Gelati Monastery Complex

Wall Painting investigations

Stakeholder:
Gelati Rehabilitation Committee

2024
March - April

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Undertaken works and executors

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Activities Conducted During the Mission, March 10-30, 2024:

- Monitoring the condition of the wall paintings and salt activity throughout the Gelati Monastery complex.

- Invasive research (sampling) salts (throughout the stratigraphy) in the Nativity of the Virgin Mary Church and partially in St. George's Cathedral.

- Moisture content survey in the structure of the Church of the Nativity of the Virgin Mary using infrared thermography and electrical resistance meters.

- Downloading environmental condition data for the winter season of 2024.

- Formulating an analytical research strategy for the wall paintings in the Church of the Nativity of the Virgin Mary, involving both invasive (sampling) and non-invasive (X-ray fluorescence spectroscopy, multispectral imaging) methods. This includes field analysis and laboratory sampling to assess painting layers, coating technology, and current condition.

- Conservation interventions: stabilization of critical areas of the wall paintings and determination of a long-term conservation methodology (ongoing process).

The following members of the conservation group carried out the works:

- **International Wall Painting Conservation Group Leaders:**
    - Lisa Shekede
    - Stephen Rickerby

- **Co-supervisors of the Georgian Group:**
    - Lela Ninoshvili
    - Mariam Sagaradze

- **Senior Conservators:**
    - Nana Khuskivadze
    - Sofia Mikaberidze

- **Junior Conservators:**
    - Ella Saakian
    - Eter Toloraya
    - Mariam Todua

It is important to note that the wall painting conservation group collaborates closely with international institutions and experts.
•Salt and Building Material Research: Additional research in this field is being led by Steffen Laue, Professor of Natural Sciences in the Conservation-Restoration Program at Potsdam University of Applied Sciences. The first stage of the research was completed in December 2023, with the second stage concluding in March 2024.
•Consultation on Environmental Conditions and Salts: The group is also advised by Dr. Christina Blauer, a conservation scientist and mineralogy expert, on matters related to environmental conditions and salt activity.

1. Aim of the mission

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The primary objectives of the March 2024 mission were:

- Continuing the ongoing monitoring of the wall paintings, salt activity, and environmental conditions across the Gelati Monastery complex. This effort aims to assess the extent of damage and track the dynamics of the factors contributing to deterioration.

- Advancing the non-invasive analysis of the condition and technological composition of the wall paintings in the main space of the Church of the Nativity of the Virgin Mary at Gelati. This includes the use of multispectral imaging and portable X-ray fluorescence spectroscopy, as well as the collection and synthesis of existing research. The goal is to deepen the understanding of the painting's technology and condition, identify deterioration mechanisms, and reduce the need for invasive studies.

- Developing a technical research strategy for the wall paintings in the main space of the Church of the Nativity of the Virgin Mary and collecting samples for invasive analysis.

Nativity of the Virgin Mary and St. George's churches:

- **Salt Composition Analysis:** Invasive research was conducted to determine the composition of salts, a primary cause of interior deterioration, particularly in the Nativity of the Virgin Mary Church and partly in St. George's Cathedral. Salt samples were taken from both the interior surfaces and the stratigraphic layers. The research aims to: identify the precise salt composition, trace the source of the salts, and assess their activity in relation to environmental conditions, with the goal of stabilizing the salts.

- **Moisture Content Analysis:** The moisture levels were examined in areas of water infiltration that have been recorded over the past decade in the structure of the Nativity of the Virgin Mary Church. This was done using infrared thermography, electrical resistance meters, and micro-core analysis.

- **Conservation Interventions:** remedial conservation measures were implemented to stabilize critical areas of the wall paintings in the Nativity of the Virgin Mary Church. This included the first stage of developing a long-term conservation strategy, based on field studies, laboratory analysis, and testing conducted on the monument.

2. Technical investigation strategy

2. Technical investigation strategy

Overview of principles and aims

Wall paintings are intrinsic to their architectural context, and buildings are physical systems in which each element has the potential to affect painting condition. For conservators to understand aspects of deterioration and develop appropriate and compatible conservation approaches and remedial interventions, it is necessary to acquire information on the materials constituting the entire building stratigraphy, that is:

- the paint layers (all aspects of stratigraphy from ground layers to coatings and glazes)
- the secondary support (the plaster layer/s) of all painting phases
- the primary support (the stone, rubble/mortar infill etc.) of all building phases

later repair materials (such as gypsum- and cement-based repairs)

In the present investigation, information which has already been gathered from previous analysis will be drawn on and not duplicated unnecessarily. In the spirit of minimal intervention as much information as possible will be derived from non-invasive investigations, and invasive sampling will be kept to a minimum. Only as much material as is needed will be sampled and no more, and samples will only be obtained from discreet areas already opened by damage or deterioration. Samples are to be taken to answer specific questions relating to conservation, and if possible, to answer multiple questions in a single sample.

2. Technical investigation strategy

Painting technology investigations

For wall painting conservation, the information required from the study of painting technology is more complex than for other aspects of stratigraphy, and a good background education in wall painting technology is required for its interpretation, together with scientific understanding of the physical and chemical properties of materials, and contextual knowledge of local and regional traditions and practices.

Questions can be broken down into three main categories:

- those which pertain to condition, for example by connecting unaltered and altering materials and linking them with specific deterioration phenomena. (
- those which add to our understanding of significance, for example establishing the use of rare or costly materials, document previously unacknowledged aspects of palette or method, establish continuity or adaptation of traditional practices etc.
- those which increase knowledge of painting phases, dating, and workshop practice.

From April 2023 to February 2024, visual examination of the wall paintings in the main space of the Church of the Nativity of the Virgin Mary at Gelati, using a portable microscope, was supplemented by technical non-invasive research methods.

In addition to portable microscopy, these methods included multispectral imaging and in-situ analysis with portable X-ray fluorescence spectroscopy.

To gain more detailed insights into the pigments and the nature of the damage, microscopic analysis of research samples will be conducted using Optical Microscopy and IR Microscopy (cross-sections, dispersion), along with Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy (SEM-EDX).

Furthermore, techniques such as Infrared Spectroscopy (FTIR/IR Microscopy), Gas Chromatography-Mass Spectrometry (GC-MS), and/or High-Performance Liquid Chromatography (HPLC) will be employed to identify binding media, coatings, glazes, and other organic components.

2. Technical investigation strategy

Investigation of plaster layer

The primary goal of studying the plaster layers is to aid in the development of compatible conservation materials and techniques. The initial stage of research, focused on gathering essential data, has already been completed.

From April 2023 to February 2024, non-invasive in-situ studies using a portable microscope were conducted to examine each type of plaster in the main space of the Church of the Nativity of the Virgin Mary. This research revealed the physical characteristics of the plaster layers, including color, texture, filler aggregates (size, morphology, color), and organic inclusions. Additionally, the general ratio of binder to filler was identified. In-situ chemical testing was also carried out to determine the nature of the binder. (The nature of the binder of each plaster type was established by taking small scrapings of plaster. These were crushed, applied onto a glass surface and a single drop of HCl applied. This simple test can distinguish lime-based from gypsum-based plasters as lime plasters produce a vigorous effervescence on the release of CO2 whereas gypsum plasters do not. It can also provide indicators of types and quantities of acid-resistant fillers and additives by examination following complete dissolution.)

The findings showed that all plaster types were lime-based, which has guided the development and testing of lime-based conservation materials. It is important to note that the research also incorporated analytical results from studies conducted in 2021-22 (Poulieri & Cenntini 2021, Melica 2022).

To gather additional information, invasive studies are planned. These will involve collecting research samples for further laboratory analysis and testing. The research methods will include Optical Microscopy (OM), Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy (SEM-EDX), as well as X-ray Diffraction (XRD) analysis.

This detailed research is essential for collecting data on critical factors such as the porosity of the plaster, pore distribution, binder-to-filler ratio, geological or mineralogical-petrographic identification of aggregates, and the identification of organic inclusions (The three fibre types found in the plasters will also be sampled and identified microscopically). Additionally, information will be gathered on the composition of locally sourced Georgian lime, including magnesium content.

Primary support investigations

At Gelati a major contributor to wall painting deterioration is soluble salts, and a central aim of wall painting conservation is to identify salts and their sources in order to protect the paintings from further salts-related deterioration. Salts analysis is already advanced, and the identification of the building stone as dolomitic limestone in previous analysis undertaken on behalf of Restruere establishes that magnesium-containing salts species are likely to have an autocthenous origin. No further analysis of the stone is required. Information regarding the mortar and rubble infill of the core is outstanding, but structural investigations to be undertaken shortly by Studio Croci may be able to provide further insights and access for future sampling.

Research of Non-Original Materials

The study of non-original materials, such as repair layers from previous restoration efforts, focuses primarily on identifying the sources of salt formation.

Late interventions using gypsum materials are often linked to the formation of harmful sulfate-containing salts.

Another key reason for studying the characteristics of past intervention materials is to assess their compatibility with the original materials, as this can reveal causes of deterioration. For example, compatibility should be evaluated in terms of strength, density, and other properties.

In Georgia, during the second half of the 20th century, plaster fillings and edge repairs were commonly used in wall painting conservation.

In the main space of Gelati's main church, in addition to lime-based materials (containing pozzolanic material and/or sand, with a binder-to-filler ratio of 1:3), gypsum was also used (Melica, 2022, p.16).

The use of gypsum and lime repairs was confirmed by Lado Gurgenadze, head of Gelati painting conservation during the second half of the 20th century. Empirical studies and research conducted in 2022 (Melica, 2022, p.16) also confirmed that gypsum and lime fillings are easily distinguishable and do not require further in-depth laboratory analysis.

3. In-situ research methodology

3. In-situ research methodology

Portable X-ray Fluorescence Spectroscopy

X-ray fluorescence (XRF) spectroscopy is a non-destructive technique used to identify elemental compositions.

Working Principle:

An intense X-ray beam is directed onto the surface of the material being studied. This beam ejects electrons from the inner shells (K, L, and M) of the atoms, which are then replaced by outer electrons.

