Gelati Monastery
Church of Virgin
KUTAISI - GEORGIA

Studio Croci & Associati & VI Studio

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STRUCTURAL INVESTIGATIONS

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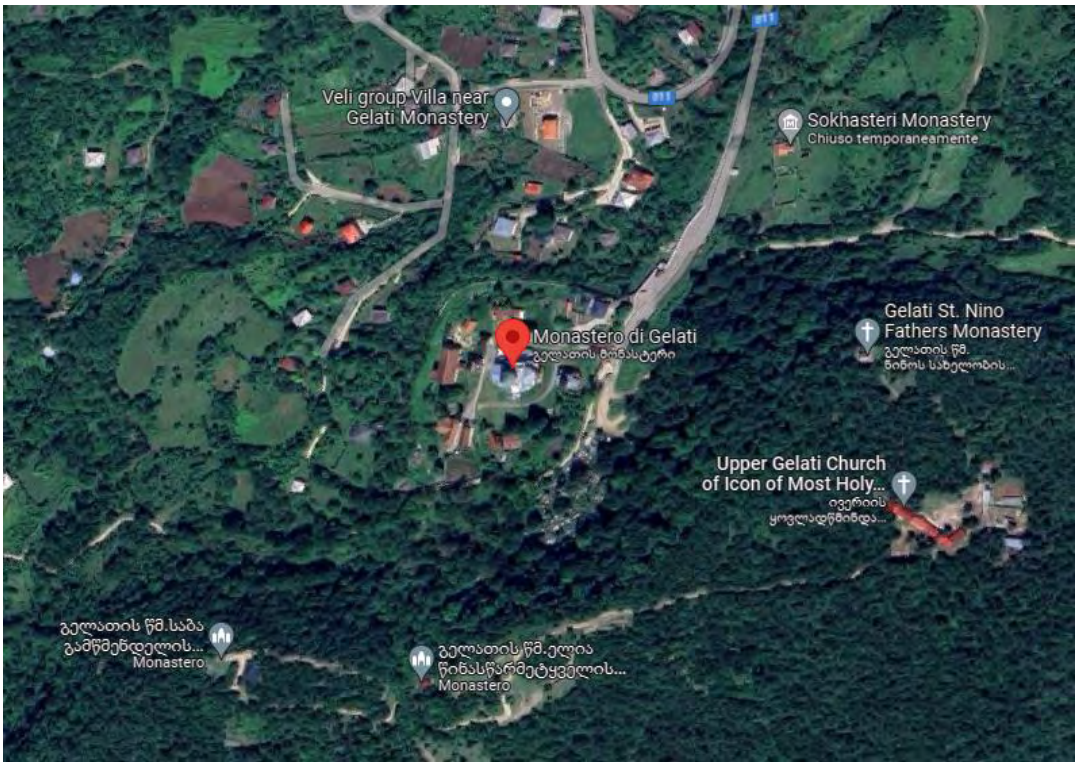
INDEX

1. INTRODUCTION

This report presents the results of the investigative surveys conducted between November 2023 and May 2024 on the structures of the "Church of the Nativity" located in the Gelati Monastery complex in Kutaisi, Georgia.



The following table summarizes the investigations carried out:

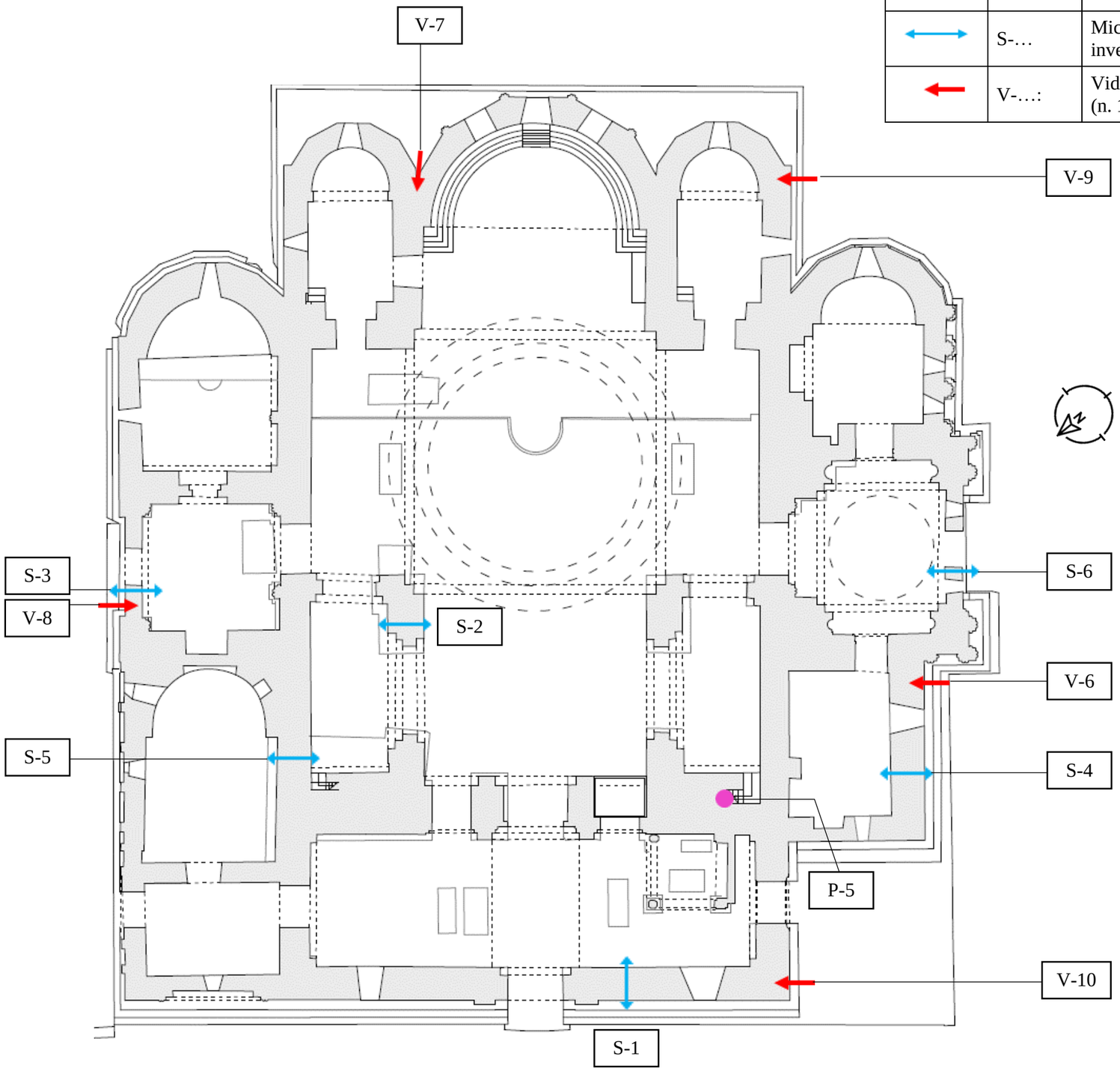
INVESTIGATIONS ON STRUCTURES	
n. 8	**MORTAR SAMPLES AND LABORATORY ANALYSIS**
n. 6	**MICROSEISMIC – SONIC INVESTIGATIONS ON MASONRY**
n. 10	**VIDEOENDOSCOPIC INVESTIGATIONS**

The locations of the investigations are illustrated below.

2. LOCATION

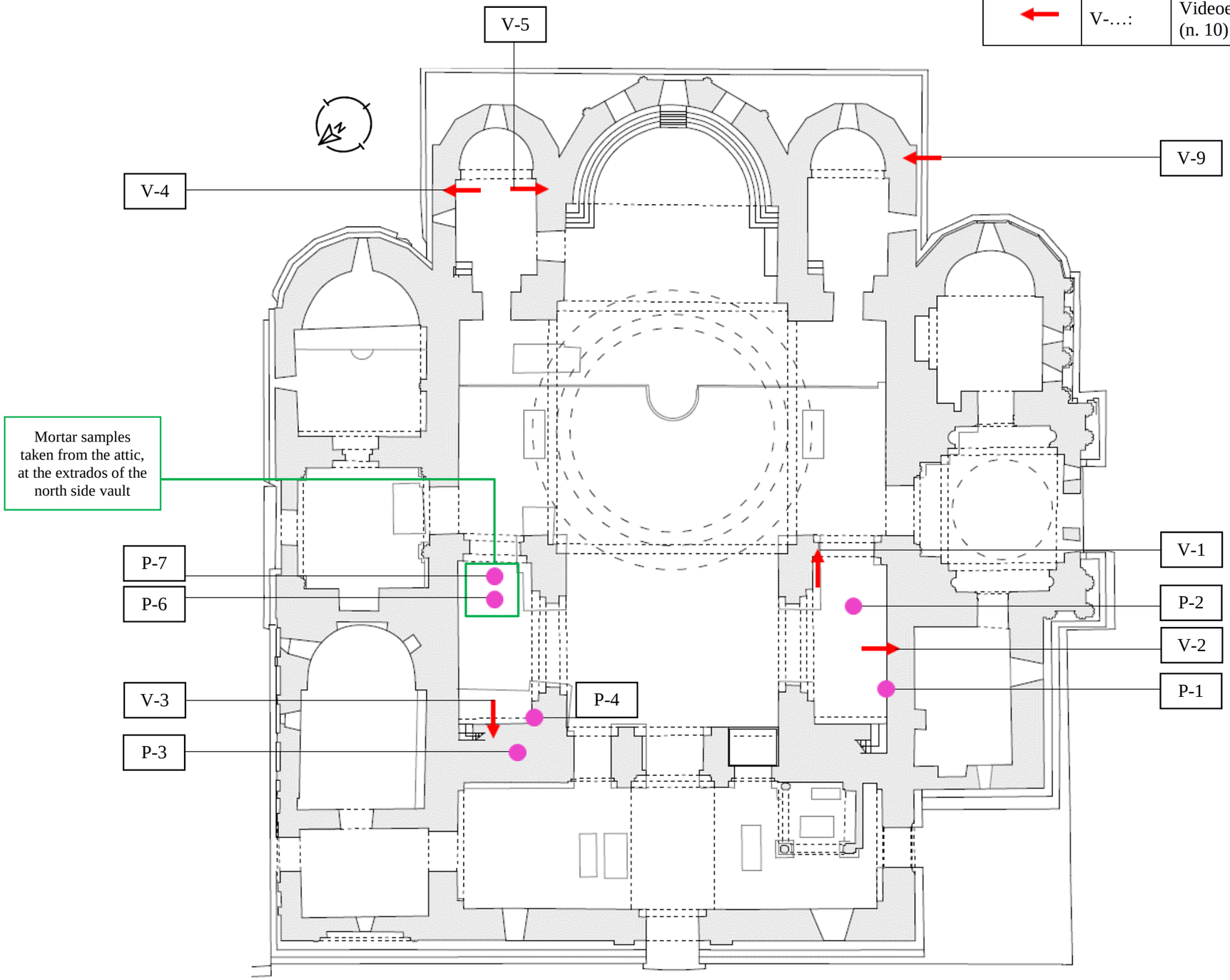
2.1. GROUND FLOOR

●	P-…:	Mortar samples (n. 8)
↔	S-…	Microseismic – sonic investigations (n. 6)
←	V-…:	Videoendoscopic investigations (n. 10)



2.2. FIRST FLOOR

●	P-…:	Mortar samples (n. 8)	M
←	V-…:	Videoendoscopic investigations (n. 10)	Vi



3. DESCRIPTION AND RESULTS OF THE INVESTIGATIONS

The following paragraph indicates the operational methods for carrying out the investigations and the results that each of them provided.

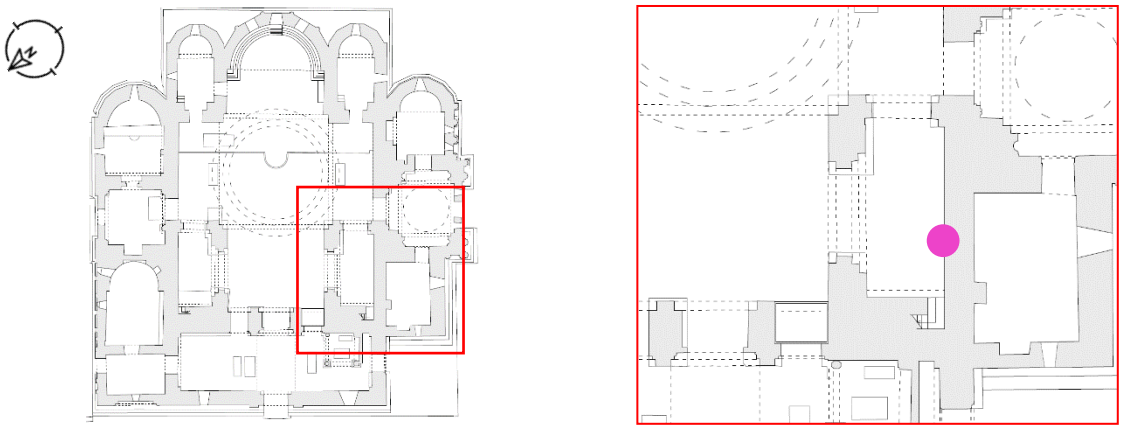
3.1. LABORATORY ANALYSIS PERFORMED ON THE SAMPLES OF MORTAR

3.1.1. *Method description*

In order to characterize the mixture used as a binder in the wall structure of the "Church of the Nativity of the Virgin", which is the main church within the Gelati Monastery complex in Kutaisi, Georgia, n. 6 samples of mortar were taken.
The mineralogical analysis of the samples was carried out at the laboratories of Pro Arte s.n.c. specialized in this field.
The investigations allowed the characterization of the matrix, the determination of the type and composition of the aggregates, the type of mixture, the evaluation of the state of conservation and the grain size distribution.

Below are the results with the location of the samples.

3.1.2. *Mortar sampling P-1 – 1° Floor*



Mortar sampling location P-1

Mortar sampling P-1

Mortar sample P-1

Macroscopic Description (UNI-NORMAL 12/83)

Dimensional Appearance	Silty arenaceous
Color	Whitish
Cohesion	Slightly tenacious and cohesive

Microscopic Description (UNI-NORMAL 12/83)

Aggregate

Granulometry	Very coarse arenaceous (2-1 mm) – coarse silty (0.062-0.032 mm)
Prevalent Granulometry	Medium-fine arenaceous(0.5-0.125 mm)
Sorting	Poorly sorted
Shape (sphericity/roundness)	Medium to very low sphericity/ angular to sub-rounded fragments
Surface Morphology	From smooth to abraded
Orientation	Not detected
Distribution	Homogeneous
Compaction	Estimated clast-matrix ratio: Medium (31%)

Particle size distribution		
Granulometric class	*mm*	*%*
Fine Conglomerate	8-4	-
Micro-conglomerate	4-2	-
Very coarse arenaceous	2-1	11
Coarse arenaceous	1-0.5	7
Medium arenaceous	0.5-0.25	30
Fine arenaceous	0.25-0.125	33
Very fine arenaceous	0.125-0.062	16
Silty	< 0.062	3

Aggregate composition

- 29%: fragments of silicate claystone
- 27%: fragments of cocciopesto
- 22%: Fragments of carbonates such as micritic limestone, sparitic limestone, marly limestone, calcite
- 10%: quartz fragments
- 5%: fragments of sandstone
- 4%: fragments of opaque minerals
- 3%: mica flakes

Type of aggregate: sand, mostly of silicatic nature and to a lesser extent carbonatic

Porosity

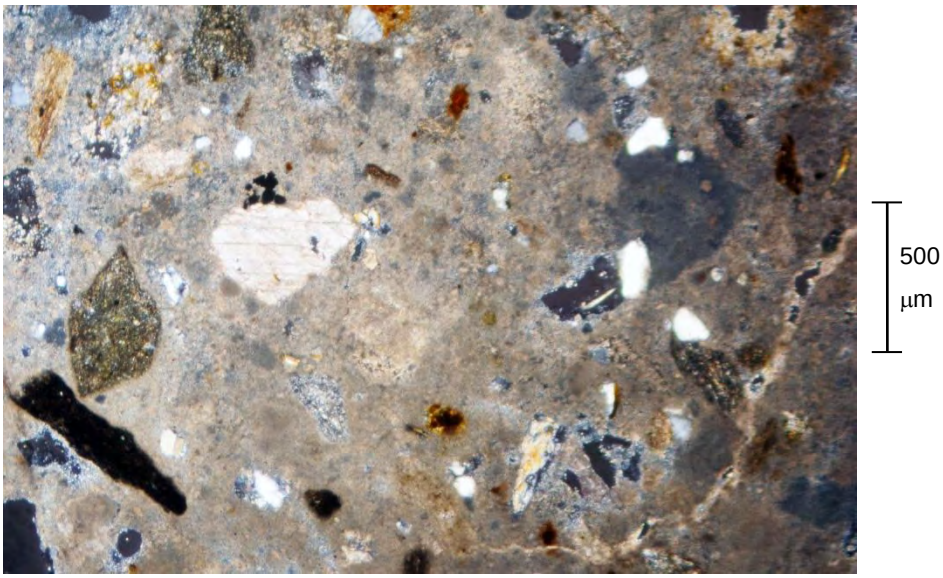
Percentage of pores	Medium (24%)
Origin of porosity	Both primary and secondary
Pore shape	Rounded vesicles and irregular voids from binder and microcracks

Matrix

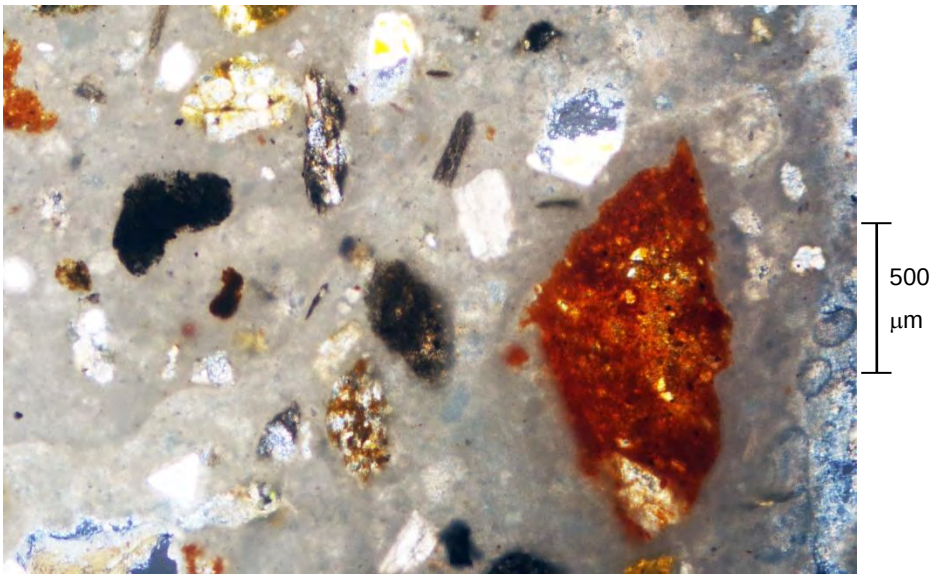
Structure	Heterogeneous due to the presence of calcareous fragments (calcinaroli)
Texture	Colloform to microsparitic ground mass
Clast/Matrix Ratio	Not detected
Composition	Carbonated aerial lime

Considerations on the mortar mix

Type of mortar mix	Whitish mortar based on carbonated aerial lime and predominantly silicate sand associated with small percentages of carbonate fragments and cocciopesto concrete. The sizes of the aggregates range is between 1.2 mm e 0.05 mm with a prevalence of medium-fine arenaceous fractions. The areal ratio between aggregates and paste binder is around values of 2/1. The mixture shows both medium primary and secondary porosity.
State of conservation	Overall, the mortar mix appears to be poorly preserved

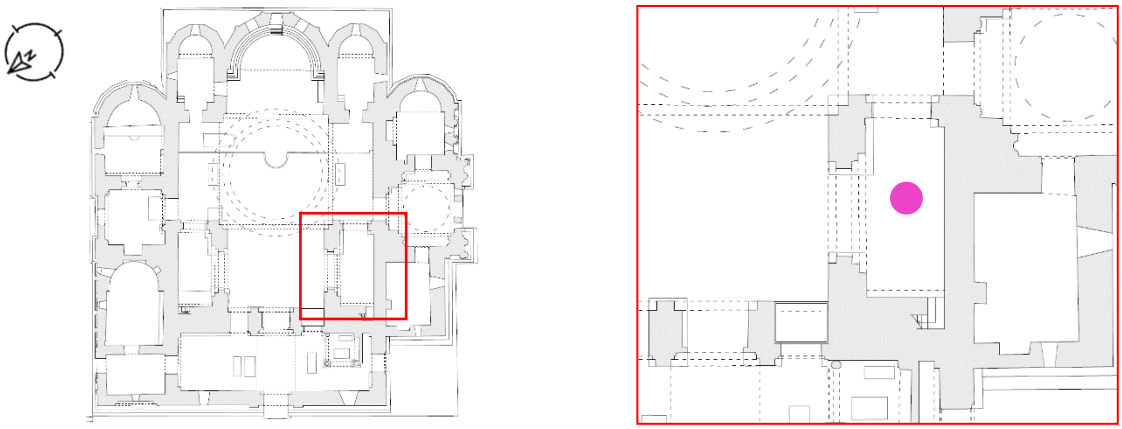


Thin section, transmitted light, 40 X, N+.



Thin section, transmitted light, 40 X, N+.

3.1.3. *Mortar sampling P-2 – Extrados of the vault – 1° Floor*



Mortar sampling location P-2

Mortar sampling P-2

Mortar sample P-2

Macroscopic Description (UNI-NORMAL 12/83)

Dimensional Appearance	Silty arenaceous
Color	Whitish
Cohesion	Slightly tenacious and cohesive

Microscopic Description (UNI-NORMAL 12/83)

Aggregate

Granulometry	Very coarse arenaceous (2-1 mm) – coarse silty (0.062-0.032 mm)
Prevalent Granulometry	Medium-fine arenaceous(0.5-0.125 mm)
Sorting	Poorly sorted
Shape (sphericity/roundness)	Medium to very low sphericity/ angular to sub-rounded fragments
Surface Morphology	From smooth to abraded
Orientation	Not detected
Distribution	Homogeneous
Compaction	Estimated clast-matrix ratio: medium-basso (26%)

Particle size distribution		
Granulometric class	*mm*	*%*
Fine Conglomerate	8-4	-
Micro-conglomerate	4-2	-
Very coarse arenaceous	2-1	7
Coarse arenaceous	1-0.5	4
Medium arenaceous	0.5-0.25	35
Fine arenaceous	0.25-0.125	38
Very fine arenaceous	0.125-0.062	14
Silty	< 0.062	2

3.1.4. ***Aggregate composition***

- 32%: fragments of silicate claystone
- 28%: fragments of cocciopesto
- 25%: Fragments of carbonates such as micritic limestone, sparitic limestone, marly limestone, calcite
- 7%: quartz fragments
- 3%: fragments of sandstone
- 3%: fragments of opaque minerals
- 2%: mica flakes

Type of aggregate: Sand, mainly of silicate nature and about 1/4 carbonate

Porosity

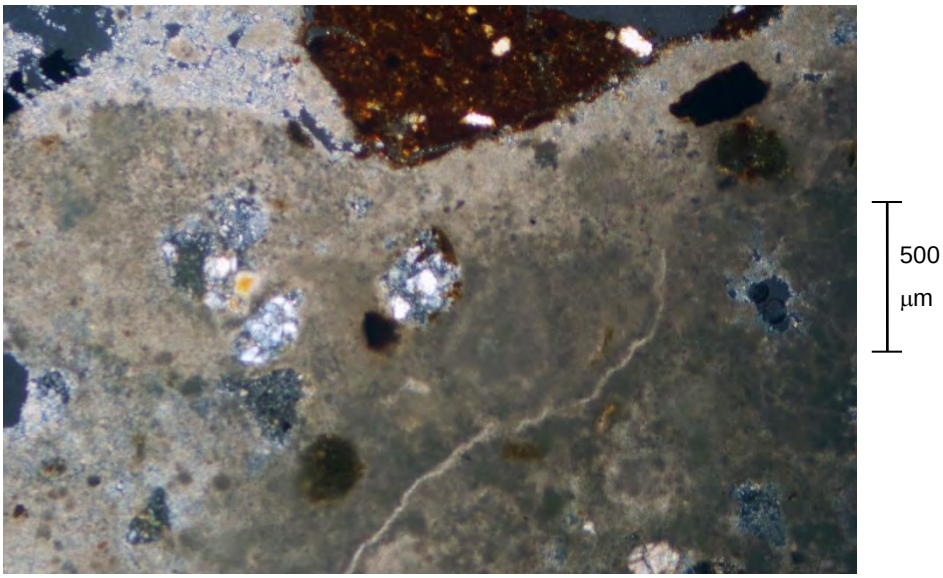
Percentage of pores	Medium-high (26%)
Origin of porosity	Both primary and secondary
Pore shape	Rounded vesicles and irregular voids from binder and microcracks

Matrix

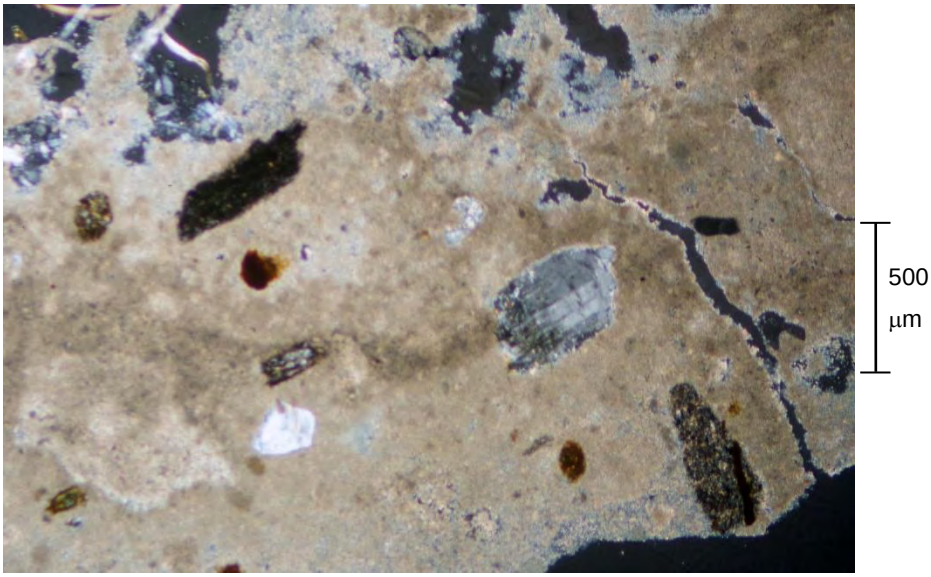
Structure	Heterogeneous due to the presence of calcareous fragments (calcinaroli)
Texture	Colloform to microsparitic ground mass
Clast/Matrix Ratio	Not detected
Composition	Carbonated aerial lime

Considerations on the mortar mix

Type of mortar mix	Whitish mortar based on carbonated aerial lime and predominantly silicate sand, with about 1/4 carbonate, with the addition of cocciopesto The sizes of the aggregates range is between 1.3 mm e 0.04 mm with a prevalence of medium-fine arenaceous fractions. The areal ratio between aggregates and paste binder is around values of 1.5-2/1. The mixture shows both medium primary and secondary porosity.
State of conservation	Overall, the mortar mix appears to be moderately preserved

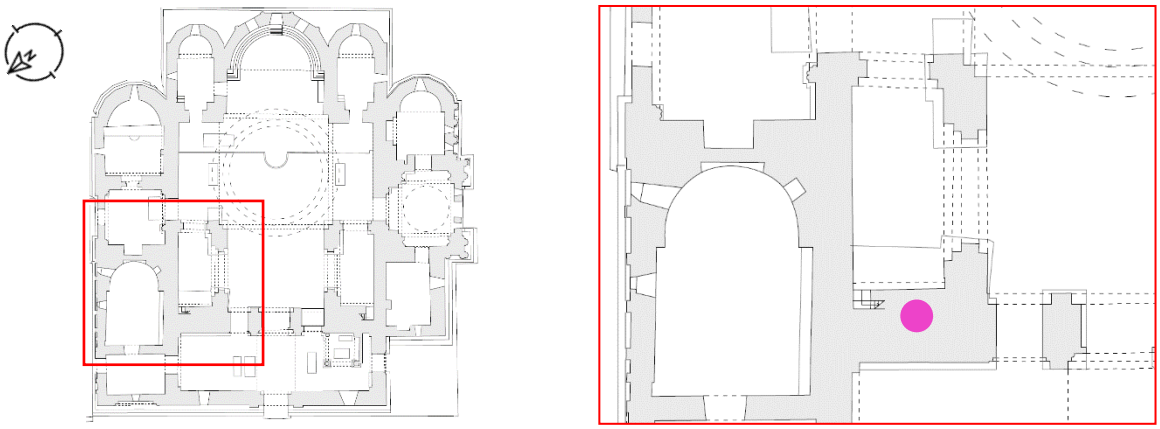


Thin section, transmitted light, 40 X, N+.



