07TH INTERNATIONAL SCIENTIFIC CONFERENCE

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Zagreb, 2nd – 3rd December 2019

PROCEEDINGS

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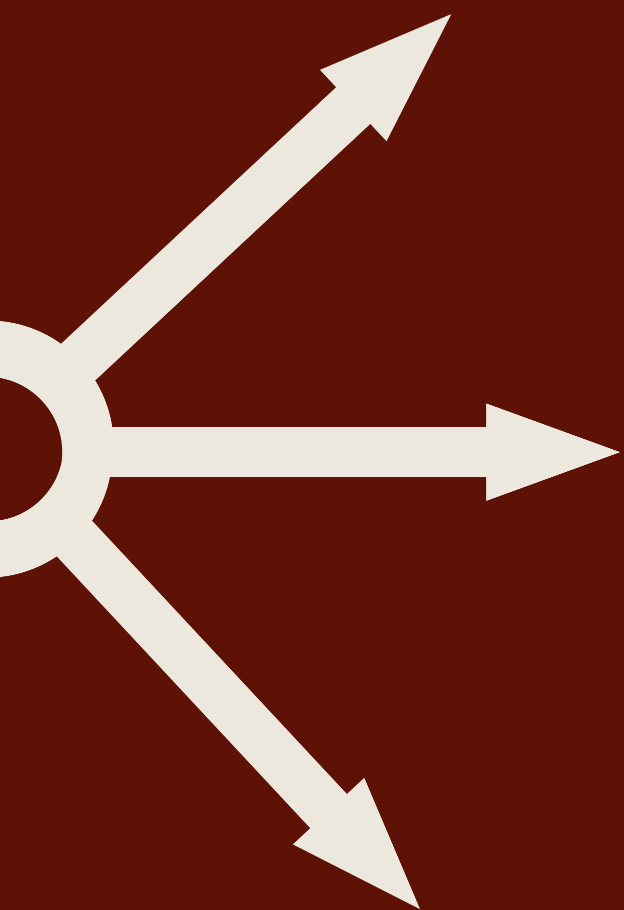

Content

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MET ARH

Preface

Ina Miloglav

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Methodology and Archaeometry (*MetArh*) is an annual scientific conference organized since 2013 by the Department of Archaeology of the Faculty of Humanities and Social Sciences of the University of Zagreb, and the Croatian Archaeological Society. The goal of the conference is to entice interdisciplinarity, critical thinking, new insights and approaches as well as new theoretical frameworks in contemporary archaeological science.

During the last 8 years, *MetArh* becomes a platform for discussion about theoretical and practical issues in two major topics of archaeological research: archaeological methodology and archaeometry. The first topic covers the development of the methodology for data acquiring, primarily through archaeological excavations and varieties of non-destructive techniques for data gathering. The second topic is focused on the application of scientific methods and techniques in data analysis. Both improve the overall archaeological methodology and ensures more reliable and valid data which leads to more comprehensive archaeological interpretation of the distant past. What makes *MetArh* different from other similar conferences, which are usually focused on specific methodological themes, is the wider perspective in observing methodology and methodological practices, also challenging traditional approaches in archaeological research, and following the creative adaptation of methods from other disciplines into archaeology. It offers an opportunity for scholars to present their work, engage in discussion and motivate young scholars and archaeology students to pursue contemporary topics and present their research.

With the intent to publish contributions from the conference in fool text publicly and freely available in 2018 started with the digital edition of the *Proceedings from the conference.*

This, third edition of the conference *Proceedings* contains five scientific papers from the 7th *MetArh* conference which was held at the Faculty of Humanities and Social Sciences of the University of Zagreb, from 2nd – 3rd of December 2019. Papers are focused on different aspects of archaeological methodology and archaeometry, including case studies from Croatia, Slovenia and Albania.

This volume is specific due to COVID-19 outbreak which disrupted life around the globe in 2020. It affected physical and psychological health and our daily routine and activities. As some studies have shown, it has affected the scientific production in the first months of lockdown as a response to a new, unpredicted and unexpected situation. As papers form the 7th *MetArh* conference were collected in spring 2020 it was very challenging to prepare this issue for publishing. So I want to thank all the authors for their contribution, as well as the reviewers and scientific board of the publication who made possible that, despite all of the circumstances, we manage to publish this volume.

Laboratory-based research on the changes caused to the *in situ* preserved archaeological remains by the heavy equipment compaction

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When planning the in situ *preservation of archaeological remains, one of the issues that need consideration are changes in the physical environment and their impact on the remains. This includes mechanical loading of the surface above the site and its consequences on the various layers and artefacts within the site. The contribution represents a laboratory-based experiment on the effects of heavy equipment compaction on archaeological remains. A set of tests was performed to understand better the changes that mechanical loading of the surface will cause to the archaeological site. In a custom-made steel case, artificial archaeological sites were created by layers of sandy silt and gravel, in which a variety of archaeological and modern artefacts were placed. To measure stress and strain, some of the artefacts were equipped with strain gauges. A servo-hydraulic piston was used to simulate static and dynamic mechanical loading. Moisture and temperature were recorded before, during and after each test. At the same time, the three-dimensional recording of the artefacts and layers, and soils stiffness measurements were performed before and after each loading.*
The obtained data allowed us to study the compression of layers and their moisture, movements of the artefacts, stresses and strains on the artefacts, and the macroscopically observable damage of the artefacts caused by loading. We were able to deduce how big of an influence grain size and moisture of the soil have, how important the type of material representing archaeological remains and their position within the soil is, that movements of the artefacts within the layers are also an important factor to consider, that vibrations are far more damaging than force alone, and that protective layer is not always best preservation strategy. With the presented results, our research has been a step towards a better understanding of the effects of heavy equipment compaction to archaeological remains and thus to the preservation of archaeological sites in situ.

Keywords*:* in situ *preservation of archaeological sites, laboratory tests, heavy equipment compaction, strain gauges, artefact deformation*

Introduction

The *in situ* preservation of archaeological remains is based on the idea that the remains are best preserved in their original environment. It allows for holistic and long-term preservation of the remains in their place of origin, where they continue to form an integral part of the local environment and are thus most valuable. It is grounded on the facts that properly executed archaeological excavation is time-consuming, logistically and financially demanding process which physically destroys the integrity of the archaeological record; that technological development will allow us to obtain more and better information with less damage to the remains; that heritage needs to be preserved for the future generations; and that under the right circumstances the *in situ* preservation is a viable option (Groenewoudt and Bloemers 1997: 128). Following the Valletta Convention (Council of Europe 1992), the integrated and long-term preservation of the remains *in situ* is thus a priority. However, it is often overlooked that even under ideal conditions and with the proper management, the process of degradation of the remains cannot be stopped, only slowed down (Huisman 2009: 181). Also, increasing human interventions are constantly changing the environment, further jeopardizing the long-term preservation of the remains (Darvill and Fulton 1998). Thus, the *in situ* preservation of archaeological remains represents a double-edged sword.

On the one hand, it offers the possibility of integrated and long-term preservation of the remains. At the same time, simultaneously increases the risk of complete destruction and loss of unique information about our heritage. Another set back in the state of research. Due to the complexity of the filed with various materials and their degradation paths under different conditions, research is expensive, logistically and methodologically demanding, time-consuming and still in its beginnings.

One of the multiple factors that need to be considered when deciding for a long-term *in situ* preservation of the remains is the impact of the environment in which the remains are preserved (Huisman 2009: 181). This includes imposed stressed caused by additional surface loading (e.g. heavy equipment and/or embankments). Previous research has already shown that stress in the soil is a major issue when dealing with proper preservation of the remains (Garfinkel and Lister 1983; Olson et al. 1988; Mathewson et al. 1992; McGowan and Prangnell 2015). In general, the additional surface load increases stress in the soil, which causes deformation and relocation of the soil particles, the expulsion of the air and/or water from the voids, and thus compression of the soil layers. The resulting settlement affects the archaeological site in various ways. The most obvious are displacement and deformation of the remains (Das and Sobhan 2013), which changes their original context and physical form. Settlement can also alter the stratigraphy, especially if the site consists of diverse materials, behaving differently under the imposed stress (de Lange et al. 2012; McGowan and Prangnell 2015). Furthermore, the loss of pore water and more tightly organised soil particles can lead to moisture changes, especially dangerous for organic remains (de Lange et al. 2012).

In the context of archaeological remains, the behaviour of various soil types under the imposed mechanical stress was studied by Hyde (2004), Sidell et al. (2004) and Avsenik (2012), while limited research also included the behaviour of the buried artefacts (Garfinkel and Lister 1983; Olson 1989; Mathewson et al. 1992; Godwin et al. 2009; McGowan and Prangnell 2015). Even though from different perspectives and various methodological procedures, results highlighted depth, orientation and type of the buried remains, soil moisture and grain size distribution, and type of the imposed load as the most influential factors. However, tangible data on how additional stress affects archaeological remains in the ground are very limited. Our research aimed to contribute towards a better understanding of the loading effects on the subsurface archaeological sites above the groundwater level. The main objective was to develop a useful methodological procedure while gathering new data on the behaviour of various materials and soil layers under loading.

Methodology

The artificial archaeological site was established in a 0.85 x 0.85 x 1.2 m steel box with perforated bottom for the water drainage. The lower layer was composed of gravel and upper of sandy silt. Layers were 0.4 – 0.45 m thick, installed gradually, through 0.05 – 0.1 m thick sublayers. During installation, each sublayer was compacted by trampling with a load of ~4.5 kN/m^2. Modern and archaeological artefacts were buried in soil layers. In tests, 1 – 3 wooden plates and piles were installed vertically and horizontally in sandy silt. In test 4 – 9 metal, glass, bone and ceramic artefacts were deposited in sandy silt and gravel (Fig. 1). Some of the artefacts were equipped with strain gauges.[1] The gauges were attached to the surface of an artefact, perpendicular to the imposed surface load (Fig. 2). To avoid potential damage, gauges were covered with ~3 mm thick layer of modelling clay and the wires were placed into the rubber hose. Since the artefacts were buried in the soil and thus the orientation of the principal axes was unknown, rosette strain gauges (WFLA-6-11-5L) were used (Fig. 2) so that strain

[1] Only modern artefacts were equipped with strain gauges. The decision was made based on the limited finances and thus number of relatively expensive strain gauges, combined with better comparability of the data among unaltered modern materials in comparison to the already changed and thus variously preserved archaeological materials.

was recorded in three separate directions (0°, +45°, -45°). Moisture (Decagon 10HS Large Volume VWC) and temperature (Decagon RT-1) sensors were positioned approximately 10 cm below and 10 cm above the specimens in the sandy silt. Sensors were not used in gravel as it is too coarse to retain water and could also damage the sensors. The spatial position of artefacts and the uppermost surface of each layer were recorded with electronic tachymeter.

Loading of the surface was performed with a servo-hydraulic piston, provided with 0.82 x 0.82 cm steel panel (Fig. 3), 2 – 12 days after the preparation of the site. The exception was test 9, in which the site was soaked with water and left for 4 months for partial consolidation. Loading in six tests was monotonic, whereas in three tests it was dynamic. In monotonic tests force was applied gradually, through 20 kN increments up to the maximum force of 160 kN (surface load 250 kN/m²).

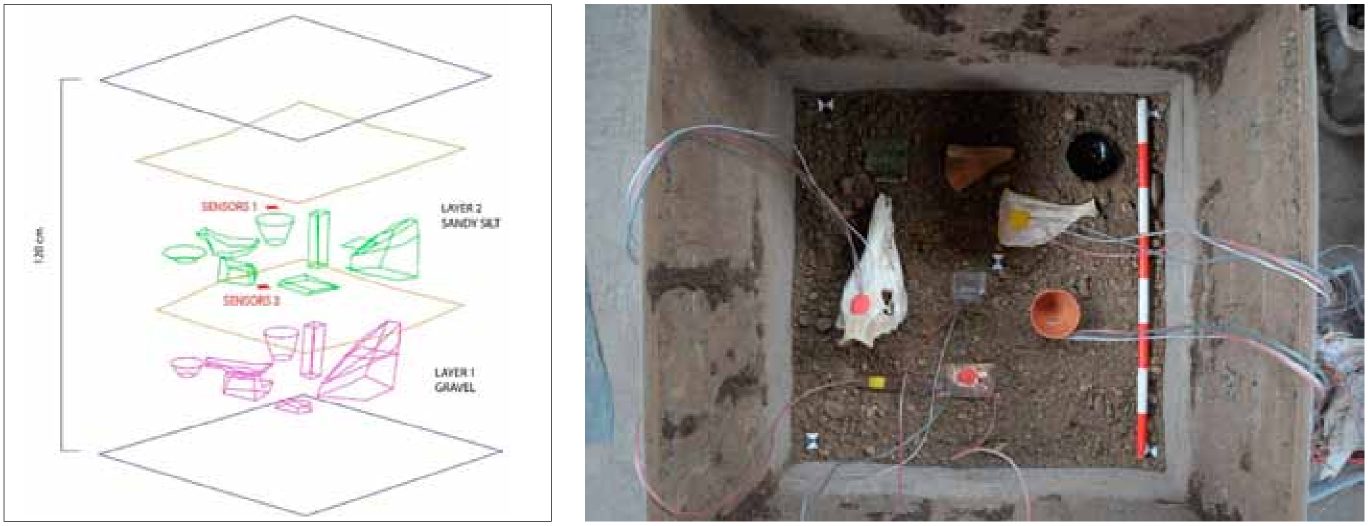


Figure 1. Schematic presentation of the artificial archaeological site (left) and an example of the specimens in gravel (right).

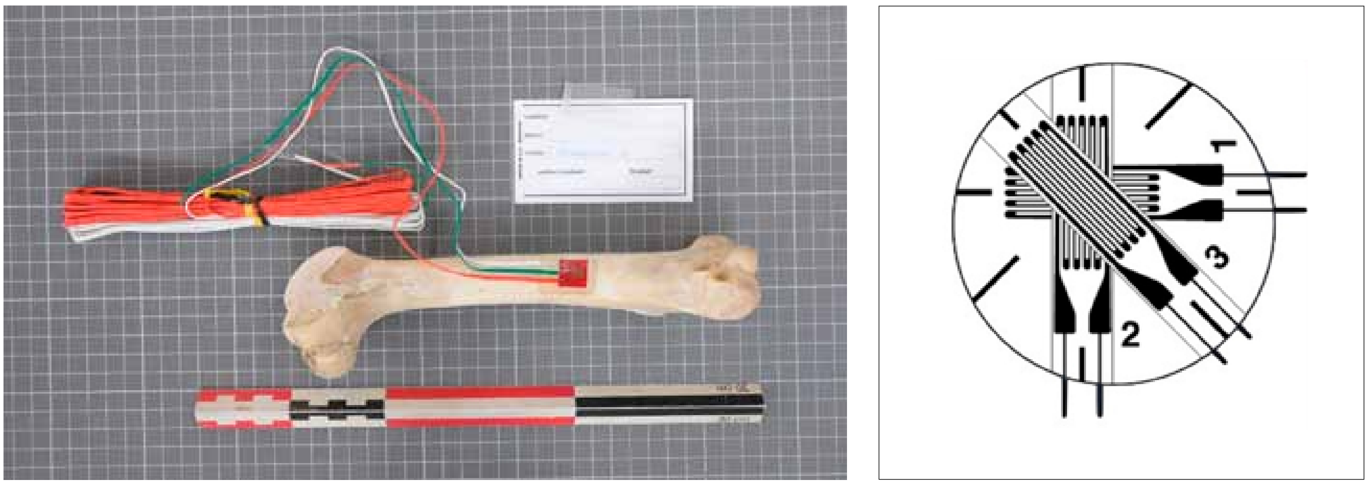


Figure 2. Artefact (femur of a pig) equipped with a strain gauge (left) and rosette strain gauge composition (right).

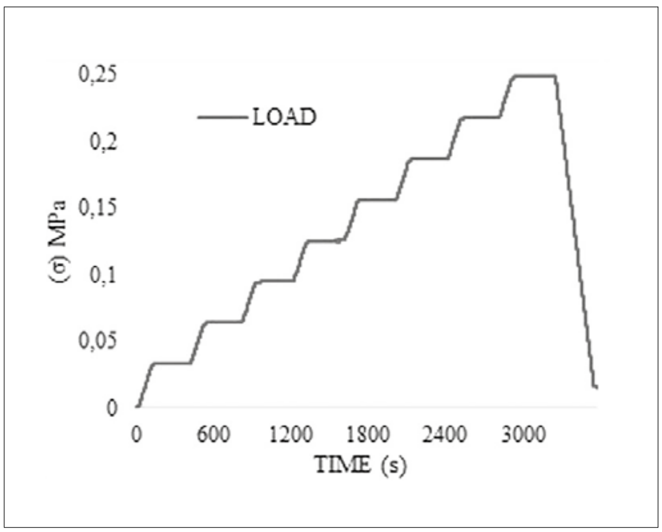
The applied force was maintained for 300 seconds after each increment (Fig. 4). In the dynamic tests, 20 kN increments reached up to the maximum force of 100 kN (surface load 150 kN/m^2). The applied force was maintained for only 100 seconds, with 6 Hz vibrations added (Fig. 5). In the first six tests, 0.25 m thick protective layer of geotextile and crushed stones were put before loading (Table 1).

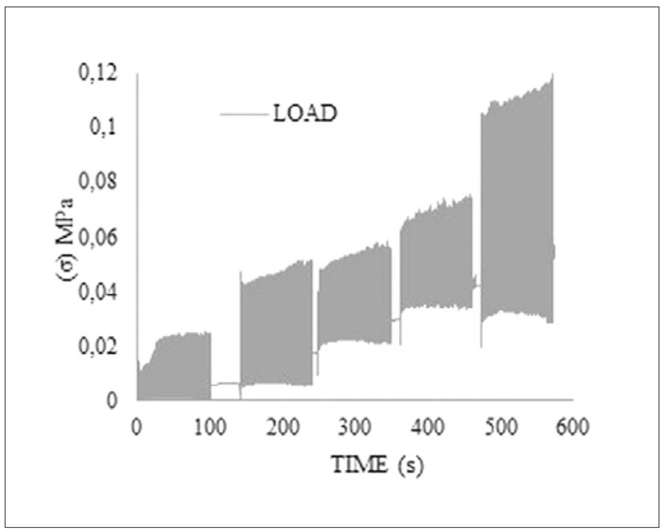
Before, during and after loading, temperature sensor, moisture sensor and dilatometer probe were used to determine temperature, moisture and stiffness for settlement prediction of the sandy silt (constrained modulus). Sensors and probe were not used in gravel as it is too coarse and thus not suitable for the tests.

Additional test 10 was performed, comparing the behaviour of archaeological and modern bones and ceramic in the exact same loading conditions. In a 40 x 30 x 50 cm big box a 0.45 m thick layer of sandy silt was installed with ceramic fragments (modern, roman, prehistoric) and animal bones (modern, roman) positioned 20 cm deep in the layer. In this test, all the artefacts were equipped with strain gauges. The surface of the sandy silt was covered with a wooden plate to spread the load on the layer equally. Monotonic loading was performed until failure of the artefacts occurred. During loading applied force and strain on the artefacts were recorded.

Figure 3. Servo-hydraulic piston and metal box with the artificial archaeological site.

Figure 4. Graphs representing monotonic (left) and dynamic (right) loading.





TEST #	ARTEFACTS	MOISTURE	PROTECTION	CONSOLIDATION	LOADING
1	Wood	22 %	Y	7 days	M
2	Wood	22 %	Y	4 days	M
3	Wood	22 %	Y	6 days	D
4	Ceramic, bones, glass, metal	21 %	Y	2 days	M
5	Ceramic, bones, glass, metal	21 %	Y	12 days	M
6	Ceramic, bones, glass, metal	19 %	Y	5 days	D
7	Ceramic, bones, glass, metal	19 %	N	5 days	M
8	Ceramic, bones, glass, metal	19 %	N	5 days	D
9	Ceramic, bones, glass, metal	18 %	N	4 months	M
10	Bone, ceramic	/	N	none	M

Table 1. Summary of the characteristics and loading conditions in each test.

After each loading and unloading, excavation and documentation of the site were performed, following archaeological methodological standards as much as possible.

During loading and unloading, strain gauges were measuring strain on the artefacts. Based on the recorded strains minimal (ε_{min}) and maximal (ε_{max}), principal strains were computed using the following equations:

$$\varepsilon_{min} = \frac{1}{2}\left[\varepsilon_1 + \varepsilon_2 - \sqrt{2\{(\varepsilon_1 - \varepsilon_3)^2 + (\varepsilon_2 - \varepsilon_3)^2\}}\right],$$

$$\varepsilon_{max} = \frac{1}{2}\left[\varepsilon_1 + \varepsilon_2 + \sqrt{2\{(\varepsilon_1 - \varepsilon_3)^2 + (\varepsilon_2 - \varepsilon_3)^2\}}\right].$$

With the addition of Young`s modulus (E) and Poisson`s ratio (v) of each artefact material, principal stresses were calculated. Minimal (σ_{min}) and maximal (σ_{max}) principal stresses were calculated using the following equations:

$$\sigma_{min} = \frac{E}{1-v^2}(\varepsilon_{min} + v\varepsilon_{max}) = \frac{E}{2}\left[\frac{\varepsilon_1+\varepsilon_2}{1-v} - \frac{1}{1+v}\sqrt{2\{(\varepsilon_1 - \varepsilon_3)^2 + (\varepsilon_2 - \varepsilon_3)^2\}}\right],$$

$$\sigma_{max} = \frac{E}{1-v^2}(\varepsilon_{max} + v\varepsilon_{min}) = \frac{E}{2}\left[\frac{\varepsilon_1+\varepsilon_2}{1-v} + \frac{1}{1+v}\sqrt{2\{(\varepsilon_1 - \varepsilon_3)^2 + (\varepsilon_2 - \varepsilon_3)^2\}}\right].$$

Using bulk unit weight (γ) of gravel and sandy silt, their thickness (z), vertical force applied to the surface (q) and I_3 coefficient (Das and Baranja 2012: 337), stress in the soil at a depth of the artefacts during loading (σ_{LOAD}) was calculated:

$$\gamma = \frac{WEIGHT}{VOLUME},$$

$$\sigma = \gamma * z,$$

$$\Delta\sigma = q * I_3,$$

$$\sigma_{LOAD} = \sigma + \Delta\sigma.$$

Results and discussion

Temperature and moisture

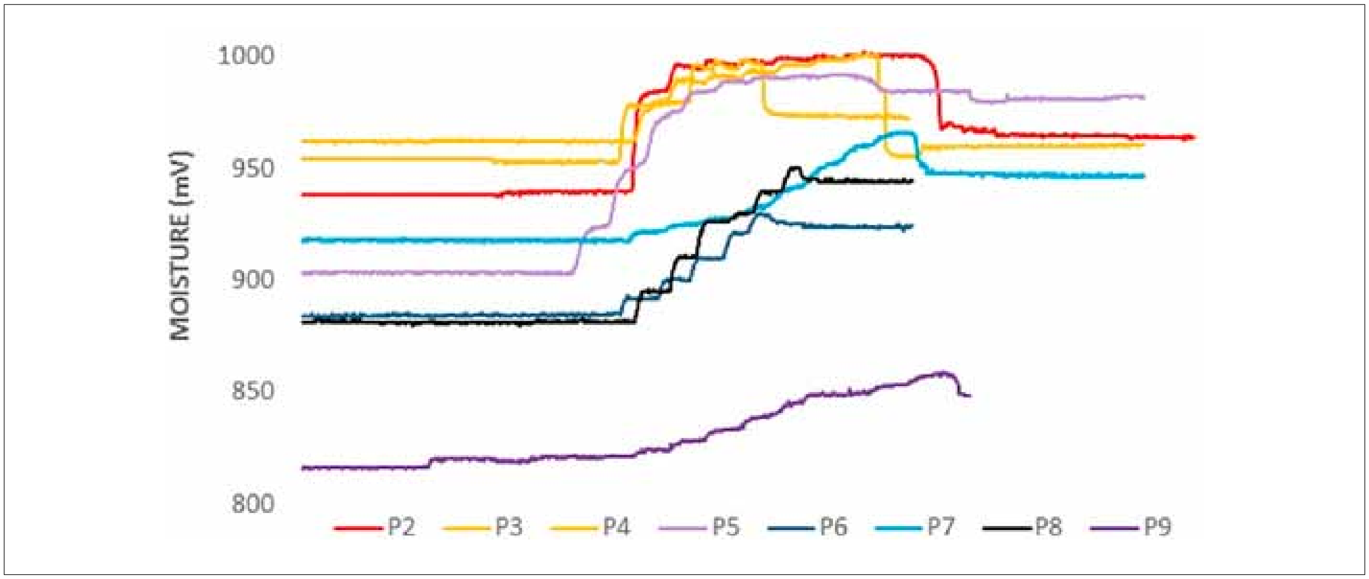
There were no significant changes in the temperature, and sensors managed to measure the temperature without any problems throughout the tests.

In all the tests moisture increased, most significantly in test 5 and least significantly in test 9 (Fig. 5). Changes presented a reaction of the sandy silt to the loading when the air was extruded from the pores. As pores in the soil were filled with either air or water, a lower proportion of air resulted in a higher proportion of water and thus higher moisture. Most significant changes in test 5 probably occurred due to the use of a protective layer and high applied force, causing high stress, air extrusion, soil compaction, and increase in moisture. Also, the protective layer contained some water, which penetrated into the sandy silt during loading and further increased its moisture. Least significant changes in test 9 are most likely a consequence of lower initial moisture and pre-consolidation process, making the layer less porous and compressible. A comparison between monotonous and dynamic loading showed a sharper, stepwise increase in the latter. However, moisture changes were mainly conditioned by an increase in the applied force (rapid growth with increasing force) and less by vibrations (absence of significant additional changes when vibrations were applied).

