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MORTAR-TYPE IDENTIFICATION FOR THE PURPOSE OF RECONSTRUCTING FRAGMENTED ROMAN WALL PAINTINGS (CELJE, SLOVENIA)

ANALIZA OMETOV ZA REKONSTRUKCIJO FRAGMENTOV RIMSKIH STENSKIH POSLIKAV (CELJE, SLOVENIJA)

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Archaeological excavations of Roman Celeia (present-day Celje, Slovenia) carried out about 30 years ago revealed the remains of a Roman residential building where more than 9000 fragments of wall paintings were found. The past manual reassembling of fragments proved to be time consuming, limiting the amount of the material that can be examined and reconstructed. However, recently work has been resumed using a software application specifically developed for fragment reassembly. Information on mortar types can provide additional data about the fragments and thus help in the reconstruction process. Fragments of the wall paintings consist of up to three preserved mortar layers, differing in their thicknesses, aggregate compositions and binder colours. Based on the mineralogical/petrographic analyses of the mortars, the investigated fragments of the wall paintings were divided into several groups. The results revealed that the first-mortar-layer aggregates of all the fragments consist of carbonate grains, while the other-mortar-layer aggregates consist of carbonate, silicate/carbonate, silicate or silicate/ceramic grains.

Keywords: wall paintings, Roman mortars, petrography, reassembling, fragments

Arheološka izkopavanja rimske Celeie (današnje Celje) pred približno 30 leti so razkrila ostanke antičnega stanovanjskega objekta, v katerem je bilo najdenih več kot 9000 fragmentov stenskih poslikav. Sestavljanje takšnega števila fragmentov zahteva veliko časa. Nedavno je bila za sestavljanje fragmentov razvita posebna računalniška aplikacija. Informacije o sestavi malte se uporabljajo kot dodatni podatki pri sestavljanju fragmentov. Fragmente stenskih poslikav sestavljajo do tri ohranjene plasti ometov, ki se razlikujejo po debelini, sestavi agregata in barvi veziva. Analizirani fragmenti so bili na podlagi mineraloško-petrografskih preiskav razdeljeni v več skupin. Rezultati so pokazali, da pri vseh fragmentih zgornjo plast ometa sestavlja agregat iz karbonatnih zrn, medtem ko agregat spodnjih plasti sestavljajo bodisi karbonatna, silikatna/karbonatna, silikatna ali silikatna/keramična zrna.

Ključne besede: stenske poslikave, antični ometi, petrografija, sestavljanje, fragmenti

1 INTRODUCTION

The characterization of ancient wall paintings provides useful information about the painting technique and pigments used. Romans used lime of high purity, while aggregates most often contained siliceous sand, crushed marble and crushed ceramic.[1–3] A similar situation can be seen on the Roman wall paintings in Slovenia where, for instance, crushed carbonate grains are characteristic of the first mortar layer of the wall paintings from Roman Emona (today's Ljubljana), while in the lower mortar layers, besides silicate sand, grains of crushed ceramics also appear.[4] On the other hand, fluvial dolomite sand with an addition of crushed ceramic[5] or, in some cases, crushed marble prevails[6] in the wall-painting mortars of the Roman-villa rustica-bath complex near Mošnje.

Archaeological excavations in Celje in 1978 uncovered the remains of a Roman residential building from the first century A.D. where more than 9000 fragments of wall paintings were found. The elongated room of the residential building, measuring 4 m × 13 m, was heated with a hypocaust; the floors were decorated with a black-and-white mosaic with a simple rosette pattern, while the preserved walls were embellished with wall paintings.

