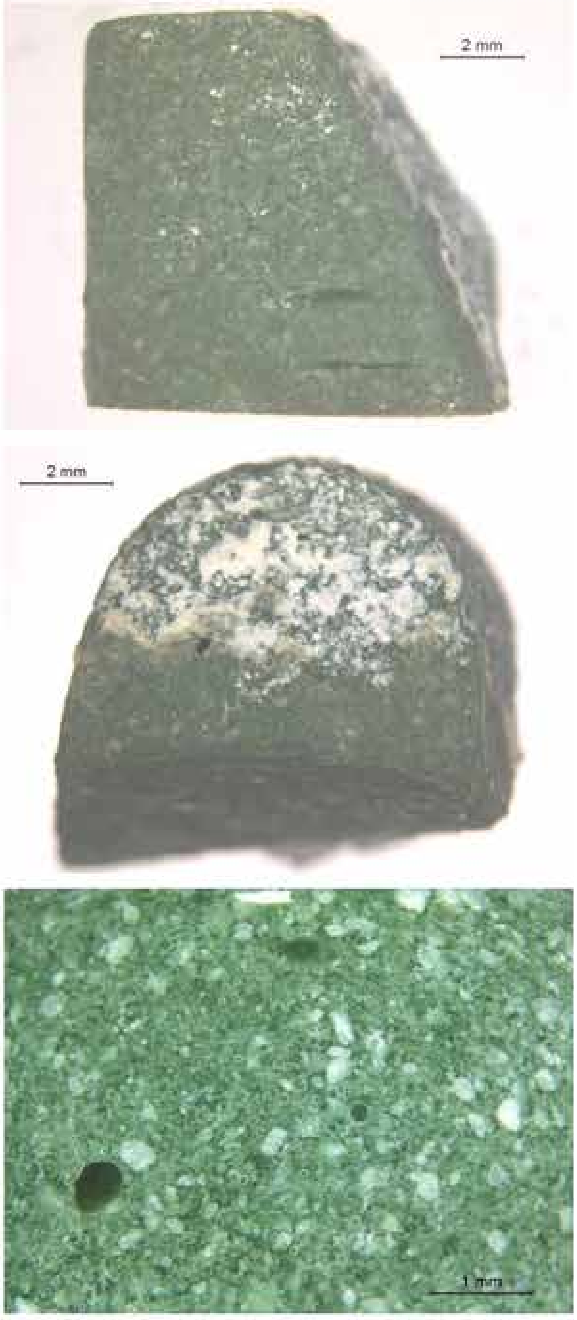
· *Optical microscope photo tessera AREA 1 sample1; from top to bottom: front, side and polished side*

Area 3 - Sample 3a - green glass paste



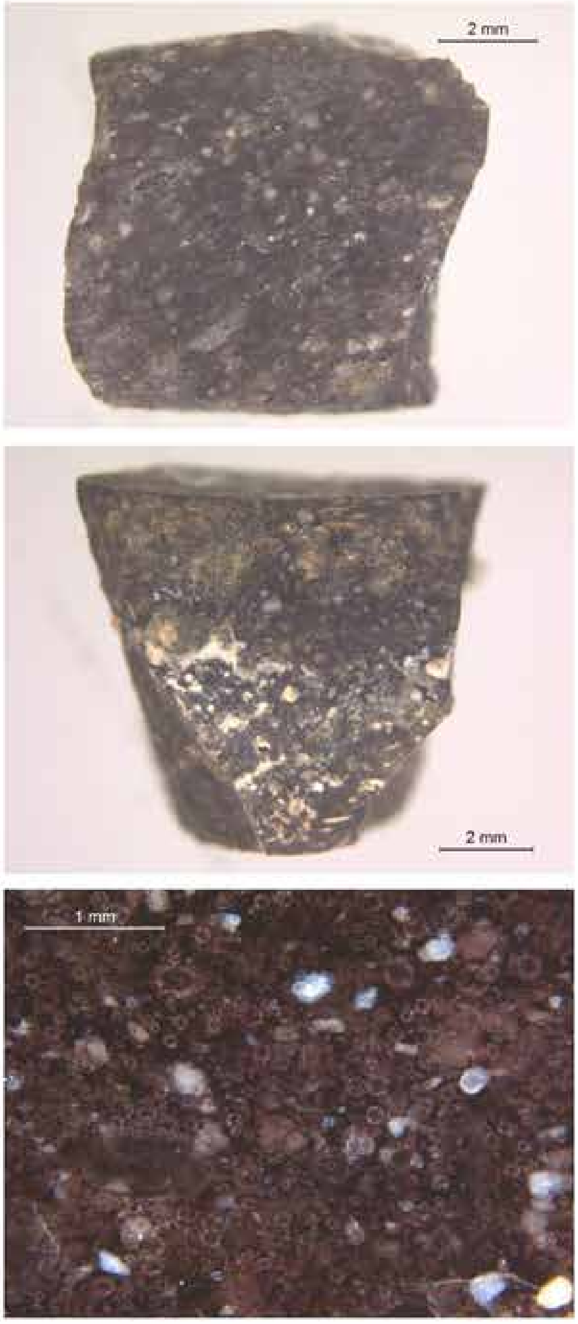
Optical microscope photo tessera AREA 3 sample 3a; from top to bottom: front and side polished at different magnifications

Area 3 - Sample 3c - green glass paste



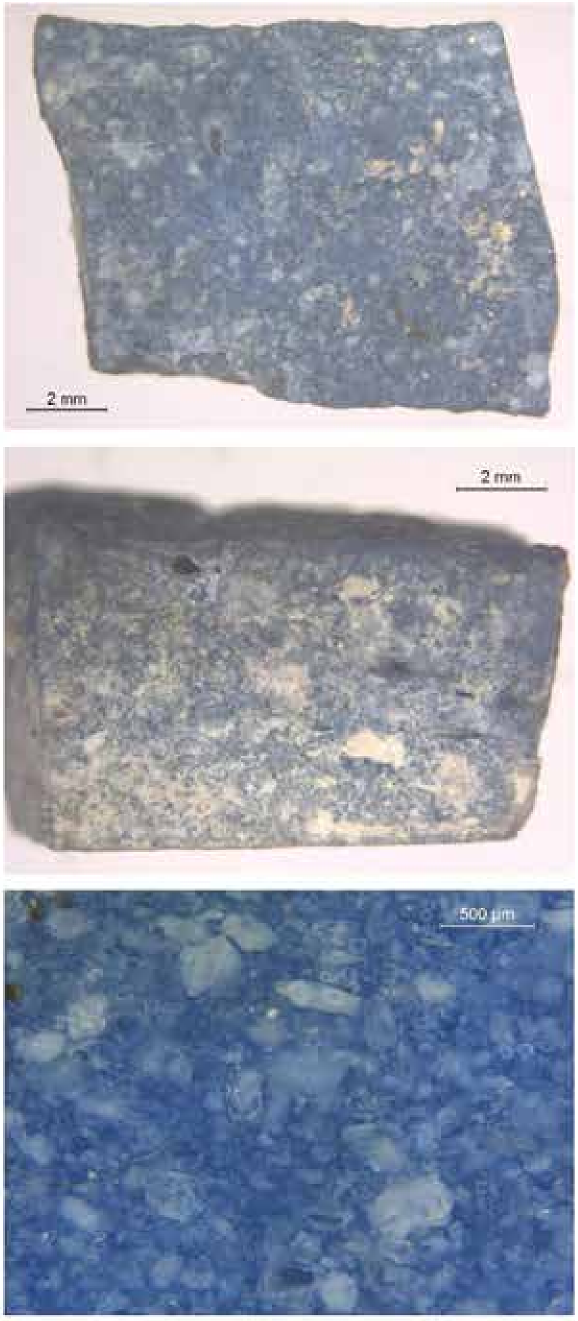
Optical microscope photo tessera
AREA 3 sample 3c; from top to bottom: front,
side and polished lateral at different magnifications

Area 4 - Sample 4 - purple glass paste



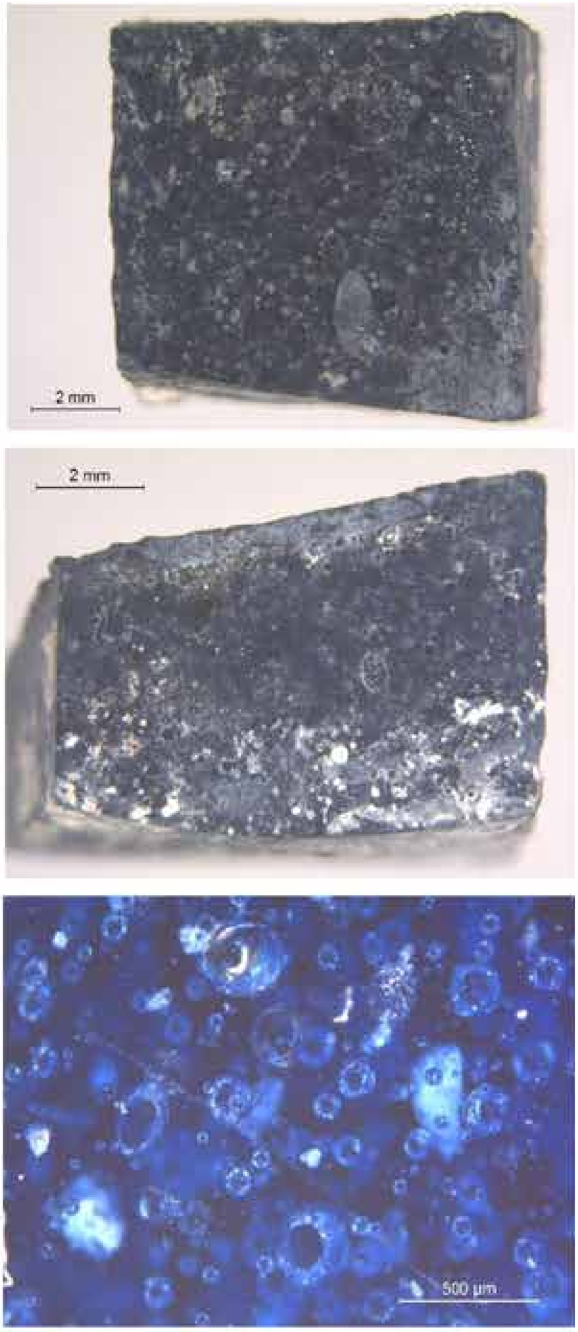
Optical microscope photo tessera
AREA 4 sample 4; from top to bottom: front,
side and polished lateral at different magnifications

Area 5 - Sample 5 - light blue glass paste



· *Optical microscope photo tessera AREA 5 sample 5; from top to bottom: front, side and lateral polished at different magnifications*

Area 6 - Sample 6a - blue glass paste

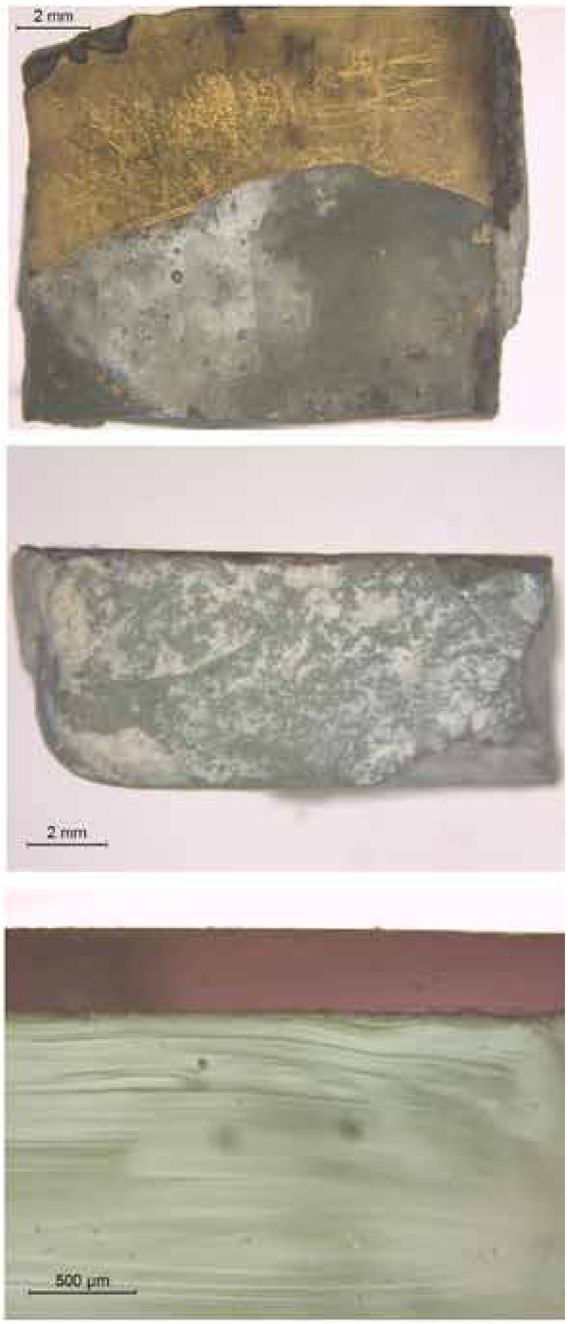


Optical microscope photo tessera AREA 6 sample 6a; from top to bottom: front, side and lateral polished at different magnifications

Area 7 - Sample 7a - Silver

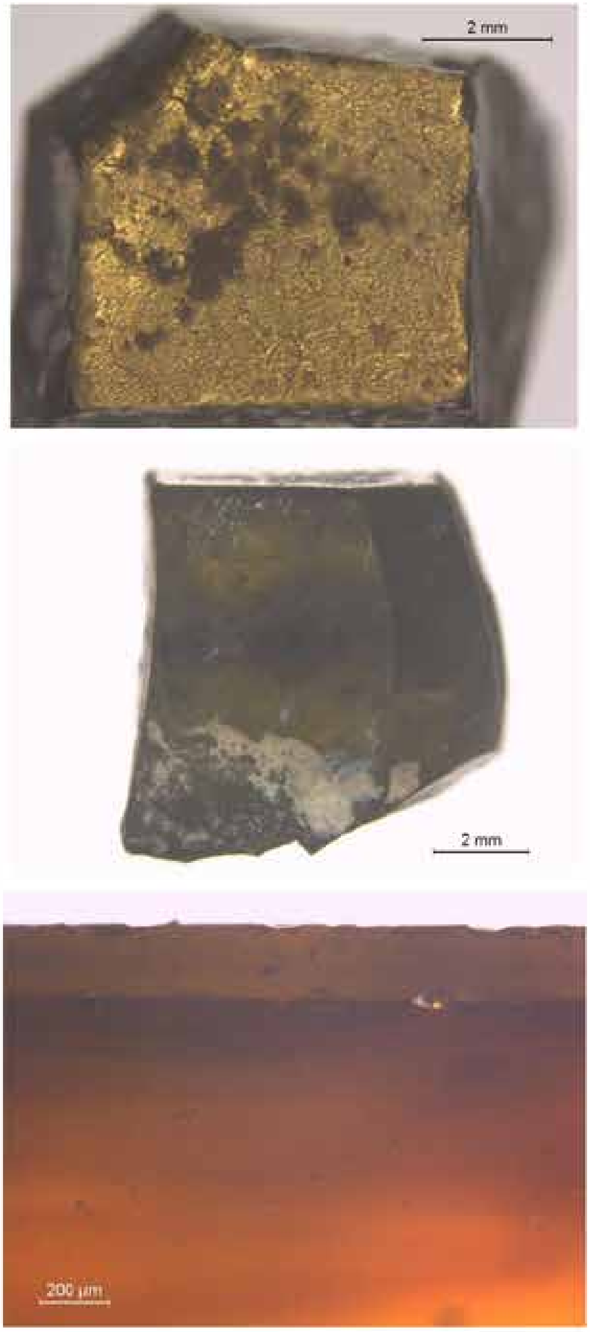
Optical microscope photo tessera AREA 7 sample 7a; from top to bottom: front, side and polished side

Area 8 - Sample 8a - restoration gold



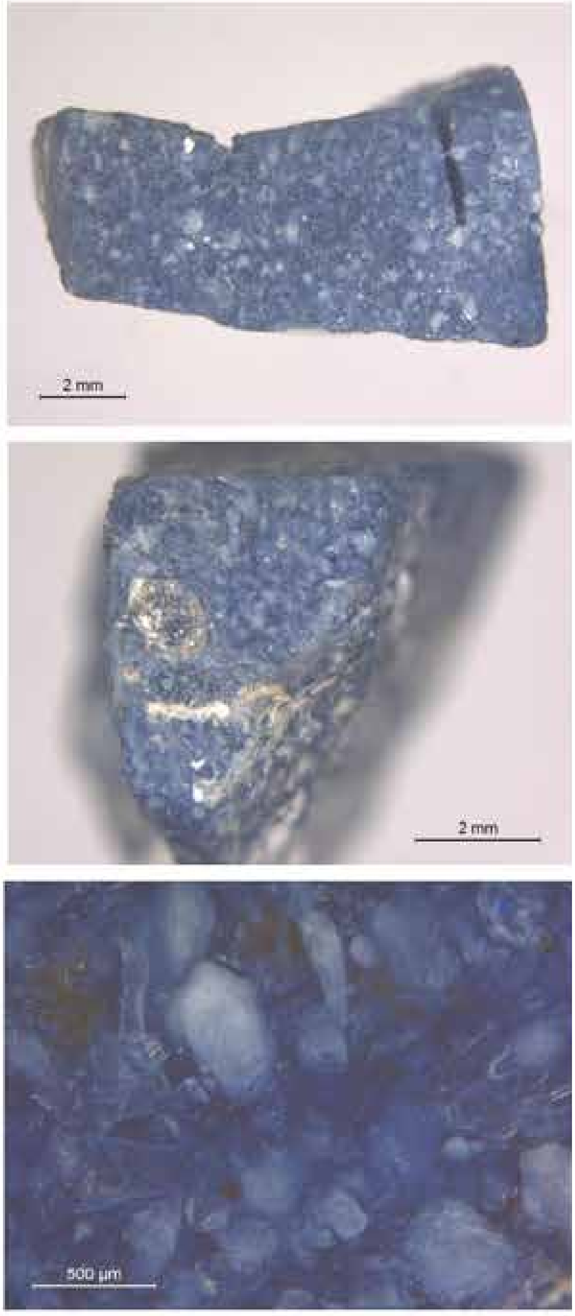
Optical microscope photo tessera AREA 8 sample 8a; from top to bottom: front, side and lateral polished at different magnifications

Area 8 - Sample d - gold with black support



Optical microscope photo tessera
AREA 8 sample 8d; from top to bottom: front, side and lateral polished at different magnifications

Area 10 - Sample 10 - blue glass paste



Optical microscope photo tessera
AREA 10 sample 10; from top to bottom: front, side and lateral polished at different magnifications

Area 13 - Sample 13a - gold

*Optical microscope photo tessera
AREA 13 sample 13a; from top to bottom: front,
side and polished lateral at different magnifications*

Area 13 - Sample 13 - gold

*Optical microscope photo tessera
AREA 13 sample 13b; from top to bottom: front,
side and polished lateral at different magnifications*

Area 13 - Sample 13c - gold

Optical microscope photo of AREA 13 sample 13c card; from top to bottom: front and side at different magnifications

Area 14 - Sample 14 - gold

Optical microscope photo of AREA 14 sample 14; from top to bottom: front, side and polished side at different magnifications

Area 13 - Sample 13 - gold

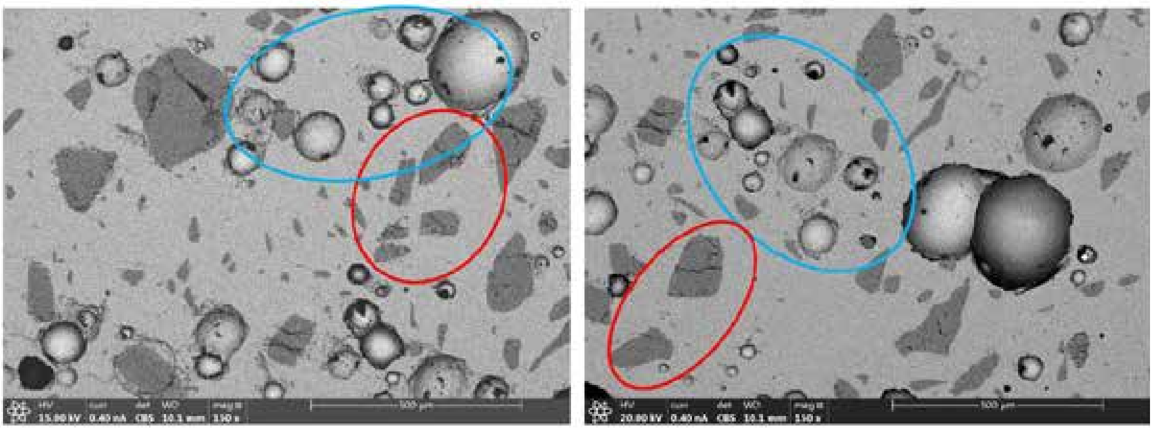
Optical microscope photo tessera AREA 13 sample 13d; from top to bottom: front, side and lateral polished at different magnifications

SEM/EDS Aanalysis

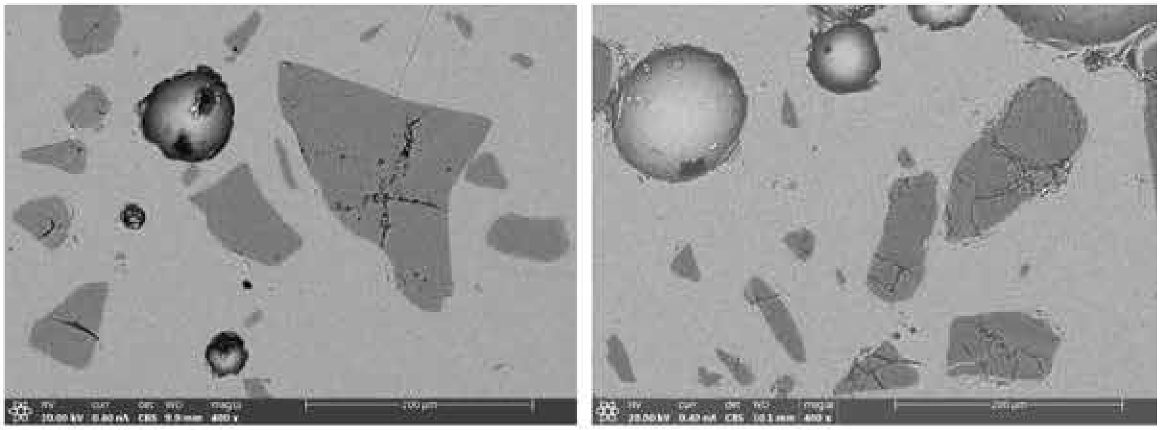
As agreed, the tesserae we subjected to SEM/EDS investigation were the following:

- 3c - Green/yellow glass paste
- 6a - Blue glass paste
- 13c - Gold Leaf
- 7b - Silver leaf, with part of the cartellina detached from the support
  SEM observations were performed both in secondary electron mode

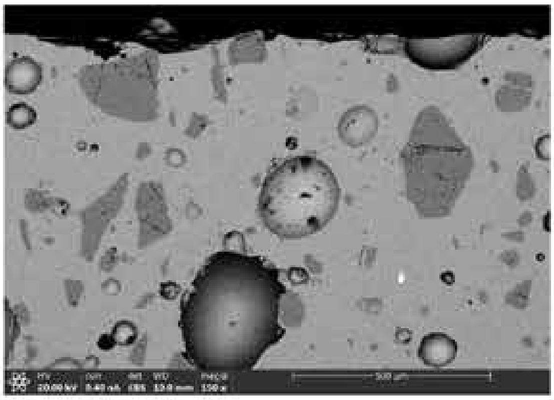
(ETD detector images) that enhance the topography of the sample surface, both in backscattered electron modes (CBS detector images) that enhance any contrasts compositional through different shades of gray. For tesserae 3c-6a-13c the following are reported only SEM images acquired in backscattered electrons; for tessera 7b the SEM images acquired in both secondary and backscattered electrons. EDS microanalyses were carried out using the following conditions of electron beam energy and current:
20 kV and 0.4 nA for all tiles (3c-6a-13c and 7b), 10 kV and 0.8 nA for some analyses performed on the altered surfaces of the silver leaf tessera 7b. The EDS microanalyses were conducted in areas ranging from a few hundred µm2 (generally in the case of point analyses of deposits and crystallisations or of thin layers) to a few hundred µm2 (generally in the case of medium analyses in potentially inhomogeneous glass), with scanning times of 100s each. In the analytical conditions used the minimum detectable amount was approximately 0.2% for most of the oxides analyzed. It is important to note that the EDS microanalysis technique in use is not able to detect light elements, particularly hydrogen (H).
In tesserae 3c-6a-13c the analyses were carried out in polished section in correspondence of a polished lateral surface (orthogonal to the exposed surface). The polishing was performed by using progressively finer grain silicon carbide abrasive paper
end from 1200 to 4000. In the tessera 7b, the analyses focused on the exposed surface due to the detachment of the folder, including the glass of the folder, the glass of the support, and a portion of the silver foil, also allowing for the assessment of potential surface alterations.
folder, the glass of the holder and a part of the silver metal sheet, other than allowing the evaluation of any states of superficial alteration of the same.



38



_39. Tesserae 3c- *More detailed SEM images of quartz bubbles and inclusions*

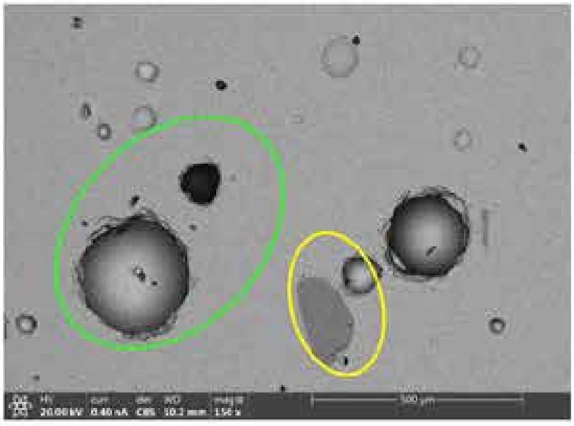


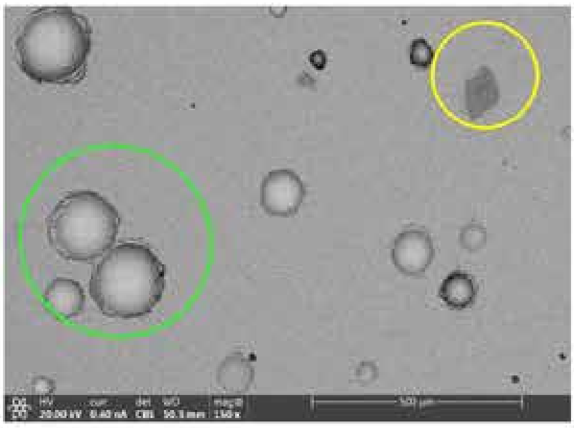
SEM image of the polished section of the tile at the e part in the image)

Tessera 3c - Green-yellow glass paste
Numerous bubbles have been recognized in the shiny section of the tessera, generally with dimensions of approximately 100μm, minimum and maximum dimensions of 20μm and 450μm (hemispherical cavities circled in blue in photo 38). Also recognized abundant crystalline inclusions consisting of angular grains with dimensions ranging from 10μm and 350μm (intermediate grey grains circled in red in Photo 38 and shown with greater detail at higher magnifications in Photo 39). These inclusions, composed exclusively of silicon (Si) and oxygen (O), are attributable to quartz grains. The colored glassy phase was uniform and homogeneous, no veins were recognized in the backscattered electrons or streaks associated with significant compositional inhomogeneities. The composition qualitative and semi-quantitative average of the glass phase alone, analyzed at different points of the shiny section of the tessera, (see in Appendix B) expressed as a percentage by weight of the oxides for most elements except chlorine (Cl). In the proximity of the exposed surface, in the polished section, no signs of alteration and/or surface microcracks were recognized.

Tessera 6a - Blue glass paste

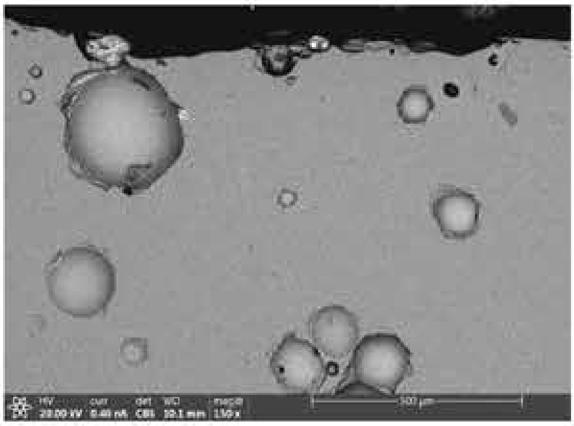
Numerous bubbles have been recognized in the shiny section of the tessera, generally with dimensions of approximately 100µm, minimum and maximum dimensions of 20µm and 850µm (hemispherical cavities circled in green in Photo 40). Also recognized some rare crystalline inclusions consisting of angular grains with dimensions between 30µm and 200µm (intermediate grey grains circled in yellow in Photo 40 and shown with greater detail at higher magnifications in Photo 41). These inclusions, composed exclusively of silicon (Si) and oxygen (O), are attributable to quartz grains. The colored glassy phase was uniform and homogeneous, no veins were recognized in the backscattered electrons, neither streaks associated with significant compositional inhomogeneities. The qualitative and semi-quantitative composition average of the glass phase alone, analyzed at different points of the polished section of the tessera, (see in Appendix B), expressed as a percentage by weight of the oxides. In the proximity of the exposed surface, signs of alteration and/or superficial microcracks were recognized (Photo 42).



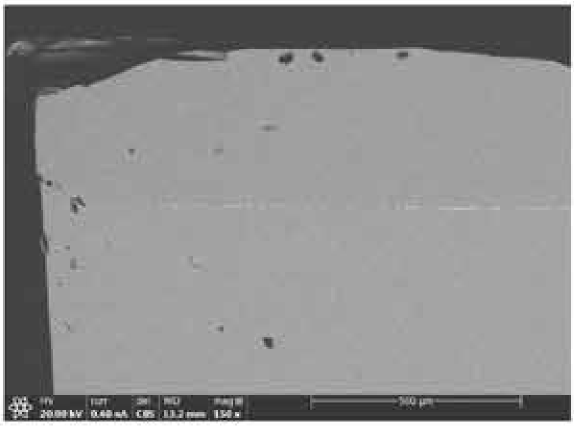


40. Tesserae 13c

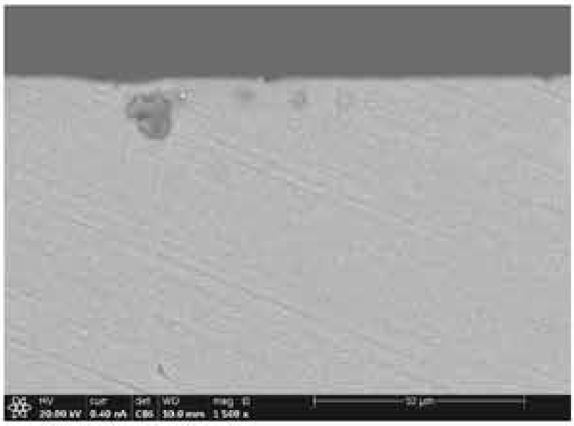
41. Tesserae 13c



41. Tesserae 13c



43. Tesserae 13c. ***SEM image in backscattered***



43. Tesserae 13c ***SEM image in backscattered***

Tessera 13c – Gold Leaf

In the glossy section of the tessera the thickness of the cartellina was found to be approximately 370 μm. The support and cartellina glasses appeared uniform and homogeneous: in backscattered electrons no veins or streaks associated with significant compositional inhomogeneities were recognized (Photo 43).

Near the exposed surface of the cartellina, in the section shiny no signs of alteration and/or superficial micro-cracks were recognized. The gold metal leaf, with a thickness considerably less than 1 μm (it was measured a thickness of about 300 nμ), was found to be quite continuous and well preserved (Photo 44). Its composition was analyzed at various points of the section by EDS microanalysis: the constituent metal was found to be composed mainly of gold (Au 97.5%) with lower silver content (Ag 2.5%). The qualitative composition of the support glass and of the cartellina was found to be the same, with slight variations in the concentration of some elements, particularly manganese (Mn), iron (Fe), phosphorus (P) and calcium (Ca). A comparison between some of the EDS spectra obtained from the analysis of the glasses of the support and the cartellina are reported in Photo 45; the average semi-quantitative compositions are reported in Appendix B.

Tessera 7b – Silver Leaf

SEM observations and EDS microanalyses were conducted on the exposed surface of the tessera in which a part of the cartellina had detached from the support and from some residues of the pseudo-reflective silver metal foil present in an area of approximately 2 mm2 in the centre of the tessera (Photo 46).

Glass of the cartellina

In correspondence with the cartellina, SEM observations highlighted the presence of a strongly micro-fractured and flaked glassy surface, with removal of a good part of the flakes of the most superficial layer and propagation of microfractures also in the layer below (Photo 47). The thickness of the flakes in the process of detachment, determined along the lateral surface of the tessera, was found to be approximately 10 μm (Photo 48). The microanalyses EDS of the cartellina glass were performed at 20 kV and 10 kV at the surface of the flakes in detachment, of the underlying detachment surface and, for comparison, in correspondence of a fracture surface representative of the unaltered glass. No significant differences were found between the EDS spectra obtained at 20 kV and 10 kV: in both analytical conditions, both the glass of the flakes in detachment and the glass of the surface underlying detachment layers appear to be strongly de-alkalized, showing an important reduction of the sodium (Na) signal compared to the unaltered glass of the analyzed cartellina in fracture.

Photo 49 shows a comparison between the EDS spectra obtained at 20kV in the different areas analyzed; Table 17 in Appendix B reports the results of the qualitative compositional analyses and semi-quantitative averages of the different areas analyzed in EDS at 20kV.

Glass of the support

On the surface of the support that emerged due to the detachment of a part of the cartellina, SEM observations (Photo 50) highlighted the presence of a glassy surface without metal foil and strongly micro-fractured near the edges of the tessera, residual portions of continuous metal foil in the central part of the tessera and deposits of micro-particles/micro-crystals in the intermediate zones. EDS microanalyses of the support glass were performed at 20kV in correspondence of the glass surface without metal foil and strongly micro-fractured along the edges of the tessera and, for comparison, in correspondence with a fracture surface representative of the unaltered glass. Table 17 in Appendix B shows the results of the analyses qualitative and semi-quantitative compositional averages in EDS at 20kV: the surface glass micro-fractured is found to be strongly de-alkalized, showing an important reduction of the sodium (Na) signal compared to the unaltered glass of the support analysed in fracture.

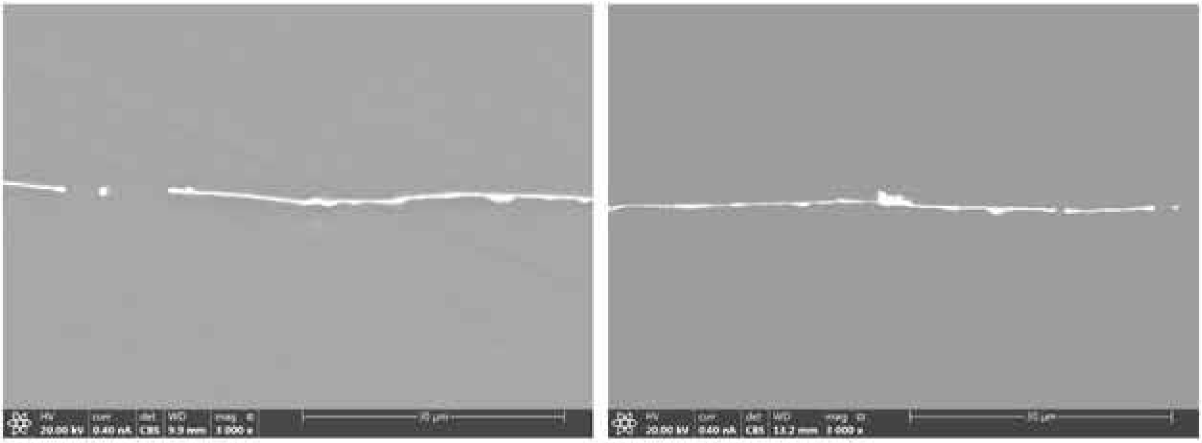
Silver foil and alteration products

In SEM the metal foil residues in the central part of the tessera appeared to be made up of portions of a thin continuous lamina (Photo 51). Based on the compositional analysis In EDS the continuous lamina was found to be made exclusively of silver (Ag >99%).