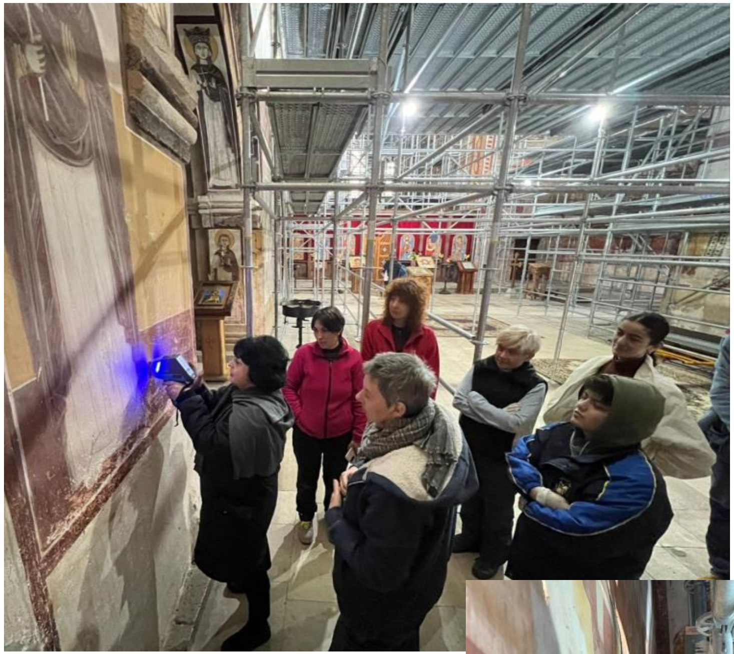
As this occurs, energy is released, corresponding to the difference between the inner and outer electron orbitals, allowing the identification of the element.

In March 2024, portable XRF equipment from the National Museum of Georgia was employed to study the wall paintings in the main space of the Church of the Nativity of the Mother of God at the Gelati Monastery complex. Technical support and consultation were provided by the museum's conservation expert, Mrs. Nino Kalandadze.

The primary goal of using this equipment was to identify potential pigments based on prior visual, multispectral, and microscopic examinations.

Additionally, it helped develop a strategy for invasive testing, aiming to minimize the need for sampling.

More than 90 locations on the monument were analyzed to determine elemental compositions.



Left: *Use of portable XRF at Gelati Monastery. Instructions was provided by National Museum's conservator Mrs. Nino Kalandadze.*

Right: *Use of portable XRF at Gelati Monastery*

3. In-situ research methodology

Portable X-ray fluorescence (pXRF) spectroscopy, such as the ProSpector 3 model, is a powerful non-destructive tool for determining the elemental composition of materials. It is especially useful for analyzing the content of heavy metal elements, ranging from sulfur (S) to uranium (U), in a variety of applications, including archaeological studies, heritage conservation, and material science.

Analytical Sample Categories Using pXRF:

1.Natural Minerals and Artificial Pigments
The pXRF is highly effective in identifying and quantifying the presence of metal-containing natural minerals and pigments. Key categories include:

1. **Lead-Containing Pigments:** e.g. red lead, lead white
2. **Copper-Containing Pigments:** e.g Azurite (blue), malachite (green))
3. **Iron-Containing Pigments:** Earth pigments (e.g., ochres), golds
4. **Silver-Containing Pigments:** Singur (a silver-based pigment)
5. **Cadmium-Containing Pigments:** Cadmium yellow (cadmium sulfide), cadmium red
6. **Zinc-Containing Pigments:** Zinc white (zinc oxide)
7. **Arsenic-Containing Pigments:** Realgar (arsenic sulfide)
8. **Zirconium-Containing Pigments:** Zirconium yellow, zirconium blue

2. Identification of Precious Metals
pXRF is also utilized in detecting the presence of precious metals in artifacts, particularly:

Gold: Used in gilding material on wall paintings

	ProSpector 3
X-Ray Tube	W, 40 kV (option 50 kV)
Primary Filters	Single
Collimators	Single
X-Ray Detector	SDD (option – large area Fast SDD)
Detector Window	Be, 12 um
Detection Range	S – U
CCD Camera	Sample view (option)
Temperature correction	Yes
Barometric correction	No
Bluetooth	Option
Wi-Fi	Option
GPS	No
Ingress Protection	IP65
He purge	No

ზემოთ: *XRF ProSpector 3-ის ტექნიკური მონაცემები*

Multispectral imaging

Multispectral imaging is a non-invasive imaging technique used to indicate and differentiate between original and non-original materials in artworks, such as paintings or murals. It is particularly useful for mapping the planar distribution of these materials, aiding in conservation, restoration, and condition assessment.

Key Features of Multispectral imaging:

1. Use of Different Spectral Ranges

Multispectral imaging involves capturing images across different ranges of the electromagnetic spectrum, including:

1. **Infrared (IR)**
2. **Visible light**
3. **Ultraviolet (UV)**

2. Each spectrum provides unique information about the luminescent and reflective properties of materials, such as pigments, binders, and other organic substances.

3. Characterization of Materials

This technique is employed to:

1. Identify differences between original and non-original materials.
2. Visualize the distribution of pigments and organic substances on the surface.
3. Distinguish between various layers of paintings, including overpaints, restorations, and retouching.

4. By analysing how different wavelengths interact with the materials, conservators can map out the composition of the artwork.

5. Infrared Light for Sub-Surface Investigation

Infrared light, particularly at longer wavelengths, can penetrate beneath the surface layers of the artwork. This allows the detection of:

1. **Under-drawings** or sketches beneath the paint.
2. **Hidden features** or inscriptions that may not be visible to the naked eye.
3. **Preparation techniques**, such as those used in Gelati wall paintings, which may include details about the materials or methods employed in the base layers.

6. Ultraviolet Light for Surface Analysis

UV light highlights fluorescence and surface properties of materials, revealing:

1. Varnish layers and degradation.
2. Organic substances like resins, glazes, and binders.
3. Restoration areas and repaintings (non-original parts of the painting).

7. Combined Analysis for Comprehensive Insights

By combining infrared, visible, and ultraviolet imaging, multispectral photography can differentiate between materials that may appear identical in the visible spectrum but have distinct characteristics under other wavelengths. This is critical for identifying original materials versus modern additions or repaintings, aiding in the accurate assessment of the artwork's authenticity and condition.

3. In-situ research methodology

Multispectral imaging

In the case of the Gelati wall paintings, infrared photography is particularly useful for investigating underlying preparatory techniques, such as underdrawings or compositional adjustments, offering a deeper understanding of the artistic process and material use in the creation of these historical works.

Ultraviolet (UV) light, due to its short wavelength, does not penetrate deeply into materials, providing information limited to the surface layer. When applied to the Gelati wall paintings, UV light is used to reveal differences between original and non-original organic materials, as well as to help identify various pigment types. Also similar to infrared, it is worth noting that in combination with visible spectrum photography, it may reveal distinguishing features between the same material or between original and non-original materials (repaintings).

Multispectral photography was employed in the research to gather comprehensive data on the materials and techniques used in the artwork. The process involved the following types of photography, each targeting specific objectives:

Part of the equipment used for multispectral photography was shared by the Technical Research Center of painting named after E. Privalova "Betania".

1. Reflectance of the Visible Spectrum

Objective:

•**Material Characterization:** Identify and distinguish different pigments and materials based on their appearance under normal light conditions.

•**Material Distribution:** Map the spatial arrangement of various materials across the artwork's surface.

•**Research Strategy Identification:** Inform subsequent analysis steps based on initial findings in the visible spectrum.

2. Infrared reflectance

Purpose:

•**Detection of Material in Depth:** Infrared light penetrates beneath the surface layers, revealing hidden features such as underdrawings, preparatory sketches, or subsurface changes.

•**Distribution of Materials:** Identify deeper layers of materials, offering insights into the original creation process and later restorations or modifications.

3. In-situ research methodology

3. Ultraviolet luminescence

Purpose:

•**Characterization of Organic Materials:** UV light causes organic substances, such as varnishes, binders, and certain pigments, to fluoresce, aiding in their identification.

•**Material Distribution:** Highlight differences between original and non-original materials, particularly those that fluoresce under UV light.

•**Condition Detection:** Assess the preservation state of surface materials, revealing degradation, overpainting, or restorations.

4. Visible induced luminescence

Purpose:

•**Characterization of Specific Materials:** Identify unique materials like Egyptian blue, Han's lurch, Han's violet, cadmium-based pigments, and varnishes, which exhibit distinct luminescent properties when excited by visible light.

•**Distribution of Materials:** Map where these specific pigments and materials are located within the artwork.

•**Condition Detection:** Evaluate the condition of these materials, such as signs of wear, restoration, or chemical changes.

Each type of photography serves to provide a layered understanding of the materials and their condition, guiding conservation strategies and deepening insight into the artwork's history and techniques.

3. In-situ research methodology

One of the key non-invasive visual research methods used in the study of the Gelati Monastery complex is the microscopic examination of materials through a hand-held portable microscope.

Portable Microscope Usage:

•**Types of Microscopes:** Two types of portable microscopes with magnification ranges from **10X to 250X** are employed in the research. These microscopes are versatile for both on-site wall observations and detailed material analysis in field laboratory conditions.

•**Imaging Capabilities:**

The portable microscope offers the ability to capture both **photos and videos**, utilizing:

- **Incident light** for standard observation.
- **Raking light** to reveal surface texture, depth, and details that might not be visible with direct lighting alone.

•**Ultraviolet Light Integration:**
The microscope is equipped with **ultraviolet light** functionality, allowing for the observation of organic materials that fluoresce under UV light. This is particularly useful for identifying organic binders, varnishes, and other substances on the surface of the artwork.

This non-invasive technique is essential for closely examining fine details of the materials used in the wall paintings, helping to analyze the condition and composition without causing any damage.

The Dino-Lite Pro II AD4113T 10x-50x, 220x Digital Microscope

The Dino-Lite AM7115MT-FUW, 20 – 220x Digital Microscope

ზემოთ: *მხატვრობის მიკროსკოპული შესწავლა*

ქვემოთ: *საველე ლაბორატორიულ პირობებში პორტატული მიკროსკოპის გამოყენების მაგალითი*

Images: Use of Flir IR camera for assessing surface temperature of the walls

Infrared (IR) thermography

Infrared (IR) thermography is a non-contact imaging technique that uses thermographic devices to capture and display the spatial distribution of surface temperatures. By detecting infrared electromagnetic waves reflected from a surface, IR thermography provides temperature data in a visual format, often as a color gradient or black-and-white image.

Key Features of Infrared Thermography:

•Surface Temperature Mapping:

Each pixel in the thermographic image corresponds to specific surface temperature data. This information can be displayed in two forms:

- **Quantitative Data:** Numerical values representing the exact temperature at different points on the surface.

- **Qualitative Information:** Visualization of temperature variations across the surface, helping to identify patterns or irregularities.

Infrared (IR) thermography

Applications in Research and Conservation:
IR thermography is particularly valuable for examining the condition and structure of historical monuments and artworks. In the case of the Gelati monastery complex, it is used to:

•Detect building materials:
It helps identify different building materials (e.g., stone piles) by analyzing temperature differences that may indicate the presence of specific materials.

•Determine moisture distribution:
Variations in surface temperature can reveal areas affected by moisture, which may impact the preservation of the wall paintings or structure.