Soil compaction

During loading, soil compacted due to the extrusion of air and water from the pores. The pore pressure dropped, and the load was transferred to the solid particles, which moved into a denser structure, causing soil compaction (Das and Sobhan 2013: 364-365). Compaction of sandy silt was higher in comparison to gravel, as the latter is coarse-grained and thus less compressible than the former. Additionally, monotonic loading caused more changes in the sandy silt while dynamic in gravel, indicating that higher force had more impact on the more compressible sandy silt while vibration on the less compressible gravel (Fig. 6). This can be explained with the compaction of coarse-grained soil being optimal when a combination of pressure and vibration is applied. In coarse-grained soils, the pressure itself merely increases the effective stresses and thus the friction between the solid particles of the soil, which makes movements of the particles difficult. Vibrations reduce friction between particles and facilitate their movement into a denser structure. In fine-grained soils, compression is conditioned by pressure and kneading, while vibrations merely increase the water pore pressure (Briaud 2013: 701). Worth mentioning is test 9, in which compaction was small, most likely due to pre-consolidation already causing some naturally occurring, gravity and water draining induced compression. Interestingly protective layer in some of the tests increased compaction, most significantly when vibrations were applied. This indicates that the additional weight of the protective layer in combination with vibrations increases soil compaction.

Figure 5. Moisture changes.



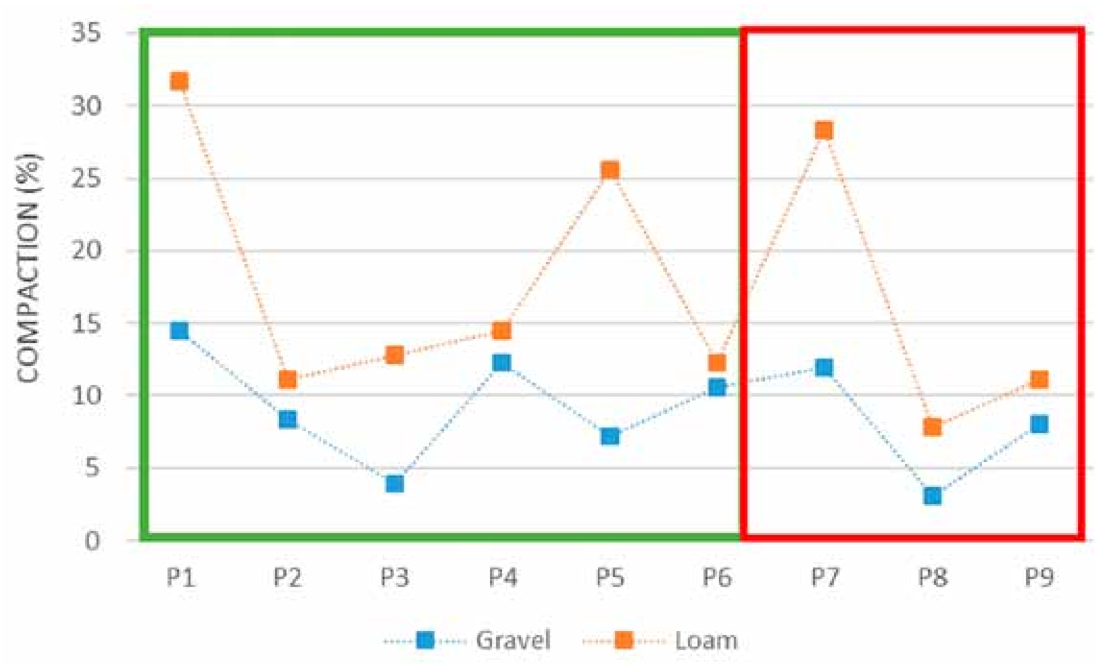


Figure 6. Compaction of gravel (blue) and loam (orange) due to loading.

Soil compressibility

Constrained modulus (M) increased after loading, making the soil less elastic and more compressed. Since modulus reflects the resistance of a substance to compression and is defined by the ratio between the change in pressure and volume, its increase was expected. However, the significance of its changes differed based on the moisture and presence of vibrations. In general, higher soil moisture and the use of protective layer lead to less compression than lower soil moisture and lack of protective layer.

Stress in the soil

Changes in the soil stress are consistent with the magnitude of the applied force. They were the lowest in the cases of dynamic loading (tests 3, 6 and 8), and highest in the cases of monotonic loading with a protective layer (tests 1 – 6). Additionally, the observed lower increase in stress in gravel could be attributed to a decrease in the impact of loading with increasing depth (Sohne and Soehne 1958; Das and Sobhan 2013: 166). Comparisons with the results of the study carried out by Godwin et al. (2009: Appendix 1) show that calculated total stresses during loading are similar to the stresses at a depth of 0.25 m caused by a plough and a heavy roller (25 kPa – 30 kPa), and a five-ton combine on tracks or five-ton combine with tires with an air pressure of 1 bar (50 kPa – 80 kPa). At greater depths, between 0.55 m and 0.65 m, similar stress (50 kPa – 80 kPa) is caused by a two-ton tractor, and a five- and ten-ton combine with tires with an air pressure of 1 – 2 bar (Godwin et al. 2009: Appendix 1: 16-19).

Displacement and damage

In test 1 – 3, only wooden specimens were used, placed in the sandy silt either vertically or horizontally. The results show that there was more displacement of horizontally placed specimens than of vertically placed specimens. Furthermore, the displacement of horizontally placed specimens was more dependent on the magnitude of the applied force and less on vibrations. In contrast, the opposite is true for the displacement of vertically placed specimens (Fig. 7).

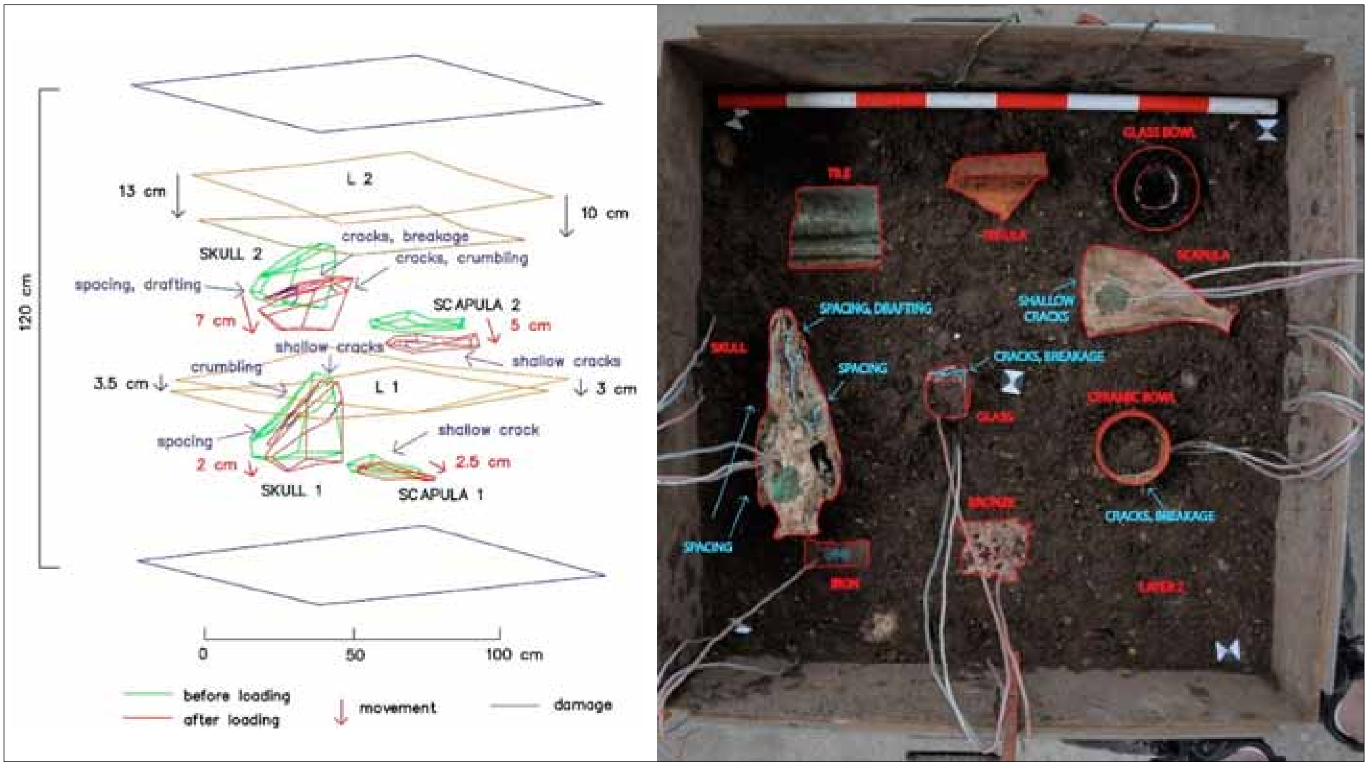


Figure 7. Schematic presentation of artefact displacement and damage due to loading (left) and partially excavated artefacts in loam with marked damage caused by loading (right).

In tests 4 – 9, where other materials were used, the average displacement in the sandy silt was approximately twice as large as in gravel. Additionally, higher moisture and lack of protective layer in monotonic tests increased the displacement. At the same time, the impact of vibrations was unpredictable and more severe in the case of the protective layer. On the other hand, lower moisture and pre-consolidation limited the displacement, most likely on account of lower porosity and denser structure of the soil.

With wooden artefacts, damage mainly presented as surface abrasions or small cracks, only in one case artefact broke. On average, the magnitude of the force had

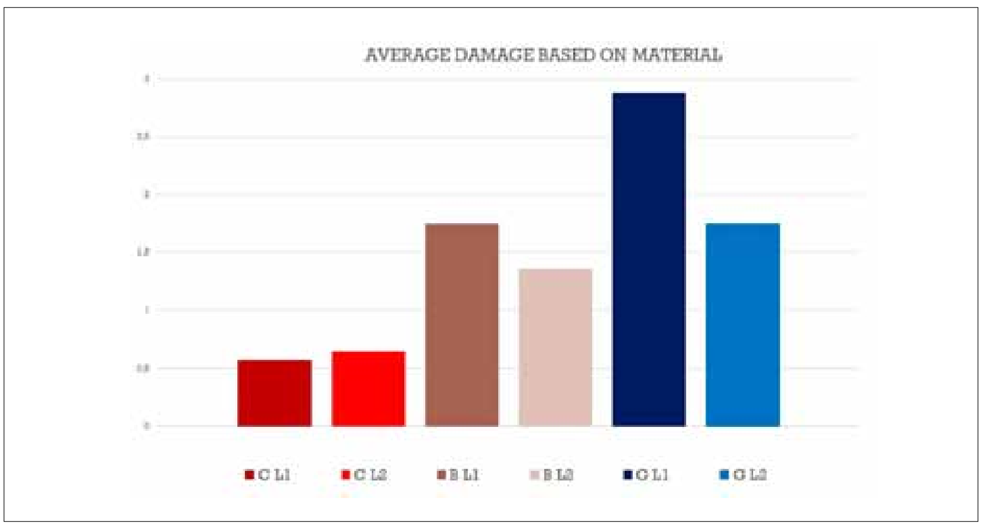


Figure 8. Average damage of different artefacts in gravel and sandy silt (C = ceramic; B = bone; G = glass; L1 = gravel; L2 sandy silt).

more impact on the damage than vibrations, and vertically placed artefacts suffered more damage than horizontally placed artefacts, likely due to the parallel orientation of the latter and perpendicular orientation of the former to the surface load. Other materials suffered more damage when placed in gravel than in sandy silt. This was expected as gravel is more coarse, less moist and less compressible, facilitating the transition of stress from the soil particles to the artefacts (Sidell et al. 2004; Booth and Spandl 2009). While higher moisture limited the damage, pre-consolidation and protective layer, especially in combination with vibrations, increased it. Furthermore, an inverse relationship was observed with damage and displacement. The more the artefacts moved, the less damage they suffered.

Considering each material separately, metal artefacts suffered no visually observable damage, while 21.4 % of ceramic, 62.5 % of glass and 64.2 % of bone artefacts did (Fig. 8). However, bone artefacts only obtained small scale damage, such as abrasions, chipped edge and shallow cracks, while ceramic and especially glass artefacts cracked or even broke completely. The damage of the artefacts was consistent with the material they were made of. Metal is extremely resistant and ductile, which means that high stresses are necessary for damage to occur. Fresh bone is also resistant and ductile and needs to be under high stress to break. The frequently occurred, yet small-scale damage in bones can be explained with its irregular, physically pronounced shape.

On the other hand, ceramic and glass are fragile materials, prone to crack. Furthermore, in test 10 all archaeological artefacts broke, while significantly less damage was observed in the modern artefacts. The results clearly highlight that archaeological artefacts are much more fragile than modern ones. This is understandable, as the exposure of the archaeological artefacts to the environment altered their physical, chemical and biological characteristics, weakening their structure and resistance to stress (Boskey et al. 1999; van der Meulen et al. 2001).

Stress and strain

In tests 4 – 9, compressive and tensile stresses and strains were recorded on the artefacts, reflecting their shrinkage, elongation and breakage (Fig. 9). Due to applying compressive force, compressive stresses and strains prevailed. The exception is bone artefacts. In scapulae, equal presence of compressive and tensile stresses and strains was observed, probably due to their flat shape. In the skulls, compressive stresses with tensile deformations were observed, indicating flexion of the skull, probably due to its physically pronounced and hollow shape. Even though there are too many variables for the recorded stresses and strains, and deformations of the artefacts to be directly correlated to a specific condition and/or loading, some patterns were observed. The pro-

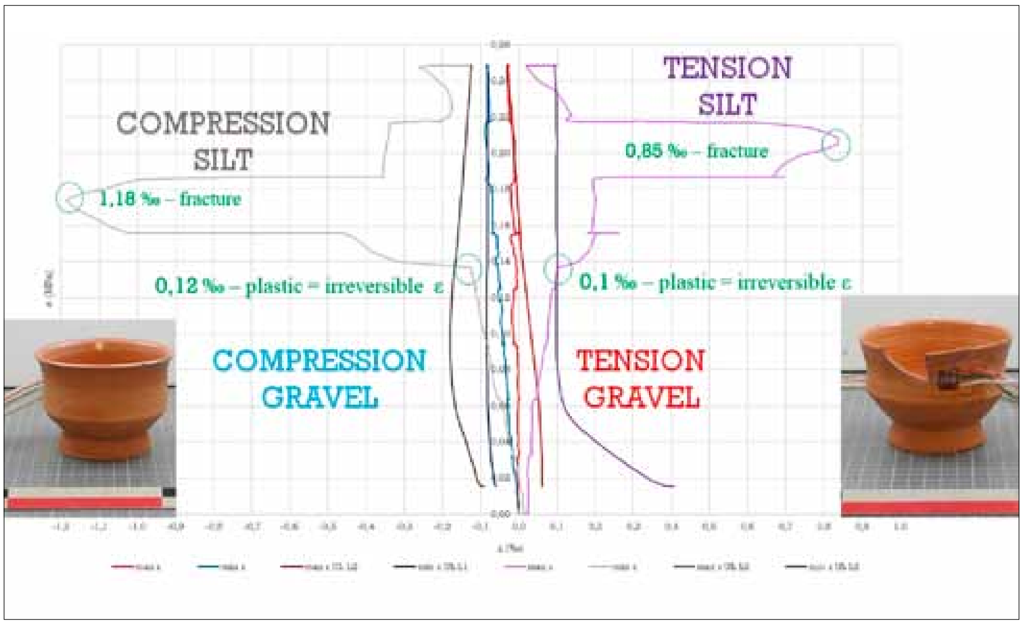


Figure 9. An example of the results obtained with strain-gauges placed on the ceramic bowl in gravel and sandy silt during loading and unloading of the artificial archaeological site. The blue and red lines represent strain in the bowl in gravel, which only suffered minimal damage (chipped edge), while the grey and purple of strain in the bowl in sandy silt, which cracked right under the strain gauge.

tective layer caused higher stresses, deformations and damage (negative impact) in bronze, iron and bone artefacts in gravel and smaller (positive impact) in sandy silt. The exception is bone artefacts in dynamic tests, where stresses, deformations, and damage were greater in the sandy silt. In ceramic artefacts, the protective layer reduced stresses, deformations and damage of the artefacts (positive impact) in gravel, while increased them (negative impact) in sandy silt. In the case of glass, the protective layer increased stresses, deformations and damage to the artefacts (negative impact) in the gravel and sandy silt. The comparison between the impact of force magnitude and vibration shows that the vibrations caused greater stresses, deformations and damage in bronze artefacts in gravel, bone artefacts in gravel and glass artefacts in gravel and sandy silt. In the remaining cases, the magnitude of the force had a higher impact, causing higher stresses, deformations and damage. Preconsolidation reduced stresses, deformation, and damage in most artefacts (positive impact). The exception is bone artefacts in gravel and glass artefacts in gravel and sandy silt, where pre-consolidation caused higher stresses, deformation and damage (negative impact).

Conclusion

The results of the tests present significant changes in moisture due to additional surface loads, a connection between the soil compaction and displacement of artefacts, and an increase in damage when the displacement of artefacts is limited. An unpredictable and negative impact of vibrations was also observed, especially when using the protective layer. Although somewhat simplified, the results of the strain gauges and macroscopic damage on the artefacts (bone, ceramics, glass) are consistent. The highest deformations were recorded in the artefacts in the gravel in tests 6, 8 and 9 and the sand silty in tests 5 and 6. Average macroscopic damage of the artefacts was highest in the sandy silt in tests 5, 6 and 9 and the sandy silt in tests 5 and 6. With highest deformations and macroscopic damage in tests 5, 6 and 9, the negative impact of the protective layer and vibrations was confirmed, especially in the case of their combination, and the negative impact of soil pre-consolidation. Differences were also observed between relatively elastic, solid or thick-walled metal and bone artefacts and brittle, hollow and thin-walled ceramic and glass artefacts. Deformations and macroscopic damage of the former were most dependent on the vibrations and the type of soil in which they were buried while the latter on the magnitude of the force applied to the surface of the site.

The results of this study are not sufficient to produce reliable values of stresses and strains within which the artefacts are safe from damage caused by additional surface loads. The simplification of extremely complex situations occurring in real cases was simply too great. Also, the soil has a pronounced and unpredictable effect on the measurements and behaviour of the artefacts, a good understanding of which would require additional tests. Nevertheless, some useful data were obtained. The metal artefacts were not damaged in any of the tests. The bone artefacts suffered various, minor damages, but only the bones from archaeological contexts broke. However, the transition to nonlinear deformations in modern bone artefacts was observed and should not be neglected as it indicates that deformations approached limits when permanent damage of the bone structure occurs. Ceramic and glass artefacts suffered the most damage, in some cases even broke completely. The stresses in the ground that caused damage of the artefacts are comparable to the stresses caused by a heavy roller and a five-ton combine on caterpillars or tires with an air pressure of 1 bar at 0.25 m, while at greater depths, between 0.55 m and 0.62 m, comparable stresses in the ground are caused by a 2t tractor and a 5t and 10t combine with tires with an air pressure of 1 – 2 bar (Godwin et al. 2009: Appendix 1: 16-19).

Regarding the protective layer, Avsenik (2012: 76, 124) mentions that in the absence of artefacts in the upper 50 cm of the ground, the protective layer is not recommended as its construction and additional weight causes excessive soil deformation and could damage the artefacts deeper in the ground. The present study showed that the use of a protective layer could do more harm than good. When considering the protective layer, in addition to its own weight and the depth of the remains, it is also necessary to take into account the physical properties of the soil and the types of artefacts present in the soil. The grain size and moisture of the soil have a strong impact on the plasticity and bearing capacity of the soil. At the same time, the type of material and the state of preservation determine the mechanical properties of the artefacts and thus their response to mechanical loads. In the performed tests, ceramic and glass artefacts were the most sensitive to mechanical loading, which is consistent with their mechanical properties and hollow, more pronounced 3D geometric shape. The orientation of the artefacts should not be neglected either, as Dain-Owens and co-workers report (2009: Appendix 2: 28) that the most prone to damage are the artefacts, which lie perpendicular to the direction of the loading force.

In addition to damage, it is necessary to consider the displacement of the artefacts and the compaction and compression of the soil. They can cause changes in the environment, such as a decrease or rise in moisture, in the stratigraphy of the site and/or to the context of the archaeological remains. In our tests, the less compressible gravel compacted for up to 8 cm, while the more compressible sandy silt up to 20 cm. On average, the artefacts in gravel moved for 5 cm and in sandy silt for 9 cm. It should be noted that most of the tests were performed in poorly consolidated soil, but even after a longer, 4-month consolidation, both type of soils still compacted for 5 cm, and the artefacts moved for 1.5 – 4 cm. Furthermore, it is necessary to understand that the spatial distribution of soils and artefacts in the site was artificial and thus uniform. Archaeological sites are characterized by diversity in the dimensions and spatial distribution of different soils and types of the remains. Thus, different compaction of soil with different properties and an additional impact on the stratigraphy and/or context of the remains is expected (Huisman 2012: 64-66). Also, the mechanical load caused changes in the soil structure and moisture that could increase further in the long run. The denser position of solid soil particles means lower porosity and thus lower humidity and/or limited water flow through the soil. It also cannot be overlooked that the loading of the site was only performed once. In a study by Goodwin et al. (2009: Appendix 1: 24), cyclic loading caused a 10 % increase in soil stress, meaning that cyclical loads would cause additional changes. Based on the obtained results, it can be deduced that previously proposed theories on better stress transfer from coarse-grained soil to the artefacts compared to transfer from fine-grained soil (Sidell et al. 2004; Booth and Spandl 2009) and decreasing impact of loading with depth (Das and Sobhan 2013: 169) are too simplistic. It is necessary to acknowledge all environmental factors, physical properties of the soils and the properties of the materials present. The proper understanding of the mechanical loading of the surface on the buried archaeological remains requires a complex preliminary study, based on the characteristics of the soils and materials present at the site and additional simulations and/or tests.

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Patterns everywhere: Geophysical prospection strategies at archaeological sites in Northern and Eastern Croatia

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Between 2014 and 2019 several geophysical prospection campaigns on archaeological sites in Northern and Eastern Croatia were realised. Survey layout, data and interpretation from the Hallstatt site of Jalžabet (Varaždin), from the Late Bronze Age and Iron Age site of Dolina (Nova Gradiška), and several prehistoric and Roman sites in Slavonia are presented and discussed in this paper. All data sets can be considered as incomplete since the investigations faced several serious

constraints. Firstly, intensive agricultural use and small property sizes result in limited accessibility of the areas to be investigated. On no account a complete coverage of the site's cores was possible. Secondly, the limited budgets also implicate a methodological narrowness.
Do these resulting incomplete data sets contribute to increase our archaeological knowledge? From a purely scientific point of view, a total coverage not only of the "site" but also of the surrounding "landscape" is self-evident. In fact, archaeological fieldwork and research in today's "austerity societies" remain mere wishful thinking. Yet, couldn't we consider this kind of prospection campaigns as a full-value tool in archaeological research?
Due to the wide availability of multi-channel equipment, data collection has become a standard procedure during the last 15 years. By contrast, the archaeological interpretation of the data is a matter of permanent epistemological development. The combination of the mentioned incomplete data sets and poor documentation of archaeological information on historical excavations and surveys present a challenge for both archaeologists and geophysicists.
The presented examples prove that substantial archaeological information can be gathered even from limited data sets. Taking into account geological, geomorphological and archaeological information, prevents us from both, merely describing geophysical data as well as from over-interpreting. It is self-evident that all information is assembled and presented in GIS, so that continuous reworking of the data is possible for all involved parties.

Keywords: *Magnetic prospection, geophysics, GIS, data interpretation, Croatian archaeology*

Introduction

Archaeological sites in northern and eastern Croatia have been the subject of geophysical investigations for a long time, especially in the decades since 2000 several sites were more or less systematically surveyed. Neolithic sites, often located in the extensive alluvial plains are especially suitable for large-scale magnetic surveys (Botić 2017; Ložnjak Dizdar et al. 2017), while hillfort sites from Bronze Age, Roman sites such as military camps and settlements, and medieval sites require a wider methodological approach combining magnetic, GPR and geoelectric prospection (Mušič et al. 2013; Sekelj Ivančan and Mušič 2014).

Landscape conditions in the Pannonian basin, along the alluvial plains of the main rivers Mura, Drava, Sava, and the Danube offer very good conditions for large-scale geophysical prospection using multi-sensor equipments, as it has been the case with magnetic prospection for more than two decades. Less accessible sites, found in hilly and forested areas, demand more complex methodological approaches and the use of more flexible equipment. When dealing with stone architecture, then GPR and geoelectrical prospection are complementary methods to the magnetic survey or even alternatives (Mušič and Horn 2019).

Of the utmost importance in all prospecting projects is the archaeological interpretation of the data. It is crucial that the data sets only represent a small section of the soil parameters influenced by humans, and that they can only cover parts of archaeological landscapes. The first one is due to the methodology, the second to the fact that areas are not accessible because of agricultural use, forestation or lack of permits. Thus, all data sets, presented in this paper are to be considered as fragmentary data.

Methodological remarks

All presented data sets contain magnetic data since magnetic prospection was applied as a principal method. At one site, the Hallstatt burial mound of Jalžabet the GPR was used as a complementary method. At all other sites, a second and complementary method would have been recommendable, however, the prevailing circumstances did not permit for further prospection works.

a) Magnetic prospection

Magnetic anomalies are caused by changes in the complex magnetic properties of the soil. The amplitude of the magnetic anomalies is determined by the contrast between the different magnetic susceptibilities of archaeological structures and surrounding uninfluenced soil, as well as by the volume and depth of the magnetic structure. Two types of magnetisation can be observed at magnetic measurements: the induced and the remanent magnetisation.