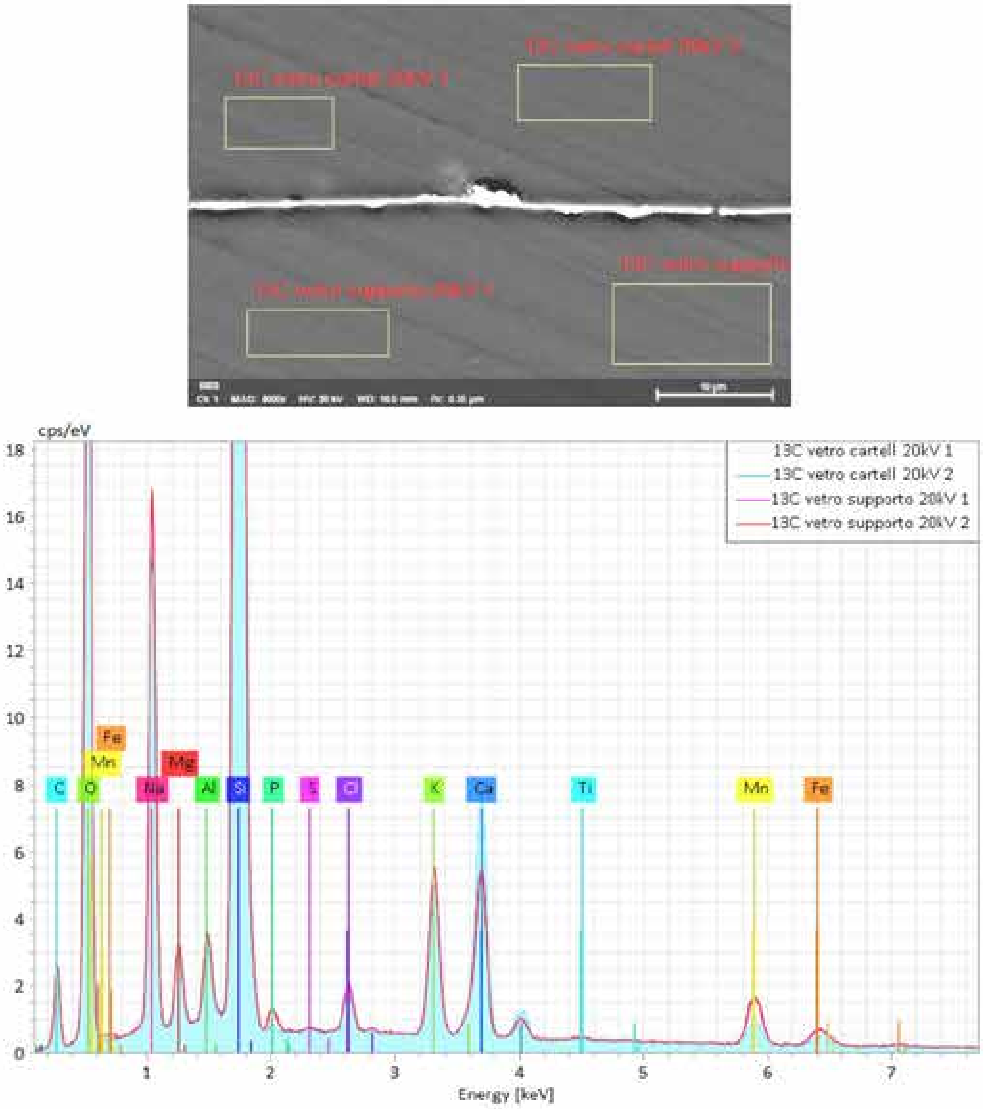
Moving away from the central part of the tessera, the portions of continuous metal foil appeared increasingly fragmented and showed an increasingly porous structure, until switch to an exclusively porous material made up of compact aggregates of micro- particles/micro-crystals (Photo 52). As shown in Photo 53 in such aggregates of micro-particles/micro-crystals EDS analyses have detected the presence of chlorine (Cl) in association with silver (Ag): it is presumably a product of alteration of the metal foil of silver following its attack and corrosion by an agent containing chlorine.

Other products of alteration on glass surfaces

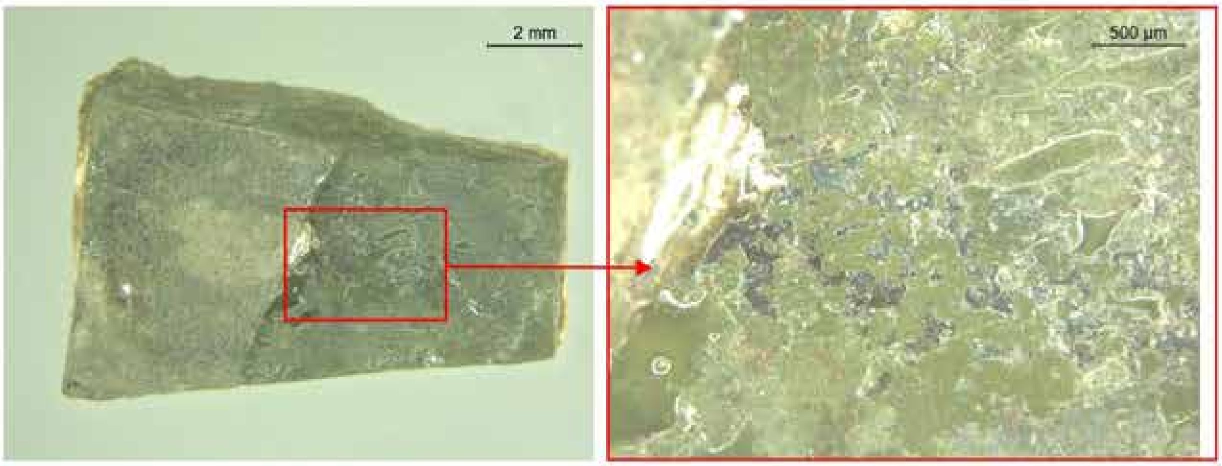
Micro-crystalline deposits were detected on the glass surface of the folder attributable to a single phase based on sulphur (S), oxygen (O), sodium (Na) with traces of calcium (Ca). On the glass surface of the support, in addition to the aggregates of micro-particles/micro-chlorine (Cl) and silver (Ag) based crystals, some other micro-deposits have been recognized crystalline. These were found to be mainly attributable to the following two phases crystalline: a phase based on sulfur (S), oxygen (O), sodium (Na) with traces of calcium (Ca), a second phase based on sulfur (S), oxygen (O), potassium (K).



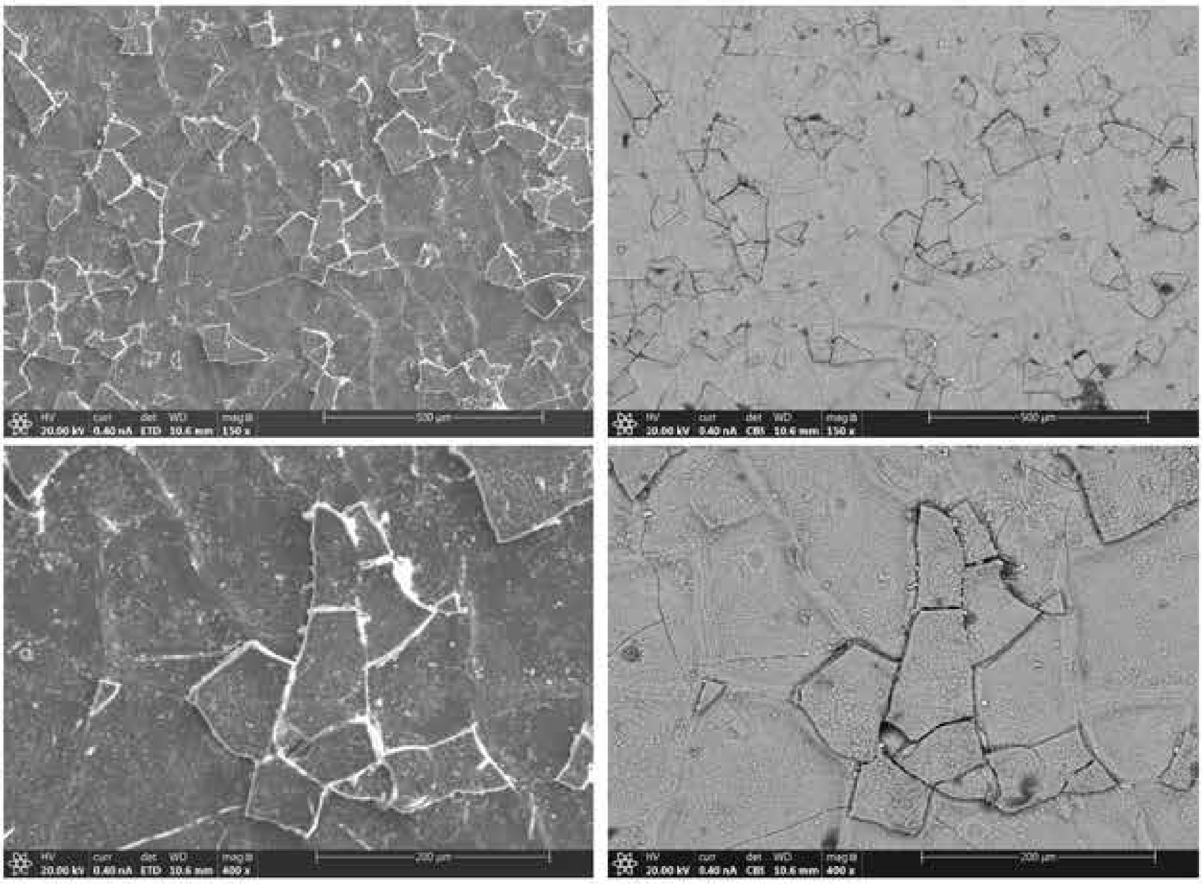
44. Tessera 13c- *Backscattered electron SEM images of the gold metal leaf in the polished section of the tile*



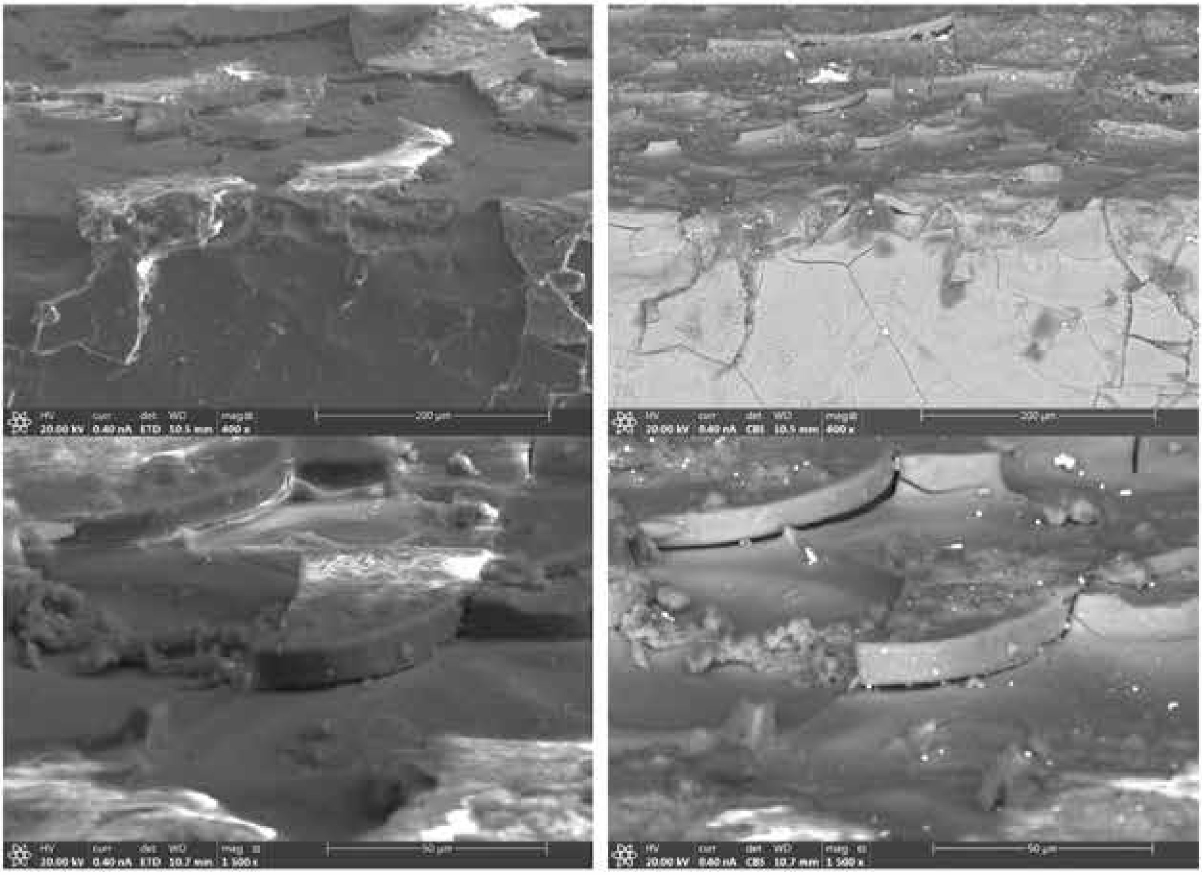
45. Tessera 13c – *Comparison between some EDS spectra acquired at 20kV at the glass of the support and the folder. The areas analyzed are indicated in the SEM image above*



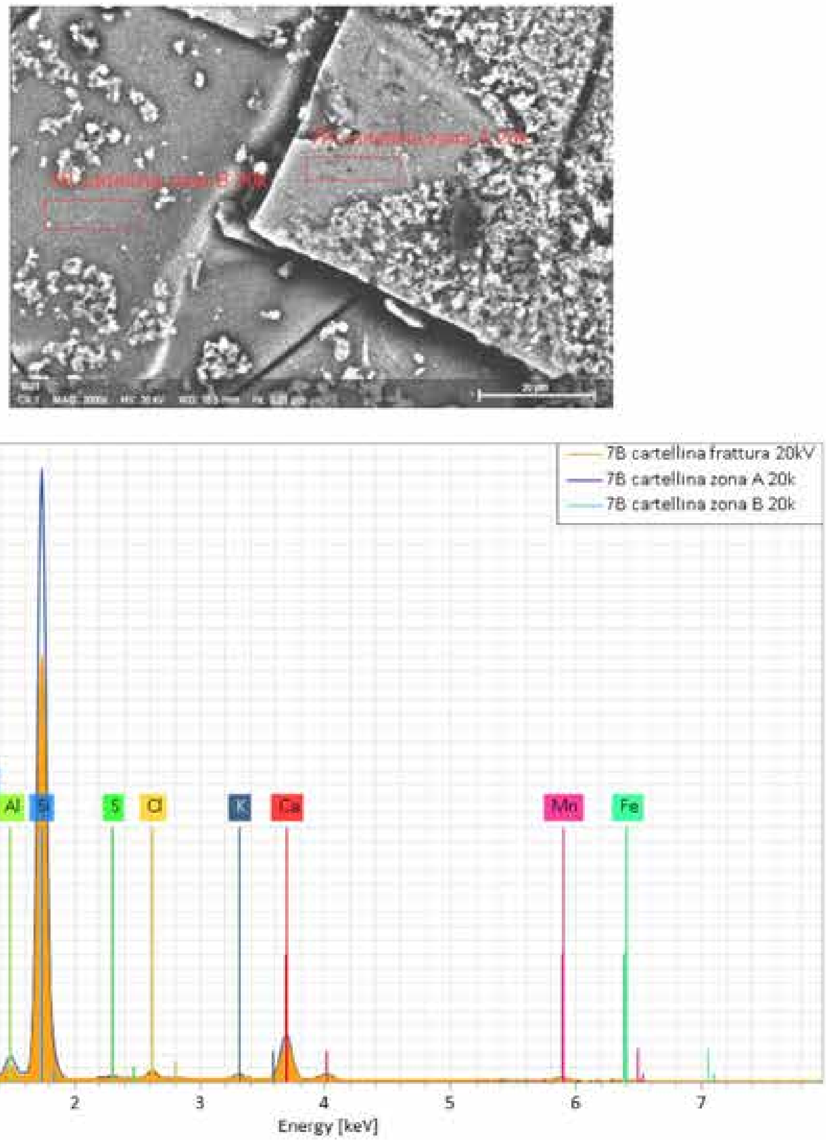
46. Tessera 7b Optical microscope images of the exposed surface of the card, where a part of the folder had detached from the support (left image) and from some residues of the grey, pseudo-reflective silver metal foil present in the centre of the card (in the detail image on the right)



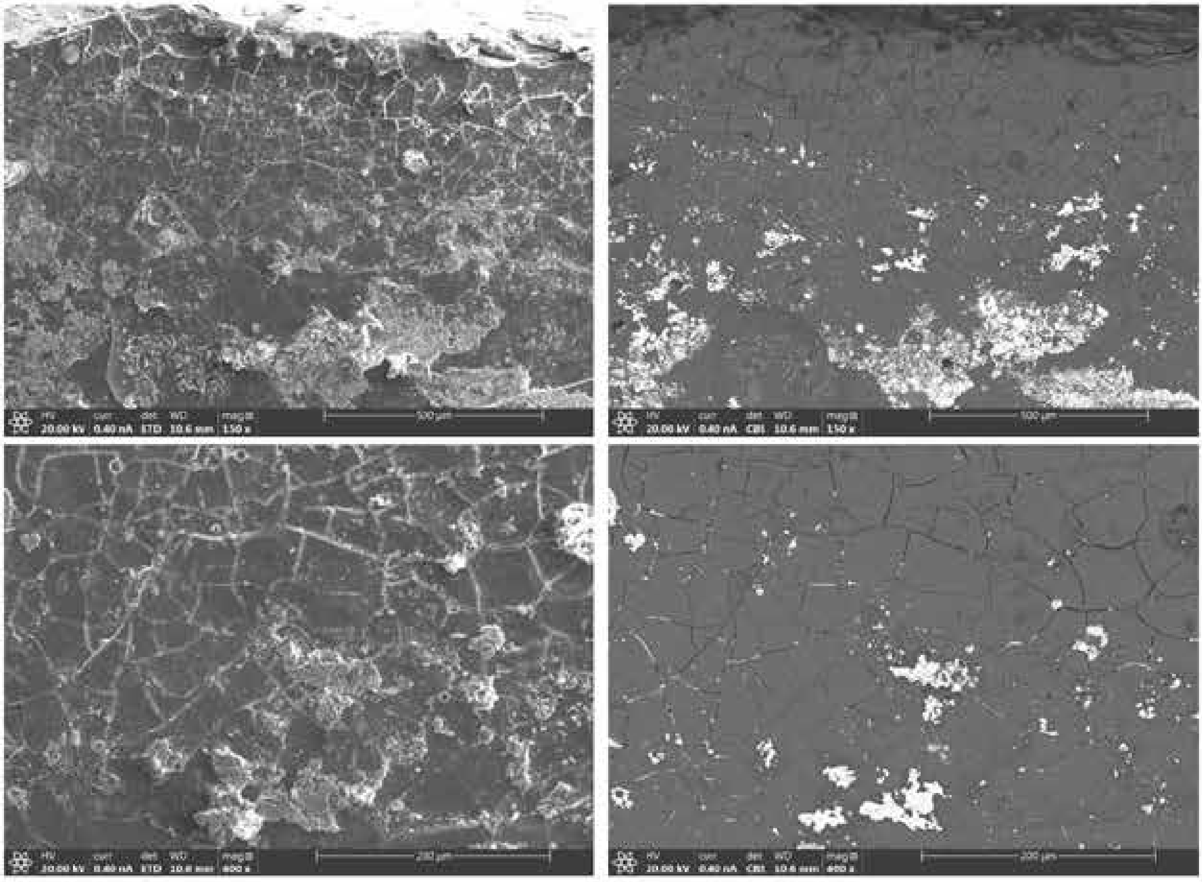
47. Tessera 7b – SEM images (in secondary electrons on the left, in backscattered electrons on the right) of the exposed surface of the folder



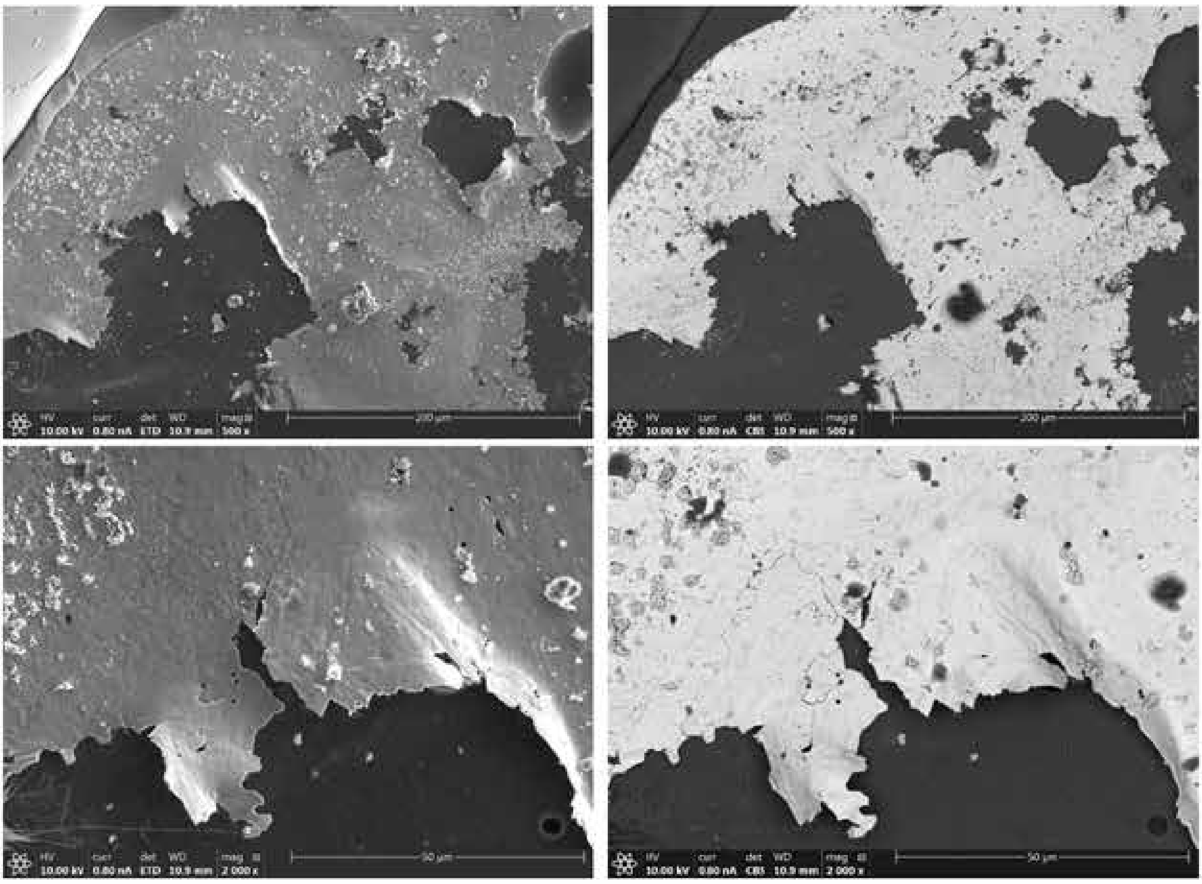
48. Tessera 7b– *SEM images SEM images (in secondary electrons on the left, in backscattered electrons on the right) of the glass surface flakes of the folder during the detachment phase*



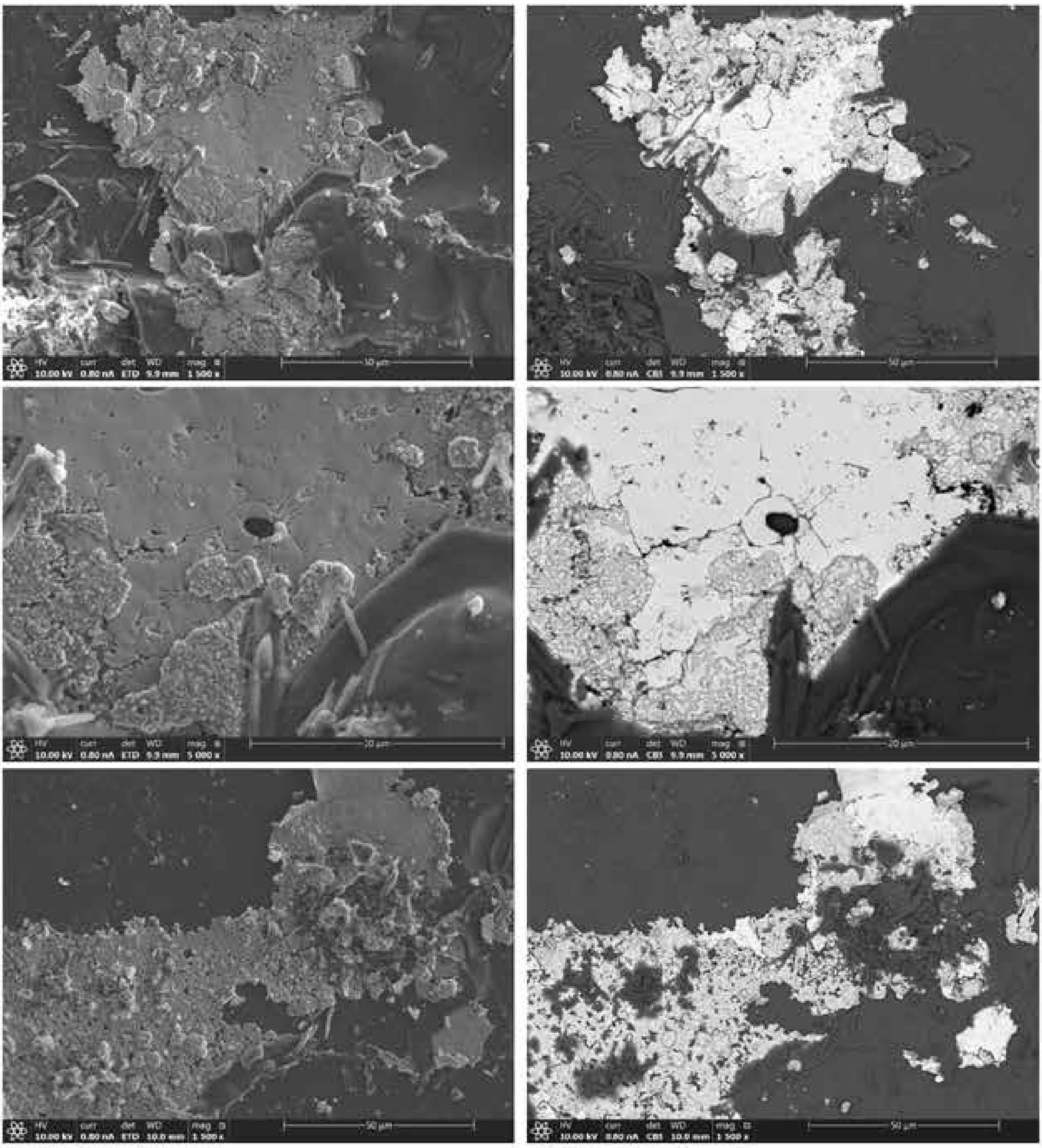
49. Tessera 7b- 20kV EDS spectra at the surface regions of the folder shown in the SEM image above and, for comparison, in the glass of a fracture surface



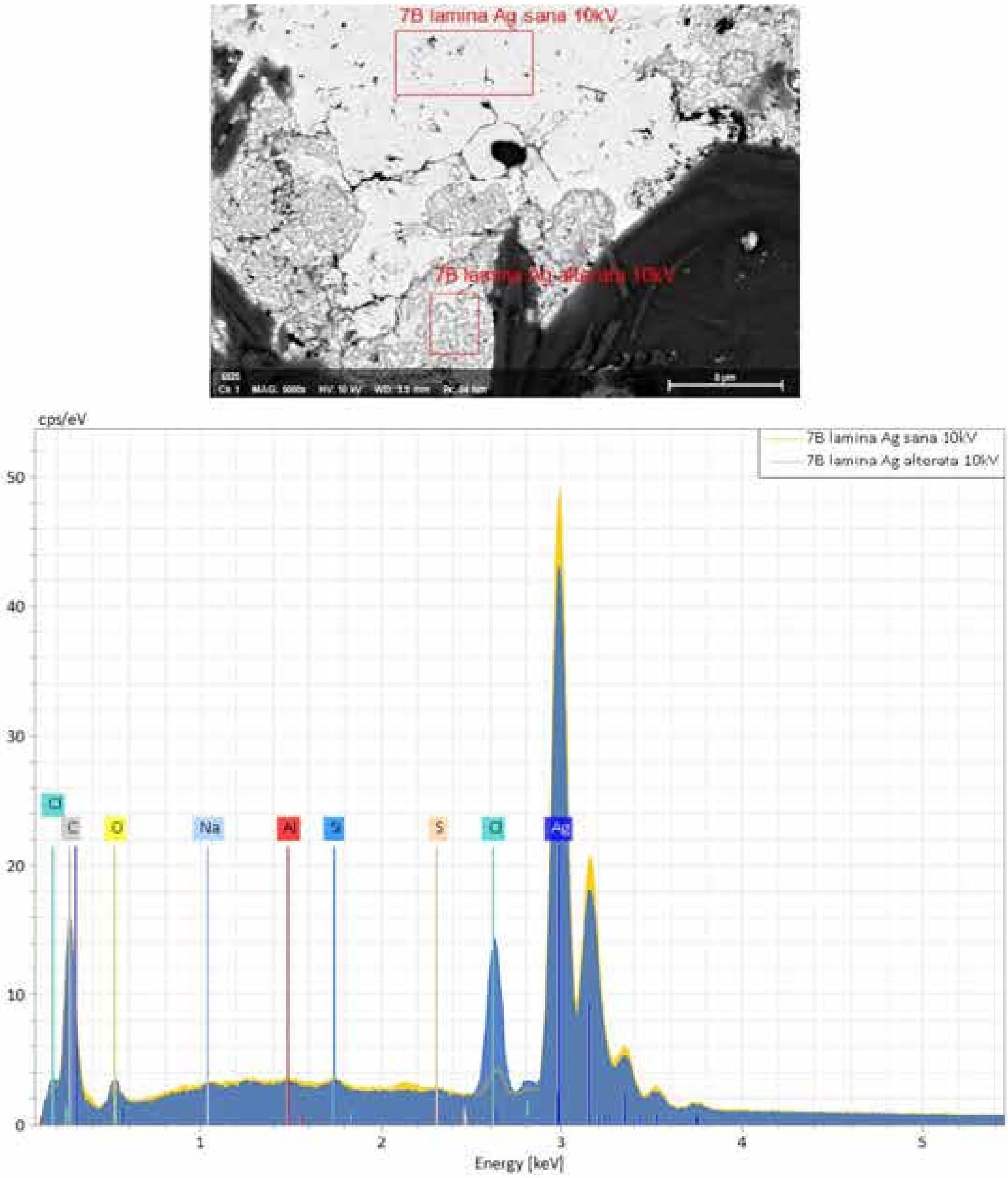
50. Tessera 7b– SEM images (in secondary electrons on the left, in backscattered electrons on the right) of the support surface, micro-fractured and with deposits, along the edges of the tile



51. Tessera 7b – *SEM images (in secondary electrons on the left, in backscattered electrons on the right) of the residues of "healthy" continuous silver metal foil adhered to the surface of the support in the central part of the tile*



52. Tessera 7b – SEM images (in secondary electrons on the left, in backscattered electrons on the right) of the "altered" porous silver metal foil residues



53. Tessera 7b – *EDS spectra at 10kV corresponding to the areas of silver metal foil shown in the SEM image above and corresponding to a portion of "healthy" continuous foil and to a portion of "altered" porous foil*

54. (Next page)The different concentrations of potassium and magnesium produces three different groups in the base glass of the tesserae with metal leaves

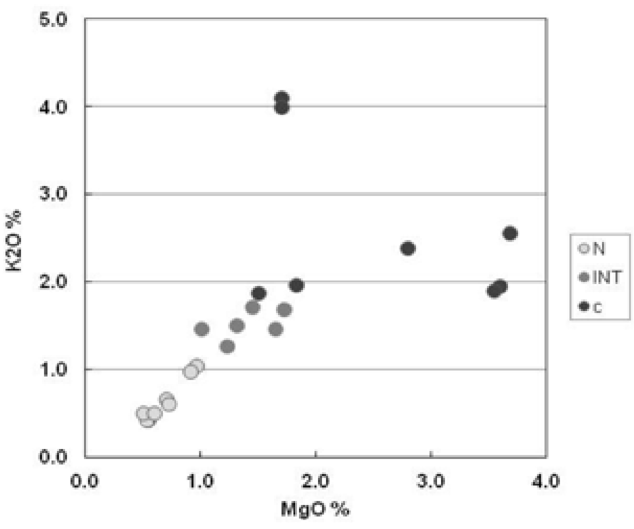
The exposed surface of the gold and silver leaf tesserae also appears to be in a discreet state of conservation. The back of most of the metal leaf tesserae (the surface opposite the visible one) is rough, with adhering residues of generally reddish or yellowish powder, similar to terracotta. These are surfaces formed by placing the glass in a plastic state on a layer of refractory powder and pressing the plate (*pizza*) from the side of the *cartellina* to ensure good adhesion between the layers. The powder acts as a release agent during hot forming, preventing the molten glass from adhering to the casting plane. In other tesserae, the back is relatively smooth and free of adhering residues. This type includes the colored glass pastes, the first silver tesserae, and some of the gold tesserae.

Analysis of the Tesserae

Base Glass

The base glass is the transparent, uncolored glass obtained by melting fluxes and vitrifying agents. For glass pastes, the composition of the base glass is calculated by subtracting the concentrations of coloring, opacifying, and related elements from the analysis; the concentrations of the remaining oxides, attributable to the flux and silica, are then recalculated to 100%.

It is observed that all the glasses are mainly composed of silica (SiO_2), sodium oxide (Na_2O), and calcium oxide (CaO) and are therefore called soda-lime-silica glasses. One exception is a gold leaf tesserae that also has a high lead content (PbO about 15%), which, as we know from Karlo Bakuradze's intervention in the 1980s, comes from the Cathedral of Saint Petersburg and has therefore been excluded from subsequent investigations. Observing the following diagram, where the concentrations of potassium and magnesium are indicated, it is noted that the samples form three distinct groups; the same distinction into three groups is observed by plotting the concentrations of other elements, particularly phosphorus and sodium, in similar graphs. The differences can be interpreted in terms of changes in the flux, as discussed below.



Natron-type glass

The most compact group, with low concentrations of potassium ($K_2O < 1\%$), magnesium ($MgO < 1\%$), and phosphorus (P_2O_5 0.1%), and high sodium (Na_2O 16-22%), represents natron-type glasses, a mineral based on sodium carbonate associated with minor amounts of chlorides and sulfates, generally extracted in Egypt. It was used as a flux mixed with siliceous-calcareous sand also extracted in Egypt or the Levantine area of the Mediterranean. This group includes the first silver leaf tesserae 1, 7a, and 7b, as well as the gold leaf tesserae 13d.

Sodic plant ash-type glass

The group of samples with higher concentrations of potassium and magnesium (greater than 2%) and phosphorus (greater than 0.2%) belong to sodic plant ash-type glasses. These are ashes of halophytic plants that grow in saline soils, particularly in the Levantine area of the Mediterranean; they are mainly composed of sodium and calcium carbonates and were used as glass fluxes mixed with silica. This group includes gold leaf tesserae with very dispersed compositional values; in particular, tesserae 13b (colorless glass) differs from the other gold tesserae (very dark greenish glass) and from 13a. The latter two, very similar in composition to each other, have the unusual characteristic of having quite different compositions between the support (greenish) and the *cartellina* (colorless).

Intermediate-type glass

A third group of samples has potassium and magnesium concentrations intermediate between those of the natron and sodic ash groups, as well as relatively low sodium and alumina values similar to those of the natron group. This group is exclusively composed of colored glass pastes. Most scholars believe that glasses with intermediate compositions were produced by melting natron-type and sodic ash-type glasses together. The production of natron-type glass ceased between the 8th and 9th centuries, replaced by the new sodic ash-type glass; the transition from one glass to the other was not immediate but lasted several centuries, completing only around the 12th-early 13th century when sodic ash-type glass was exclusively produced. This hypothesis is justified by the fact that the intermediate composition has been verified only in analyses of glasses worked between the ninth and thirteenth centuries. In particular, intermediate compositions have been found in the analysis of tesserae from Byzantine mosaics in Italy (Torcello, Monreale), Greece (Hosios Loukas, Daphni), and Turkey (Hierapolis).

Metal Leaf Tesserae

Observing the golden fields of the Gelati mosaics, areas with different shades can be seen. The appearance of these tesserae results from numerous factors, including the color of the glass of the *cartellina* and the support. The analyses of the sampled tesserae have shown that the different appearance corresponds to tesserae of various compositional groups:

- 1. Colorless glass for both the *cartellina* and the support with natron-type composition, equal (or very similar) between the support and the *cartellina*: silver tesserae 1, 7a, and 7b (support with slight greenish tint in the latter) and gold tesserae 13d (support with slight yellowish tint);
- 2. Colorless glass for both the *cartellina* and the support; sodic ash-type composition equal for the support and the *cartellina*: gold tesserae 13b;
- 3. Colorless glass *cartellina* and greenish support with sodic plant ash-type composition; marked difference in the composition of the support compared to the *cartellina*: gold tesserae 13;
- 4. Very dark olive green glass (black on thickness) for both the *cartellina* and the support with sodic ash-type composition, colored with iron and manganese; equal composition for the support and the *cartellina*;
- 5. Colorless support glass and brown-purple *cartellina*, industrial raw material-type composition also containing lead: restoration tesserae from Saint Petersburg.

The final color (completely decolorized, or partially, in light green or yellow tints) of the glass of all the metal leaf tesserae was obtained with manganese, regardless of the type of glass. The glass was intentionally colored in the two tesserae from Saint Petersburg: support decolorized with manganese and antimony and *cartellina* colored with manganese and intensely colored with additions of iron and manganese.

Colored Glass Pastes

The base glass composition of all the colored glass pastes is of the intermediate type.

Colorants

- Blue - Cobalt was used as a colorant, added in modest quantities (CoO about 0.1%). Until the 19th century, it was added in the form of a mineral in which cobalt was associated with other elements. By identifying the elements accompanying it, it is possible to trace the type of mineral used and, in some cases, its origin and dating. The blue tesserae of the Gelati mosaic were colored with the same mineral in which cobalt was associated with iron, as well as traces of copper and lead. The origin of this mineral is not known, but it was used as early as the Roman period and, as far as is known, no later than the 13th century.
- Green - The glass of these tesserae was colored with copper additions. The yellow-green tesserae was also analyzed using SEM-EDS to verify whether yellow pigments (crystalline particles) had been used to vary its tone, which the investigations did not confirm.
- Purple-Brown - The analyzed tesserae was colored with manganese added in a quantity (about 2%) greater than the iron concentration (1.5%).