Due to the large amount of fragments concentrated in the elongated room of the archaeological site, it is still unknown whether the fragments actually belonged to the Roman residential building or perhaps to a pit where the Romans deposited the material during a renovation process. The majority of the fragments are monochromatic (most often of white, red, green, blue, black or yellow colour), but on some of them various motifs such as animals, flowers and various patterns can be recognized. The pigments identified were Egyptian blue, vermilion, red ochre, yellow ochre and green earth,[7,8] which were all common pigments of the Roman period.[9,10] The excavated fragments were first transported to the Regional Museum in Celje and in 1989 to the Restoration Centre of the Institute for the Protection of Cultural Heritage of Slovenia. The manual reassembly process of the fragmented wall paintings performed 30 years ago proved to be time consuming and limiting the amount of the mate-

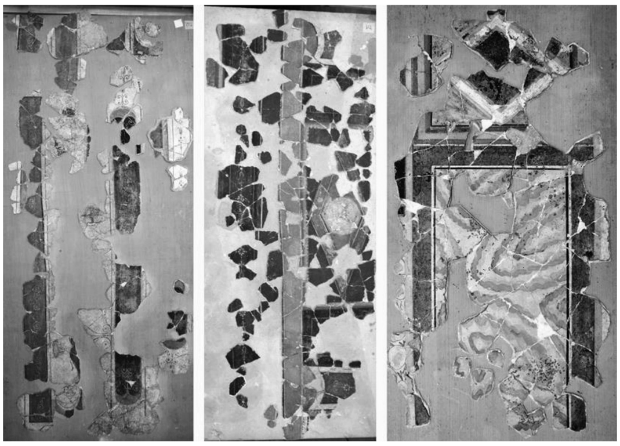

Figure 1: Wall paintings with various motifs reconstructed in 1989
Slika 1: Leta 1989 rekonstruirane stenske poslikave z različnimi motivi

Figure 3: Scanning a wall-painting fragment
Slika 3: Skeniranje fragmenta stenske poslikave

rial that could be examined and reconstructed. **Figure 1** shows three wall paintings reconstructed in 1989, measuring about 200 cm in length and 30 cm to 90 cm in width.

A total of 9521 fragments thus still remained disassembled and are now documented and stored in 166 boxes. Given the large scale of the fragments and a high quality of the wall paintings, a decision for a reconstruction of the wall paintings and a presentation of the remaining fragments was made. In June 2010, a systematic cleaning and consolidation of the fragments began. The fragments were consolidated using nanoparticles of calcium hydroxide (nanolime) which is compatible with the lime-mortar layers of the wall paintings.

Due to the large number of fragments, it is difficult to have a comprehensive overview of the entity of the excavated wall paintings, but fortunately several systems for a virtual reconstruction of the wall-painting fragments, such as the computer-assisted reassembly of the wall paintings from the Akrotiri excavations in Thera (Santorini), Greece[11] or the 3D reassembling of the parts of the wall paintings belonging to the Mycenaean civilization (c. 1300 BC), enabled us to overcome this problem.[12] Another advantage of a virtual reconstruction is also that it eliminates the physical contact with the fragments and thus prevents additional damage to the original pieces. Additionally, a system for a computer-assisted documentation and reassembling of the wall-painting fragments named Pedius[13] was developed especially for the Celje wall paintings.[14,15] Its online version, e-Pedius, is a newly developed computer program intended not only for restorers but also non-experts.

By means of the Pedius system, all the fragments were digitized (in 2D) and assigned a unique identification number (**Figure 2**). Capturing images of the fragments was carried out in two ways: with a scanner (**Figure 3**) or with a digital camera.

After the upload of the images in the database, a user can start an interactive assembling of the fragments (**Figure 4**). Since there is no need to manipulate the actual valuable fragments, the reassembling can also be performed by non-expert users. With the computer support, the assembling is much accelerated since the program provides some suggestions based on the colour of the surface, the lines, etc.