The induced magnetisation is ascribed to the effect that the elementary magnets of a matter are enhanced by external magnetic fields (e.g. the Earth's magnetic field), and, therefore, partly align with it. The magnetic susceptibility describes the propensity for this alignment, determining the strength of the enhancement of the magnetic field. The highest magnetic susceptibility values in soils are observed at ferromagnetic or ferrimagnetic minerals like the iron oxides magnetite and maghaemite. These minerals occur ubiquitously in the soil, forming microscopically small grains.

While the induced magnetisation requires an external magnetic field for its development, the remanent magnetisation stays fixed in a material after its creation. The most important type of magnetic remanence is caused by heating a material over its specific Curie temperature so that the elementary magnets become mobile and align with the external Earth's magnetic field. During the subsequent cooling, the alignment of the magnets is conserved and consequently, the burnt material becomes a strong magnet. Since the average Curie temperature of soil components is around 650°C, fireplaces, kilns, layers of burnt daub and other burnt material, and accumulations of pottery can be detected on the base of this effect (Fassbinder 2017).

Another important magnetic phenomenon is diamagnetism. Structures mainly composed of diamagnetic materials, like quartz or calcite, cause noticeable negative anomalies. Diamagnetic materials literally repel the external magnetic field and form a strong magnetic field in the opposite direction, so that the resulting anomaly field has negative amplitudes. Based on this effect, buried constructions of limestone or sandstone, as well as fills of sand and calcareous sediments, can be identified in the magnetic data as anomalies with negative amplitudes of the magnetic gradient.

Figure 1. Fluxgate gradiometer array LEA MAX with 10 sensors during measurements at the prehistoric site of Dolina (Brod-Posavina county).

For the magnetic investigation, arrays of Förster fluxgate gradiometer probes mounted on a light and foldable cart were used (Fig. 1). Depending on the topographical and surface conditions of the investigated sites, there were taken between 5 and 10 fluxgate sensors. These gradiometer arrays are components of the convertible LEA MAX system (Zöllner et al. 2011).

The Förster FEREX fluxgate gradiometer probes register the vertical gradient of the vertical component of the Earth's magnetic field with an accuracy of 0.1 nT. The measured gradient (the difference between two vertically arranged sensors in a gradiometer probe) is insensitive to the typical large fluctuations of the Earth's magnetic field and is determined only by the magnetization of local anomalies in the ground (Schmidt 2009). The sensor separation and thus the profile distance was 0.5 m.

The data positioning for the magnetic survey was realised by means of differential GPS, using two GNSS receivers NovAtel SMART V1 in RTK mode (Real-Time Kinematic) to achieve a relative accuracy of 2 cm. The coordinate system in use during the magnetic measurements was UTM WGS84. When available, the coordinates of fixed points, located at the archaeological sites were used to correct the position of the base with the result that the absolute accuracy of the positioning reaches a level of ±2 cm. If no fixed points were available, the coordinates of the base were corrected by a RINEX data post-processing using the correction data of EUREF stations in Croatia. After data acquisition and processing, the results were re-projected into the project coordinate systems UTM ETRS89 or HTRS96 Croatia TM by means of the open-source Cartographic Projections library GDAL.

As a next step, the binary magnetic data were decoded and merged with the GPS data using a script-based decoding routine (ealdec). The actual data processing comprised of an offset and a drift correction of the data sets of each channel. Applying another script in an UNIX shell (ealmat), spike values were excluded from the correction. The maximum order of polygon fitting was set to the value of 2. Subsequently, all decoded and corrected profiles were summed up into one single file. This file was subjected to a grid routine producing a Surfer7-compatible grid with an equidistant mesh of 0.25 m. At the end, this grid file was used to generate a GeoTIFF image, that can be projected into GIS projects and served as a base for the archaeological interpretation.

b) Interpretation base

Interpretation of geophysical data is more than just a description of measured values and their spatial distribution, or equalisation of measured values and archaeological features. In most cases, the data are interpreted qualitatively as many surveys are strictly non-invasive, which means that neither test excavations nor material sampling for laboratory testing are included. The reason for this, on the one hand, is the limited means and capacities and, on the other hand, the high quality of qualitative interpretations, which, according to experience, serve as a solid basis for further work such as excavations. Thus, the interpretation drawings display the result of an approach that combines the knowledge of physical properties of the soil with the descriptive and comparative methods of archaeological interpretation (Neubauer and Eder-Hinterleitner 1997; Meyer 2013).

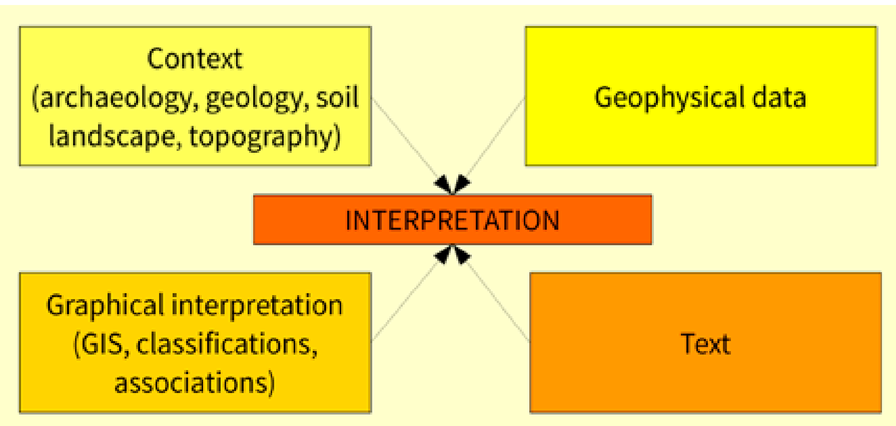

Figure 2. Scheme for interpretation of geophysical data from archaeological sites.

Needless to say that the precarious character of any qualitative and comparative interpretation has to be taken into account since the reading of geophysical data can evermore be subject to new or evolving hypotheses and knowledge.

The minimum requirements for the interpretation of geophysical data in archaeology include both, a georeferenced graphical and a descriptive part which does not only repeat the graphical interpretation, but it also includes an evaluation of the chosen methodology, considerations on the certainty and the plausibility of the interpretation (Fig. 2).

Since the majority of the data comes from magnetic surveys, the basis for interpretation is explained more detailed here only for magnetic data. For more specific insights into the interpretation of GPR data see Conyers 2012, for example.

The general approach to classify the magnetic anomalies is to distinguish them respectively by means of their amplitudes, polarisation and shape. Secondly, the spatial distribution, geometric patterns and spatial interrelationships of anomalies and their clusters were taken into account in the interpretation. Of course, comparative observations of similar archaeological sites and the data obtained there, were of crucial importance to check the archaeological plausibility of the interpretation.

As part of the first step, anomalies of unambiguously modern and thus archaeologically irrelevant origin, in most cases indicating ferromagnetic objects, are separated and marked. Magnetic anomalies of modern ferromagnetic objects usually show very high amplitudes of the Z component of the vertical gradient. Depending on size, distance from the sensor and magnetisation, they can reach several hundred Nanotesla. Moreover, these anomalies mostly have a clear dipole character. Especially, wire fences, electricity poles and scrap metal deposits cause anomaly patterns of strong amplitudes and alternating polarisation. In the case of surveys on agricultural land, it is furthermore required that linear anomalies with both positive and negative polarisation, that could be associated with traces of agricultural processing such as ploughing have to be identified by comparison with field observations in order to avoid misinterpretation of linear structures. Especially, the typical small plot size, observed in large parts of Slavonia, can cause a high density of these agricultural magnetic anomalies.

The next step is to sort the remaining anomalies that were assumed to have an archaeological or geomorphological background. In order to structure these anomalies, several classes are introduced with corresponding causal physical structures.

Since the predominant natural rocks in Northern and Eastern Croatia are Neogene limestones and sandstones, it can be assumed, that these materials are also found at archaeological sites as a construction material. Quartz and calcite, the minerals forming these rocks are diamagnetic matters, i.e. they repel the external magnetic field and cause negative magnetic anomalies. For this reason, negative anomalies in a linear arrangement can usually be associated with foundation remains. The plausibility of these assumptions can be checked by mapping wall remains visible on the surface, identifying the right angles and comparing the position of the assumed structures with the topographic situation. However, it is also possible that the limestones and sandstones with accompanying minerals show a superposition of diamagnetic, paramagnetic and ferromagnetic effects, resulting in diffuse anomaly patterns with very weak amplitudes. This may explain some difficulties in the identification of ancient construction remains in magnetic data of the region, as well as provides the justification for using the GPR or geoelectrics as complementary methods.

Negative anomalies of less strict geometric appearance also originate at accumulations of predominantly diamagnetic material, found at backfills of sand or calcareous material. These backfills may refer to ramparts or remains of prehistoric or ancient excavation works. Eventually, negative anomalies are observed at negative, i.e. excavated structures which were refilled shortly after. In these cases, the material mixture, although chemically identical to the surrounding soil, causes the original magnetization, the sum of induced and remanent magnetization, to be reduced by the remanent part, which disappears when the material is randomly mixed (Fassbinder 2015).

Besides firm construction remains, other archaeological features can be identified in magnetic data. Firstly, circular, ellipsoid and rectangular positive anomalies with low to moderate amplitudes (in the range of 1 to 10 nT) and extensions between 1 and a few meters often can be attributed to pit fillings. These features can reflect the positions of construction pits in relation to the building remains, working and storage pits and burials on necropoleis. A detailed archaeological interpretation of these type of anomalies is only possible under consideration of their spatial archaeological context. The weak positive values of the magnetic gradient origin in an increased

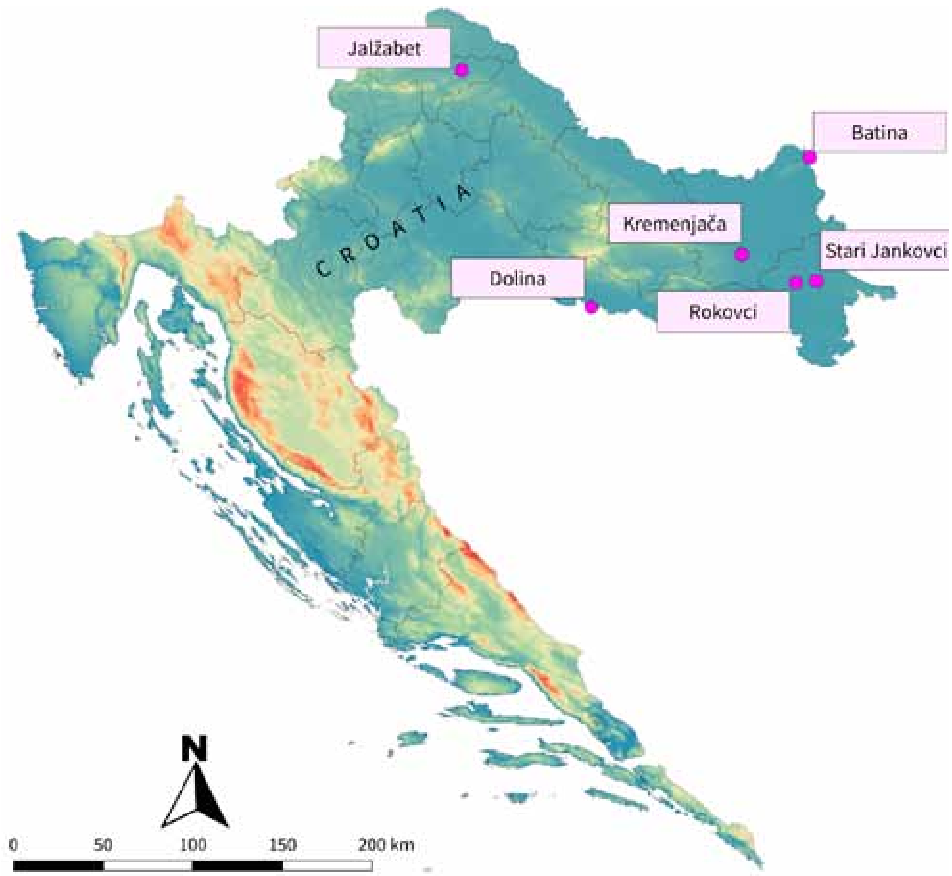

Figure 3. Location of the mentioned sites in Northern and Eastern Croatia.

magnetisation, where both, induced and remanent magnetisation occur. The induced magnetisation is caused by an increased content of ferrimagnetic iron oxides in the pit fillings. That is an effect of conversion of low magnetised iron oxides into ferrimagnetic oxides such as maghaemite and magnetite in combustion processes and by microbiotic influence (Fassbinder 2017). In addition, anomaly patterns which are associated with ditch fillings show the similar amplitude and polarisation characteristics with linear geometry.

Furthermore, clearly recognisable magnetic dipole anomalies with medium amplitudes and north-south orientation of the dipoles usually occur in magnetic data of archaeological sites. In fact, all magnetic anomalies are composed of magnetic dipoles, but in gradiometer data, measured at a short distance from the magnetised objects and materials, only the magnetic anomalies of higher magnetised objects appear as recognizable dipoles. If these dipole anomalies, under the assumption that they do not reflect modern effects, are arranged in clusters or are found inside of assumed buildings and in their surroundings, respectively, they can be considered as accumulations of predominantly thermoremanent material indicating remains of furnaces, hearths or other human-made fireplaces. Features of this type have been observed and described at numerous archaeological sites (Aitken 1970; Linford and Canti 2001, for example).

Eventually, magnetic anomalies reflecting natural structures and features can also be identified in most data sets. Elongated or extensive zones with apparently irregular order of positive and dipole anomalies often correlate with bedrock outcrops, silted-up water courses and other geomorphological structures. The prevailing complex anomaly patterns depend on the material properties of rocks and soil minerals and layer thickness.

Another class of natural effects are magnetic anomalies coming from lightning strikes. Amplitudes and polarisation are often similar to magnetic anomalies from remains of ovens, however, they lack the archaeological context and are found at highly exposed places. Depending on the geological conditions, these anomalies have a dipole or multi-pole character and very variable shapes, including long curved lines or butterfly shapes (Jones and Maki 2005).

All anomaly classes described are presented in different colours and hatchings in the interpretation drawings (see legends). For reasons of clarity, the anomalies of modern origin are not displayed on some of the interpretation maps.

Overview of the described sites and surveys

Of the more than 30 sites investigated since 2014, 6 are presented in this paper (Fig. 3): Magnetic prospection and a GPR survey were carried out at the Hallstatt site of Jalžabet (Varaždin county) during two campaigns in 2016 and 2019. The Late Bronze Age and Early Iron Age site of Dolina (Brod-Posavina county) was investigated by magnetic measurements in 2014. Since 2018 magnetic prospection works have been carried out at the Neolithic site of Kremenjača near Gorjani (Osijek-Baranja county). A total of 4 survey days since autumn 2018 and an area of 20 ha has been investigated. The prehistoric and Roman necropoleis of Gradac and Sredno, located on the loess ridge of Bansko brdo in the archaeological landscape of Batina (Osijek-Baranja county) were surveyed by means of magnetic prospection in autumn 2016. The case study of Stari Jankovci (Vukovar-Srijem county), also from autumn 2016, is an example of a targeted investigation of an assumed burial mound that resulted in containing a major Roman burial. The half dozen case studies are completed by the investigations in the surroundings of the medieval site of Rokovačke zidine (Vukovar–Srijem county), realised in March 2018. The total area of all surveys is about 53 hectares.

The Hallstatt site of Jalžabet (Varaždin county)

The Early Iron Age site of Jalžabet was subjected to two geophysical prospection campaigns using both, magnetic prospection and GPR surveys.

The site of Jalžabet is located at the southern rim of the Drava valley, 18 km to the southeast of Varaždin. It is situated in the contact zone between the tertiary hills in the South crossed by water courses flowing into the Drava and the river plain. The plains are covered by thick layers of alluvial sediments. On the slopes, there can be expected colluvial soils and older river terraces.

The site with the striking Early Iron Age burial mound of Gomila belongs to a large prehistoric landscape, characterised by settlements and necropoleis. The entire area can be assumed to have a diachronic stratigraphy, which is partly confirmed by the results from excavations. Many smaller elevations have been identified so far by the use of LiDAR data and field surveys. However, it has to be suspected, that the majority of the burial mounds are almost completely flattened (Šimek and Kovačević 2014).

Archaeological investigations at a flattened mound, called "Hügel II" revealed a complex funerary monument, comprising a pebble-paved plateau, a rectangular burial chamber of stones, and dromos marked by stones. Small finds in large numbers and the organic remains found in the originally wooden funerary chamber proved the cremation of a horse (Šimek 1998). Under consideration of the results of the geophysical survey of 2016, a large-scale excavation started at the burial mound of Gomila in September of 2017 (Kovačević 2018).

The geophysical investigations were effectuated in the surroundings of the burial mound of Gomila and on the mound itself. In autumn 2016, an area of about 4 hectares was measured, located on isolated fields around the mound. Further measurements were impeded by the inaccessibility of the field due to crops. Thus, the second campaign was projected for the spring season and realised in March of 2019. Then almost 10 hectares of ploughed fields were investigated. Partly, the gradiometer array had to be carried by hand, which slowed down the fieldwork. Nevertheless, it was still possible to survey about 3 hectares per day. Additional GPR measurements were applied on a smaller part of the plateau of the Gomila tumulus in order to obtain a better database for the interpretation of the expected funerary structures inside the mound.

The aim of the investigation was to work towards a clearer understanding of the overall setting of the assumed prehistoric landscape around the Gomila tumulus. The magnetic data from the immediate surroundings of the tumulus prove the existence of a ditch system with at least one entrance and probably a stone row outside the ditch. Possible sites of flattened tumuli were identified in the area to the northeast of the Gomila tumulus. The correlation between terrain and the prehistoric structures becomes visible in two, North-South running extensive ditch systems, framing the Gomila and a larger area of the settlement remains. The combination of magnetic and GPR data from the tumulus revealed many details including the rough dimensions of the burial chamber and information on the preservation status of the burial. The stone rows found around the burial chamber reflect as negative magnetic anomalies and as highly reflective zones in the GPR data, respectively. Direct verification of

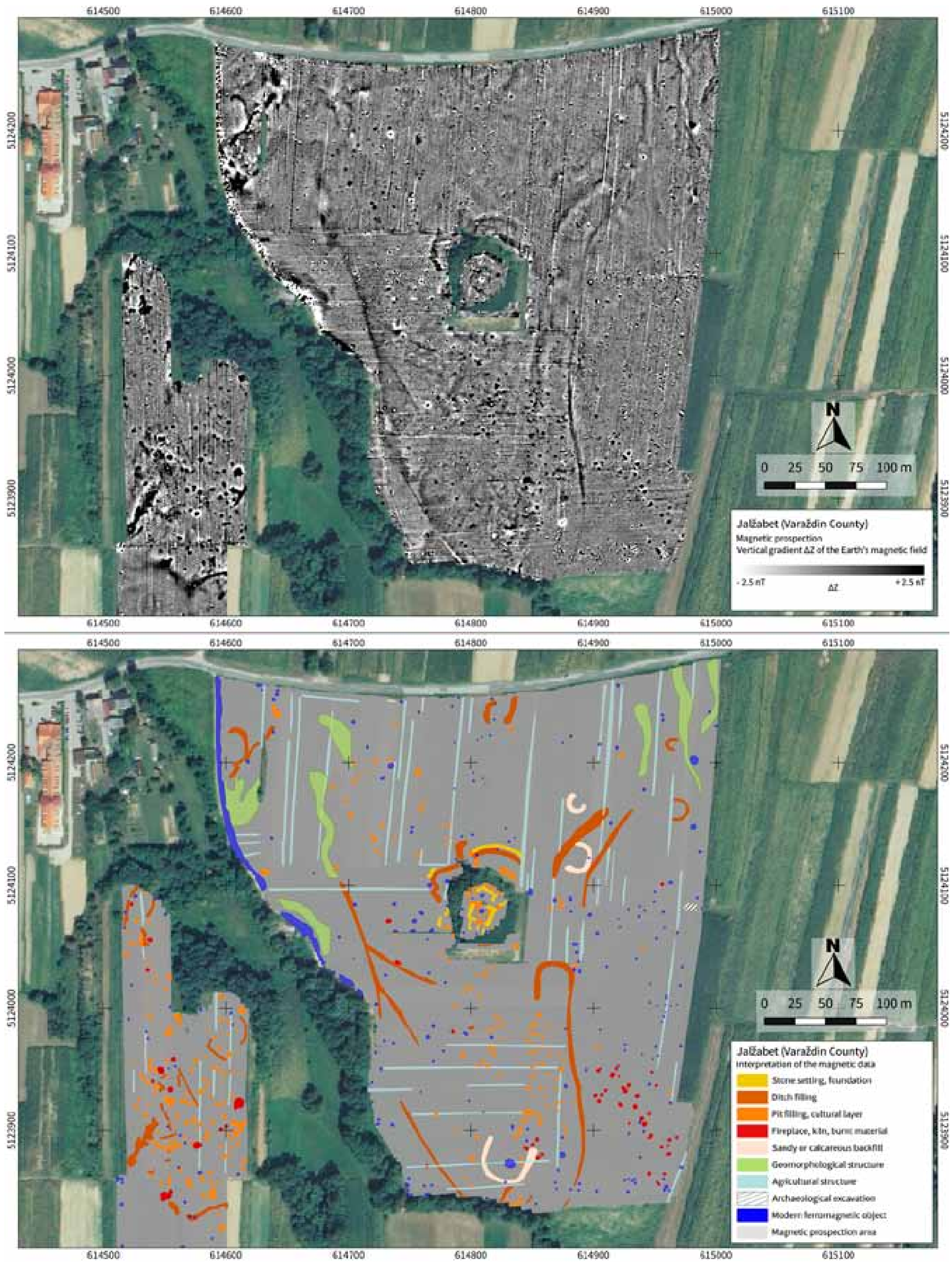

Figure 4. Jalžabet: Magnetic data and archaeological interpretation (Coordinate system: WGS 84 UTM zone 33 North, EPSG: 32633, orthophoto: geoportal.dgu.hr).

the burial chamber was not possible due to modern contamination in the central part of the plateau. Magnetic data and their interpretation are presented in Figure 4. Nevertheless, future archaeological research and additional geophysical surveys are strongly recommended for verifying the observations derived from the data and to clear up the temporal and spatial relations between the different archaeological structures.

The Late Bronze Age and Iron Age site of Dolina (Brod-Posavina county)

In November 2014 magnetic measurements were carried out on the prehistoric site of Dolina (Brod-Posavina county) on the northern bank of the Sava river. The objectives were to prove the existence of presumed Late Bronze Age and Iron Age settlements and to explore their internal structure. The measurements were carried out at two sites with surface finds that suggested settlement remains in the soil. At the western site, an area of 2.6 hectares was investigated, at the eastern site an area of 2.9 hectares. In addition, magnetic measurements were carried out north of the settlement on the area of the prehistoric necropolis of Glavičice with a total of 4.6 hectares.

The site is located on the northern terraces of the Sava river. In this area, alluvial forests alternate with agricultural land, mainly grassland and cornfields. Therefore, the magnetic measurements had to be limited to the grassland areas and the harvested fields.

Lithologically, the Sava floodplain is characterised by Pleistocene and Holocene sediments of the Pannonian Basin. Due to periodic flooding, hydromorphic soils such as Pseudogley dominate (Vidaček et al. 2001). This soil

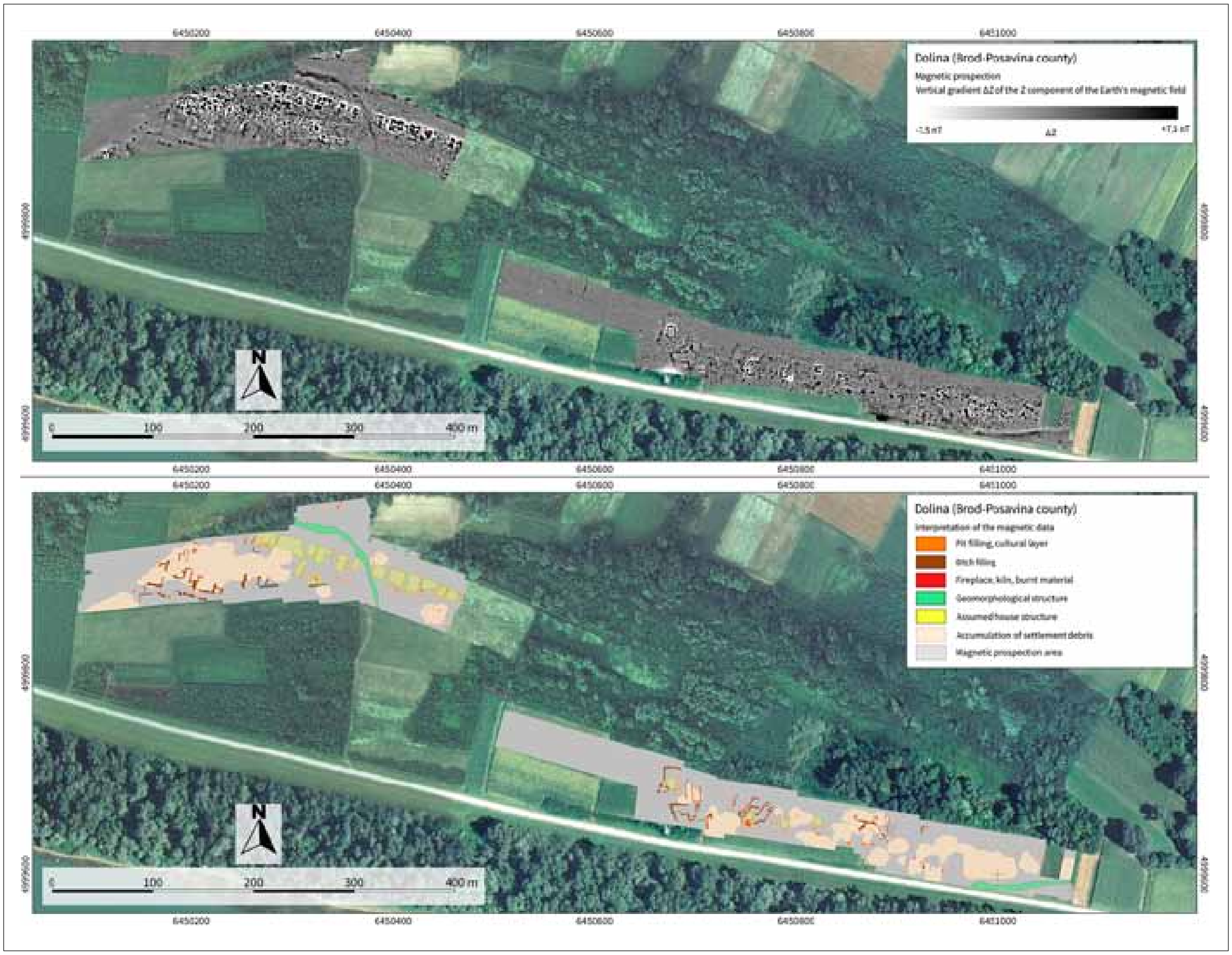

Figure 5. Dolina – Late Bronze Age and Early Iron Age settlement: Magnetic data and archaeological interpretation (Coordinate system: MGI 1901 Balkans Zone 6, EPSG: 3908, orthophoto: geoportal.dgu.hr).

type is characterised by oxygen deficiency and high clay content and offers satisfactory conditions for magnetic investigations at archaeological sites.