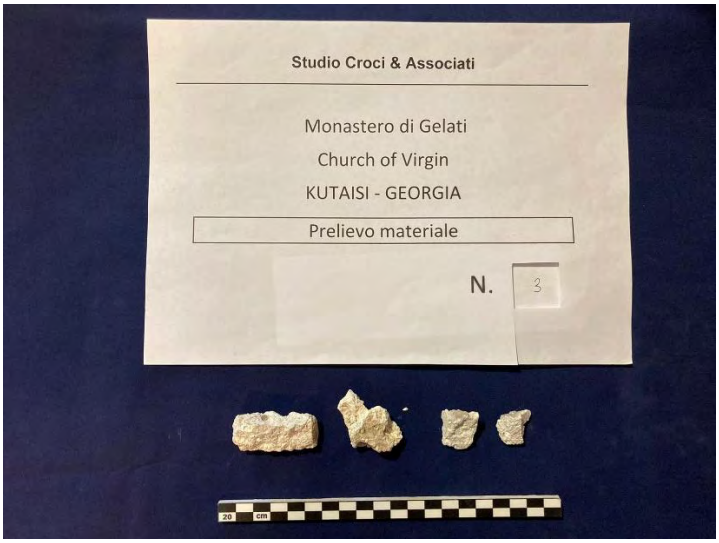
Thin section, transmitted light, 40 X, N+.

3.1.5. *Mortar sampling P-3 – 1° Floor*



Mortar sampling location P-3

Mortar sampling P-3



Mortar sample P-3

Macroscopic Description (UNI-NORMAL 12/83)

Dimensional Appearance	Silty arenaceous
Color	Whitish
Cohesion	Slightly tenacious and cohesive

Microscopic Description (UNI-NORMAL 12/83)

Aggregate

Granulometry	Medium arenaceous (0.5-0.25 mm) – coarse silty (0.062-0.032 mm)
Prevalent Granulometry	Arenaceous fine (0.25-0.125 mm)
Sorting	Well-sorted
Shape (sphericity/roundness)	Medium to very low sphericity/ angular to sub-rounded fragments
Surface Morphology	From smooth to abraded
Orientation	Not detected
Distribution	Homogeneous
Compaction	Estimated clast-matrix ratio: basso (25%)

Particle size distribution		
Granulometric class	*mm*	*%*
Fine Conglomerate	8-4	-
Micro-conglomerate	4-2	-
Very coarse arenaceous	2-1	-
Coarse arenaceous	1-0.5	-
Medium arenaceous	0.5-0.25	31
Fine arenaceous	0.25-0.125	46
Very fine arenaceous	0.125-0.062	21
Silty	< 0.062	2

3.1.6. ***Aggregate composition***

- 26%: quartz fragments
- 23%: fragments of silicate claystone
- 20%: carbonate fragments such as micritic limestone, sparitic limestone, calcite
- 18%: fragments of sandstone
- 6%: mica flakes
- 2%: Fragments of feldspar

Type of aggregate: river-alluvial sand, mostly of silicate nature and about 1/5 carbonate

Porosity

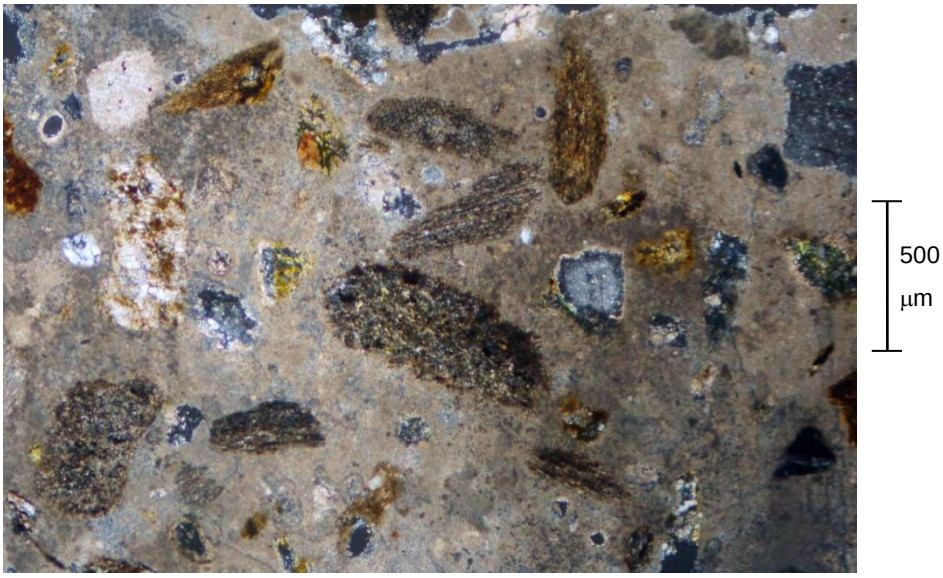
Percentage of pores	High (28 %)
Origin of porosity	Both primary and secondary
Pore shape	Rounded vesicles and irregular voids from binder with the presence of numerous microcracks

Matrix

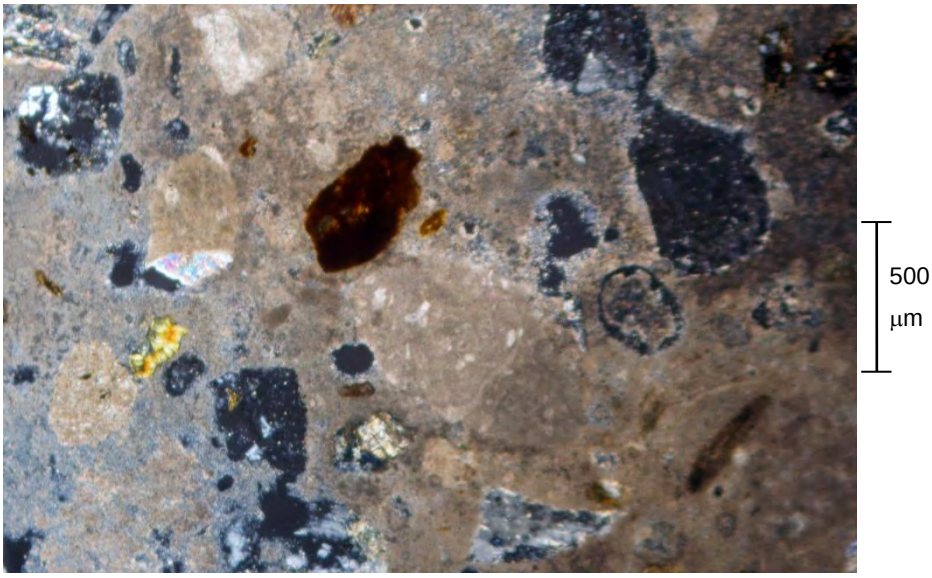
Structure	Fairly homogeneous
Texture	Colloform to microsparitic ground mass
Clast/Matrix Ratio	Not detected
Composition	Carbonated aerial lime

Considerations on the mortar mix

Type of mortar mix	Whitish mortar based on carbonated aerial lime mixed with river-alluvial sand, mostly of silicate nature and to a lesser extent carbonate, composed of quartz, silicate claystone fragments, carbonate fragments, sandstone, mica, and feldspar. The sizes of the aggregates range is between 0.45 mm e 0.04 mm with a prevalence of the fine arenaceous fraction. The areal ratio between aggregates and paste binder is around values of 1.5/1. The mixture shows a high porosity, both primary and secondary.
State of conservation	Overall, the mortar mix appears to be poorly preserved

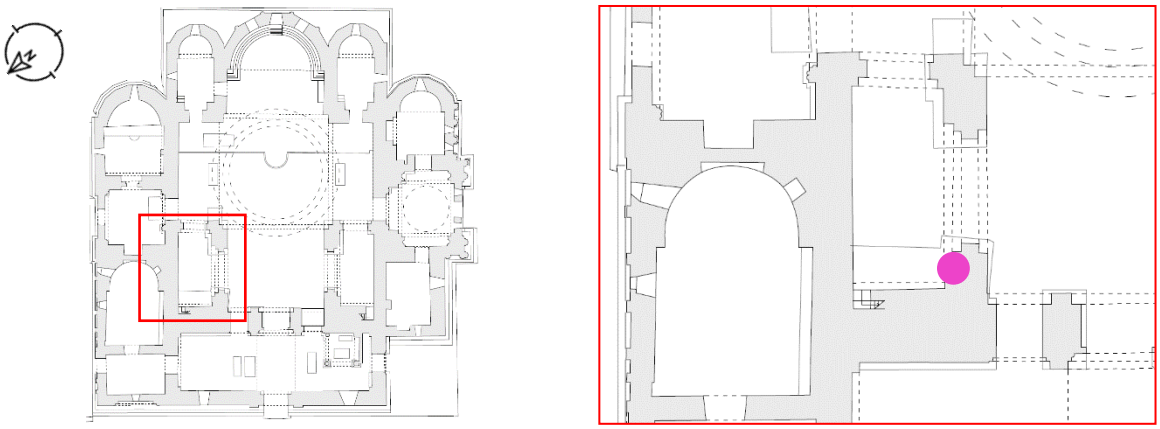


Thin section, transmitted light, 40 X, N+.



Thin section, transmitted light, 40 X, N+.

3.1.7. *Mortar sampling P-4 – Pillar – 1° Floor*



Mortar sampling location P-4

Mortar sampling P-4

Mortar sample P-4

Macroscopic Description (UNI-NORMAL 12/83)

Dimensional Appearance	Silty arenaceous
Color	Whitish
Cohesion	Fairly tenacious and cohesive

Microscopic Description (UNI-NORMAL 12/83)

Aggregate

Granulometry	Medium arenaceous (0.5-0.25 mm) – coarse silty (0.062-0.032 mm)
Prevalent Granulometry	Arenaceous fine (0.25-0.125 mm)
Sorting	Well-sorted
Shape (sphericity/roundness)	Medium to very low sphericity/ angular to sub-rounded fragments
Surface Morphology	From smooth to abraded
Orientation	Not detected
Distribution	Homogeneous
Compaction	Estimated clast-matrix ratio: medium (34%)

Particle size distribution		
Granulometric class	*mm*	*%*
Fine Conglomerate	8-4	-
Micro-conglomerate	4-2	-
Very coarse arenaceous	2-1	-
Coarse arenaceous	1-0.5	-
Medium arenaceous	0.5-0.25	34
Fine arenaceous	0.25-0.125	48
Very fine arenaceous	0.125-0.062	16
Silty	< 0.062	3

Aggregate composition

- 28%: quartz fragments
- 26%: fragments of silicate claystone
- 25%: carbonate fragments such as micritic limestone, sparitic limestone, calcite
- 14%: fragments of sandstone
- 4%: mica flakes
- 3%: fragments of feldspar

Type of aggregate: river-alluvial sand, mostly of silicate nature and about 1/4 carbonate

Porosity

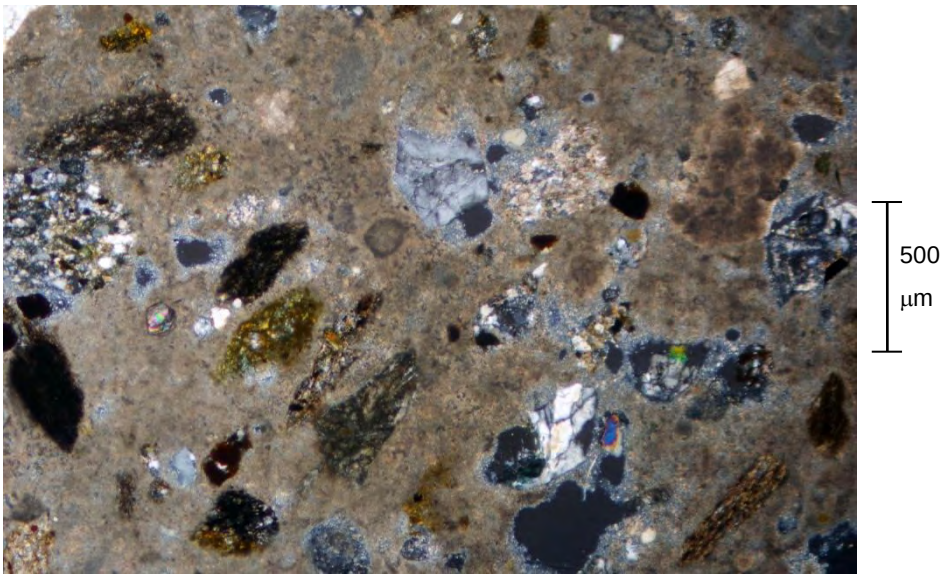
Percentage of pores	Medium-High (25%)
Origin of porosity	Both primary and secondary
Pore shape	Rounded vesicles and irregular voids from binder with the presence of microfessure

Matrix

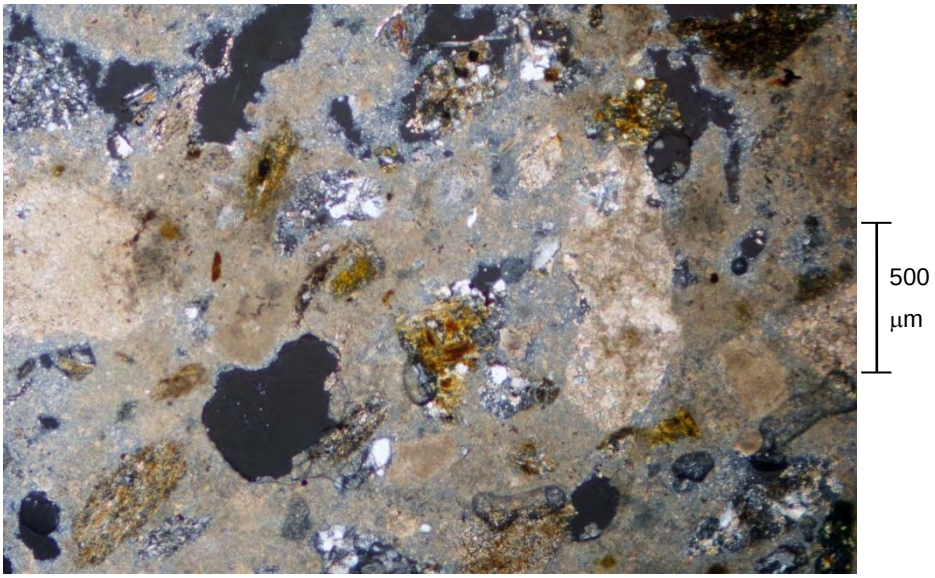
Structure	Heterogeneous due to the presence of calcareous fragments (calcinaroli)
Texture	Colloform to microsparitic ground mass
Clast/Matrix Ratio	Not detected
Composition	Carbonated aerial lime

Considerations on the mortar mix

Type of mortar mix	Whitish mortar based on carbonated aerial lime mixed with river-alluvial sand, mostly of silicate nature and to a lesser extent carbonate, composed of quartz, silicate claystone fragments, carbonate fragments, sandstone, mica, and feldspar. The sizes of the aggregates range is between 0.48 mm e 0.04 mm with a prevalence of the fine arenaceous fraction. The areal ratio between aggregates and paste binder is around values of 2/1. The mixture shows a medium to high porosity, both primary and secondary.
State of conservation	Overall, the mortar mix appears to be fairly preserved

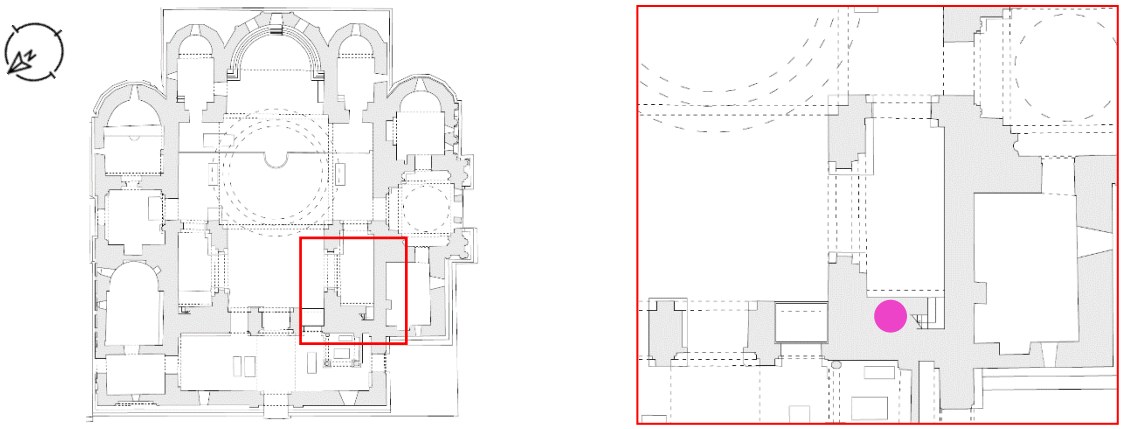


Thin section, transmitted light, 40 X, N+.



Thin section, transmitted light, 40 X, N+.

3.1.8. *Mortar sampling P-5 – Stairwell - Ground Floor / 1° Floor*



Mortar sampling location P-5

Mortar sampling P-5

Mortar sample P-5

Macroscopic Description (UNI-NORMAL 12/83)

Dimensional Appearance	Conglomeratic-silty arenaceous
Color	Whitish
Cohesion	Slightly tenacious and cohesive

Microscopic Description (UNI-NORMAL 12/83)

Aggregate

Granulometry	Fine Conglomerate (8-4 mm) – coarse silty (0.062-0.032 mm)
Prevalent Granulometry	Arenaceous fine (0.25-0.125 mm)
Sorting	Poorly sorted
Shape (sphericity/roundness)	Medium to very low sphericity/ angular to sub-rounded fragments
Surface Morphology	From smooth to abraded
Orientation	Not detected
Distribution	Homogeneous
Compaction	Estimated clast-matrix ratio: medium (30%)

Particle size distribution		
Granulometric class	*mm*	*%*
Fine Conglomerate	8-4	23
Micro-conglomerate	4-2	-
Very coarse arenaceous	2-1	7
Coarse arenaceous	1-0.5	8
Medium arenaceous	0.5-0.25	10
Fine arenaceous	0.25-0.125	32
Very fine arenaceous	0.125-0.062	17
Silty	< 0.062	3

Aggregate composition

- 35%: fragments of cocciopesto
- 27%: fragments of silicate claystone
- 14%: Fragments of carbonates such as micritic limestone, sparitic limestone, marly limestone, calcite
- 12%: fragments of sandstone
- 9%: quartz fragments
- 3%: mica flakes

Type of aggregate: sand, mostly of silicate nature and a small part carbonate

Porosity

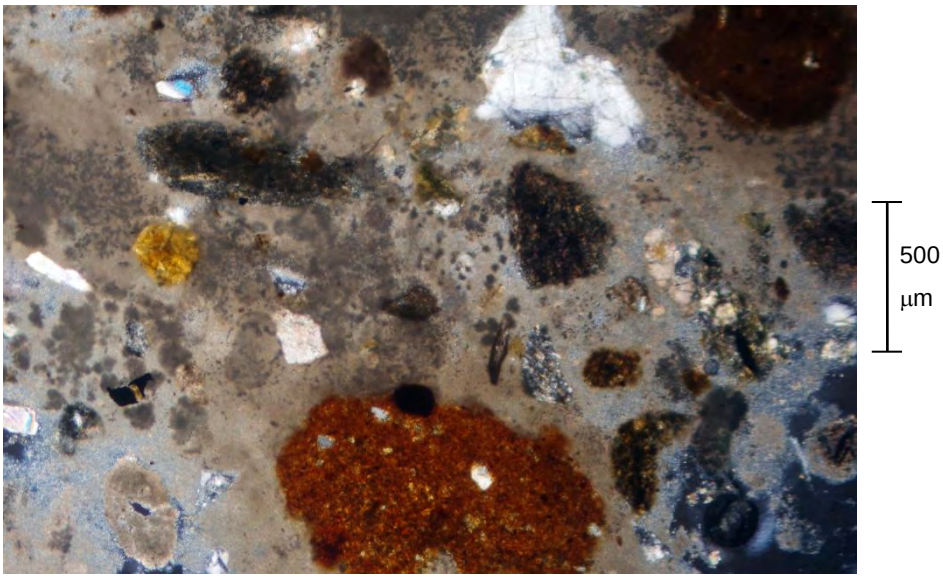
Percentage of pores	High (27%)
Origin of porosity	Both primary and secondary
Pore shape	Rounded vesicles and irregular voids from binder with the presence of microfessure.

Matrix

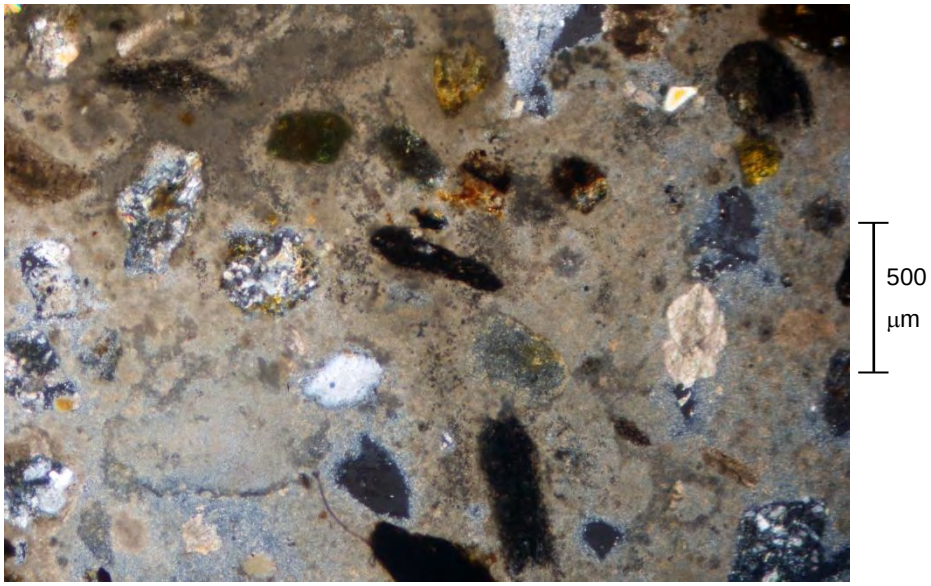
Structure	Heterogeneous due to the presence of calcareous fragments (calcinaroli)
Texture	Colloform to microsparitic ground mass
Clast/Matrix Ratio	Not detected
Composition	Carbonated aerial lime

Considerations on the mortar mix

Type of mortar mix	Whitish mortar based on carbonated aerial lime and sand, mostly of silicate nature and to a lesser extent carbonate, composed of silicate claystone fragments, carbonate fragments, sandstone, quartz, and mica. A significant percentage of cocciopesto has been added to the sand. The sizes of the aggregates range is between 0.45 mm e 4.9 mm with a prevalence of the fine arenaceous fraction. The areal ratio between aggregates and paste binder is around values of 2/1. The mixture shows a high porosity, both primary and secondary.
State of conservation	Overall, the mortar mix appears to be moderately preserved

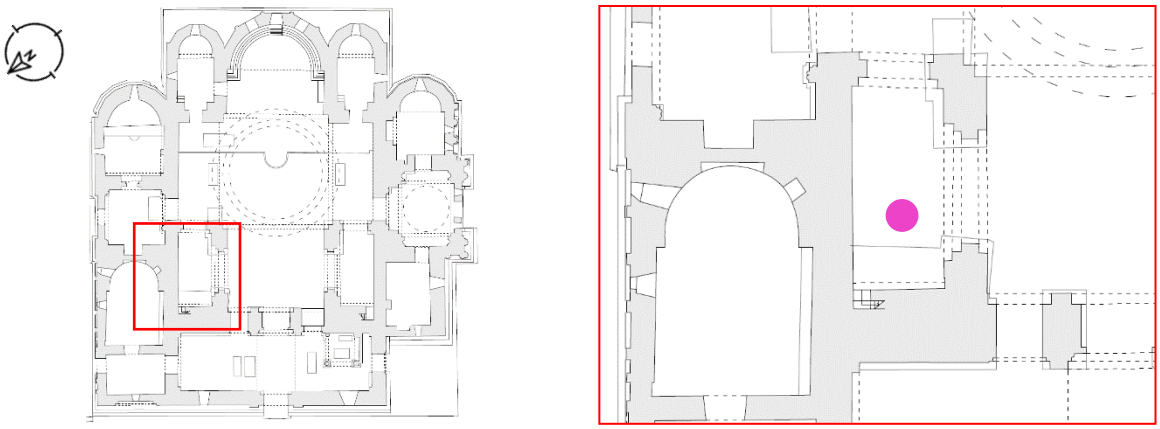


Thin section, transmitted light, 40 X, N+.