Opacifier

The translucent effect was obtained with a large quantity of bubbles and coarse quartz grains of both angular and rounded shapes, demonstrating that ground quartz was used and that the addition was made directly in the molten glass immediately before working the plates.
This is a not very effective technique (it makes the glass semi-transparent rather than opaque and allows obtaining no more than three or four color shades) but very economical and easy to use. As far as is known, it would have been developed exclusively for the production of mosaic tesserae in the Byzantine context, probably around the 8th-9th century, and subsequently used, at least until the 15th century, also in non-Byzantine glassmaking centers.

Conclusions

The analyses of the glass mosaic tesserae removed from the Gelati mosaic, carried out at the laboratories of the Venetian Glass Experimental Station (Murano, Venice), allowed us to ascertain that the colored glass pastes are composed of soda-lime-silica glass with a composition intermediate between natron-type and sodic ash-type compositions, opacified with additions of ground quartz and bubbles. The blue tesserae were colored with a cobalt mineral containing iron and traces of copper and lead. The combination of these characteristics refers to Byzantine glass technology between the 10th and 13th centuries. These are therefore tesserae belonging to the original mosaic.

The three silver leaf tesserae and tesserae 13d gold are composed of natron-type glass and are also to be considered as belonging to the original mosaic of Gelati.
The other gold leaf tesserae have a variety of compositions that refer to different restoration interventions that must have involved the gold fields between the 15th and 19th-20th centuries, with the substitution of original tesserae. If the composition of tesserae 13b refers to glass production in the 16th-17th century and that of the tesserae from Saint Petersburg to production in the late 19th-20th century, the temporal placement of the two tesserae 13, equal to each other, in which the composition of the glass of the support differs significantly from that of the *cartellina*, is more problematic. This is a particular never observed by the author, nor found in analyses published by other authors. These are compositions incompatible with production before the 16th and after the mid-19th century. Finally, the composition of the dark tesserae, also from Saint Petersburg, can be traced back to the same time period.
An interesting note resulting from the close-up analysis of the tesserae texture is the presence of some round silver leaf (metal foil) tesserae, slightly larger than the tesserae themselves, and irregularly shaped gold leaf tesserae. These tesserae are inserted into the decoration without an apparent rule and would suggest reused tesserae.
(see Photo 23, white arrows and Photo 55)

56. Tesserae with silver leave cut according to a round shape that does not match with the profile of the other tesserae.

Another interesting note identified during this preliminary study is the extensive presence of colored tesserae cut along the edges of the of the mosaic plates, the socalled "pizza." This indicates at least two very important things: first, the mosaic was certainly made using new colored tesserae, cut from the *pizza* for the mosaic; second, the metal leaf tesserae, in gold and silver, not showing traces of *pizza* edges and thus evidence of possible cutting on site, could also be at least partially reused. (Photo 23 green arrow and Photo 56) This hypothesis could be consistent with the presence, mentioned above, of round silver leaf tesserae.

One of the promising aspects of the restoration intervention, in addition to the restoration of the material and the bedding layers of the tesserae, will be the in-depth study of the traces of original workmanship. The cleaning and removal of the stuccoing derived from past restoration interventions will allow the identification of technical details useful for filling those gaps in knowledge that today do not allow us to read all the secrets of this magnificent work.

Regarding the color palette used for this mosaic, we can undoubtedly affirm that it is very rich: 22 colors. Of these, two are metal leaf, four are limestone, one is black stone, one is terracotta, and 14 are glass paste. It is interesting to note that Leila Khuskivadze, who had direct access to Karlo Bukuradze's experience, lists in her publication as many as 31 colors, which she names individually. The difference could be determined by the fact that in the same colored *pizza*, different color veins can be found. It will be very interesting, at the end of the cleaning, when the surface of all the tesserae will be visible in its actual nature, to verify the real consistency of the color palette. (Photo 57)

In the note, we attach the list of colors proposed by Leila Khuskivadze.[12]

57. The color palette of the tesserae

12. L. Khuskivadze, ibidem, p.40. Gold, silver, dark grey, light grey, black, completely black, dark brown, light brown, yellowish brown, reddish brown, red, bright red, brick red, pink, lilac pink, dark lilac, light lilac, green, dark olive green, grass green, light green, dark green, malachite green, marine greenish, lapis lazuli, aquatic color, ultramarine blue, greyish blue, light blue, sky blue, greyish.

STATE OF CONSERVATION

When discussing the assessment of the state of conservation of a work, it is rare to encounter such contrasting opinions as those generated by the Gelati mosaic in the eyes of observers. We have heard very serene opinions speaking of a good state of conservation, and at the same time, dramatic opinions speaking of imminent catastrophe. We ourselves have found our opinions changing over the short duration of a site visit. The truth is that the complexity of the state of conservation of the Gelati mosaic is perhaps the main risk to its survival. This is to say that the more we understand its true condition, the more we realize that underestimating the risks the mosaic faces every day would be a fatal mistake.

It is equally rare to have a precedent like the restoration intervention by the Georgian team in the 1980s, led by Karlo Bukuradze, in which not only decisive initiatives were taken for the mosaic's survival, but very advanced procedures, which we would call very modern today, were followed in describing the state of the artifact at the time of the intervention and in documenting what was done. These documents were transferred to us in their entirety, both in the descriptive part and in the graphic component. (Photo 1)

With this privilege, we believe it is appropriate to open the chapter describing the state of conservation of the mosaic by quoting what Karlo Bakuradze describes in his report: "... at the end of the 1970s, the state of the Gelati mosaics attracted the attention of specialists and the entire Georgian society.
The reason for this particular attention was the explosions in the stone quarries of Motsameta near Gelati, which had caused a serious threat to the entire Gelati Monastery Complex and particularly to its mosaics. The concerns of our society were manifested on the pages of magazines and newspapers, which produced positive results. The explosions were stopped. But the Gelati mosaics needed urgent help. To a common visitor, the state of conservation of these mosaics might have seemed good, but the expert eye did not miss its actual state.

The state of conservation of the Gelati mosaics was serious. First of all, the connection between the mosaic and the wall was very concerning; most of it was detached from the wall and was at risk of collapsing. Only 15% of the mosaic area was consolidated to the wall, more than 80% of the mosaic plaster was detached from its original base.

1. Karlo Bakuradze on the scaffolding during the restoration work in the '80s

The detachment of this plaster from the masonry was not very large and varied from 1 millimeter to 20 millimeters. With the wind, the movement of air between the mosaic plaster and the wall was particularly strong.
Furthermore, the mosaic tesserae in some parts had fallen and were broken.
A very evident crack ran along the entire left side of Christ's face. Undoubtedly, the explosions in the nearby stone quarries, as well as the large fluctuations related to aircraft flyovers, played a role in the deterioration of the state of conservation of the mosaics. But the main reason for its serious state of conservation probably should have been the state of emergency of the building itself. As it appears, for a long period of time, rainwater descended from the basin and seeped between the masonry and the plaster. For this reason, the lower part of the mosaic was particularly damaged, approximately from the sides of the figures, as moisture mainly accumulated in the lower part. This fact could be the reason why the lime plaster of the mosaic in that area was relatively weaker, which was confirmed by the analysis of the plaster of this surface area. At the end of the 16th century, this damaged part of the mosaic was plastered and repainted with a fresco, while in the 19th century, after plastering again, it was repainted with oil paints. The gold background of this part of the mosaic ($4\ m^2$) had been plastered to straighten it. As for the mosaic tesserae preserved on the figures, their consolidation and veiling were carried out in a very approximate manner. The southern part of the aforementioned area of the mosaic was particularly damaged: here the tesserae were missing and the plaster was much weaker. The weakness of the base plaster of the mosaic was evident even in the blurred contours of the right wing of St. Archangel Michael and the left wing of St. Archangel Gabriel, roughly painted with black color, which also covered the adjacent tesserae. Separate and quite large sections in the upper part of the mosaic were also damaged, which at the time had been filled with a lime solution, painted, and drawn with small rectangles to imitate the arrangement of the mosaic tesserae. Large alteration spots could be seen on the hair of Archangel Michael, partially on his halo, as well as from the hairline of Archangel Gabriel to the outline of his halo. A part of the hair bow of Archangel Gabriel was covered with white lead, and the fake tesserae that adorned the bow were in light blue. A large circular black spot (86x86 cm) stood out above the halo of Archangel Gabriel. The Labarum of Archangel Gabriel was also severely ruined.

Deterioration was also present on the face of the Virgin Mary, on the face and neck. An intervention with oil paints created a relatively large spot on the right cheek of the Virgin Mary. In our practice, we have found such spots, for example, the spots present on the face of the Virgin Mary of Kintsvisi and also on the face of John the Baptist of Alvani are caused by the stuccoing of the lacunae and consequently by the veiling. The deterioration in these cases was undoubtedly caused by an arrow, while at Gelati, as at Alaverdi, it resembles more a bullet. The tesserae detached due to the aforementioned events caused the detachment of other tesserae, in which the bats also contributed greatly without a doubt. Even during our restoration site, there were cases where bats were hanging from the tesserae, causing them to disconnect from the cast of the already shaken tesserae.

The cavities caused by the falling of the tesserae were sometimes not even filled with plaster but were quite roughly repainted directly with a brush to cover the white spots. In some parts after the restoration, the cavities remained in white (for example, on the halos of the Archangels).

It should also be noted that the black dots scattered here and there (for example, on the halo of Archangel Gabriel) are formed due to the detachment of a thin layer of enamel/glass above the golden tesserae. As is known, to obtain such tesserae, the gold is interposed between the upper and lower layers of enamel/glass, sometimes colored and then cut into appropriate cubes/tesserae. On the shiny surface of the mosaic, the tesserae that no longer have the upper layer of enamel/glass are perceived as dull and blackened points.[2]

I believe it is difficult not to share the positive opinion that we have formed today regarding the professional quality of our Georgian colleagues who, in the 1980s, took on the responsibility of saving the Gelati mosaic. The description of the state of conservation of the mosaic is very detailed and clear. The bad news is that in many passages we can recognize some of the problems that we find today, a sign that some aggressors are still at work. This sadly confirms that when intervening on an artifact, no matter how competent the team of restorers is, if preventive conservation issues such as the rehabilitation of architectural structures or interventions on the surrounding environment (climate control) are not addressed, the risks are not eliminated.

After this long and interesting preamble, let's look at the state of conservation of the mosaic as it appears today, starting from the preparation layers and moving towards the mosaic surface.

Deterioration of the Preparation Layers

The preparation layers are composed of lime mortar, siliceous aggregates, and straw: they constitute, in three layers, the substrate and the leveling layer of the mosaic. Once the water from the mixture has evaporated through the drying process, the mortar is naturally stable. Unless external factors intervene.

2. Karlo Bakuradze, Ibidem, pp. 1-4

In the case of Gelati, the preparation layers are severely degraded in percentages close to 89% of the extent of the area where the mosaic is still present today: they appear pulverized, fractured, detached, or even washed away. As in the areas of severe detachment where at least one of the two preparation layers, the deepest one, no longer exists. In many other areas, the layers appear fractured and inconsistent.

Detachments

We are faced with three types of detachment, related to the layer they affect: the first is the detachment between the masonry structure in dolomite blocks and the deepest layer; the second is between the deep layer and the intermediate layer; the third is between the leveling layer and the underlying layer and the leveling layer and the tesserae. In the latter case, given the thinness of the layer (about 2 mm), it is almost impossible to distinguish the two levels of detachment. In areas of significant detachment, highlighted in red in the mapping, the deepest layer has practically disappeared. (Detachment mapping)

2-5. Into the detached areas of the mosaic today we can find residues of the original mortar setting beds. We can also find undefined materials inserted during the 1980 restorations.

6. Plate of the detached areas

Fractures and Cracks

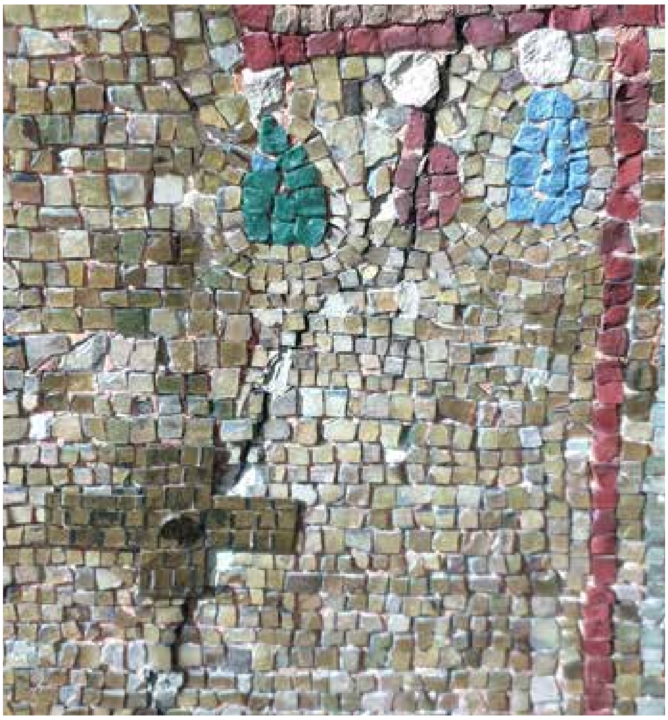
Another form of deterioration affecting the structure of the mosaic consists of fractures, which are clearly visible, and cracks, which are less visible, that we can observe on the tessellation. These do not affect the tesserae but the underlying preparation layers. They are the result of deformations of the substrate but could also be the price the mosaic has paid due to vibrations caused by external factors, such as explosions in the Metsameta quarry.

Deformations

These anomalies on the level of the mosaic are caused by problems in the support layers. Bulges, detachments filled with dust, are the origin of areas that not only appear detached but also irregular in the coplanarity of the mosaic surface, representing, in addition to an aesthetic problem, a risk to the stability of the tessellation. (Mapping of cracks and deformations)

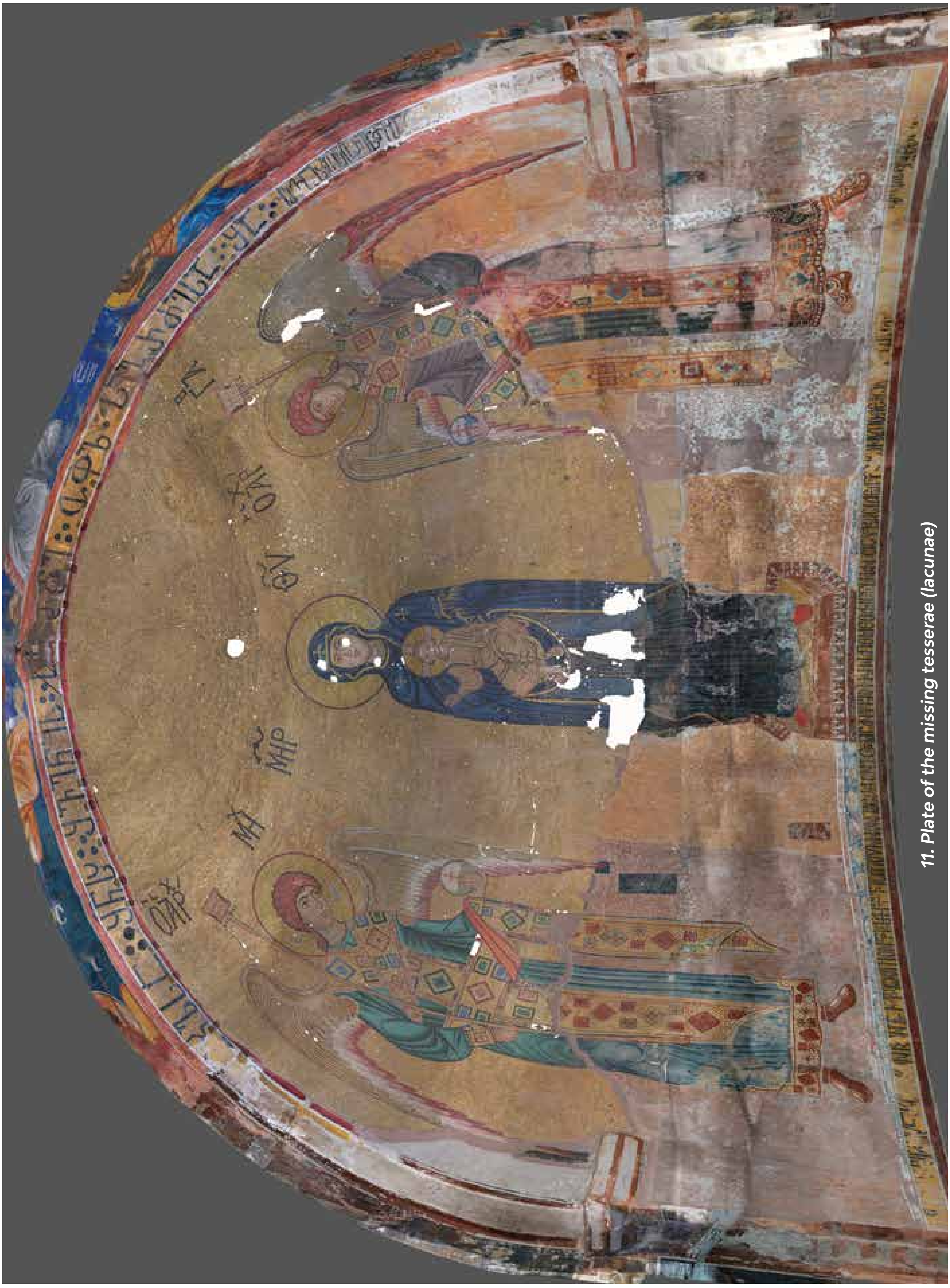
Lacunae

The areas, both extensive and punctiform, that today are without tesserae, represent the tragic culmination of the phenomena just mentioned. They are the price the mosaic has paid for the collapse of the leveling and containment layers of the tesserae. They not only represent an irreversible phenomenon of damage but are also an element of great destabilization and potential risk as they no longer interpret the unitary function of the mosaic texture. The totale surface of missing tesserae in the mosaic as it is today is 11.700 cm^2 equivalent to 2,5% of the actual surface, wich corresponds to approximately to 16.000 tesserae. (Lacunae mapping) (Detailed lacunae mapping)

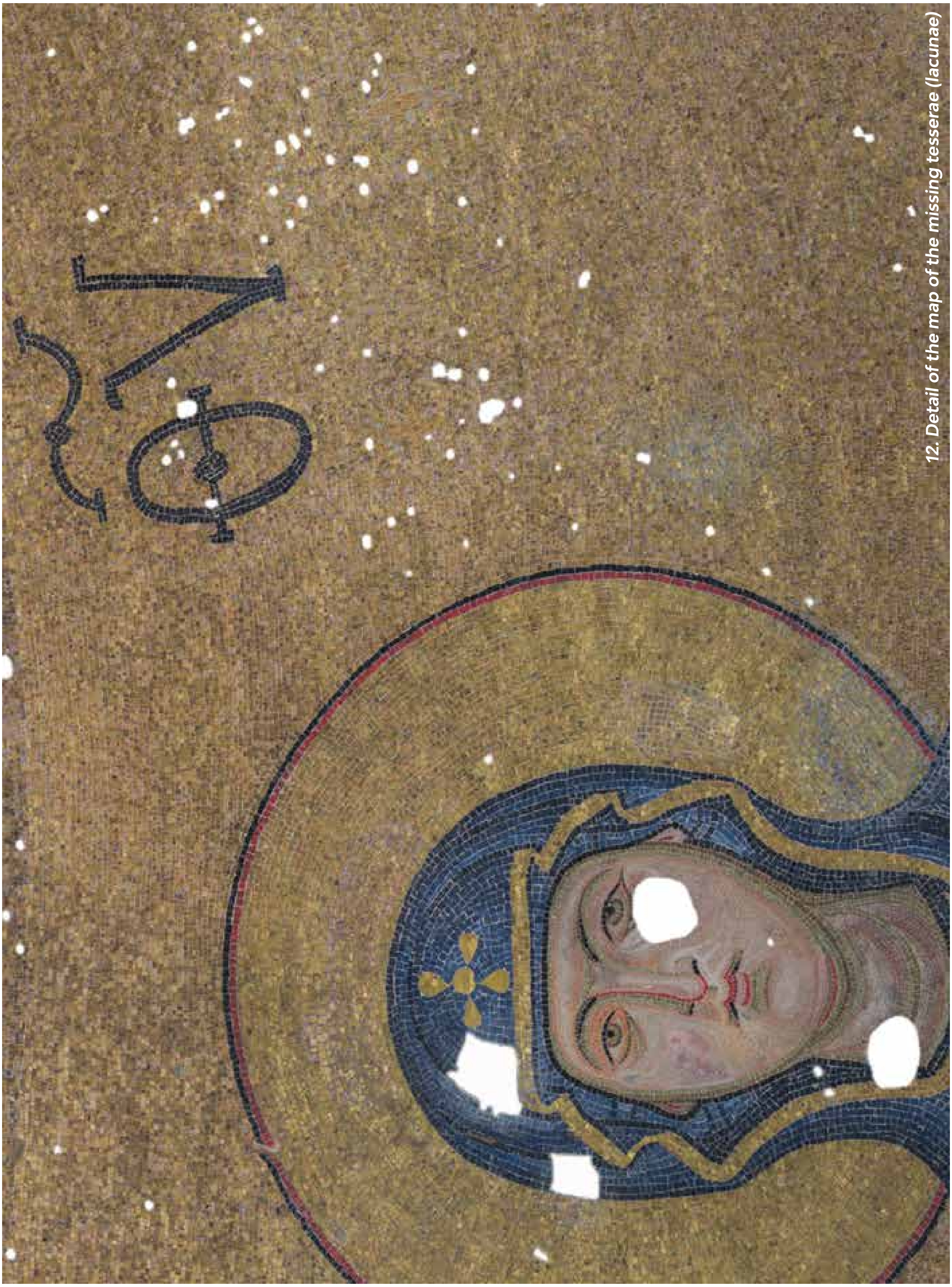


7-9. The mosaic surface today appears to be affected by several cracks.

10. Plate of cracks and deformations



11. Plate of the missing tesserae (lacunae)



12. Detail of the map of the missing tesserae (lacunae)

Deterioration of the Tesserae

The tesserae are composed of limestone, terracotta, glass, paste, gold, and silver leaf. These materials have very different levels of fragility among them.
Of the stone materials, the first four, in limestone, due to their crystalline texture, fine grain, and low porosity, are resistant to degradation; the fifth, in natural holocrystalline stone, sensibly schistose, of brown-black color, with grayish lamellar minerals, is instead very vulnerable and shows evident phenomena of flaking.
Terracotta, due to its high porosity, is also vulnerable.
Regarding the glass tesserae, any artifact of this category exposed to the environment undergoes transformations limited to the surface, as glass is a non-porous material. These are generally slow processes that depend on multiple parameters including the composition of the glass and the conservation environment; the consequent degradation is sometimes so modest that it is not perceptible to the naked eye, while in other cases it reaches levels that compromise the conservation of the artifact itself. Such phenomena are particularly complex because, in addition to depending on various factors, they occurred over very long periods of time. For mosaic tesserae, the causes of degradation are even more complex to define because over time they may have been exposed to exceptional situations (fires, infiltrations from the masonry, improper restorations, etc.) to which it is generally difficult or impossible to trace.

13-16. Example of crystallized soluble salts

The glass tesserae with silver leaf, in particular, show advanced phenomena of deterioration. In these tesserae, the degradation takes on a particular appearance, spreading concentrically from the edge towards the center of the tesserae, as seen, for example, in the photo of tesserae 7a. This determines the loss of brilliance of the lamina and, as the phenomenon progresses, the detachment of the *cartellina*. The structure itself makes these tesserae particularly delicate and more exposed to degradation phenomena.

Being formed by three layers (the metallic lamina is fixed between two layers of glass) and obtained by cutting plates, the lateral surfaces of these tesserae leave the silver lamina exposed to the atmosphere. In these points, the silver can undergo, in unfavorable environmental situations or in the case of particularly aggressive events, phenomena of oxidation.

Analyses of deteriorated tesserae of this type have generally highlighted the formation of dark compounds of sulfur and silver. Therefore, the formation of chlorine and silver compounds highlighted in the analysis of the silver tesserae of Gelati is surprising. The progress of the alteration process was also favored by the composition of the natron-type glass of these tesserae. Glasses, in fact, depending on their chemical composition, react (and alter) differently in contact with the environment.

17-18. The glass tesserae with silver leaf shows advanced phenomena of deterioration on a particular appearance, spreading concentrically from the edge towards the center of the tesserae.

The glass of the silver tesserae of Gelati is among the least durable of those analyzed, both due to the high concentration of sodium (Na_2O 17.5-22%) and the relatively modest concentration of calcium (CaO 6-7.4% for tesserae 7a and 7b).
There are multiple critical environmental parameters for the conservation of glass materials. Among these, the main one is high humidity and the formation of condensation on the surfaces.
In this case, the thin film of water deposited on the glass develops its corrosive action with leaching reactions (extraction of alkalis from the glass) and corrosion (destruction of the network and formation of fragile layers such as silica gel). In this sense, the thin empty space that forms at the interface between the glass of the *cartellina* and the support following the corrosion of the silver lamina becomes a particularly unfavorable point that accelerates the deterioration process of the glass with the formation at the interface of layers of degraded fragile glass and alkali salts (sodium sulfate), phenomena well highlighted by SEM-EDS analyses.

In conclusion, regarding the degradation phenomena, they are evident in all the tesserae.
More markedly in the black schistose tesserae, partly in the terracotta, extensively in the gold tesserae, but very markedly only in the silver tesserae, many of which are in a precarious and delicate state of conservation. It seems that the phenomenon was triggered (or markedly accelerated) by the oxidation of the metallic lamina with the formation of unusual chlorine and silver compounds and the consequent corrosion of the surrounding glass and formation of fragile layers of degraded glass type silica gel and saline deposits type sodium sulfates.

The surfaces of the Gelati mosaic and wall paintings show important signs of the presence of salts. We can see them in the most bizarre forms when they are crystallized and not see them when they are solubilized.
In both cases, the result is the pulverization of the limestone and terracotta tesserae, the exfoliation of the schistose tesserae, the whitening of the glass, and the fall of the *cartellina*.

Scientific analyses, carried out in three different points of the mosaic, indicate that the salts are composed of:

Sample 1: Mainly calcite, gypsum (calcium sulfate dihydrate), and portlandite (calcium hydroxide);

Sample 2: Potassium nitrate, aftitalite (potassium and sodium sulfate);

Sample 3: Mainly potassium nitrate, quartz, and aftitalite (sodium and potassium sulfate) in smaller quantities, plagioclase in traces. (see Photo 13-16 and 19)

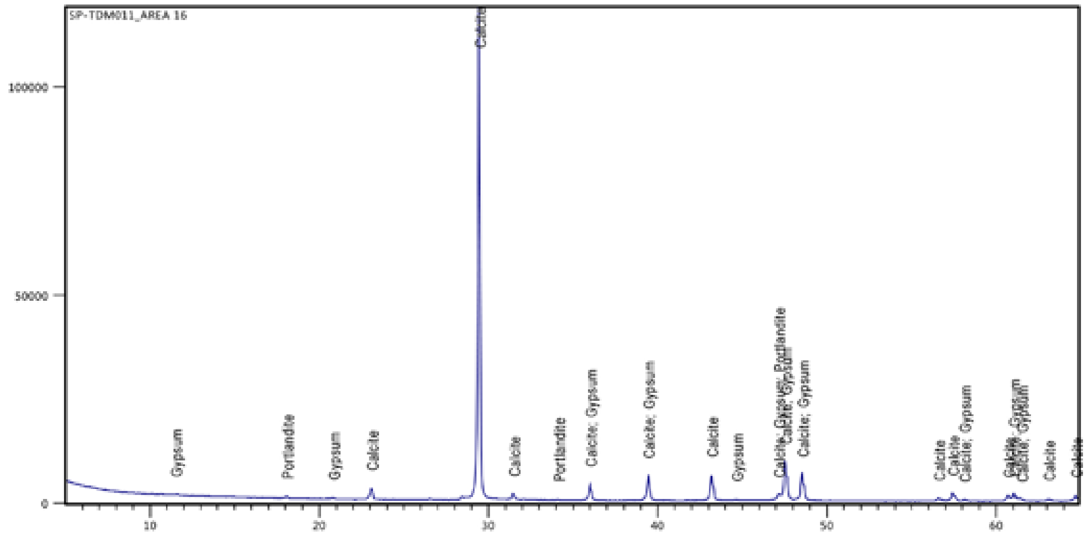
A crucial issue is the origin of these salts. One hypothesis proposed during preliminary meetings is that these came from the back of the mosaic, i.e., from the structure in dolomitic stone blocks, which could slowly release structural salts. But the analysis results do not seem to confirm this hypothesis since, at least in the apse, there are no traces of salts typical of dolomite $[MgCa(CO_3)_2]$[3], i.e., magnesium carbonate and magnesium carbonate hydrate phases. Another possible source of salts from within the structure could be determined by fillings carried out in the past in the extrados of the vault in cement mortar. This could be linked to the presence of calcium sulfate (gypsum) ($CaSO_4$), but the fact that this was detected in traces seems to exclude this possibility as the primary source. The option of salt deposition on the mosaic surfaces from the internal environment of the church remains. These could have been introduced by pollutants from the external atmosphere.[4]
Or from some material used for cleaning during a past

Specie mineralogica	Stima di abbondanza relativa*	Metodo di prova
Calcite $CaCO_3$	+++	UNI EN 13925-2: 2006
Gesso $CaSO_4 \cdot 2H_2O$	Tr	UNI EN 13925-2: 2006
Portlandite $Ca(OH)_2$	Tr	UNI EN 13925-2: 2006

dove i simboli stanno per:

+ + +	Componente principale	+	Componente presente in piccola quantità
+ +	Componente presente in quantità media	tr	Componente presente in tracce
*	Dati indicativi e soggetti ad elevati margini di errore nel caso di argille, fillosilicati e zeoliti.		

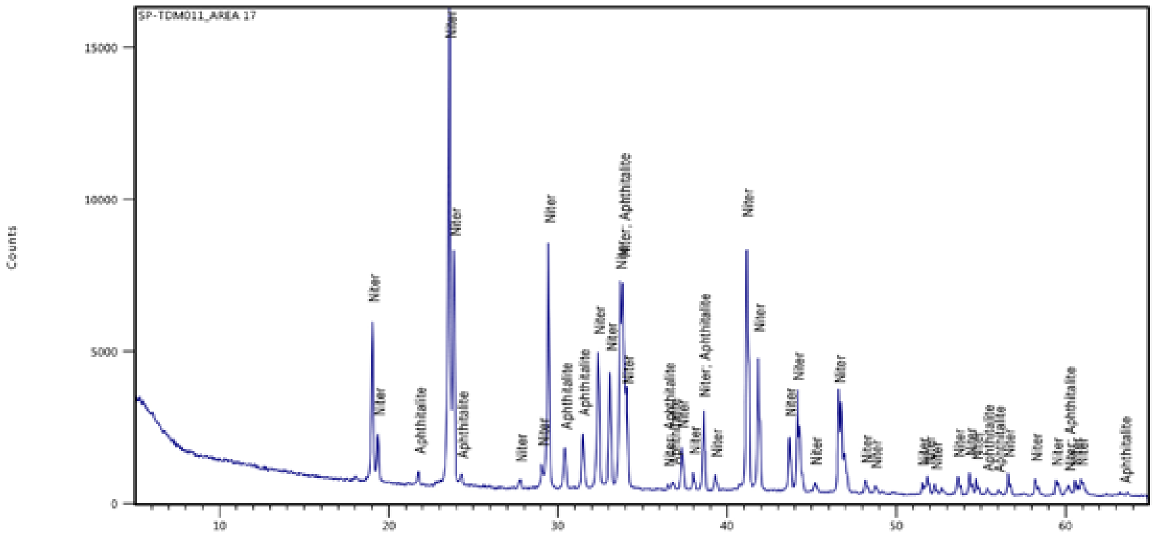
4. S. Laue, ibidem, "Summary and discussion", pp. 8-10;



Specie mineralogica	Stima di abbondanza relativa*	Metodo di prova
Niter KNO_3	+++	UNI EN 13925-2: 2006
Aphtitalite $K_3Na(SO_4)_2$	+	UNI EN 13925-2: 2006

- dove i simboli stanno per:
-

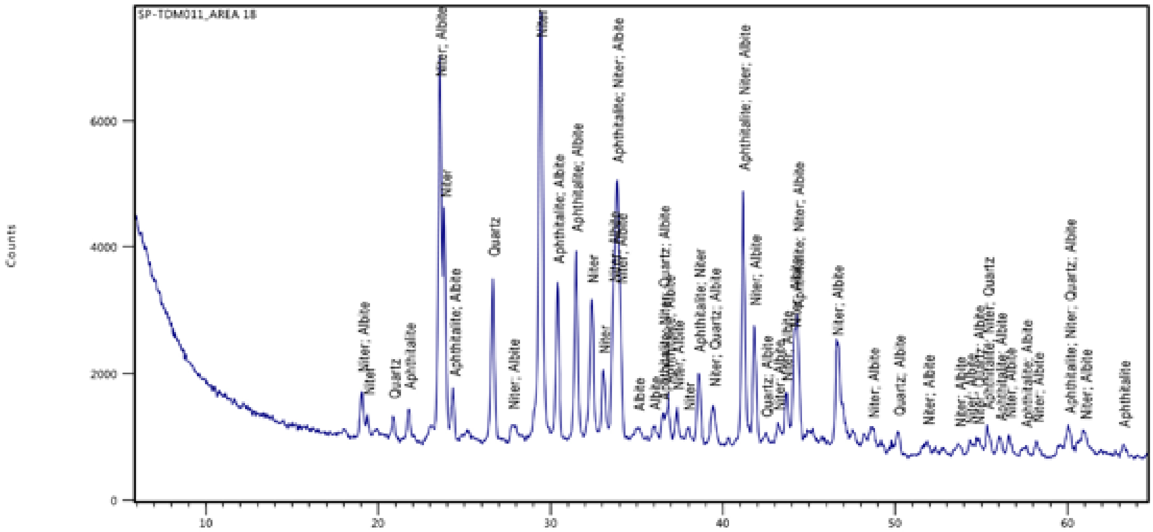
+ + +	Componente principale	+	Componente presente in piccola quantità
+ +	Componente presente in quantità media	tr	Componente presente in tracce
*	Dati indicativi e soggetti ad elevati margini di errore nel caso di argille, fillosilicati e zeoliti.		



Specie mineralogica	Stima di abbondanza relativa*	Metodo di prova
Niter KNO_3	+++	UNI EN 13925-2: 2006
Aphtitalite $K_3Na(SO_4)_2$	++	UNI EN 13925-2: 2006
Quarzo SiO_2	++	UNI EN 13925-2: 2006
Plagioclasio $CaAl_2Si_2O_8$-$NaAlSi_3O_8$	Tr	UNI EN 13925-2: 2006

- dove i simboli stanno per:

+ + +	Componente principale	+	Componente presente in piccola quantità
+ +	Componente presente in quantità media	tr	Componente presente in tracce
*	Dati indicativi e soggetti ad elevati margini di errore nel caso di argille, fillosilicati e zeoliti.		



19. The plate of soluble salt efflorescence, deformations and exfoliation

intervention, as suggested by the Stazione Sperimentale del Vetro in Venice: "... in such aggregates of micro-particles/micro-crystals, EDS analyses have revealed the presence of chlorine (Cl) in association with silver (Ag): these are presumably alteration products of the silver metallic lamina following its attack and corrosion by a chlorine-containing agent"[5], Prof. Marco Verità "... The formation of chlorine and silver compounds highlighted in the analysis of the silver tesserae of Gelati is surprising"[6], and Prof. Steffen Laue "... The reason for the high alkali content in the surfaces should be determined. Were the wall paintings possibly treated at any time with an alkaline conservation material that contains alkalis?"[7]
Prof. Stefano Ridolfi in his technical report signals the organic origin of the potassium nitrate found in abundance in the analyzed salt samples.[8] This origin could also be related to some product used in one of the previous interventions for the cleaning of the mosaic. Or it could be of animal origin, as Karlo Bakuradze recounts in his report speaking of the abundant presence of bat colonies: "... The tesserae detached due to the aforementioned events caused the detachment of other tesserae, in which the bats also contributed greatly without a doubt. Even during our restoration site, there were cases where bats were hanging from the tesserae, causing them to disconnect from the cast of the already shaken tesserae."[9] With these words, Karlo Bakuradze not only tells us that the bats detached and damaged the tesserae but also allows us to interpret the presence of colonies with consequent droppings and guano deposits. Precisely, nitrates. The origin of the salts remains an open issue and will be a topic of study and debate in the course of future studies that will be conducted in a global and holistic manner, crossing information related to the church as a whole and the environment, both internal and surrounding.

Another element that appears on the surface of the tesserae is represented by a dark veil that, depending on the type of background tesserae, appears more or less covering. This is what remains of the black smoke from the two fires that affected the mosaic in the XVI and XIX centuries. The power of damage caused to an absidal mosaic in glass is not to be underestimated, and the fact that today we have lost more than 50% of it is sufficiently eloquent. We can imagine the flames rising high towards the top of the church, licking the walls of the apse, and, brushing the summit bowl, heading towards the windows of the dome. The smoke from such an event settles on the surfaces and slowly cools, forming a very consistent greasy deposit.