At Dolina several archaeological structures are already known, e.g. the Glavičice tumuli group consisting of at least 15 tumuli and the assumed flat grave necropolis of Draganje. In the general archaeological context, the site dates to the Late Bronze Age and the Early Iron Age. However, the settlement associated to the necropoleis is hitherto testified only by numerous surface finds mainly dated between 11th and 7th centuries BC (Ložnjak Dizdar et al. 2010; 2011). The site has been subjected to intensive archaeological investigations since 2009.

The principal aim of the magnetic survey was to enlighten the spatial relationship of the contemporaneous settlement and the cemetery. Up to the magnetic survey campaign, the settlement associated with the tumuli at the position of Glavičice had been located only through field surveys. Its assumed location is on the first elevated plateau next to the Sava River. The distribution of the surface finds suggests that the settlement stretches in the east-west direction over a surface of more than half a hectare (Ložnjak Dizdar and Gavranović 2014).

The buried structures of both, the cemetery and the settlement present favourable conditions for a magnetic survey. High amplitudes of remanent magnetisation can be expected at accumulations of burnt material as to be found in the burials. Prehistoric settlements may comprise remains of collapsed houses built of wood and daub as well as fillings of ditches and pits. Furthermore, remains of kilns and fireplaces cause distinct and strong magnetic anomalies in many cases. These anomalies arise from the thermoremanent magnetisation of the repeatedly burnt materials.

The results of the magnetic survey allowed several conclusions. To the south of the necropolis of Glavičice, an area has been located where remains of human settlement are expected. The populated area is situated on a long, slightly elevated terrain and shows a clear division into three parts from north to south: In the northern part, clearly distinguishable anomalies in almost rectangular clusters probably indicate well-preserved remains of houses or other settlement structures. The structures are characterized by strong magnetic anomalies, which indicate thermoremanently magnetized material, such as fired clay and baking clay. Those are aligned along a WNW-ESE oriented line and have similar dimensions. The central part of the presumed settlement to the south is less clearly defined. Nevertheless, magnetic anomalies indicate the presence of pits, furnace remains and postholes, and in the southern part dominate linear anomalies caused by a system of filled ditches. The total of the populated area could not be accurately determined due to the limitation of the surveyed fields caused by modern agricultural activity. However, it is assumed that the settlement covered between 3 and 5 ha (Fig. 5). Archaeological excavations, based on the magnetic data, has started in 2015 and revealed an even more complex stratigraphic sequence consisting of layers of burnt clay overlaying filled pits of the older house remains (Ložnjak Dizdar et al. 2017).

The Neolithic site of Gorjani-Kremenjača (Osijek-Baranja county)

Starting in October of 2018 a large–scale magnetic survey has been realised at the Neolithic site of Kremenjača (Osijek-Baranja county). The objective of the surveys was to investigate the surroundings of an assumed ring ditch system. In contrast to other Neolithic 'ditch sites' in Slavonia, the system at Gorjani is not visible in aerial photographs (Šiljeg and Kalafatić 2016). So far, the investigated area sums up to a total of about 20 ha at the site of Kremenjača.

The site is situated in the geological formations of the Pannonian Basin. The central Đakovo-Vinkovci plateau together with the Vukovar plateau were formed along regional faults, and are covered by Quaternary deposits. The survey area, situated on the gentle slopes are shaped by alluvial sedimentation processes.

The majority of the Neolithic settlements in Slavonia belong to the Starčevo (earlier Neolithic) and the Sopot (later Neolithic) cultures. In general, the layout of these settlements is diverse and complex and still subject of investigation.

After first, unpublished geophysical surveys on a limited area, first test excavations were carried out in 2015 and 2016. From the four trial trenches, opened at the top of the Kremenjača hillock, the material found there was dated to an age of 5,000 BC and since then archaeological excavations have continued.

The magnetic data, obtained in 2018 and 2019 already provided a substantial contribution to the overall understanding of the prehistoric complex. The data indicate a multi-layered stratigraphy of prehistoric settlements which corresponds to the surface finds. Several complex ditch systems are recognised. Figure 6 shows the status of the magnetic survey and data interpretation from the end of 2018. In the southern and central part, two complex ring ditch systems are observed with axis lengths of about 150 m. With the two outer ditch systems with estimated diameters of 400 and 500 m, respectively, the ring structure can still only be assumed. The density of prehistoric structures decreases from the centre of the site toward the outer limits. The highest densities of structures are observed inside the ring ditch systems and in the north between the central ring ditch and the intermediate ditch. The geophysical data and their interpretation are a very suitable base for archaeological classification in the context of the development of Neolithic settlements in Slavonia (Šošić Klindžić et al. 2019).

The necropoleis of Gradac and Sredno in Batina (Osijek-Baranja county)

In October of 2016, a magnetic prospection was realised at the archaeological sites of Gradac and Sredno in Batina, located on the loess ridge of Bansko brdo, in the Municipality of Draž (Osijek-Baranja county). The objective of the investigation was to identify prehistoric and Roman settlement remains as well as burials of the already known prehistoric and Roman cemetery at the Sredno site. Geology and soils of the area are characterised by Pleistocene sediments of the southern Pannonian Basin. The sites of Batina lay over a plateau composed of loess deposits intercalated by poorly developed palaeosols which accumulated during the Middle and Late Pleistocene forming the northeastern edge of the Bansko

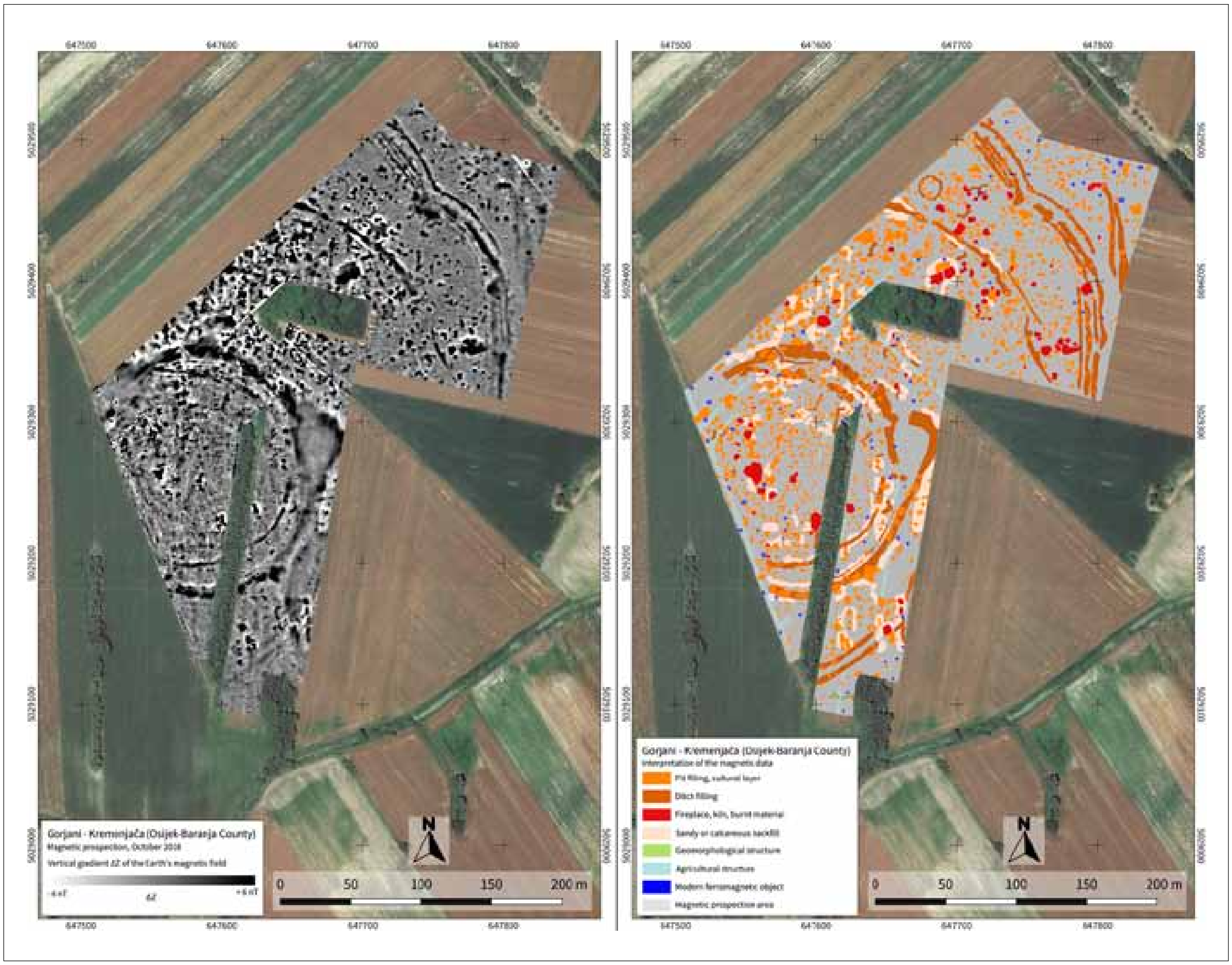

Figure 6. Gorjani – Kremenjača: Magnetic data and archaeological interpretation (Coordinate system: HTRS96 Croatia TM, EPSG:3765, orthophoto: geoportal.dgu.hr).

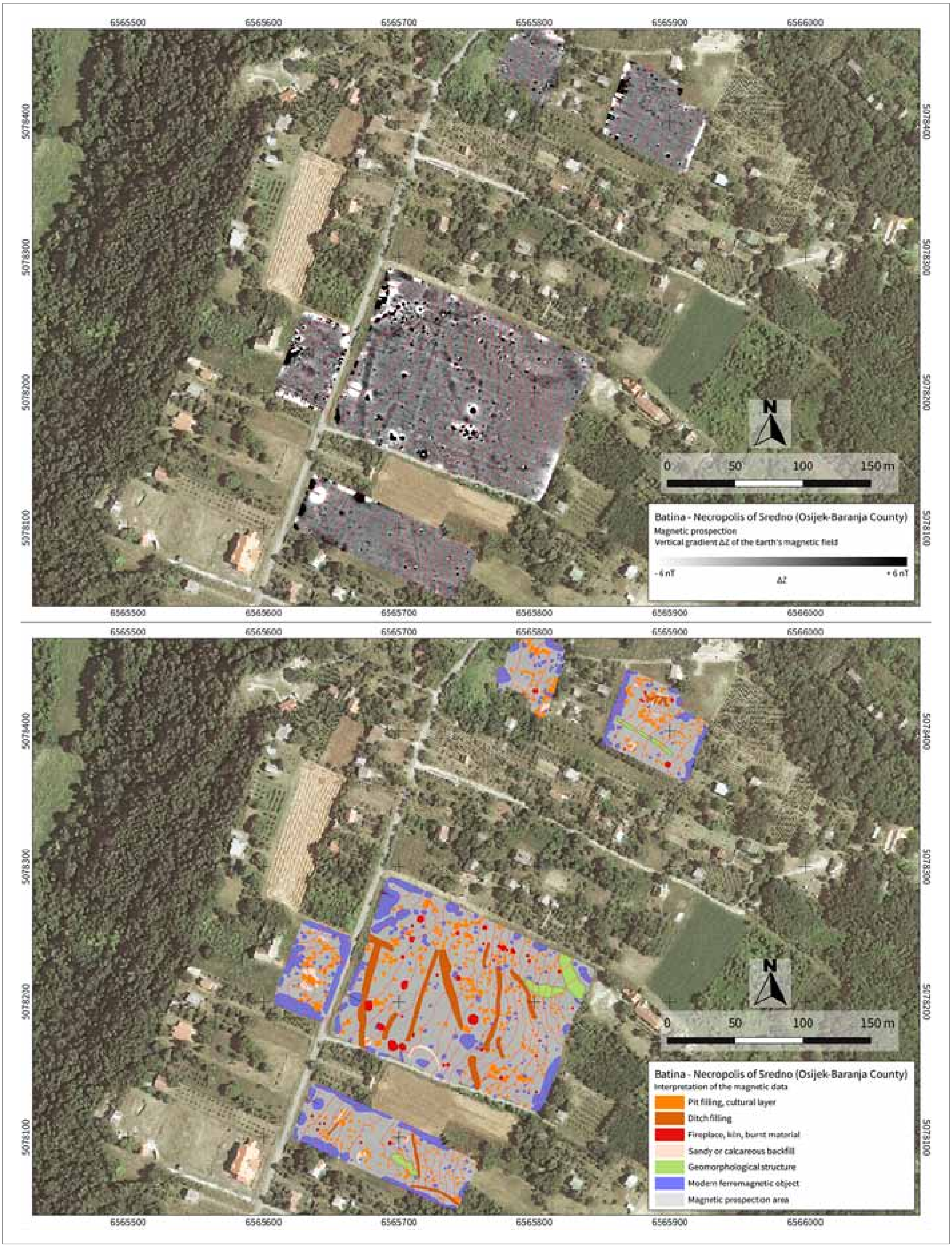

Figure 7. Batina – Necropolis of Sredno: Magnetic data and archaeological interpretation (Coordinate system: MGI Balkans zone 6, EPSG: 31276, orthophoto: geoportal.dgu.hr).

brdo. In addition to thick Pleistocene loess layers and deposits of volcanic rock, the slopes of the plateau, especially on the western and northern edges also reveal Miocene limestone and marl with igneous clastics (Velić and Vlahović 2009).

The important prehistoric and Roman sites of Batina have been subjected to archaeological investigations since 2010. The main focus has been on the Late Bronze and Iron Age settlement and cemeteries. However, the earliest evidence from human activity date back to the Neolithic (6th millennium BC). The long sequence of permanent occupation is expressed in cultural layers up to 6 m thick with rich archaeological finds like fragments of ceramic vessels, stone and metal tools, jewellery and weapons.

Already in 2008, fragments of ceramic vessels and burnt human bones were found during field surveys, pointing to the existence of a cemetery at the site of Sredno. Consequently, remains of burial mounds (tumuli) were discovered, dating to the beginning of the Iron Age (8th century BC). The tumuli contained incineration remains in ceramic vessels or in organic envelopes. So far, 61 graves from the Late Bronze Age and the Iron Age were located and partly excavated. Besides those burials, several ditches varying in width and depth were found (Bojčić et al. 2009; 2010; 2011; Hršak et al. 2013; 2014; 2015; 2016; 2017; 2018).

Of importance for local archaeological research, is also the fact that in November 1944 the Battle of Batina, one of the largest battles of World War II, took place here. It can be taken for granted that the combat operations, involving several tens of thousands of soldiers, left significant marks in the ground.

Magnetic measurements were executed on an area of approximately 3.6 ha. Despite the proximity of modern buildings and the impact of WWII, the data quality allowed for a detailed interpretation of the geophysical data (Fig. 7). The magnetic data from the cemetery site of Sredno revealed numerous archaeological features. Firstly, several clusters of incineration burials were identified, and secondly, the data gave some weak indications of the existence of flattened tumuli. Furthermore, the magnetic data showed a complex network of filled ditches in the southern part of the investigated cemetery site, confirming findings from previous archaeological excavations. Subsequent excavations revealed several new incineration graves in very good coincidence with the magnetic data interpretation, However, also burials of a fallen soldier of the Batina battle were discovered (Hršak et al. 2018).

A burial mound near Stari Jankovci (Vukovar-Srijem county)

The archaeological site of Stari Jankovci is located east of Vinkovci (Vukovar-Srijem county). It consists of at least four tumuli, of which three are known and located inside the forest. They are up to 8 meters high. For a long time, their context and place in time have been unknown. The fourth and already flattened tumulus lies outside of the forest and is recognised as a smaller elevation in the flat terrain.

This tumulus and its immediate surroundings were subjected to magnetic measurements on an area of about 0.5 ha. The archaeological interpretation of the magnetic data is hindered on the western side by numerous groups of strong dipole anomalies reflecting modern deposits. However, the data obtained from the area of the tumulus itself allow a detailed interpretation (Fig. 8). Two very strong circular dipole anomalies stand out in the centre of that structure. They probably reflect a large accumulation of burnt material and ferromagnetic objects, pointing to major incineration burials. Around the two dipoles, linear positive anomalies reflect earthen features which refer to the construction of the mounds. Also, in association to these anomalies, smaller linear negative anomalies are visible and reflect stone settings, probably from diamagnetic sandstone. Recent archaeological excavations revealed a two-wheeled Roman chariot with the fossilised remains of two horses in a large burial chamber (Fig. 8). The finding corresponds with one of the large dipole anomalies. Thus, the dipole anomalies originate in the strong magnetisation of iron parts of the chariot and the horses' harnesses as well as from the burnt material associated with the burial.

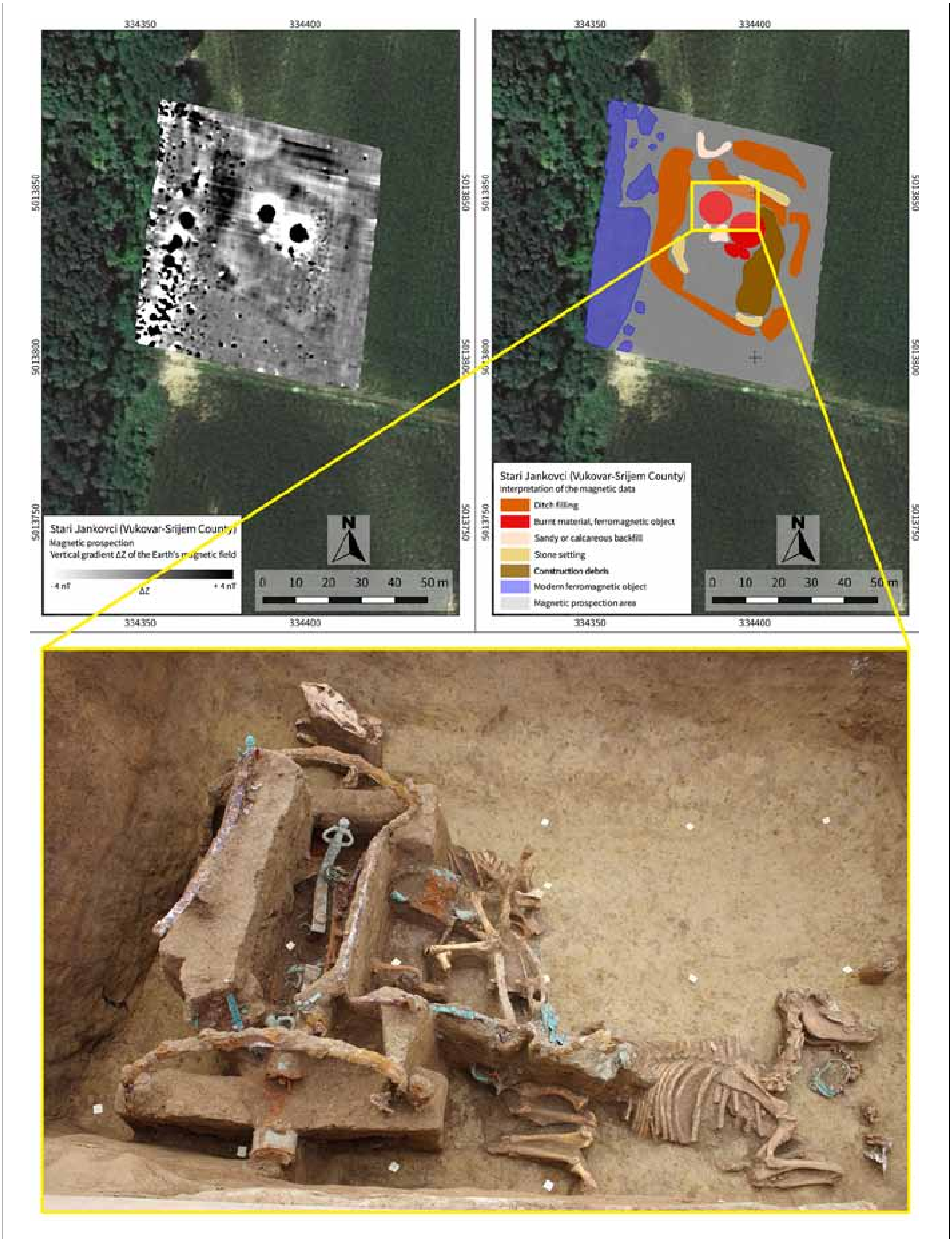

Figure 8. Tumulus near Stari Jankovci: Magnetic data, archaeological interpretation and a photograph of the Roman chariot, excavated in 2019 (Coordinate system: ETRS89 UTM zone 34N, EPSG: 25834, orthophoto: geoportal.dgu.hr, photograph: Boris Kratofil).

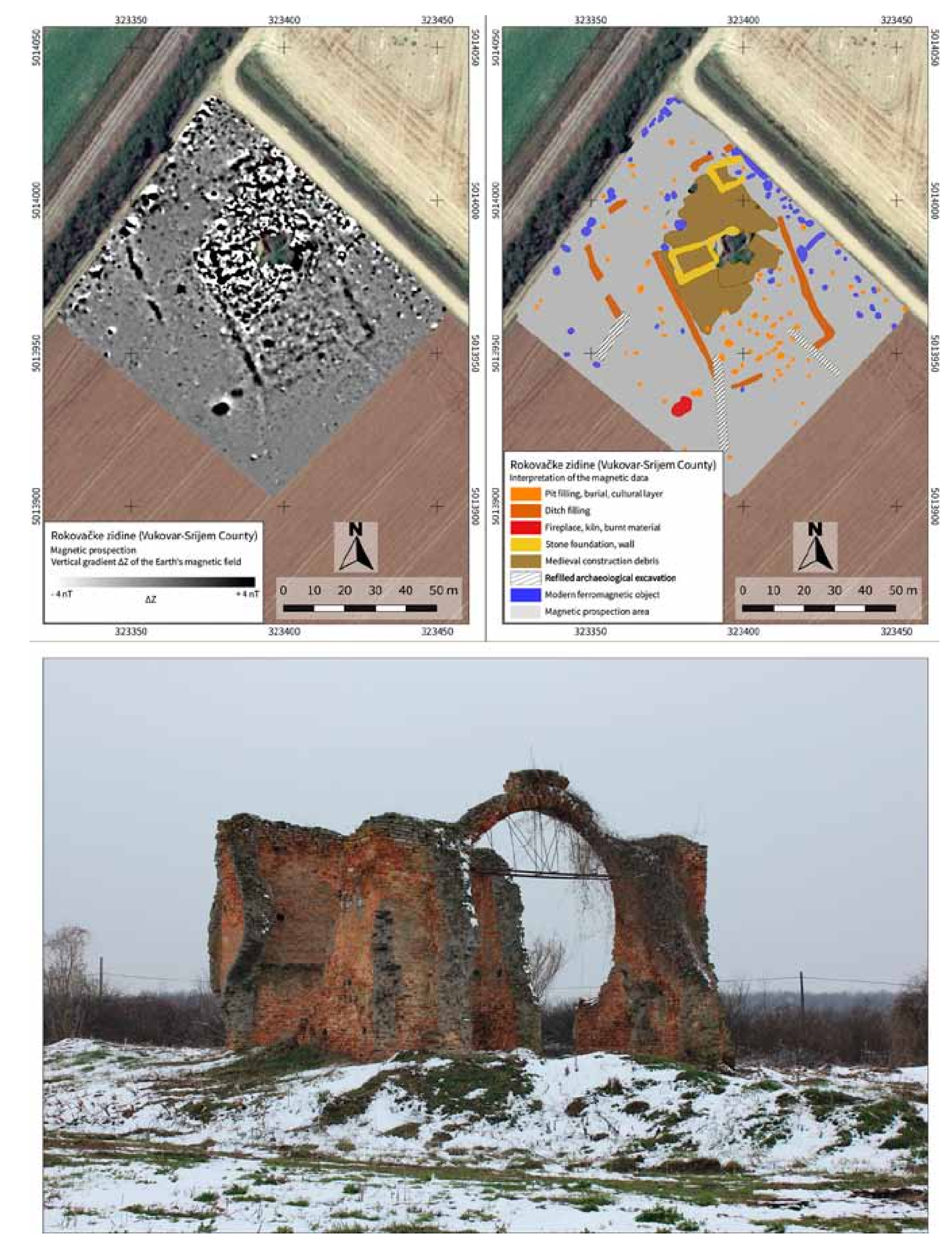

Figure 9. Rokovačke zidine: Magnetic data, archaeological interpretation and terrain conditions at the church's ruins (Coordinate system: ETRS89 UTM zone 34N, EPSG: 25834, orthophoto: geoportal.dgu.hr, photograph: Cornelius Meyer).