Thin section, transmitted light, 40 X, N+.

3.1.9. *Mortar sampling P-6.1 – Attic - North side vault*



Mortar sampling location P-6.1

Mortar sampling P-6.1

Mortar sample P-6.1

Macroscopic Description (UNI-NORMAL 12/83)

Dimensional Appearance	Silty arenaceous
Color	Whitish
Cohesion	Fairly tenacious and cohesive

Microscopic Description (UNI-NORMAL 12/83)

Aggregate

Granulometry	Very coarse arenaceous (2-1 mm) – coarse silty (0.062-0.032 mm)
Prevalent Granulometry	Coarse and medium arenaceous (1-0.25 mm)
Sorting	Moderately sorted
Shape (sphericity/roundness)	Medium to very low sphericity/ angular to sub-rounded fragments
Surface Morphology	From smooth to abraded
Orientation	Not detected
Distribution	Homogeneous
Compaction	Estimated clast-matrix ratio: medium-high (43%)

Particle size distribution		
Granulometric class	*mm*	*%*
Fine Conglomerate	8-4	-
Micro-conglomerate	4-2	-
Very coarse arenaceous	2-1	11
Coarse arenaceous	1-0.5	28
Medium arenaceous	0.5-0.25	32
Fine arenaceous	0.25-0.125	17
Very fine arenaceous	0.125-0.062	9
Silty	< 0.062	3

Aggregate composition
- 86%: quartz fragments
- 10%: Fragments of feldspar
- 4%: fragments of silicate claystone
Type of aggregate: Sand, exclusively of quartz-silicate nature

Porosity

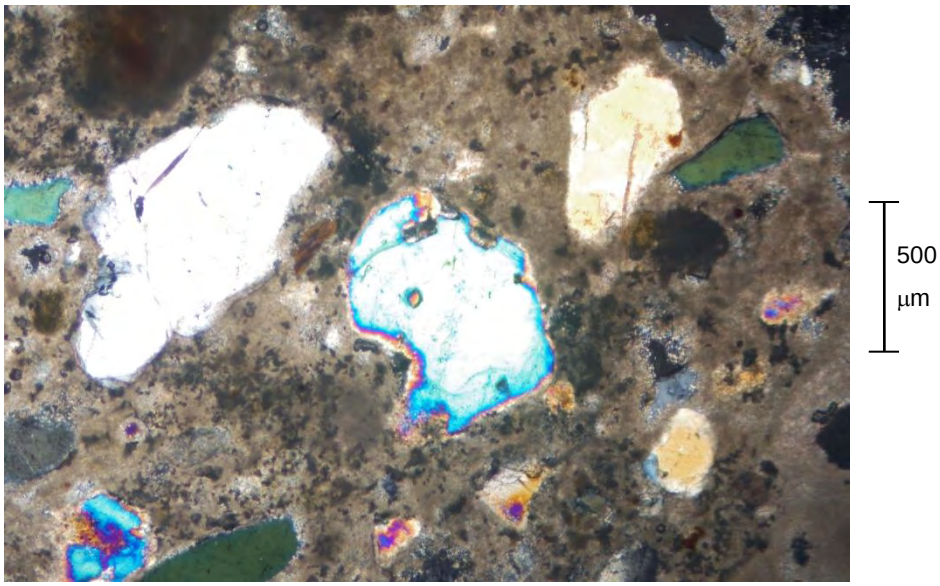
Percentage of pores	Medium (22%)
Origin of porosity	Both primary and secondary
Pore shape	Rounded vesicles and irregular voids from the binder

Matrix

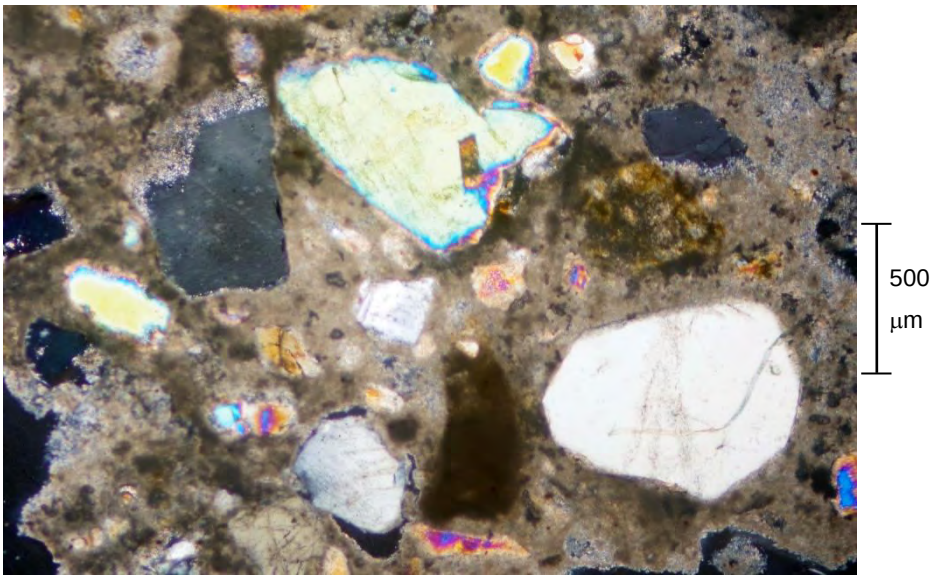
Structure	Heterogeneous due to the presence of calcareous fragments (calcinaroli)
Texture	Colloform to microsparitic ground mass
Clast/Matrix Ratio	Not detected
Composition	Carbonated aerial lime

Considerations on the mortar mix

Type of mortar mix	Whitish mortar based on carbonated aerial lime and sand, exclusively of silicate nature composed of quartz, feldspar, and silicate claystone. The sizes of the aggregates range is between 1.4 mm e 0.05 mm with a prevalence of the medium-coarse arenaceous fraction. The areal ratio between aggregates and paste binder is around values of 3/1. The mixture shows both medium primary and secondary porosity.
State of conservation	Overall, the mortar mix appears to be well preserved

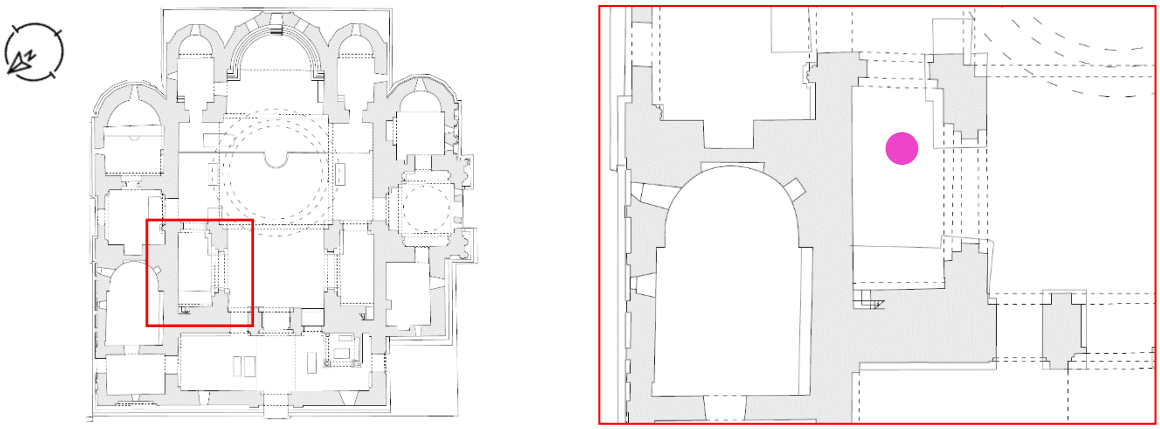


Thin section, transmitted light, 40 X, N+.



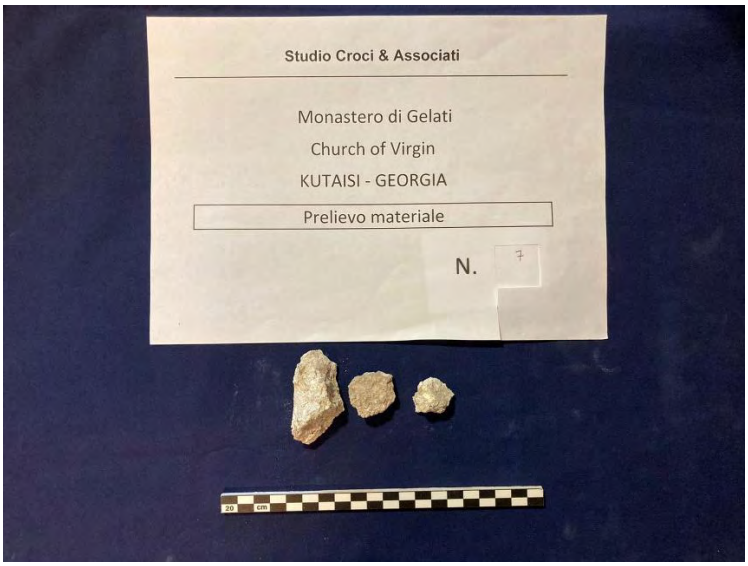
Thin section, transmitted light, 40 X, N+.

3.1.1. *Mortar sampling P-7 – Attic - North side vault*



Mortar sampling location P-7

Mortar sampling P-7



Mortar sample P-7

Macroscopic Description (UNI-NORMAL 12/83)

Dimensional Appearance	Silty arenaceous
Color	Whitish
Cohesion	Moderately tenacious and cohesive

Microscopic Description (UNI-NORMAL 12/83)

Aggregate

Granulometry	Very coarse arenaceous (2-1 mm) – coarse silty (0.062-0.032 mm)
Prevalent Granulometry	Medium arenaceous (0.5-0.25 mm)
Sorting	Moderately sorted
Shape (sphericity/roundness)	Medium to very low sphericity/ angular to sub-rounded fragments
Surface Morphology	From smooth to abraded
Orientation	Not detected
Distribution	Homogeneous
Compaction	Estimated clast-matrix ratio: medium-high (42%)

Particle size distribution		
Granulometric class	*mm*	*%*
Fine Conglomerate	8-4	-
Micro-conglomerate	4-2	-
Very coarse arenaceous	2-1	6
Coarse arenaceous	1-0.5	19
Medium arenaceous	0.5-0.25	33
Fine arenaceous	0.25-0.125	24
Very fine arenaceous	0.125-0.062	15
Silty	< 0.062	3

Aggregate composition

- 32%: fragments of silicate claystone
- 29%: quartz fragments
- 17%: carbonate fragments such as micritic limestone, sparitic limestone, calcite
- 13%: fragments of sandstone
- 5%: mica flakes
- 4%: Fragments of feldspar

Type of aggregate: river-alluvial sand of mostly silicatic nature and to a lesser extent carbonate

Porosity

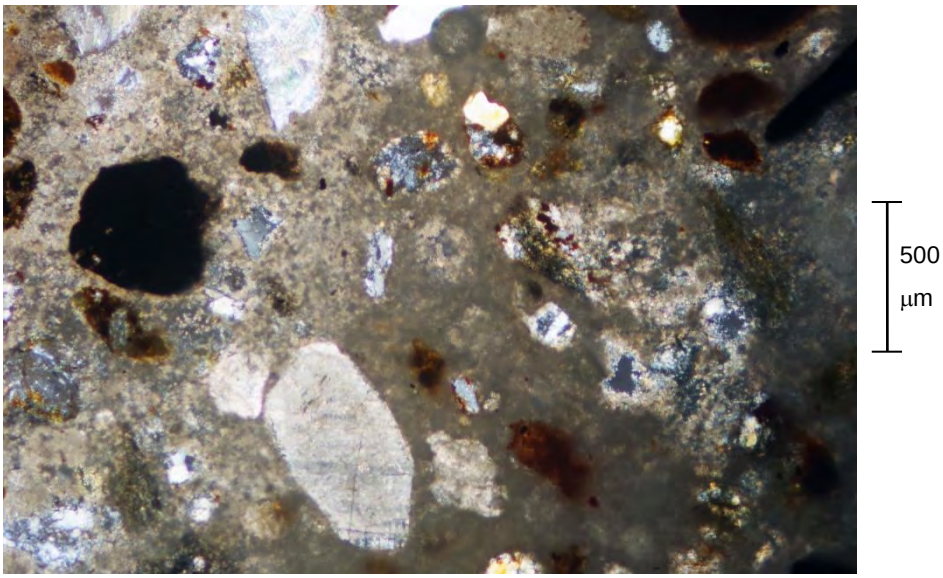
Percentage of pores	Medium (22%)
Origin of porosity	Both primary and secondary
Pore shape	Rounded vesicles and irregular voids from binder with the presence of microfessure

Matrix

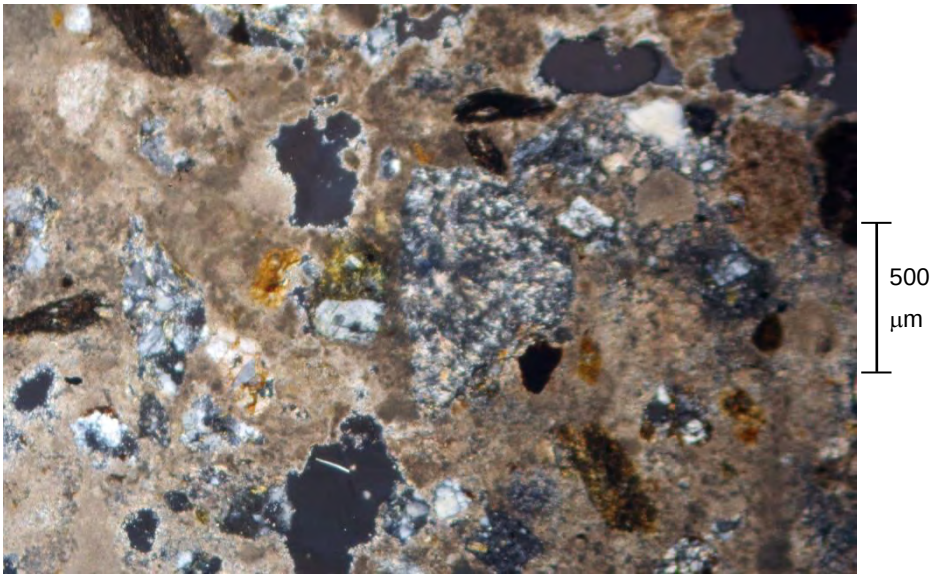
Structure	Heterogeneous due to the presence of calcareous fragments (calcinaroli)
Texture	Colloform to microsparitic ground mass
Clast/Matrix Ratio	Not detected
Composition	Carbonated aerial lime

Considerations on the mortar mix

Type of mortar mix	Whitish mortar based on carbonated aerial lime and river-alluvial sand, mostly of silicate nature and to a lesser extent carbonate, composed of silicate claystone fragments, quartz, carbonate fragments, sandstone, mica, and feldspar. The sizes of the aggregates range is between 1.3 mm e 0.04 mm with a prevalence of the medium arenaceous fraction. The areal ratio between aggregates and paste binder is around values of 2.5/1. The mixture shows both medium primary and secondary porosity.
State of conservation	Overall, the mortar mix appears to be fairly preserved



Thin section, transmitted light, 20 X, N+.



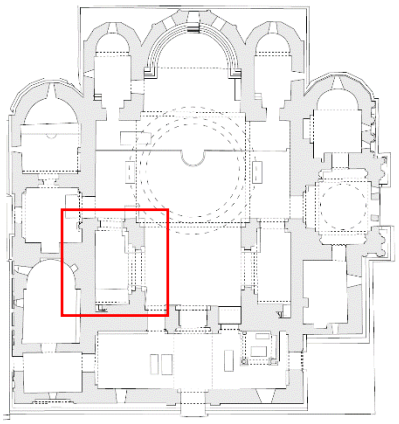
Thin section, transmitted light, 40 X, N+.

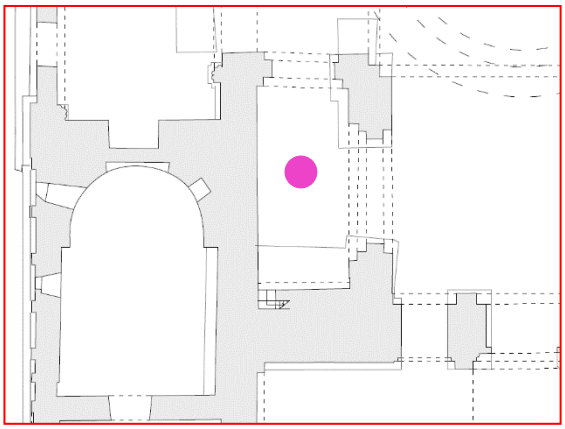
3.2. COMPRESSION TESTS ON MORTAR SAMPLE

3.2.1. *Method description*

In addition to the samples taken to determine the composition of the material, it was selected n.1 mortar sample from which a specimen was obtained to be subjected to a compression test. The test was carried out at the "testing and materials laboratory" of the Faculty of Engineering of the University of Rome - La Sapienza.

3.2.2. *Mortar sampling P-6.2 – Attic - North side vault*





Test location

Mortar sampling P-6.2

Mortar sample P-6.2

Sample	Material	R/C (1)	High	Base		Density	Compression strength.
			[mm]	[mm]	[mm]	[kg/m^3]	[MPa]
M-6.2	Mortar	R	39	41	39	1462	4.2

(1)R= Sample rectified by face levelling
C= Sample rectified by capping

3.3. MICROSEISMIC – SONIC INVESTIGATIONS ON MASONRY

3.3.1. *Method description*

The sonic pulse velocity method is applied for measuring the transit time of sonic pulses (stress waves) in masonry structures.
This transit time and the calculated sonic pulse velocity result in basic information about the quality and consistency of the masonry element under investigation. The velocity is influenced by the composition of the masonry as well as by the presence of heterogeneity, voids and deteriorated areas.
The sonic pulse velocity test can be carried out in different ways, according to the different transmission methods. The direct transmission method, for sonic waves involves passing of a stress wave through the thickness of the masonry wall. The initiation and reception points of the stress waves are in line with each other, on opposite sides of the masonry element.

Sonic investigations are carried out using the so-called "transparency" technique, which consists of placing a transmitter and receiver on opposite faces of the same wall in order to determine the value of the longitudinal wave propagation velocity through the thickness of the wall. By measuring the velocities, it is possible to make comparative assessments of the degradation state and homogeneity of the masonry. Due to the high levels of dispersion encountered during this type of testing, it is generally not possible to establish analytical relationships with the elastic moduli and strength of the material itself.
By calculating the percentage ratio between the standard deviation (σ) and the average velocity (Vm), an index is established to evaluate the uniformity of the velocity throughout the structural element. Comparing this index to a reference value (7 ÷ 10%), which takes into account measurement errors and typical variations encountered in masonry, provides an accurate assessment of the uniformity of the investigated area. In general, it can be stated that high values of σ/Vm indicate the possible presence of cracks/cavities and are typically indicative of heterogeneous masonry.
For the execution of sonic investigations, real-time sampling instrumentation is used, allowing the waveform to be displayed on a laptop computer monitor and enabling the simultaneous acquisition of signals from the sensors.

The equipment used has the following technical characteristics:

Laptop computer	model Asus Tek U5A
	microprocessor Intel Pentium
	80 GB hard drive
Data acquisition card	16 acquisition channels
	16-bit resolution
	conversion time 20 μs
	direct transfer to memory (DMA)
	sampling rate 83 kHz
Signal conditioning modules	
	gain adjustment (1-10-100) for each channel
	instrument power supply with stabilized voltage
	Adjustable low-pass and high-pass filters
Accelerometer sensors	Model IC - piezoresistive sensor
	sensitivity 1 Volt/g
	full-scale ± 5 g
	linear frequency response in the field 0 ÷ 1000 Hz
Connection cables	Coaxial type RG58

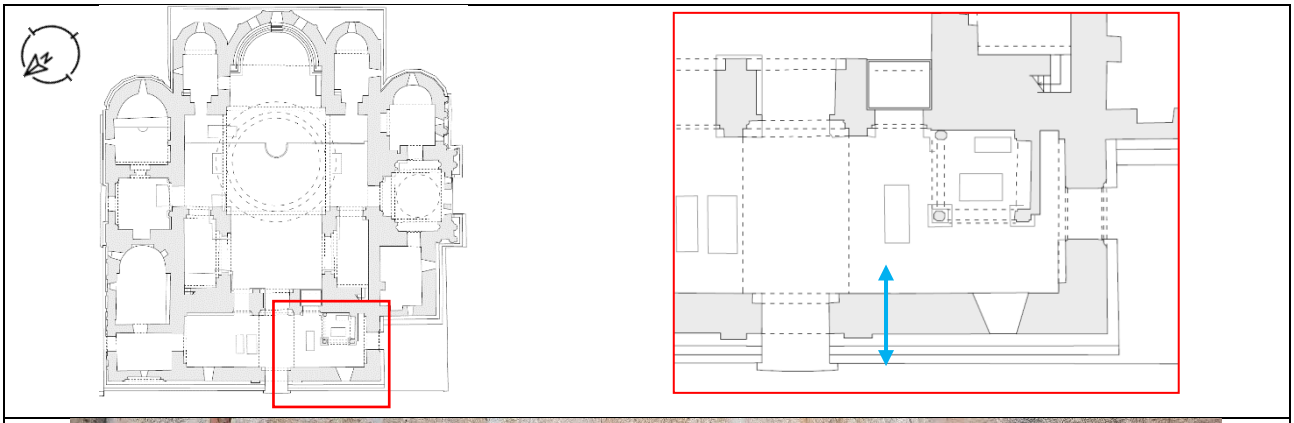
The system calibration was carried out in order to determine the optimal hardware and software configuration for correct wave recording.
A good definition of the acquisition parameters allows in the signal processing phase to have a sufficient number of points for determining the propagation speed of the elastic wave.

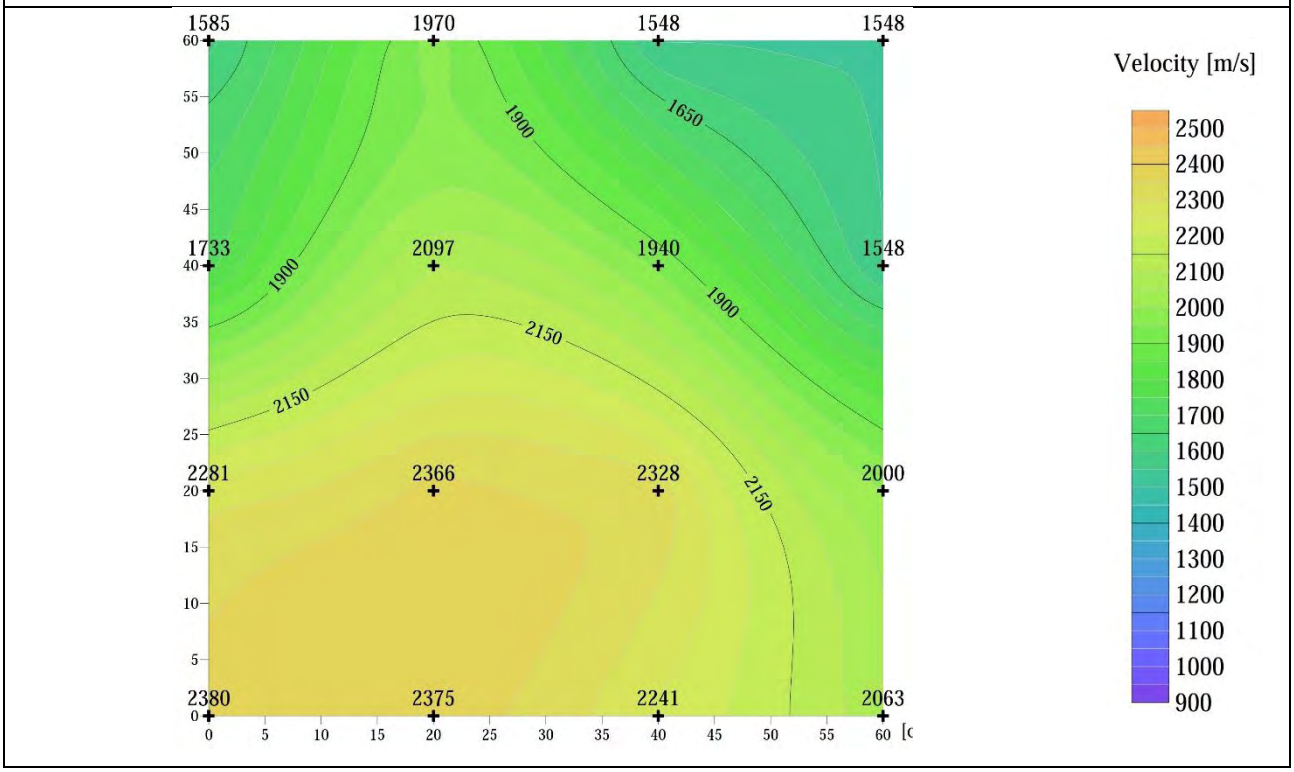
- Signal amplification carried out by signal conditioning modules:1
- Gain set via software:1
- Graphic full scale: ± 0.005 ÷ ± 0.01 g
- Sampling rate: 40000 Hz/channel (40000 acquisitions per second per channel)

Each measurement is performed by placing the piezoelectric transmitter on one part of the structural element to be investigated and the receiver on the opposite side. Given the distance "d" between the receiver and transmitter, the velocity of the sonic wave through the walls is derived as the ratio "d/t".