This deposit must have been the focus of the restorers of the 16th and 19th centuries who, probably only during the second intervention, managed to significantly lighten it. The question remains powerful as to what material they used for this purpose. They could have used soaps or other aggressive materials, perhaps chlorine-based, which, it is useful to remember, was first synthesized in the mid-1700s. It is important to specify that the traces of combustion that we find on the surfaces today do not represent a cause for concern as they are not an active aggressor. It is exclusively an aesthetic interference that will be removed during cleaning, as tests have shown possible. (see Photo 11-12)

Metallic Elements

The restoration intervention of the 1980s involved the insertion of numerous brass pins into the mosaic to anchor it to the masonry structure. After the visual survey and the instrumental investigation (Geo-radar and Pacometro) we could draw the following scenario, reporting three kind of metals:
A. Threaded brass dowels inserted into bushings placed inside the stone blocks with a cross-shaped brass plate screwed on top. These dowels were used to anchor the mosaic to the structure of the detachment points;
(Photo 20)

20. An example of the brass pins used during the restoration of the '80s

5. R. Falcone, N. Favaro, M. Vallotto, Stazione Sperimentale del Vetro, Report 000210569, Venice 2024, p. 24
6. M. Verità, Technical Report, Venice 2024, p. 6
7. S. Laue, ibidem, "Summary and discussion", pp. 8-10
8. S. Ridolfi, Ars Mensura, Gelati Monastery, Diagnostic Investigation, Technical Report, Rome 2024
9. K. Bakuradze, L. Khuskivadze, Restoration of Gelati Mosaics, Tbilisi 1990, p. 3

21. A detail of the plate of lacunae and cracks

B. Brass plates shaped like V and Z screwed onto bushings placed inside the stone blocks. These plates were used as containment edges; (Photo 22)
The above groups are made of 135 elements which are visible; 108 non visible that we detected instrumentally;
C. Filiform steel elements embedded in a net-like shape within the leveling layer in which the detached parts of the mosaic were relocated. These elements are anchored to the stone by means of folded steel nails. These elements are 5. They have been detected instrumentally, with two of them confirmed with photographs. (Photo23)
We believe that the decision to proceed in this manner was correct for what it regards the type A. and B. The application of these pins has even allowed the mosaic to survive to this day. Nevertheless, we must report that the crosses mounted on the internal pins, which are exposed to the atmosphere, exhibit oxidation phenomena with the production of copper chloride. These elements will need to be removed. (Photo 24)
Type C., which we believe to be iron, inserted within the mortar used to reapply some detached sections of the mosaic, needs also to be removed.

22. A cross-shape head of the brass pins

23. Metal wires introduced into the mosaic mortar setting during the restoration of the '80s

24. Brass plates shaped like V and Z

Unidentified Material

Near the brass pins, within the mosaic, spherical filiform clusters of unidentified material were found. This material does not appear to be metallic because it was not detected by either the geo-radar or the pacometer. We believe it could be a solution that the restorers had used to distance the mosaic from the wall at the time of inserting the brass pins. It will be interesting to learn more about the origin of these inserts. (Photos 25)

25. Unidentified material discovered with the endoscope into the mosaic gap

Stuccoing

As in the case of the metal pins, the stuccoing represents an important element of the current state of the mosaic. These are the result of at least three restoration interventions that have followed one another over the last five centuries and are very different from each other. We know from Karlo Bakuradze that at the time of his arrival, numerous and varied stuccoing stood out on the surface of the mosaic, an evident result of previous interventions. Some of these were left in brown color, some were finished with porporina, others hinted at a mimetic rendering simulating the mosaic. (Photo 26-27) A part of this stuccoing was removed and replaced, while a good percentage was left in place. To these were added all the stuccoing carried out during the intervention of the 1984-90, executed with methods that we will see in detail in the chapter dedicated to the intervention of Karlo Bakuradze. An interesting note is represented by the extensive stuccoing with a dark blue background with which, presumably at the beginning of the 19th century, the lower part of the mosaic was regularized. As is evident from the magnificent historical photo from the mid-19th century [10] on the occasion of the restoration that followed the second fire, it was desired to consolidate the mosaic simply, but I would add providentially, by covering it with a plaster skim. This plaster was then painted with a dark tone, reminiscent of black smoke.
Probably to testify that at the time the mosaic surfaces had not yet been cleaned thoroughly. With this intervention, it was therefore desired to consolidate, rectify, and uniform the lower part of the mosaic from a chromatic point of view, straddling the lost and residual bands. (Photo 28)

26-27. Traces of black smoke are still clearly visible on the surfaces of the mosaic

10. The photo comes from the archive of the National Museum of Tbilisi and was kindly provided by Prof. Davit Lortkipanidze

28. Plate of stuccoing

Historical Interventions

As we have seen in the previous pages, we know from sources that the Gelati Monastery has been vandalized at least twice, once in 1508 and again in 1759. On both occasions, the church was set on fire.[1]
Evidence of these events can be seen in the fragmentary state of the mosaic, of which only a little more than 50% remains, and the traces of black smoke still visible on the tessellated surface.
We know from a historical photo that before 1874, the mosaic was restored and the lower part was re-plastered with figurative frescoes and partly with a dark background. (Photo 1)
This is an incredibly important piece of evidence that provides us with a series of information. Firstly, the fresco component of the area once occupied by the mosaic is larger than it is today. This means that for a certain period, part of the mosaic was covered with plaster.
The only explanation for this is that after the fire (the first or the second), the restorer (or the artist) realized the instability of the remaining mosaic and probably demolished part of it but preserved as much as possible. The only means available at the time was to cover it with a layer of plaster, the same on which a layer of dark blue paint was then applied.
Observing the photo, it is evident that we are dealing with a restoration that not only sought to save the remaining mosaic but also to restore legibility to the whole, both by reproducing half of the lost figures and by providing a homogeneous chromatic background, probably consistent with the black smoke that still veiled the church's surfaces. The photo also allows us to appreciate other details of the mosaic's state of conservation in the second half of the 19th century. For example, the large gap in the upper right bowl is visible; damage to the Madonna's face can be seen; it is noted that the Child's foot was already pictorially integrated, and numerous small gaps are distributed over the entire surface of the mosaic. Generally, we also learn that the surface is effectively covered by a dark veil, as highlighted in Christ's right hand. Another important piece of information is that almost the entire lower half of the apse is affected by a severe phenomenon of salt crystallization, a clear sign that the problem is much older than any modern environmental pollution and that we must hypothesize that the state of the roofs was already in poor condition at the time, allowing rainwater to enter the masonry structure. Finally, it is noted that the golden band under the Child's foot passes underneath it, while in Bakuradze's reconstruction, the foot is above the band. As expected, there do not appear to be any metallic elements.

1. An image of the mosaic dated 1974

Some of the things we noticed in the photo are reported with the photos that Karlo Bakuradze skillfully took at the beginning of his intervention. We present some of the most significant ones. The photo of the lower part of the Child allows us to appreciate in detail the position of the foot and the old pictorial restoration, as well as the many gaps that alter its surface. (Photo 2)

2. A photo of the foot of Christ before the restoration of the 80's

1. Shemokmedi Gulani (Q103b), 1749, Georgian National Center for Manoscript, (plus an added later inscription) Kindley provided by Ketevan Asatiani

In the next one, we see the lower part of Archangel Michael still covered by the layer of plaster painted dark blue, also dotted with gaps. (Photo 3)
We can appreciate the layer applied to the tesserae in photo 4. (Photo 4)

3-4. The images show the presence of a dark stucco overlapping the mosaic

Photo 5 provides us with further important information: the restorer who preceded Bakuradze used at least two techniques for integrating the gaps: one by filling the voids with a brown background; a second by treating the background with paint in a yellow tone on which lines were painted with a brush to simulate the mosaic's texture. (Photo 5) It is worth reporting the photo that documents the face of Mary on which, in 1984, the same damages we see today appeared. A final photo we want to present is the one representing the lower part of Archangel Michael: from this, we can see that under the plaster painted dark blue, the trace of a fragment of an angel's wing appears.

This is clear evidence of the presence of two restorations that followed the fires and that what we see surmounting the mosaic in the lower part and covering it with a black background is probably the second, realized after 1759. (Photo 6-7)

5. Two different techniques used for integrating the gaps before the restoration of the '80s

6. Evidence of the presence of two restorations that followed the fires

7. The face of Mary on which, in 1984, the same damages we see today appeared.

From this we understand that a red pictorial finish with red ochre was spread over the plaster made of lime and dispersed aggregates of various shapes and colors.

The stratigraphy continues with a green pictorial layer made up of Orpiment yellow (of which larger fragments can be observed) and Prussian blue. A blue layer of Prussian blue was spread over the surface.

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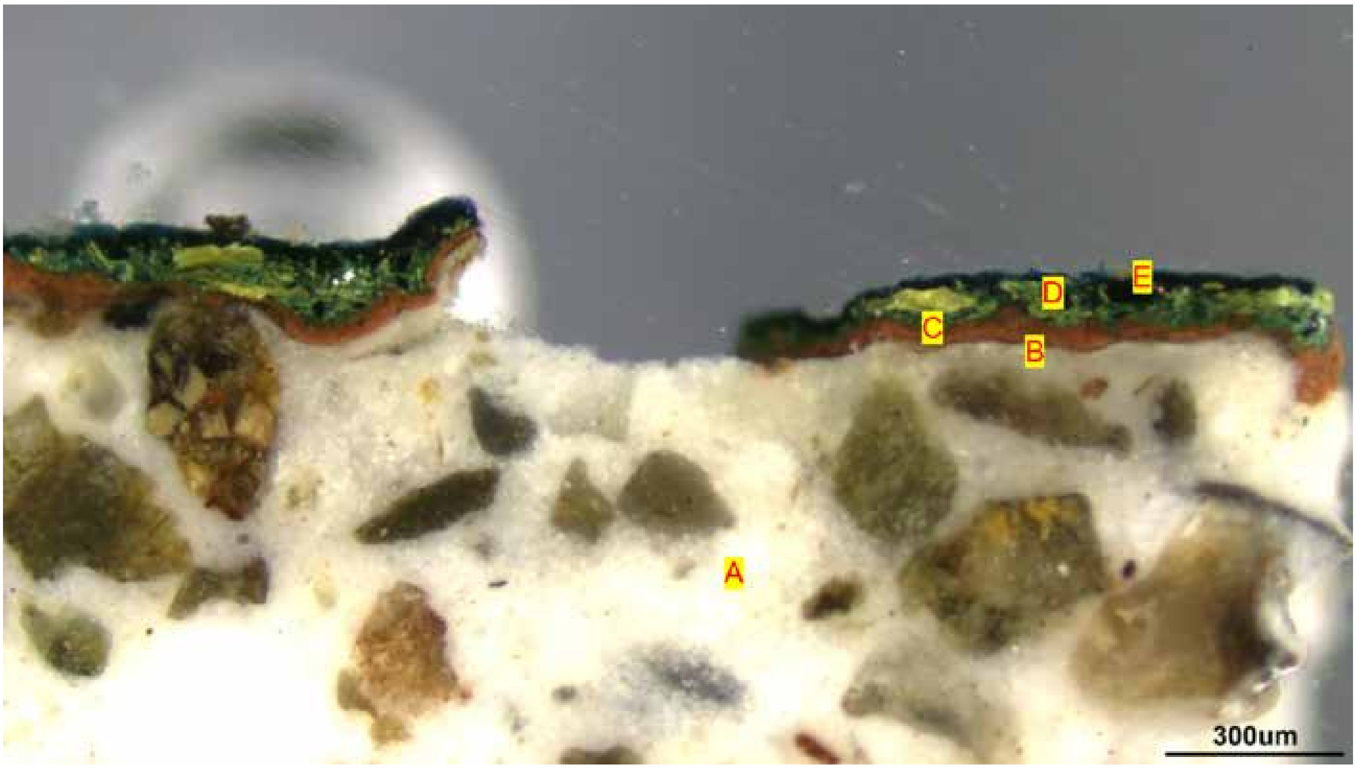
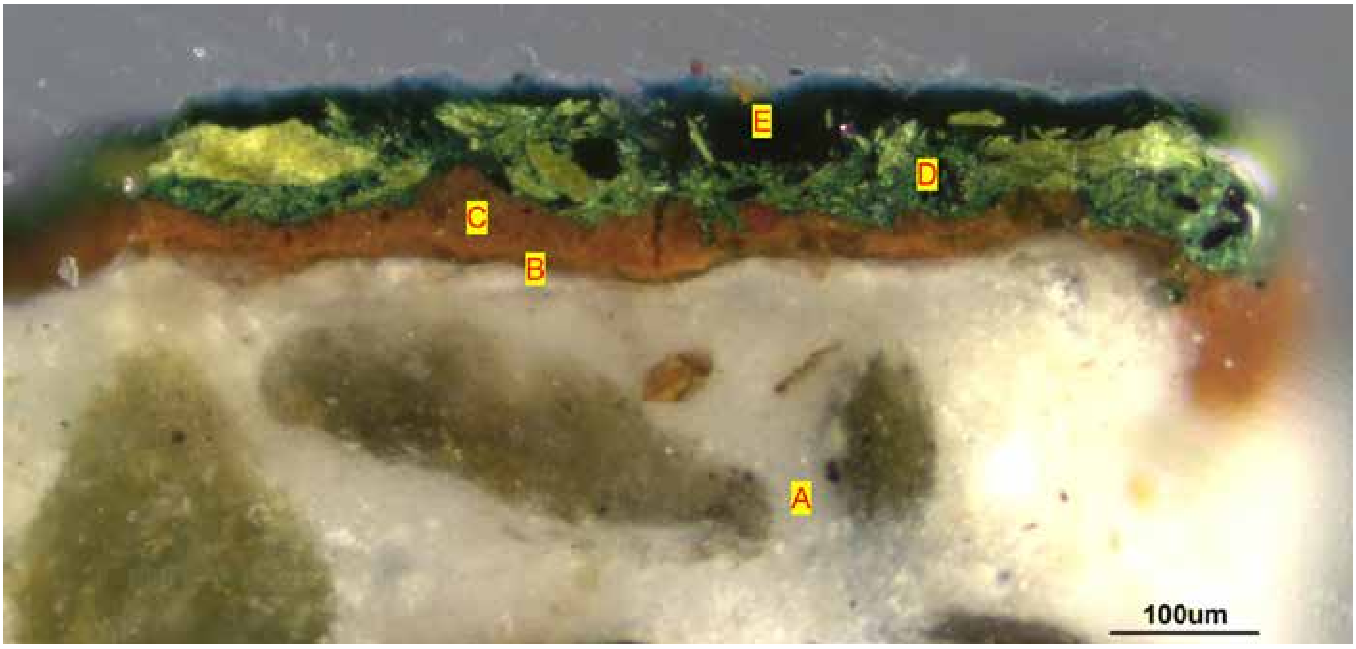


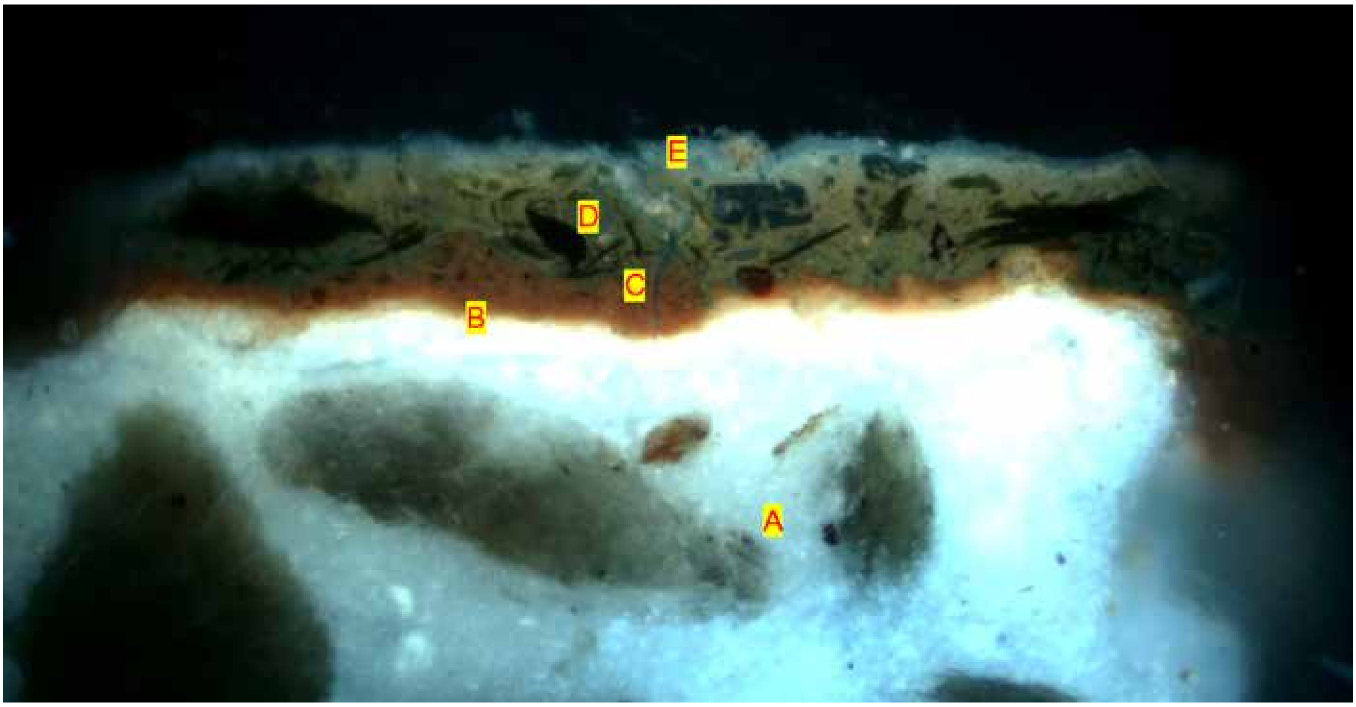
This area has been investigated with SEM/EDS and micro-FTIR and the results told us that we have:

Stratum	Layer nature for correlation between optical microscopy and ESEM-EDS analysis
A	White plaster based on lime with dispersed aggregates of various shapes and colors.
B	Thin layer of organic nature. Maximum thickness 10 µm.
C	Red layer, thickness of 15-25 µm, with calcium carbonate and red ochre
D	Green layer, thickness of 45-50 µm, with orpimento and prussian blue.
E	Thin layer of prussian blu, thickness 15-20 µm.

In this regard, Karlo Bakuradze left us with a fascinating hypothesis that we are currently unable to confirm or refute: "...at the end of the 16th century, this damaged part of the mosaic was plastered and repainted with a fresco, while in the 19th century, after plastering it again, it was repainted with oil colors."[2]

Photo of the sample as is at MPOM





2. Bakuradze, ibidem, page 2

8. An image of the scaffolding of the 1984-90 restoration campaign

When Karlo Bakuradze first touched the mosaic, he must have felt a shiver of fear. Not so much because of the scaffolding on which he had climbed, whose safety standards we can probably doubt (Photo 8), but because of the situation he found. A mosaic largely detached from the masonry support, full of gaps, with various types of fillings interfering with the original texture, dirty, and still partially patinated with black smoke.

We must add that the 1980s were the time when the technique of in situ consolidation of mosaics took its first steps, to be fully codified in the 1980s. Therefore, Karlo Bakuradze faced this complex intervention with a rather limited set of technical tools. But his methodological approach was not limited because his choices were all widely acceptable. We recall his words again to appreciate his strategy: "...We considered the most appropriate conservation methodology to save the mosaics of Gelati.

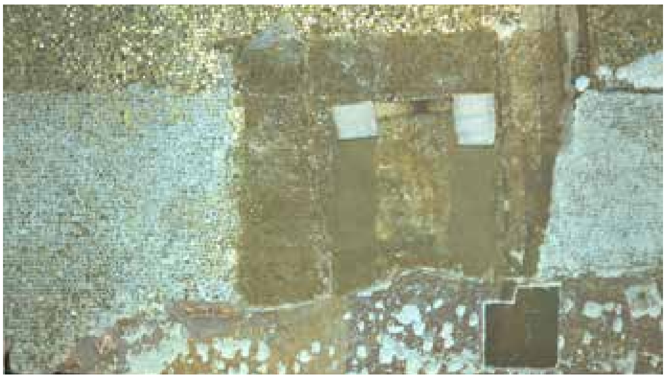
Three types of mosaic conservation are known:

- 1. Both the mosaic and the plaster are detached and deposited on a new surface, where it is reconstructed either on the original plaster (if it is healthy) or on another.
- 2. The layers of the mosaic and plaster are detached but are still solid, and it is possible to consolidate them by injecting binder/mortar (glue, lime, etc.).
- 3. The mosaic is reinforced with metal plates, for example, through so-called dowels.

As ascertained, the flow of water and humidity over the years have negatively influenced the lime plaster of the Gelati mosaic. Both the base and the surface of the lime plaster have lost the ability to absorb any liquids/binding mortars, which in this case would weigh down the plaster. It was physically impossible to fix these surfaces. Therefore, we considered it more justified to reinforce the Gelati mosaics mainly with metallic elements, which would keep the mosaic and its plaster solid. However, in a specific case, we had to resort to the first restoration method.

This concerns the entire lap of the Virgin Mary's dress (4 m2) and part of her halo, detached from the wall, with disintegrated plaster, crumbled lime, and detached parts that were impossible to reinforce with metal plates and mortar edges. We had to remove this area piece by piece, replace the base, and put it back in place. We divided the entire area into 12 parts and performed the aforementioned intervention. Afterward, we filled the missing areas and applied the glazes. It took us a year to complete this work. (Photo 9-10)

The rest of the mosaic was restored using the third method. The consolidation of the mosaic by means of dowels is one of the most common methods in modern mosaic restoration. The dowel we used is a brass rod with a copper cross-shaped plate at the end (in the past, dowels were made of iron). During the fixing of the mosaic with dowels, we were guided by the basic principles of this method. First, the bulging area of the mosaic is determined. In advance, its grid is prepared on tracing paper so that the distance between the squares is precise and the tesserae are numbered. The surrounding area is covered with a thin fabric (bandage) and epoxy resin/wood glue to reinforce it. The protruding area is also covered with fabric cut to the shape of the plate with which we will fix this area. After the glue dries, this fabric is removed with a scalpel. The mosaic tesserae are transported onto it, cleaned of plaster, as well as the framed plaster layer of this area. The underlying plaster is drilled with drill bits of different sizes (first 5mm, then 7mm, and 10mm) so that vibrations are minimal. Finally, the drill enters the stone to a depth of 3-5cm. A clamping axis is placed in the entire depth of the drilled stone, which can be screwed from the inside and outside and is fixed to the coplanarity of the stone surface with epoxy glue. When the glue dries, a copper plate is fixed to the clamping axis, inserted in place of the previously removed tesserae. This plate should closely approach the plaster. (Photo11)



9-10. Two images showing the process of detachment of the mosaic.

11. An image showing the team of restorers of Bakuradze'e team. On the left we can see a young Lado Gurgenadze

Subsequently, the phase of fixing the tesserae in their intrinsic place begins. These parts are gradually filled with plaster (first halfway, the remaining part - still halfway, and finally filled with the plaster mass, which is applied to the removed mosaic tesserae). These tesserae are fixed to the surface with glue. To reinforce the mosaic surface, it is necessary to apply a laminated paper with a shock-absorbing stick, some layers of soft material (several layers of bandages and sanitary napkins), and another wooden board. When the glue hardens, the space between the tesserae is filled with lime tinted in the original color in which they were placed. Subsequently, the fabric is removed from the surrounding area. Obviously, the tesserae that are remounted in their place have become higher by the thickness of the previously inserted copper plate, i.e., 2mm, but it is not visible from the outside. In the future, when a restorer needs it, they will easily find the intervention area. (Photo12)

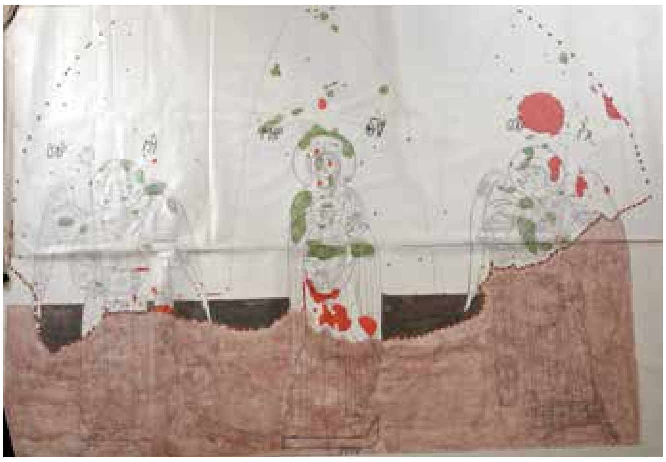
These types of interventions were applied in very large degraded areas, where both plaster layers were removed from the wall. Instead, where the degradation zone was small, interventions of another type were made. Without gluing the fabric, we took two or three tesserae, rarely a single tesserae, drilled the surface to the wall, and connected the clamp shaft in the drilled wall, fixing the copper plate above the tesserae. After a glaze, these plates are hardly distinguishable from the surrounding tesserae. They are not harmful to the mosaic itself, nor do they weigh it down.

In this case, the modification we introduced regarding the size of the dowel should be particularly important. Compared to the common size of the dowel, we made it smaller. The length of the clamp shaft we used is 5cm, and the thickness of the copper plate is 2mm. According to the restorer Milorad Medić, if a dowel of these dimensions manages to securely fix the mosaic, obviously its artistic effect is undeniable: it is less evident on the mosaic's surface. We have no doubts about the reliability of the clamps used in Gelati, and therefore the size we chose seems fully justified. (Photo13)

12. An image of Karlo Bakuradze when filling a lacuna by inserting tesserae

13. The lower part of the Virgin during the process of filling lacunae with painted tesserae

The work carried out in Gelati, in addition to the interventions for the consolidation of the mosaic, also included the cleaning of the tesserae, the filling of the gaps, and the integration. In some cases, it was necessary to remove dirt and sometimes oil paint from the tesserae, which was really a great complication. The filling and integration of the gaps were carried out in the so-called less artistic areas, for example, the background or the area of the halo.



The areas where the artist's stylistic handwriting was visible were left intact. For example, the large stain on the right cheek of the Virgin Mary, made with oil colors, was not touched. We removed the 19th-century stuccos from both the painting and the mosaic. In the lower part of the mosaic, we consolidated the entire background mosaic that had just appeared, with the relative filling, from below with metal plates and lime mortars. The restored mosaic background here is relatively simple because the cavities between the tesserae were filled with lime mortar and left white. Quite large parts that represented an imitation of the mosaic were also restored."[3]

One thing that strikes us very much about Bakuradze's attitude is the attention he pays to documentation and the artistic quality of the integrations made with painted mortar. We have received mappings of considerable size, rich in details.
(Photo14-16)

14-16. Graphic documentation made during the 1984-90 restoration

3. Bakuradze, ibidem, pages 4-6

So virtuosic that some of his panels are preserved on display at the Kutaisi Museum. (Photo17-19)
Apart from this detail, we feel we can say that the clarity with which Bakuradze describes the situation he faced is the worthy parallel of the quality of the operational choices applied. If we wanted to add another comment, we can easily imagine what other scenario we could have expected from an intervention that aimed to be important and decisive in the 1980s. A scenario that did not materialize thanks to the modern vision of the Georgian restorer.

Finally, we want to remember another member of the group who worked on the mosaic in the 1980s, Lado Gurgenadze, whom we had the pleasure of meeting during a visit to the scaffolding of the Gelati mosaic and whose desire to share the experiences of that intervention we appreciated. Lado was extremely generous in reporting unwritten details of the intervention and providing us with the photographic documentation that we can treasure today in the comparisons we need.
To him, of course, go our esteem and thanks. (Photo20)

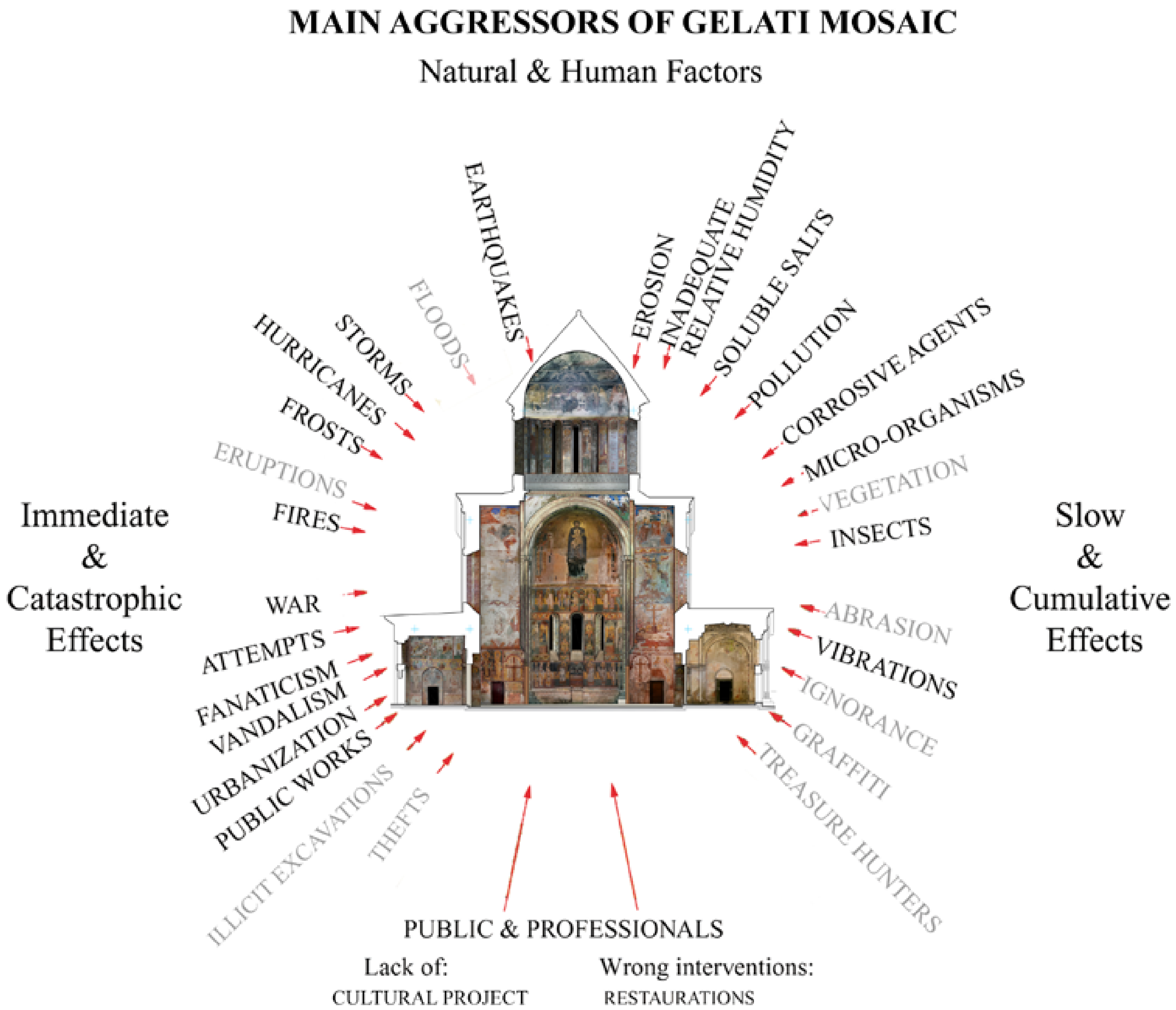
17. Museum of Kutaisi. Karlo Bakuradze. The Virgin Mary of Gelati.
18. The main hall of the Museum of Kutaisi.
19. Museum of Kutaisi. Karlo Bakuradze. The Archangel Michael.
20. 2023, Lado Gurgenadze during a visit in Gelati.

Risk Assessment

Deterioration

The current state of preservation of the Gelati Monastery mosaic is the result of the interaction of at least five factors: the materials and techniques used in its creation; the long interaction with the structure containing it; the series of events, both traumatic and non-traumatic, that have marked its history; exposure to the surrounding environment; past restoration interventions. All these elements have played a synergistic role, each contributing to the overall phenomenon of degradation.
It is very difficult, if not almost impossible, to determine exactly to what extent each factor has contributed to the current state.

What is important is to understand how, as a whole, we have arrived at the current situation and to correct its premises.
Let's examine the extent to which the problem of deterioration applies to the various components of the mosaic, starting with the macro aggressors, both natural and human, which, in hierarchical order, may have generated immediate and catastrophic effects.



Immediate and Catastrophic Effects

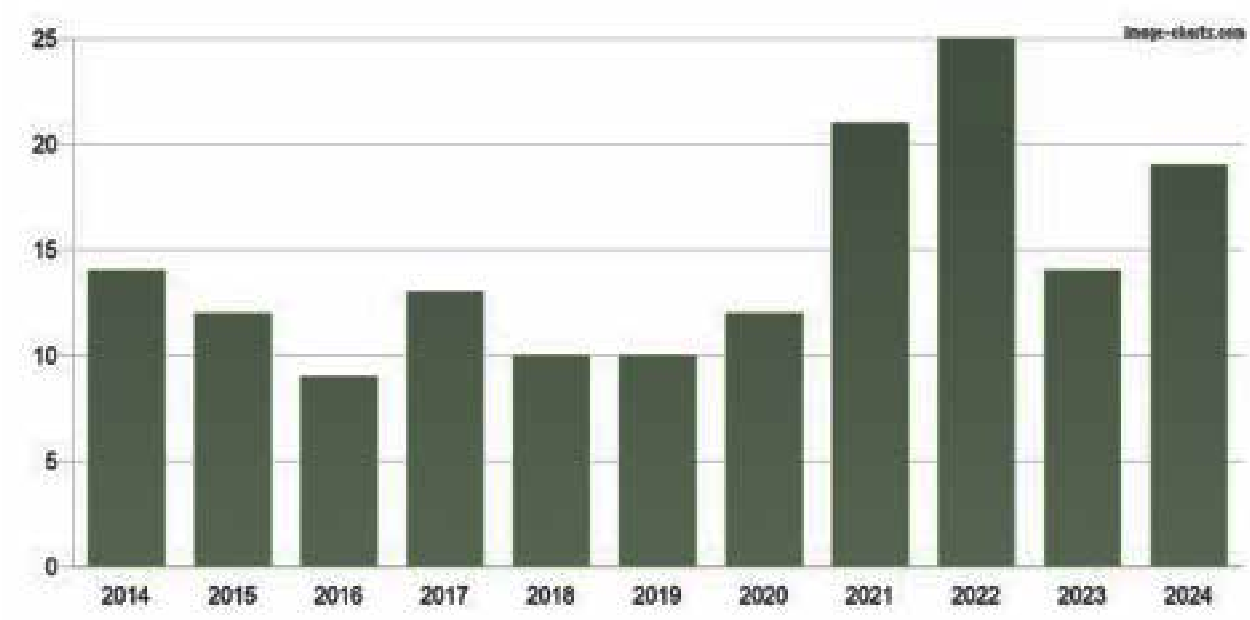
Earthquakes

A total of *146 earthquakes* with a magnitude of four or above have struck within 300 km (186 mi) of Kutaisi in the past 10 years. This averages to 14 earthquakes per year, or 1 per month. On average, an earthquake will hit near Kutaisi roughly every 25 days.

A relatively large number of earthquakes occurred near Kutaisi in 2022. A total of 25 earthquakes (mag 4+) were detected within 300 km of Kutaisi that year. The strongest had a 5.3 magnitude. (Photos 1-2). [1]

Likelihood: Likely; *Severity*: High.

Yearly earthquaes within 300 km of Kutaisi with magnitude of 4 or above



MAGNITUDE	EARTHQUAKES	PERCENTAGE
MAG. 4	140	95.89%
MAG. 5	6	4.11%
MAG. 6	0	0.0%
MAG. 7	0	0.0%
MAG. 8	0	0.0%
MAG. 9	0	0.0%
MAG. 10	0	0.0%

Strongest earthquaes near Kutaisi in the past 10 years

Strongest earthquakes near Kutaisi

STRONGEST IN 10 YEARS:	STRONGEST SINCE 1900:
MAG 5.3	MAG 7
On Sep 27, 2022 18:08.	On Apr 29, 1991 13:12.

1. Kutaisi Earthquake Report, https://earthquakelist.org/georgia/imereti/kutaisi/#latest-earthquakes-mag-2-distance-smart).