The medieval site of Rokovačke zidine (Vukovar–Srijem county)

In March of 2018, a magnetic survey was realised on the medieval site of Rokovačke zidine near Rokovci (Vukovar–Srijem county). Based on historical sources and prior archaeological research, the site was identified as a 15th-century church, that most probably was part of a Franciscan monastery (Petković and Rapan Papeša 2011).

The investigated site is located a few kilometres to the south of Vinkovci. The landscape of the region is shaped by the Bosut river. Numerous archaeological sites in the surroundings of Vinkovci are concentrated along the meandering and slowly flowing river. In the middle of the completely flat fields between Vinkovci and Rokovci, the ruined walls of the medieval church called Rokovačke zidine, rise up. There has been much debate about the age and function of the building. It is assumed that the surviving walls date back to the 15th century and that they belonged to a Franciscan monastery founded at a place of a previous medieval village (Petković and Rapan Papeša 2011). The remains of the church are composed of baked bricks and ashlar. Those rise out of a slightly elevated plateau with a surface of not more than 2.000 m². It is reasonable to assume that the plateau consists essentially of the debris of the church and its no longer visible adjacent buildings.

In order to obtain information on adjacent buildings and the spatial organization of the monastic complex, the magnetic array LEA MAX was used to investigate a total surface of approximately 0.9 ha. The gradiometer system was set up with respectively, 10 and 7 fluxgate gradiometer probes. Depending on the different surface conditions on the site, it was either moved on wheels or carried by hand. The obtained data indicate the existence of a ditch forming a rectangular enclosure of the religious complex. Furthermore, the ground plans of two adjacent buildings were identified. Numerous pits, found in the area to the south of the church, suggest the existence of a necropolis (Fig. 9).

Conclusion

Measured by effort and benefit, the systematic investigation of archaeological sites with geophysical methods is a highly effective tool. The archaeological record and the natural conditions found in large parts of Northern and Eastern Croatia favour the application of the magnetic prospection as primary investigation method. Thanks to the development of light-weight and flexible magnetometer arrays, the survey of large areas in a short time is possible. Using human power to drive the equipment daily outputs of up to 6 hectares are achievable. The productivity can be increased by using ATVs for pulling the magnetometer arrays. In this manner, daily surveys of 25 hectares are feasible, given favourable surface conditions. However, the typical small plot sizes of the region and the requirements of field owners and tenants often impede the use of motorised vehicles, which may cause considerable damage to fields and crops.

The value of geophysical surveys can further be enhanced by the application of more than one method. In the case of urban surveys and investigations of Roman and medieval sites, the GPR can yield complementary results which can support the process of data interpretation. Geoelectrical and GPR measurements are also recommended at the investigation of complex sites such as burial mounds or multi-phase settlements. In contrast to magnetic surveys, geoelectrical and GPR data allow to determine the depth of located structures with sufficient precision. However, typical alluvial soils of Slavonia are less suitable for georadar investigations due to their high clay content and the resulting strong attenuation of the electromagnetic waves.

Besides the advanced equipment and the consideration of the environmental conditions, the simple truth is that the value of a geophysical survey is essentially determined by the quality of data processing and interpretation. Only with a detailed analysis, which must also include a consideration of its reliability, geophysical data can be used to plan excavations or protective measures at threatened monuments. Therefore, it must be emphasized again that geophysical data cannot provide a direct image of ground structures, even if the interpretation drawings sometimes suggest this, but only open small information windows to the structures in the subsoil that refer to the respective geophysical parameter recorded.

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Image-based modeling approach in documenting Early Christian memorial chapel in Velić, Croatia

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Systematic archaeological excavations in the Velić village, near Trilj, began in 2013. By 2019 we revealed the remains of a rectangular ground plan building with a semicircular apse. It consists of the antechamber and three chambers: central chamber with an apse, south chamber, and north chamber with an east-west oriented barrel-vaulted tomb (Tomb 1), which was unfortunately quite devastated. In addition to this devastation, excavation campaigns have been characterized by the extreme poverty of small finds, which prevents accurate dating of the site. Nevertheless, the building can be roughly dated to the period of Late Antiquity and interpreted as an Early Christian memorial chapel. This assumption was reinforced in the 2019 excavation campaign when another barrel-vaulted tomb (Tomb 2) was detected below the central chamber with an apse. This time it was sealed and intact. It had a small square antechamber with a vertical stone slab serving as a door to the tomb. Its barrel-vaulted ceiling was completely preserved, and skeletal remains of four individuals were identified laying down on two flat stone plastered beds in the grave chamber.
Although the tomb and its state of preservation were astonishing, the archaeological excavation faced a daunting task of documenting the buried structure and its content. Since image-based modeling has been used as a practical and detailed documentation tool on the site so far, it was only natural to approach this part of the excavation in the same manner. This paper will present difficulties and solutions that we came across during the documentation process of this barrel-vaulted tomb as well as some conclusions and interpretations of the tomb and the larger complex around it.

Keywords: *Velić, Early Christian memorial chapel, barrel-vaulted tomb, archaeological documentation, image-based modeling, photogrammetric 3D models*

Introduction, context, site

Archaeological site discussed in this paper is located in the area of the Velić village, 6 km northeast of Trilj, along the north side of the state road connecting Trilj and Livno in Bosnia and Herzegovina. The site, situated on a plateau overgrown with young forest and low vegetation, remained unknown until 2011 after which it undergoes archaeological surface survey on several occasions and, from 2013, systematic archaeological excavations with the conservation of the discovered architecture (Tončinić and Demicheli 2013; Tončinić et al. 2014; 2015; Bubić 2015; Tončinić et al. 2016; 2017; 2018; 2019). In addition

Figure 1. Remains of a rectangular building with an apse located in the vicinity of Velić (Archive of the Velić project, VEL19-003, made by: M. Vuković).

to this research, in 2014 a student project was launched with the aim of mapping the surrounding structures currently visible in the landscape. Today, this project also encompasses the creation of a 3D model of the site as well as the mapping of historical road communications in the wider area (Bužanić et al. 2017; 2018; Tončinić 2020: 375-378).

To this day we have excavated, documented, and preserved the remains of a rectangular ground plan building (dims. 8.46 x 10.52 m) with a semicircular apse (2.74 m wide and 1.92 m deep) (Fig. 1). The structure is oriented east-west, with a slight deviation towards the southeast. It consists of a smaller rectangular antechamber and three chambers of different sizes and shapes: central

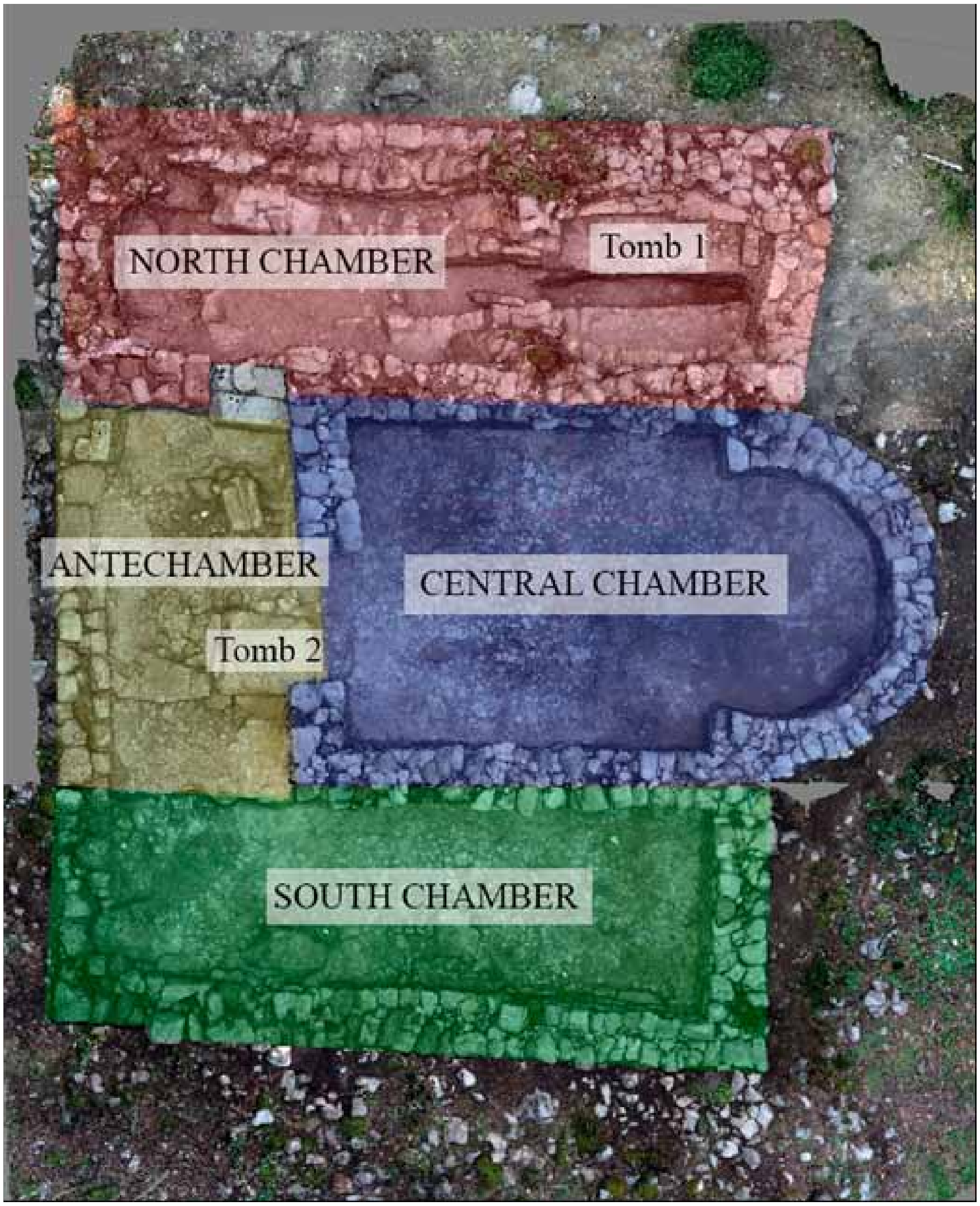


Figure 2: Colored display of chambers and tombs within the excavated building (Archive of the Velić project, made by: M. Vuković).

chamber with an apse at its eastern end, south chamber, and north chamber that contains a barrel-vaulted tomb (Tomb 1) (Fig. 2). The building has a plastered floor (Tončinić 2020: 372).

The entrance to the antechamber (dims. 6.70 x 2.20 m) of the object is located on the west and defined by a threshold consisting of two stone slabs of different dimensions. The central part of the structure occupies the largest chamber (internal dims. 3.75 x 4.35 m) with its entrance to the west, from the antechamber, and the aforementioned apse to the east. The south chamber (internal dims. 8.46 x 3.40 m) is entered directly from the antechamber, without any visible threshold, doors, partition walls or denivelation, while at the north end of the antechamber lies a stone threshold used to descend into the north chamber (internal dims. 7.86 x 2.17 m). Its walking surface is on a somewhat lower level than a walking surface of the antechamber, the central, and the south chamber, and its walls are partially laid on the bedrock. In the east part of the north chamber, there is a stone barrel-vaulted tomb.

The object is roughly dated to the period of Late Antiquity and interpreted as an Early Christian memorial chapel (Tončinić 2020: 375). A small number of small finds was recorded during the archaeological research; it is mostly consisted of a greater number of amorphous pottery, several fragments of utility ware and poorly preserved metal findings. For now, the only indication for determining the date comes from poorly preserved mid-4th century coin discovered at the entrance to the tomb in the north chamber. The possibility that the coin was originally a grave good which reached the site of the discovery during the devastation of the tomb is not excluded. However, bearing the context of the discovery in mind, it is more probable that it reached the site before the time of the erection of the memorial chapel, and that the time of minting, between 348 and 361 AD, represents *terminus ante quem non* for construction (Tončinić 2020: 374).

Tomb 1

The aforementioned barrel-vaulted tomb (dims. 9.04 x 3.32 m), whose discovery in 2011 was the reason behind the surface survey and the preservation of this archaeological site, has a square entrance to the west. Originally, it was sealed with the vertically placed stone slab which was found in its proximity. Stairs, partially embedded into bedrock, were used to descend into the burial chamber (Tončinić 2020: 372–373). The barrel vault made of properly hewn slabs of "muljika" (soft local limestone) has not been preserved; however, the east wall of the tomb follows the shape of an arch, with traces of plaster that have been documented (Fig. 3). Therefore, it is highly likely that the vault was made of "muljika" stone slabs vertically stacked next to each other and joined with plaster – in a similar fashion to other vaulted tombs (see: Bubić 2016: 23-25, 53, 62, 126, 129). Inside the tomb, along its north and south walls, are stone plastered beds

Figure 3. East wall of the Tomb 1 (Archive of the Velić project, VEL13-dig0202, author: D. Tončinić).

Figure 4. Cross-section of the Tomb 1, view looking south tomb wall (Archive of the Velić project, made by: M. Vuković).

that serve to lay the deceased, with a narrow channel-like ossuary in between used for depositing skeletal remains. A skeleton was documented on the south bed, with its skull oriented to the east. Anthropological analysis has shown that it belongs to a male individual between the ages of 50 and 60 (Šlaus et al. 2013). Parts of the skeleton were documented in the ossuary as well as at the entrance to the tomb. This discovery, along with the fact that the doors of the tomb were found open, confirms that the tomb was devastated at a hitherto unknown period. The devastation was further evidenced by the scattered parts of skeletons in the central chamber with the apse, presumably belonging to a male and a female, both over the age of 40 (Šlaus et al. 2018).

Documenting Tomb 1

In a very early stage of systematic archaeological excavations, it was clear that documenting the site would prove to be a challenge due to the narrow shape of the discovered vaulted tomb. As the vaulted ceiling of the tomb has collapsed, the birds-eye perspective of the tomb was clear, but the sidewalls and the remains of the vault were hard to approach and document as there was not enough space inside the tomb to get a perspective wide enough for proper documentation of the walls. Additionally, there was a problem with measuring points with the total station as most of the tomb was obscured from the view of the measuring device due to the angle of view and the depth of the tomb compared to the local terrain. The mentioned factors necessitated the search for a documentation method different from what was the standard at that time for this type of excavations.

After short experimentations with laser scanning and image-based modeling, it became clear that the latter method would provide the necessary level of detail and precision. The efficiency of this method compared to laser scanning has already been proven on archaeological sites (Gonizzi Barsanti et al. 2012). The problem with the terrestrial laser scanner in this instance was similar to the problem that arose with the total station: when the scanner was placed outside of the tomb it did not capture all the points inside due to the unfavorable angle, and it was not possible to set the scanner inside the tomb. This problem could have perhaps been solved by using a hand-held scanner for measurements but at the time we didn't have access to such equipment. The image-based modeling approach, on the other hand, satisfied the documentation standards and was also a more cost-effective solution.

Due to the already mentioned features of the tomb, the plan for acquiring the images for the 3D model was complex and the resulting web of images covered the tomb itself from all possible angles. While acquiring the images it was important to consider the final goal, which was to gain a 3D record of the site which would enable the acquisition of all the necessary measurements as well as the necessary orthophoto plans for the technical drawings of the site. These include vertical perspective, side

Figure 5. The discovery of Tomb 2 in phases – a) square "muljika" stone slab covering Tomb 2 (VEL19-dig005); b) Tomb 2 after the removal of the stone slab (VEL19-dig054); c) entrance to the burial chamber (VEL19-dig087); d) human osteological remains at the south bed (VEL19-dig101). Archive of the Velić project, authors: a) V. Matijević, b, c) D. Tončinić, d) M. Vuković.

perspectives, and cross-sections (Fig. 4). To achieve the best result, the images were taken vertically to the surface that was being recorded, so that the potential distortions on the orthophoto plans would be minimized.

Documenting the tomb's surroundings

The image-based modeling approach proved efficient, precise, and fast, so it was quickly implemented on other excavations as well as in the subsequent seasons on the Velić site. As the research progressed, the rectangular building surrounding the tomb began to take shape. As each segment of the building was explored, a detailed 3D model was created. The time spent on the site each year was limited, which is why the excavation of the building spanned over several seasons. Recognizing that this is not an archaeologically ideal situation, image-based modelling approach was accepted as the best solution. This allowed the team to combine the data from multiple seasons in order to get a clear view of the building, enabling the formation of a detailed technical plan of the structure. At the same time, it allowed the combination of the 3D model of the excavated building and the 3D model of the surrounding area (Bužanić et al. 2017; 2018; Tončinić 2020: 377, Sl. 15).

Tomb 2

On the floor of the antechamber at the entrance to the central chamber of the building, a square "muljika" stone slab (dims. 1.20 x 0.90 m) was discovered in 2019 (Fig. 5a). Initially, it was considered to be a simple grave covered with a stone slab; however, lifting the large stone slab uncovered an entrance to a Tomb 2 with a small antechamber and large stone doors still in their original grooves (Fig. 5b-5c).

Tomb 2 has a rectangular ground plan (internal dims. 2.18 x 1.72 m with an average height of 1.60 m) and is oriented east-west, with the entrance located on its west side. The entrance contains a threshold; a tall stair which descends directly into an ossuary (average width of 0.45 m), i.e., a space between two beds (cca. 0.60 m wide each). Barrel vault of the tomb is completely preserved. "Muljika" stone slabs, of which the vault is built, are placed in a similar fashion to those in the Tomb 1. Both of the beds, like the ossuary, contained human osteological remains (Fig. 5d). Anthropological analysis has shown that the remains belong to four deceased individuals: a younger male subject (18-25 years old) whose skeleton rested on the south bed while some bones were also found in the ossuary, and three children (aged: 9-11 years; 4.5-5.5 years; and 3-4 years) (Novak and Carić 2019). The bones of the first child were scattered on the north bed and in the ossuary. The second child was laid on the south bed, with the position opposite to the man's so its head was to the east, and the youngest child was also buried on the north bed, with some bones documented in the ossuary. The skeletons are not entirely preserved and were most likely disturbed by rodents whose remains were also documented in the tomb. There were no other archaeological findings recorded.

Documenting Tomb 2

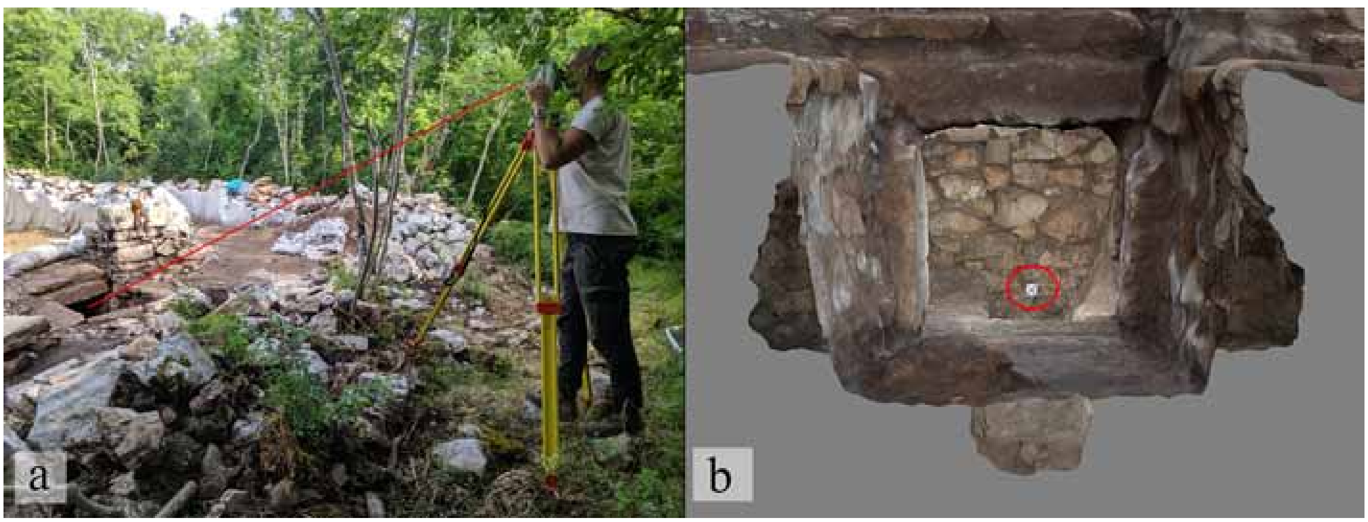
The state of the tomb, together with the skeletal remains, was documented upon entry, and the second set of images was taken after the skeletons were cleared from the dirt. This approach enabled a clear picture of all three phases of exploring the tomb, and more importantly, provided data regarding the exact position of the skeletal remains inside the tomb.

After the human remains and the layers of the soil inside the tomb were removed, the structure was ready for the documentation process. The narrow entrance presented a problem not only during the excavations but also during the measuring of data on the site. By placing the total station at the correct angle outside the tomb (Fig. 6a) we were able to measure two ground control points (GCPs) inside the tomb, at the bottom of the ossuary situated between the two beds (Fig. 6b). Three additional GCPs were situated outside the tomb, in, and around the antechamber next to the entrance.

To acquire the necessary data, a RICOH GR II camera was used in combination with a monopod when needed, and an additional light source was mounted on a helmet because of the dark conditions inside the tomb.

The basis for a good and precise photogrammetric 3D model is image overlap; ideally, the overlap between the two images should be more than 80% (Agisoft LLC 2019). The problem with the overlap in this particular case lays

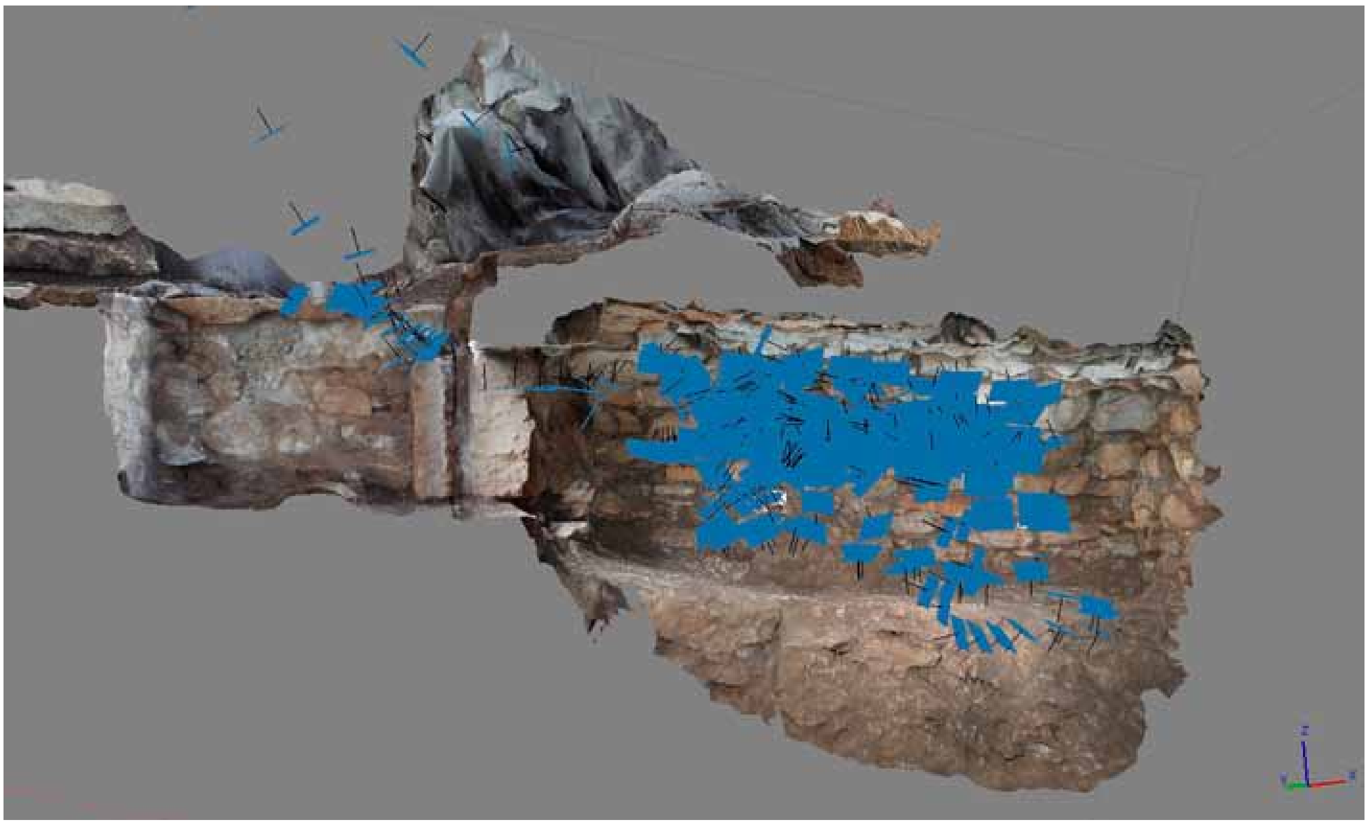
Figure 6. Documentation process – a) positioning of the total station regarding the tomb entrance (VEL19-dig0128); b) ground control point (GCP) inside the tomb (VEL19-MV). Archive of the Velić project, authors: a) V. Matijević, b) M. Vuković.



in the fact that the inside of the tomb was connected to the surface only by the narrow entrance, and that was the only connecting and overlapping area between the two perspectives (Fig. 7). To make sure that the precision of the model will be good enough for the extraction of the orthophoto views, additional relative measurements were taken with a measuring tape inside the tomb itself. This approach allowed for the creation of a 3D model of the inside of the tomb with accurate relative measurements, which can also be used for the creation of orthophoto plans. Nevertheless, the goal was to combine the data from the outside and the data from the inside so that, later on, this dataset could be combined with all the previous excavation seasons. The result was a complex pattern of recorded images, revolving mostly around the singular contact point at the antechamber and the entrance itself. It was important to cover the entrance from all possible angles as well as the inside of the tomb, including the bottom of the tomb, sidewalls, and the vaulted ceiling.