The data is presented both in tabular and graphical form. In particular, the graphical representation uses a color-coded visualization of the recorded velocity values at the grid nodes, which allows a quick visual assessment of any mechanical characteristic non-uniformities within the structural element.

3.3.2. *Sonic investigation S-1 - Ground Floor*





MICROSEISMIC – SONIC INVESTIGATION S1

OPERATORS:	Russo/Amici/Niccolai	**DATE:**	04/11/2023
SITE	Church of the Nativity of the Virgin	**LOCATION:**	Gelati - Georgia
FLOOR:	Ground	**STRUCTURAL ELEMENT:**	Perimeter wall
ELEMENT:	Masonry	**HEIGHT:**	97 cm

PLASTERED WALLS	
ISSUER	NO
RECEIVER	NO

CONSOLIDATED WALL	NO
WALL THICKNESS (cm)	130
GRID DISTANCE (cm)	20 x 20

WAVE DIRECTION INTERNAL→EXTERNAL

BEAT n°	RECEPTION n°	TIME (ms)	VELOCITY (m/s)
1	1	0.82	1585
2	2	0.66	1970
3	3	0.84	1548
4	4	0.84	1548
5	5	0.75	1733
6	6	0.62	2097
7	7	0.67	1940
8	8	0.84	1548

WAVE DIRECTION INTERNAL→EXTERNAL

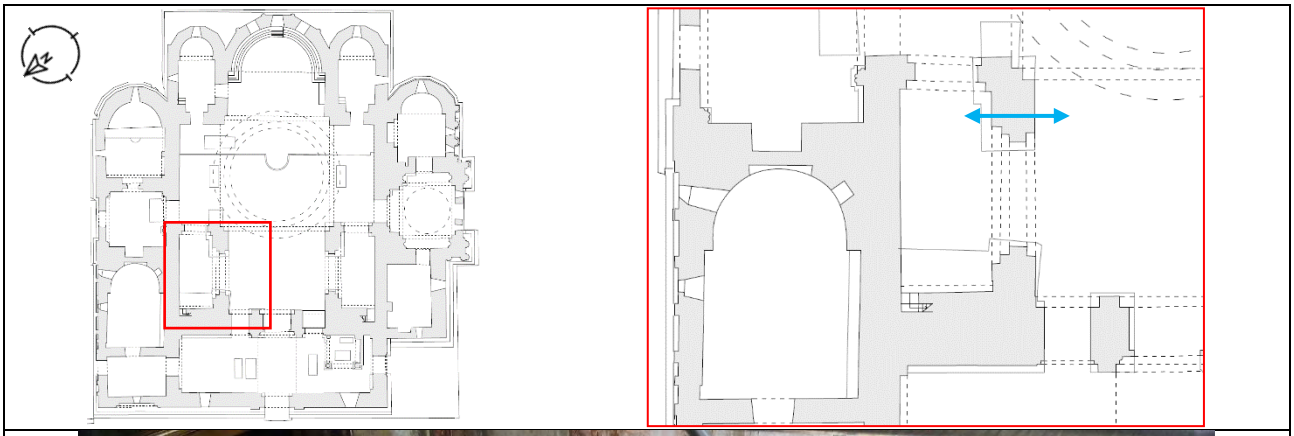
BEAT n°	RECEPTION n°	TIME (ms)	VELOCITY (m/s)
9	9	0.57	2281
10	10	0.55	2366
11	11	0.56	2328
12	12	0.65	2000
13	13	0.55	2380
14	14	0.55	2375
15	15	0.58	2241
16	16	0.63	2063

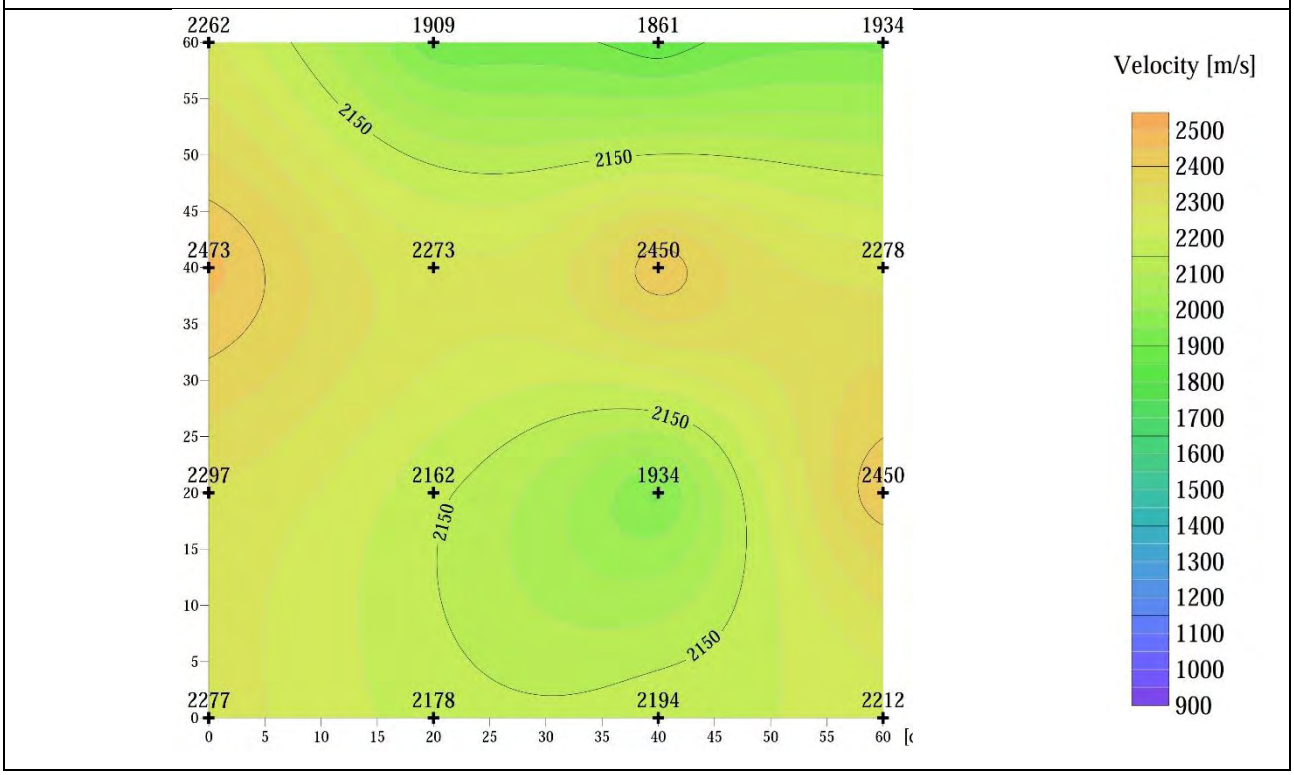
Vm (m/s)	**σ (m/s)**	**σ / Vm (%)**
2000	310	15.5

SONIC INVESTIGATION Sn-1

Location of the color map on the investigated element

3.3.3. *Sonic investigation S-2 - Ground Floor*





MICROSEISMIC – SONIC INVESTIGATION S2

OPERATORS:	Russo/Amici/Niccolai	**DATE:**	04/11/2023
SITE	Church of the Nativity of the Virgin	**LOCATION:**	Gelati - Georgia
FLOOR:	Ground	**STRUCTURAL ELEMENT:**	Perimeter wall
ELEMENT:	Masonry	**HEIGHT:**	24 cm

PLASTERED WALLS	
ISSUER	NO
RECEIVER	NO

CONSOLIDATED WALL	NO
WALL THICKNESS (cm)	147
GRID DISTANCE (cm)	20 x 20

WAVE DIRECTION INTERNAL→EXTERNAL

BEAT n°	RECEPTION n°	TIME (ms)	VELOCITY (m/s)
1	1	0.65	2262
2	2	0.77	1909
3	3	0.79	1861
4	4	0.76	1934
5	5	0.59	2473
6	6	0.65	2273
7	7	0.60	2450
8	8	0.65	2278

WAVE DIRECTION INTERNAL→EXTERNAL

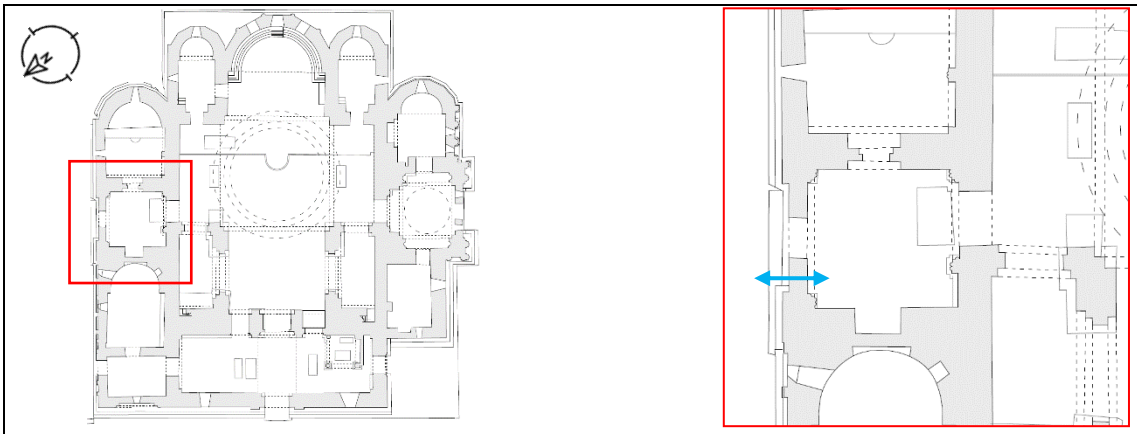
BEAT n°	RECEPTION n°	TIME (ms)	VELOCITY (m/s)
9	9	0.64	2297
10	10	0.68	2162
11	11	0.76	1934
12	12	0.60	2450
13	13	0.65	2277
14	14	0.68	2178
15	15	0.67	2194
16	16	0.66	2212

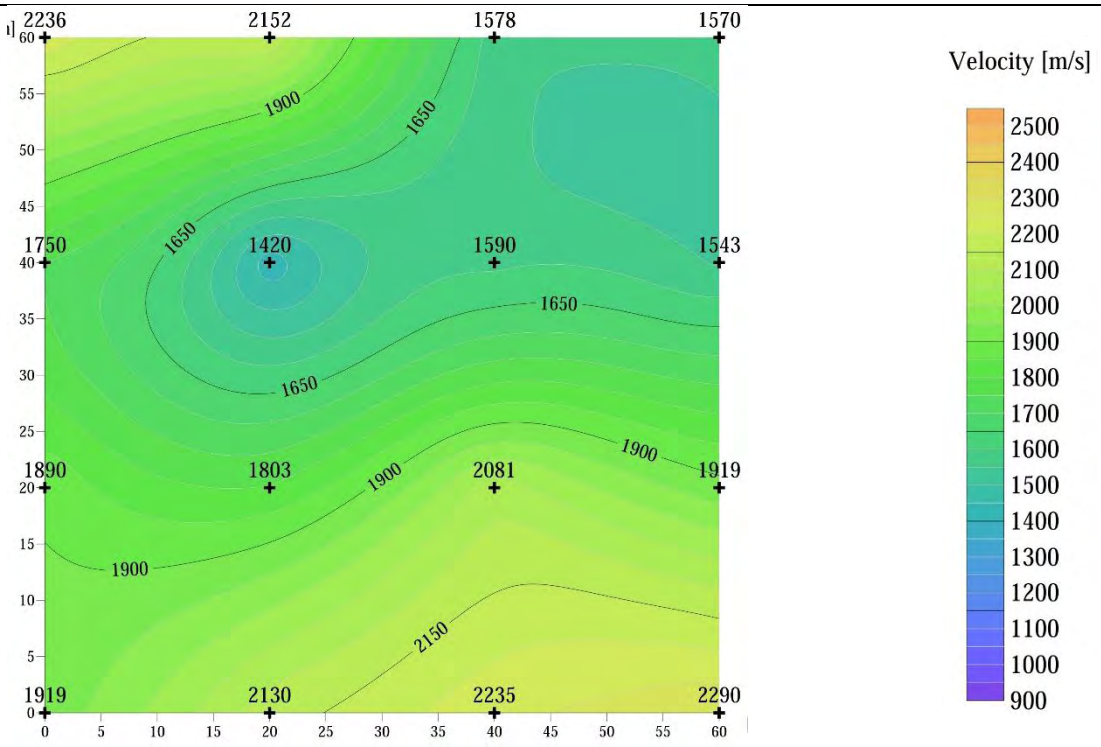
Vm (m/s)	**σ (m/s)**	**σ / Vm (%)**
2196	189	8.6

Sonic investigation S-2

Location of the color map on the investigated element

3.3.4. *Sonic investigation S-3 - Ground Floor*





MICROSEISMIC – SONIC INVESTIGATION S3

OPERATORS:	Russo/Amici/Niccolai	**DATE:**	04/11/2023
SITE	Church of the Nativity of the Virgin	**LOCATION:**	Gelati - Georgia
FLOOR:	Ground	**STRUCTURAL ELEMENT:**	Perimeter wall
ELEMENT:	Masonry	**HEIGHT:**	94 cm

PLASTERED WALLS	
ISSUER	NO
RECEIVER	NO

CONSOLIDATED WALL	NO
WALL THICKNESS (cm)	71
GRID DISTANCE (cm)	20 x 20

WAVE DIRECTION INTERNAL→EXTERNAL

BEAT n°	RECEPTION n°	TIME (ms)	VELOCITY (m/s)
1	1	0.32	2236
2	2	0.33	2152
3	3	0.45	1578
4	4	0.45	1570
5	5	0.41	1750
6	6	0.50	1420
7	7	0.45	1590
8	8	0.46	1543

WAVE DIRECTION INTERNAL→EXTERNAL

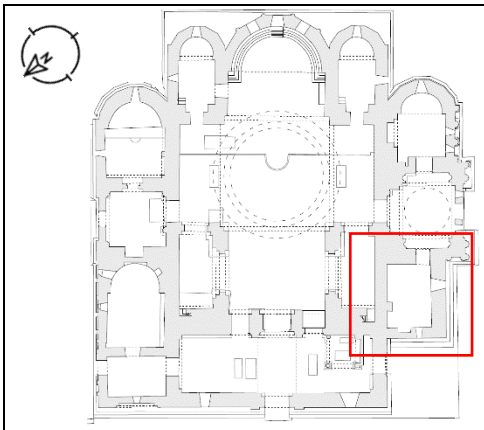
BEAT n°	RECEPTION n°	TIME (ms)	VELOCITY (m/s)
9	9	0.38	1890
10	10	0.39	1803
11	11	0.34	2081
12	12	0.37	1919
13	13	0.37	1919
14	14	0.33	2130
15	15	0.32	2235
16	16	0.31	2290

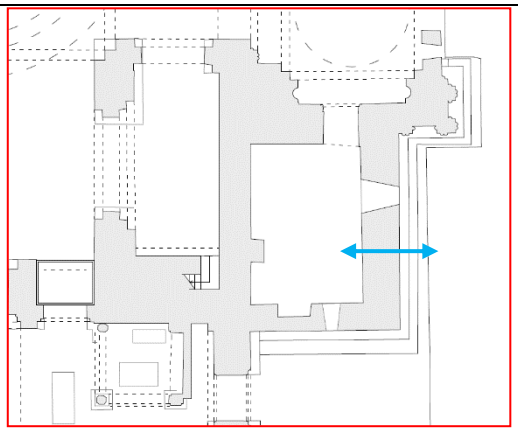
Vm (m/s)	**σ (m/s)**	**σ / Vm (%)**
1881	276	14.7

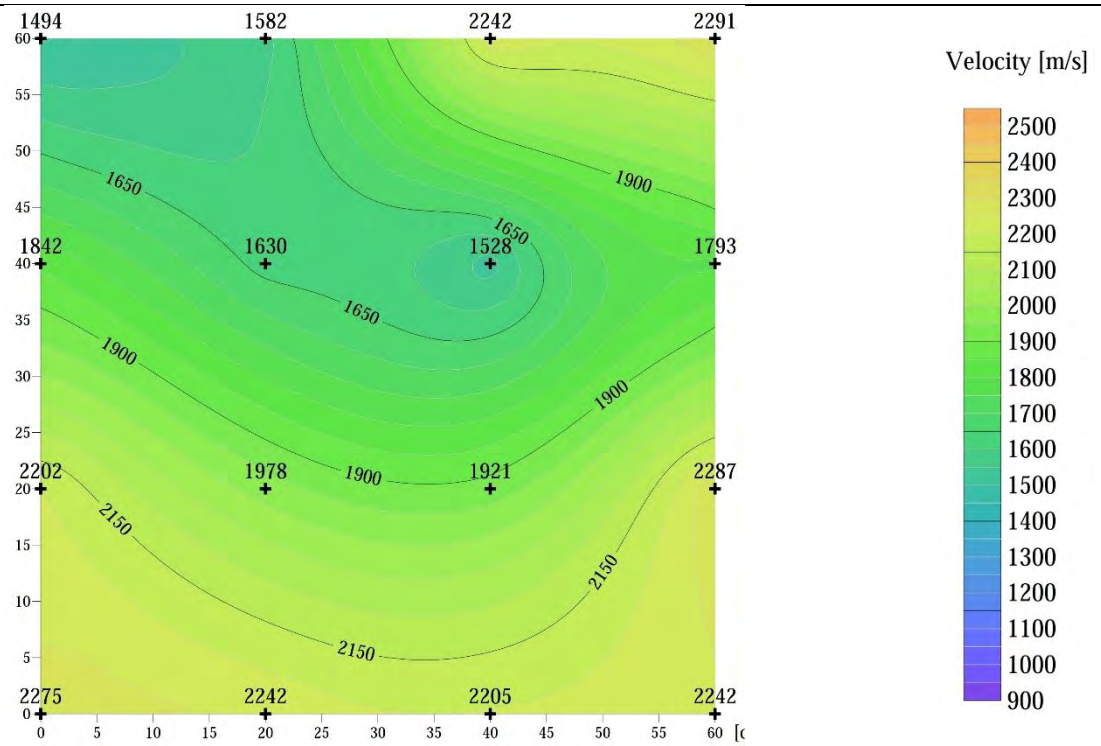
Sonic investigation S-3

Location of the color map on the investigated element

3.3.5. *Sonic investigation S-4 - Ground Floor*







MICROSEISMIC – SONIC INVESTIGATION S4

OPERATORS:	Russo/Amici/Niccolai	**DATE:**	04/11/2023
SITE	Church of the Nativity of the Virgin	**LOCATION:**	Gelati - Georgia
FLOOR:	Ground	**STRUCTURAL ELEMENT:**	Perimeter wall
ELEMENT:	Masonry	**HEIGHT:**	130 cm

PLASTERED WALLS	
ISSUER	NO
RECEIVER	NO

CONSOLIDATED WALL	NO
WALL THICKNESS (cm)	135
GRID DISTANCE (cm)	20 x 20

WAVE DIRECTION INTERNAL→EXTERNAL

BEAT n°	RECEPTION n°	TIME (ms)	VELOCITY (m/s)
1	1	0.90	1494
2	2	0.85	1582
3	3	0.60	2242
4	4	0.59	2291
5	5	0.73	1842
6	6	0.83	1630
7	7	0.88	1528
8	8	0.75	1793

WAVE DIRECTION INTERNAL→EXTERNAL

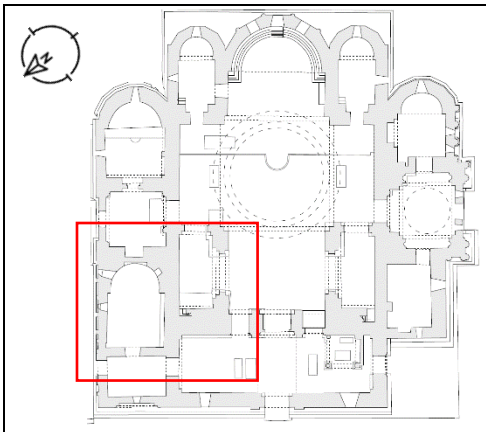
BEAT n°	RECEPTION n°	TIME (ms)	VELOCITY (m/s)
9	9	0.61	2202
10	10	0.68	1978
11	11	0.70	1921
12	12	0.59	2287
13	13	0.59	2275
14	14	0.60	2242
15	15	0.61	2205
16	16	0.60	2242

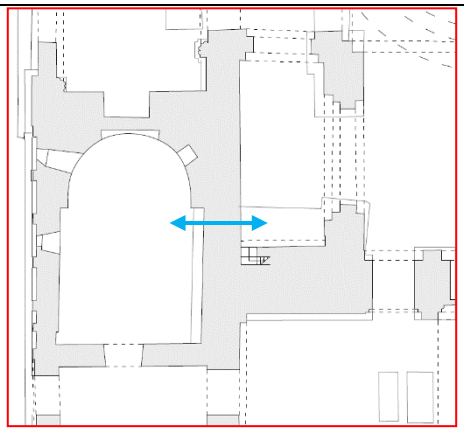
Vm (m/s)	**σ (m/s)**	**σ / Vm (%)**
1984	291	14.7

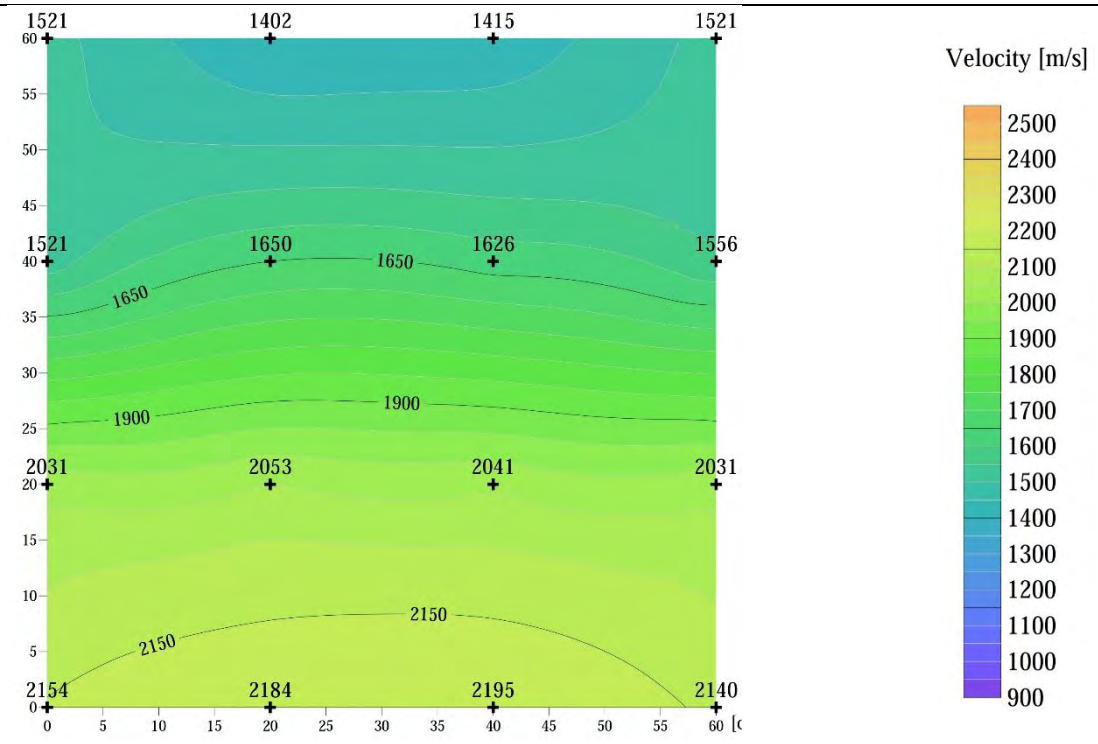
Sonic investigation S-4

Location of the color map on the investigated element

3.3.1. *Sonic investigation S-5 - Ground Floor*







MICROSEISMIC – SONIC INVESTIGATION S5

OPERATORS:	Russo/Amici/Niccolai	**DATE:**	04/11/2023
SITE	Church of the Nativity of the Virgin	**LOCATION:**	Gelati - Georgia
FLOOR:	Ground	**STRUCTURAL ELEMENT:**	Perimeter wall
ELEMENT:	Masonry	**HEIGHT:**	50 cm

PLASTERED WALLS	
ISSUER	NO
RECEIVER	NO

CONSOLIDATED WALL	NO
WALL THICKNESS (cm)	65
GRID DISTANCE (cm)	20 x 20

WAVE DIRECTION INTERNAL→EXTERNAL

BEAT n°	RECEPTION n°	TIME (ms)	VELOCITY (m/s)
1	1	0.43	1521
2	2	0.46	1402
3	3	0.46	1415
4	4	0.43	1521
5	5	0.43	1521
6	6	0.39	1650
7	7	0.40	1626
8	8	0.42	1556

WAVE DIRECTION INTERNAL→EXTERNAL

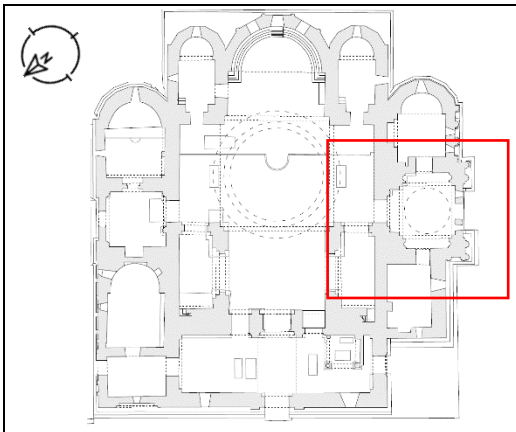
BEAT n°	RECEPTION n°	TIME (ms)	VELOCITY (m/s)
9	9	0.32	2031
10	10	0.32	2053
11	11	0.32	2041
12	12	0.32	2031
13	13	0.30	2154
14	14	0.30	2184
15	15	0.30	2195
16	16	0.30	2140