Storms

From the reports of Karlo Bakuradze, Leila Khuskivadze, and many of the people we interviewed, wind, rain, and snow have been invasive presences at Gelati. This is still evident today in the dome windows, which were bricked up in a crude attempt to prevent water and wind from entering the church. These phenomena at Gelati can take on disastrous characteristics, and some of the damage we see today on the mosaic is likely due to these factors. For example, wind has been observed creating a strong, recurring draft that enters through an opening in the apse roof, penetrating and circulating behind the detached area of the mosaic. As noted in the study by Tariel Kiparoidze and Lasha Shartava,[2] ventilation was even induced for conservation purposes.[3] This phenomenon is not new, as Karlo Bakuradze also mentions it in his report.[4] Regarding the infiltration of water and wind, it is unnecessary to elaborate, as the damage this can cause to the internal mortar layers of the mosaic, the tesserae, and the system of solubilization and salt migration is all too obvious. Karlo Bakuradze also complained about this problem in the 1980s. (Photos 3). *Likelihood*: Likely; *Severity*: Significant

Frost

In the presence of wet or even slightly damp surfaces, frost can cause damage: from surface detachment of the tesserae to the fall of tesserae and the pulverization of the internal mortars of the preparatory layers.
Likelihood: Unlikely; *Severity*: Moderate

Fires, Vandalism, War

History tells us that the Gelati Monastery and the church, in particular, have suffered at least two known fires in the last 5 centuries. The first, in 1508, was caused by the *Tartars* (read Ottoman Turks), the second in 1759 by a tribe from the North.[5] Traces of these fires are macroscopically recognizable in the large gap at the base of the apse's bowl, where the mosaic has been virtually swept away for more than 50% of its extent, and more lightly, in the deposit of black smoke remaining in some areas of the mosaic despite the presumed cleanings carried out in the 18th, 19th, and 20th centuries. (Photos 4). While we may optimistically think that vandalism seems unlikely in the future, we cannot ignore that the risk of fire is always present in places of worship where carpets, drapes, wooden coverings, candles, and incense burners are always present.
Regarding the risks of war, Karlo Bakuradze also mentions the problem of the impact of low-flying warplanes on the mosaic. And this is not a matter of many years ago.[6] *Likelihood*: Likely; *Severity*: High

Lack of Conservation Intervention

Given the current state of the mosaic, a significant risk factor would be a lack of conservation intervention. In practical terms: doing nothing. This would leave the mosaic exposed to all currently potential risks.
Likelihood: Unlikely; *Severity*: Moderate

1-An opening in the apse roof today produces access for wind.
2. The flame shows how wind can circulate behind the mosaic.
3. Traces of smoke are still evident on the surfaces

2. T. Kiparoidze, L. Shartava, "Technical report with photo and graphic documentation regarding the new sondages," Tbilisi, 2022
3. Initially, the idea of ventilating to dry the walls is not wrong. However, it is inappropriate to facilitate forced circulation behind a mosaic at risk of collapse.
4. K. Bakuradze, ibidem, page 2
5. Mentioned in the manuscript of the so-called Shemokmedi Gulani (Q103b) executed in 1749 (Georgian National Center of Manuscripts), kindly reported by the Specialist Ketevan Aasatiani;
6. Karlo Bakuradze, ibidem, page 2

Incorrect Interventions

The history of cultural heritage is marked by a long list of negative examples of incorrect conservation interventions. In the case of mosaics, this scenario often involves the detachment of mosaic surfaces and perhaps their reapplication on cement or resins, or in many other options to which human unpredictability has accustomed us. *Likelihood*: Unlikely; *Severity*: High

Urbanization

The Gelati mosaic is part of a unique and unified context that includes the Church, the Monastery, and the surrounding landscape. It is only in the unity and respect of this whole that true conservation work can be achieved. *Likelihood*: Likely; *Severity*: Significant

Slow and cumulative effects

Now let's analyze the risk factors with slow and cumulative effects.

Vibrations

In the 1970s, the Gelati mosaic suffered from the consequences of explosions in the Motsameta stone quarries. These may have significantly contributed to the detachment of the mosaic portion from the wall structure, which was later anchored by Karlo Bakuradze with brass pins. It took a movement supported by public opinion and a strong press campaign to stop the phenomenon.[7]

Today, it will be sufficient to restore the compactness of the mosaic structure by consolidating and filling the voids behind the mosaic in the detached parts.

Likelihood: Possible; *Severity*: Significant

Inadequate Relative Humidity

High relative humidity can facilitate the formation of condensation on the mosaic surfaces. This can activate the degradation of glass, metal laminae, and tesserae, leading to progressive deterioration of the original material, up to the fall of tesserae and *cartelline*. Additionally, fluctuations in relative humidity can facilitate salt instability, supporting processes of solubilization and crystallization, which are particularly damaging to the mosaic and decorated surfaces. *Likelihood*: Very Likely; *Severity*: Significant

Soluble Salts

Closely related to the previous topic is the problem of the presence of soluble salts on the decorated wall surfaces of the Gelati church. We find abundant traces of these on the mosaics, and we know that this issue is a significant problem for painted surfaces.

Regarding the mosaic, we have been able to verify how closely this is related to the seasons and the resulting climate, and we have also been able to observe evident damage on the surfaces.

Likelihood: Very Likely; *Severity*: Significant

Pollution

Although pollution does not currently seem to be a problem, the presence of soluble salts suggests that it may have been in the past.[8]

Likelihood: Very Unlikely; *Severity*: Moderate

Microorganisms

For the moment, this does not seem to be an issue affecting the mosaic surfaces. We use the conditional because, in particular situations of relative humidity, temperature, and salts, the risk of microorganisms is always lurking.

Especially on surfaces where there may be organic residues from previous restoration interventions or biological residues.

Likelihood: Unlikely; *Severity*: Moderate

Insects and Animals

From the endoscopic investigation, (Photo 5)

we have seen that the detached mosaic suffers from the presence of insects inside the structure. These can exert both a mechanical action of crumbling the mortars and a chemical action of attacking the calcium carbonate of the mortar due to the acidic products of their metabolism.

Regarding animals, we know from Karlo Bakuradze[9] that bats have been a problem, both before and during his intervention. In addition to the mechanical damage these animals cause to the tesserae, the deposit of their droppings represents a source of organic deposits with a high salt content.

The insect problem will be eliminated by restoring the voids behind the mosaic. Animals do not currently pose an active problem, and any organic deposits will be removed with cleaning.

Likelihood: Likely; *Severity*: Moderate

4. Spiders and other insects were detected inside the detached areas of the mosaic

7. N. Ghvinepadze. "...it was built by Aghmashenebeli!", newspaper "Communist," January 1, 1988.
8. Steffen Laue, "Church of the Virgin (Gelati) Salt analyses – Part II," Potsdam, 2024
9. Karlo Bakuradze, ibidem, page 3

Old Restoration Interventions

It is known that the mosaic has suffered two fires, in the 16th and 18th centuries. Consequently, we can interpret with some certainty that these fires were followed by at least two restoration interventions.

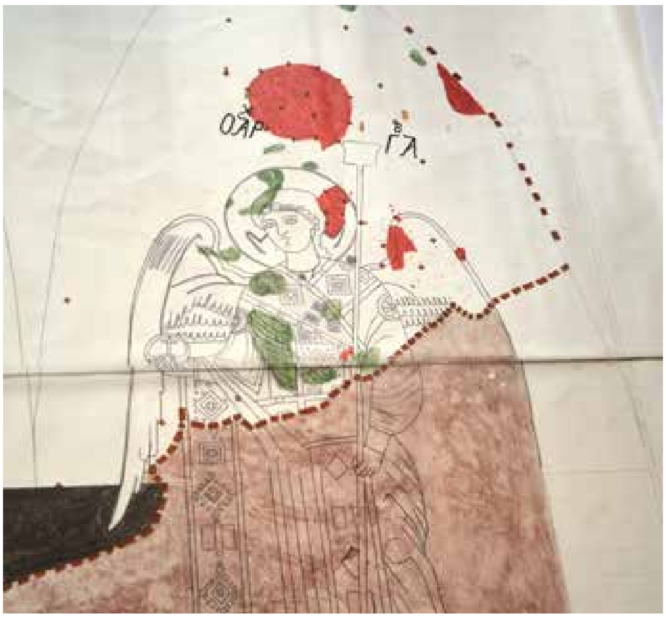
What materials were used for consolidation, filling, and, even more importantly, for cleaning, we do not know today. However, we do know that traces of chlorine[10] were found in the silver lamina tesserae, which activated a form of irreversible and very damaging deterioration for the original material. Regarding the material used to consolidate the mosaic, we have some clues that give us interesting suggestions. For example, the fact that to consolidate the lower part of the mosaic, which probably survived the two fires in precarious conditions, the restorers decided to apply a layer of plaster over the mosaic and then paint it a dark blue color. This is clear evidence that the mosaic was still dark with soot.

We also know from Karlo Bakuradze that when he began the restoration in 1984, the mosaic presented numerous inclusions in painted plaster to close gaps. (Photo 7)

Today, we still find traces of those interventions, and in some, we have also found purpurin, to simulate the gold of the tesserae. In general, these materials do not seem to have damaged the mosaic. However, it is good practice to remove them and replace them with stable and compatible materials with the originals.

Something different, however, are the inserts that appear to be made of iron applied with the function of a net within some mortar patches made in the 1980s intervention to reapply the mosaic. These represent a risk element because iron is unstable and tends to oxidize and swell over time.

Likelihood: Likely; *Severity*: Minor



Smoke from Candles and Incense

The natural life of a place of worship involves the use of candles and incense as focal points of the liturgy that takes place in sacred buildings.

Unfortunately, the result of this liturgy is the release of smoke rich in fats into the internal environment. The smoke rises and settles on the surfaces, in our case, the frescoes on the walls and the mosaic of the apse. The patina that forms as a result of this process has three negative characteristics:

- 1. Its covering nature, which gradually dulls the surfaces.
- 2. Its dark tone, which dulls the color of the surfaces and gradually nullifies the reflective power of the mosaic's glass.
- 3. The creation of a greasy and adhesive surface that provides an excellent bed for dust deposition in the air.

Far from suggesting changes to practices related to centuries-old liturgy, we can instead improve the process by maintaining the same habits but drastically reducing their negative effects.

Likelihood: Very Likely; *Severity*: Moderate

Dust

Dust is a subtle aggressor whose damaging action manifests through slow and cumulative effects. It is constantly brought into the monument by the visits of pilgrims and tourists, whose movement contributes to raising fine particles that settle on the surfaces of both the mosaic and the frescoes.

The surfaces, made viscous by the presence of greasy fumes from candles and incense, provide an ideal environment for dust accumulation, which attaches and penetrates the materials, further aggravating the situation.

The contamination not only compromises the clear reading and brilliance of the mosaic but can also interfere with the properties of the various materials, leading to a faster degradation of what remains of its original appearance.

It is estimated that the accumulation of dust can lead to a gradual loss of detail and definition, compromising the perception of the mosaic over time.

Likelihood: Very Likely; *Severity*: Moderate

5. A drawing produced during the 1984-90 restoration

10. R. Falcone, N. Favaro, M. Vallotto, Stazione Sperimentale del Vetro, REPORT N. 000210569, Venice 2024, p. 24

Risk Matrix

The Risk Matrix is a recognized assessment tool used to identify and visualize the risks associated with our monument.
In the next Plate, we have stored all the risks, associating each with likelihood and severity values. By multiplying these two factors, we obtained a risk index that allows us to quantify and compare the impact of the various aggressors.

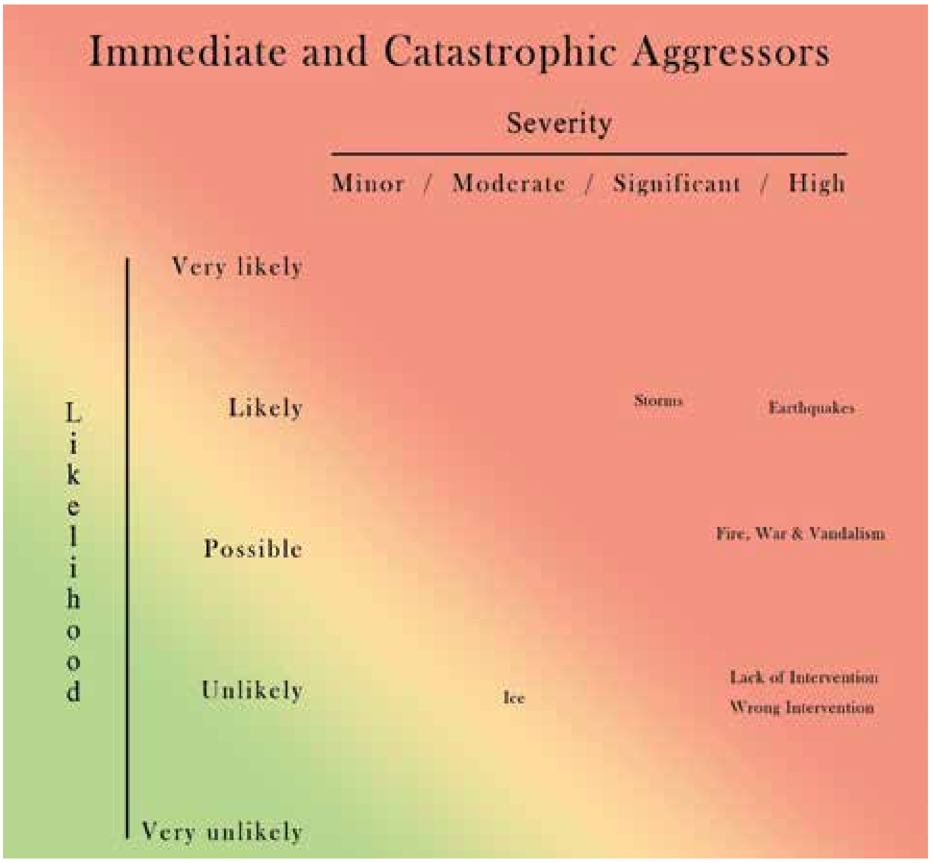


Plate 1. *Severity and Likelihood of Immediate and Catastrophic Aggressors*

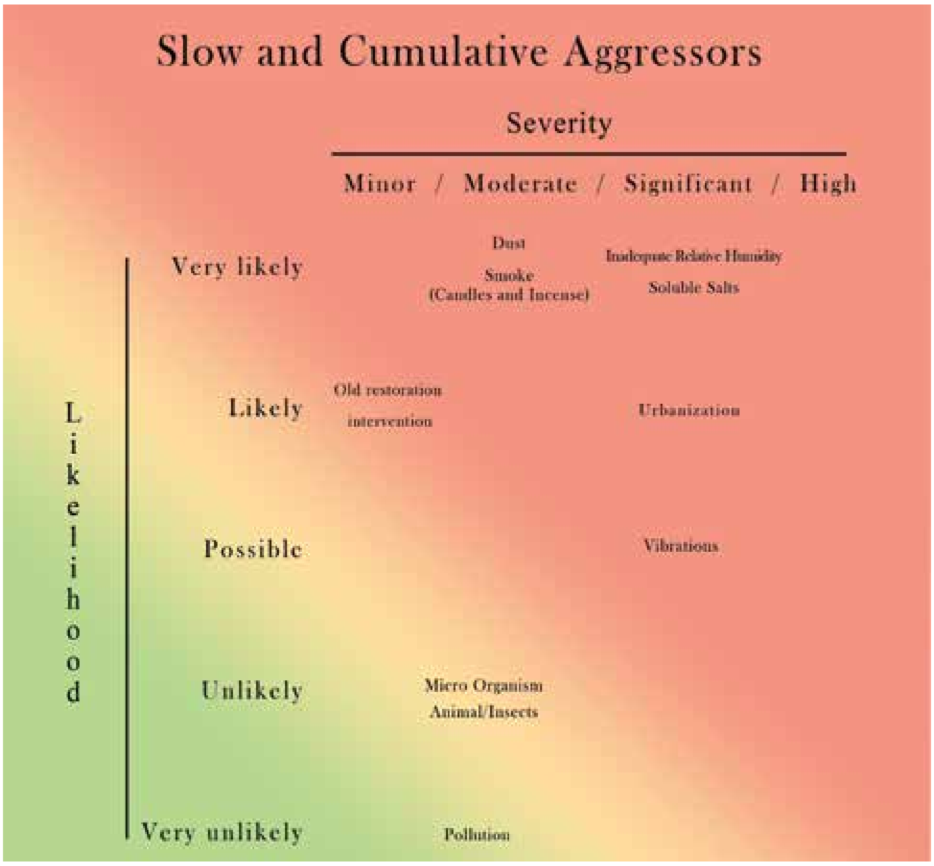
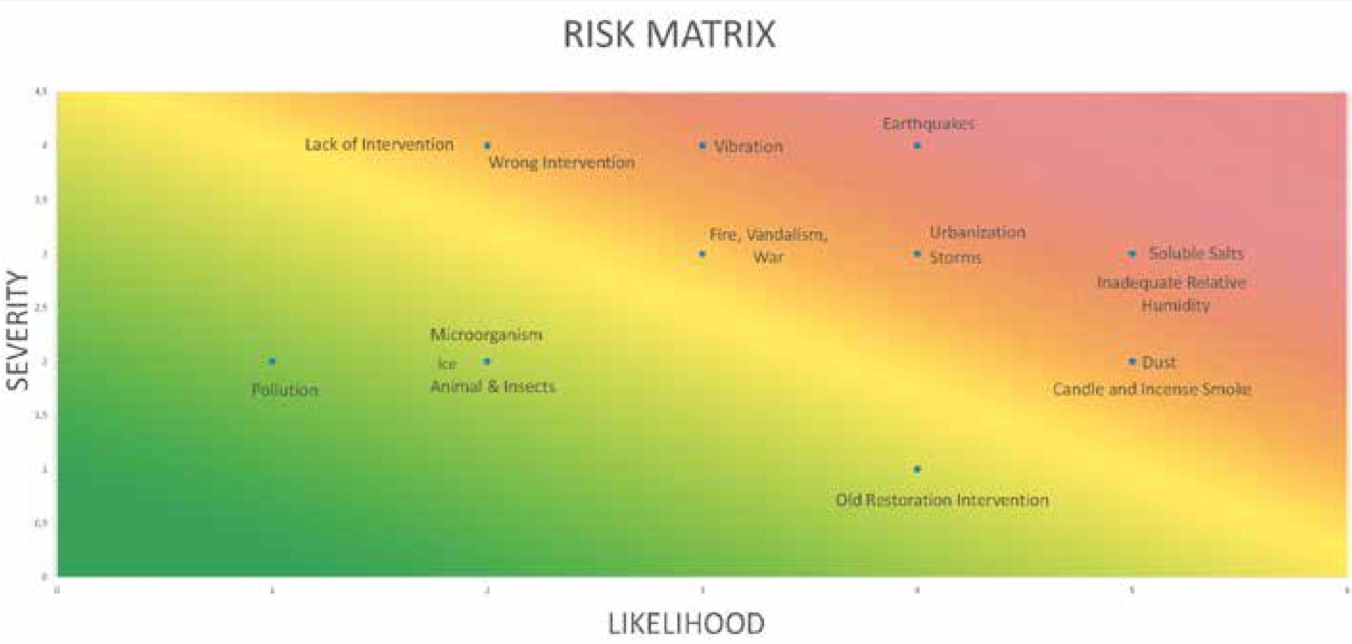


Plate 2. *Severity and Likelihood of Slow and Cumulative Aggressors*

id	Aggressors	Risk Description	Impact Description	Likelihood	Severity	RISK (L*S)
4	Earthquakes	In the last 10 years, Kutaisi has recorded 146 earthquakes with a magnitude of 4 or higher, averaging 14 events per year.	The risk of structural damage to the mosaic and the entire church is high, potentially leading to losses in artistic and cultural integrity.	4	4	16
12	Soluble Salts	The presence of soluble salts on the surfaces of the mosaic is a problem related to varying climatic conditions.	These salts contribute to surface degradation and can cause aesthetic and structural damage.	5	3	15
11	Inadequate relative Humidity	High relative humidity can promote the formation of condensation, damaging the materials of the mosaic.	Deterioration of original materials could lead to the falling of tesserae and sheets, compromising the mosaic.	5	3	15
5	Storms	The Gelati area is frequently subjected to wind, rain, and snow, causing structural damage, especially to the mosaic.	Continuous exposure to these elements can severely compromise the preservation of the mosaic, accelerating degradation	4	3	12
1	Fire, War, Vandalism	The monastery has suffered historical fires, and there is currently a fire risk due to the presence of flammable materials. Vandalism and war damage are also concerning.	Fires can cause substantial damage to the mosaic and the structure, while conflicts may lead to external and structural damages.	3	4	12
16	Urbanization	Urbanization can alter the surrounding landscape, compromising the visual and cultural integrity of the monastery, and its spiritual significance.	The development of services can cause an increase in traffic, noise and air pollution, threatening the serenity and spirituality of the place.	4	3	12
15	Dust	The dust, stirred up by pilgrims and tourists, actively settles on the mosaic surfaces, exacerbated by the greasy residues from candles and incense	Dust accumulation obscures the visual integrity of the artwork and can chemically and physically alter the original materials, resulting in a gradual loss of detail and vibrancy	5	2	10
14	Smoke of Candles and Incense	The use of candles and incense during liturgical practices produces greasy smoke that settles on surfaces, particularly affecting the frescoes and mosaics.	The greasy deposits not only diminish the visual clarity and vibrancy of the mosaics but also interfere with the materials' properties, accelerating degradation	5	2	10
7	Vibrations	The mosaic has suffered damage due to explosions from stone quarries, leading to detachments and the need for consolidation.	Vibrations cause material distress and potential detachment from the wall support.	3	3	9
3	Wrong Intervention	Poorly executed conservation interventions can further damage the mosaic, such as detaching surfaces or using inappropriate materials.	Such errors can compromise the mosaic's stability and aesthetics, causing irreversible damage.	2	4	8
2	Lack of Intervention	Ignoring the mosaic and failing to implement conservation interventions would expose the cultural asset to active risks.	This would lead to accelerated deterioration and permanent losses in historical and cultural value.	2	4	8
13	Old Restoration Interventions	The mosaic has undergone two fires, in the 16th and 18th centuries. Consequently, it is likely that at least two restoration interventions followed these incidents.	Unknown materials used for consolidation, filling, and cleaning could cause irreversible deterioration, particularly due to found traces of chlorine in silver sheets.	4	1	4
10	Micro organisms	Currently, this does not seem to be an issue affecting the mosaic surfaces; however, in specific conditions of humidity and temperature, the risk of microorganisms is always lurking.	They can cause biological damage and deterioration of surfaces if left uncontrolled.	2	2	4
8	Animal and Insects	Presence of insects within the detached mosaic can deteriorate materials and create structural damage, while bats present further risks.	Insects contribute to the degradation of materials, and bat droppings can compromise the stability of the mosaic.	2	2	4
6	Ice	Freezing, in conditions of humidity, can cause damage to the mosaic, such as detachment and pulverization of the mortars.	The action of freezing could lead to significant damage and the loss of mosaic tesserae.	2	2	4
9	Pollution	Although currently, the issue appears absent, the past suggests potential exposure to pollution.	Historical pollutants could have damaged wall surfaces and the mosaic, exacerbating the situation.	1	2	2

We have graphically represented all the identified aggressors, classifying them based on two fundamental parameters: the likelihood index and severity.
The position of each aggressor in the matrix provides a clear visual representation, illustrating which risks require immediate attention and which can be monitored with less urgency.
This approach will allow us to prioritize conservation and protection interventions, ensuring more effective management of potential threats to our precious heritage.



To quantify the urgency with which it is advisable to address the aggressors to resolve the related deterioration, we have given a numerical value to the speed and extent of aggression:

- 1 for slow and cumulative processes,
- 2 for fast and catastrophic processes.

By multiplying these speed coefficients by the risk index, we have created a plate in which we give a priority value for intervention to each aggressor.

Aggressors	Likelihood	Severity	RISK (L*S)	Speed	Priority
Earthquakes	4	4	16	2	32
Fire, War, Vandalism	3	4	12	2	24
Storms	4	3	12	2	24
Lack of Intervention	2	4	8	2	16
Wrong Intervention	2	4	8	2	16
Inadequate relative Humidity	5	3	15	1	15
Soluble Salts	5	3	15	1	15
Urbanization	4	3	12	1	12
Smoke of Candles and Incense	5	2	10	1	10
Dust	5	2	10	1	10
Vibrations	3	3	9	1	9
Ice	2	2	4	2	8
Animal and Insects	2	2	4	1	4
Micro organisms	2	2	4	1	4
Old Restoration Interventions	4	1	4	1	4
Pollution	1	2	2	1	2

Risk Treatment

The treatment of risks associated with the Gelati Monastery Mosaic is a fundamental process for the preservation and conservation of the monument, both in the short and long term. This requires the implementation of both corrective and preventive measures to eliminate the risks identified in the previous assessment and, where risks are inevitable, to mitigate them.
Below are the proposed treatments based on the risk factors, organized according to immediate and cumulative categories.

Immediate Risks

Earthquakes
Structural Restoration: Restoring the structural stability of the mosaic through consolidation and filling of voids in the bedding layers is fundamental and urgent to restore the original structural coherence with the objective of limiting the resonance of the mosaic and the structure with the consequent risk of collapse.

Storms
Roof Restoration: Implement effective coverings that prevent water infiltration and limit exposure to atmospheric agents.

Frost
Roof Restoration: Restoring the roofs and controlling the internal temperature of the church will be sufficient measures to address this risk.

Fires, Vandalism, and War
Fire Alert Systems: To mitigate the risk of fire, it will be necessary to implement passive measures such as the removal or limitation of flammable materials such as carpets and wood. It will also be appropriate to implement behavioral corrections that protect against accidental flame falls and the confinement of flammable materials within the church (i.e., placement in areas distant from possible flame sources). It will also be necessary to implement active protection measures such as flame detectors and extinguishers.

Lack of Conservation Intervention
Implementation of Conservation Plan and Project: Develop a conservation and restoration program, long-term preventive conservation, and routine maintenance, with clear deadlines and responsibilities.

Incorrect Interventions
Evaluation of Each Intervention: Ensure that actors, those responsible, operators, and conservators have proven experience and are prepared, sensitive, and adequately trained in best practices for conservation and restoration.

Risks with Slow and Cumulative Effects

Vibrations
Vibration Monitoring: Limit interventions on external structures that may produce vibrations and restore the compactness of the mosaic structure by consolidating and filling the voids behind the mosaic in the detached parts.

Inadequate Relative Humidity
Climate Control: Implement passive measures to contain air circulation within the church, such as the installation of double doors and window regulation. At the same time, active measures to control relative humidity and temperature values should be implemented.

Soluble Salts
Extraction Interventions: Perform treatments to extract soluble salts from the surfaces and apply indirect climate control measures.

Pollution
Regular Evaluation:
Conduct inspections and environmental assessments to monitor pollution.

Microorganisms
Periodic Cleaning, Environmental Control: Implement a cleaning plan to remove organic residues and contamination. The extraction of soluble salts will also play an important role in preventing the development of microorganisms.

Insects and Animals
Space Restoration: Eliminate voids and cracks that could host insects.

Old Restoration Interventions
Material Replacement: Replace incompatible materials with more stable solutions that favor the conservation of the mosaic.

Smoke from Candles and Incense
Usage Regulation: Establish regulations for the use of candles and incense, directing the places of ignition away from the surfaces. Promote the use of beeswax candles and natural incense to reduce the emission of toxic fumes. Regarding candles, it may be useful to distinguish between candles lit for votive purposes, and thus used by the faithful, and those lit and used for liturgical purposes, and thus used by the clergy. For the first group, which also represents 90% of the phenomenon, it is suggested to:
1. Move the candle lighting planes to areas distant from the frescoed walls and the apse.
2. Use natural beeswax candles that, not containing paraffin, emit purer smoke and use purified and short wicks.

For the second group, it is believed that the use of beeswax candles and purified and short wicks will be sufficient.
Regarding incense, it is raccomanded the use of natural ingredients.

Dust

Cleaning Programs and Internal Environment Interventions: Implement a regular cleaning program to remove dust and deposits using vacuum cleaners. It will also be necessary to regulate the flow of visitors and the faithful to reduce the environmental impact on the surfaces and introduce dust containment measures such as specific carpets. An additional useful measure will be the installation of a pump capable of introducing filtered air into the church to create positive pressure inside the church relative to the outside: this will generate a forced circulation from the inside to the outside, preventing dust from entering.

Conclusion

The treatment of risks for the Gelati Mosaic requires a targeted and calibrated approach, where each proposed measure is designed to mitigate specific risks and is constantly monitored to perfect its performance.
It is imperative that all actions taken are supported by a monitoring and review program to ensure the effectiveness of protection and conservation measures over time. Collaboration with local authorities and the community will be fundamental to the lasting success in safeguarding this precious cultural heritage.

6. A map of the thermo-vision survey

Field and Laboratory Tests

As part of the research, some field and laboratory tests were required. They were of two different kinds: one, to be carried out in situ which was related to restoration treatment tests; one, to be taken in university laboratory, related to study the behavior of the mortars to be used as consolidant, both in case of small detachments and to fill the large voids identified into the structure of the mosaic.

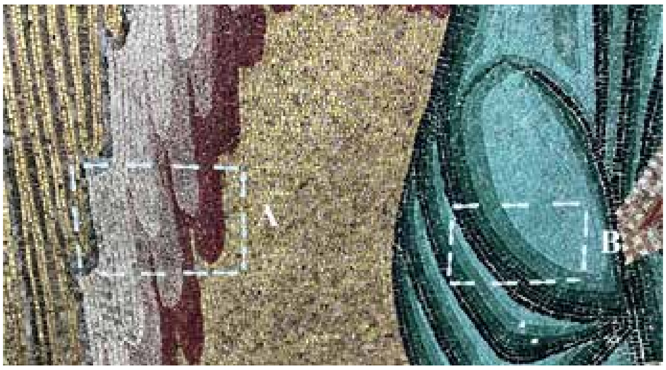
Restoration Treatment Test

This experience was carried out in Gelati, July 2024. A team of four specialist applied a series of potential procedures for cleaning, removal of painted plaster from previous Interventions, extraction of soluble salts, consolidation of the detachments, consolidation of white limestone tesserae, consolidation of black schist tesserae, aesthetic balancing/finishing. Due to the nature of the mosaic, its actual conditions and the specificity of the aggressors, some methods showed to be more appropriate than others. It is important to stress out that a good approach in conservation is always to stay critical and defensive and learn from the experiences in progress. This is to say that what the treatment tests reveal is to be taken as useful guideline which must be applied in a flexible way, with continuous monitoring of efficiency and effects.
Here we report the results of the tests.

Cleaning

Removal of Soot Deposits and Coherent Deposits
TEST 1 (Tesserae A): From pink and white stone tesserae, black schist tesserae, gold tesserae, and red glass pastes
Poultice with a layer of paper tissues in contact with the tesserae and paper pulp soaked in a solution of 30g/L ammonium carbonate and 25g/L EDTA in distilled water. Contact time: 1 hour.
Result: Positive. The poultice solubilized the thick, tenacious, and grayish greasy deposit on the stone tesserae, allowing its removal with water and brushing. After the final rinse, any residue of the solution used was extracted by applying distilled water on a cellulose sheet left on the surface until completely dry. (Photos 1-2-3)

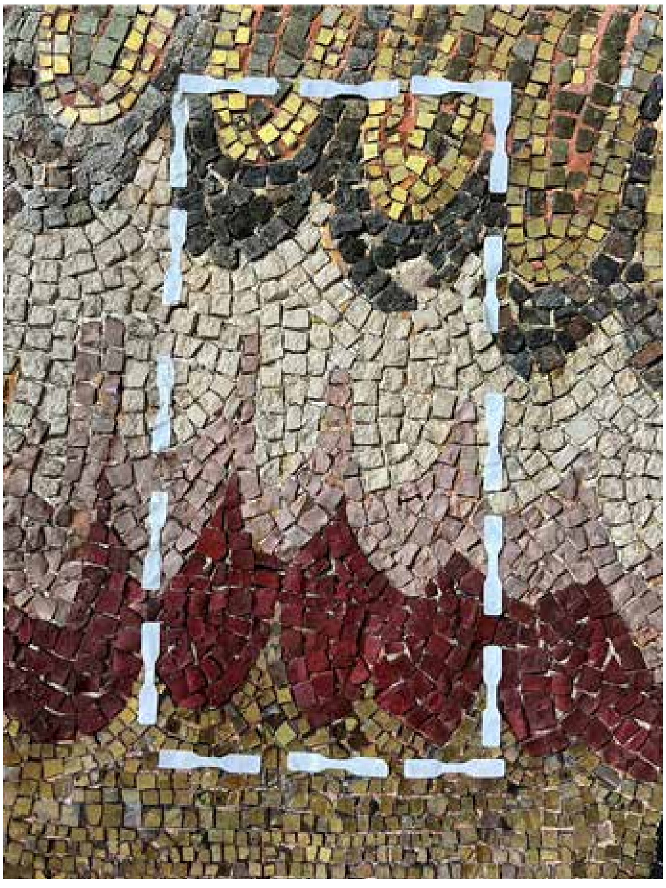
TEST 2 (Tesserae B): From green glass pastes in gradation
Poultice with a layer of paper tissues in contact with the tesserae and a cellulose sheet soaked in a solution of 30g/L ammonium carbonate. Contact time: 1 hour.
Result: Positive. The poultice solubilized the grayish greasy deposit from the glass pastes, even the more porous ones, allowing complete removal with water and brushing. After the final rinse, any residue of the solution used was extracted by applying distilled water on a cellulose sheet left on the surface until completely dry. (Photo 4)



1. TTest cleaning A and B. The areas before the poultice application; 2. During the application; 3 Result of the cleaning test; 4. Result of the cleaning test B

TEST 3 (Tesserae C): From pink and white limestone, black schist tesserae, and red glass pastes
Poultice with a layer of paper tissues in contact with the tesserae and paper pulp soaked in distilled water. Contact time: 1 hour and 30 minutes.
Result: Ineffective. The poultice with only water can only partially solubilize the greasy layers. (Photos 5-6)

TEST 4 (Tesserae C): In the same area as Test 3, a poultice of cellulose pulp soaked in a solution of 30% ammonium carbonate in demineralized water was applied, with a layer of paper tissues interposed in contact with the tesserae.
Result: Positive on the glass pastes but insufficient on the stone tesserae, which remain partially grayed by greasy layers even after repeated rinsing and brushing.
(Photos 7-8)



TEST 5 (Tesserae D): From gold tesserae.
Poultice with a layer of paper tissues in contact with the tesserae and a cellulose sheet soaked in a solution of 30g/L ammonium carbonate. Contact time: 1 hour.
Result: Positive. The poultice solubilized the grayish greasy deposit from the gold leaf tesserae, allowing complete removal with water and brushing. The tesserae regained their lost brightness, which had been dulled by deposits. After the final rinse, any residue of the solution used was extracted by applying distilled water on a cellulose sheet left on the surface until completely dry.

Removal of Painted Plaster from previous interventions

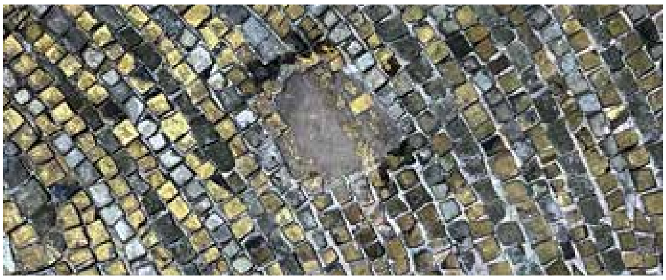
Four types of plaster fillings for lacunae were identified:

- 1. Plaster made with white or pinkish paste, then painted to imitate tesserae with a black outline to simulate the shadow of the interstice; or incised and painted to imitate the mosaic with a relief effect (Photo 13). These plasters belong to the intervention carried out in 1984-1990 by the team of experts led by restorer Karlo Bakuradze of the Central Department of Protection of Georgia's Historic and Cultural Monuments.
- 2. Plaster made with gray, rough paste, often overflowing onto the surface of the tesserae bordering the lacuna, painted coarsely with mimetic intent, often with a uniform color.

TEST 6 (Tesserae E): From blue glass paste tesserae in the gradation of the Virgin Mary's mantle.
Poultice with a layer of paper tissues in contact with the tesserae and a cellulose sheet soaked in a solution of 30g/L ammonium carbonate. Contact time: 1 hour.
Result: Positive. The poultice solubilized the grayish greasy deposit from the tesserae, allowing complete removal with water and brushing. After the final rinse, any residue of the solution used was extracted by applying distilled water on a cellulose sheet left on the surface until completely dry.

- 3. Smooth plaster with dove-gray paste, retouched to imitate mosaic with mimetic intent
- Plasters of this type present on the gold background retain residues of bronze powder to imitate gold. From archival photographs of the restoration in the 1980s, these plasters were already present at the time of the intervention.
- 4. Plaster on the face, neck, dress of the Virgin, and the right foot of Child (Photos 16-17). These plasters have residues of paint to restore the missing parts without imitating the tesserae. Only the part of the Child's foot is well preserved. According to the publication by L. Khuskivadze,[1] this intervention dates back to the 19th century when "the left cheekbone of the Virgin's face was covered with oil paint to protect it from rainwater which drained from the damaged vault above."

All types of fillers were soluble in water.



1. L. Khuskivadze, The mosaic of Gelati,Tbilisi 2005

Test performed: local application of a poultice with paper tissues and water left to act for 15-30 minutes. Followed by mechanical removal with a scalpel.
Result: Positive. Once moistened, the plasters are easily removed with a scalpel, detaching from the substrate, exposing, where present, the original mortar with the preparatory color and the imprint of the fallen tesserae.

Extraction of Soluble Salts

Right area of the apse, Archangel Gabriel: in this area, there is a significant phenomenon of crystallization and efflorescence of soluble salts that has caused the pulverization of calcareous tesserae and exfoliation of black schist tesserae, along with an extensive phenomenon of detachment of *cartelline* from gold leaf tesserae, a phenomenon present to a lesser extent on all the gold leaf tesserae of the apse decoration (Photos 18-20).
Test performed: three areas to be treated were identified, spaced apart and comprised within a 1-square-meter area entirely covered with salts in the form of filiform efflorescences, crystallizations, and reprecipitations in the form of white crusts adhering to the tesserae.
The entire area was preliminarily dusted to remove the efflorescences and prevent their re-solubilization during extraction.
A total of 4 poultices with compresses of paper pulp soaked in distilled water were applied in direct contact with the tesserae and interstitial mortar on the selected areas (Photos 21-22).
The first poultice was kept moist on the surface for about three hours to allow the solubilization of the salts present inside the tesserae and the underlying mortar.
Once the areas were moistened, the compresses were

uncovered and left to dry completely to allow the solubilized salts to migrate to the surface of the poultice. After drying, the process was repeated three more times without covering the compresses.
The material used for extraction was collected in various containers, labeled, and numbered to be subjected to electrical conductivity analysis, which provide useful data for planning the number of cycles necessary to neutralize the phenomenon.