•Identify Voids or Separations:
IR thermography detects hidden voids, separations, or air pockets within the structure, providing insight into potential structural issues or deterioration.

•Monitor Conservation Material Distribution:
During remedial interventions, IR thermography is used to track the movement and distribution of conservation materials (e.g., adhesives, grouts, alcohols, water) as they are applied to the structure, ensuring effective and even coverage.

This technique provides critical insights into both the surface and underlying structure without causing any physical disturbance, making it an essential tool in conservation and restoration efforts.

Images: *use of Topdon IR camera.*

The **electrical resistance meter** is additional methods for indicating humidity levels within a structure. In the Gelati Monastery complex, the **BL Compact B2** device is employed, a non-invasive tool that uses the **dielectric constant/radio frequency measurement principle** to assess moisture content.

Features of the Electrical Resistance Meter:
•Non-Invasive Testing:
The BL Compact B2 provides a non-destructive means of indicating moisture using a **versatile ball sensor**, which can sense humidity in various types of building materials without damaging the structure.

•Moisture Distribution Mapping:
The device is capable of indicating and mapping moisture on **walls, ceilings, and floors**, offering a spatial understanding of how moisture is distributed across different surfaces.

However, limitations of this method should be taken into consideration, especially in the areas, where the salt content is high.

3 Specifications

3.1 Technical Specifications

Display:	3-line display
Display resolution:	0.1%
Reaction time:	< 2 s
Storage conditions:	+ 5° to + 40° C
	- 10° to + 60° C (short-term)
Operating conditions:	0° to + 50° C
	- 10° to + 60° C (short-term)
Power supply:	9 V battery
Usable types:	Type 6LR61 or Type 6F22
Dimensions:	190 x 50 x 30 (L x W x H) mm
Weight:	approx. 180 g

3.2 Intolerable Ambient Conditions

- Condensation, continuously high air humidity (> 85%) and wet
- Continuous dust exposure and flammable gases, vapours or solvents
- Continuously high ambient temperatures (> + 50° C)
- Continuously low ambient temperatures (< + 0° C)

4.4 Display Values (Digits) in Relation to the Bulk Density

Density (specific wt.) of the building material kg/m³	Corresponding Relative Air Humidity 30 — 50 — 70 — 80 — 90 — 95 — 100 Display in Digits					
	very dry	normal dry	semi dry	moist	very moist	wet
up to 600	10 - 20	20 - 40	40 - 60	60 - 90	90 - 110	more than 100
600 -1200	20 - 30	30 - 50	50 - 70	70 - 100	100 - 120	more than 120
1200 -1800	20 - 40	40 - 60	60 - 80	80 - 100	110 -130	more than 130
above 1800	30 - 50	50 - 70	70 - 90	90 - 120	120 - 140	more than 140

Hydromette BL Compact B 2

***Images:** specification of the equipment: The GANN BL Compact B2 device*

The GANN BL Compact B2 device was shared by expert Stefan Simon, a member of the Gelati International Rehabilitation Committee.

3. In-situ research methodology

Application in the Gelati Monastery:
In the main space of the **Church of the Nativity of the Virgin Mary**, the electrical resistance meter is used to:

•**Identify Moisture-Containing Locations:**
The device provides **qualitative information** by pinpointing specific areas with moisture infiltration, such as damp spots or areas prone to water damage.

•**Perform Comparative Moisture Analysis:**
By comparing **numerical data** collected from different areas over time, the device helps assess changes in moisture content. This is particularly useful for monitoring the effectiveness of interventions and identifying recurring moisture problems.

Data Collection Areas:
•**Northern Wall of the Western Arm (February-March 2024):**
Measurements were taken in the location of water infiltration on the northern wall, specifically in the **fourth register scene with Christ before Caiaphas**, which experienced moisture issues earlier in the year.

•**Micro-core sampling survey Locations:**
Additional measurements were collected from the **west and east walls of the northern arm** of the main space using micro-core sampling surveys. These areas were investigated to determine **salt** and **moisture content** deeper within the walls, supplementing surface moisture data.

The data gathered from the BL Compact B2 device provides additional insights for moisture management, enabling targeted conservation efforts to protect the historical structure.

***Images** USE of the electro resistance meter - GANN BL Compact B2 device*

4. Summary of investigation results

4.1 Study of the Plaster Layer

Painted scheme 1 (early)

The study of the early painting layer in the western arm of the main space of the **Church of the Nativity of the Mother of God** is conducted using both **non-invasive** and **invasive** methods.

Location and condition of the early painting layer:

•The early painting layer is found on the **northern and southern walls** of the vault of western arm, specifically in areas where the **16th-century painting layer** has deteriorated or is missing.

•On the **northern wall of the western arm (N6)**, fragments of plaster are also observed.

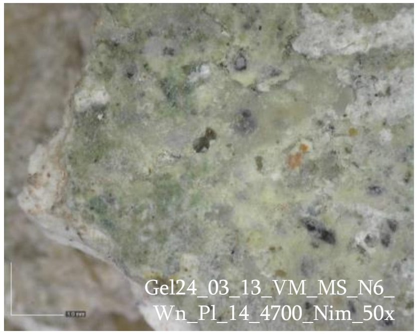
Categories of the early painting layer:

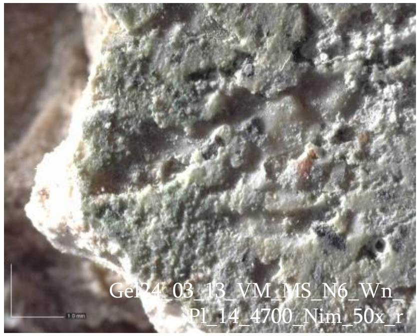
The early painting layer is divided into three main categories:
1. The unidentified unpainted plaster patches(4.2.1.1):
Small, preserved portions of the early layer that have yet to be fully identified or analyzed.
2. The main plaster layer (4.2.1.2):
The plaster layer which has majority of the remaining paint layer
3. Preparatory Layer (4.2.1.3):
A preparatory layer that was applied to prepare the surface for the paint layer.

Main plaster layer is characterised with a light gray colour. The plaster is up to 1 cm thick, with a fine-grained inorganic aggregate filler, composed of materials with different colors and morphologies. These fillers provide a stable base for the painting and help in understanding the technical processes used by the original artists.

In areas where the main plaster layer is present, a preparatory layer of uneven thickness is found, typically thin, up to 0.2 cm, and composed of an inorganic aggregate filler. This preparatory layer is well-processed and features a smooth, uniform texture. Its composition closely resembles that of the main plaster layer, making it challenging to visually distinguish between the two layers. During field laboratory studies, samples were collected from the main plaster layer. Microchemical analysis using hydrochloric acid confirmed that lime is the primary binder in the plaster layer.

Left: *main plaster layer of the early painted scheme.*





4. Summary of investigation results

4.1 Study of the Plaster Layer

Painted Scheme 2 (16th Century)
The plaster layer of the 16th-century wall paintings in the arms of the main space of the **Cathedral of the Nativity of the Virgin Mary** is studied using both **non-invasive** and **invasive** methods. The research incorporates findings from previous analytical studies to provide a comprehensive understanding.

Methods of Investigation:
•Non-Invasive Methods:
- **Visual Observation** using a **portable microscope** and **macro photography** allows for the detailed inspection of the plaster without causing damage.

•Invasive Methods:
- **Microchemical Testing,** including **optical microscopy (OM/SM), scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDX),** and **X-ray diffraction (XRD)** provide detailed chemical and structural analysis of the plaster.

These methods offer insights into the composition and stratigraphy of the plaster layers across the different arms of the church.

Findings:
• Composition variation by arm:
The number and composition of plaster layers in the **late 16th-century painting** differ between the arms of the church, and even between specific scenes within each arm.
- The composition of the **late painting** layers is notably distinct from that of the **early painting** layers, reflecting different materials and techniques used at various times.

•Six main types of plaster identified:
Based on **visual observation** (using the portable microscope and macro photography), **six distinct types of plaster** were identified, each with unique compositional characteristics. These findings are consistent with the results of **microchemical tests** and previous analytical studies.
Plaster Composition:
•Lime as Binder:
According to **microchemical analysis** (using hydrochloric acid), **carbonate material (lime)** serves as the binder in all six types of plaster. This is a common feature across all the plaster layers.
•Inorganic Aggregates and Organic Inclusions:
While lime is the binder, the key differences between the six types of plaster are found in:
- The **amount of inorganic aggregates** (e.g., sand, minerals).
- The presence and type of **organic inclusions** (e.g., fibers, plant matter), which vary between plaster types.

4. Summary of investigation results

4.1 Study of the Plaster Layer

Painted Scheme 2 (16th Century)

The study of the plaster layers in the arms of the Cathedral's main space revealed six distinct types of plaster, each with varying compositions of inorganic aggregates and organic inclusions.

Type 1:

•**Composition:**

- **Binder:** Lime.
- **Inorganic Aggregates:** High quantity of aggregate fillers.
- **Organic Inclusions:** Yellow-colored, straw-like fibers.

•**Description:** This type of plaster is rich in both inorganic and organic components, where the straw inclusions are prominent and add texture to the mix.

Type 2:

•**Composition:**

- **Binder:** Lime.
- **Inorganic Aggregates:** Large quantity of river sand as the main aggregate filler.
- **Organic Inclusions:** White, transparent fibers.

•**Description:** The combination of river sand and white transparent fibers provides this plaster type with a distinctive texture and structure, likely contributing to its durability.

Type 3:

•**Composition:**

- **Binder:** Lime.
- **Organic Inclusions:** Straw fibers.

•**Description:** A simpler mixture, this plaster consists only of lime binder and straw, with no additional inorganic aggregates. The straw fibers likely serve as reinforcement within the plaster.

Type 4:

•**Composition:**

- **Binder:** Lime.
- **Inorganic Aggregates:** Small amount of river sand.
- **Organic Inclusions:** White, transparent fibers.

•**Description:** This type features a more delicate balance of lime binder with fewer inorganic aggregates, relying on white fibers for additional strength and texture.

Type 5:

•**Composition:**

- **Binder:** Lime.
- **Inorganic Aggregates:** Large amount of river sand.
- **Organic Inclusions:** White, transparent fibers.

•**Description:** Similar to Type 2, but with a greater concentration of river sand, this plaster is designed for durability and structural support with added organic fibers for flexibility.

Type 6:

•**Composition:**

- **Binder:** Lime.
- **Organic Inclusions:** Large-sized and abundant organic inclusions.

•**Description:** This plaster stands out for its high quantity and large size of organic inclusions, which could provide significant reinforcement and texture, possibly aiding in moisture retention or evaporation control.

A table summarizing the results of these plaster studies, including detailed analysis of their composition and potential functional roles, can be found on the following page.