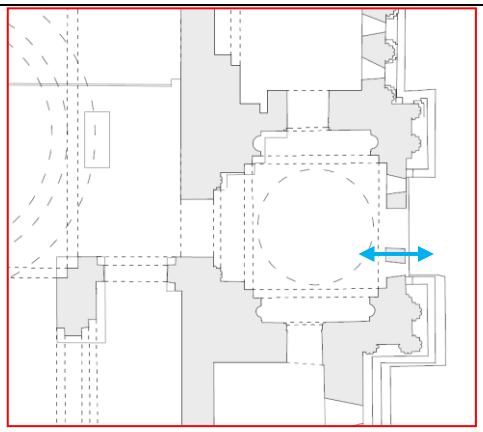
Vm (m/s)	**σ (m/s)**	**σ / Vm (%)**
1815	298	16.4

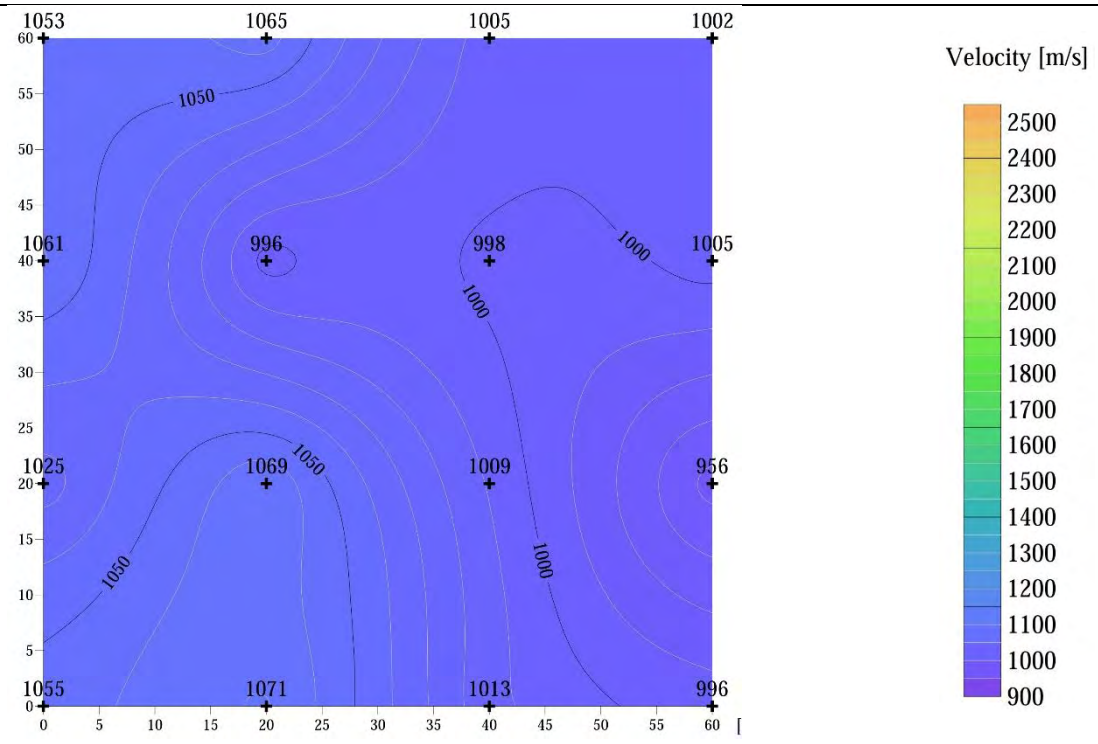
Sonic investigation S-5

Location of the color map on the investigated element

3.3.1. *Sonic investigation S-6 - Ground Floor*







MICROSEISMIC – SONIC INVESTIGATION S6

OPERATORS:	Russo/Amici/Niccolai	**DATE:**	04/11/2023
SITE	Church of the Nativity of the Virgin	**LOCATION:**	Gelati - Georgia
FLOOR:	Ground	**STRUCTURAL ELEMENT:**	Perimeter wall
ELEMENT:	Masonry	**HEIGHT:**	50 cm

PLASTERED WALLS	
ISSUER	NO
RECEIVER	NO

CONSOLIDATED WALL	NO
WALL THICKNESS (cm)	65
GRID DISTANCE (cm)	20 x 20

WAVE DIRECTION INTERNAL→EXTERNAL

BEAT n°	RECEPTION n°	TIME (ms)	VELOCITY (m/s)
1	1	0.62	1053
2	2	0.61	1065
3	3	0.65	1005
4	4	0.65	1002
5	5	0.61	1061
6	6	0.65	996
7	7	0.65	998
8	8	0.65	1005

WAVE DIRECTION INTERNAL→EXTERNAL

BEAT n°	RECEPTION n°	TIME (ms)	VELOCITY (m/s)
9	9	0.63	1025
10	10	0.61	1069
11	11	0.64	1009
12	12	0.68	956
13	13	0.62	1055
14	14	0.61	1071
15	15	0.64	1013
16	16	0.65	996

Vm (m/s)	**σ (m/s)**	**σ / Vm (%)**
1023	33	3.2

Sonic investigation S-6

Location of the color map on the investigated element

3.4. VIDEOENDOSCOPIC INVESTIGATIONS

3.1. *Method description*

Videoendoscopic investigation consists of a slightly invasive technique primarily applied to determine the condition and type of masonry structures.

The inspections are carried out within drill holes with a diameter of 20 mm, performed using a rotary hammer drill (core destruction), after cleaning the hole.

The investigations are carried out using a rigid or flexible probe equipped with a camera and axial lighting.

The videoscope is connected to a digital recording system, which allows the storage of video inspections of each drill hole.

This investigative technique allows us to identify the presence of internal cavities and lesions, the state of conservation of the walls, the type and state of the mortars, as well as the presence of any rubble masonry present in the internal area of the masonry itself.

For each inspected hole, a schematic graphic representation illustrating the stratigraphic sequence of the masonry layers encountered, some photo frames extracted from the video footage, and an attached digital copy of the entire recording will be provided.

3.1.1. *Videoendoscopic investigation V-1 – 1° Floor*

Structural element: *Pillar*

Location: *First floor*

Hole:

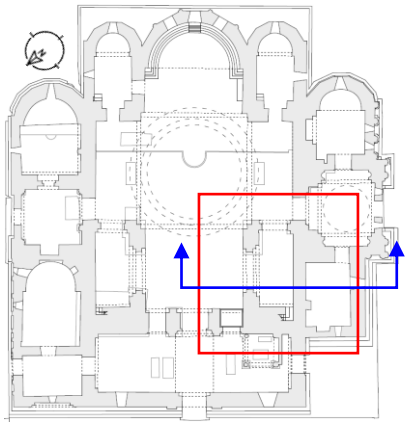
Diameter: 20 mm

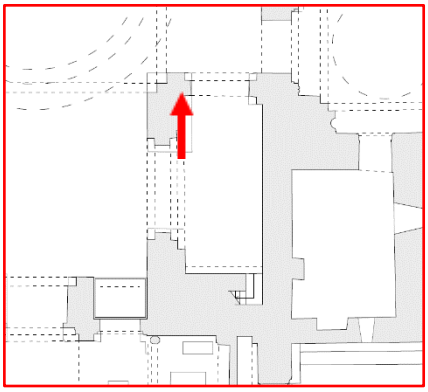
Hole direction: horizontal

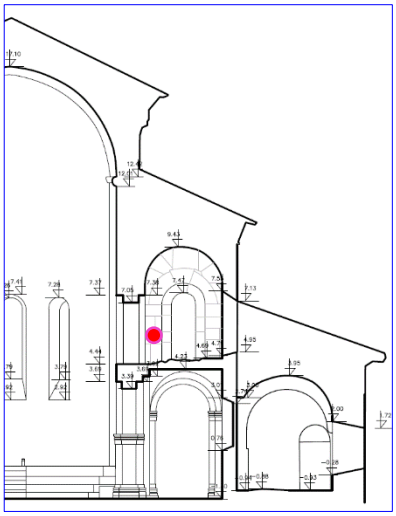
Length: 102 cm – Not passing

Distance from left: 30 cm

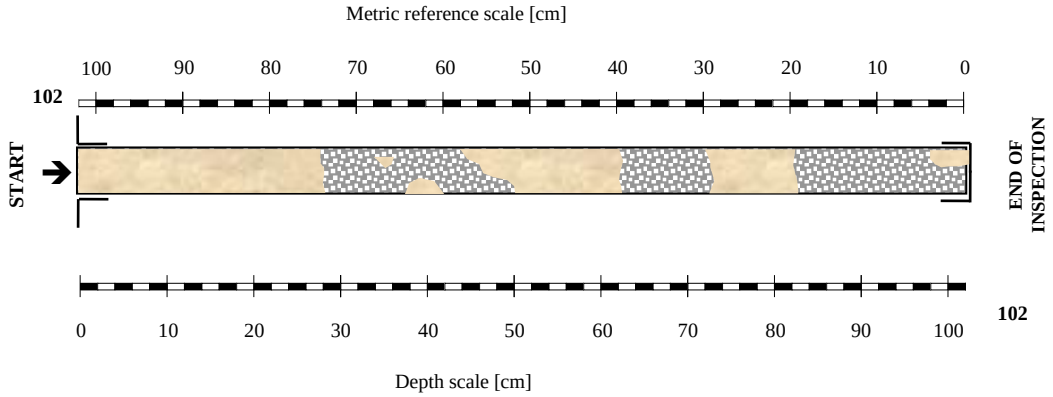
Height from the ground: 112 cm







Section



KEY

Mortar mix

Limestone

Frames extrapolated from the video footage


Depth 0 cm (start)


Depth 3 cm


Depth 13 cm


Depth 23 cm


Depth 32 cm


Depth 42 cm


Depth 52 cm


Depth 65 cm


Depth 72 cm


Depth 82 cm


Depth 92 cm


Depth 102 cm (end of inspection)

3.1.2. *Videoendoscopic investigation V-2 – 1° Floor*

Structural element: *Perimeter wall*

Location: *First floor*

Hole:

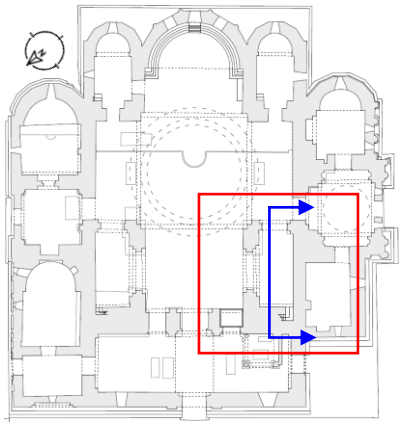
Diameter: 20 mm

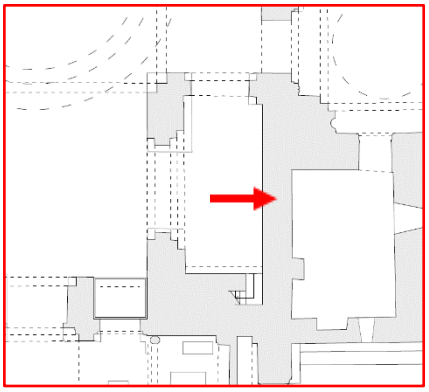
Hole direction: horizontal

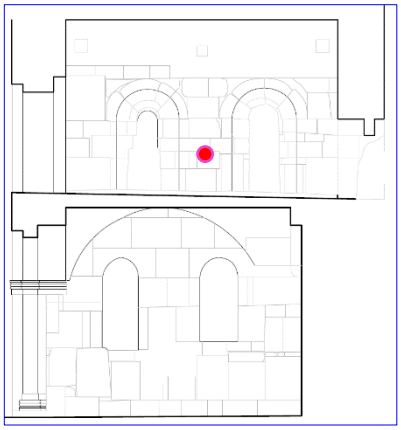
Length: 116 cm – Not passing

Distance from left: 75 cm

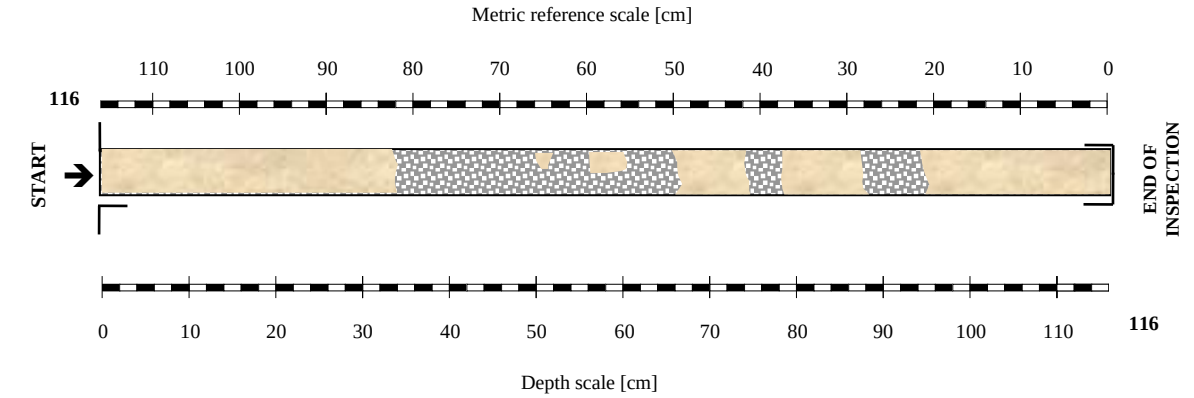
Height from the ground: 100 cm



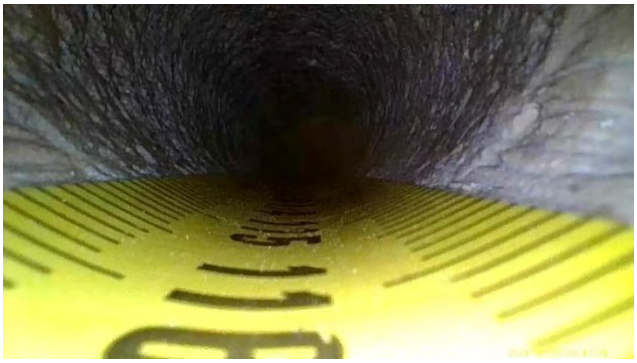




Section



Frames extrapolated from the video footage


Depth 0 cm (start)


Depth 12 cm


Depth 26 cm


Depth 35 cm


Depth 46 cm


Depth 56 cm


Depth 67 cm


Depth 77 cm


Depth 86 cm


Depth 96 cm


Depth 104 cm


Depth 116 cm (end of inspection)

3.1.3. *Videoendoscopic investigation V-3 – 1° Floor*

Structural element: *Perimeter wall*

Location: *First floor*

Hole:

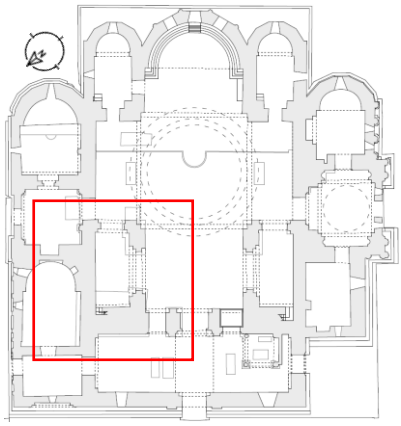
Diameter: 20 mm

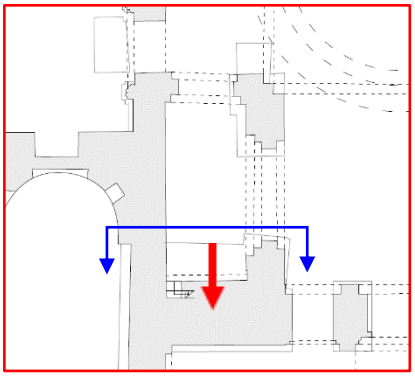
Hole direction: horizontal

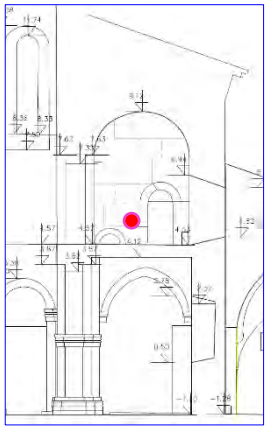
Length: 120 cm – Passing

Distance from left: 65 cm

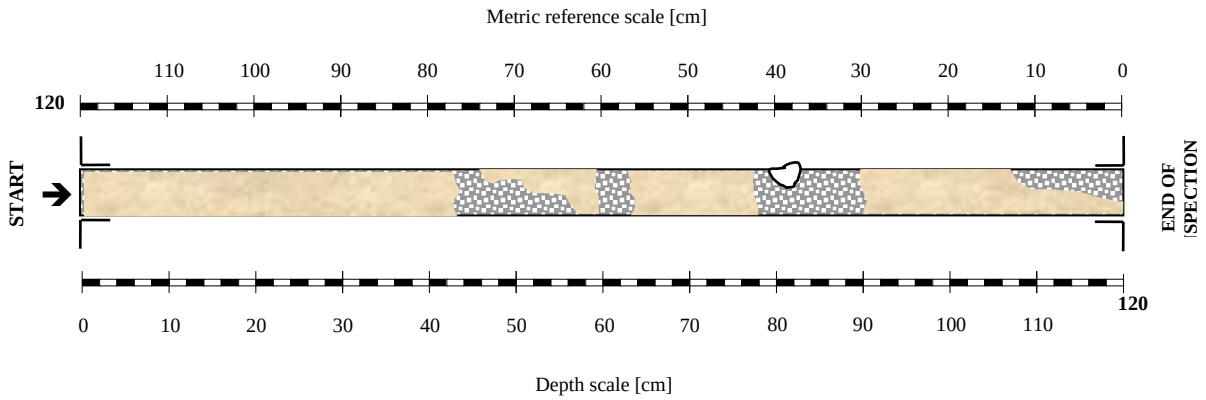
Height from the ground: 116 cm







Section



KEY

Mortar mix Limestone Cavity

Frames extrapolated from the video footage


Depth 0 cm (start)


Depth 17 cm


Depth 29 cm


Depth 40 cm


Depth 50 cm


Depth 60 cm


Depth 70 cm


Depth 80 cm


Depth 90 cm


Depth 100 cm


Depth 105 cm


Depth 120 cm (end of inspection)

3.1.4. *Videoendoscopic investigation V-4 – 1° Floor*

Structural element: *Perimeter wall*

Location: *First floor*

Hole:

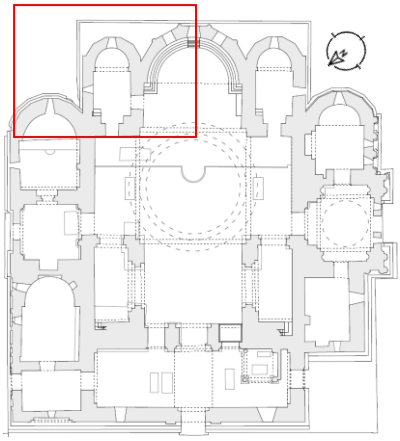
Diameter: 20 mm

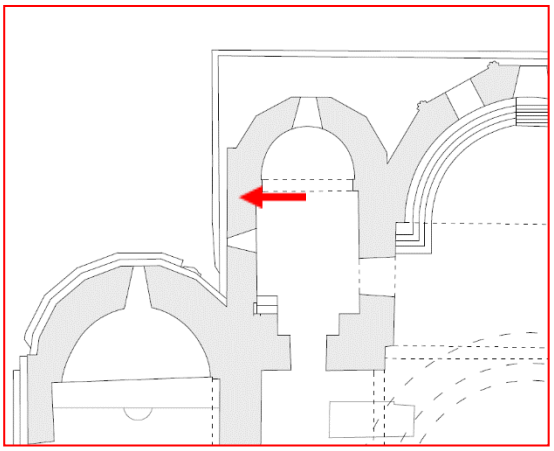
Hole direction: horizontal

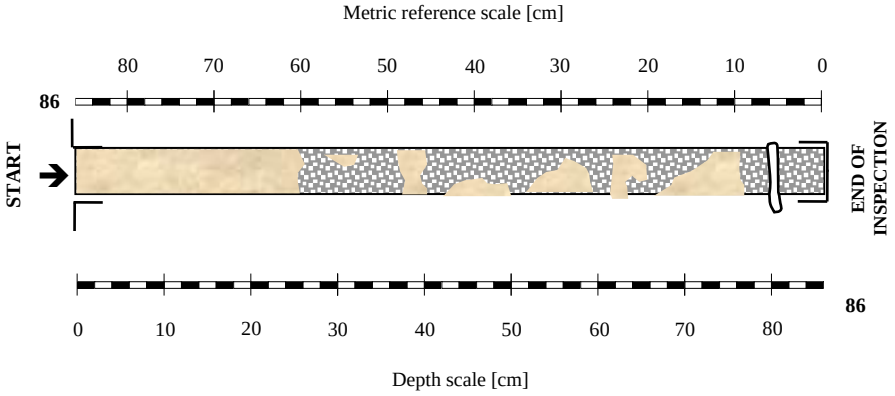
Length: 85 cm – Not passing

Distance from left: 50 cm

Height from the ground: 115 cm







KEY

Mortar mix Limestone Cavity

Frames extrapolated from the video footage


Depth 0 cm (start)


Depth 7 cm


Depth 17 cm


Depth 21 cm


Depth 28 cm


Depth 33 cm


Depth 42 cm


Depth 50 cm


Depth 57 cm


Depth 66 cm


Depth 72 cm


Depth 86 cm (end of inspection)

3.1.5. *Videoendoscopic investigation V-5 – 1° Floor*

Structural element: *Inner wall*

Location: *First floor*

Hole:

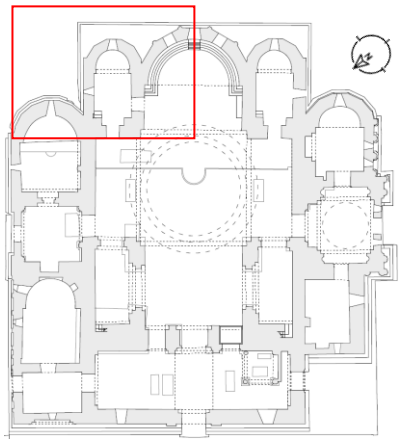
Diameter: 20 mm

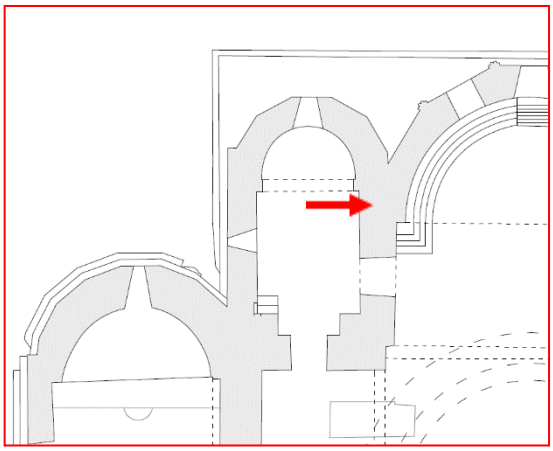
Hole direction: horizontal

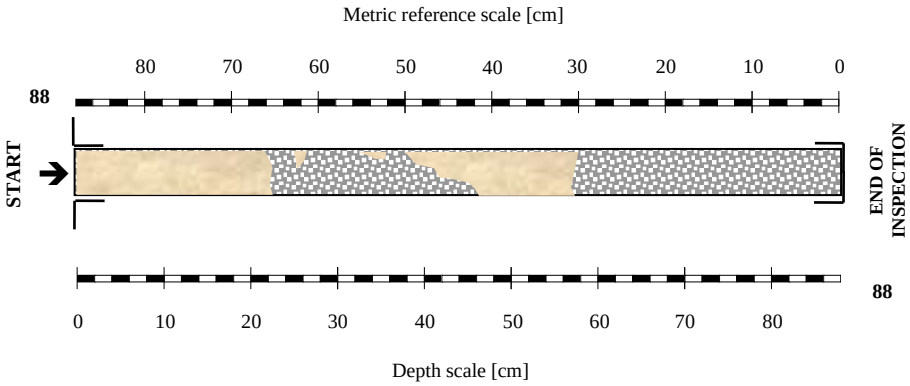
Length: 103 cm – Not passing

Distance from left: 40 cm

Height from the ground: 103 cm







KEY

Mortar mix

Limestone

Frames extrapolated from the video footage


Depth 0 cm (start)


Depth 9 cm


Depth 17 cm


Depth 25 cm


Depth 33 cm


Depth 40 cm


Depth 47 cm


Depth 52 cm


Depth 59 cm


Depth 66 cm


Depth 74 cm


Depth 88 cm (end of inspection)

3.1.6. *Videoendoscopic investigation V-6 – Ground Floor*

Structural element: *Perimeter wall*

Location: *Ground floor*

Hole:

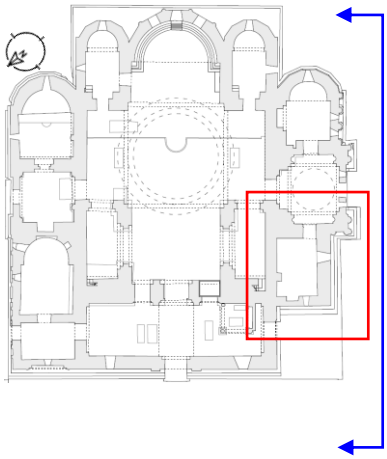
Diameter: 20 mm

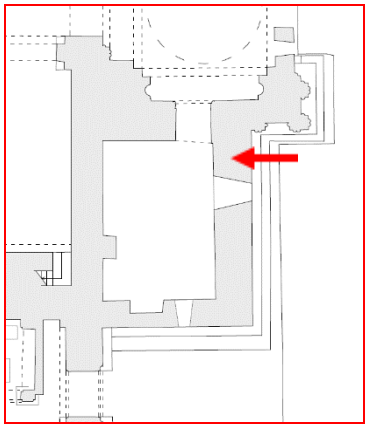
Hole direction: horizontal

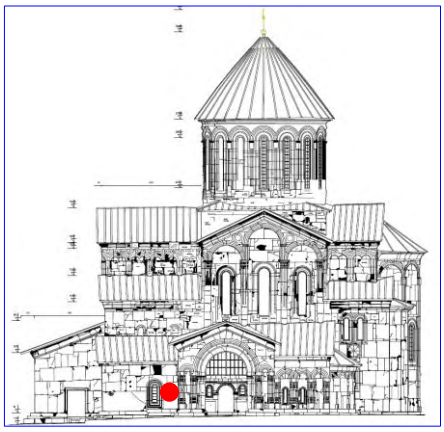
Length: 90 cm – Not passing

Distance from right: 110 cm

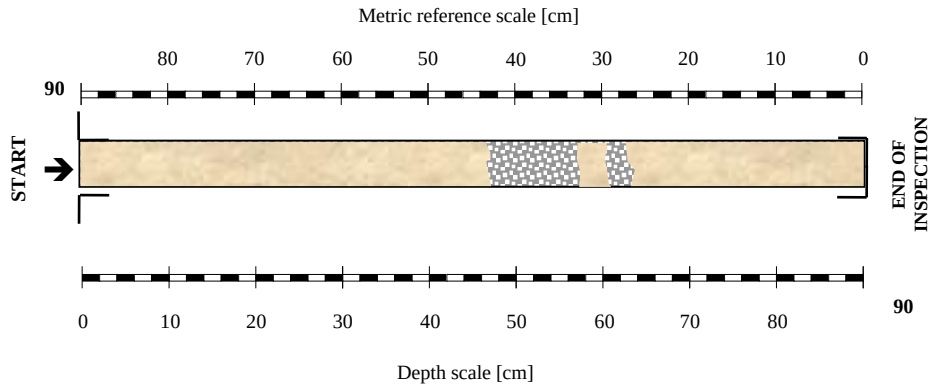
Height from the ground: 155 cm







Elevation



KEY

Mortar mix

Limestone

Frames extrapolated from the video footage


Depth 0 cm (start)


Depth 10 cm


Depth 15 cm


Depth 21 cm


Depth 32 cm


Depth 40 cm


Depth 45 cm


Depth 54 cm


Depth 61 cm


Depth 69 cm


Depth 79 cm


Depth 90 cm (end of inspection)

3.1.7. *Videoendoscopic investigation V-7 – Ground Floor*

Structural element: *Perimeter wall*

Location: *Ground floor*

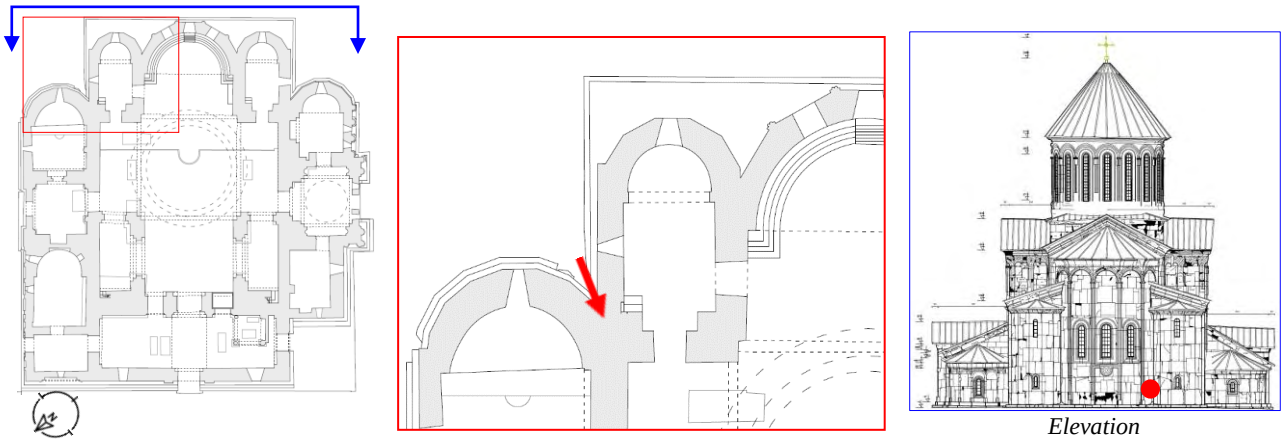
Hole:

Diameter: 20 mm

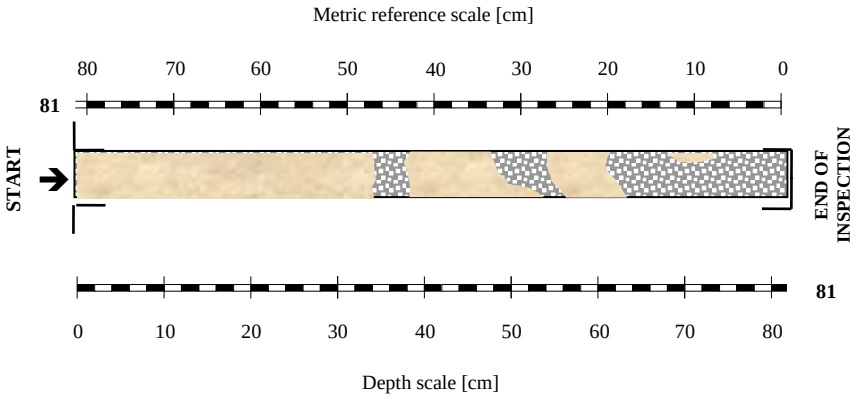
Hole direction: horizontal

Length: 81 cm – Not passing

Height from the ground: 114 cm



Elevation



KEY

Mortar mix

Limestone

Frames extrapolated from the video footage


Depth 0 cm (start)


Depth 6 cm


Depth 12 cm


Depth 19 cm


Depth 25 cm


Depth 33 cm


Depth 41 cm


Depth 49 cm


Depth 57 cm


Depth 61 cm


Depth 67 cm


Depth 81 cm (end of inspection)

3.1.8. *Videoendoscopic investigation V-8 – Ground Floor*

Structural element: *Perimeter wall*

Location: *Ground floor*

Hole:

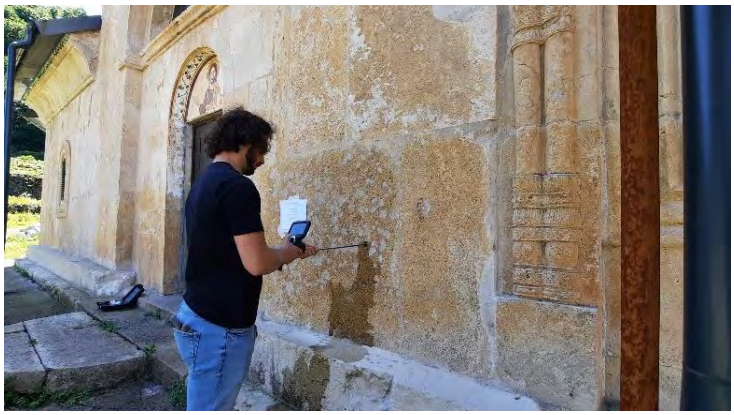
Diameter: 20 mm

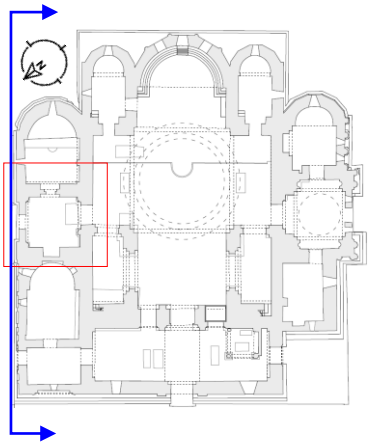
Hole direction: horizontal

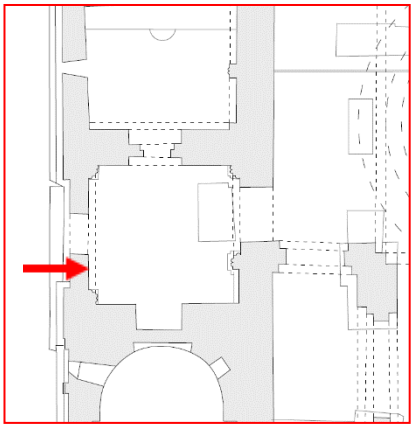
Length: 90 cm – Not passing

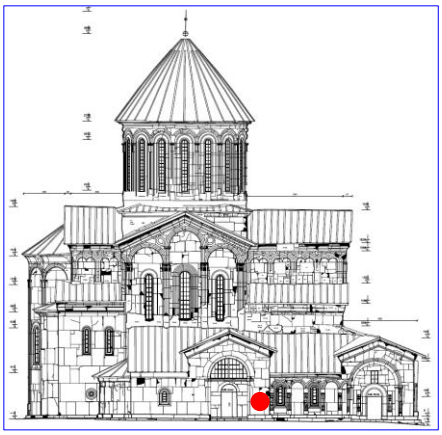
Distance from left: 103 cm

Height from the ground: 62 cm

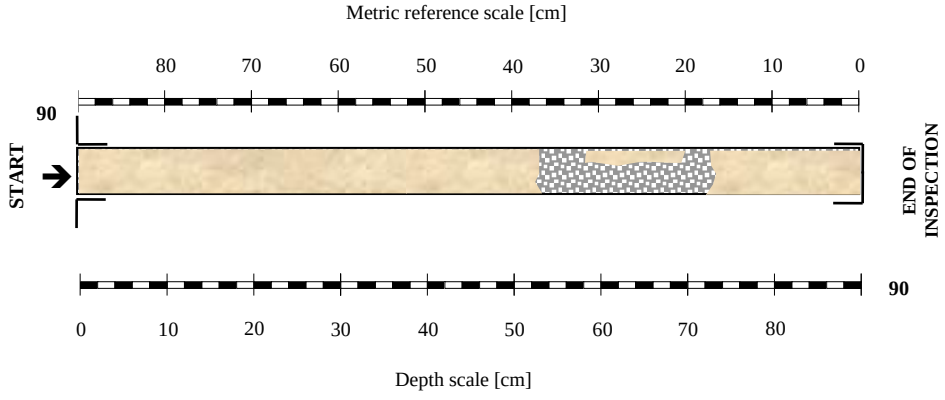








Elevation



KEY

Mortar mix

Limestone

Frames extrapolated from the video footage

Depth 0 cm (start)

Depth 8 cm

Depth 15 cm

Depth 24 cm

Depth 30 cm

Depth 38 cm


Depth 46 cm


Depth 55 cm


Depth 60 cm


Depth 70 cm


Depth 76 cm


Depth 90 cm (end of inspection)

3.1.9. *Videoendoscopic investigation V-9 – Ground Floor*

Structural element: *Perimeter wall*

Location: *Ground floor*

Hole:

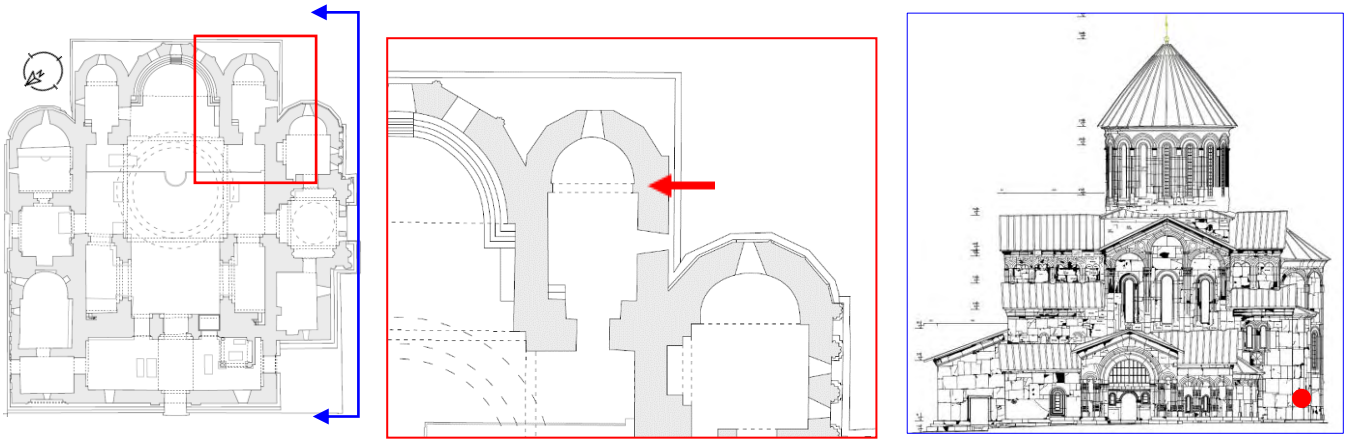
Diameter: 20 mm

Hole direction: horizontal

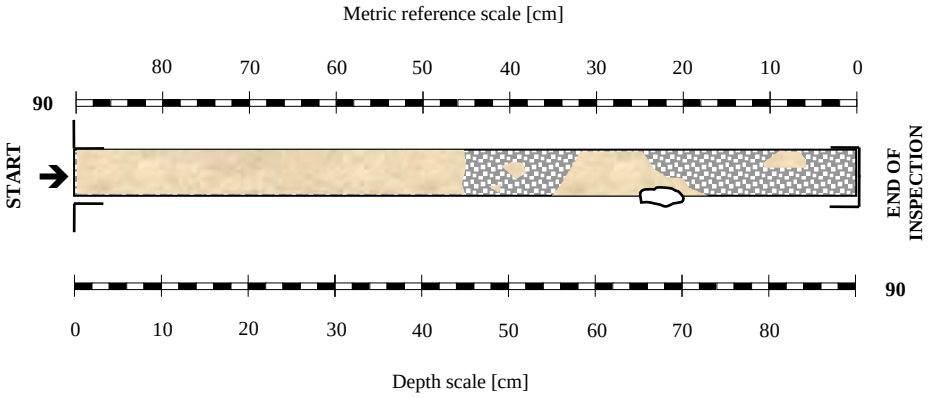
Length: 90 cm – Not passing

Distance from left: 80 cm

Height from the ground: 77 cm



Elevation



KEY

Mortar mix Limestone Cavity

Frames extrapolated from the video footage


Depth 0 cm (start)


Depth 5 cm


Depth 13 cm


Depth 21 cm


Depth 31 cm


Depth 39 cm

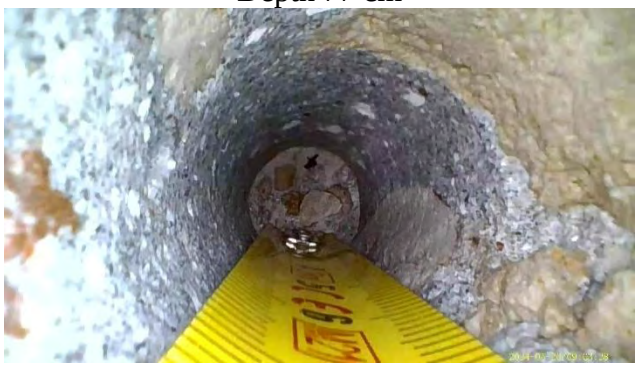

Depth 45 cm


Depth 53 cm


Depth 61 cm


Depth 77 cm


Depth 84 cm


Depth 90 cm (end of inspection)

3.1.10. *Videoendoscopic investigation V-10 – Ground Floor*

***Structural element**: Perimeter wall*

***Location**: Ground floor*

Hole:

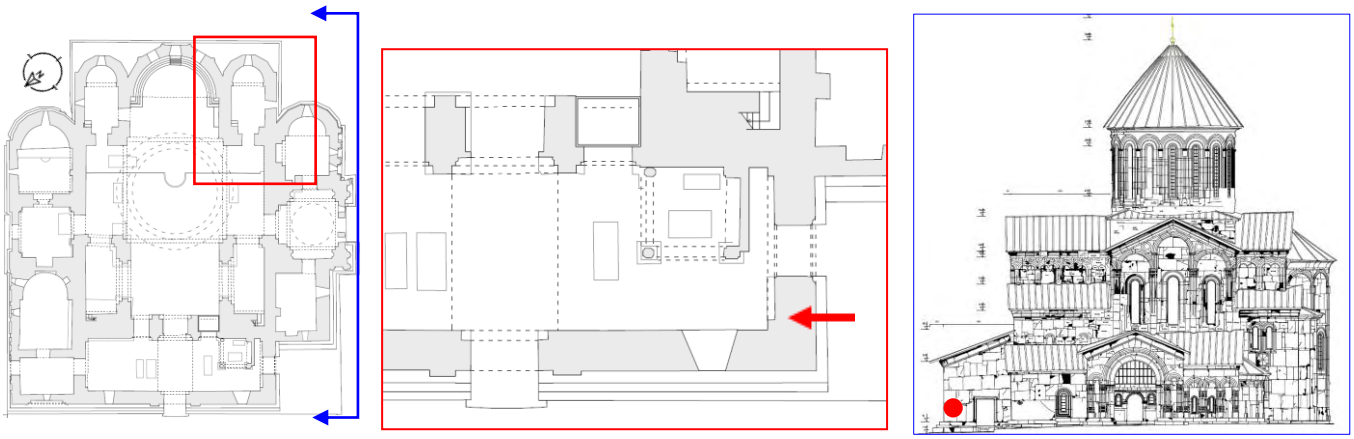
Diameter: 20 mm

Hole direction: horizontal

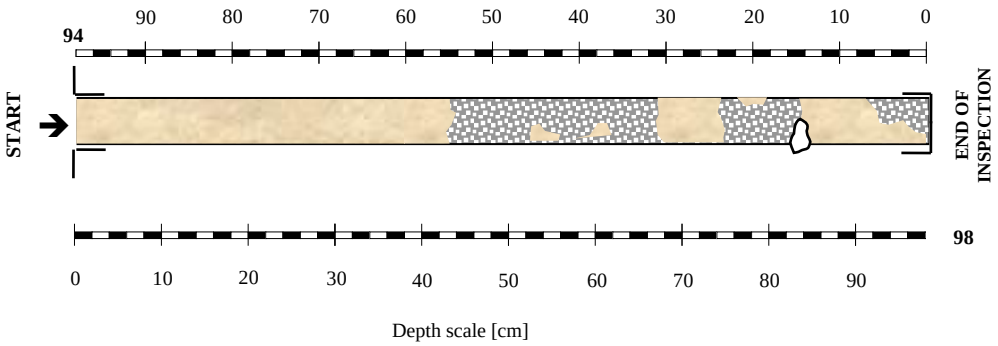
Length: 98 cm – Not passing

Distance from left: 55 cm

Height from the ground: 125 cm



Elevation



KEY

Mortar mix Limestone Cavity

Frames extrapolated from the video footage


Depth 0 cm (start)


Depth 10 cm


Depth 18 cm


Depth 27 cm


Depth 35 cm


Depth 43 cm


Depth 52 cm


Depth 61 cm


Depth 70 cm


Depth 76 cm


Depth 84 cm


Depth 98 cm (end of inspection)

4. CONCLUSIONS

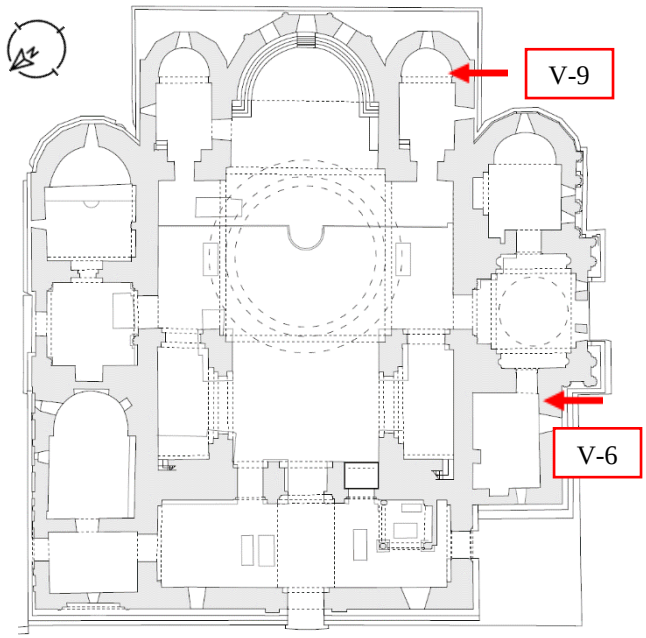
The structural investigation campaign conducted on the masonry of "Church of the Nativity of the Virgin", which is the main church within the Gelati Monastery complex in Kutaisi, Georgia, included the following activities:

INVESTIGATIONS ON STRUCTURES	
n. 8	**MORTAR SAMPLES AND LABORATORY ANALYSIS**
n. 6	**MICROSEISMIC – SONIC INVESTIGATIONS ON MASONRY**
n. 10	**VIDEOENDOSCOPIC INVESTIGATIONS**

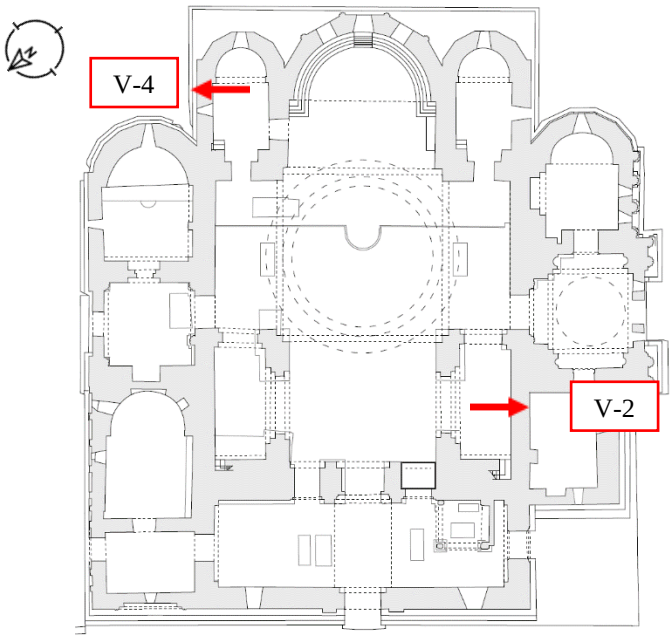
Through the videoendoscopic investigations, carried out on the wall elements, it was possible to establish that the masonry structure is a three-layered one: the two external faces, made of limestone blocks, enclose an internal less regular layer made of mortar and limestone fragments end irregular smaller blocks.

The limestone blocks that form the external layer of the perimeter walls have been examined on the ground floor and are found to have a thickness ranging from 34 cm to 52 cm. The blocks of the internal face of the walls have a reduced thickness, between 22 cm and 32 cm, as do the blocks that constitute the faces of the walls that divide the interior spaces of the first floor.

The videoendoscopies V-6, V-9 and V-2, V-4 are shown here as an example.



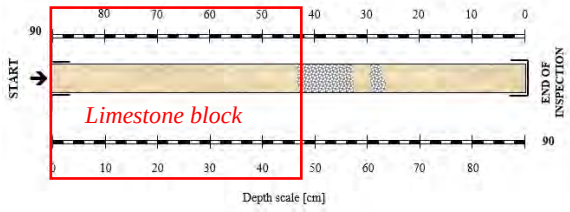
Ground Floor



First Floor

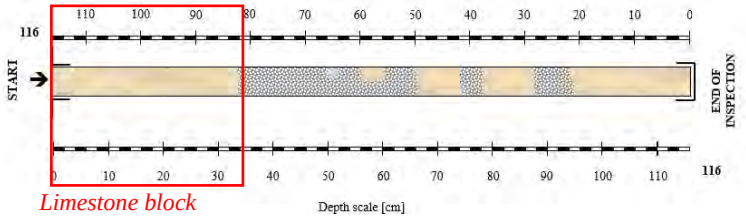
V-6

Metric reference scale [cm]



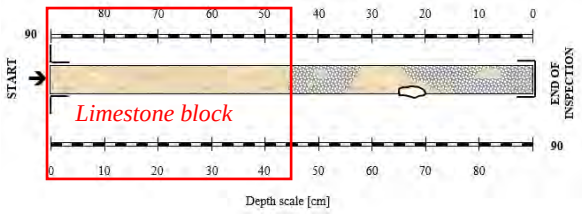
V-2

Metric reference scale [cm]



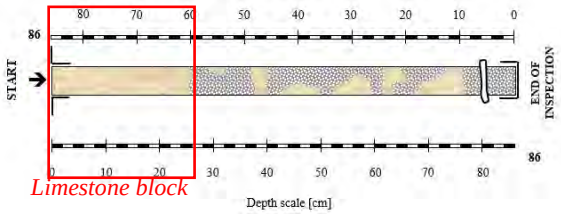
V-9

Metric reference scale [cm]

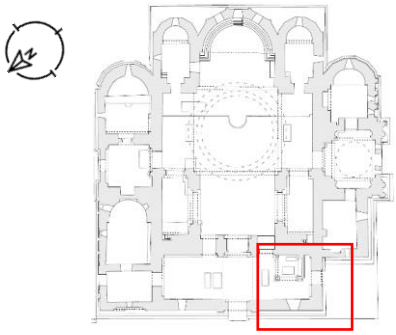


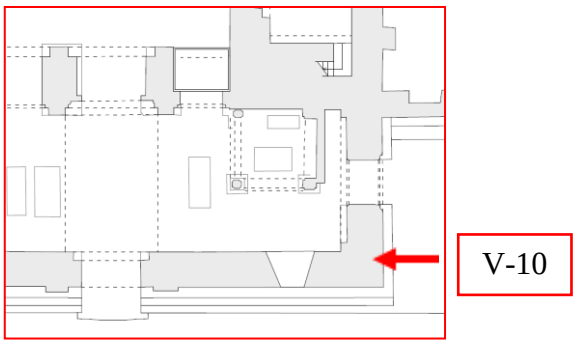
V-4

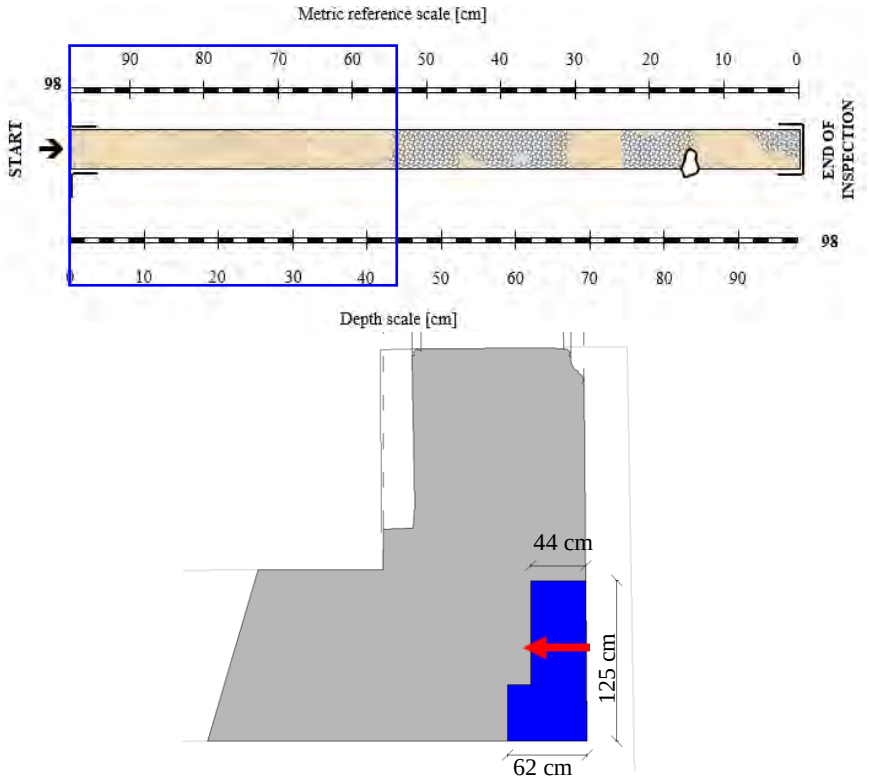
Metric reference scale [cm]



The videoendoscopic investigation V10 has affected the external wall, right close to the east corner of the building.