Deep Consolidation

Two deep consolidation tests were performed with pre-mixed hydraulic lime mortar PLM-SM, 24 hours apart. This is a compound specifically designed to fill the detachments of the preparatory layers of the mosaic from the masonry support, free of soluble salts, and maintains the vapor permeability of the masonry. Once hardened, the consolidant has physical and mechanical characteristics similar to traditional lime-based mortars.
Given the severity of the detachments present, affecting almost 90% of the surfaces, it was decided to perform the consolidation tests in a restricted area in the lower zone of the left wing of Archangel Michael, where anchoring pins inserted during the 1984-1990 intervention are present, in addition to the perimeter restoration edging.
The area was found to be completely detached from the support. After moistening the infiltration zone with 50% water and ethyl alcohol, the consolidant was injected with a syringe until it emerged from the lower edge. The injected material quickly and without obstacles reached the lower containment edge, confirming the current state of almost complete detachment of the plaster from the support. To safely perform the consolidations, a mechanical external support system for the mosaic will therefore need to be set up in advance with props that will allow supporting the mosaic during the entire consolidation phase.

Consolidation of White Limestone Tesserae

The white limestone tesserae are affected by a phenomenon of decohesion/disintegration, especially in the right area of the apse where severe salt efflorescence is occurring. To restore the original mechanical properties to the limestone and prevent further material loss, a consolidant based on nanophasic calcium hydroxide dispersed in isopropyl alcohol (nano-lime) was tested. The nanoparticles penetrate the porous structure of the material and into the cracks, reacting with atmospheric carbon dioxide to precipitate as calcium carbonate, binding the decohesive material. Among the characteristics that make this consolidant perfectly compatible with carbonate matrix materials are excellent water vapor permeability, absence of chromatic variations or glossy effects, maintenance of hydrophilicity, and absence of hydrophobic surface films.
Consolidation was performed on the white limestone in the area of cleaning test A, Archangel Michael area, by

applying the product with a brush until saturation.
Result: Positive. The limestone no longer exhibits superficial material loss and remains unaltered in its optical properties.

Consolidation of Black Schist Tesserae

This type of tesserae, which is severely degraded, exhibits the classic tendency of schist to exfoliate along parallel planes. This endogenous characteristic is aggravated by the ongoing phenomenon of solubilization and crystallization of soluble salts, which, by blooming on the surface, exert pressure in the material's porosities, detaching it into thin lamellae.
Test performed: consolidation with a brush using Estel 1000, ethyl silicate in White Spirit solution until saturation. The active principle is absorbed by capillarity until it reaches the solid core of the tesserae. Reacting with atmospheric moisture, it transforms into silicon dioxide, binding the decohesive or exfoliated particles.
Result: Positive. The tesserae no longer lose superficial material and appear more compact and consistent, maintaining their optical properties unaltered.

Aesthetic Balancing/Finishing

After the cleaning tests, aesthetic balancing was performed with watercolor retouching of the interstitial spaces lacking original coloring to minimize the optical disturbance caused by the whiteness of the setting mortar.

Plate of the test areas

Experimental program to study mortars for for filling large gaps

The aim of this experiment is to develop and characterize lightweight, cement-free injection mortars, intended for the conservation and restoration of the mosaics.[1]

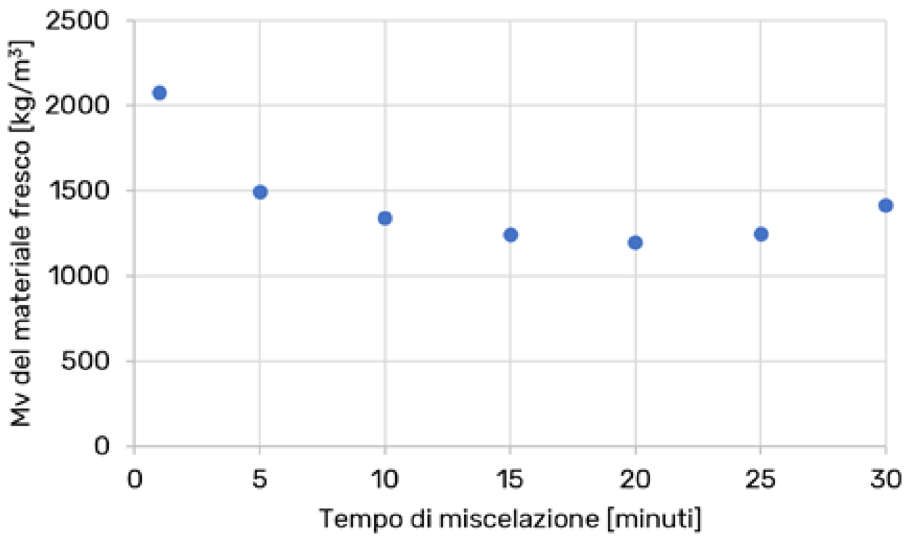
In particular, in collaboration with Centro di Conservazione Archeologica, four types of binders potentially suitable for the production of mortars with which to perform the restoration operations have been identified:

- Air lime and cocciopesto;
- Air lime and pozzolana;
- Natural hydraulic lime (NHL) and cocciopesto;
- Natural hydraulic lime (NHL) and pozzolana.

The general characterization of the mixtures which are the object of this study was preceded by a preliminary part in which, for each of the four types of binder identified above, a screening was conducted to evaluate:

- the presence of any incompatibilities of the binding systems with the super-fluidifying additive and with the aerating additive; the influence of the type of binder,
- the water/binder ratio and the sand/binder ratio on the properties of mortars in the fresh state (workability, density) and in the hardened state (compressive strength).

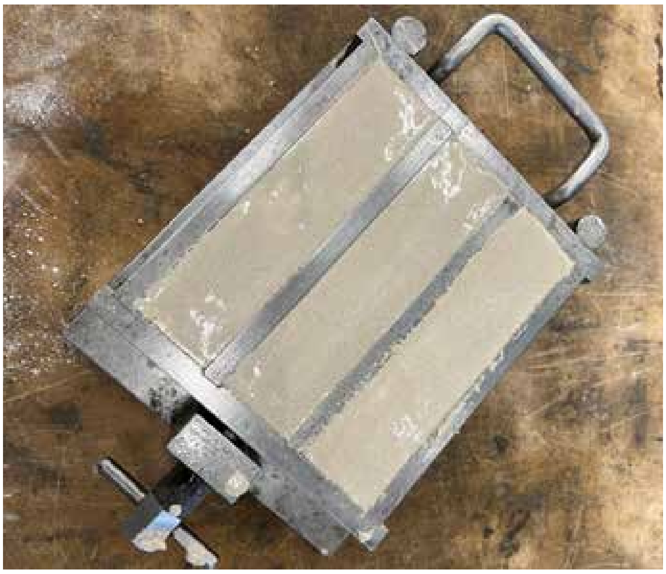
Preliminary results have shown that the super-plasticizing additive used is more effective in NHL-based systems than in those prepared with air lime. Furthermore, considering that mixtures in which the binding part is composed of 80% natural hydraulic lime (NHL) and 20% cocciopesto seem to offer the best performances both in terms of workability and mechanical resistance to compression, the optimization of the mixture has so far been concentrated on mortars based on "NHL + Cocciopesto".
In particular, it was observed that a water/binder ratio of 0.80 and a sand/binder ratio of 3.00 represents a good solution for obtaining mortars with optimal rheology and mechanical compressive strength adequate for the restoration of mosaics.
Subsequently, with the aim of formulating mortars that can be easily poured through a tube with an internal diameter of approximately 10 mm, tests were conducted to calibrate the optimal dosage of super-plasticizing additive. In particular, the experimental tests. The studies have shown that a dosage of super-plasticizing additive in powder form equal to 1% of the binder mass represents a valid compromise for obtaining mortars characterized by adequate fluidity and free from evident segregation phenomena.
Finally, to obtain sufficiently lightened mortars, tests were conducted to optimize the dosage of the air entraining additive and the mixing time following its introduction into the mix. The graph shown in Plate 1 shows the trend of the density of the mortar in the fresh state as a function of the mixing time, following the addition of a quantity of air entraining additive corresponding to 5% by mass with respect to the binding component. From the analysis of the graph it is clear that the optimal mixing time is approximately 10 minutes; in fact, extending the mixing up to 20 minutes, in addition to being difficult to apply on site, would result in a negligible reduction in density .
Plate 1



1. The tests are carried out by L. Coppola and D. Coffetti, University of Bergamo, Laboratories of Enginering

Starting from the above considerations, an optimal formulation was defined for a mortar based on hydraulic lime and cocciopesto, the composition of which is reported in Plate 2 .

Componente [-]	Quantità [parti]
Calce Idraulica	80
Cocciopesto	20
Sabbia 1.5-2.5 mm	60
Sabbia 1 – 1.5	75
Sabbia 0.5 – 1	75
Sabbia 0.25 – 0.5	30
Sabbia 0 – 0.25	60
Acqua	80
Additivo super-fluidificante	1
Additivo aerante	5



The Centro di Conservazione Archeologica are underway on this system.
In particular, to date it has been observed that:

- The mixture is fluid enough to be easily poured through a tube with an internal diameter of 10 mm. In fact, the Marsh cone test (Photo 1) showed that the emptying time of 1 litre of material, carried out with a ø 10 mm nozzle, was equal to 90 seconds;
- A dosage of 5% of air entraining additive and a mixing time of 10 minutes allowed us to reach a density in the fresh and hardened state of approximately 1250 kg/m^3 and 1050 kg/ m^3 respectively .
- The compressive strength of the mortar samples 7 days after packaging is close to 0.30-0.50 MPa ;
- A 40 mm layer of material, applied on a travertine block and stored in a humidity-controlled environment (RH ≥ 60%), does not show significant cracking or detachment phenomena after 15 days.

The other tests foreseen in the protocol are currently underway and, similarly to what has already been conducted for the "NHL + Cocciopesto" mixtures, the optimization of the formulations of the mortars made with the other three types of binder is underway.

Preventive Conservation

Planned Activities

The study on the state of conservation of the mosaic of the Virgin in the Monastery of Gelati has highlighted a significant critical issue: the detachment of the mosaic from the masonry structure in the upper part of the apse bowl, with measurements ranging from 1 mm to 20 mm, covering an area of approximately 35 m^2. (Photo 1)

As described in the section dedicated to Risk Assessment, this represents a risk of capital importance: a risk of collapse of an entire portion of the mosaic, currently mitigated only by the providential presence of the brass pins applied by Karlo Bakuradze during the intervention in the 1980s. To address this situation, it is extremely urgent to restore the physical continuity between the mosaic and the supporting structure, even more so in anticipation of any necessary interventions on the architecture of the apse, outside the church, to restore the protective coverings from the rain.

The same operation of consolidating the mosaic, which will involve filling the detachment from the structure with a lime-based mortar that must be applied to necessarily wet and thus heavier surfaces, requires the application of an external preventive protection structure for the mosaic. This structure will support the surfaces during the delicate phase of consolidation.

However, this structure must rest on a mosaic surface made consistent through the application of a protective veiling that must cover the entire surface affected by the detachment and the subsequent consolidation work.

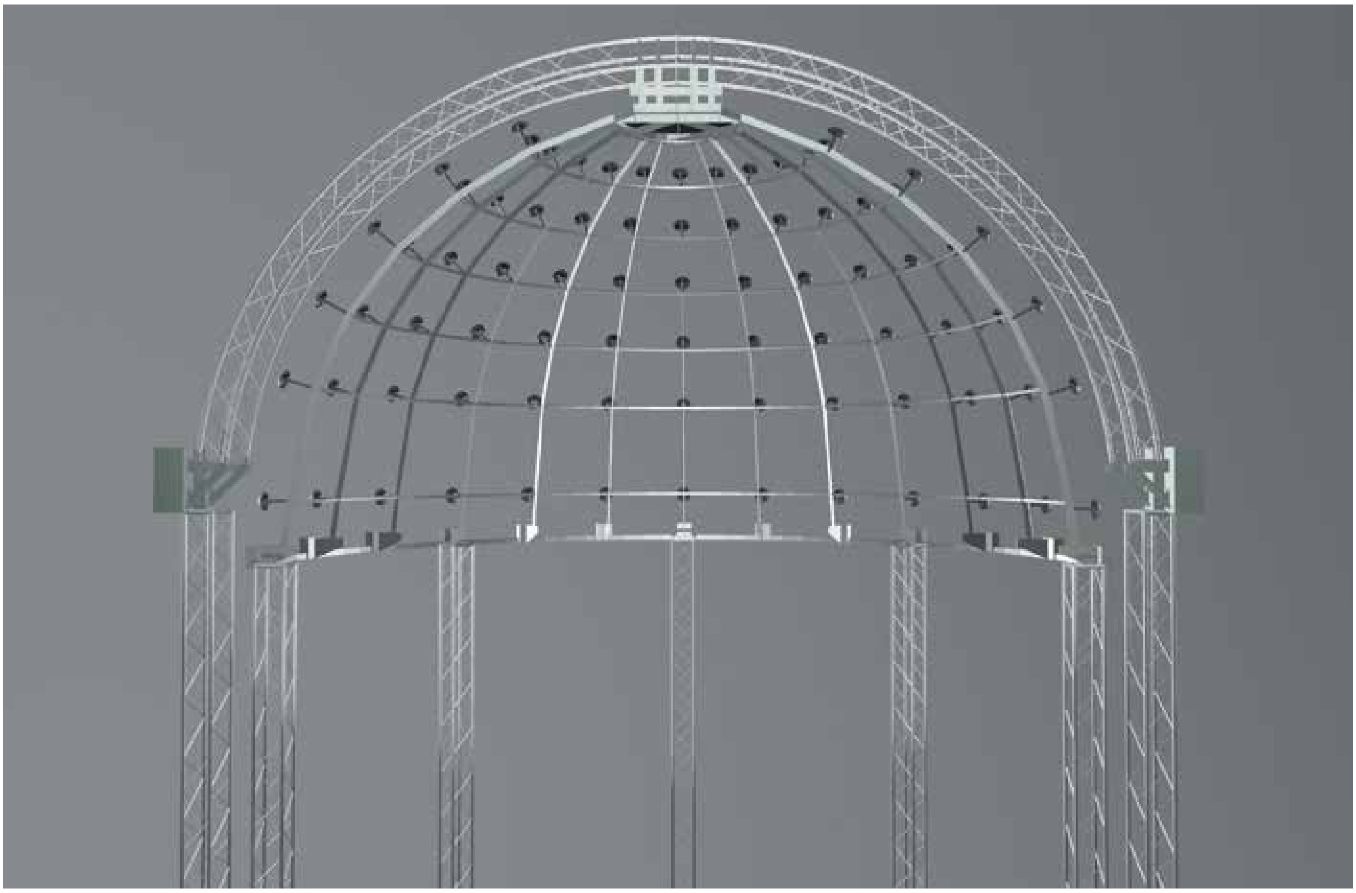
To carry out this operation, some preventive activities must be performed on the mosaic:
- Review of the adhesion state of the tesserae and temporary securing of unstable ones;
- Review of the bedding layers of the tesserae and consolidation of points showing instability and/or fragility;
- Dry cleaning of the mosaic surfaces;
- Consolidation of the *cartellina* of the gold and silver leaf tesserae;
- Dry removal of crystallized salts;
- Pre-wet cleaning of small sections of the mosaic;
- Veiling the mosaic with cotton gauze.

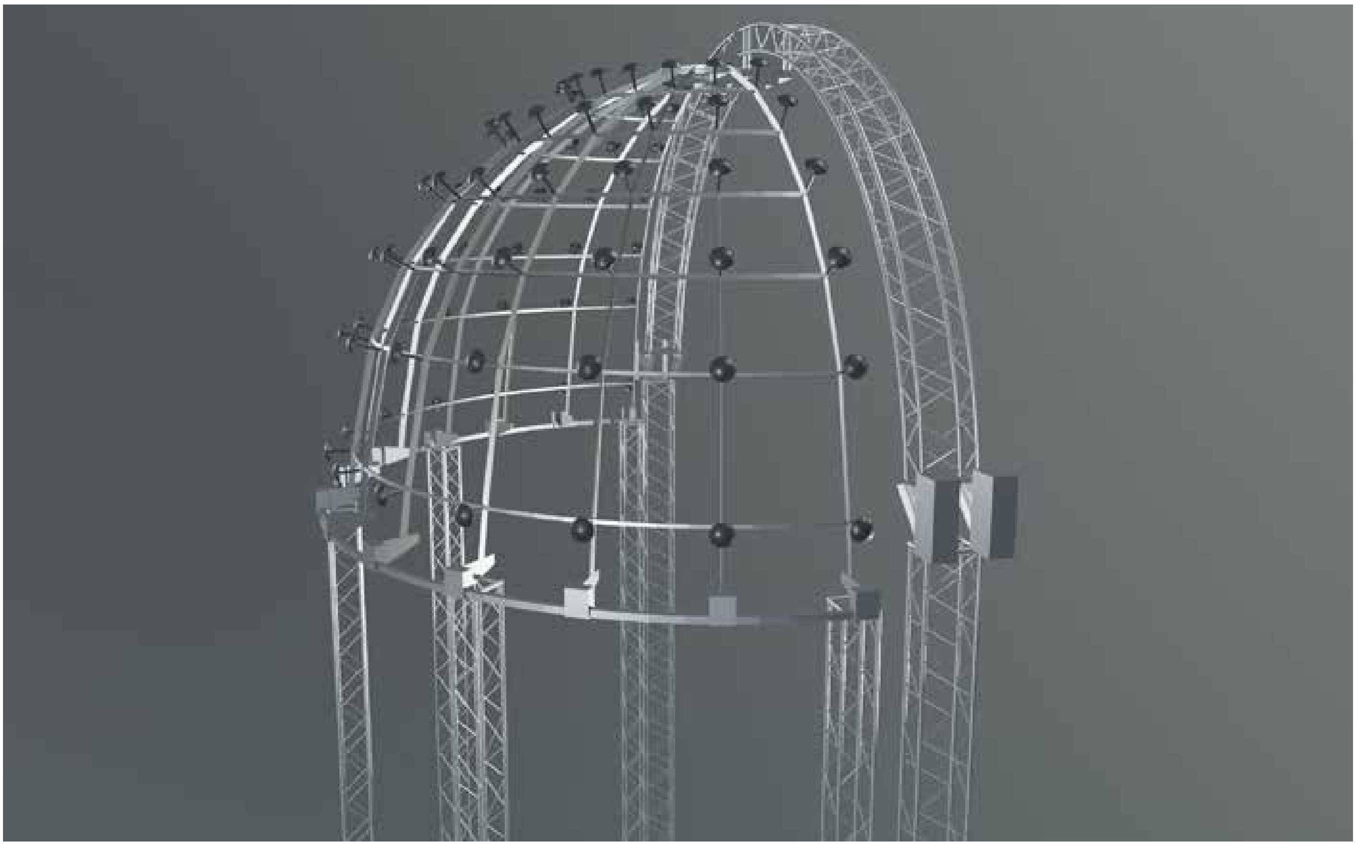
Only after completing these preliminary operations can the preventive protection structure be installed, followed by the application of support props in contact with the mosaic.

These activities are better described below.

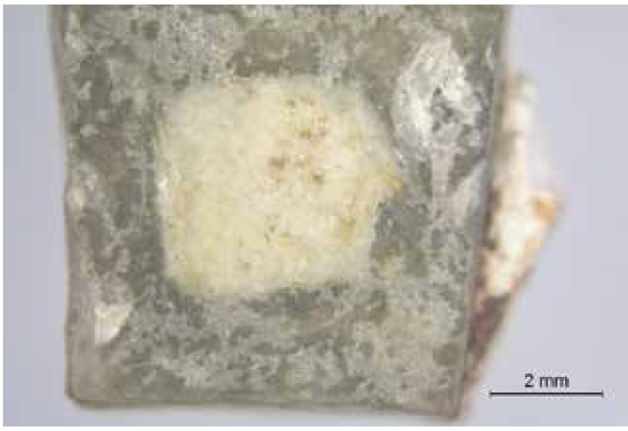
Verification of the state of the tesserae and emergency intervention: securing before restoration activities.

1. Derail pf the plate of detachments





Before proceeding with the planned work for the restoration of the mosaic, it is necessary to carefully verify the adhesion of the tesserae to the original bedding layers and of the *cartellina* to the body of the gold and silver leaf tesserae. Starting from the documentation produced during the planning phase, the tesserae will be individually verified, and any detachments or fragility will be highlighted using colored labels to proceed with preliminary fixings. The work will be carried out on individual tesserae and limited areas. All collected information will update the documentation produced during the planning phase.



Blocking of tesserae and superficial consolidation of the original mortar

All critical issues identified in the previous verification phase must be resolved before any other operation. This will be done by performing a temporary fixing of the individual unstable tesserae. The surface to be treated will be dusted with gentle air jets and, where possible, with light brushing using soft brushes.
In all cases where the adhesion of the tesserae to the laying bed is unstable, the following will be done:

A) In the case of a few units: Re-adhesion by extraction and repositioning using PLM SM diluted with water to form a mortar. The area will be initially moistened. Once the tesserae are reapplied, it will be necessary to wait for the partial hardening of the consolidant before proceeding with the removal of excess from the joints and surface. The whiteness of the mortar will be reduced by retouching with a watercolor wash applied to the still-fresh mortar.

B) In areas with instability of multiple tesserae: Consolidation will be carried out by infiltrating hydraulic mortar into the interstitial spaces. The area will be protected if necessary with cotton gauze applied with 10% Paraloid B72 before consolidation. Infiltration will be performed with a syringe using PLM SM diluted with water until a fluid compound is obtained. After waiting for the mortar to begin hardening, the veiling will be removed with acetone, the surface will be cleaned of resin, excess consolidant will be removed, and the whiteness of the mortar will be reduced with watercolor retouching.

Pre-dry cleaning of the mosaic.

Pre-dry cleaning is an operation that must be performed exclusively to selectively and progressively remove incoherent deposits from the surfaces, which would otherwise be consolidated on the surface of the tesserae by the resin/glue used to adhere the protective gauze during the subsequent veiling. It will be carried out by mechanical dry removal: the surfaces will be dusted with soft brushes and vacuumed to eliminate dust deposits, including those concentrated in the interstitial spaces. In this phase, salt efflorescence will also be removed to prevent solubilization, migration to surrounding areas, or reabsorption into the support during wet cleaning.

Consolidation of the *cartellina*

Point-specific and generalized consolidation of the cartelline protecting the gold and silver tesserae will be carried out by injecting acrylic polymers in solution, such as 10% Paraloid B72 in acetone. For tesserae already lacking *cartellina*, and thus with visible gold leaf, preliminary tamponing of the surface will be performed using acetone-soaked cotton, followed by the application of the above-described acrylic solution with a brush.
)

Pre-wet cleaning for small sections (where possible)

The pre-wet cleaning procedure will be performed on very limited areas where the presence of the brass pins from the 1980s restoration allows for safe intervention. This operation will allow the removal of the most superficial, weakly coherent dirt, facilitating limited fixing of dirt deposits and/or any salts during the subsequent veiling phase. Deposits present in the interstitial spaces will also be removed with gentle mechanical action using soft-bristled brushes, natural sponges, and finishing with scalpels.

Veiling of the mosaic

All areas affected by the severe detachment of the mosaic from the masonry structure of the upper apse bowl (see map in red) will be protected by applying a layer of cotton gauze directly onto the mosaic surface, possibly reinforced by a second layer. This operation will be carried out using two possible adhesives:

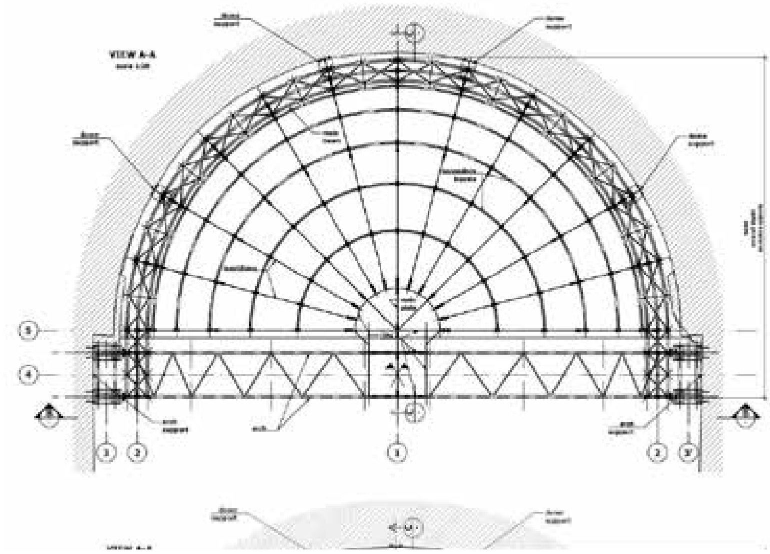
A. a natural flour glue, or

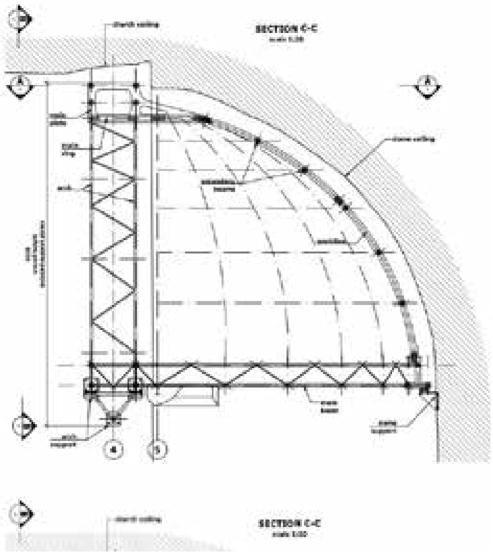
B. an acrylic resin (Paraloid B72) in acetone.

- The first solution (A) involves the use of a natural, non-toxic material that is soluble in hot water or steam. However, it has a limited lifespan and is vulnerable to microorganism attacks;
- The second solution (B) offers great stability over time and resistance to possible biological attacks. However, it is a synthetic material that requires abundant use of solvents for application and, especially, for removal. Thus, an efficient but toxic solution.

The choice between the two solutions will depend on the expected duration between the preventive protection intervention and the actual restoration.

This duration will be conditioned by interventions on the architecture outside the church and the scheduling needs of the final conservation intervention by the Client. If the expected duration is less than 24 months, option A will be proposed; if a longer duration is expected, option B will be pursued.

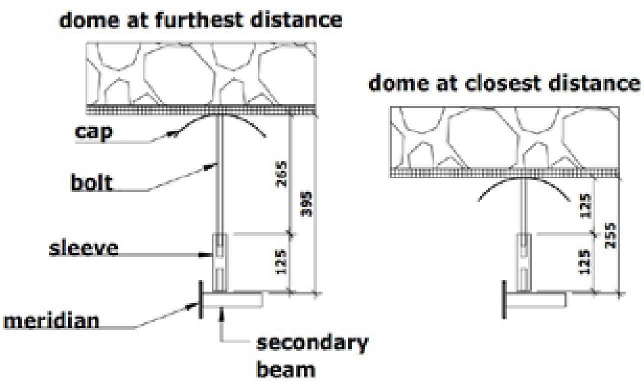




Installation of the preventive protection structure

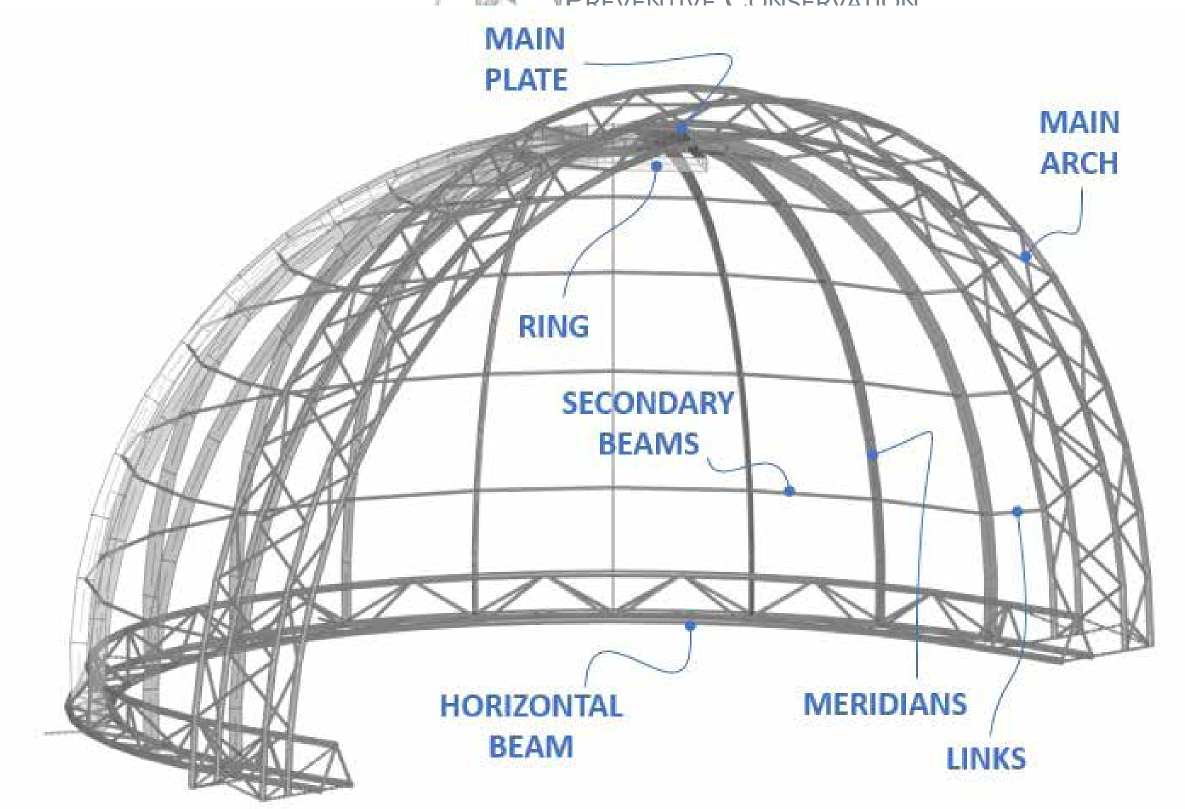
Once the upper part of the mosaic affected by the severe detachment is protected with veiling, the installation of the steel preventive protection structure will proceed. This has been designed as a modular structure, prefabricated in the workshop according to the project draft realized during the preliminary phase of the study. As described here following., it is a radial contrast structure that supports a widespread system of small props, which guarantees the stability of the mosaic parts during the mortar replacement and consolidation operations. The structure, depending on which of the three proposed hypotheses is chosen, will be anchored to points on the masonry structure, or it will rest on 7 pillars that will discharge directly to the ground, on the adequately protected altar floor. The pillars, also made of steel, will descend vertically into the space left free between the scaffolding and the masonry of the apse.

The contrast structure is made of steel and must be structurally independent from the platform, where the operators walk, to prevent vibrations induced by people from damaging the mosaics.
The design philosophy underlying the metal structure is divided into two distinct scenarios, both conceived to safeguard the integrity of the mosaic above.



The first scenario involves the construction of a steel structure designed to manage the localized detachment of some portions of the mosaic, while ensuring limited deformations. The steel structure is designed to cope with these unexpected events, simulating the random fall of portions of mosaic at critical points, where the applied load reaches around 200 kg. The idea is to preserve the load-bearing function of the structure even in the presence of such anomalies, ensuring that the overall deformations are less than 5 mm.
This approach allows maintaining a high structural performance, ensuring that the residual part of the mosaic continues to be adequately supported and that the overall geometric arrangement does not undergo significant alterations capable of inducing further damage.

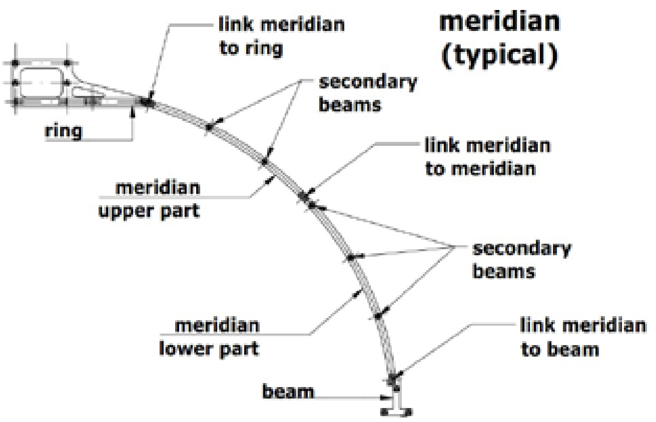
In the second scenario, the focus is on the capacity of the structure to withstand the pressure exerted by the injection mortar, used for the consolidation and stabilization of the mosaic. The assumed pressure is equal to 0.1 kPa, a value that, although limited, applied on the entire surface represents a significant stress to manage. The design in this case focuses on the optimization and lightness of the steel structure, ensuring that the pressure of the mortar does not induce deformations or instabilities that could compromise the integrity of the entire system.
This dual design strategy allows for the development of two extremely versatile and resilient structural solutions. The first ensures the protection and support of the mosaic in the presence of local detachments, preserving its integrity and artistic value. The second ensures that the structure is able to adapt effectively to the stresses during the mortar injection operation. The result is the definition of two structural solutions, each designed to respond optimally to different stress conditions. This approach allows for the structural intervention to be calibrated on the basis of the most probable scenarios, while maintaining the principles of lightness, simplicity and respect for the artistic value of the work.



In both scenarios, due to the geometric irregularity of the dome, the use of a height-adjustable prop system is essential, capable of adapting precisely to the (irregular) geometry of the vault. The arrangement and spacing of the meridians and beams were designed to facilitate the restorers' interventions: the operators can thus work comfortably between one mesh and another of the structure, approaching the mosaics without compromising their stability. Furthermore, the structures must guarantee, in both design scenarios, levels of resistance and rigidity such as to effectively support the props during the execution of the interventions. This requirement ensures that, regardless of the operational stresses or environmental conditions, the structural support remains reliable and safe.

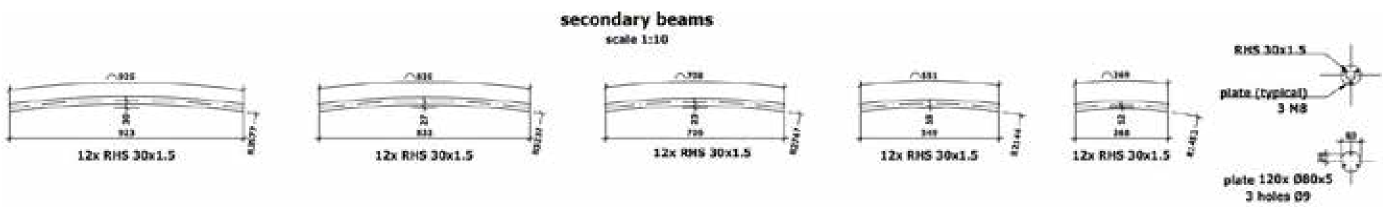
Structure 1: description

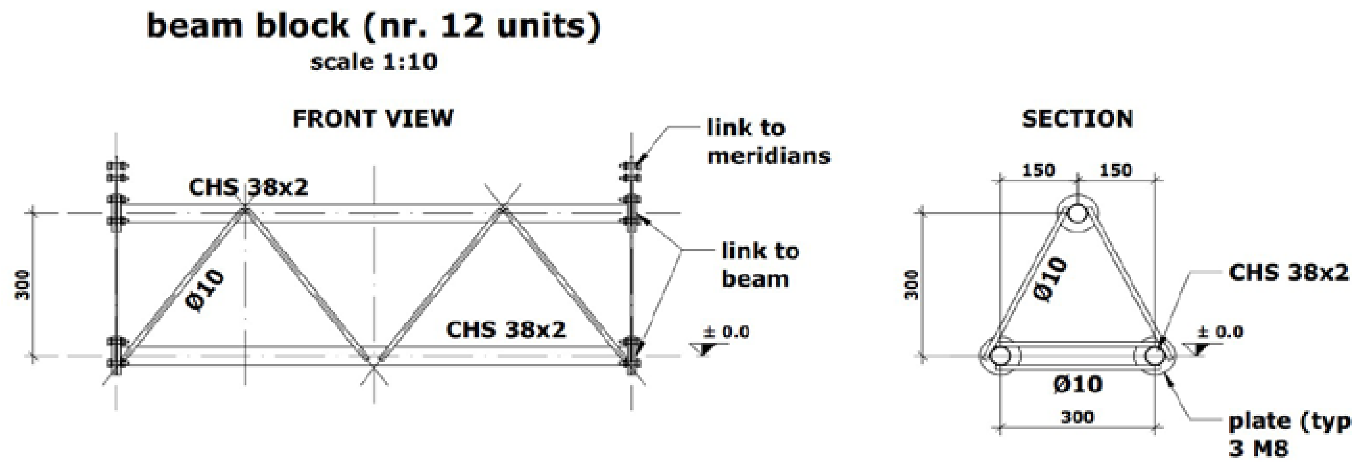
The structure is three-dimensional with a geometry approximately equal to a quarter of an ellipse with a transverse footprint of around 8m/9m (apse size and main arch size), a total height of around 5m and a depth of 4-5m. The structure is entirely made of metal carpentry with bolted joints on site.