4. Summary of investigation results

Plaster type	Composition according to the investigation undertaken in 2021-22	2024 March - sampling (MCT, XRD, OP/ST)	Microscopic images of plasters	Initial result of chemical and XRD analysis	Statues
Type 1	Not done	1 (Ws_Pl_4)		Lime-based (carbonate) with inorganic sediments	On-going
Type 2	Si – 8 (ST, OM-RL, HT, OM-TL) და 9 (ST, OM-RL, HT, OM-TL, FT-IR): Binder: Calcite Non-organic filler: Fluvial sand Organic inclusion: Straw Proportion (binder to filler): 2:1 N6_ 40: Organic inclusion: animal origin, classified as wool, and others of plant origin probably attributable to hemp. Wool is obtained from the fleece of sheeps.	1 (Ws_Pl_5)		Lime-based (carbonate) with inorganic sediments	On-going
Type 3	Si – 11 (OM-TL, FT-IR): biner: hydromignesite and calcite Non-organic filler: does not have Organic inclusion: Straw	6 (Sw_Pl_1, Sw_Pl_2.1, Ww_Pl_3.1, Ww_Pl_3.2, Ws_Pl_6, Ne_Pl_9)		MCT: Lime-based (carbonate) without sediments; XRD: High amount of dolomite and low amount of calcite	On-going
Type 4	Si – 10 (ST, OM-RL, HT, OM-TL, FT-IR): Binder: hydromagnesite and calcite Non-organic filler: Fluvial sand Proportion (binder to filler): 3:1	2 (Sw_Pl_2.2, Se_Pl_7)		MCT: Lime-based (carbonate) with inorganic sediments; XRD: High amount of calcite and low amount of dolomite and quartz	On-going
Type 5	Si – 12 (OM-TL) Binder: Calcite Non-organic filler: Fluvial sand Organic inclusion: Straw? Proportion (binder to filler): 1:1	5 (Ne1_2, Ne3_1, Ne2_1 and Nw_1_1, Ne_Pl_10) 1 (Ne_Pl_15 Transparent organic fibre)		MCT: Lime-based (carbonate) with inorganic sediments; XRD: High amount of calcite and low amount of dolomite and quartz	On-going
Type 6	Not done	1 (Ne_Pl_11)		MCT: Lime-based (carbonate) with inorganic sediments;	On-going

4. Summary of investigation results

4.1 Study of the Plaster Layer

Painted Scheme 3 (17^{th} century)

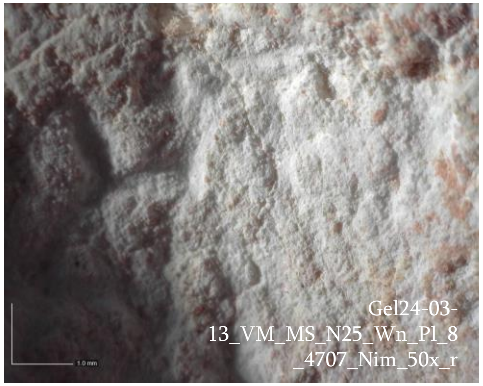
The study of the seventeenth-century wall paintings in the main space of the Church of the Nativity of the Virgin Mary employs both non-invasive (visual observation with a portable microscope) and invasive methods.

The plaster layer from the late 17th-century painting in the western arm of the church visually resembles the third type of plaster layer from the 16th century, which is a mixture of lime and organic inclusions.

In-situ laboratory studies, including microchemical analysis with hydrochloric acid, reveal that the plaster layer is bound by carbonate material (lime) and does not contain any filling aggregates.

__Left:__ 17^{th} century paintings from the main space of the Virgin Mary, west arm, lower tier.
Plaster with lime binder and organic inclusions.

__Below:__ Microscopic photographs show the plaster of the seventeenth-century layer, which is lime-based in nature and has no inorganic aggregates.



4.2 Study of the Painting Layer

From April 2023 to February 2024, non-invasive studies were conducted on the painting layer in the main space of the Church of the Nativity of the Virgin Mary, utilizing visual examination with a portable microscope. During the March 2024 mission, these existing study results were compiled, an analytical research strategy was established (including research questions and both non-invasive and invasive methods), and further investigations into the painting layer were carried out.

Painted scheme 2 (16th Century)

The main space of the Church of the Nativity of the Virgin Mary has a painting layers from the 16th century. These layers encompass several periods within the century, each distinguished by its painting style. While the execution techniques are largely consistent, there are notable differences, such as the use of specific pigments in particular schemes, which may suggest that different artist groups worked in Gelati.

From the initial study of the painting layer, including visual observations and characterizations, the following research issues were identified:

Research Question 1: What constitutes the basic palette of the painting, specifically regarding the use of earth pigments?

Visual observations and microscopic studies categorized and characterized the earth pigments by color. The identified earth pigments include shades of yellow, two shades of orange, three shades of red, and green. Overall, these pigments are in good condition.

Analytical research from 2021-2022 confirms the extensive use of earth pigments (see Report 24, November 23, 2022, Melica's Report Part II, p. 15; appendices).

During the March 2024 mission, the composition of these pigments was further verified through non-invasive element analysis using a portable X-ray fluorescence spectroscope. The presence of iron and potassium was confirmed in the pigments, corroborating their identification as earth pigments. Consequently, no additional research is planned for these pigments.

Right: *South Arm, South Wall, The church of the virgin Mary. Example of the use of different earth pigments*

4.2 Study of the Painting Layer

Research Question 2: What blue pigments were used, and what alterations have occurred?

Three types of blue pigments were identified on the 16th-century painting layer, categorized as dark blue, light blue, and greenish blue (see the summary report of the wall painting of the main space of the Church of the Nativity of the Virgin Mary in Gelati, April 2023 - February 2024).

•**Dark Blue:** This pigment appears in the vault of the west arm and the upper (IV) register, including scenes C14, S7, S8, W6, N5, and N6. In these scenes, dark blue is used consistently for backgrounds, clothing, and other decorative elements, either in its pure form or mixed. It is also present in the upper (IV) register of the north wall of the north arm, scene N7, depicting the cosmos, where it serves as the background of the arch and for the saints' vestments, either pure or mixed.

Analytical results from 2021-2022 identified dark blue as Smalt (see Report 24, November 23, 2022, Melica's Report Part II, p. 15). During the March 2024 mission, a portable X-ray fluorescence spectroscope was used to verify the presence of Smalt in two contexts: 1) at locations where Smalt had already been identified in previous studies, and 2) at locations where no prior analysis had been conducted and identification was needed.

According to XRF data, cobalt (Co) predominates in the dark blue areas analyzed, confirming the presence of Smalt.

On the west wall of the west arm and in the chamber, there are areas where this dark blue pigment has been damaged. Instead of the original blue, a thin layer of unwanted greenish-blue is present, unevenly distributed on the surface. Research from 2021-2022 identified this greenish-blue as cobalt-chrome blue. A portable X-ray fluorescence spectroscope was used to verify previously studied locations and to identify the same type of blue at additional sites. The XRF analysis detected small amounts of cobalt and chlorine, corroborating the findings of earlier studies.

The presence of the greenish-blue pigment raises a new research question: Is this greenish-blue part of the original paint, used during repair or restoration, or is it a result of alteration?

To address this, samples will be collected from both undamaged and damaged areas. These samples will undergo stratigraphic and elemental analysis using optical microscopy, scanning electron microscopy, and energy dispersive X-ray spectroscopy (SEM-EDX).

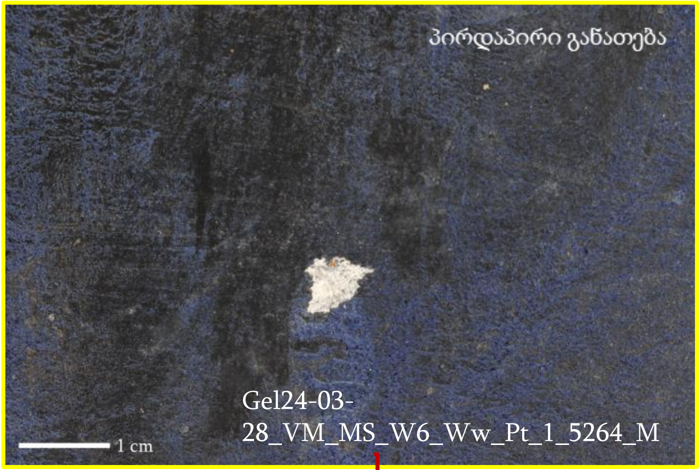
4. Summary of investigation results

4.2 Study of painting layer

Research Question 2: Used blue pigments and their alteration

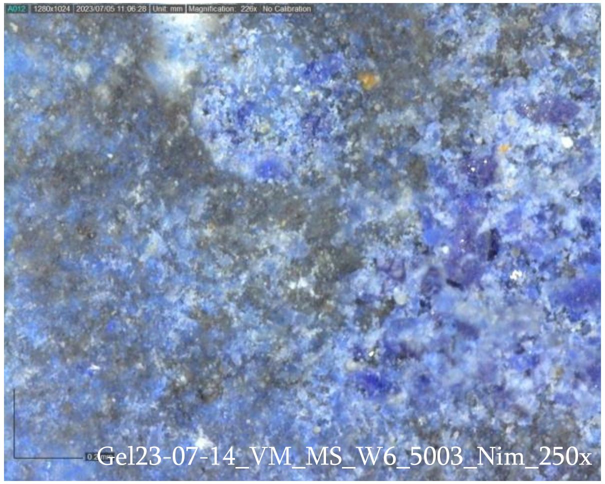
In 2021-2022, samples were collected from the western wall of the West Arm (depicting the Prayer in the Garden of Gethsemane) for an analytical study of the blue pigments. pigment samples were also taken from undamaged sections. The study identified the dark blue pigment as smalt and the weathered/light blue as cobalt-chrome blue (see Report 24, November 23, 2022, Melica's Report Part II). However, the mechanism of blue pigment deterioration was not determined in this study. As a result, the March 2024 mission aimed to investigate the causes of the blue pigment alteration and to assess the technology and potential repainting involved. Additional samples were collected from the same location, as the painting had already sustained damage.

Left: *Upper register of the west wall of the western vault, Christ in the Garden of Gethsemane, study area in dark blue.*



Left: *previously sampled area was used for for further studies.*

Right: *damaged area sampled for further studies.*



Right: *undamaged area with a portable microscope, 250X magnification, where the characteristic structure of smalt is clearly visible.*

4.2 Study of the Painting Layer

Research Question 2: Blue Pigments Used and Their Alteration

Light blue is found exclusively on the vault of the north arm and in the scenes of the upper two registers (C13, W7, W11, N7, N11, N12, E5, E7(?)). It appears in the background in its pure form and on clothing and decorative elements mainly as mixtures. Notably, on this part of the north wall, light blue is used alongside lapis lazuli and smalt, as well as a third type of blue, greenish blue, which is prominently featured on the saints' garments in the upper register of the north wall.