The finished and georeferenced 3D model covered all the necessary surfaces and included all the data needed for a precise orthophoto extraction (Fig. 8). The model was generated from a dense point cloud containing approximately 3 million points, and after georeferencing and bundle adjustment the resulting error in the data was 1.6 cm. The precision of the data was additionally tested by overlapping extracted orthophoto views from a two separate 3D models: the one containing all the data and georeferenced by GCPs, and the one containing only the data from the inside of the tomb with relative referencing done by tape measurers. The conclusion of the test was that the difference between the two datasets is negligible (less than 2 cm) for our documentation process.

Figure 7. Overlapping area between the inside of the tomb and the surface through the narrow entrance (Archive of the Velić project, made by: M. Vuković).



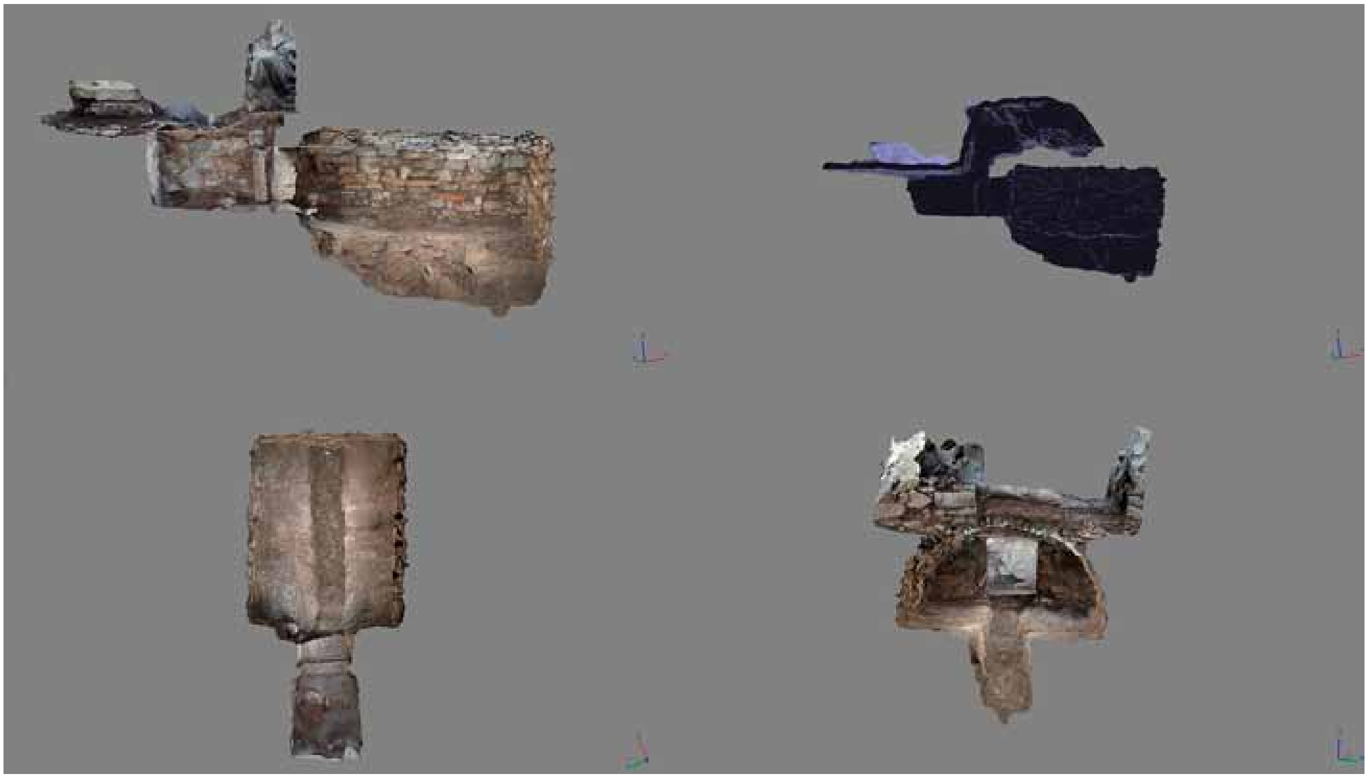
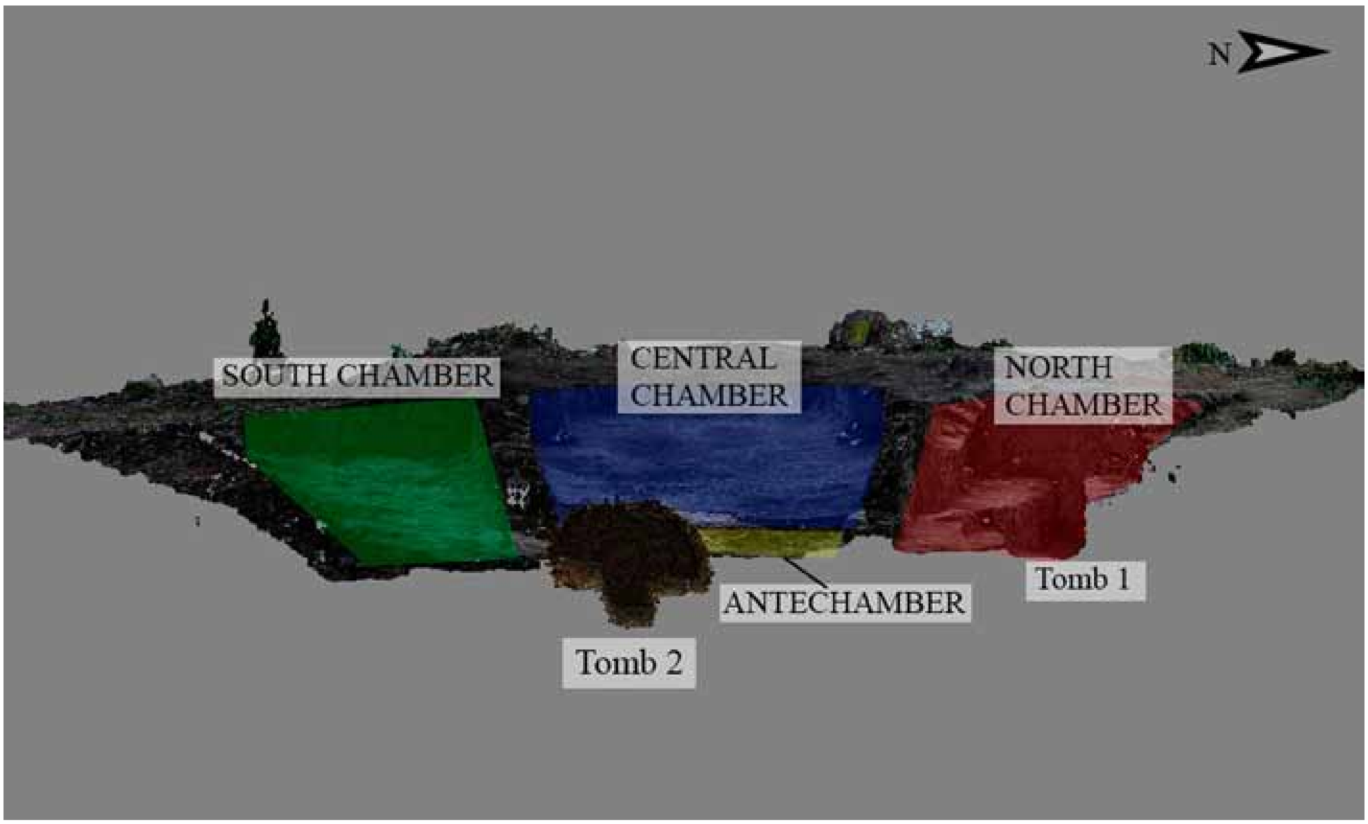


Figure 8. Orthophoto extraction (Archive of the Velić project, made by: M. Vuković).

Figure 9. Understructure view of the excavated building in the vicinity of Velić (Archive of the Velić project, made by: M. Vuković).



Conclusion and further work

This paper presented the difficulties and the solutions that came across during the documentation process of the Early Christian memorial chapel in Velić and especially of the barrel-vaulted tomb (Tomb 2). Although documenting excellently preserved and intact Tomb 2 has proved challenging, the team managed to acquire a complete georeferenced image-based model which was then successfully merged with the models from the previous excavation seasons and thus completing the general view of this Early Christian memorial chapel (Fig. 1). While analyzing the merged data, two things became apparent. With the addition of Tomb 2 at the northern side of the building, the southern side of the apsed building shows a lack of understructures (Fig. 9), and the second obvious conclusion was that there is enough space for another tomb. It is tempting to expect that further research could yield more understructures (probably barrel-vaulted tombs) whose entrances are concealed better underneath the plastered floor of the southern side of the apsed building. Examples of barrel-vaulted tombs underneath plastered floors are known in other sites as well. Naturally, it is necessary to ask oneself whether one can expect more than one privileged grave beneath the Early Christian memorial chapel. As we previously concluded there is enough space for another barrel-vaulted tomb between Tombs 1 and 2. It is interesting that in the entrance hall, north of the entrance to the central room of the building and the entrance to Tomb 2, a fragment of an architectural element (VEL 19 PN 12) reminiscent of the door jambs of Tombs 1 and 2 was documented in 2019. It was documented in the area where the floor in the entrance hall has not been preserved, and where there was a breach in the substructure of the floor. By analyzing the complete georeferenced image-based model of the Early Christian *memoria*, the location of the possible door jamb and the destroyed floor seem to suggest a possible entrance to an additional tomb next to Tomb 2. Given the documented traces of the devastation of the Tomb 1 and the scattered bones in the central chamber with the apse, it is possible that that is a devastated entrance to another tomb. The question of the possible existence of additional tombs under the Early Christian memorial chapel in Velić could be answered by future archaeological excavations.

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A discussion on the theoretical and methodological ramifications of classification and typology of archaeological material: a Perspective from the Late Prehistoric Pottery (Albania)

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The paper deals with the theoretical and methodological underpinnings of classification in Albanian studies of late prehistory. By focusing on the case of pottery analysis, I discuss to what extent research in the classification and typology of archaeological data contributes to interpretations within potential patterns of materials. In so doing I follow a twofold perspective. First, I discuss some notable scholarly contributions which for almost 10 decades have elaborated extensively on this matter. It must be stressed that in Albania and more broadly in southeastern Europe such agendas yet remain peripheral and not fully explored. Second, with a specific focus on Albania, I deal with the ramifications of a conceptual synthesis in the classification of pottery material and to what extent reconstructing the chaîne opératoire from the attributes of the end-product are beneficial in answering an array of scientific queries. The application of the conceptual approach shifts the analysis of late prehistoric pottery from a simple scheme of classification which at most serves as a data organizational tool, to a cohesive framework that intends to measure and evaluate the properties of pottery based on a specific research query. A classification scheme was created for every site and time period. Then, either the vessels grouped in the 'shared concepts' or vessels containing particular attributes categorized as 'individual concepts' were compared among sites in order to measure the quantitative representation of the network's models or potential connections in regional and intra-regional scale. The benefits of this scheme in pottery classification and to what extent potential patterns with weak quantitative profile impact comprehensive analysis to understand regional and intra-regional networks and beyond are some of the questions I address in the last section.

Keywords: *classification, typology, type-variety system, intuitive decisions, shared system of concepts.*

An overview on theoretical and methodological approaches in the classification of artefacts

In this section, I take a wider view on the theoretical and methodological approaches that shaped discussion and research in classification and typology. For a variety of reasons, this discussion has been not at all considered as a question of potential interest in the studies of prehistoric material in Albania and beyond.

The inextricable connection between types and varieties or subtypes with their pertinent cultural groups comprised a pivotal argument which from the 1940s to 1970s led to crucial works in prehistory (Krieger 1944; Ford 1954; Rouse 1960; 1972). In 1944, Alex Krieger published an emblematic paper that marked an important step in the way the classification of artefacts was to be conceptualized. In particular, he treated the 'what's' and 'how's' that define the types and subtypes in archaeological data. Therefore, the *type* came considered as an indispensable element to define the characteristics of a cultural unit and its potential relationships, and also served as an organizational tool upon which further examinations were carried out. *Subtype,* on the other hand, comprised an integral division within the type (Krieger 1944: 271-288). Krieger did offer an integrated synthesis with a strong emphasis on the systemic level, but his theoretical premise type-subtype inherited three main limitations. *First*, it perceived the attributes of the data only and exclusively as a derivate of a pertinent cultural group. *Second*, it reduced highly the possibility to consider the degree of variability, or understand to what extent the choices of the artisan and its expertise give particular properties to the data. *Third*, Krieger perceived the change over time as a unified process and lacks to pay any attention to the immediate circumstances and conditions that a particular context may yield.

Rouse (1960; 1972) argued for a classification strategy that viewed any kind of data under the cultural perspective. Indeed, he recognized that *intuitive* decisions of the scholar interfere significantly to the objectivity of interpretations and of course to any potential result. However, the quantitative applications to groups and patterns could remedy any subjective choice that visual classification yielded. Rouse took a broader focus on cultural remains and produced a three-pier system of classification comprised of *worked* and *unworked* equipments or artefacts. This group was based on the attributes of manufacture and use, for example, houses, axes, and vessels. From the qualitative profile, the attributes of the artefact were classified into aesthetic and functional. In a similar vein with Krieger, he used roughly similar perceptions to describe the classes and types within a category of data. A *class* defined a cluster of attributes classified on the basis of morphological, descriptive, phonetic, natural, or intrinsic properties. On the other hand, the types comprised 'patterns' of attributes encountered in a set of features that became the subject of research. A further attempt following the classification of the cultural remains into taxa and types regard their hierarchical organization into a larger scheme, a process which is alternatively known as taxonomic classification which organizes systematically several classes (Rouse 1972: 50-53). Rouse attempted to confine a universal order of classification that was based on the process of data collection, and its organization and interpretation. In terms of conceptualization and application, Rouse's work did not deviate considerably from that of Krieger's. Again, the equalization among the artefacts, culture, and people constrains the discussion into a problematic scheme in which any variability resulted from individual choices: other issues such as occasional expressions, or the background and expertise of the artisan, did not gain attention at all.

The equalization between culture and types or classes was mostly applied in the classification of pottery. Moreover, pottery was used as a crucial group of data for developing a classification approach coined as the 'type-variety system' (Colton and Hargrave 1937; Colton 1952; Ford 1954; Wheat et.al. 1958; Gifford 1960). The approach introduced two basic aspects. *First,* it promoted at best a cohesive connection between culture and types. *Second*, it brought a dynamic perspective that integrated the theoretical underpinnings with the methodological applications by using the properties of pottery data.

In a similar vein with Rouse, Gifford (1960: 342-343) defined the so-called pottery type as a group of attributes that bear cultural salience. Moreover, through a pottery type, one can perceive openly the shared concepts of a culture and also the degree of interactions within it. The artisan embodies his production attributes and features of a pertinent cultural environment into his craft which Gifford refers to as a *shared system of concepts*. Thus, a type must represent a group of individual choices that reflect other dimensions including the artisan's status within the social environment, imitations, and other kinds of influences. The variety on the other hand, bears variations, strictly associated with the individual choices but relational to the type (Gifford 1960: 345). Gifford elaborated on this approach which had earlier been introduced by a group of authors, including him (Wheat et. al. 1958).

It must be stressed that during the 1960s the type-variety system was rather popular but remained within vague boundaries that evoked essential problems in the classification of pottery. Most of its critiques focused on the perceptions of type and varieties and their frozen equalization with culture. Much later, Dwight Read (2007:94) would argue that simply by assigning cultural salience to a type one cannot easily distinguish nor fully analyze the dimensions of a repertoire. According to him: *not all the possible quantitative dimensions of an artefact are culturally salient and even for a culturally salient dimension, there will be variation arising from the fact that* *the value for a dimension need not to be mapped in an identical manner onto each artefact* (Read 2007: 199). Among other remarks, Read (2007: 56-57) noticed the problematic gap between the assignment of types and varieties and the role that the intuitive choices of the scholar played on such definition. Against this backdrop, he introduced an approach that combined inductive and deductive principles and elaborated a classification system that relies on a triple conceptual association among the *cultural unit*, the *actions of artisan*, and the *properties of artefacts*. Read succeeded to produce a methodological framework that was narrowly defined under the premises of 'thinking' and 'action' and the extent they are confined by the means of culture, exchange, individual expressions, imitations, and inheritance. Type and typology yet remained a valid avenue of his approach, however, as Read (2007: 199-240) argued, such a scheme was to be pursued through comprehensive analysis and selection of qualitative attributes through the evaluation of every ideational and physical action that produces an artefact from the extraction of the raw material to the formation of the end-product. The quantitative dimension became an irreplaceable parameter for measuring the significant groups and patterns of a repertoire. Reads remedied rather significantly the discrepancies of the type-variety system by avoiding the intuitive choices of the scholar and dissolving the imperative connection between culture and types.

Much earlier, Adams and Adams (1991) had provided yet another beneficial advancement especially for the methodological implications of classification and typology. They recognized the complexity of the matter and saw rather skeptically the potential for a cohesive classification scheme that could be universally applied to the archaeological data. The immense variety and nature of the data was a crucial impediment that greatly complicated this endeavor. Instead, Adams and Adams applied a purpose-oriented approach to a particular set of data, with the case of Medieval Nubian Pottery. They distinguished three kinds of purposes together with their corresponding categories including: basic (descriptive, comparative, analytical, intrinsic, interpretative, and historical), instrumental (ancillary, incidental), and multiple (Adams and Adams 1991: 158-168). It's to be expected that this new conceptual order did not fully avoid intuitive decisions. However, the approach offered an effective conceptual and methodological framework that facilitated further analysis of the data and certainly opened a venue to address more specific scientific queries.

In addition, I dealt in this section with the theoretical and methodological approaches that in the last decades contributed a great deal to the discussion of classification in the archaeological artefacts. It remains however valid, that such a vivid debate on various matters yet lacks to offer a cohesive approach that can be cogently applied to any kind of archaeological data. Despite the attention that each of the above approaches gives to the methodological framework, especially with pottery, they rather perceive it in a perfect state of preservation and give insufficient attention to the fragmentary state in which this kind of data is collected in the field and how the low degree of preservation could impact further analysis of the qualitative or quantitative profile. This is a limitation that none of the above authors considers or addresses as a crucial impediment in the classification process.

The classification of artefacts in Albanian studies: an overview on the current state of research

Pottery studies of late prehistory in Albania, have been carried out within the framework of the culture-historical approach. Due to the simplistic implications that such approach evokes, classification and typology was generally overlooked and not treated as a question of potential importance. Any interpretation or discussion so far continuously focuses on the qualitative properties[1] of the archaeological artefacts, mainly pottery and metal finds. I have discussed elsewhere the dynamics of research geared especially towards the qualitative and quantitative profile of repertoires that massive campaigns of fieldwork have produced in Albania (Agolli 2019: 25-42).

However, even with the qualitative profile, classification and typology in the most simplistic terms find their utilization only with the organization and order of the archaeological data. With pottery, for instance, complete vessels were organized according to schemes of classification that was ordered on the basis of *fabric* (mostly designated by macroscopic examinations) and *vessel form* organized according to the interrelated type-variety system. For each designated group, accounts were mostly provided regarding regional and intraregional comparanda with an exclusive focus on cultural affinities. The parameters and attributes that designate the types or varieties are hardly mentioned, making this

[1] The qualitative profile it refers to diagnostic traits of pottery data created by the artisan that shape measurable features.

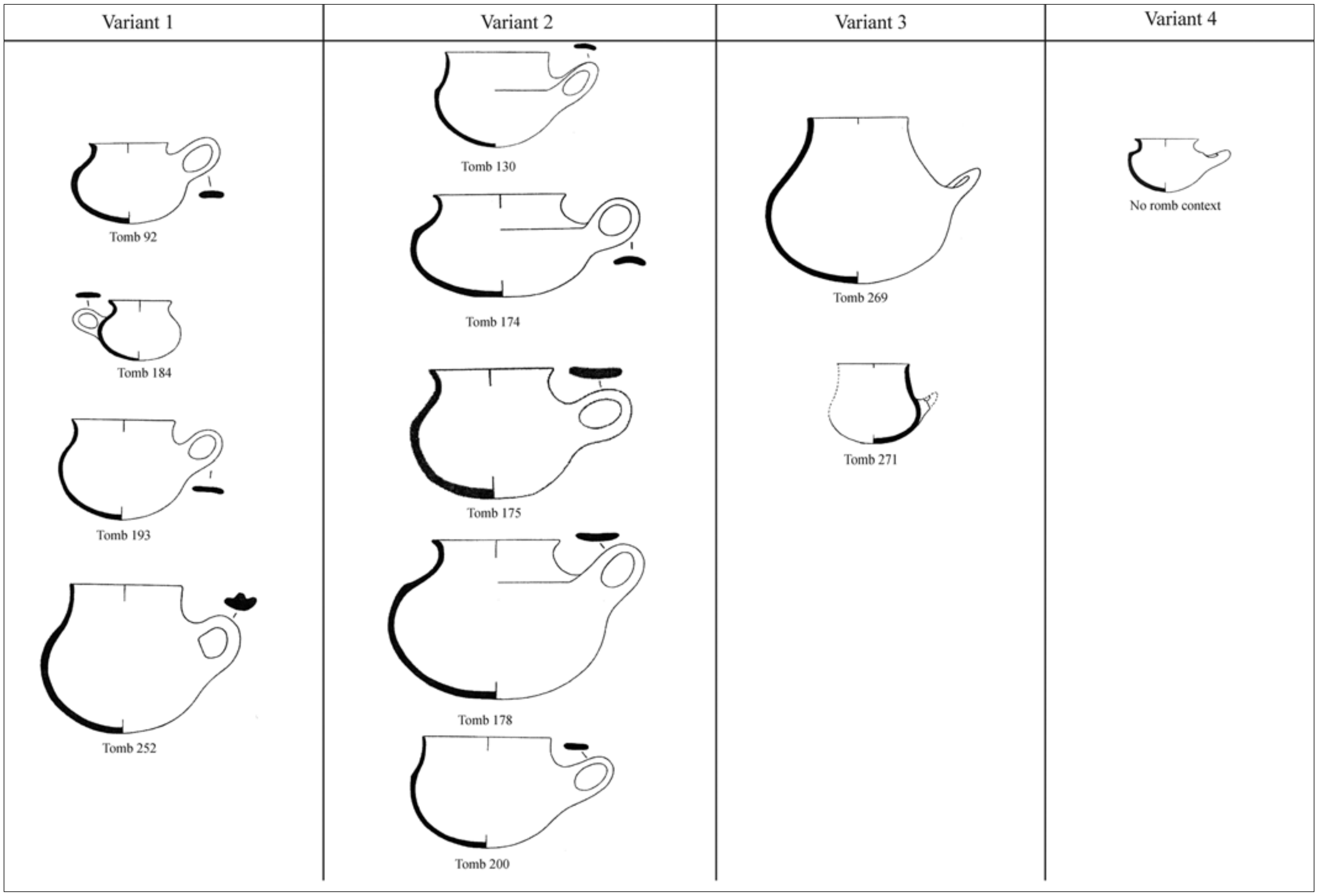

Figure 1. Type-Variety applied in the classification of one-handled vessels - the case of Rehovë Tumulus (Aliu 2012).

process highly subjective. In other words, it seems likely that such undertaking relies heavily on the intuitive decisions of the archaeologist. For instance, in the case of Rehovë tumulus, (Aliu 2012: 167-187), the crucial attribute that designates the <u>*types*</u> in the handmade pottery assemblage is the number of handles; other features like, the form of neck or body and handle emplacement rather vaguely define the <u>*varieties*</u> (see Fig. 1) (Aliu 2012: 168-169). Aliu does not provide much background on the 'how's' and 'why's' of such a strategy in the classification of material. Furthermore, this strictly taxonomic approach is noticed in papers that focus on much conclusive matters including cultural background and continuity, or even ethnogenesis (Aliu 1984; 1994; 1995; 1996; 2002; Andrea 1985; 2009; Bodinaku 1989; 1990; 2001; Hoti 1981; Jubani 1969; 1982; 1983; Korkuti 1969; 1971; 1981; Korkuti - Bunguri 1996; Prendi 1956; 1957; 1959; 1966; 1974; 1977). At any case, qualitative properties of pottery mainly describe salient parameters like decoration, vessel form, or handle form and location are compared in synchronic or diachronic order attempting to derive connections and networks with neighboring cultures. Some crucial conclusions of Albanian prehistory have relied on this kind of reasoning.