Figure 2: Fragment with an identification number
Slika 2: Fragment z identifikacijsko številko

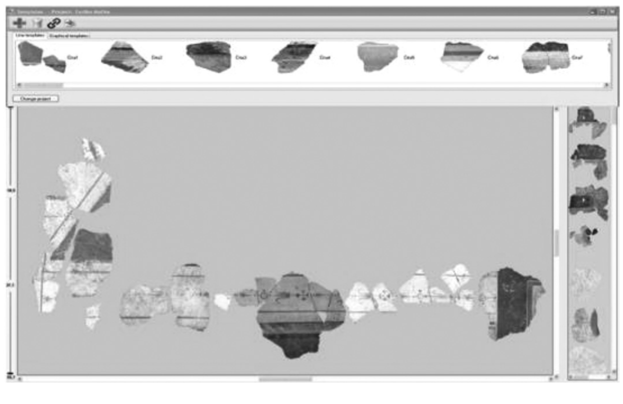

Figure 4: Example of interactive assembling of wall-painting fragments in Pedius
Slika 4: Zgled interaktivnega sestavljanja fragmentov stenskih poslikav v Pediusu

As the information on the mortar types can provide additional data about the fragments and help in the reconstruction process, the study deals with a mineralogical/petrographic characterization of the mortars of the Roman wall-painting fragments. The results obtained may not only help in the reconstruction of the fragmented wall paintings but also contribute new knowledge about Roman mortars and the technology of wall paintings in Slovenia and worldwide.

2 EXPERIMENTAL WORK

2.1 Materials

A total of thirty samples were selected among the fragments (**Table 1**). The fragments of the wall paintings consist of up to three preserved mortar layers that vary in their thicknesses, aggregates and binder colours.

2.2 Methods

In order to characterise the textures of the mortars and define the contents of particular aggregate components, the content of the binder and their ratios, our first approach was to examine thin sections of the fragments by means of optical microscopy. Polished thin sections of the mortar samples were studied with light microscopy using an Olympus BX-60 equipped with a digital camera (Olympus JVC3-CCD).

Raman spectra of the studied areas of the polished thin sections of the samples were obtained with a Horiba Jobin Yvon LabRAM HR800 Raman spectrometer equipped with an Olympus BXFM light microscope. Measurements were made using a laser-excitation line 785 nm, and a Leica 50× objective. The spectral resolution was about 1 cm^{-1}.

Table 1: Groups of analyzed samples
Tabela 1: Skupine analiziranih vzorcev

I. White binder of 1^{st} layer			
Group	Subgroup	Composition	Sample
A – 1^{st} layer thickness: 2–5 mm	A – 1	1^{st} layer: Carbonate grains 2^{nd} layer: Carbonate grains 3^{rd} layer: Silicate grains	HTM 9, HTM 12, HTM 21
	A – 2	1^{st} layer: Carbonate grains 2^{nd} layer: Carbonate grains 3^{rd} layer: Silicate grains (with ceramic grains)	HTM 16, HTM 47, HTM 48
	A – 3	1^{st} layer: Carbonate grains 2^{nd} layer: Silicate grains 3^{rd} layer: Silicate grains	HTM 6, HTM 7, HTM 8, HTM 11, HTM 14, HTM 45, HTM 50, HTM 53
	A – 4	1^{st} layer: Carbonate grains 2^{nd} layer: Carbonate grains : Silicate grains = 2 : 1 3^{rd} layer: Silicate grains (with ceramic grains)	HTM 17, HTM 20
	A – 5	1^{st} layer: Carbonate grains 2^{nd} layer: Carbonate grains : Silicate grains = 2 : 1 3^{rd} layer: Silicate grains	HTM 49, HTM 52
	A – 6	1^{st} layer: Carbonate grains 2^{nd} layer: Silicate grains (with ceramic grains) 3^{rd} layer: Silicate grains (with ceramic grains)	HTM 46
B – 1^{st} layer thickness: 6–10 mm	B – 1	1^{st} layer: Carbonate grains 2^{nd} layer: Carbonate grains 3^{rd} layer: Silicate grains	HTM 13
	B – 2	1^{st} layer: Carbonate grains 2^{nd} layer: Silicate grains	HTM 10, HTM 15
	B – 3	1^{st} layer: Carbonate grains 2^{nd} layer: Silicate grains 3^{rd} layer: Silicate grains (with ceramic grains)	HTM 18
	B – 4	1^{st} layer: Carbonate grains 2^{nd} layer: Silicate grains (with ceramic grains)	HTM 19
II. Red binder of 1^{st} layer			
C – 1^{st} layer thickness: 2–5 mm	C – 1	1^{st} layer: Carbonate grains 2^{nd} layer: Carbonate grains 3^{rd} layer: Silicate grains	HTM 51, HTM 54
	C – 2	1^{st} layer: Carbonate grains 2^{nd} layer: Carbonate grains 3^{rd} layer: Carbonate grains	HTM 58
	C – 3	1^{st} layer: Carbonate grains (calcite) 2^{nd} layer: Silicate grains	HTM 55
	C – 4	1^{st} layer: Carbonate grains (calcite) 2^{nd} layer: Carbonate grains : Silicate grains = 2 : 1	HTM 56, HTM 57