Studies from 2021-2022 identified this light blue as artificial lapis lazuli (see Report 24, November 23, 2022, Melica's Report Part II, p. 15). Since artificial lapis lazuli began to be used in the 19th century, its presence in the main space suggests it may be from a later repair or restoration.

Two key factors must be considered:

1. The visual characteristics of the light blue (identified as artificial ultramarine) are used not only in backgrounds but also in well-preserved garment areas. Therefore, the results from the 2021-2022 study should be re-evaluated. It is essential to clearly differentiate between the original and restored pictorial layers and to establish the methods used for their separation.

2.The inscriptions in the background of the scenes are applied over the lapis lazuli layer. If this lapis lazuli layer dates from the restoration period, then the inscriptions must also be from that period.

Given the above information, the following research questions regarding lazurite have been identified:

•What is the composition of the light blue pigment? Is it artificial or natural lapis lazuli? Is the pigment original to the painting or was it applied during a later restoration?

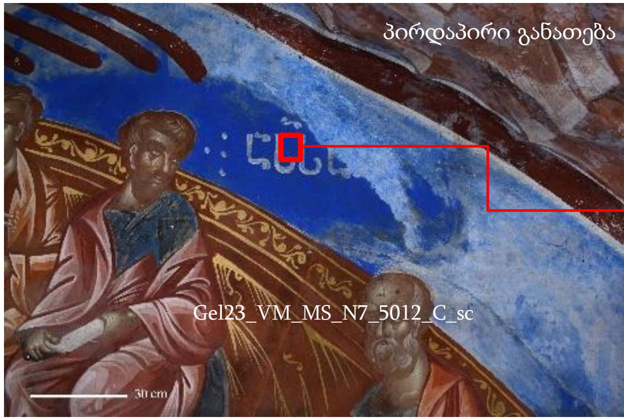
•What constitutes the light blue suit? What is the mechanism behind the suit's damage, specifically the color change from black to white?

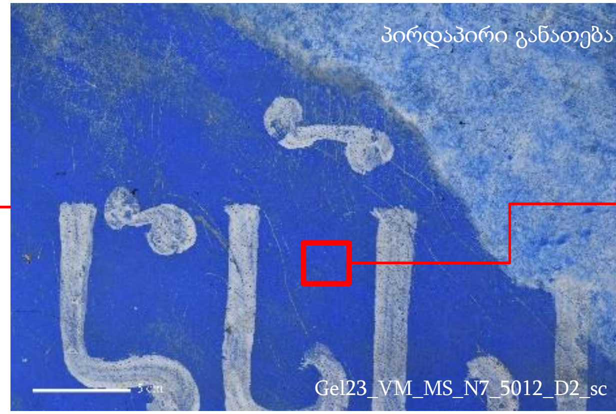
To address these questions, a sample of the light blue paint with an intact cover was taken from the northern vault. This sample will be used to determine the stratigraphy of the painting, the composition of the cover, and whether the pigment is natural lapis lazuli or artificial.

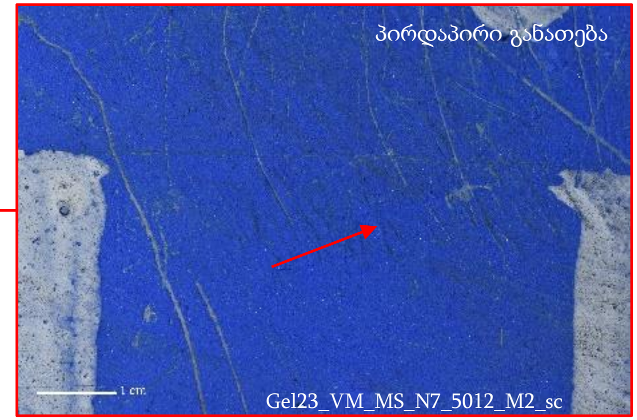
The sample will be analyzed using stratigraphic methods and elemental analysis through optical microscopy, scanning electron microscopy, and energy dispersive X-ray spectroscopy (SEM-EDX).

4.2 Study of the Painting Layer

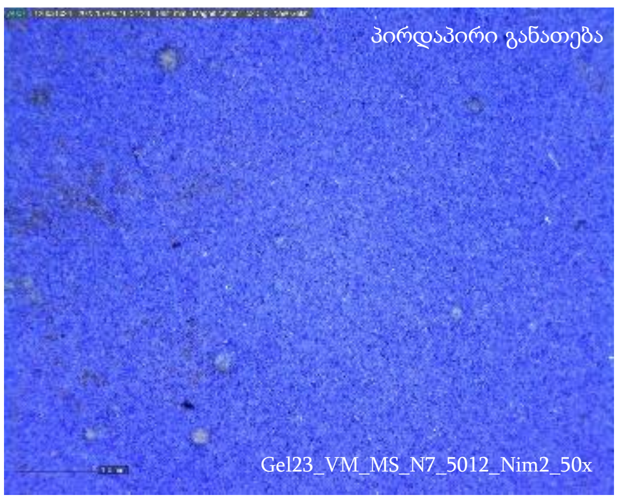
Research Question 2: Blue Pigments Used and Their Alteration

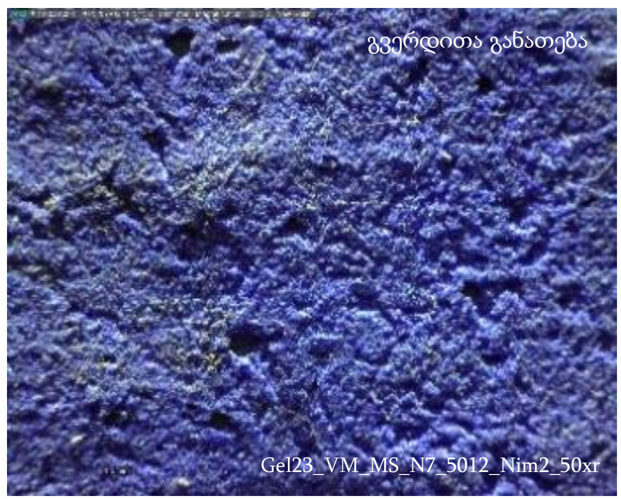






Above: *The north wall of the North Arm. Used light blue, with undeteriorated and deteriorated area.*





Left: *Photograph of the study area with a portable microscope at 250x magnification.*

4.2 Study of the Painting Layer

Research Question 2: Blue Pigments Used and Their Alteration

A third type of pigment, greenish-blue, is used extensively in the 16th-century painting, except at the level of the vault in the western arm. This greenish-blue is found primarily in the clothing treatments in the upper registers of the northern vault, while in the other scenes of the main space, it is used for backgrounds, clothing, and decorative elements.

According to the analytical research conducted in 2021-2022, a sample of the greenish-blue pigment from the clothing on the northern wall was identified as azurite. Visual observation reveals that in many areas, this blue pigment has undergone a color alteration, transitioning to green—a common characteristic of azurite degradation.

During the period from April 2023 to March 2024, further visual analysis highlighted azurite of varying granule sizes. For example, in the upper registers of the southern arm, the azurite appears in a finer fraction and is applied in a more uniform layer. In contrast, in the lower registers of the western arm, the azurite is coarser and applied very thinly, allowing the underlying base to create the primary tone while the azurite defines the final color. During the March 2024 mission, azurite was verified in nearly every scene.

Analysis of azurite pigment alteration

In the areas analyzed using portable X-ray fluorescence spectroscopy, a significant amount of copper (Cu) was detected, confirming the presence of azurite. The research questions are divided into the following directions:

1. Pigment Alteration:

1. In nearly all areas, even where the alteration is not visible to the naked eye, a portable microscope reveals completely altered pigment with distinct light green particles, indicating the early stages of alteration.
2. In some locations, where blue should be present, there is an intense neon green, which likely represents one form of azurite alteration.

2. To confirm whether these phenomena represent true pigment alteration and determine the specific type of alteration, samples were taken for further analysis using optical microscopy and scanning electron microscopy combined with energy dispersive X-ray spectroscopy (SEM-EDX).

3. Loss of the Painting Layer:

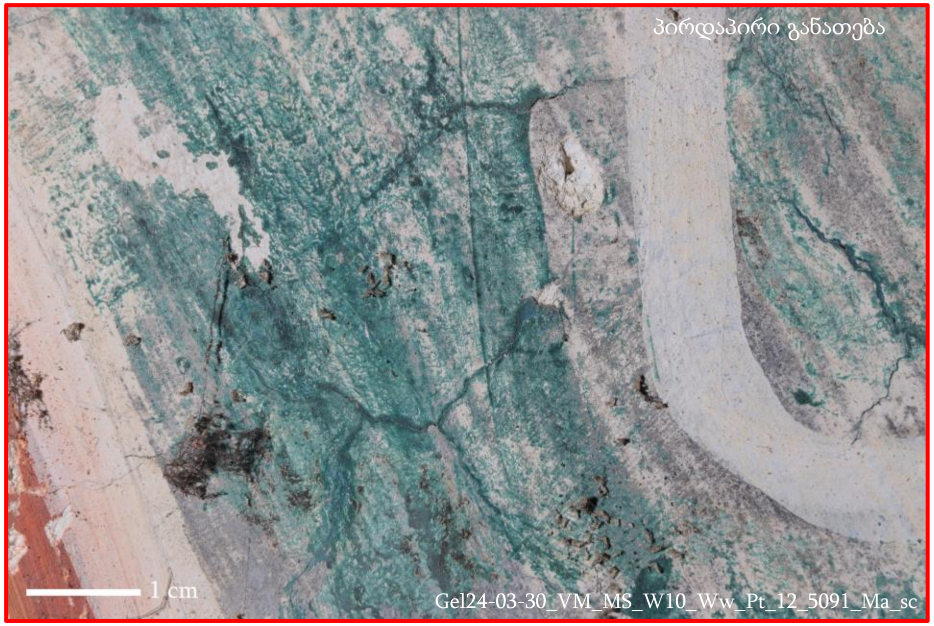
1. In areas painted with azurite, complete loss of the painting layer has been observed in some places, with only a few remaining pigment particles detectable under a portable microscope.
2. Notably, in areas where the painting layer is lost, the azurite was originally applied with one distinctive type of finish: white, using thick layers, with strong contrasts of light and shadow, giving the appearance of a nearly completed painting.

4.2 Study of the Painting Layer

Research Question 2: Blue Pigments Used and Their Alteration

It is worth noting that the same type of background can also be observed beneath fully preserved azurite. The causes of these losses and the factors contributing to them remain unclear and require further research.