The main elements of the structure are:

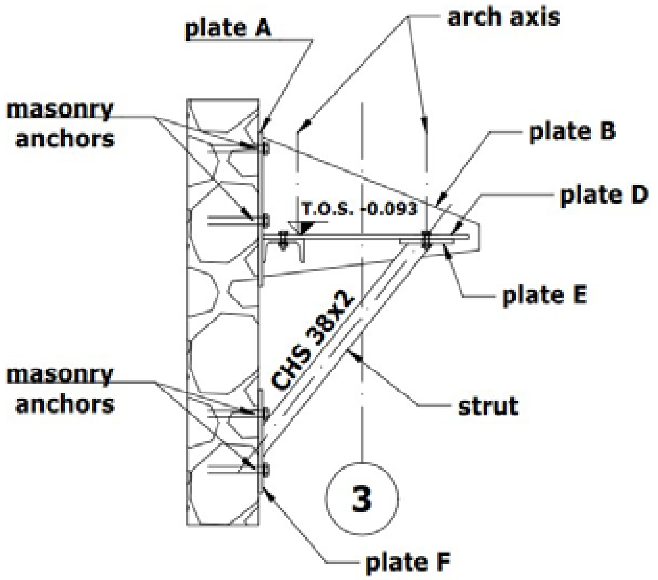
- the vertical beams, called meridians, which form the main framework and are made with plates cut and shaped (80mmx6mm) to follow the curvature of the dome;
- the secondary horizontal beams that connect and stiffen the meridians, as well as allowing the props for the mosaics to be freely positioned, are made with 30mm box profiles;

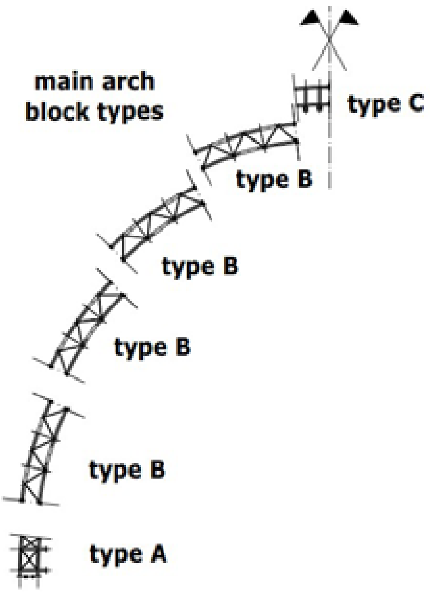


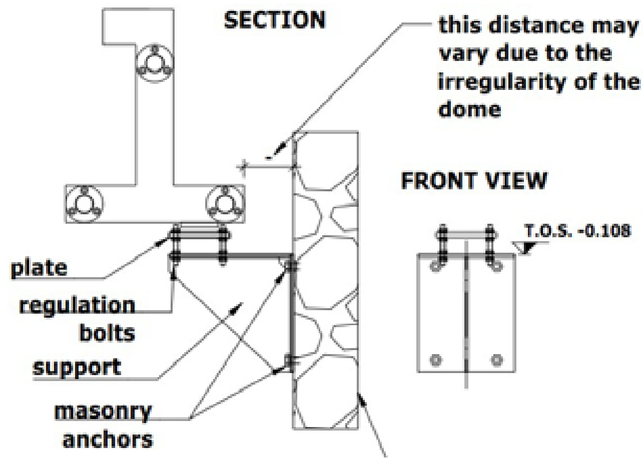


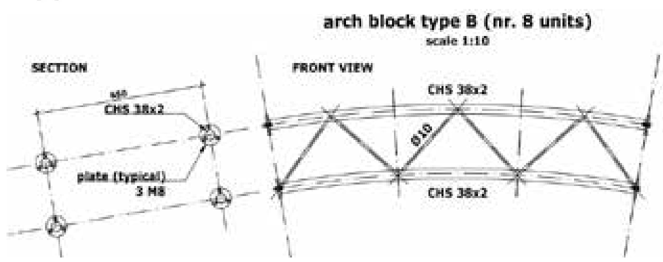
- the horizontal arched beam that connects all the meridians at the base is made with lattice ashlars made with 38mm diameter tubes and 10mm diameter bars;
- the vertical arch that supports all the meridians (top) and the horizontal beam (bottom), is made with lattice ashlars made with 38mm diameter tubes and 10 mm diameter/ 16mm diameter bars. (

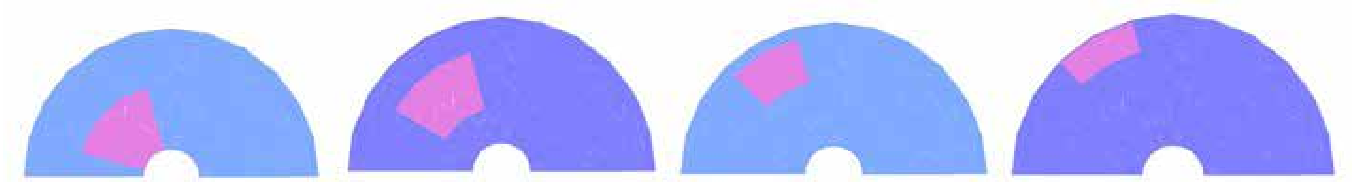
The support points of the structure are two at the base of the vertical arch (Photo 26) and four supported by the horizontal arch beam on the side of the apse.

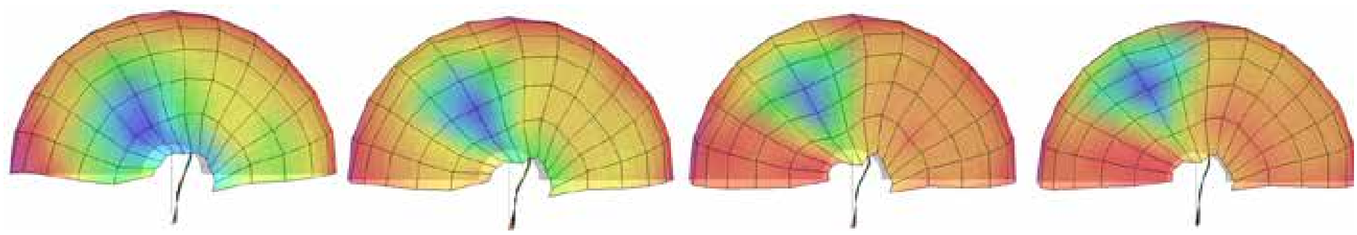












Structure I scenario: Sizing of the Structure

The self-weight of the structure is less than 1000 kg, to which approximately 300 kg of permanent supports (props) are added if all mounted at the same time. The sizing of the structures is carried out assuming a detachment of a portion of the canopy equal to around 200 kg, in the most unfavourable position so as to have a contained vertical deformation of less than 5 mm

Due to the low number of supports on the apse side and the severe loading conditions assumed in the analysis, the reactions at the support points in ultimate conditions (factored loads) require significant anchorages (e.g. 4M12).
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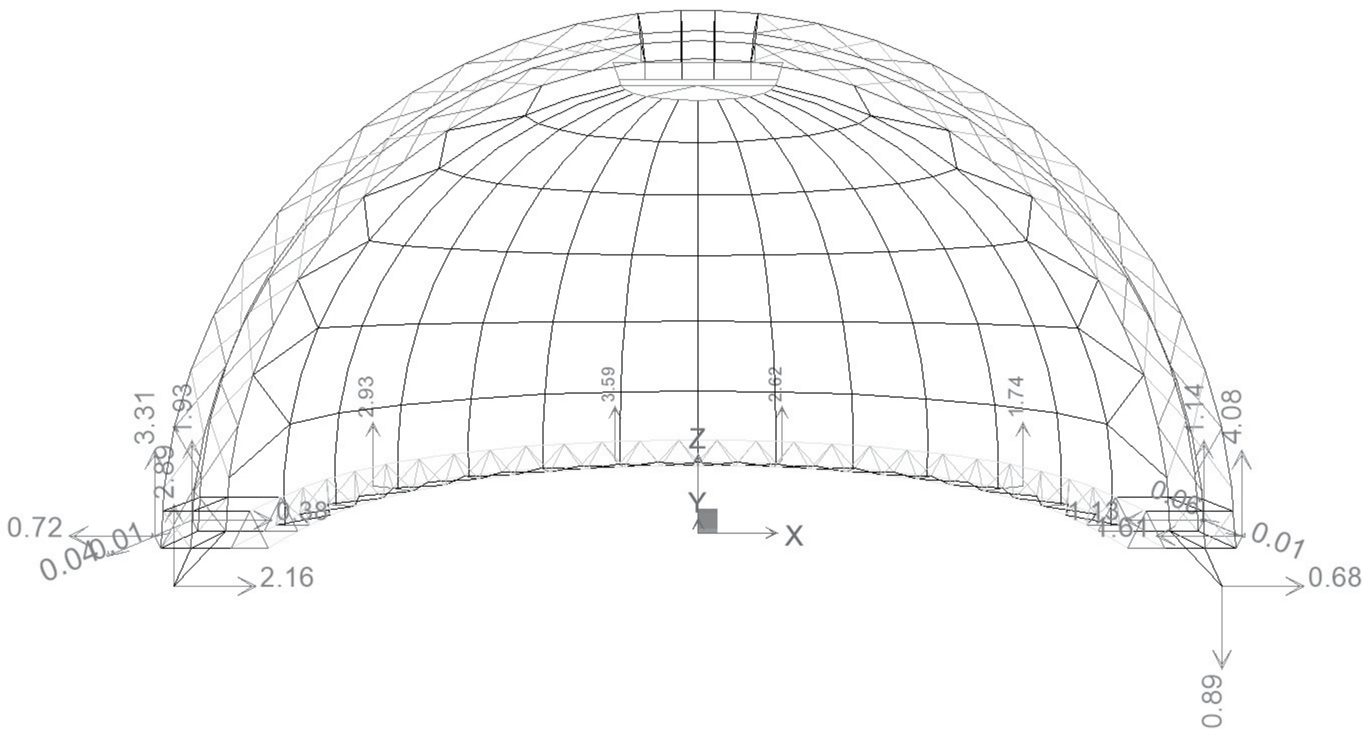
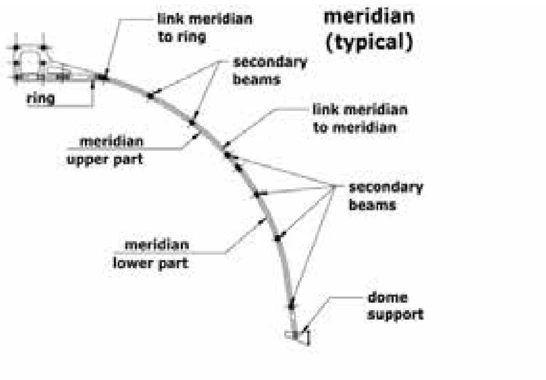
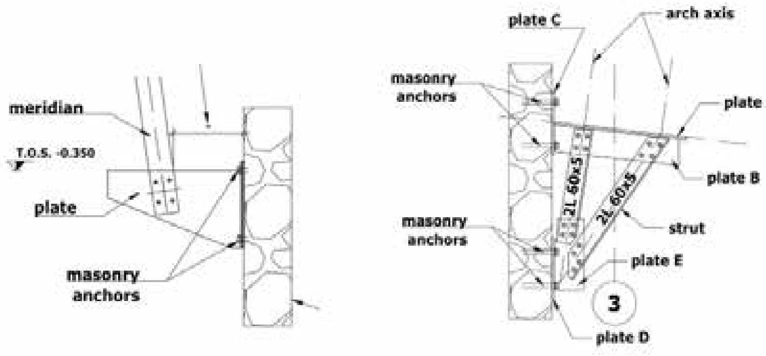
Structure II scenario

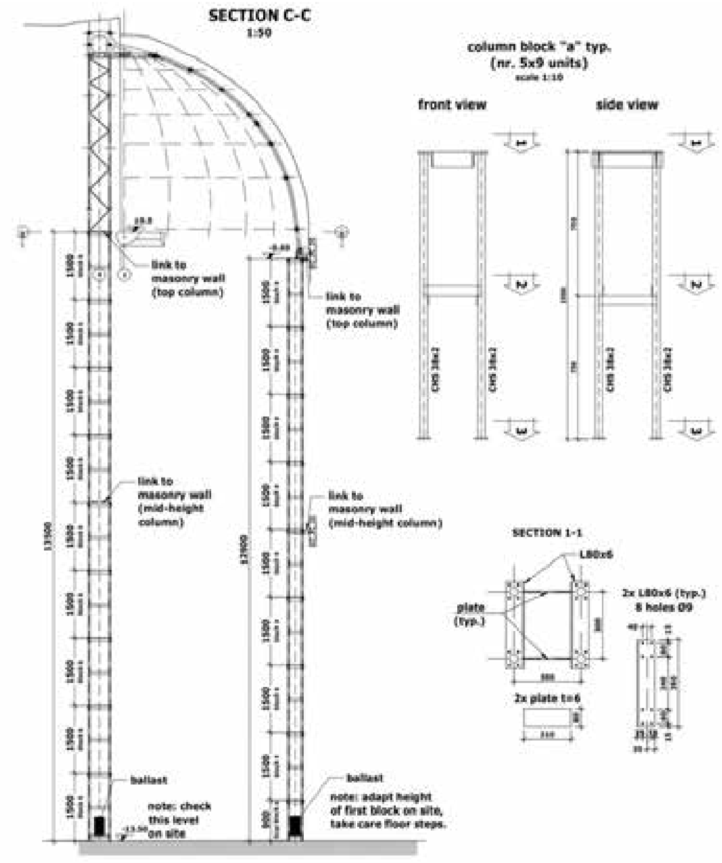
The adoption of the second scenario hypotheses has allowed to significantly reduce the visual and structural impact of the steel solution on the dome, leading to the creation of a variant compared to the original configuration. In particular, the following changes have been introduced:

- **Removal of the horizontal arch beam** (Photo 14): by eliminating this element, a slimmer and less invasive profile was obtained, improving the integration of the structure with the pre-existing architecture.
- **Reduction of the severity of the hypotheses on live loads:** the adoption of less extreme loads has allowed to optimize the sizing of the components, still ensuring an adequate safety margin without weighing down the structure.



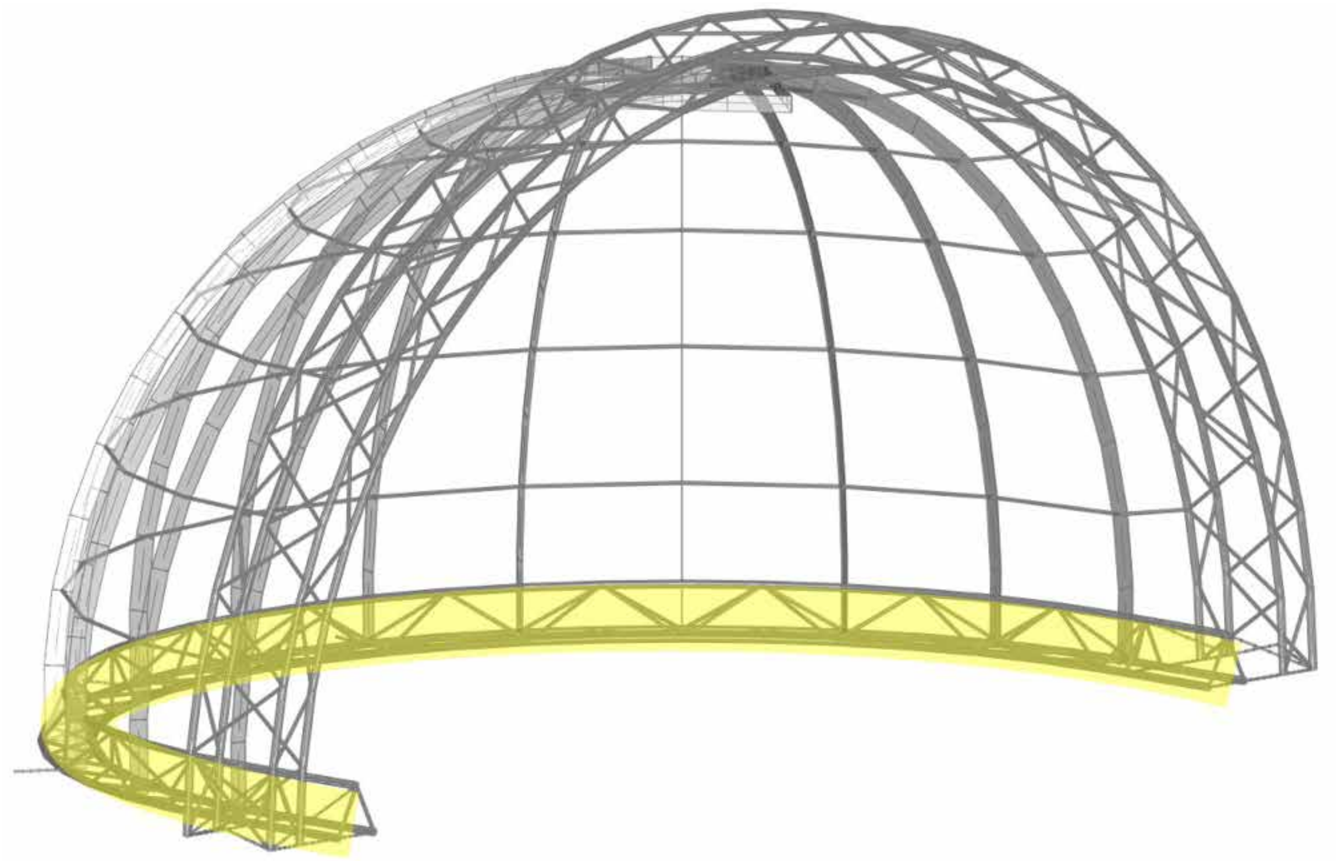


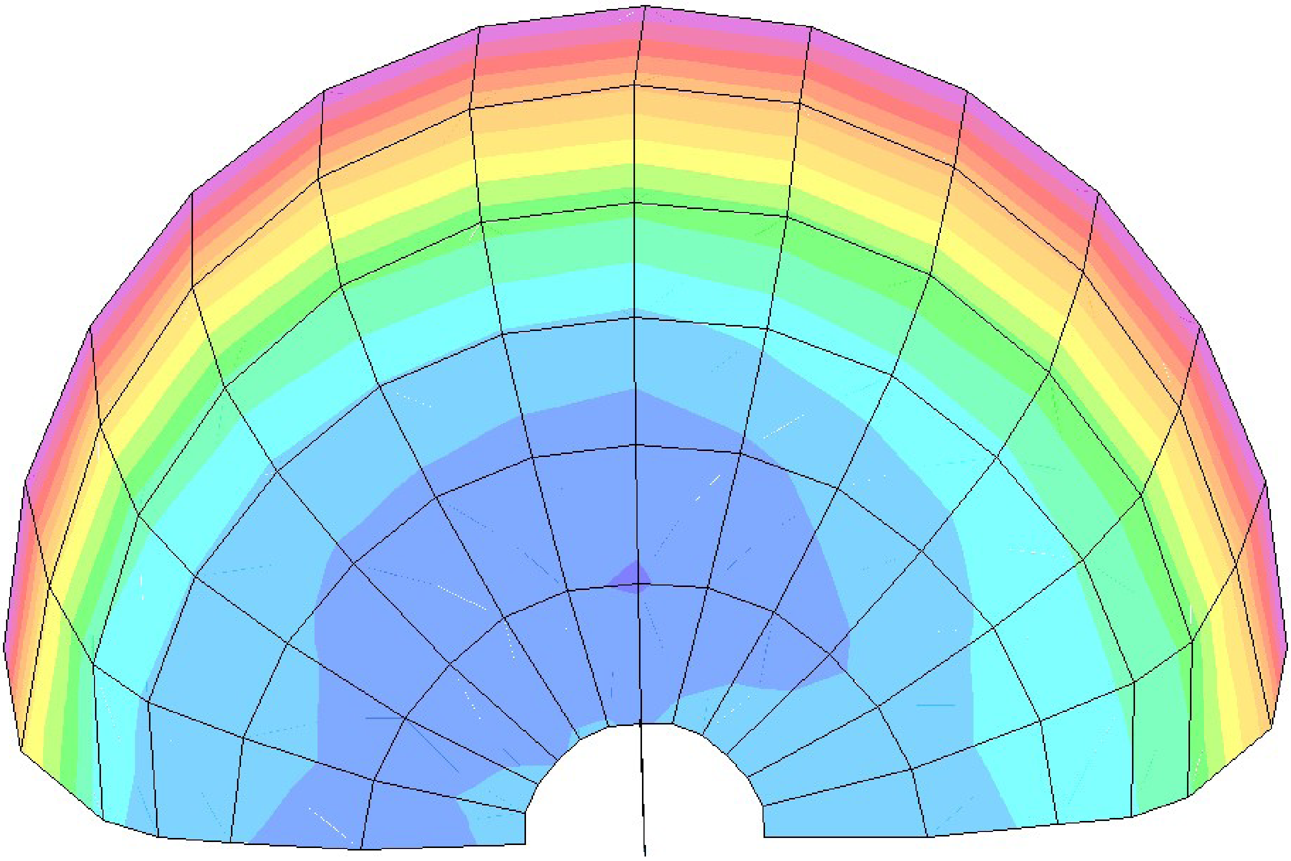




- **Insertion of support points in a widespread manner or alternatively insertion of columns from the base**: to ensure better structural stability, it is possible to adopt a widespread support system, positioning a support point at the base of each meridian. This approach has allowed to obtain a more balanced distribution of the loads, reducing the point stresses on the structure and improving the overall resistance. However, to minimize interference with the masonry and limit the number of holes needed to install the supports, an alternative solution based on a column system was also studied. This configuration includes a support that starts from the base and develops in height, offering an effective alternative to distributed supports. In total, the installation of seven supports is planned, each consisting of four interconnected lightweight tubes, thus ensuring both the structural rigidity and the lightness necessary to avoid excessive overloads. This solution, although it requires the insertion of columns from the ground, allows for improving the stability of the entire structure, adapting to the specific needs of the context without compromising the integrity of the existing masonry.).
- **Lightening of the structure, both of the meridians and of the main arch**: through careful optimization of the materials and sections, it was possible to obtain a lighter structure, capable of preserving the delicacy of the dome without compromising the necessary resistance and rigidity.

The overall weight of the new structure has been kept to less than 750 kg, contributing to a lighter and less invasive solution. The live load, generated by the mortar injections and the self-weight of the dome, is assumed to be uniformly distributed with an approximate value of araound 0.1 kPa, applied in both radial and vertical directions to realistically simulate the stresses to which the structure is subjected. Structural analyses confirm that the maximum deformations induced by this new live load remain limited, not exceeding 3-4 mm, which guarantees the stability and integrity of the intervention. Furthermore, to comply with the aesthetic and functional criteria of conservation, the anchors positioned on the side of the apse have been redesigned with a smaller diameter (M8) compared to the original solution, thus ensuring less invasiveness.





It is advisable that the installation of the structure will be carried out by the same specialized technicians who produced it, assisted by conservators from the CCA.

Application of support props in contact with the mosaic. Once the steel structure is installed, it will finally be time to insert the mosaic protection props. These elements will be placed between the steel crossbeams that make up the skeleton of the structure and will rest on the veiling that protects the tessellation. They will be made of inert and flexible material and will exert a slight contact function with the mosaic without producing any pushing force: as clearly premised, this is a preventive protection solution designed to cope with unforeseen traumatic events and support during consolidation operations, not actual support. For unforeseen traumatic events, we refer to seismic events, accidents during possible work on the exterior of the church, structural collapses of the masonry, or explosions.

This is perhaps the best moment to delve into a concept of mosaic fragility that directly relates to the function of the preventive protection structure. The mosaic is made with glass tesserae applied to a rigid support base of mortar. After eight centuries of interaction with the environment, the glass and mortar system has become a rigid, crystalline, non-flexible system. A system that closely resembles an eggshell: applying a punctual pushing force on an eggshell would not modify the shape of the egg but would generate irreversible breaks.
The same would happen if we were to apply punctual pushing forces on the mosaic: it would fracture like a crystal glass. For this reason, the steel structure is designed not to push the mosaic but only to support it from the outside if necessary. Even when proceeding with the insertion of the consolidation mortar to fill the voids between the mosaic and the masonry, the props placed between the steel structure and the mosaic will exclusively exert a preventive support function while waiting for the mortars to set.

Conservation and Restoration

When all complementary phases of the restoration of the internal surfaces of the church of the Monastery of Gelati are completed, and no further work is planned on the exterior of the architectural structures affecting the apse area, it will be time to proceed with the final phase of the conservation program for the mosaic of the Virgin. This phase will be long, delicate, and progressive; the work must be carried out allowing ample time for the materials to settle. Operations will be conducted with the utmost professionalism, with full awareness that this is a historic event, to be realized step by step with absolute consciousness. An irreproducible event, in which every step must be carefully considered and verified over time. In which external pressures that do not follow strictly technical instances will not be admitted. An intervention in which humanistic historical study, technical analysis of materials and original techniques, scientific investigations, conservation methodology and technology, documentation, and information dissemination will proceed in parallel in a single, irreproducible CULTURAL PROJECT with the aim of restoring the mosaic of the Virgin to worship and universal enjoyment.

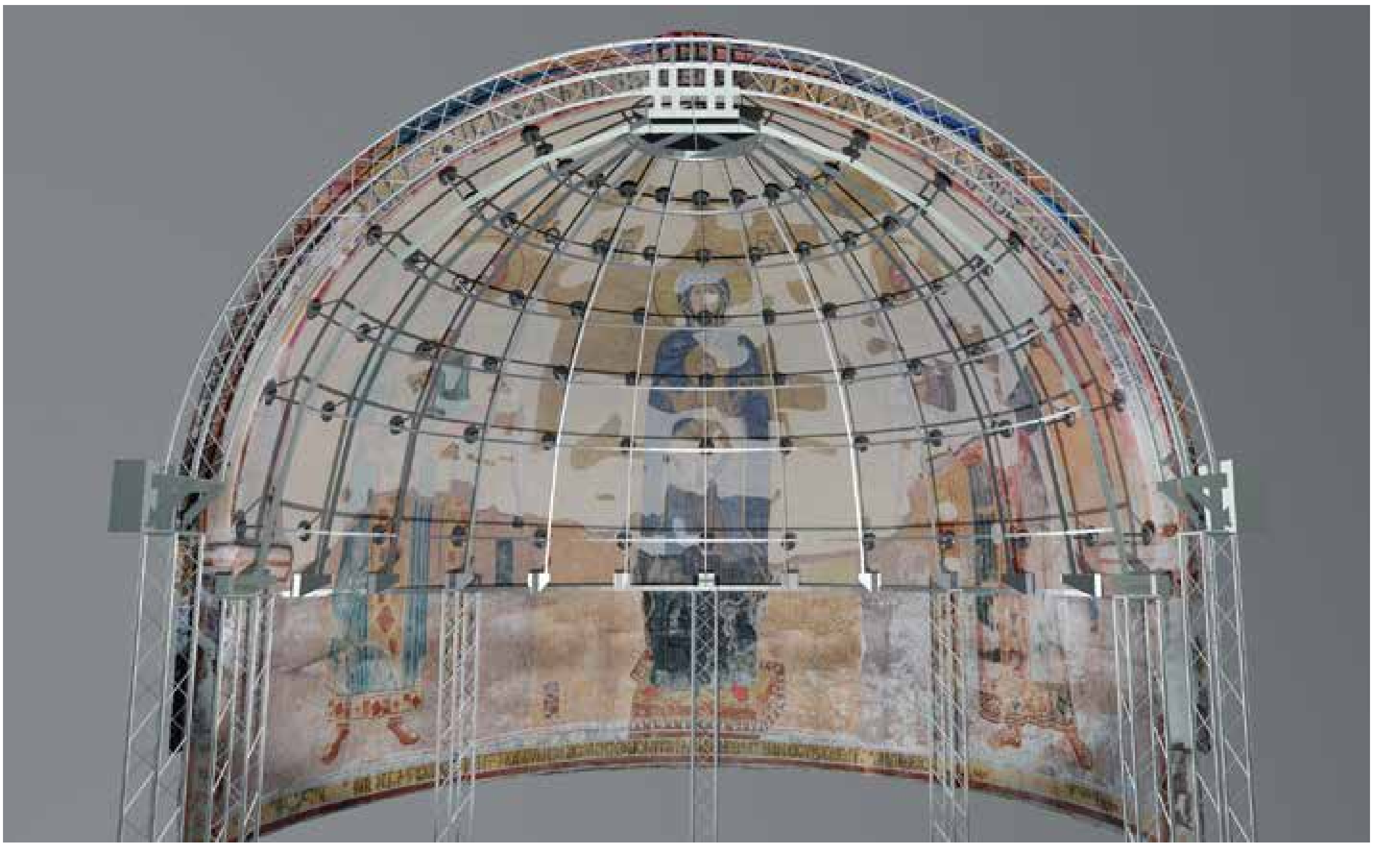
The intervention will begin with monitoring the state of conservation of the surfaces following the time interval between the preventive operations carried out and the actual start of the conservation intervention.
The state of the surfaces, any recurrence of degradation phenomena, with particular reference to the efflorescence of soluble salts, and any new instabilities of the tessellation, fractures, or fissures not previously detected, and new detachments of cartelline and tesserae will be evaluated and documented again.

This further evaluation over time will be a very important indicator for constructing the conservation history of the monument necessary for monitoring the evolution of degradation phenomena and planning interventions for future protection.

This evaluation will mark the starting point from which the technical operations described here will begin.

Verification of the state of the tesserae

Before proceeding with the planned restoration work on the mosaic, it is necessary to carefully verify the adhesion of the tesserae to the original bedding layers and of the *cartellina* to the body of the gold and silver leaf tesserae. Starting from the documentation produced during the planning phase, the tesserae will be individually verified, and any detachments or fragility will be highlighted using appropriate colored labels to proceed with preliminary fixings. The work will be carried out on individual tesserae and limited areas. All collected information will update the documentation produced during the planning and preventive protection phases.



Securing of the tesserae and superficial consolidation of the original mortar

All critical issues identified in the previous verification phase must be resolved before any other operation. This will be done by temporarily securing the unstable individual tesserae. The surface to be treated will be dusted with gentle air jets and, where possible, with light brushing using soft brushes.

In all cases where the adhesion of the tesserae to the bedding layer is unstable, the following will be done:

- In the case of a few units: re-adhesion by extraction and repositioning using PLM SM diluted with water to form a mortar. The area will initially be moistened with water. Once the tesserae are reapplied, it will be necessary to wait for the partial hardening of the consolidant before removing the excess from the joints and surface. The whiteness of the mortar will be attenuated by retouching with a watercolor wash applied to the still-fresh mortar.
- In areas with instability of multiple tesserae: consolidation will be carried out by infiltrating the interstitial spaces with hydraulic mortar. The area will be protected with gauze applied with 10% Paraloid B72 before consolidation. An infiltration with a syringe of PLM SM diluted with water will be performed until a fluid compound is obtained. After allowing the mortar to begin hardening, the gauze will be removed with acetone, the surface will be cleaned of resin, the excess consolidant will be removed, and the whiteness of the mortar will be reduced with watercolor washes.
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Consolidation by infiltration of detached areas

The consolidation of the mosaic to the support and preparation layers must be carried out by deep injections of a hydraulic consolidating mixture, similar in components to the original mortar.
The chosen consolidating mixture is PLM-SM, as suggested by the study conducted by the Engineering Laboratory of the University of Bergamo, with two specifications:

- A. Without the addition of acrylic resin (Acryl AC33) for thin voids (<190-280 microns);
- B. With the addition of acrylic resin (Acryl AC33) for more pronounced voids (>190-280 microns). This is a compound specifically designed to fill the detachments of the preparatory layers of the mosaic from the masonry support, free of soluble salts, and maintaining the vapor permeability of the masonry. Once hardened, the consolidant has physical and mechanical characteristics similar to traditional lime-based mortars.

The infiltrations of PLM SM will fill the thin voids present between the preparation layers, anchoring the detached areas to the support.

The following sequence of operations will be performed:

- Identification of areas to be consolidated: starting from the maps prepared during the planning phase, the detached areas will be confirmed by manual acoustic detection, documented, and highlighted on the surface with adhesive labels;
- Identification of access points to the detached area: to perform the injections, existing cracks and/or gaps will be used where necessary, creating access holes by temporarily removing one or two tesserae, temporarily placing them on a clay support;
- Deep cleaning of the areas to be consolidated: dirt and debris present in the area to be consolidated will be removed with repeated washes with water and ethyl alcohol (50% mixture) and suction to allow the introduction of the consolidant. The local imbibition of the plasters with water and alcohol will also facilitate the penetration of the consolidant and the setting process;
- Infiltrations of the consolidant: injections of the consolidant will be performed with a syringe, repeating the operation until the voids are completely filled.

At the end of the intervention, the removed tesserae will be repositioned in situ on a bed of lime mortar.

Consolidation will begin at the base of the area originally realized in mosaic and today partially decorated with fresco.

Starting from the frescoed inscription, work will progressively proceed upward toward the apse, until reaching the mosaic area protected by the veiling realized in the preventive phase.

Consolidation of areas with detachments of approximately 20 mm

This refers to the area in the upper part of the apse vault (highlighted in red in the mapping), previously affected by the preventive protection intervention and protected with gauze. The same area was treated with a cleaning procedure and extraction of soluble salts and was affected by the insertion of brass pins during the restoration intervention of 1984-90.
This area will be consolidated starting with a procedure similar to that used for the lower parts, where evidence of micro-detachments exists. Infiltrations of PLM-SM mixture without the addition of acrylic resin (Acryl AC33) will be performed. With this method, all adjacent areas, transitioning between the already consolidated mosaic and the void areas, will be consolidated.
Once this operation is completed, consolidation/filling of all detachment areas between the apse masonry and the mosaic will begin.

Always starting from the bottom, work will progressively proceed by pouring the mixture developed for this project by the University of Bergamo into the voids. It is expected that the consolidating material will be injected into the mosaic by natural fall, using 100 ml veterinary syringes connected to flexible tubes. This practice will allow the method to be perfected by increasing or decreasing the capacity of the injectors.
Consolidation will be preceded by washing with a 50% hydroalcoholic solution to moisten the contact surfaces.
The procedure will be very slow to allow the sedimentation of the injected material and the complete filling of the voids. It is also intended to allow the evaporation of water and the partial hardening of the injected material before inserting new consolidant. For this reason, consolidant infiltrations will be performed at 24-hour intervals. An attempt will be made to proceed at height over the entire extent of the void, progressing upward by a few centimeters per day. It is expected that this process will take no less than six months to complete.

Control, treatment of brass pins, and removal of cross heads

Concurrently with the progress of consolidation, the extraction of the brass pins applied during the 1984-90 intervention and the removal of the crosses that currently contrast the pin on the mosaic surface will be performed. This will allow verification of the state of conservation of the pin and, if necessary, proceed with the treatment and stabilization of the metal with specific products containing corrosion inhibitors. This will be followed by the reinsertion into the original point or eventual replacement of only the pin stem, eliminating the surface cross, which, once consolidation is complete, will no longer need to perform a support function. The pin will be inserted by deepening the penetration into the mosaic by about 10 mm, as necessary to camouflage its presence by inserting a tesserae.

Removal of brass edges

The providential restoration intervention of the 1980s returned a mosaic anchored to the wall with a large number of metal pins and with brass plates that border the perimeter, performing a true containment function. All edges and part of the shelves were then covered with a brown-painted plaster. This plaster and all brass shelves will be removed, effectively freeing the mosaic section. This section will be replastered with a lime-based mortar. (Photo 14)

Detachment of areas with internal metal mesh

Analysis of the surfaces using ground-penetrating radar and a pacometer signaled the presence of metal mesh within some areas of the mosaic affected by the intervention of the 1980s. This mesh was applied to create reinforcement in the mixture used to reapply the detached mosaic portions, as confirmed by the photo of the intervention. Unlike the brass pins, which are stable due to the nature of the material itself, these elements are dangerous: first, because we believe it is iron; second, because metal within a mosaic structure can always represent an element of instability. Lastly, because after consolidation, its function will no longer be necessary.

To remove these metal elements, the area affected by the presence of metal will be veiled with cotton gauze and 10% acrylic resin Paraloid B72 in acetone, and the entire portion of integration or mosaic within which the mesh is present will be removed. The area will be cleaned of all restoration materials, and a new bedding layer of lime mortar will be applied in direct contact with the exposed masonry with the detachment. The mosaic will be reapplied on the new fresh bedding layer.

Removal of the veiling on the area affected by preventive protection

Upon completion of the consolidation of the strongly detached areas of the upper part of the apse vault, the protective veiling will be removed, and the props will be dismantled. The removal of the veiling will be performed using different methods depending on the adhesive used for the application of the gauze:

A. In the case of veiling with flour glue, a humid chamber will be created with hot steam, and the removal will be completed manually with rinses with warm water and brushes to completely remove any residual glue traces.

B. In the case of veiling with acrylic resin Paraloid B72, removal will be performed using compresses of cotton soaked in acetone and subsequent finishing with a tampon.

Once freed from the temporary protective veiling, the entire strongly detached area, now restored, will begin the actual restoration, consisting of the following operations:

Consolidation of the *cartellina*

Point-by-point and generalized consolidation of the *cartelline* protecting the gold tesserae will be performed by injecting acrylic polymers in solution, such as 10% Paraloid B72 in acetone. In tesserae already lacking *cartellina*, and therefore with visible gold leaf, preliminary tamponing of the surface with acetone-soaked cotton will be performed, followed by brush application of the above-described acrylic solution. This process will be continuous throughout the intervention due to the extent of the phenomenon.

Consolidation of white calcareous tesserae

The white calcareous tesserae are affected by a phenomenon of decohesion/disintegration, especially in the right area of the apse where there is a severe phenomenon of saline efflorescence. To restore the original mechanical properties to the limestone and prevent further material loss, consolidation with nano-calcium hydroxide dispersed in isopropyl alcohol will be performed. The nanoparticles penetrate the porous structure of the material and the fissures and react with the carbon dioxide present in the atmosphere, precipitating as calcium carbonate and binding the decohesed material. Among the characteristics that make this consolidant perfectly compatible with carbonate matrix materials are excellent water vapor permeability, absence of color changes or gloss effects, maintenance of hydrophilicity, and absence of hydrophobic surface films.
Consolidation will be performed by applying the product with a brush until saturation and will be repeated until the original material's solidity is fully restored.

Consolidation of black schistose tesserae

This type of tesserae, which is highly degraded, exhibits the classic specific tendency of schist to exfoliate along parallel planes. This endogenous characteristic is aggravated by the ongoing phenomenon of solubilization and crystallization of soluble salts, which, by blooming on the surface, exert pressure in the material's porosities, detaching it into thin lamellae.