Recently, a few studies that focus on quantitative analysis and attempt to avoid pre-defined and intuitive assumptions have been discussed (Aliu and Bejko 2009; Agolli 2009; 2014). Among others, an interesting example is associated with the classification and typology of the fibulae found in the prehistoric cemeteries of the Kolonje plateau (Aliu and Bejko 2009: 59-103). As a case study to demonstrate how subjective qualitative analysis can be, Aliu and Bejko have agreed to apply two contradictive methods in the classification of the fibulae repertoire. *The first*, known as the traditional method, is based on a type-variety system with types and varieties assigned arbitrarily such as XYZ. Among other narratives, mostly touching upon which cultures can be attested based on the preponderance of these types and varieties outside Kolonjë plateau, with the case of the spectacle fibulae especially, the form of the 'eight' (single or double) between the discs is considered as a salient/definitive attribute. *The second*, named as the 'independent' method implies the statistical inference. This method does not disqualify the principles of the traditional method but avoids to claim any pre-defined preference among them.[2] The seriation and correspondence analysis identify as a significant typological feature the section of the wire and no single or double 'eight' figure between the discs. For both authors, however, this distinction may also bear chronological significance (Aliu and Bejko 2009: 85, 94).

Bejko and Aliu attempted to integrate 'peacefully' this contradiction between these conceptual and methodological approaches, which must be said could hardly be combined. This is at best seen from the controversial results that each of these methods yielded. Despite this outcome, however, the implication of the statistical inference with the classification of the archaeological data must be considered as a successful attempt to challenge the simplistic typological schemes that rely on visual evaluations of physical properties.

Although various recent studies do not address the theoretical implications of classification as a central query they do give careful attention to the macroscopic and microscopic observations of the pottery properties and, while focusing on the compilation of catalogues, offer to the greatest extent a coherent and detailed emphasis on the physical and aesthetic properties. Above all, they avoid any intuitive decision that gives prevalence to the qualitative properties of the data (Gori 2015; Krapf 2014; Pevnick and Agolli 2014). This amount of research allows for subsequent research attempts to further address innovative theoretical and methodological agendas.

In addition, the theoretical and methodological underpinnings of classification and typology in late prehistoric archaeological pottery in Albania yet remains at a seminal stage. Despite some sporadic innovative attempts, the type-variety system of classification yet is simply used as a tool that helps to bring order to the data at which the intuitive decisions of the archaeologist play a key role. The main purpose here is been the designation of groups with similar properties through a strategy that perceived 'pots = people' and searched mainly for cultural affinities in both inter and intra-regional scale.

The benefits of the conceptual classification approach in the analysis of late prehistoric pottery in Albania

In this section, I focus on the implications of the conceptual classification framework. I applied this approach in my dissertation research on the late prehistoric pottery of Albania (Agolli 2014). Given the quantitative and qualitative profile of pottery repertoires encountered mostly in tumuli burials, the application of a classification framework that took a comprehensive overview on the properties of the pottery data was of great relevance.[3] This became even more valid if into consideration was taken the fact that largely these repertoires were comprised of complete or nearly complete vessels, meaning they possess the potential to accommodate a full synopsis the evaluation of properties adapted from the aforementioned approaches of Read and Adams and Adams.

The research was oriented towards two specific queries; *to evaluate the regional networks among the late prehistoric communities (Albania) in a synchronic and diachronic perspective as well as to evaluate the innovation of pottery production over time at the site level.* The measurement of similarities and differences among pottery repertoires at various sites comprised the backbone of this analysis (Agolli 2014: 40-46). Each repertoire was classified through a scheme that attempted to avoid when possible intuitive decisions and employed a conceptual framework that focused on the ideational profile of the material,[4] an approach elaborated in detail by Dwight Read (Read 2007). The principal parameter of classification took into investigation attributes that could be obtained from the properties of the *end-product*. I attempted to analyze the ideational profile by taking a detailed synopsis at three primary parameters: *fabric, vessel formation,* and *decoration*. Fabric and surface treatment are treated very briefly in Albanian publications and systematic evidence for both parameters was not collected systematically. Detailed observations of the qualitative attributes of pottery created a comprehensive understanding of attributes that occurred most commonly and were classified as - *shared concepts*. On the other hand, attributes that marked rare occurrence were classified as - *individual concepts*.[5] Each pottery

[2] From a personal communication, each author applied to the repertoire a different methodology. Aliu chose to apply the traditional method and Bejko reprocessed the data by using the seriation and correspondence analysis.

[3] The research conducted analysis in the pottery assemblages recovered in 35 tumuli, 1 shaft cemetery and 10 settlements. In total, an amount of 1476 complete vessels was subject of analysis.

[4] The ideational profile defines the understanding of the steps an artisan takes during the process of production.

repertoire was situated within a key diagram that counted on identifying choices undertaken in the making of pottery. The scheme of the key diagram has not yet been applied to the pottery studies. In mortuary analysis however, this technique has offered tangible results regarding the distribution of data properties (Brown 1971; Morris 1987; Papadopoulos 2005). Brown described the key diagram as a mechanism to express the partitioning of attribute space by a series of variables coded for an independently measured dimension (Brown 1971: 90). I proposed that this method held a great potential for pottery analysis, especially for the separation of choices implied in the object.

The choices (concepts) made on vessels were divided into five aspects defined either as absolute or relative distinctions. Thus, those decisions that can be clearly distinguished were assigned as absolute distinctions, such as handles, number of handles, and their location, the form of the base, and techniques of decoration. The categories of the form of neck and vessel size were defined as relative distinctions on account of their fluid variability. In the majority of cases, the form of the neck remained an attribute with no salient distinction and thus remained a relative attribute. For instance, in every chronological phase, depending on the general properties of the repertoire, the form of the neck is roughly defined as short, cylindrical, conical, or elongated. Vessel size has been classified as small-medium or large. Such distinctions were based on macroscopic observation in which both classes may be clearly separated. This attribute was also assigned as a relative distinction. Any assumption regarding vessel function was not considered, since the repertoire or archaeological context offered no conclusive determination. Each of the chronological phases of the site was assigned its own group of concepts, according to the degree of variability.

Given that this paper deals with the theoretical and methodological underpinnings, I turn now to the potential outputs of the conceptual framework. Despite the quantitative profile, once vessels were distributed according to the pre-defined attributes in the key diagram, at least in the shared system of concepts, the most representative and homogeneous groups were those comprised of five to six vessels at maximum. For instance, in the case of Prodan tumulus, the shared system of concepts in the fourth division dropped to four, three or even two vessels. Not to mention that ten vessels within this repertoire embodied individual concepts and could not be situated in any group at all (see Fig. 2). The tumulus of Prodan served as an example but such quantitative profile did not offer any potential for further analysis that could involve the statistical inference at other sites as well.

However, the conceptual classification based on the qualitative attributes produced a strong background to conduct regional and intra-regional comparisons as well as measure how innovative choices among sites could be measured in the diachronic order. Several questions related to any meaningful distribution of vessel forms and decorative techniques, or any pattern which at one site could be more significant than in another could be assessed only through the weak quantitative profile that groups in the key diagrams offered. Nevertheless, comparisons among site groups could be made, and some preferential connections between sites and distance were identified. However, again this classification lacked to offer a solid typology with a meaningful quantitative representation (Agolli 2017: 319-326).

Another crucial aspect of the conceptual framework is its capacity to produce a clear background for potential groups that combinations of attributes could create among various sites. Given that the framework breaks down each attribute separately based on the degree of homogeneity, it does not offer a grasp on the degree to which two or three attributes among various groups are combined and if altogether they could yield potential groups. Here perhaps the implications of a purpose-oriented approach could contribute to understand better the quantitative significance of any possible groups that may be formed and their meaning to the regional and intra-regional networks.

However, it must be stressed that the conceptual approach did rectify three crucial aspects: *first*, it avoids the intuitive decisions that a scholar may take over the classification process. Each repertoire is categorized based on the steps conducted during the process of production. *Second*, it creates an objective overview regarding the qualitative and quantitative distribution of attributes. The progressive categorization of data into a key diagram offers a good understanding for the measurement of homogeneity and heterogeneity within a repertoire. The key diagram has the potential to measure the degree of variety as a tool to understand 'artisans'

[5] Both concepts were earlier introduced by Gifford 1960. In this research none of them bears a cultural salience, they only represent choices of the artisan physically implied in the data. For a definition of each concept see: Agolli 2014: 46-47.

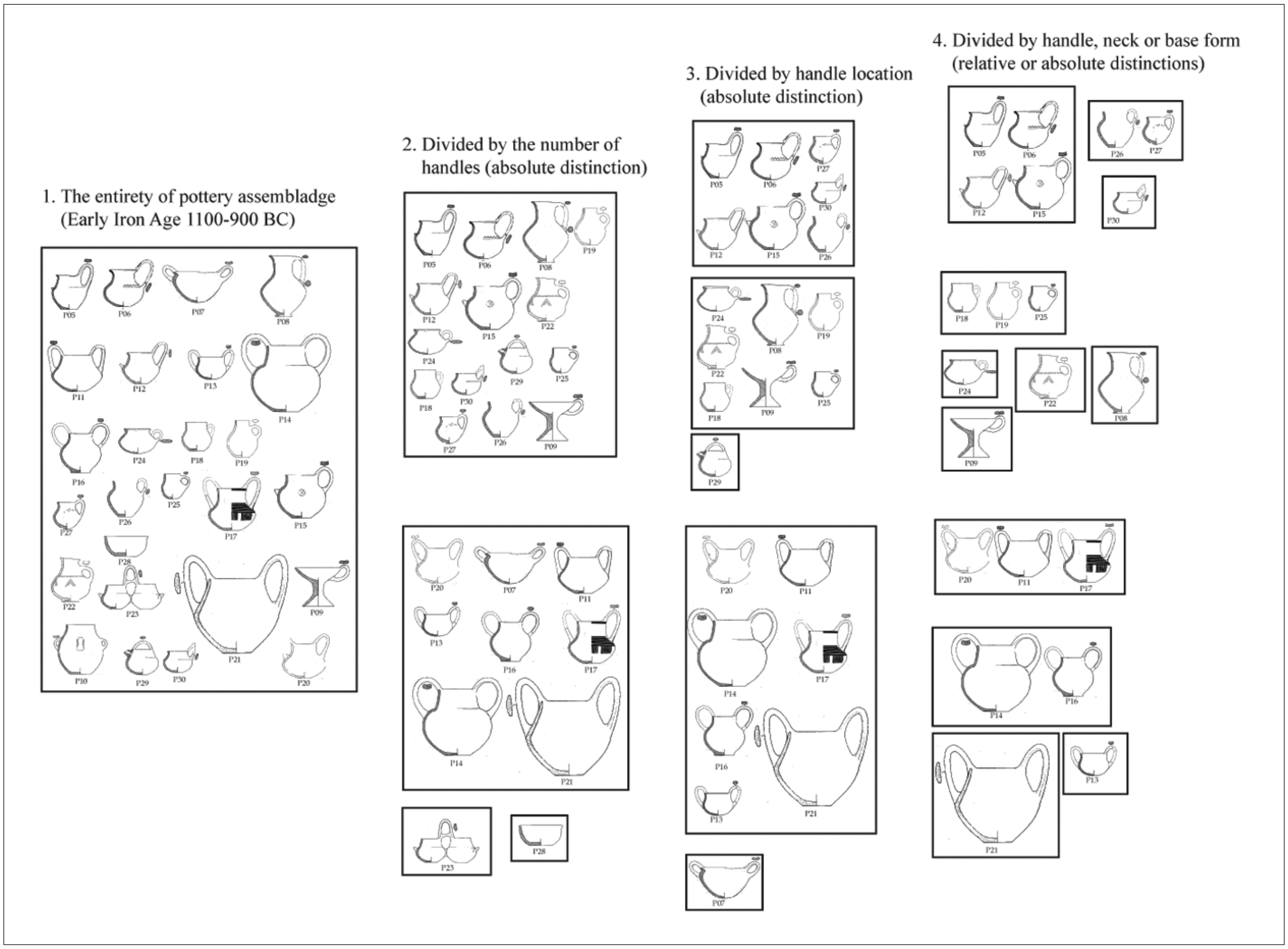

Figure 2. The formulation of the Key Diagram – the case of Prodan tumulus (Aliu 1984; Agolli 2014).

choices and how shared or individual concepts in one repertoire play a role in identifying networks outside a community. *Third*, it leaves open the possibility for further analysis, facilitating the sorting and distribution of various variables at regional and intra-regional scales. In each repertoire, the groups were quantitatively weak, however subsequent measurements that evaluate the weight of particular attributes could indicate potential patterns.

Conclusions

In this paper, I attempted to address a crucial issue which in Albanian studies of late prehistoric has a particular impact. Archaeometry and compositional analysis of the last decade have opened insightful avenues in pottery analysis making particular headway toward understanding the properties of data and the modes of production. However, with the case of the late prehistoric pottery in Albania, there are two crucial matters that make the application of a coherent classification framework rather fundamental. *First* and foremost, the current state of research and analysis does not offer a comprehensive account on the properties of the end-product. Over many decades, the excavations on tumuli burials and settlements have produced an immense number of vessels but have not quite evaluated the plethora of research questions that pottery could impose. The implications of a conceptual scheme of classification opens a venue towards new queries that involve understanding any dynamics that the quantitative and qualitative profile of a repertoire may represent, including site, regional, intraregional variability, measurement of innovation traits in the diachronic perspective, as well the degree of variability between shared and individual concepts as choices that are implied during the process of production. *Second*, above all, the application of the conceptual classification in the theoretical and methodological framework gives equal attention to any attribute. It avoids intuitive decisions and intends to offer a potential avenue to analyses and questions that pottery could prominently succeed to answer.

The paper addressed a crucially important aspect not only for the issue of classification per se but at a larger perspective to involve in the studies of material culture theoretical and methodological discourse, two parameters without which archaeology could not understand at depth issues that imply cultural or social dynamics.

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All aboard!
Quarries and transport in Roman Istria

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The great need for stone as a building material in Roman Istria is attested by a large number of quarries along the Istrian coast, and several in the interior. The more or less high-quality limestone from these quarries could have been used for the building of many villae rusticae scattered across the peninsula, or perhaps even for further distribution. In that regard, Roman Istria was connected by a system of roads, the precise heading of which we are today still uncertain. The road connecting Aquilea and Pola was called Via Flavia, and several authors suggest that a road of the same name connected Pola to Tarsatica. Nevertheless, a much cheaper system of transportation was by sea or river, and the Istrian coast is rich with many bays or coves that could have been useful to Roman sailors as safe havens or trading ports.

Keywords: *Istria, Antiquity, stone, quarries, roads, holloways, ports*

Introduction

The Roman history of Istria began with the war in 178 – 177 BC. Infamous pirates, the Histri came under Rome's notice for disturbing the normal flow of sea traffic and trade which resulted in the first Roman-Histri war of 221 BC (Matijašić 1998: 32). Having defeated the Histri, Rome wasn't planning on subduing the whole of Istria, but that became necessary not long after. The Histrian king Epulo called to arms which resulted in another conflict in 178 BC. After having defeated the Histri, Rome pacified the northern Adriatic (Matijašić 1991: 236-239; Matijašić 2017: 381). Then, after several centuries, around 45 BC, the colonies *Pola* and *Parentium* were established and romanization of the peninsula began in earnest. The colonies were es-

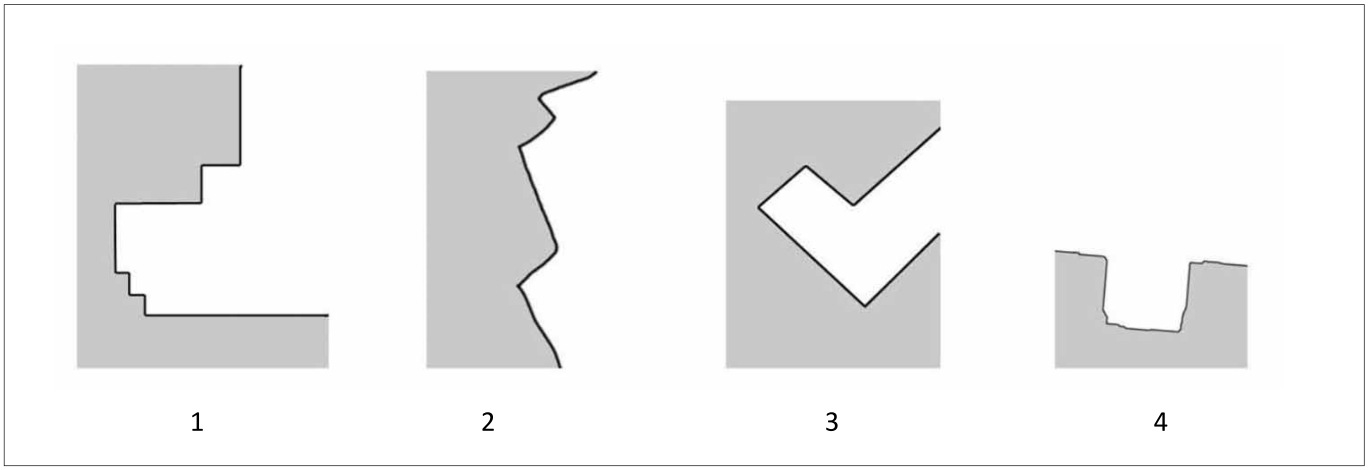


Figure 1. Examples of rectangular layouts of Roman quarries in Dalmatia, Croatia: 1 - Dugi otok, Padrare; 2 - Trogir, Sv. Ilija; 3 - Korčula, Kamenjak; 4 - Kamenjak near Molat (after: Parica 2014a: 141).

tablished as a means of giving land along the western coast of the peninsula to the veterans and other Roman citizens, and the Histri were eventually integrated into the Roman state (Matijašić 2017: 383). Roman rural estates also started developing. There are now more than 300 Roman *villae rusticae* known across the Istrian peninsula, mostly along the coast and withing a narrow strip from it, on the territories of three different *agri: Tergeste*, *Parentium* and *Pola* (Bulić 2014). Roads were built to better connect the controlled area, for quicker information exchange, but also for military and civilian, economic purposes. This connection system had an effect of improving the Roman economy (Matijašić 2009: 195). On the other hand, a less expensive and faster transportation system was by sea or river, and since Istrian coastline, especially western, is rich in bays or coves, this provided the perfect means for developing a network of seaports. There are 51 bays in Istria with the remains of Roman port facilities visible today (Koncani Uhač 2018: 205-393). From an economical perspective, the Roman ports in Istria can be divided into four main categories: colonial ports, secondary ports (for *municipia*), *villae maritimae* ports, and ports related to production centres, notably for olive oil or wine (Koncani Uhač 2018: 145-163).

Good road connectedness influenced the economic growth and one of the important branches of the Roman economy, besides the production of olive oil and wine, was quarrying. There are several known “Roman” quarries today and others are being discovered using the analysis of Airborne Laser Scanning (ALS) data. Most of them are located on the western Istrian coastline, while a small number of them are in the hinterland, but close to the supposed line of the main Roman road.

Roman quarries

In his dissertation and later work, Parica brought up several characteristics that should distinguish Roman age and Mediaeval exploitation of quarries based on quarries whose elements can be reliably dated (Parica 2014: 76). He states that the basic quarrying tool in Classical Antiquity was a 6-8 kilograms heavy two-spiked hammer which leaves between 15 and 19 *striae* per metre on the quarry face, as opposed to a lighter Medieval two-spiked hammer which can leave between 20 and 26 *striae* per metre (Parica 2014: 77). He also argues that the layout of exploited quarries should give us an indication of the period of usage. Roman quarries, he says, mostly have the rectangular layout as a result of systemic exploitation: large quantities of regular stone blocks were exploited at the fastest possible rate (Fig. 1). On the other hand, late Mediaeval and Early Modern quarries demonstrate triangular layouts with a 90˚ angle in the deepest part (Parica 2014: 79). This layout was a result of smaller, individual exploitations where several blocks were extracted in a row, forming one side of a triangle and each new segment was extracted from a different side of the triangle (Parica 2014: 79).

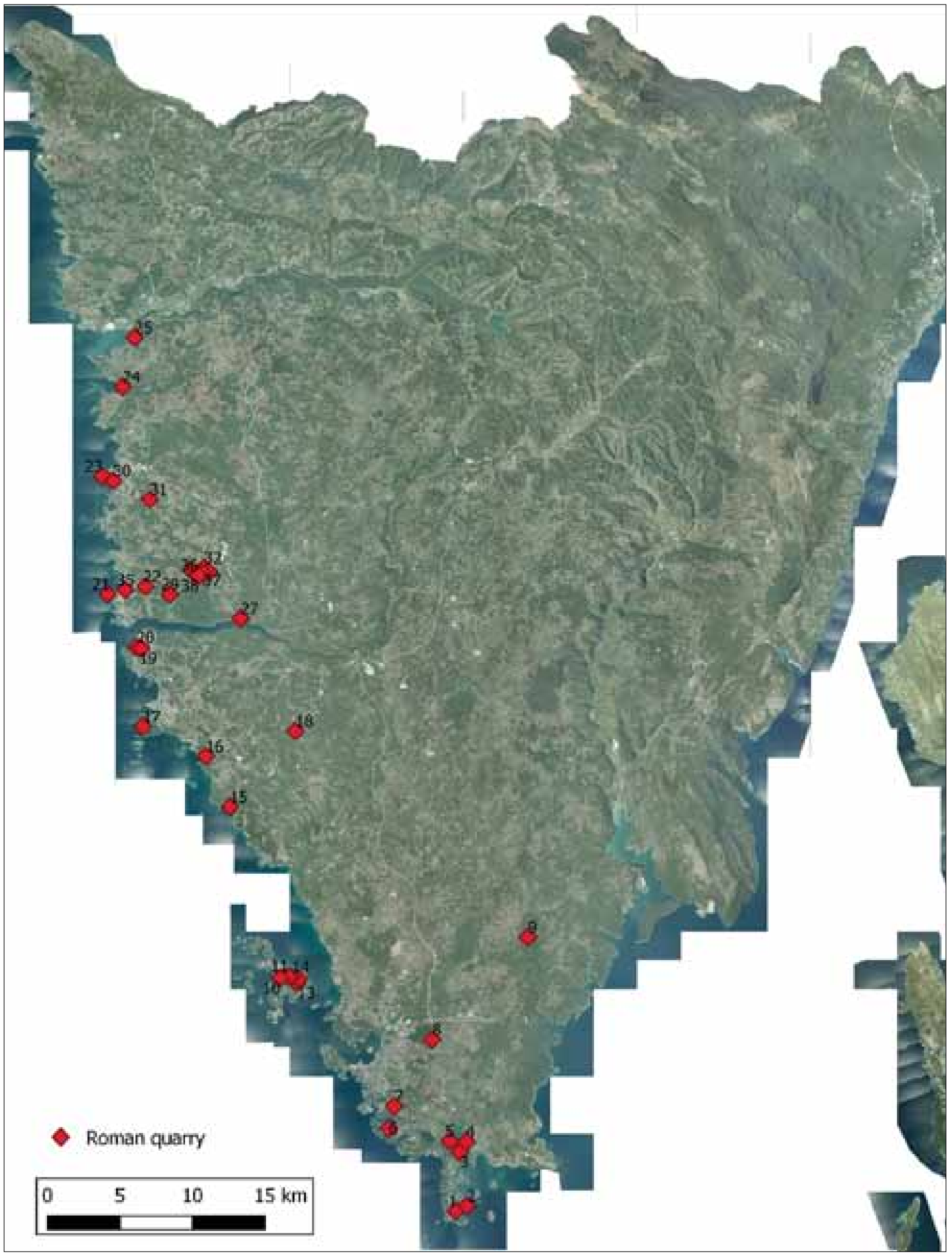


Figure 2. Probable Roman age quarries on the Istrian peninsula (made by: Katarina Šprem).

The channel chiselled in order to extract a desired stone block from the rock is called *pašarin*[1] in Croatian and this technique came to be used on the Croatian coast and islands after they fell under Roman rule (Parica 2014: 52). Therefore, the *pašarin* technique, if still seen in a quarry today, presents a sort of a chronological marker for dating the exploitation period of that part of a quarry. *Pašarini* in combination with other techniques, such as wedges or *kunjere*[2], and the use of gunpowder, are a sign of a later exploitation period, namely the Middle Ages and the modern era (Parica 2014: 60-61; Parica 2014a: 149). Even though Parica's work is based on quarries in Dalmatia that were exploited in Classical Antiquity and the Middle Ages, there should not be any differences in systems of exploitation between regions of present-day Dalmatia and Istria.

[1] *Pašarin* or *pašarina* is a traditional Dalmatian word.

[2] *Kunjere* is a traditional Dalmatian word for grooves made for V-shaped wedges used to detach the stone block (Parica 2014: 61; Parica 2014a: 6).

Figure 3. A quarry on Mugli Cape, Premantura: on the left side a pašarin, on the right side platy limestone. Height of the water bottle 21 cm (made by: Katarina Šprem).

Istrian limestone surface deposits are mostly of Cretaceous age (Miko et al. 2013) and generally of high quality. Therefore, it is not a surprise that it has also been quarried in historical and recent times and is being quarried even today (Šonje 1980; Matijašić 1998; Bratulić and Cotman 2004; Lazzarini 2012). There are several quarries on the western Istrian coastline that are thought to be of Roman age, but several of them have also been quarried in the post-Roman era; therefore, if there were any traces of Roman quarrying, they have been erased by later exploitation (Matijašić 1998: 394). We continue with the description of quarries in Istria that might have been exploited in Antiquity, starting from the south.