Below: *west wall of the west arm, composition of annunciation. One example of azurite alteration.*



4.2 Study of Painting Layer

Research question 3: Use of precious metals as decorative elements – Gold

In the 16th-century paintings in the main space of the Church of the Nativity of the Virgin Mary, gold is applied across several scenes, including all scenes of the south arm, the donor portraits in the north arm, and is particularly abundant in the east arm. The extensive use of gold in the eastern arm may be linked both to the original artistic techniques of the authentic layer and to later repairs. Due to limited access to the sanctuary, no additional research was conducted in this area during the March 2024 mission.

In previous surveys (April 2023 – February 2024), most areas where gold was used were identified through visual observation and inspection with a portable microscope. However, in some cases, where the metal layer had deteriorated significantly, confirmation was achieved using portable X-ray fluorescence spectroscopy and multispectral imaging during the March 2024 mission.

In the south arm, gold was applied to the halos (decorative borders) and various decorative elements of the Virgin's garment, particularly in the scenes depicting the cycle of the Virgin on the south wall.

On the northern wall, gold is applied solely in the **scene of the donors**, specifically on the **halos** (decorative borders) of some of the donors. Notably, the halo of Davit Agmashenebeli does not feature any gold, though gold is present on various decorative elements of the figures' clothing.

Portable X-ray fluorescence spectroscopy detected gold (Au) and other metallic elements in these areas. However, to determine the specific characteristics of the gold used, further investigation is required. Several locations were sampled to address the following questions:

- Is genuine **gold leaf** used, or is it an imitation?
- If imitation, what materials were used to replicate gold?
- What type of **gilding technique** or **suit** was applied to the gold elements?

These questions will be answered through the examination of the paint layer cross-sections and additional analytical tests on the samples.

Below: *south wall of south arm, nativity scene. Gold used on the Holy Virgin Mary*

4.2 Study of Painting Layer

Research Question 4: Lead Pigments and Their Alteration

In 16th-century paintings in the main space of the Church, significant pigment alterations can be observed, particularly in areas involving lead-based pigments. These altered pigments are found on a large scale, notably on **clothing** and **drapery**, both as a base color and as decorative accents.

The phenomenon of **pigment blackening** is evident across many scenes, including:

•All scenes in the **South Arm**
•The **middle registers** of the **West Arm**
•The scenes of the **North Arm**

Several types of lead pigment use are identified within the painting layer:

1.White Pigment – In some cases, the alteration process (i.e., blackening) is incomplete, making it possible to distinguish the original white or white-mixed pigments underneath the altered surface. This provides insight into the original colors and their changes over time.

1. Visual inspection, supported by **portable X-ray fluorescence spectroscopy (XRF)**, confirmed the presence of **lead (Pb)** in areas suspected of containing lead-based pigments. The large amounts of lead detected strongly indicate the use of **lead white** as the pigment.

Further research is required to better understand the mechanism behind this alteration process and to assess the extent of pigment degradation across different sections of the paintings.

Above: *South wall of south arm, nativity scene. An example of the alteration - blackening of white lead pigments used on the wings of angels.*

4.2 Study of Painting Layer

Research Question 4: Lead Pigments and Their Alteration

To better understand the distribution and composition of pigments and their binders on the painting layer, a **non-invasive research method**—**multispectral imaging**—was employed. This technique was used to identify differences between intact and altered sections of the white pigment.
The selected area for multispectral imaging included locations where both **intact white brush strokes** and **altered, blackened sections** were present.

Under **UV light**, a **yellow luminescence** was observed in the intact white areas, where the **lead white pigment** was still visible in the normal spectrum. This luminescence could be due to the presence of an **organic binder** used in conjunction with the lead pigment.
To further verify these findings, the luminescent sections were analyzed with **portable X-ray fluorescence spectroscopy (XRF)**, which confirmed the presence of **lead (Pb)**. In contrast, areas that appeared discolored or blackened did not exhibit luminescence under UV light. This suggests that these areas may have undergone **binder degradation** and/or the formation of an **altered lead patina** that suppresses luminescence.
Preliminary results indicate that the white pigment is indeed **lead white**, and the observed luminescence is likely associated with the presence of an organic binder. The absence of luminescence in the blackened areas points to further degradation processes, which may have contributed to the pigment's alteration.
Ongoing research is focusing on better understanding the mechanisms behind this alteration and the interaction between lead pigments and their binders.

4.2 Study of Painting Layer

Research Question 4: Lead Pigments and Their Alteration

2) Light yellow pigment

A **bright, intense yellow** color is frequently used in conjunction with white for **modeling and highlighting** in the 16th-century painting layer. This yellow pigment often appears as a mixture with white, though in some instances it may be applied in its **pure form**.
In regions with yellowish hues or where the **vibrant yellow** pigment is prominent, **portable X-ray fluorescence spectroscopy (XRF)** has detected the presence of **tin (Sn)** in addition to **lead (Pb)**. This suggests that the pigment could be **tin-lead yellow**, a historically significant pigment.

Notably, this yellow pigment is generally **well-preserved**, and no significant signs of **alteration or degradation** are observed in most cases, indicating its stability over time compared to other lead-based pigments.

Further analysis may be required to confirm the exact composition of the yellow pigment and its historical context, but its current preservation status suggests a higher resilience than other lead-based colors, such as lead white.

3) Red: It is likely that **lead red** was used as a background and for wallpaper on draperies, clothing, and decorative elements. Currently, these sections are severely disfigured; they have blackened, and the original pigment is not visible with a portable microscope.

Left: *The east wall of the south arm, an example of the use of pale yellow in modeling angels wings.*

Gel24-03-24_VM_MS_E6_5259_D

Right: *North wall of the west arm, example of lead pigment alteration.*

4.2 Study of the Painting Layer

Research Question 5: Use of red pigments

On the 16th century painting layer of the main space, an intense red pigment is used, which sometimes occurs as a lower layer, sometimes as a mixture, and gives us a pink tone.

Where it is used as a top layer, its alteration is observed. By visual observation, this pigment was identified as vermilion, which was also confirmed by a portable X-ray fluorescence spectroscope: a high content of mercury (Hg) was revealed.

We find the use of vermilion abundantly in the southern arm, both pure and in mixtures.

It is worth noting the fact that vermilion is also used in the windows of the south arm.

When vermilion is in the form of a mixture, when analyzed with a portable X-ray fluorescence spectroscope, along with mercury (Hg), other metals are also fixed: lead (Pb), copper (Cu) and others.

When observing with a portable microscope, the involvement of blue pigments is noticed. In many cases, this type of purple layer is darkened. It is mostly found on clothes and jewellery. To determine the layering of painting layers, samples were taken to confirm the use of vermilion and its mixtures.

A cross-sections will be made with the samples, which will be stratigraphically and elementally analyzed by optical microscopy and scanning electron microscopy and energy dispersive X-ray spectroscopy (SEM-EDX).

Below: *Study area photographed with a portable microscope, 250 magnification. Blue pigment inclusions are visible*

Above: *East wall of the North Arm, St. Constantine and St. Helen's scene. The use of purplish red on clothing*

4. Summary of investigation results

4.3 Salt investigation

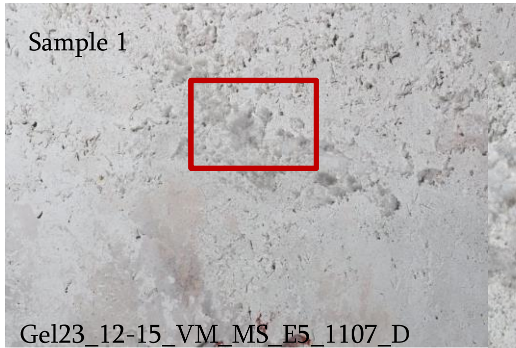
As a result of visual observation, four forms of salt efflorescence on the surface were revealed:

- Flake
- Crust
- Crystalline dots
- White haze

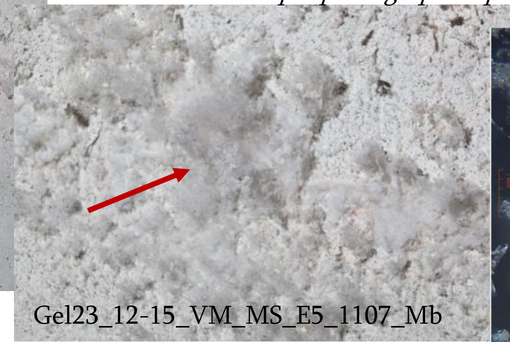
In December 2024, samples were taken from all four types of salt, as a result of analytical research (OM, XRD) it was revealed that:

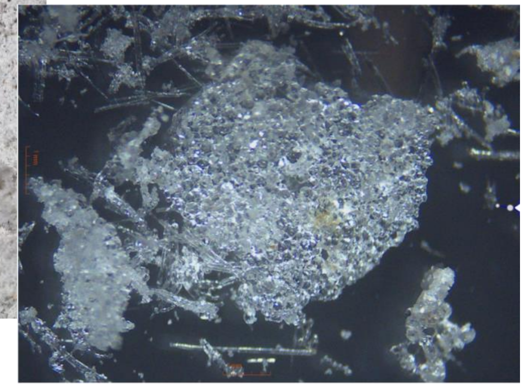
Flakes (Sample: 1, 5, 8, 9) are potassium nitrate [**KNO3**]

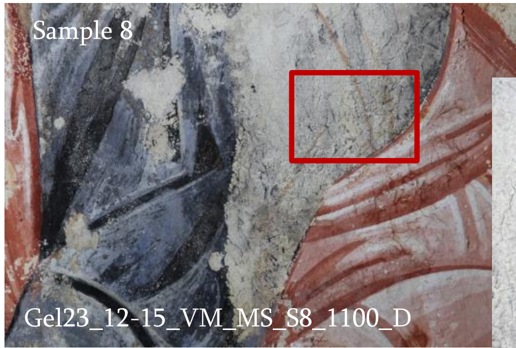
See Appendix 1 for a detailed report of the study (Laue 2024).