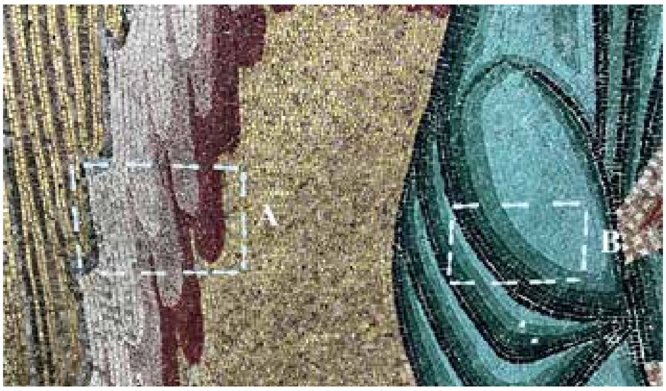
Consolidation with a brush using Estel 1000, ethyl silicate in White Spirit solution, will be performed until saturation. The active ingredient is absorbed by capillarity until it reaches the solid core of the tesserae. Reacting with atmospheric humidity, it transforms into silicon dioxide, binding the decohesed or exfoliated particles. This treatment will be repeated until the original material's compactness is achieved.

Wet cleaning

Once the mosaic is completely restored from a structural point of view, wet cleaning will be performed to remove the most coherent deposits present on the surfaces.

Based on the tests performed during the planning of the intervention, two procedures for cleaning have been defined.

- A. Poultice with a solution of 30 g/l ammonium carbonate and 25 g/l EDTA in distilled water. It will be applied to pink and white stone tesserae, black schistose tesserae, some gold tesserae, and red glass pastes with a layer of paper tissues in contact with the tesserae and paper pulp soaked in the solution and left to act for 1 hour. This will solubilize the grayish greasy deposit present on the surfaces, particularly tenacious and thick, allowing its removal with water and brushing. The operation will be repeated until the gray deposit is completely removed. At the end of the last rinse, any residues of the solution used will be extracted by applying distilled water on a cellulose sheet left on the surface until completely dry.
- B. Poultice with a solution of 30 g/l ammonium carbonate in distilled water. This second solution is suitable for cleaning green glass pastes, blue glass paste tesserae in the gradation of the Virgin Mary's mantle, some tesserae with gold and silver metal leaf. The poultice will be applied with a layer of paper tissues in contact with the tesserae and a cellulose sheet soaked in the solution and left to act for 1 hour. The poultice will solubilize the grayish greasy deposit from the glass pastes, even the most porous ones, and from the metal leaf tesserae, allowing its complete removal with water and brushing. The tesserae will regain their lost brightness, dulled by deposits. At the end of the last rinse, any residues of the solution used will be extracted by applying distilled water on a cellulose sheet left on the surface until completely dry.



The dirt deposits that remain, particularly in the interstitial spaces, will be removed with gentle mechanical action using soft-bristled brushes, natural sponges, and finishing with scalpels.

Extraction of soluble salts

The Gelati mosaic is largely affected by the presence of soluble salts. These are more evident in some areas, where the phenomenon assumes macroscopic forms. In these areas, there is an important phenomenon of crystallization and efflorescence of soluble salts that has caused powdering of the calcareous tesserae and exfoliation of the black schistose tesserae, along with an extensive phenomenon of detachment of the cartelline from the gold leaf tesserae. The latter phenomenon is present, albeit to a lesser extent, on all the gold leaf tesserae of the apse decoration. The salts will be removed from the surface and extracted from the body of the tesserae and the bedding mortar.

The entire surface will be preliminarily dusted to remove any new efflorescence. On the affected areas, paper pulp compresses soaked in demineralized water will be applied in direct contact with the tesserae and interstitial mortar for extraction. The first poultice will be kept moist on the surface for about three hours to allow the solubilization of the salts present inside the tesserae and the underlying mortar. Once the areas are moistened, the compresses will be uncovered and left to dry completely to allow the solubilized salts to migrate to the surface of the poultice. Once drying is complete, the process will be repeated at least three times without covering the compresses.

The material used for extraction will be collected in different containers, labeled, and numbered to be subjected to electrical conductivity analysis, which can provide useful data for planning the number of cycles necessary to mitigate the phenomenon.

Integration of lacunae with tesserae

In a mosaic like that of Gelati, the theme of integrating lacunae plays an important role due to the typical light-reflecting function of glass tesserae. The aesthetic and religious values of this mosaic make the theme of integration an issue that deserves the utmost attention and deep reflection. Not least because it could assume exemplary significance within a methodological dialectic that has seen rivers of words and mountains of pages flow on this subject.

To describe the extent of the lacunae problem in the case of the Gelati mosaic, it is useful to provide some data: the mosaic was made with tesserae ranging in size from 5x5 mm to 10x10 mm, averaging 10,000 to 40,000 units per square meter. It is estimated that the total number of tesserae that make up the mosaic today is approximately 681,000 units. The phenomenon of tesserae falling affects about 2.5% of the entire surface, equivalent to about 16,000 tesserae. Fortunately, this phenomenon is mainly related to the falling of single tesserae, located primarily on the gold backgrounds, drapery, and, to a lesser extent, the flesh tones.

Currently, most of the lacunae are integrated with plastering performed in various interventions, the most notable of which is the one from the 1980s of the last century.

Due to the degradation of the materials used in the various previous restorations, the plastering appears altered and dark: when the cleaning of the mosaic is completed, these altered plasterings will be very evident. When the layer of dirt and residual traces of soot is removed from the surface, the mosaic will reveal itself in a triumph of light: a carpet of gold and silver tesserae and shining glass pastes, in a rich chromatic range. The restoration plastering will appear as opaque, discolored, blackened scars.

This is the point where some methodological reflections are necessary before arriving at illustrating the technical aspects.

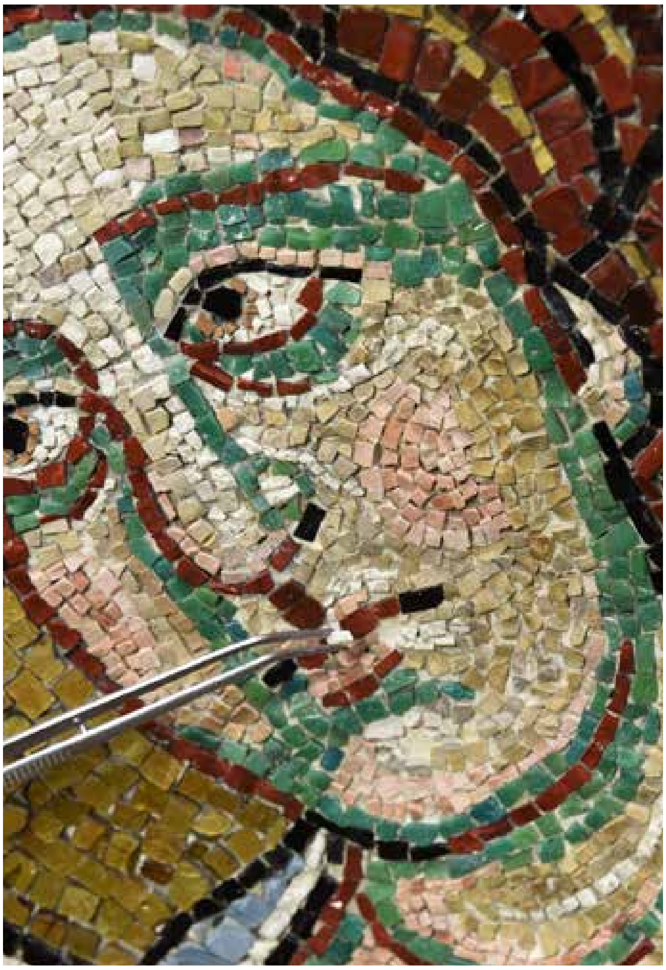
The first consideration concerns the nature of the monument and its context. The mosaic of the Virgin of Gelati represents something very different from an archaeological mosaic or a musealized mosaic, no longer in "use," intended to be enjoyed only in its historical-artistic aspect or its aesthetic value. It is a living mosaic, part of the spiritual and liturgical life of one of the sacred places on the planet. From the time of its creation, monks and the faithful have turned toward the apse vault with their prayers.

The traumatic events that interrupted the line of use for some centuries were not sufficient to interrupt its life, which today powerfully flourishes through the centuries in full continuity with the sacred history of the place.

From this first consideration arises the second: the thought of the community that lives the mosaic through liturgy and custodies it must be prioritized over professional considerations matured in totally different contexts and historical periods, especially if the community is knowledgeable, aware, and well-informed about the principles guiding the discipline of conservation.

If this community leans toward one methodological choice over another, it is a priority to respect and understand the motivations.
Thirdly, there is a more strictly technical consideration: the availability today of computer technology that allows obtaining precise documentation of interventions at the resolution of a single tesserae. The concept of the recognizability of integrations, which led Cesare Brandi to develop the method of integration with plaster tesserae modeled and painted, as exposed in his article "Notes on the techniques of wall mosaics in relation to restoration and dating"[1], is conceptually surpassed.
We can affirm that, thanks to digital graphics applied to conservation, we finally have the possibility to map and thus identify every intervention performed on the originals with precision and accessibility unthinkable until a few years ago. The debate on which method to choose to reconstruct the formal unity of the mosaic, in our opinion, has become a purely academic exercise.
Fourth consideration, no less valuable than the previous ones, are the conservative experiences carried out in 2010 on the mosaic of the Transfiguration in the church of the Monastery of Saint Catherine in Sinai and the one underway at the Baptistery of St. John in Florence. In both interventions, it was chosen to intervene in the integration of lacunae with the application of glass tesserae, and the choice was universally accepted.
For methodological completeness, it is worth recalling what the useful solutions might be to integrate the lacunae to reconstruct the unity of the mosaic's image. The first option is integration with mortar that reproduces the level and chromatic tone of the tesserae bedding layer (light beige and sub-level compared to the surface of the tesserae); the second option is to use mortar with stamping at the level imitating the tesserae and watercolor retouching; the third possibility is to use new tesserae of the same material as the missing ones.

1. Cesare Brandi, Notes on the techniques of wall mosaics in relation to restoration and dating, Bollettino dell'Istituto Centrale del Restauro, 25-26, Rome, 1956



Faced with the need to restore solidity to the mosaic fabric, made highly unstable by the presence of lacunae, and to restore legibility otherwise compromised by the mixture of different materials in chromatic and luminous refraction, the third option was chosen: the use of new tesserae made of glass with the same technology as the originals.
It is believed that this choice is fully shared by the monastic community, as it positively responds to conservation and methodological instances: any material other than mosaic tesserae would produce weaknesses in the mosaic texture and interferences in the play of light and colors that would alter the image and message of the mosaic.
Each new element added to the original mosaic will be documented on the computer[2], tessera by tessera, at a 1:1 scale using high-resolution photographic bases. In the same way, all the lacunae present on the surfaces were documented, distinguishing the two previous restorations and the falls of the last fifty years.
In this way, any possible interpretative doubt will be dispelled. If in the future it is desired to remove these integrations, which are perfectly reversible, it will be possible to locate them through close-up viewing guided by the maps documenting their position.
The new tesserae will be sourced from Venice, from the historic Orsoni furnace, where a successful search for colors[3] was conducted during this planning phase.
Using a palette of 22 colors, the tesserae will be applied to a bedding layer made of a mortar composed of lime putty and calcium powder in a 1:1.5 ratio, maintaining a slight difference in color with the original mixture, light beige for ours compared to the original white.
On this mortar, the background color will be spread as in the original, with watercolor paints in a mixture (red, black, yellow, gray), according to the type of tesserae to be applied.
On the thus prepared bedding layer, the tesserae will be applied, cut to the necessary shape and size to avoid altering the original texture.
To perform the integrations, the original design and texture will always be followed, either by reproducing repetitive lines or by tracing the imprints left by the original tesserae on the bedding mortar; in no case will free interpretations of the original design be performed.
Probably integrating a mosaic using new tesserae is a choice that we would have opposed just a few years ago. Today, we have allowed ourselves to propose this solution because the progress of documentation technology allows it. In the presence of a precise and efficient tool such as the digital documentation prepared for this project, simple both in realization and management, the risk of producing confusion between the original and restoration is practically absent.

2. For details on the documentation technique developed for this project, see: A. Costanzi Cobau, The monastery of Saint Catherine in the Sinai. Mosaic of the transfiguration. Documentation, International Conference of the ICCM, Palermo 2009.
3. Orsoni, Cannaregio, 1045, 30121 Venice

On the contrary, it would be a mistake to make operational choices that do not take into account the new technological opportunities, and it would be an even more serious mistake to mortify the original monument by polluting it with materials extraneous to its intrinsic nature, moreover ignoring the opinion of the members of the monastic community and the public of which the mosaic is an integral part of culture and faith.

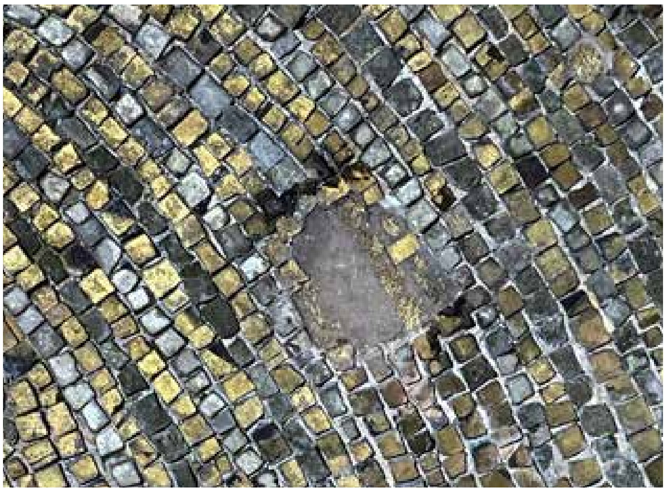
Removal of painted plastering from previous interventions

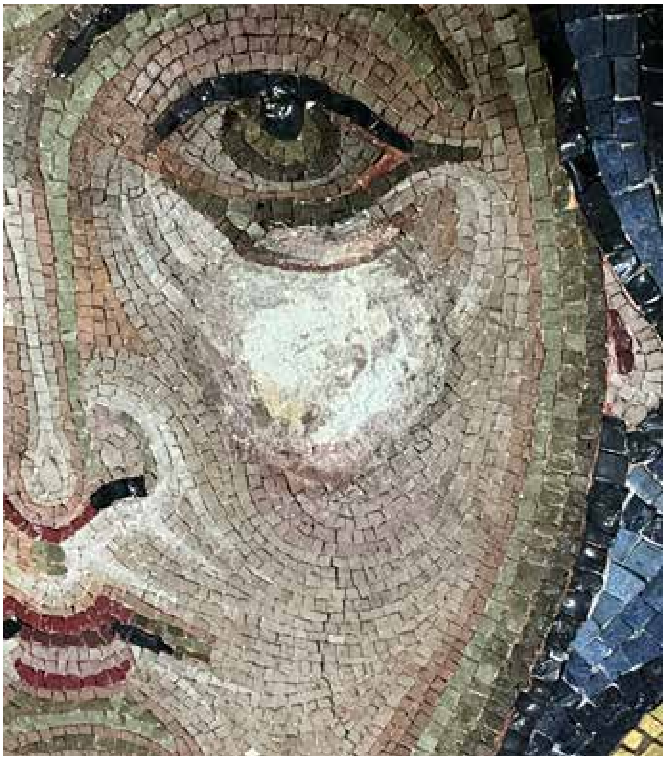
Four types of plastering to fill lacunae have been identified:

- 1. Plastering performed with white or pinkish paste, then painted to imitate tesserae with a black outline to mimic the shadow of the interstice; or incised and painted to imitate the mosaic with a relief effect. This plastering belongs to the intervention carried out in 1984-1990 by the team of experts led by restorer Karlo Bakuradze of the Central Department of Protection of Georgia's Historic and Cultural Monuments;

- 2. Plastering performed with gray, rough paste, often overflowing onto the surface of the tesserae adjacent to the lacuna, painted grossly with mimetic intent, often with uniform color.
- 3. Smooth plastering with tortora-colored paste, retouched to imitate mosaic with mimetic intent. Plastering of this type present on the gold background preserves residues of purpurin to imitate gold. From the archival photographs of the restoration of the 1980s, these plasterings were already present at the time of the intervention.
- 4. Plastering on the face, neck, dress of the Virgin, and the right foot of the Child. (Photos 35-36) These plasterings preserve residues of paint to restore the missing parts without imitation of the tesserae. Only the part of the Child's foot is well preserved. According to what is reported in the publication by L. Khuskivadze[4], this intervention dates back to the 19th century when "the left cheekbone of the Virgin's face was covered with oil paint to protect it from rainwater which drained from the damaged vault above."

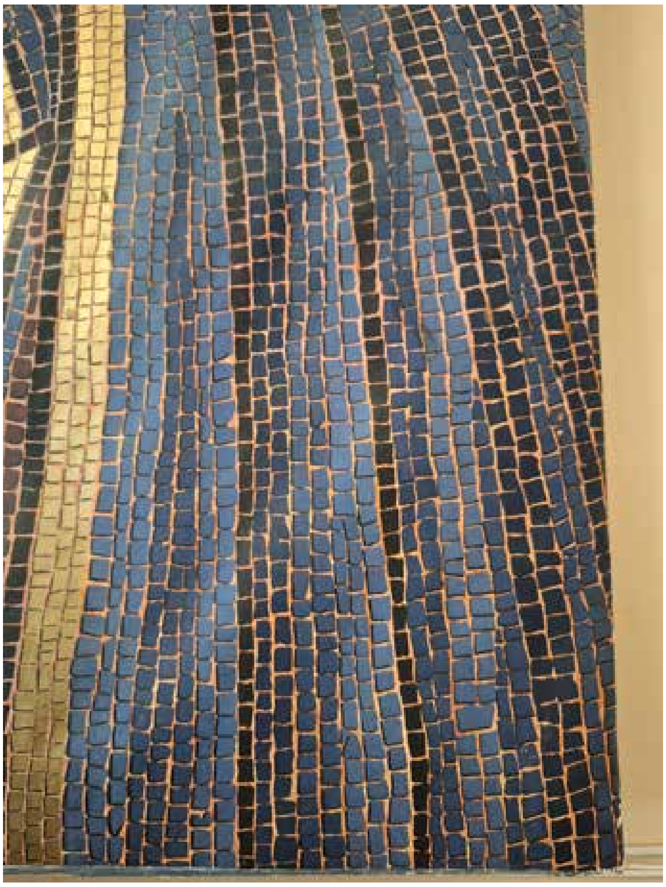
All types of paste have proven to be soluble in water and, therefore, once moistened, the plastering can be easily removed with a scalpel, detaching from the background, exposing, where present, the original mortar with the preparatory color and the imprint of the fallen tesserae. This operation requires extreme caution because over the years, the plastering has performed an adhesive function for the surrounding tesserae.





4. L. Khuskivadze, The mosaic of Gelati,Tbilisi 2005

Consequently, their removal could cause the detachment and falling of many of these. In many cases, before removing the plastering, it will be necessary to block the edges of the surrounding tesserae either with thin adhesive strips or with micro-veiling that will obviously be removed at the end of the work.



Detachment of areas with painted plastering and application on panel for musealization

Some of the areas restored in the 1980s by Karlo Bakuradze and L. Khuskivadze are true examples of technical virtuosity. It is no coincidence that some of the cartoons made by them at the time of the restoration are now on display at the Museum of Kutaisi. At the same time, the material used, tempera on plaster, does not blend well with the function of light reflection typical of glass mosaic. Therefore, it is considered important to replace these areas of pictorial restoration with mosaic made of glass tesserae without, however, downgrading from the history of the monument the work of the Georgian colleagues. Therefore, the detachment of some selected areas of this type of intervention will be performed, with subsequent application of the same on aluminum honeycomb panels (Aerolam) for musealization in the space dedicated to the history of the mosaic and restoration interventions that can be installed inside the Monastery of Gelati.

Reproduction in mosaic of selected painted plastering

The areas integrated with three-dimensional pictorial painting executed by Karlo Bakuradze's group that will be detached for musealization will be reconstructed with glass paste tesserae, faithfully reproducing the choices of the Georgian colleagues from the 1980s. The mosaic will be executed in the studio based on the design in the work and then placed in place of the plaster integrations on a fresh lime mortar bedding layer. With watercolor washes, the interstitial spaces will be chromatically harmonized so that there is no optical interference in the reading of the whole. In this way, the reflection of light will be restored in all those areas of the mosaic currently opacified by the painted plaster plastering.

Plastering of the mosaic edges

The entire perimeter area of the mosaic, previously bordered with brass shelves, then plastered and painted, will be restored with a lime-based mortar and calcareous aggregates to cover and fill the mosaic section. Tests will be conducted with different aggregates and proportions to find a suitable color to mimic its presence.

Final consolidation of the *cartellina*

Upon completion of the lacunae integration intervention, one or more consolidation of the *cartelline* will be performed. The extent of this operation will depend on

the durability of the previous consolidations. At this time, it is not possible to predict how many consolidation will be necessary. Consolidation will be point-by-point and generalized and will be performed by injecting acrylic polymers in solution, such as 10% Paraloid in acetone.

Final cleaning

Upon completion of the conservation intervention, a final wet cleaning will be performed to remove all residues from the work. This operation will be carried out with poultices of cellulose sheets soaked with distilled water in contact with the tesserae, followed by rinsing and brushing and mechanical finishing with scalpels. The operation will be repeated until the deposits are completely removed. In the presence of any carbonate residues due to the work with lime mortars, localized poultices with a 2.5% EDTA solution in deionized water followed by rinsing and brushing will be performed.

Final extraction of soluble salts

Before proceeding with the last planned operation, the aesthetic finish, it will be appropriate to proceed with a series of poultices for the extraction of soluble salts. Although this operation has already been performed several times, it can be predicted with some certainty that the surfaces will not be completely stabilized in terms of soluble salt content. For this reason, it will be necessary to apply poultices of paper pulp soaked in distilled water in direct contact with the tesserae and interstitial mortar for 3 hours. Once the areas are moistened, the poultices will be uncovered and left to dry completely to allow the solubilized salts to migrate to the surface of the poultice.

Aesthetic finish

The restoration intervention will conclude with a chromatic revision using watercolor to homogenize any whitening of the interstitial spaces. The aesthetic finish, perfectly reversible with water, will be carried out with progressive steps until the originally existing chromatic balances in the material dialogue between preparatory undercoats and polychrome tessellation are reestablished.

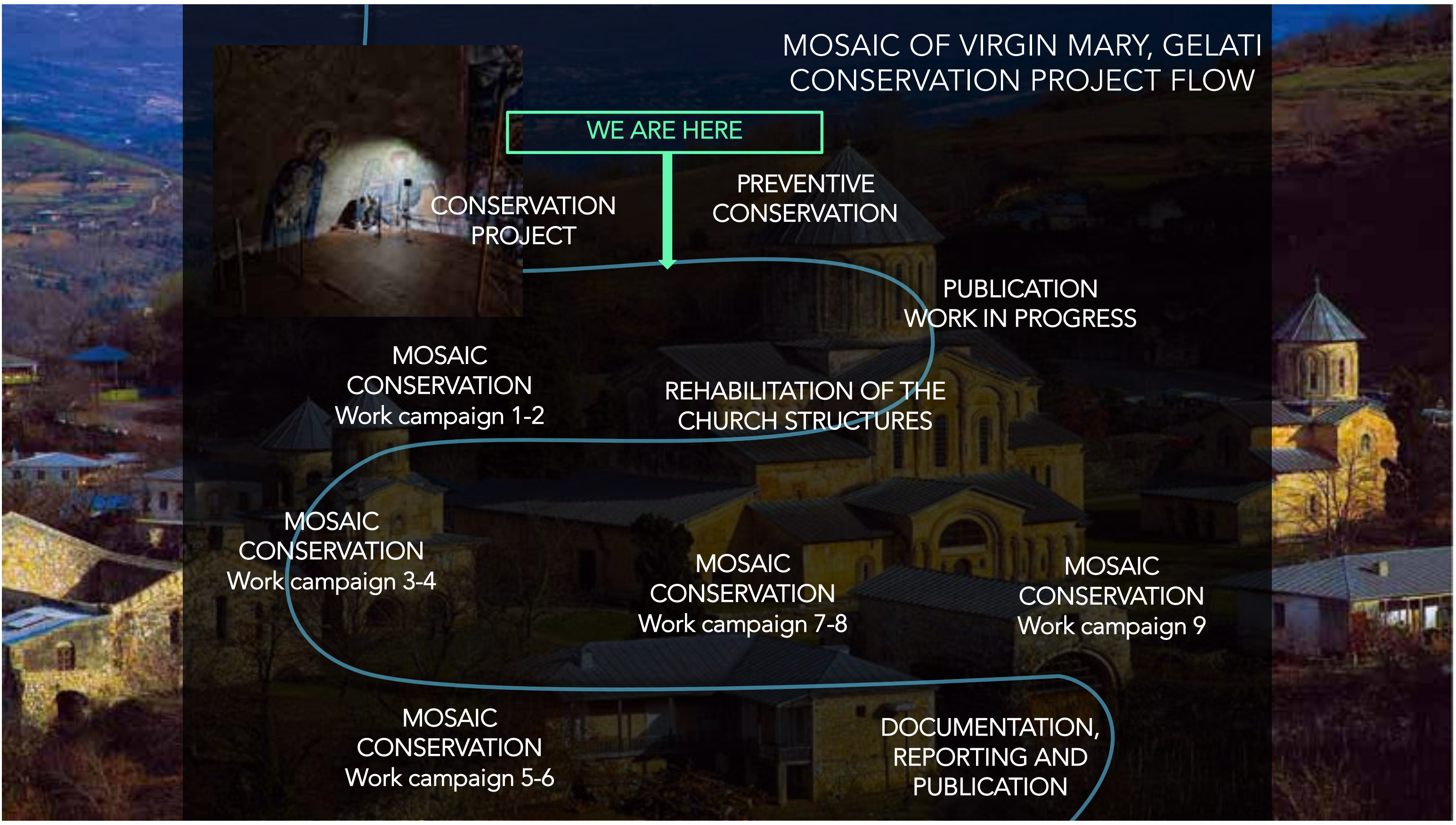
Documentation

The entire intervention will be constantly documented both graphically and photographically, as well as on video. The documentation obtained to date for the planning phase will be verified and updated based on the operations to be carried out and based on the new information that the restoration intervention will make available.

Conclusions

When a year ago we gave ourselves 12 months to study Gelati's mosaic and produce the executive project for the restoration, it seemed like a reasonable amount of time. Others even judged it too long. Today we realize that it was a very short time, in which we had to rush through every stage to keep our promise. As in any research, there were procedures that responded well to expectations, some less so. Others were introduced during the work in progress to try to complete aspects that did not end as expected. One consideration applies to all of them: the results we have presented in this study are the product of observation, research and experimentation carried out on a mosaic in precarious conditions and sometimes poorly legible due to deposits of surface dirt. This is to say that the study does not end here, but must continue in the future throughout the conservation process. We are satisfied with the results, but we also recognize their numerous limitations and partialities.
An example of all is the documentation: this is a process for which the level of cleaning of the surfaces is crucial and often our reading has been made difficult by the deposits that today limit visibility. Therefore, the documentation that we attach to this study should be understood as a graphic basis to be studied in depth and integrated throughout the conservation process.

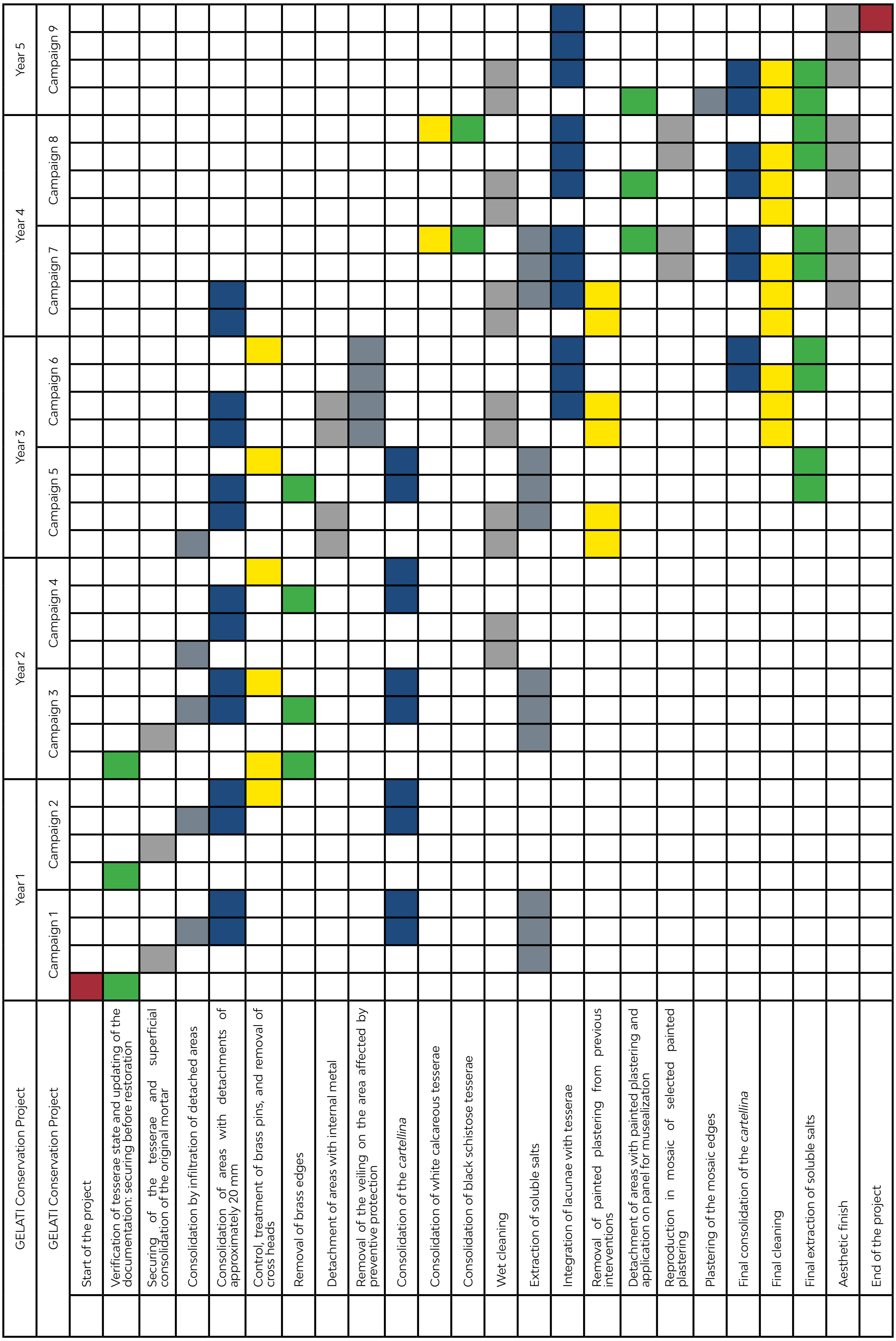
When we thought about the intervention strategy for this mosaic a year ago, we were aware that the state of the mosaic surfaces required extreme caution and that some fundamental information had to be acquired before anything else: its nature, history, and state of preservation. And so it was. Today we know these aspects better and we have been able to identify the strategy and procedures for the conservation intervention more freely. We also produced the tools that not only allowed us to plan the intervention, but also allowed us to trace a POINT ZERO from which to start for all interventions to be performed in the future. We produced an anamnesis of the mosaic that allowed us not only to produce a diagnosis, but also to define the treatment. In all of this, a very important role was played by historical and iconographic research, which allowed us to verify crucial information. Today the process is complete and all that is left is to proceed.



Referring to some of the questions that we had on the table one year ago, I would like to recall some of them and see which answers we have today.

- The nature of the salts and their origin: even if we still do not know the exact source of the salts, we know, at least the ones we have identified on the mosaic surfaces, that they are mainly of an organic origin, that they do not come from the inner structure just like they do not come from external environmental pollution. We know that they need to be studied more, but, more important, we know that they must be removed and we also know how to extract them;
- The consistency of the original materials, from the tesserae to the bedding and structural mortars: today we know that the bedding layers of the mosaic are made of two 10 mm strata made basically of lime with a limited addition of aggregate and straw plus a 2 mm setting bad made of lime. The tesserae are made of five type of limestone;
  one dark silicate rock;
  metal leaf tesserae, both gold and silver;
  semi-opaque colored tesserae in blue, green, brown-purple (glass pastes);
  opaque red and translucent black tesserae, for a total palette of 22 colors;
- The origin, type and extent of the detachments between the mosaic and the preparation layers: we know that 89% of the mosaic is detached and just under half of these are up to 20 mm wide. The causes of the detachment are multiple: water infiltration, wind circulation into the wall structure and vibrations caused by the explosions of a nearby quarry.
- Severity and extent of salt crystallization damage within the body of the tesserae with particular reference to the condition of the gold and silver tesserae *cartellina*: the presence of chlorine (Cl) in association with silver (Ag) allow to think that in a certain moment in the past a chlorine-containing agent was used to clean the mosaic.
- The function now performed by the large number of metal restoration pins inserted in the 1990s and before: the function is still positive and they represent a guarantee for the survival of the mosaic. The quality of the brass used to produce the pins prevents metal deterioration and expansion. Only the superficial cross-shaped heads show signs of copper deterioration and will be removed.
- The state of the areas detached and reapplied during previous restorations: we still do not know the material that was used to relay the mosaic. What we know is that in some areas metal elements were inserted into the setting layer and they will be removed.
- The state of the restoration additions: these also will be removed because the same nature of the material used (stucco) that is not light-reflecting. They will be replaced with glass tesserae.
- The reconstructions that Bakuradze made in the lower part of the dress of Maria with painted stucco: for the same reason, no reflection of light, these areas will be replaced with glass tesserae.
- The state of the lower areas of the apse where the mosaic is lost and areas was replaced with pictorial reproductions: this will be restored and maintained as witness of a masterful restoration intervention.

Activity	Weeks									
	1	2	3	4	5	6	7	8	9	10
Executive design of the protection structure;	■	■								
Structure construction			■	■	■	■				
Review of the adhesion state of the tesserae and securing			■							
Review of the setting-bed layers and pointing consolidation			■							
Dry cleaning				■						
Consolidation of the *cartellina*			■	■	■					
Dry removal of crystallized salts					■					
Pre-wet cleaning					■	■				
Veiling of the mosaic			■	■	■	■				
Installation of the protection structure							■	■	■	■


GELATI Conservation Project
Year 1
Year 2
Year 3
Year 4
Year 5
GELATI Conservation Project
Campaign 1
Campaign 2
Campaign 3
Campaign 4
Campaign 5
Campaign 6
Campaign 7
Campaign 8
Campaign 9
Start of the project
Verification of tesserae state and updating of the documentation: securing before restoration
Securing of the tesserae and superficial consolidation of the original mortar
Consolidation by infiltration of detached areas
Consolidation of areas with detachments of approximately 20 mm
Control, treatment of brass pins, and removal of cross heads
Removal of brass edges
Detachment of areas with internal metal
Removal of the veiling on the area affected by preventive protection
Consolidation of the cartellina
Consolidation of white calcareous tesserae
Consolidation of black schistose tesserae
Wet cleaning
Extraction of soluble salts
Integration of lacunae with tesserae
Removal of painted plastering from previous interventions
Detachment of areas with painted plastering and application on panel for musealization
Reproduction in mosaic of selected painted plastering
Plastering of the mosaic edges
Final consolidation of the cartellina
Final cleaning
Final extraction of soluble salts
Aesthetic finish
End of the project

In practical terms the proposal for the conservation of the mosaic of Gelati is structured in two phases: a preventive conservation campaign, to be implemented as soon as possible; an actual conservation process, to be implemented after that some pending questions will be resolved.
These questions are related to the surrounding environment of the church and are:

- the roof to be rehabilitated;
- water infiltration to be eliminated;
- the risk of condensation on the mosaic surface to be prevented;
-the original rainwater drainage functions to be reestablished from the roof level down to the ground;
- the underground channels for capturing and disposing of rainwater and groundwater to be reopened and restored to their original functions.

The preventive conservation

We have calculated for this program a necessary time span of 4 months, of which the first 6 weeks will be in the studio and workshop, while the following 10 weeks will be on site in Gelati. A group composed of 1 engineer, 3 metalworkers, 10 conservators which will rotate in groups of 5, 1 video maker will be allocated to this program.

Conservation-restoration program

When the Preventive Conservation will be complete and all additional interventions will be carried out on the structure of the church, the conservation-restoration program can start.

We foresee for this operation a period of four and a half years during which we will organize nine on-site work campaigns lasting two months each. The waiting times between one campaign and the next are of a technical nature and are instrumental to the sedimentation and setting times of the mortars. We will provide a pool of 15 conservators who will rotate in groups of five, as well as the assistance of an engineer, a scientist and a video maker.
With this study we believe we have laid the foundations and provided the tool to achieve an ambitious, urgent and necessary result: the structural restoration and safety of the mosaic of the Virgin at Gelati. But this will not be enough to satisfy the enormous cultural, symbolic and religious potential that the mosaic at Gelati embodies by its very nature. And it is not even the only goal we want to achieve. Just to stay in the technical field, one of the collateral results that this project will provide will be to ensure the conditions for the future protection of the mosaic, meaning a plan for ordinary maintenance and preventive conservation that intervenes on the environment. Added to this are a series of more ambitious and broader objectives, and also more necessary and just: the maximum access of the mosaic and the church and the universal dissemination of the themes linked to the mosaic, to Gelati, to the "Academia". The former will be achieved by returning the mosaic to its original function: a beacon of light, an instrument of prayer, a messenger of hope. The latter guaranteeing, both during and after the intervention, the maximum dissemination of information on what is being done on the mosaic and maximum access to the places of the intervention in progress. Relaunching the universal spirit of the place: inclusion, faith and knowledge.