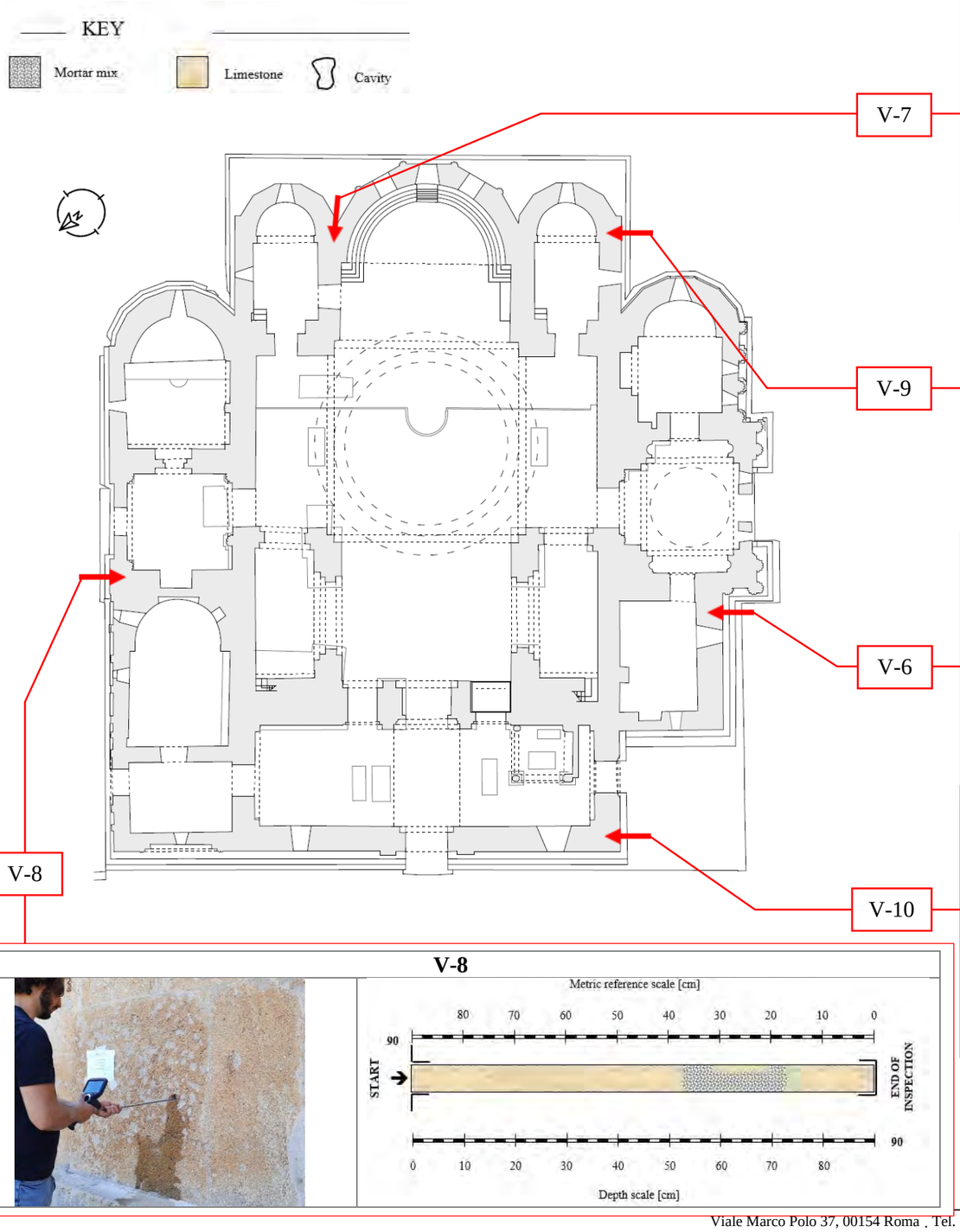


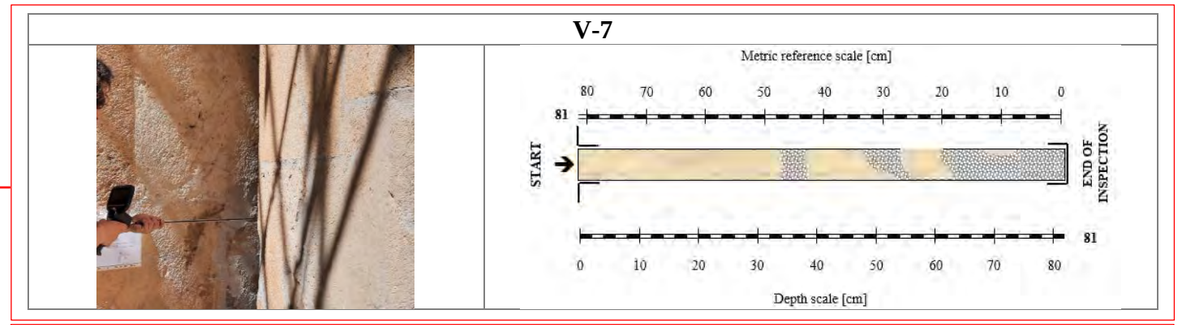


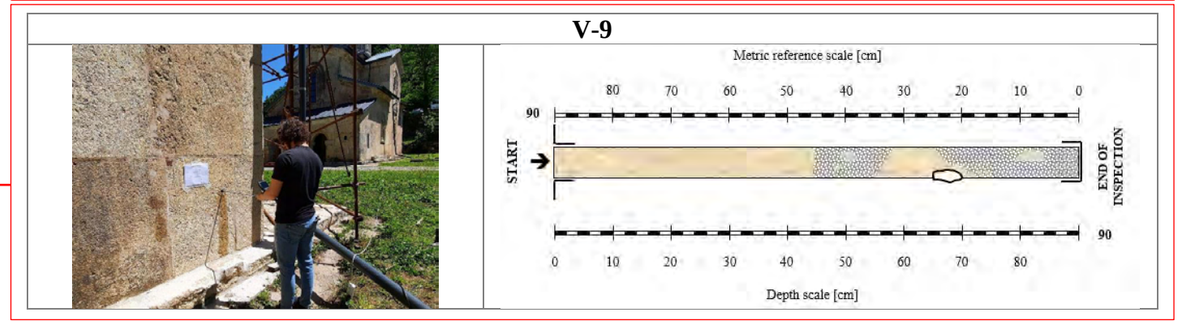


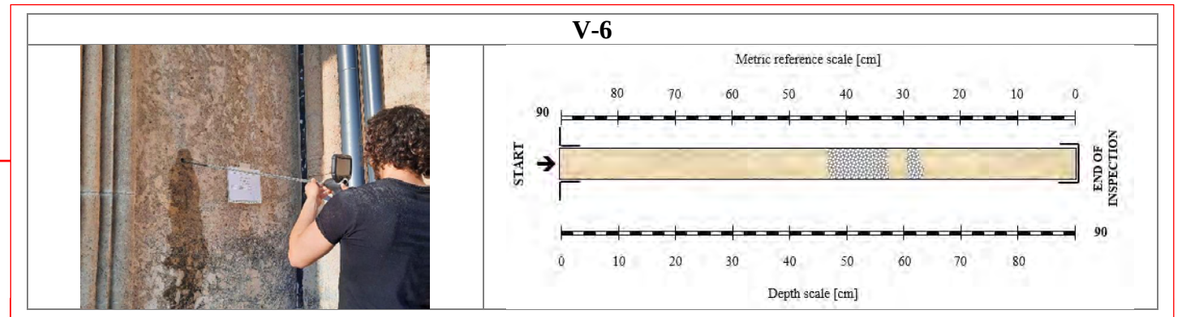
The test allowed us to verify that the external corner block, which is visible from outside and constitutes the external face of the three-layered masonry, has an L shape.

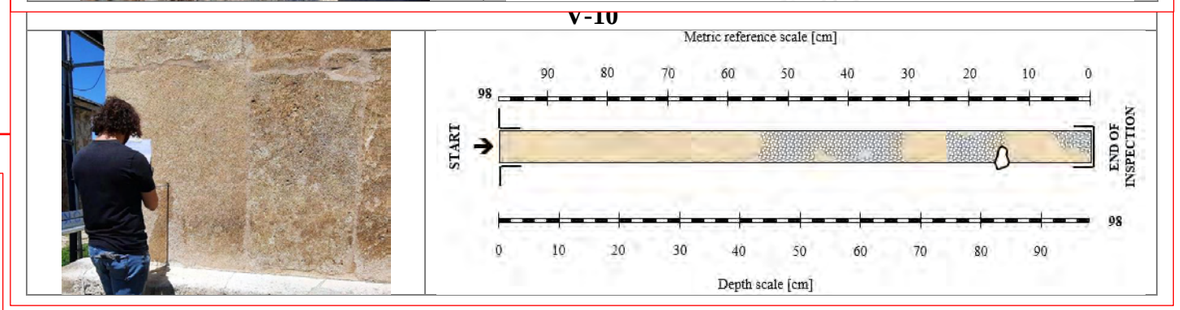
4.1.1. *Overview – Videoendoscopic investigations – GROUND FLOOR*



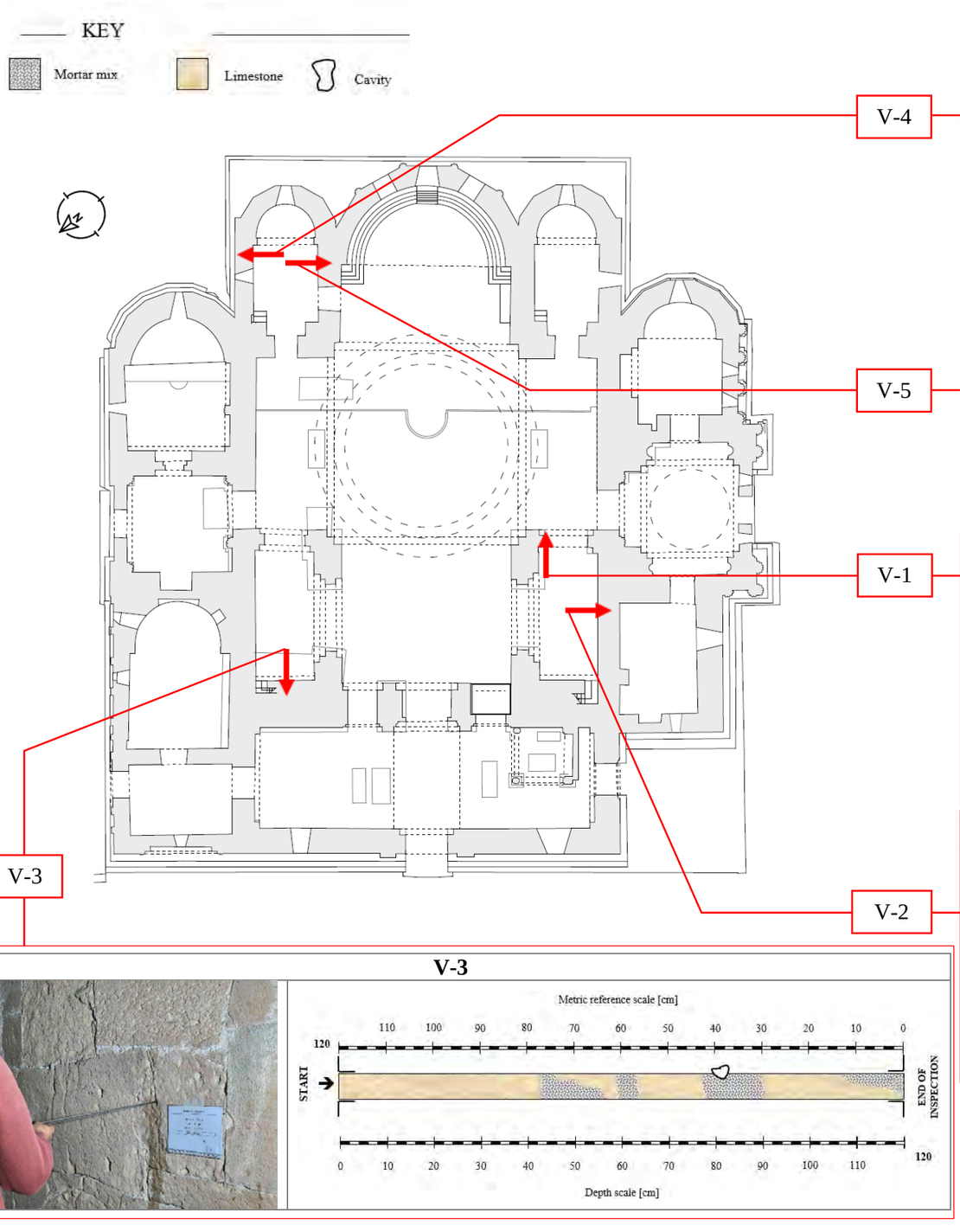




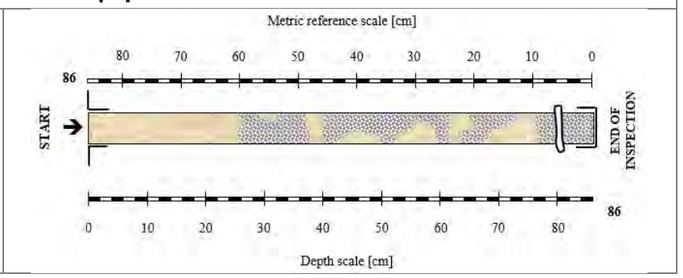




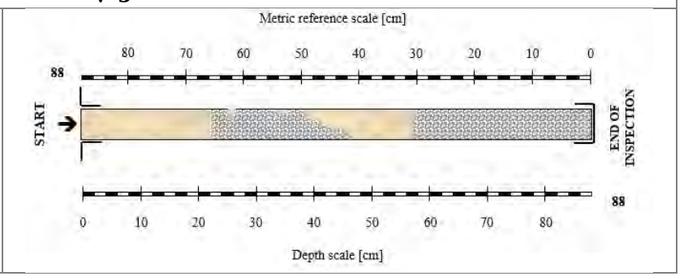
4.1.2. ***Overview – Videoendoscopic investigations – 1° FLOOR***



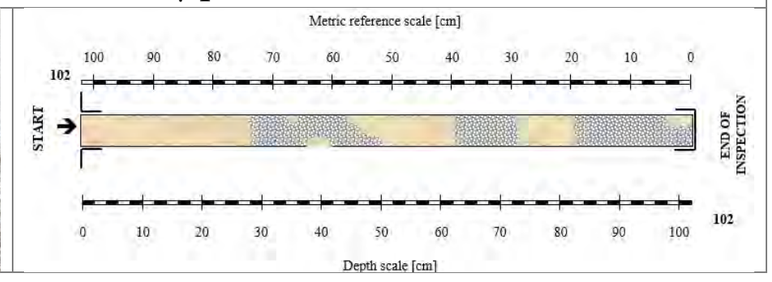
V-4



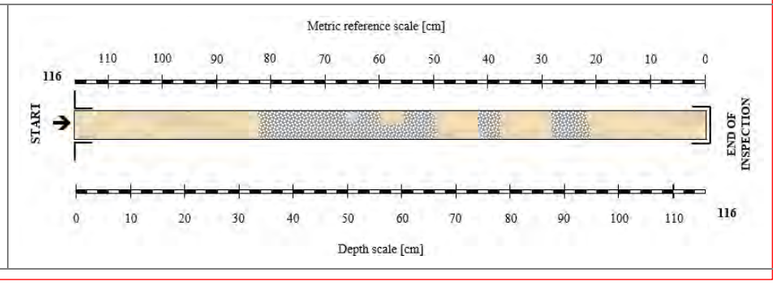
V-5



V-1



V-2



V-3

The internal layer of the masonry, enclosed between the 2 layers of square limestone blocks, appears to be generally compact, with a few rare cavities.
In order to characterize the mixture used as a binder in the wall structure, n. 7 mortar samples were analyzed. The mineralogical-petrographic and chemical-instrumental study of the samples taken was carried out at the laboratories of Pro Arte s.n.c, specialized in this field.
The aforementioned investigations allowed the characterization of the matrix, the determination of the type and composition of the aggregates, the type of mixture, the evaluation of the state of conservation and the grain size distribution.
The analyses showed that the samples consist of a mixture of whitish mortar based on carbonated aerial lime and predominantly silicate sand.
The sizes of the aggregates range is between 1.4 mm and 0.04 mm with a prevalence of medium-fine arenaceous fractions.
The mixture shows medium-high porosity (over 22%) both primary and secondary. The matrix is mostly heterogeneous due to the presence of calcareous fragments (calcinaroli).

As regards the mechanical characteristics of the mortar, in addition to the samples taken to determine the composition of the material, 1 sample of mortar was selected and used to obtain a specimen to be subjected to a compression test.

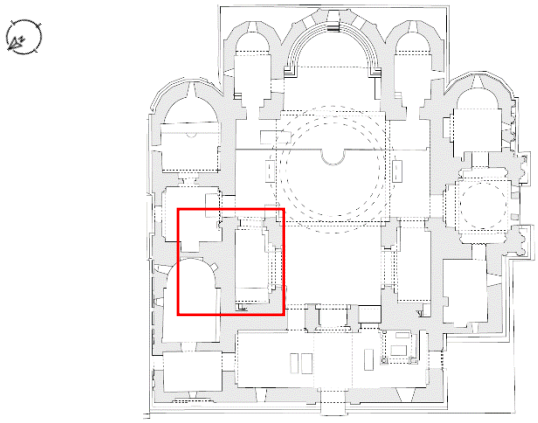
The test was carried out at the "testing and materials laboratory" of the Faculty of Engineering of the University of Rome - La Sapienza.

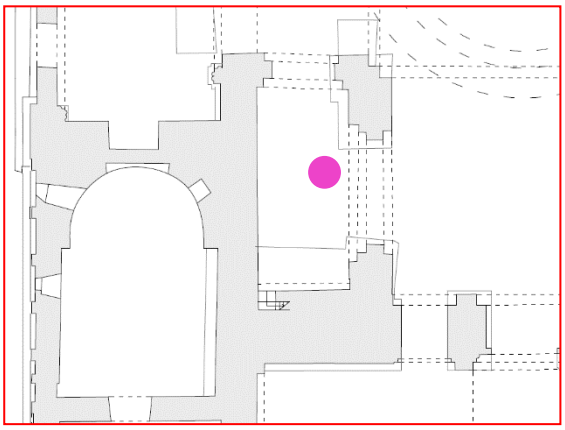
The test results are summarized in the following table:

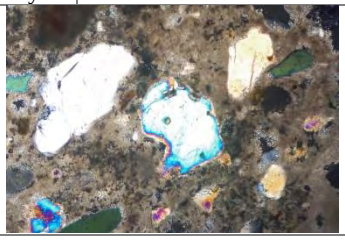
Sample	**Material**	**R/C (1)**	**High**	**Base**		**Density**	**Compression strength.**
			[mm]	**[mm]**	**[mm]**	**[kg/m^3]**	**[MPa]**
M-6.2	Mortar	R	39	41	39	1462	4.2

(1)R= Sample rectified by face levelling
C= Sample rectified by capping

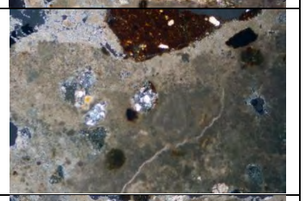
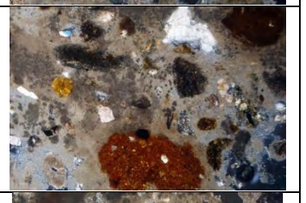
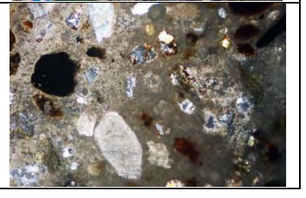
Part of the sample, extracted from the attic, on the North side vault, was also subjected to mineralogical-petrographic and chemical-instrumental tests, which have shown that it's composed by whitish mortar based on carbonated aerial lime and sand, exclusively of silicate nature composed of quartz, feldspar, and silicate claystone.



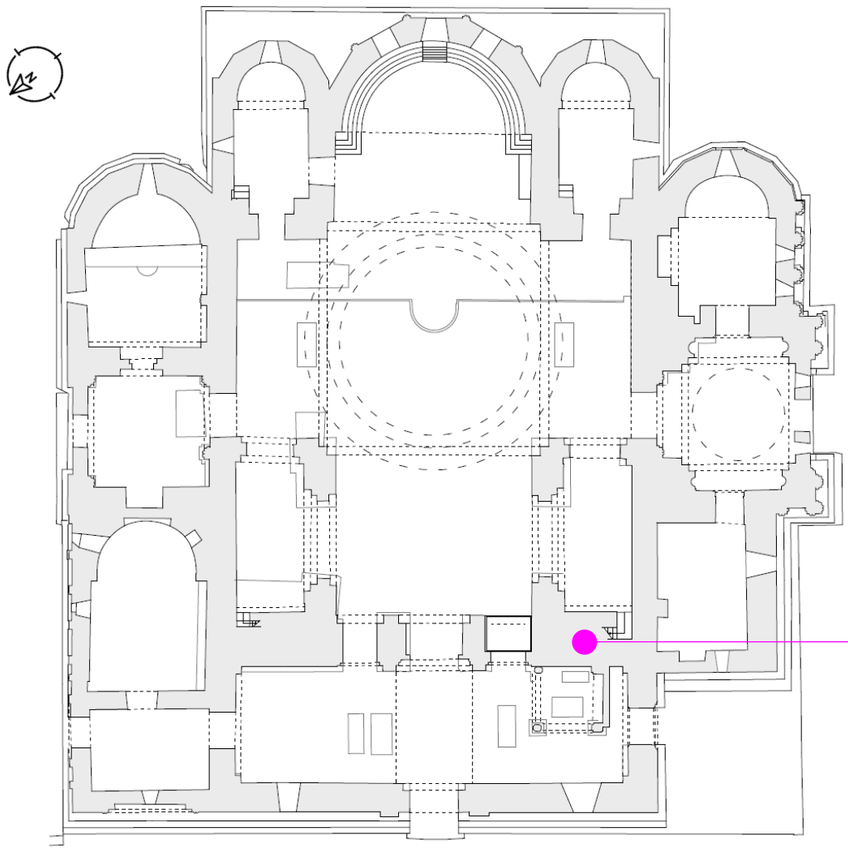


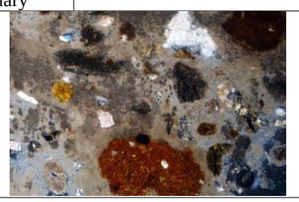
P-6.1		
Description	**Aggregate**	**Matrix**
Whitish mortar based on carbonated aerial lime and sand, exclusively of silicate nature composed of quartz, feldspar, and silicate claystone	Between 1.4 mm e 0.05 mm with a prevalence of the medium-coarse arenaceous fraction.	Heterogeneous due to the presence of calcareous fragments (calcinaroli) - Carbonated aerial lime
Areal ratio aggregates/paste binder	**Porosity**	**State of conservation**
3/1	Medium (22%) Both primary and secondary	Well preserved
		

4.1.3. ***Summary table - Laboratory analysis performed on the samples of mortar***