Below: *North arm of the Cathedral of the Virgin Mary (E5). Sampling location of flaky salt N1 and microscopic photograph of potassium nitrate.*

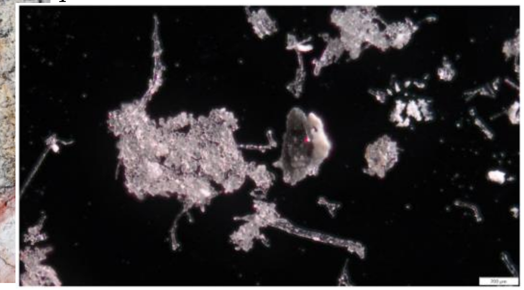


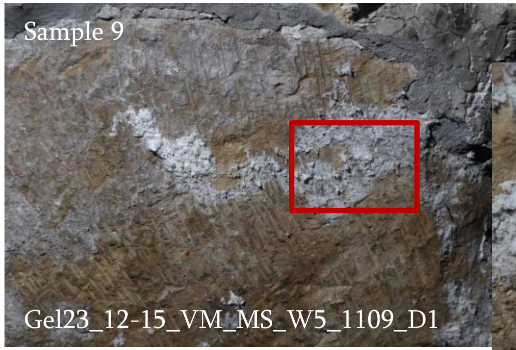




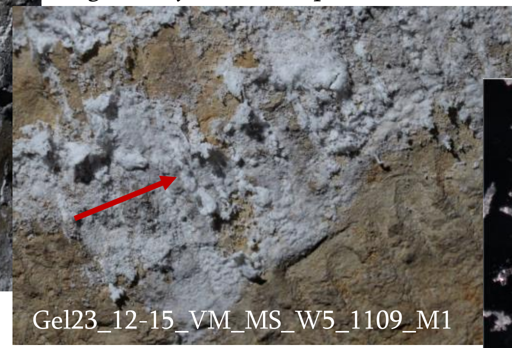
Below: *West arm of the Cathedral of the Virgin Mary (S5). Sample 8.*

Below: *Sample 8 – microscopic image of potassium nitrate*

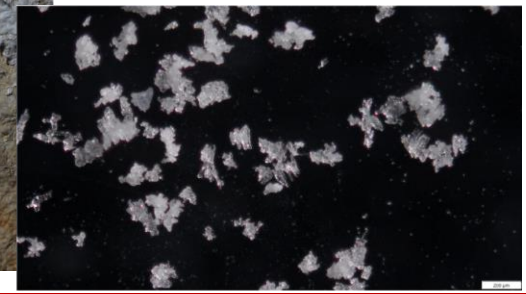




Below: *South arm of the Cathedral of Virgin Mary (W5). Sample 9.*



Below: *Sample 9 – microscopic image of potassium nitrate*

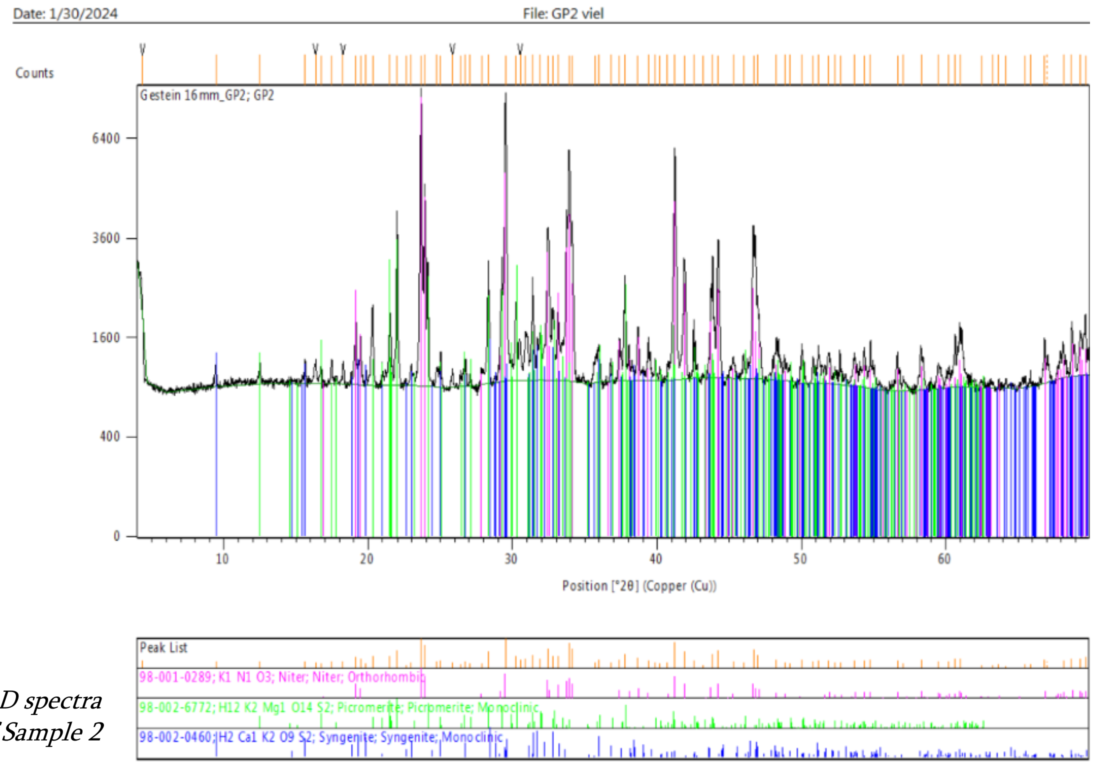


4.3 Salt Research

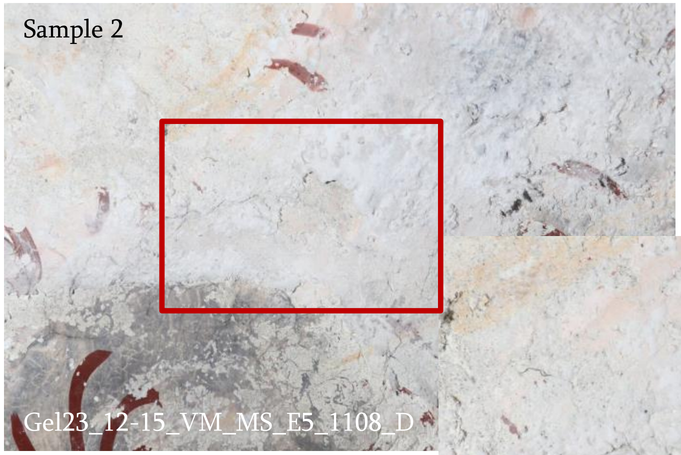
As a result of analytical research (OP, XRD) it was revealed that:

Potassium nitrate [KNO_3] and a small amount of Picromerite [$K_2Mg(SO_4)_2 \cdot 6H_2O$] and syngenite $K_2Ca(SO_4)_2 \cdot H_2O$] are also recorded in crustal salts (samples: 2, partially 5).

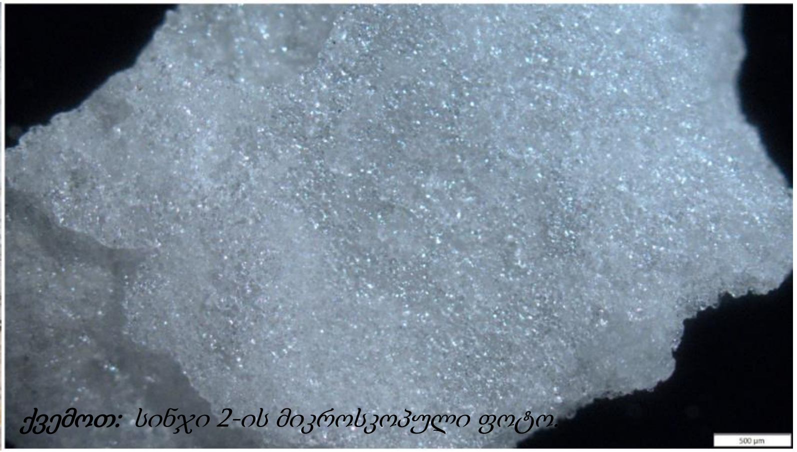
See Appendix 1 for a detailed report of the study (Laue 2024).



Right: *XRD spectra of Sample 2*



Above and right: *North arm of the Cathedral Sample 2 location.*



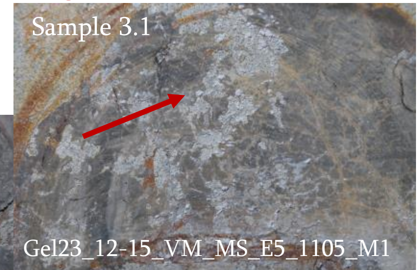
4.3 Salt Research

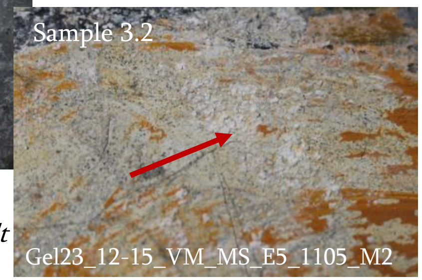
As a result of analytical research (OP, XRD) it was revealed that:

The main salt of crystalline dots is magnesium-containing carbonates: in two cases (samples: 3.1, 3.2) dipingite [$Mg_5(CO_3)_4(OH)_2{\cdot}5H_2O$] and a small amount of gypsum [$CaSO_4{\cdot}2H_2O$] are recorded, in two additional cases (samples: 6 , 10) and Nesquehonite [$MgCO_3{\cdot}3H_2O$] and a small amount of Dipingite [$Mg_5(CO_3)_4(OH)_2{\cdot}5H_2O$].

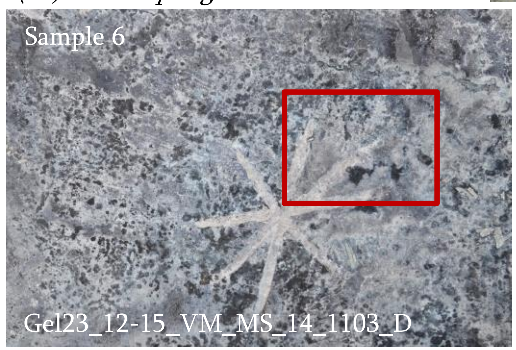
For a detailed report of the study (Laue 2024), see Appendix 1:

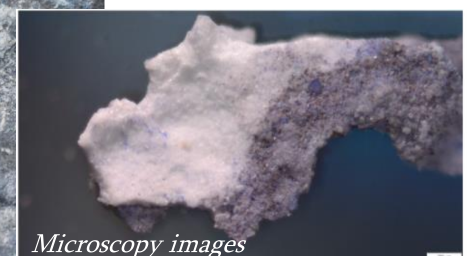
Below and to the right: *North arm of the Cathedral of the Virgin Mary (E5). 3.1 and 3.2 Sampling location.*



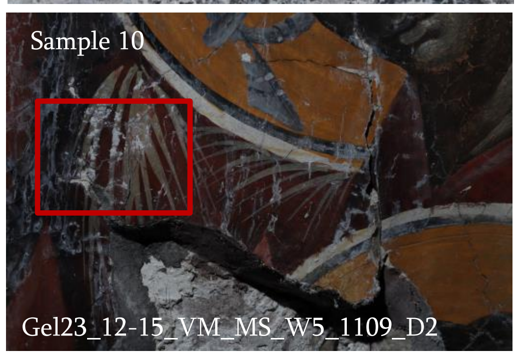


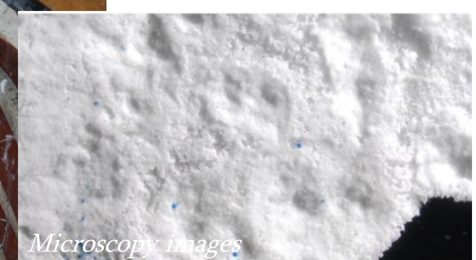
Below and to the right: *the western arm of the Cathedral of the Virgin Mary, vault (14). N6 sampling location.*





Right: *South arm of the Cathedral of Cathedral (W5). N10 sampling location.*

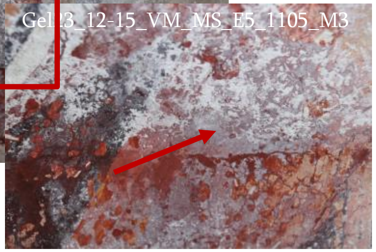




4.3 Salt Research

As a result of analytical research (OP, XRD) it was revealed that:Similarly, the main salt of the white spots of point crystallization (samples: 4, 7) are magnesium carbonates: hydromagnesite [$Mg_5(CO_3)_4(OH)_2·4H_2O$] and nescuhonite [$MgCO_3·3H_2O$], as well as a small amount of dipnigite [$Mg_5(CO_3)_4(OH)_2·5H_2O$].