3 RESULTS AND DISCUSSION

Each fragment has a multilayered structure typical for the wall paintings that consist of two or three separate mortar layers followed by the paint layer (**Figure 5**). As seen in **Table 1**, the first mortar layer (from the top outer layer) always contains a white carbonate aggregate but varies in the binder colour and layer thickness (the latter could vary between 2 mm and 10 mm). The aggregate of the second mortar layer, which is normally between 5 mm and 16 mm, most often consists of carbonate grains, followed by silicate grains or even a mixture of the two. Furthermore, the third mortar layer (the inner layer), with a thickness of up to 30 mm, mainly consists of silicate grains, sometimes with an addition of crushed ceramics. What binds them is the air lime or, in the cases of ceramic grains, the hydraulic binder and air lime. Lime lumps were present in all the samples from all the mortar layers, and they varied in size from 0.2 mm to 3 mm. Fissures were observed in most of the lower-layer samples with a silicate-sand aggregate, while the upper outer layers with carbonate grains were generally more compact.

The fragments were divided into two main groups based on the binder colour of the first mortar layer: (I) the fragments with white binder (most frequent – 24 fragments) and (II) the fragments with red binder (rare – 6 fragments). The samples of the first main group were, according to the thickness of the first layer, furthermore divided into two groups; (A) the samples with the thickness of the first mortar layer between 2 mm and 5 mm (19 fragments) and (B) the samples with the thickness of the first mortar layer between 6 mm and 10 mm (5 fragments). On the other hand, the second main group with the coloured binder consists of merely one subgroup, containing the samples whose first-layer thickness is between 2 mm and 5 mm. Considering the mineralogical/petrographic compositions of the mortar layers, the samples were grouped into 14 subgroups.

The common characteristic of the first mortar layers of all the samples is an exclusive presence of carbonate grains. Carbonate grains, determined by Raman microspectroscopy, are mostly represented by dolomite (**Figure 6a**), while calcite (**Figure 6b**) is observed only in a few samples (HTM 55, HTM 56, and HTM 57).

Most of the dolomite is represented by semi-angular grains (**Figure 7a**) with a small amount of subrounded grains. Crushed dolomitic rock was most probably used as an aggregate (cf. the wall paintings from the Roman site near Mošnje with round grains of dolomite indicating a fluvial deposit).[5] In addition, a coarse-grained sparry calcite (**Figure 7b**) may indicate the use of crushed marble.[1,6,16]

Furthermore, the grains in the aggregate are poorly sorted, between 0.02 mm and 3.0 mm in size. The binder is lime, mostly compact with rare fissures. In all three samples with the coarse-grained sparry calcite, the