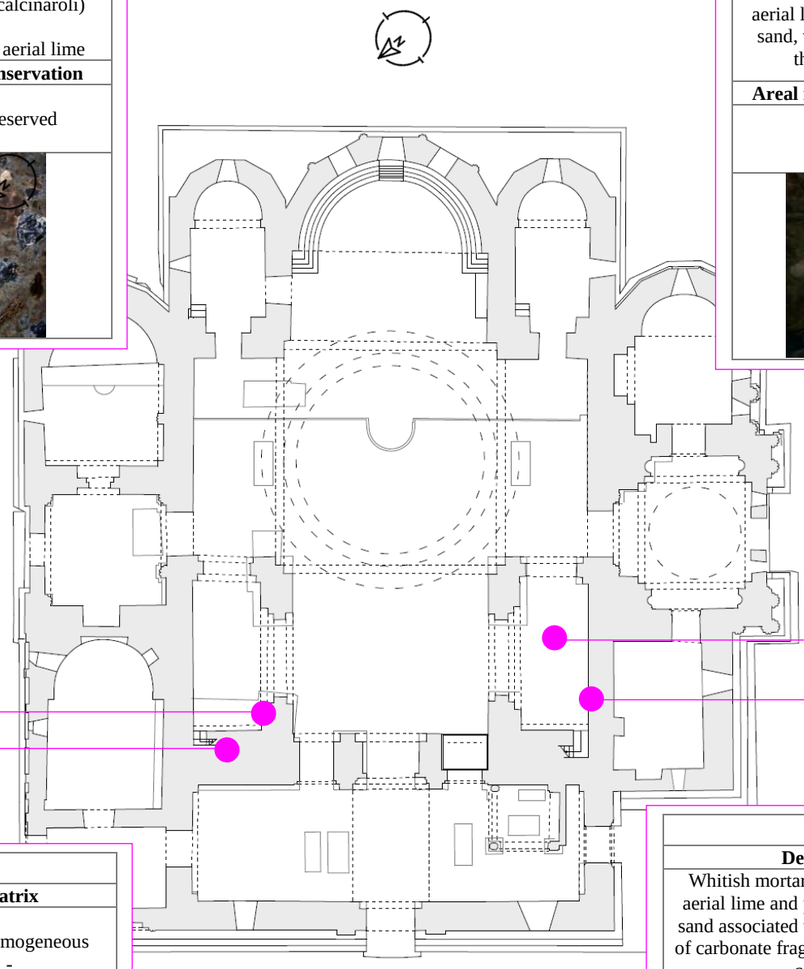
TEST	LOCATION	DESCRIPTION	AGGREGATES	POROSITY	MATRIX	CONSERVATION	THIN SECTION
P-01	1° Floor	Whitish mortar based on *carbonated aerial lime* and predominantly *silicate sand* associated with small percentages of carbonate fragments and cocciopesto concrete.	between 1.2 mm e 0.05 mm with a prevalence of medium-fine arenaceous fractions	Medium (24%) Both primary and secondary	Heterogeneous due to the presence of calcareous fragments (calcinaroli) - Carbonated aerial lime	poorly preserved	
P-02	1° Floor	Whitish mortar based on *carbonated aerial lime* and predominantly *silicate sand*, with about 1/4 carbonate, with the addition of cocciopesto	between 1.3 mm e 0.04 mm with a prevalence of medium-fine arenaceous fractions	Medio-high (26%) Both primary and secondary	Heterogeneous due to the presence of calcareous fragments (calcinaroli) - Carbonated aerial lime	moderately preserved	
P-03	1° Floor	Whitish mortar based on *carbonated aerial lime* mixed with *river-alluvial sand*, mostly of *silicate* nature and to a lesser extent carbonate, composed of quartz, silicate claystone fragments, carbonate fragments, sandstone, mica, and feldspar	between 0.45 mm e 0.04 mm with a prevalence of the fine arenaceous fraction.	High (28 %) Both primary and secondary	Fairly homogeneous - Carbonated aerial lime	poorly preserved	
P-04	1° Floor	Whitish mortar based on *carbonated aerial lime* mixed with *river-alluvial sand*, mostly of *silicate* nature and to a lesser extent carbonate, composed of quartz, silicate claystone fragments, carbonate fragments, sandstone, mica, and feldspar.	between 0.48 mm e 0.04 mm with a prevalence of the fine arenaceous fraction.	Medium-High (25%) Both primary and secondary	Heterogeneous due to the presence of calcareous fragments (calcinaroli) - Carbonated aerial lime	fairly preserved	
P-05	Ground Floor	Whitish mortar based on *carbonated aerial lime* and *sand*, mostly of *silicate* nature and to a lesser extent carbonate, composed of silicate claystone fragments, carbonate fragments, sandstone, quartz, and mica. A significant percentage of cocciopesto has been added to the sand.	between 0.45 mm e 4.9 mm with a prevalence of the fine arenaceous fraction.	High (27%) Both primary and secondary	Heterogeneous due to the presence of calcareous fragments (calcinaroli) - Carbonated aerial lime	moderately preserved	
P-06	Attic	Whitish mortar based on *carbonated aerial lime* and *sand*, exclusively of *silicate* nature composed of quartz, feldspar, and silicate claystone	between 1.4 mm e 0.05 mm with a prevalence of the medium-coarse arenaceous fraction.	Medium (22%) Both primary and secondary	Heterogeneous due to the presence of calcareous fragments (calcinaroli) - Carbonated aerial lime	well preserved	
P-07	Attic	Whitish mortar based on *carbonated aerial lime* and *river-alluvial sand*, mostly of silicate nature and to a lesser extent carbonate, composed of silicate claystone fragments, quartz, carbonate fragments, sandstone, mica, and feldspar.	between 1.3 mm e 0.04 mm with a prevalence of the medium arenaceous fraction.	Medium (22%) Both primary and secondary	Heterogeneous due to the presence of calcareous fragments (calcinaroli) - Carbonated aerial lime	fairly preserved	

4.1.4. ***Overview - Laboratory analysis performed on the samples of mortar – GROUND FLOOR***



P-5		
Description	**Aggregate**	**Matrix**
Whitish mortar based on carbonated aerial lime and sand, mostly of silicate nature and to a lesser extent carbonate, composed of silicate claystone fragments, carbonate fragments, sandstone, quartz, and mica. A significant percentage of cocciopesto has been added to the sand.	Between 0.45 mm e 4.9 mm with a prevalence of the fine arenaceous fraction.	Heterogeneous due to the presence of calcareous fragments (calcinaroli) - Carbonated aerial lime
Areal ratio aggregates/paste binder	**Porosity**	**State of conservation**
2/1	High (27%) Both primary and secondary	Moderately preserved
		

4.1.5. *Summary table - Laboratory analysis performed on the samples of mortar – FIRST FLOOR*

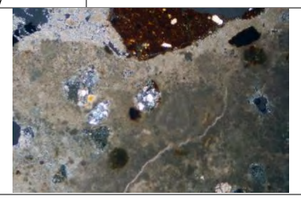


P-4

Description	Aggregate	Matrix
Whitish mortar based on carbonated aerial lime mixed with fluvio-alluvial sand, mostly of silicate nature and to a lesser extent carbonate, composed of quartz, silicate claystone fragments, carbonate fragments, sandstone, mica, and feldspar.	range is between 0.48 mm e 0.04 mm with a prevalence of the fine arenaceous fraction.	Heterogeneous due to the presence of calcareous fragments (calcinaroli) - Carbonated aerial lime
Areal ratio aggregates/paste binder	**Porosity**	**State of conservation**
2/1	Medium-High (25%) Both primary and secondary	fairly preserved

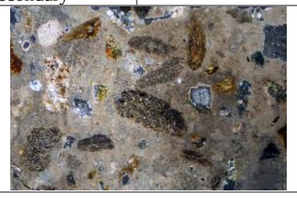
P-2

Description	Aggregate	Matrix
Whitish mortar based on carbonated aerial lime and predominantly silicate sand, with about 1/4 carbonate, with the addition of cocciopesto	between 1.3 mm e 0.04 mm with a prevalence of medium-fine arenaceous fractions	Heterogeneous due to the presence of calcareous fragments (calcinaroli) - Carbonated aerial lime
Areal ratio aggregates/paste binder	**Porosity**	**State of conservation**
1.5-2/1	Medio-high (26%) Both primary and secondary	moderately preserved

P-3

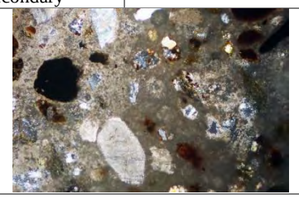
Description	Aggregate	Matrix
Whitish mortar based on carbonated aerial lime mixed with fluvio-alluvial sand, mostly of silicate nature and to a lesser extent carbonate, composed of quartz, silicate claystone fragments, carbonate fragments, sandstone, mica, and feldspar	between 0.45 mm e 0.04 mm with a prevalence of the fine arenaceous fraction.	Fairly homogeneous - Carbonated aerial lime
Areal ratio aggregates/paste binder	**Porosity**	**State of conservation**
1.5/1	High (28 %) Both primary and secondary	poorly preserved

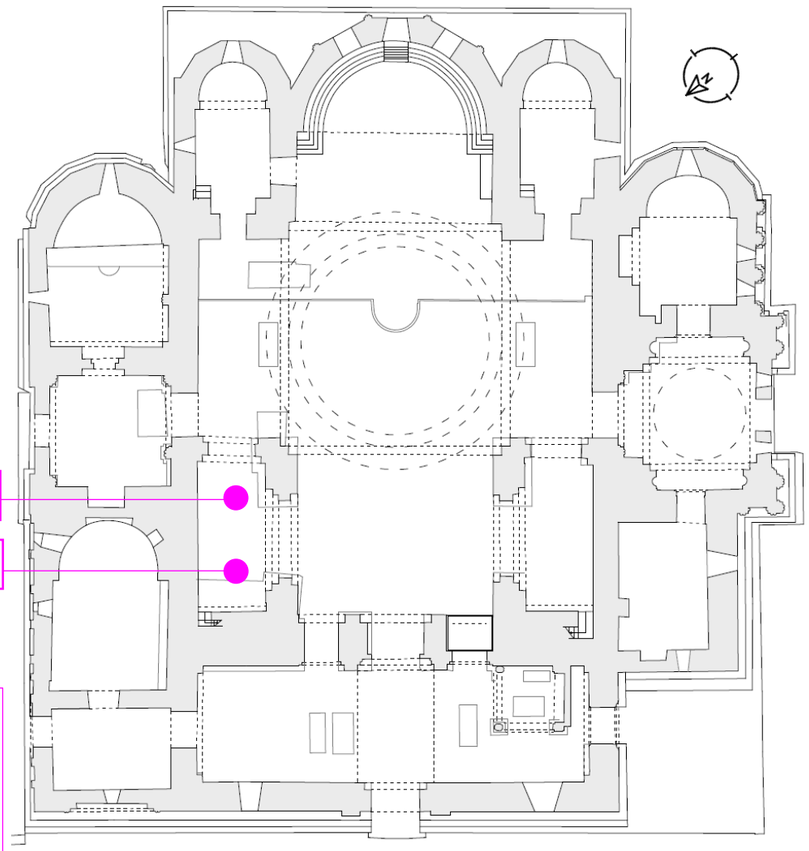



P-1

Description	Aggregate	Matrix
Whitish mortar based on carbonated aerial lime and predominantly silicate sand associated with small percentages of carbonate fragments and cocciopesto concrete.	Between 1.2 mm e 0.05 mm with a prevalence of medium-fine arenaceous fractions	Heterogeneous due to the presence of calcareous fragments (calcinaroli) - Carbonated aerial lime
Areal ratio aggregates/paste binder	**Porosity**	**State of conservation**
2/1	Medium (24%) Both primary and secondary	Poorly preserved


4.1.6. *Summary table - Laboratory analysis performed on the samples of mortar – ATTIC (north side vault)*

P-7		
Description	**Aggregate**	**Matrix**
Whitish mortar based on carbonated aerial lime and river-alluvial sand, mostly of silicate nature and to a lesser extent carbonate, composed of silicate claystone fragments, quartz, carbonate fragments, sandstone, mica, and feldspar.	Between 1.3 mm e 0.04 mm with a prevalence of the medium arenaceous fraction.	Heterogeneous due to the presence of calcareous fragments (calcinaroli) - Carbonated aerial lime
Areal ratio aggregates/paste binder	**Porosity**	**State of conservation**
2.5/1	Medium (22%) Both primary and secondary	Fairly preserved
		



P-6.1		
Description	**Aggregate**	**Matrix**
Whitish mortar based on carbonated aerial lime and sand, exclusively of silicate nature composed of quartz, feldspar, and silicate claystone	Between 1.4 mm e 0.05 mm with a prevalence of the medium-coarse arenaceous fraction.	Heterogeneous due to the presence of calcareous fragments (calcinaroli) - Carbonated aerial lime
Areal ratio aggregates/paste binder	**Porosity**	**State of conservation**
3/1	Medium (22%) Both primary and secondary	Well preserved
		

Through the sonic investigations, carried out using the so-called "transparency" technique, it was possible to determine the value of the longitudinal wave propagation velocity through the thickness of the masonry elements.

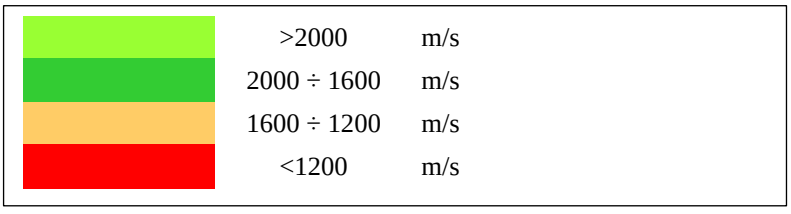
By measuring the velocity, it was possible to carry out a comparative analysis of the state of degradation and homogeneity of the masonry.

N. 6 areas were investigated.

The data collected and processed are presented below both in tables and graphical form.

In the graphical display we refer to a chromatic representation of the recorded velocity values, which allows an immediate vision of any non-uniformity of the mechanical characteristics within the structural element.

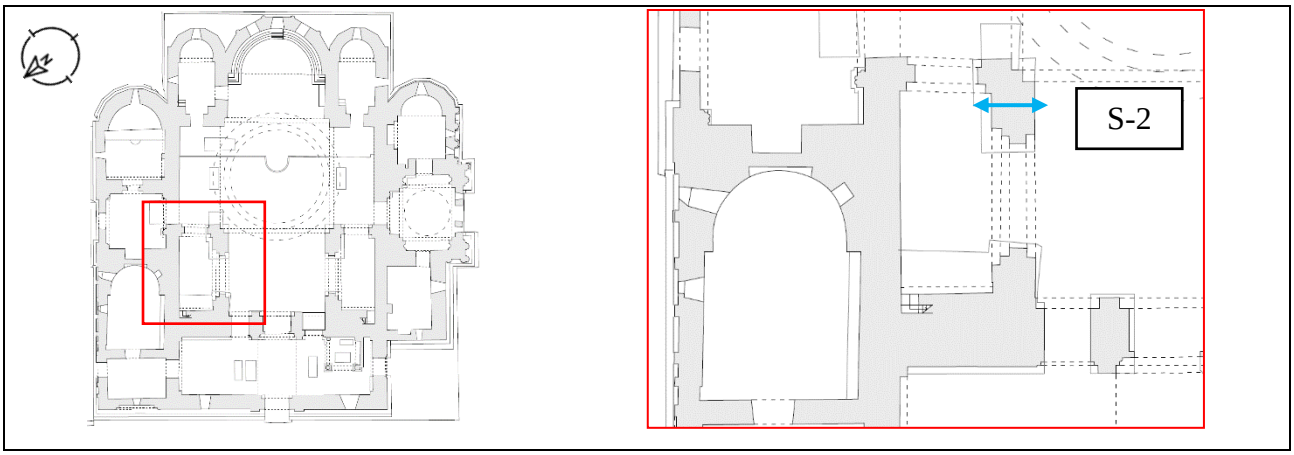
n.	Height	Thickness	Vm	σ	σ/Vm
	[cm]	[cm]	[m/s]	[m/s]	[%]
S1	97	130	2000	310	15.5
S2	24	147	2196	189	8.6
S3	94	71	1881	276	14.7
S4	130	135	1984	291	14.7
S5	50	65	1815	298	16.4
S6	50	65	1023	33	3.2

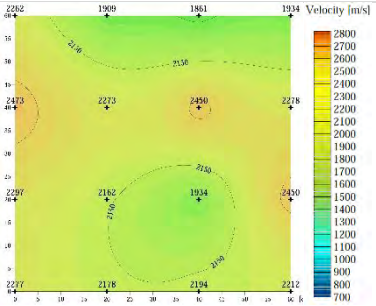
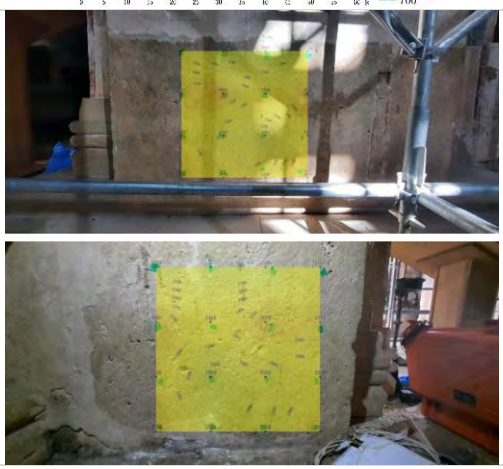


The velocity values detected are, in most cases, around 2000 m/s and are an indication of homogeneous masonry, which does not present particular internal defects and irregularities.

The high value of the percentage ratio between the standard deviation (σ) and the average velocity (Vm), observed in most of the tests, is related to substantial differences in compactness and the mechanical characteristics existing between the limestone blocks and the internal mortar mix.

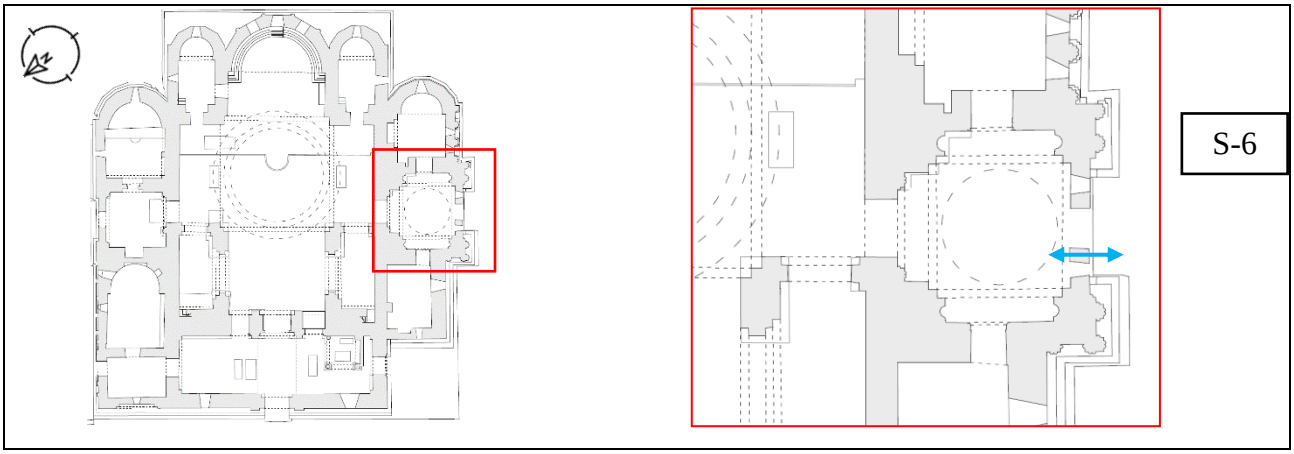
The sonic test S-2 performed on the pillar provided the highest average velocity value of 2303 m/s which are typical values of a masonry with good characteristics.

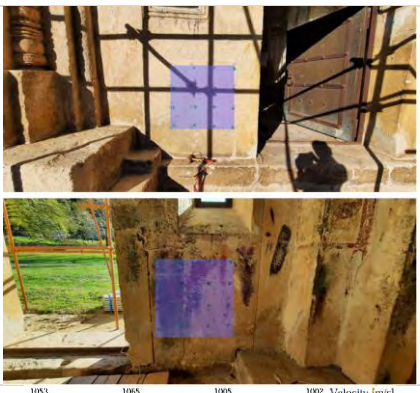
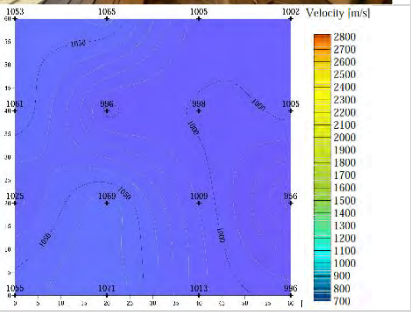


	S2
Thickness	147
V_m [m/s]	2196
σ [m/s]	189
σ/V_m [%]	8.6
Color maps	
Location	

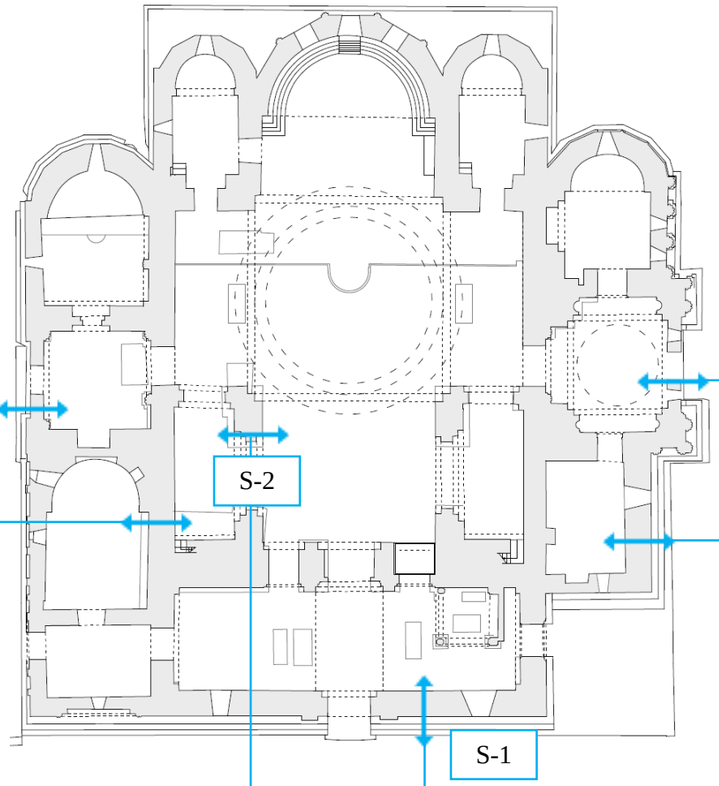
From the results of the sonic investigations it is possible to see how the lowest values of the velocity propagation were recorded by the S-6 test.

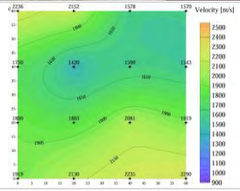
The masonry investigated therefore presents less performing characteristics.

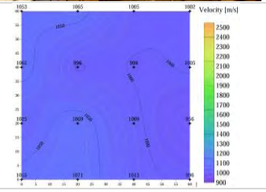


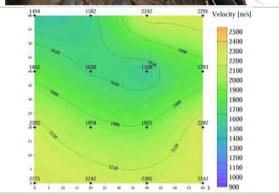
	S6
Thickness	65
V_m [m/s]	1023
σ [m/s]	33
σ/V_m [%]	3.2
Location	
Color maps	

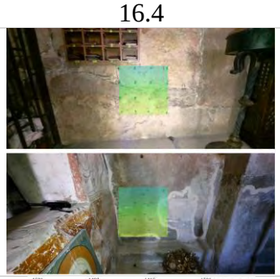
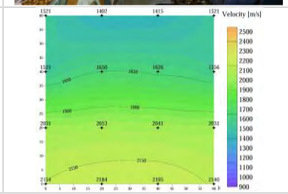
4.1.7. ***Overview - Microseismic – sonic investigations on masonry – GROUND FLOOR***

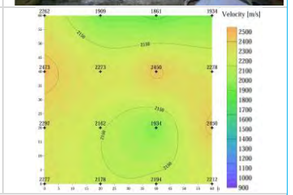


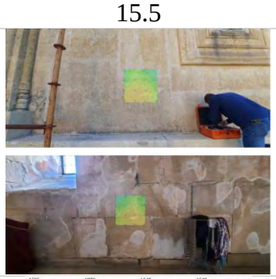
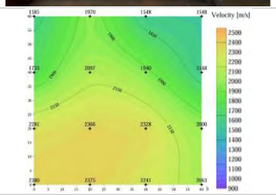
	S3
Thickness	71
V_m [m/s]	1881
σ [m/s]	276
σ/V_m [%]	14.7
Location	
Color maps	

	S6
Thickness	65
V_m [m/s]	1023
σ [m/s]	33
σ/V_m [%]	3.2
Location	
Color maps	

	S4
Thickness	135
V_m [m/s]	1984
σ [m/s]	291
σ/V_m [%]	14.7
Location	
Color maps	

	S5
Thickness	65
V_m [m/s]	1815
σ [m/s]	298
σ/V_m [%]	16.4
Location	
Color maps	

	S2
Thickness	147
V_m [m/s]	2196
σ [m/s]	189
σ/V_m [%]	8.6
Location	
Color maps	

	S1
Thickness	130
V_m [m/s]	2000
σ [m/s]	310
σ/V_m [%]	15.5
Location	
Color maps	

5. ANNEX

5.1. ANNEX 1 – TEST CERTIFICATE

DIPARTIMENTO DI INGEGNERIA STRUTTURALE E GEOTECNICA

SAPIENZA UNIVERSITÀ DI ROMA

Certificato nr. 2023-00206-E Pagina 1 di 1

DA ASSOGGETTARE A BOLLO IN CASO D'USO AI SENSI DEL D.P.R. 642/72

CERTIFICATO DI PROVA

RICHIEDENTE:
SPC Srl
VIALE MARCO POLO, 37
00154 ROMA - RM

Committente:
La richiesta NON riporta la firma del direttore dei lavori
Dati forniti dal richiedente:
Cantiere: Monastero di Gelati - Church of Virgin - Kutaisi - Georgia.
Campioni di: Prisma in malta.

DATA DI IMMISSIONE07/11/2023
Protocollo: 2023-00151-E Certificato: 2023-00206-E
DATA DI EMISSIONE: 14/12/2023

RISULTATI DELLE PROVE A COMPRESSIONE

N°	Dati forniti dal richiedente			Contrassegno rilevato sul provino	Dimensioni [mm]			Data di prova	Massa vol. [kg/m³]	Tens. di rottura [N/mm²]	TR
	Contrassegno	Data di prelievo	Classe di resistenza		a	b	h				
1	M6_2			M6_2	39	41	39	07/12/23	1462	4.2	A

Note:
TR = Tipo Rottura, A = soddisfacente; B(x) = non soddisfacente; Tipo(x) vedi paragrafo8 fig. 2 della UNI EN 12390-3:2003
[N.D. Non dichiarato]

DIPARTIMENTO DI INGEGNERIA STRUTTURALE E GEOTECNICA SAPIENZA UNIVERSITÀ DI ROMA

Lo Sperimentatore
(Giuliano Manganozzi)

Il Direttore
Prof. Ing. Sebastiano Rampello

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