For a detailed report of the study (Laue 2024), see Appendix 1:



Above and right: *North arm of the Cathedral of Virgin Mary (E5). Microscopic photo of sampling location of sample 4.*

Bottom: *Sample 4, magnesium carbonates observed in the XRD spectrogram.*

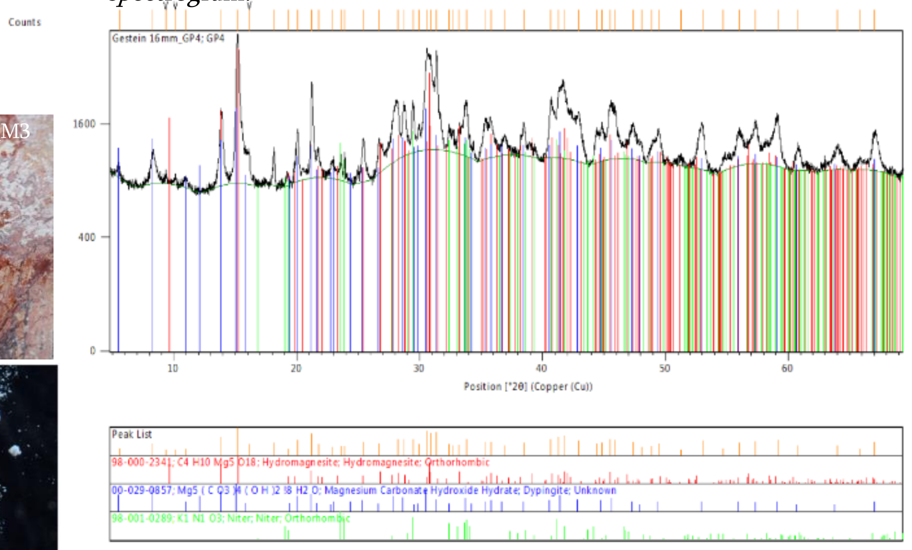
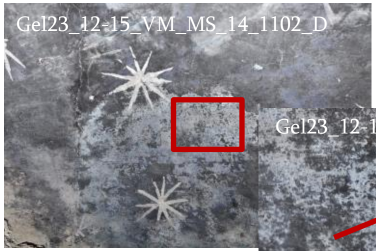
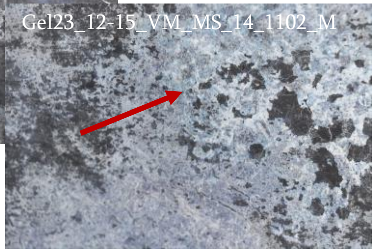
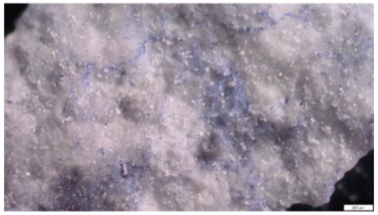


fig. 10: Sample 4, XRD spectrum







Above and to the right: *the western arm of the Cathedral of the Virgin Mary, Vault(14). Microscopic photo of sampling location of sample 7.*

ქვემოთ: *ნიმუში 4, XRD-ის სპექტროგრამაზე დაფიქსირებული მაგნიუმის კარბონატები.*

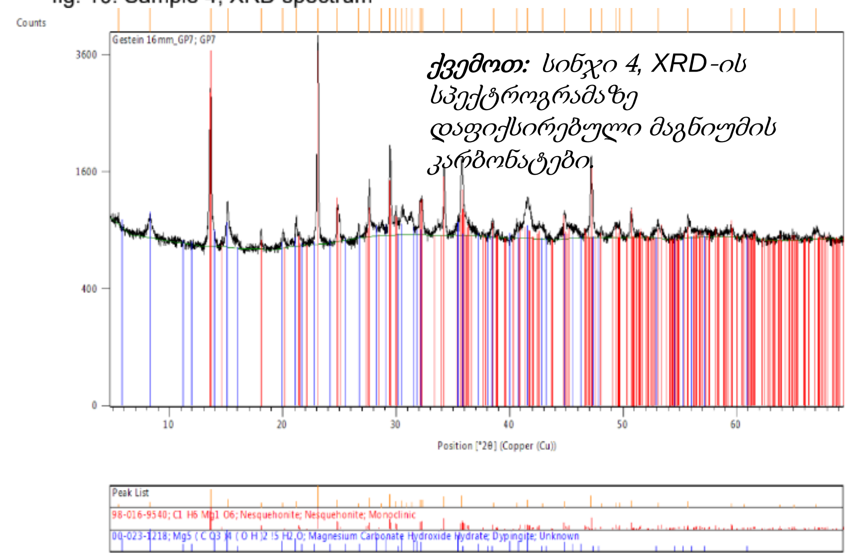


fig. 16: Sample 7, XRD spectrum

4.3 Salt Research

Main Identified Salts:

•Magnesium carbonate

•Magnesium sulfate

•Potassium nitrate

Probable Sources of Magnesium Carbonate:

•Dolomitic construction stone and plaster

Sources of Magnesium Sulfate:

•**Magnesium:** Dolomitic limestone present in the original material

•**Sulfate:** Conservation materials from previous periods (plaster fillings, roofing material)

Probable Sources of Potassium Nitrate:

•**Potassium:** Original material content (zinc yellow, cobalt yellow, smalt, green earth)

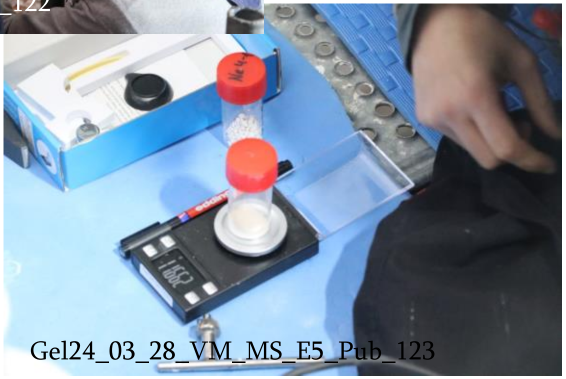
•**Nitrates:** Introduced through the roof and the painting's surface by the activity of living organisms

Additional samples of salts, construction materials, and salinity were taken to confirm the probable sources.

An additional 10 superficial salt samples were collected.
To determine the presence of salts and moisture in the stratigraphy samples were taken from 4 locations, with 5-7 samples collected at varying depths from each location, totalling 24 samples. These samples include both stone and clay layers (refer to previous pages for information on clay samples).

Analytical studies performed on the salt samples include optical microscopy, ion chromatography (IC), and X-ray diffraction (XRD).

Left: *The process of sampling the stratigraphy through core sampling to determine the composition of salts.*



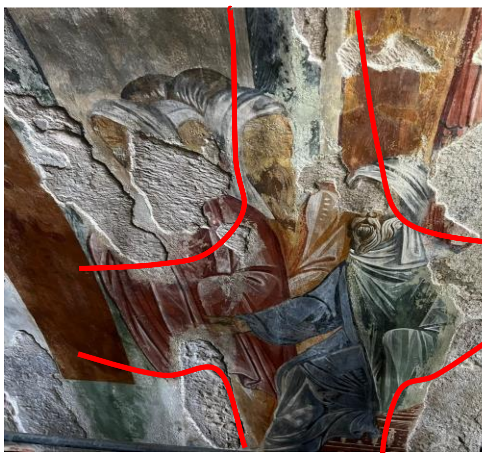
Right: *The process of weighing a sample to determine the moisture content of the structure.*

4.4 Moisture Research

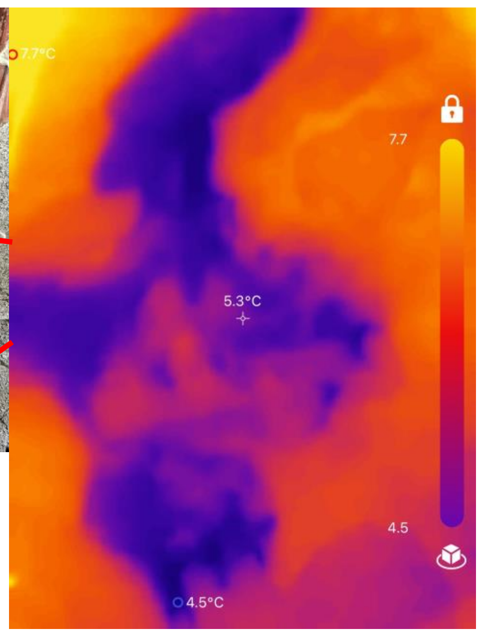
Using non-invasive survey techniques (**visual observation**, **infrared thermography**, and **electrical resistance meters**,) areas of moisture were identified in the scene on the north wall of the western arm: **Christ with Caiaphas (N6).**

High moisture content was recorded at this location on **February 5-6** and **March 27, 2024**.

The moisture concentration originates at the joints between the building stones of the base layer and gradually spreads into the plaster layer, indicating a pattern of moisture migration through the structure.



Above: *Moisture-rich locations are marked in red (interior area of the red shapes.*



Above: *Using an electrical resistance meter to determine moisture content in a structure. A reading above 120 units indicates a high amount of moisture.*

Left: *moisture captured by an infrared thermography camera (blue spots)*