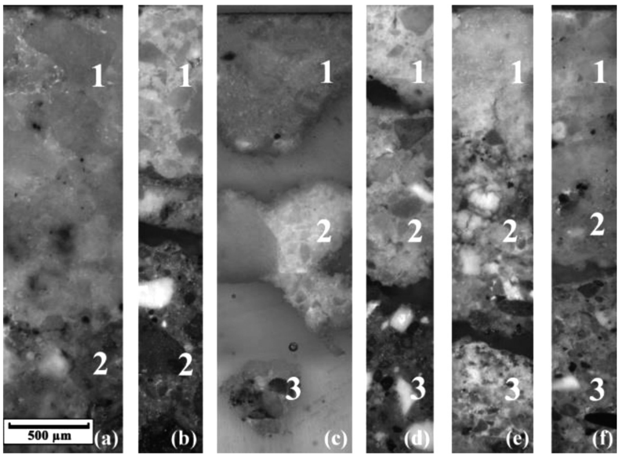

Figure 5: Wall-painting fragments representing various groups with different mortar layers: a) group B-2, sample HTM 10, b) group B-4, sample HTM 19, c) group C-1, sample HTM 54, d) group A-2, sample HTM 47, e) group A-3, sample HTM 7, and f) group B-1, sample HTM 13; Legend: 1: 1st mortar layer, 2: 2nd mortar layer, 3: 3rd mortar layer; light microscope, reflective light, crossed polars, 5-times magnifications

Slika 5: Fragmenti stenskih poslikav, razdeljeni v različne skupine glede na sestavo ometov: a) skupina B-2, vzorec HTM 10, b) skupina B-4, vzorec HTM 19, c) skupina C-1, vzorec HTM 54, d) skupina A-2, vzorec HTM 47, e) skupina A-3, vzorec HTM 7 in f) skupina B-1, vzorec HTM 13; legenda: 1: prva plast ometa, 2: druga plast ometa, 3: tretja plast ometa; svetlobni mikroskop, refleksijska svetloba, navzkrižni nikoli, 5-kratna povečava

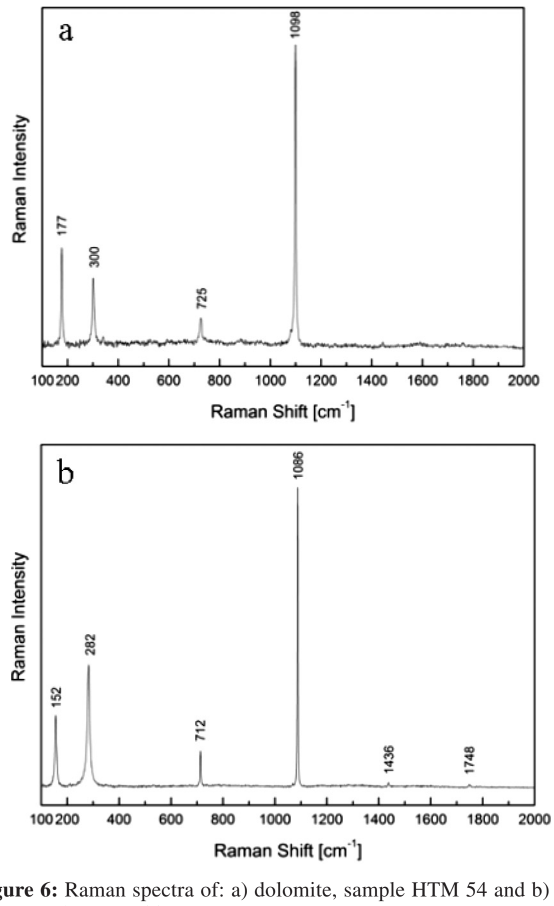

Figure 6: Raman spectra of: a) dolomite, sample HTM 54 and b) calcite, sample HTM 55

Slika 6: Ramanski spekter: a) dolomita, vzorec HTM 54 in b) kalcita, vzorec HTM 55 binder is red due to the addition of red ochre (hematite) pigment (**Figure 8**). A slightly red-coloured binder was also observed in some Emona samples, which was due to the addition of red ochre,[4] whereas Weber[16] reported additions of red ochre or cinnabar to the lime.

Regarding the second mortar layers, in general, three types of aggregate were observed: layers with predominant grains of carbonate, layers with carbonate grains and an addition of silicate grains or layers with prevailing silicate grains. Silicate aggregates such as quartz, chert and lithic grains of sedimentary and magmatic rocks were observed. Grains are rounded, subrounded and angular, measuring between 0.03 mm and 3.75 mm. In contrast to the wall paintings from some other archaeological sites in Slovenia where ceramic grains were observed exclusively in the first mortar layers,[4,5] ceramic grains measuring between 0.04 mm and 2.90 mm were present in the second layer of the two samples (**Figure 7c**).

In all the samples, the aggregate of the third mortar layer consists mostly of silicate grains, except for the HTM 58 sample where carbonate grains are present. The silicate aggregate is composed of subrounded quartz, rounded lithic grains of chert, quartz sandstone, magmatic rocks, some angular grains of feldspar and mica (**Figure 7d**). The grains measure between 0.06 mm and 3.50 mm in size. In some samples, significant amounts of ceramic grains in a size between 0.5 mm and 3 mm are present (for comparison: ceramic grains in the Emona samples are rare and observed only in a few samples.)[4]

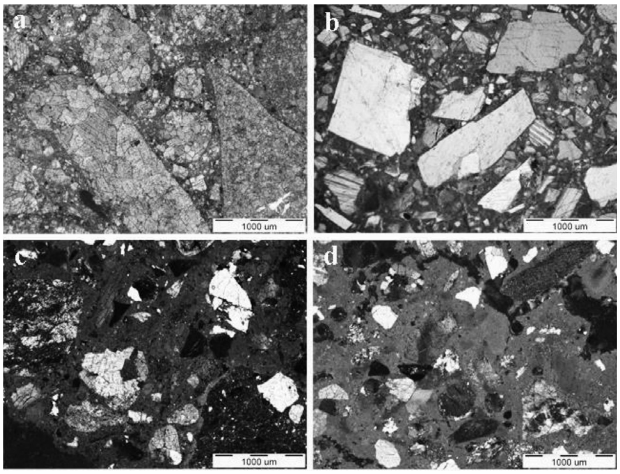

Figure 7: a) Dolomite aggregate in the first mortar layer, group B-2, sample HTM 10; light microscope, transmission light, parallel polars, b) coarse-grained calcite and slightly red-coloured binder in the first mortar layer, group C-4, sample HTM 56; light microscope, transmission light, parallel polars, c) ceramic particles in the second mortar layer, group B-4, sample HTM 19; light microscope, transmission light, crossed polars, d) silicate grains in the third mortar layer, group A-3, sample HTM 8; light microscope, transmission light, crossed polars

Slika 7: a) Zrna dolomita v zgornji plasti ometa, skupina B-2, vzorec HTM 10; svetlobni mikroskop, transmisijska svetloba, vzporedni nikoli, b) debelozrnat kalcit in rahlo rdeče obarvano vezivo v zgornji plasti ometa, skupina C-4, vzorec HTM 56; svetlobni mikroskop, transmisijska svetloba, vzporedni nikoli, c) zrna keramike v drugi plasti ometa, skupina B-4, vzorec HTM 19; svetlobni mikroskop, transmisijska svetloba, navzkrižni nikoli, d) silikatna zrna v tretji plasti ometa, skupina A-3, vzorec HTM 8; svetlobni mikroskop, transmisijska svetloba, navzkrižni nikoli

The results show that the wall-painting fragments with more sophisticated motifs or patterns, such as multiple colours (groups A-1, A-4, A-5, B-1, C-2, C-4), had two or even three mortar layers prepared with a carbonate aggregate or at least a mixture of carbonate and silicate, while those with monochromatic colours usually had only one carbonate layer followed by silicate sand. Vitruvius[17] wrote in his book about the correct method of plastering walls and ceilings and of making a quality base for wall paintings that plaster would not crack and would be without defects if the walls were covered with three layers of sand mortar and as many layers of marble mortar. The use of marble powder in the top layers improved the polishing effect and produced a mirror-like sheen on the surface. It is presumed that for the mortar layers with a mixture of carbonate and silicate grains (the second layer) crushed dolomite was mixed with fluvial sand. Dolomite was crushed most probably to obtain the so-called "polvere di marmo", but normally limestone was used.[18]

An addition of ceramic powder reduces the water permeability and increases the mechanical strength, which is attributed to the hydraulic reaction with lime in the presence of water at the edge of the ceramic particles.[19] This highly hydraulic lime has been used since the Roman times for rendering and plastering the buildings situated in the places with a high relative humidity, such as baths.[20]

The fragments of the same group display very similar micro-stratigraphic sequences and materials and therefore very probably belong to the same construction phase or room. Thus, such a large number of groups could indicate the existence of several different phases of the construction and different rooms.

The petrographic composition of the mortar aggregate could reflect local geological conditions. Since deposits of the upper and middle Triassic dolomite occur in the Celje area,[21] we could assume that the dolomite aggregate originated from the quarry in the vicinity. Fur-

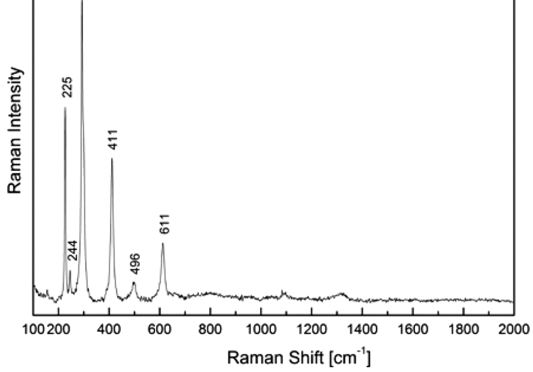

Figure 8: Raman spectra of red ochre (hematite), sample HTM 56

Slika 8: Ramanski spekter rdečega okra (hematit), vzorec HTM 56 thermore, the round-grain aggregate from the lower mortar layers suggests a fluvial origin from the rivers nearby the archaeological site, most probably the alluvial deposits of the Savinja River. A possible source of the coarse-grained calcite could be the abandoned marble quarry in Pohorje (40 km from the archaeological site) active in the Roman times.

4 CONCLUSIONS

The characterisation of the wall-painting mortars from the archaeological site in Celje revealed differences between the mortars employed and contributed to the knowledge of the Roman wall-painting technique. The samples were divided into two main groups based on the binder colour and three groups based on the thickness of the first mortar layer. According to the mineral/petrographic compositions of the layers, the fragments were further divided into 14 different subgroups. Such a large number of groups may indicate the existence of several different phases of the construction and different rooms, keeping in mind that the fragments did not necessarily belonged only to the room in which they were found.

The results revealed that the common characteristic of the first layers of all the samples was the exclusive presence of carbonate grains. In majority, carbonate grains were represented by dolomite, while coarse-grained calcite was found only in three samples that also indicated the use of crushed marble. The aggregates from the lower mortar layers consisted of only carbonate grains or silicate sand, or even of a mixture of both. An addition of ceramic grains was observed in some cases. Since crushed ceramic was commonly used in damp places such as hypocaust, baths and the lower parts of walls, we can say that some of the analyzed samples might have belong to such rooms, maybe also being part of the hypocoust where the fragments had been found.

A reassembly of wall-painting fragments requires that the fragments be put together in the right way to form the original artwork. Any knowledge of the compositions of the mortars (thickness, colour, mineral composition) not only gives us information about the technique, but also helps us reconstruct the object. A combination of an analysis and specific computer programs, such as Pedius, can help restorers reassemble the fragments faster and more effectively.

Acknowledgements

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