On the eastern coast of the Premantura peninsula there is a quarry in the Porto Rosso bay (Fig. 2: 1). There are traces of Roman quarrying in the form of visible *pašarini.* Also, the southern coast of a nearby small island of Šekovac seems to have been "cut" and the quarry is situated below the sea level which could date the exploitation to Antiquity (Fig. 2: 2). The quarry is of a rectangular shape which would also suggest Roman age; however, a more detailed survey is needed. Next, while walking through the Vižula Archaeological Park we noticed a quarry across the sea on the Mugli cape of the Premantura peninsula (Fig. 3), whose location and appearance are very similar to the small quarry on Šekovac island (Fig. 2: 3). The surface layer is platy limestone between 1 and 2 meters thick, and below is a deposit of architectural stone. Again, the rectangular shape and the location almost below sea level would suggest Roman age. However, the technique of extracting slabs of platy limestone does not leave any traces due to the fact that the rock mass has both horizontal and vertical cracks which naturally separate the slabs without any need for cutting (Parica 2014: 32). Therefore, dating such a quarry is a much more problematic topic. Nevertheless, during the field survey, a fragment of pottery was found, most likely dated to Late Antiquity. Also, the quarry is located on the coastline which is a perfect location for maritime transport. There are several *villae rusticae* sites nearby which could have been built using stone from this quarry (Bulić 2014).

The Vižula peninsula itself also contains a Roman age quarry (Fig. 2: 4) where "Istrian soft stone" was quarried (Džin and Miholjek 2016). Premanturski školjić island in the northern part of Medulin bay has had its whole southern coast cut by exploitation (Fig 2: 5; Matijašić 1998: 395). Its location is also perfect for maritime transport and it is nearby several *villae rusticae* sites for which this quarry could have provided the stone.

Two quarries located in Banjole are about 350 meters from the coast (Fig. 2: 6). One at the site of Rupice was certainly used during Austro-Hungarian times, but there were several half-worked columns and a woman's head carved in stone found in it forty years ago (Matijašić 1998: 395). The *Cavae Romanae* quarry near Vinkuran is the place whence the stone for the outer curved wall of the Pola Amphitheatre was extracted (Fig. 2: 7; Crnković 1991: 396). Even today it bears the name *Cavae Romanae* which could signify its Roman age, or rather a local tradition which reflects its Roman Age use. This quarry is located about 500 meters from Veruda Bay, with a slope of terrain that could have facilitated transport by land to the coast (Šonje 1980: 151). On the eastern edge of Šijana in Pula (Fig. 2: 8) a hill was cut off by a modern quarry, but traces of stone blocks extraction for making sarcophagi were clearly visible at one point (Šonje 1980: 152). Furthermore, on the western slopes of the valley between Marčana and Mutvoran (Fig. 2: 9) there is a large quarry that was probably used in Antiquity as several stone monuments of Pula and Nesactium, the latter of which is nearby were made of such a stone (Matijašić 1998: 398). This should, of course, be verified by further analysis, one of which should be petrography.

The Brijuni islands are also rich in quality stone (Fig. 4). Due to monumental sites, such as the Roman villa in Verige Bay, one can assume the exploitation of stone in Antiquity in several locations: a quarry in Gospina Bay (Val Madonna), the zoo quarry, Čufar quarry, a quarry under Gradina, and Koch quarry, which is also one of the most exploited quarries on the islands (Premužić - Ančić and Gašparović 2017: 80). Most of these quarries were also used in the Middle Ages, but not as intensively as the material from abandoned Roman buildings that was available, which could satisfy the rather modest needs for stone building material (Matijašić 1998: 398).

Moving north along the western Istrian coast, we see traces of stone exploitation at the St. Damijan cape (Fig. 2: 15). It is believed the quarry was not used after Antiq-

Figure 4. Probable Roman age quarries on Veli Brijun Island (made by: Katarina Šprem).

uity. It covers an area of about 300 m^2, and it is assumed that about 1000 m^3 of stone blocks could have been removed from this place (Matijašić 1998: 396). Like the quarry at the location of Monte delle Arni (Fig. 2: 16), it is in a very convenient location for further transport of stone blocks. At the aforementioned site, Monte delle Arni south of Rovinj, sarcophagi and their unfinished lids have been recorded until recently, which further testifies to their use in Antiquity (Matijašić 1998: 396). Near Rovinj, at Montauro cape (Fig 2: 17), lies the largest quarry in this part of Istria. It is believed it was used in Antiquity due to its convenient location very close to the coast, although there is no direct evidence (Matijašić 1998: 396).

North of Rovinj, there are quarries in Soline Bay and at St. Eufemija cape (Fig. 2: 19, 20). Soline Bay is located at the entrance to the Lim Channel, and traces of Roman exploitation are clearly visible in the quarry. The stone is thinly layered, so only smaller blocks could have been extracted. On the adjacent hill near St. Eufemija cape, there are also traces of stonemasonry visible. According to Šonje, sarcophagi were made from these blocks (Šonje 1980: 152). Near the town of Bale, 6 km from the coast, there are remains of a small quarry with visible traces of extracted round blocks (Fig 2: 18). Matijašić believes the stone blocks probably weren't carried far from this location and that the extracted stone was used to make monolithic recipients for olive oil plants in a nearby rural villa (Matijašić 1998: 399).

North of the Lim Channel there is a quarry on the islet of St. Juraj near Vrsar (Fig. 2: 21). It shows traces of Roman stone exploitation, but no large blocks of stone were extracted here (Matijašić 1998: 399). The quarry itself is in a very steep location and along a shallow shore, which makes it unsuitable for boarding large stone blocks on vessels (Šonje 1980: 152-153). There is also a quarry on the south side of the hill called Monte Ricco (Gavanov vrh; Fig. 2: 22). A Roman water cistern, as well as a villa rustica, were recorded on the hill itself (Buršić-Matijašić and Matijašić 2016: 17-25), and their interconnection should be examined by petrographic analyses. Furthermore, a part of a hill on which the old town Vrsar lies has been completely cut off and levelled by quarry activity (Fig 2: 35; Fig. 5). Close by, the stone on the island of St. Nikola near Poreč (Fig. 2: 23) is of exceptional quality. The layers of limestone are up to eight meters thick, and there are almost no vertical cracks, so it is considered, along with its convenient location, very suitable for use in Antiquity (Matijašić 1998: 399). In addition,

Figure 5. A quarry located on the north-western part of the old town Vrsar (photo by: Katarina Šprem).

Figure 6. Negative features seen in the landscape on a LiDAR visualization, Vrsar municipality (made by: Katarina Šprem).

Šonje believed that a monolithic block from which the dome of Theodorik's Mausoleum in Ravenna was made had been extracted from this quarry (Šonje 1980: 153). Benčić mentions two other Roman quarries in the vicinity of Poreč – Naftaplin beach on the coast (Fig. 2: 30), and S. Angelo (Fig. 2: 31) less than 3 kilometres in the hinterland, where the remains of an unfinished Roman sarcophagus can be seen today (Benčić 2019: 115). Quarries at Vabriga and Tarska vala near Poreč (Fig 2: 24, 25) do not show any signs of Roman exploitation today. However, that may be so due to the proximity of the sea, which is conducive to the transportation of extracted stone and continuous exploitation. Furthermore, the proximity of Poreč could result in traces of Roman exploitation being lost due to modern exploitation for the need of construction works in the modern town. Tarska vala is the northernmost place on the western Istrian coast from which stone could be extracted for the needs of the northern coast (Matijašić 1998: 399).

The case of LiDAR quarries

A new technology developed in recent decades gave us the ability to detect quarries that have been otherwise overgrown in vegetation and therefore hard to spot in aerial photographs or during field surveys: Airborne Laser Scanning (ALS) or LiDAR. The whole area of the municipality of Vrsar was laser-scanned in 2017, and different LiDAR visualizations enable us to spot negative features which more often than not turn out to be quarries (Fig. 6). As a part of the *ArchaeoCulTour* project[3], several negative features were selected for a targeted field survey (Fig. 11).

[3] Full name *The Archaeological Landscape in a Sustainable Development of Cultural Tourism in the Municipality of Vrsar, HRZZ-PAR-2017-02-1; https://ffpu.unipu.hr/cirla/projekti/archaeocultour.*

Figure 7. Traces of striae visible on a quarry face in a quarry near the village of Flengi (photo by: Robert Matijašić).

Thus, an abandoned quarry near Flengi village was spotted and surveyed (Fig 2: 36). No traces of modern stone extraction tools were observed and one of the quarry's faces displayed traces of *striae* associated with the usage of the two-spiked hammers (Fig. 7). A quarry of similar characteristics, but of much larger dimensions was surveyed on a hill called Biškupovi vrhi in Vrsar municipality (Fig. 2: 29). The quarry exhibits *striae* on one of its faces as well as at least four visible *pašarini* around 18 to 20 cm wide (Fig. 8). The width of *pašarini* in Roman quarries in Dalmatia, Croatia, is mostly around 20 cm, up to the maximum width of 60 cm. The wider *pašarini* were conditioned by a man's breadth and were thusly intended for a greater excavation depth and work within the *pašarini* themselves (Parica 2014: 137).

Figure 8. Traces of striae and a pašarin in a quarry on the Biškupovi vrhi hill (photo by: Katarina Šprem and Robert Matijašić).

Figure 9. A second quarry on the Biškupovi vrhi hill (photo by: Katarina Šprem).

The other quarry also located on Biškupovi vrhi was partly submerged in freshwater, so no striae were visible at the time of the survey, but its rectangular layout could point to Roman usage (Fig. 9).

Several quarries between the villages of Flengi and Delići in Vrsar municipality also exhibit traces of *striae* and *pašarini* with the width of around 20 cm, and they possess a rectangular layout (Fig. 2: 32, 37, 38; Fig 10.). However, a more detailed look should be undertaken.

Figure 10. Striae on a quarry face and a pašarin visible on two quarries in the vicinity of the village Flengi (photo by: Katarina Gerometta).

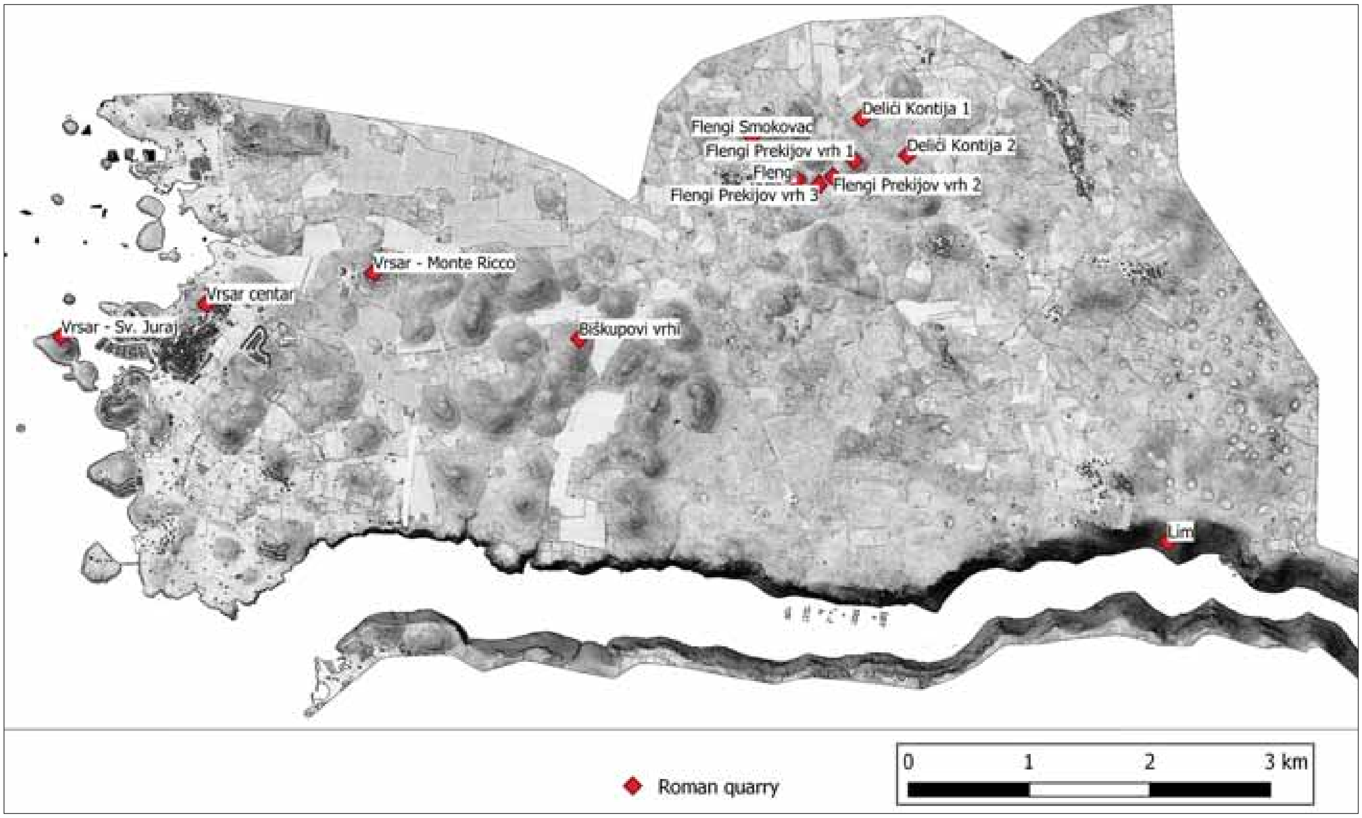


Figure 11. Probable Roman Age quarries in Vrsar municipality; several of them have been discovered using Airborne Laser Scanning data (made by: Katarina Šprem).

Transport in Roman Istria

Istria's transport system is conditioned by its geographical location and the natural features of the terrain and waters. Istria is surrounded on two sides by the sea, while in the north it is separated by Ćićarija, which is easiest to cross in only two or three places (Matijašić 1998: 417-418). Also, marshy valleys and river flows in northern Istria are obstacles to the establishment of road routes. The southern part of the Istrian peninsula is more easily manageable since the relief is flatter and without river flows (Matijašić 1998: 418). Roman roads often followed the routes of prehistoric paths that connected the most important settlements (Matijašić 2009: 197). However, the Istrian road network was probably established immediately after the colonization of the peninsula during Augustus' reign (Matijašić 1998: 419). The control of a conquered area is exercised through the establishment of military checkpoints that must be physically connected, and therefore roads were built and arranged that could be operated more quickly and safely (Matijašić 2009: 195). Although roads were being built for more efficient military management of space, civilian traffic was also moving through them. In this way, road construction technology has contributed to the progress of society (Matijašić 2009: 196). Nonetheless, roads in coastal areas were an alternative to maritime transport and were used mainly in the winter season when less navigation was possible (Matijašić 2009: 200).

From the fragment of Diocletian's Price Edict (*Edictum De Pretiis Rerum Venalium*) found in Aphrodisias in Caria, the price ratios of different modes of transport can be estimated. Thus, the ratio of the sea to the river downstream to the river upstream to land transport costs of 1: 3,9: 7,7: 42 was extrapolated (Russell 2014: 95), which explains why the focus of Roman politics was on maritime transport (Matijašić 1998: 419). The indented western coast of Istria was very important for traffic; this coast was connected to the surrounding areas already in prehistoric times by maritime trade, but also by looting and pirating (Gabrovec and Mihovilić 1987: 322-324). Every little bay from Medulin in the south to Savudrija in the north could have provided anchorage and shelter for ships and later had an even larger economic impact due to the import and export of various products. On the other hand, the eastern coast of Istria, Liburnian, was steep and inaccessible (Matijašić 1998: 419). In any case, navigation itself depended on weather and seasonality, as well as economic and other needs. The short-distance navigation along the coast was especially developed, and this type of navigation almost completely replaced land transport. The main navigable route ran between the larger islands and the mainland so that the vessels were protected from the high seas, and again close enough to a cove to take shelter when needed (Matijašić 2009: 201).

Roman ports and docks

The term "port" refers to a naturally or artificially protected sea, lake or river basin where ships can find shelter from waves, currents, tides and ice, where they can load, land or tranship cargo, food and water, make repairs and where the crew can rest (Koncani Uhač 2018: 65). There was a very extensive network of ports along the eastern Adriatic coast where ships could dock, and goods could be transhipped. In addition to the larger cities, which all had ports, smaller settlements, as well as individual *villae rusticae* or groups of villas, had their own port. *Municipii* also had ports (Matijašić 2009: 201).

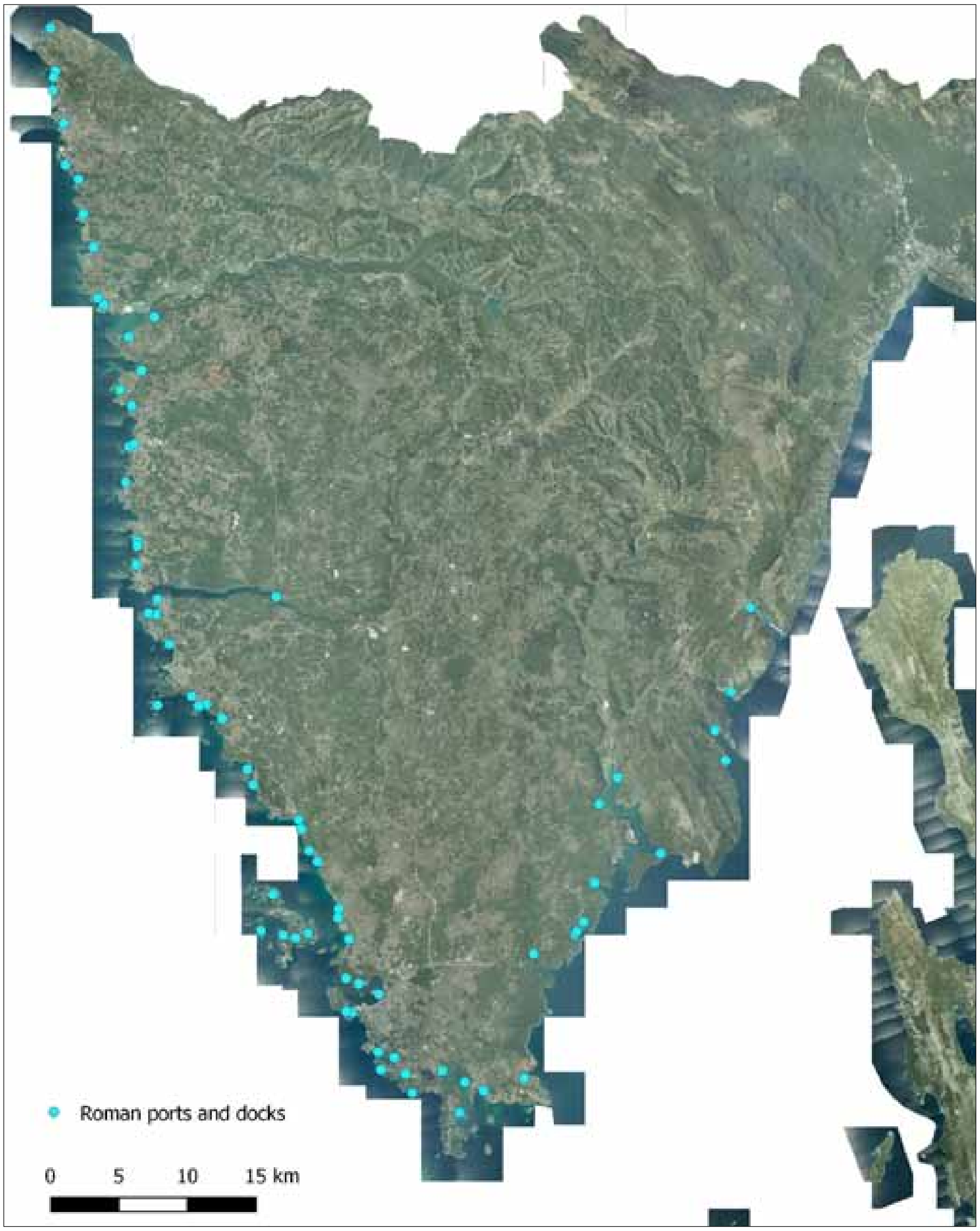


Figure 12. Roman ports and bays which could have been used without the need for port facilities (made by: Katarina Šprem).

The dense rural settlements around the colonial cities also had access to the sea. There are many examples of such settlements in Istria (Matijašić 2009: 202). Archaeological excavations of such ports show they are mostly dated to the 1st century when they were built as parts of residential and rural buildings (Koncani Uhač 2018: 141). However, some examples of natural anchorages and bays on the Istrian coast that were used in the Roman period show traces of use in prehistory (Mihovilić 1997) as well as Late Antiquity and the early Middle Ages (Brusić 1980; 2010), even until today.

Ports on the Istrian coast were densely distributed in Roman times (Fig. 12) and they can be divided into several groups (Koncani Uhač 2018: 143-145). According to the method of construction, they can be divided into natural ports - naturally protected bays which, by their morphology, enabled the safe anchoring of ships in case of bad weather or rest during navigation, and artificial ports - bays that were adapted for the protection of ships (Koncani Uhač 2018: 144-145).

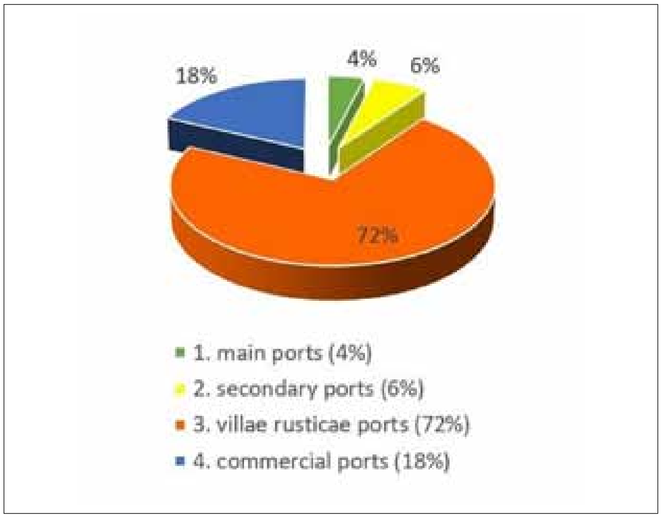
Marie-Brigite Carre and Francis Tassaux divided the ancient ports of Istria according to their size and importance in relation to economic context (Carre and Tassaux 2009: 65-78). Thus, the Roman ports can be divided into main (colonial) ports, secondary ports (municipal ports and agglomerations of settlements), ports of individual *villae rusticae* and ports related to individual production complexes (commercial ports) (Carre and Tassaux 2009: 69). Despite this division, some examples of ports on the Istrian coast cannot be attributed solely to one type of port, as their purpose can be multiple. The major ports on the Istrian coast had the function of city ports that belonged to political and territorial centres or colonies. Such ports include the colonial port of *Tergeste*, as well as the ports of *Pola* and *Parentium*, and the ports of the Late Antique urban settlements *Ruginium* (Rovinj), *Humago* (Umag) and *Silbio* (Savudrija) (Koncani Uhač 2018: 148). Through these main ports products from various Mediterranean regions were imported to Istria (Koncani Uhač 2018: 145-148). Secondary ports, on the other hand, are side ports to which agglomerations of settlements or towns of municipal status gravitated. Through these ports, unobstructed loading and unloading of goods could be ensured towards rural villas in the hinterland. An example of such a port is the one in Budava Bay which was used by *municipium Nesactium* (Vizače). Also, the ports of the *Flanona* (Plomin) and *Alvona* (Labin) could be classified as secondary ports (Koncani Uhač 2018: 148).

Almost every *villa maritima* in Istria had a port, and the majority of the total number of ports in Istria belongs to this category (Fig. 13). Through these ports, local products were concentrated towards a larger export port, either secondary or major (Koncani Uhač 2018: 151). They had observation posts that served to control sailing routes, and as such also served as landmarks on the coast. While *villae maritimae* had a pronounced economic component during the early Empire, their purpose became more defensive during the late Empire (Begović and Schrunk 2012: 327-344). Like maritime villa ports, commercial ports were also used for loading and unloading of certain commercial products. The main economic activity of Roman Istria was the production of olive oil or wine, while other important products were stone, lime, timber, fish products and others (Koncani Uhač 2018: 162-166).

Land routes in Roman Istria

As mentioned before, after the conquest of a certain territory, the Romans set up military checkpoints through which they observed and intervened in case of need. To better connect these checkpoints, roads were built to make travelling between them faster and safer (Fig. 15; Matijašić 2009: 195). The quality of the roads built was largely dependent on their military and economic importance, and the Romans built them in all areas they conquered. Traffic routes linking major urban settlements and other centres outside of Istria are known only

Figure 13. Percentage of ports in Istria according to their size and importance in relation to economic context (made by: Katarina Šprem, after: Koncani Uhač 2018).



in their basic directions (Fig. 14). Our knowledge of the Roman roads network depends largely on the accidental findings of road tracks (Matijašić 1998: 420).

The western part of the road that connected *Aquileia* with *Pola* was called *Via Flavia*. Two milestones of the mentioned roads from the times of Vespasian were found in Pula and Vodnjan (Matijašić 1998: 421). It is also possible that a longer coastal road was used to support the maritime route along the western coast of Istria. In the Late Antiquity, settlements like *Sapparis* (Sipar), *Humagum* (Umag) and *Neapolis* (Novigrad) were formed along this side road (Matijašić 1998: 424). Smaller roads probably connected Poreč and Červar, as well as Poreč with Vrsar. South of the Lim Bay Barbariga was probably connected to the Rovinj area and with Pula (Matijašić 1998: 425). The road connecting Pula with Rijeka is also referred to by some authors as *Via Flavia*, some consider it an extension, but there is no confirmation for this. The road went from Pula through the Double Gate and continued in almost a straight line to *Nesactium*. One branch probably descended from *Nesactium* to Budava Bay. The road could have gone from *Nesactium* to Barban where it would cross Raša bay (Matijašić 1998: 426) or a shorter route through Mutvoran to Raša bay where it would cross the sea to Trget (latin *Traiectum?*) (Bosio 1991: 214). The road then con-

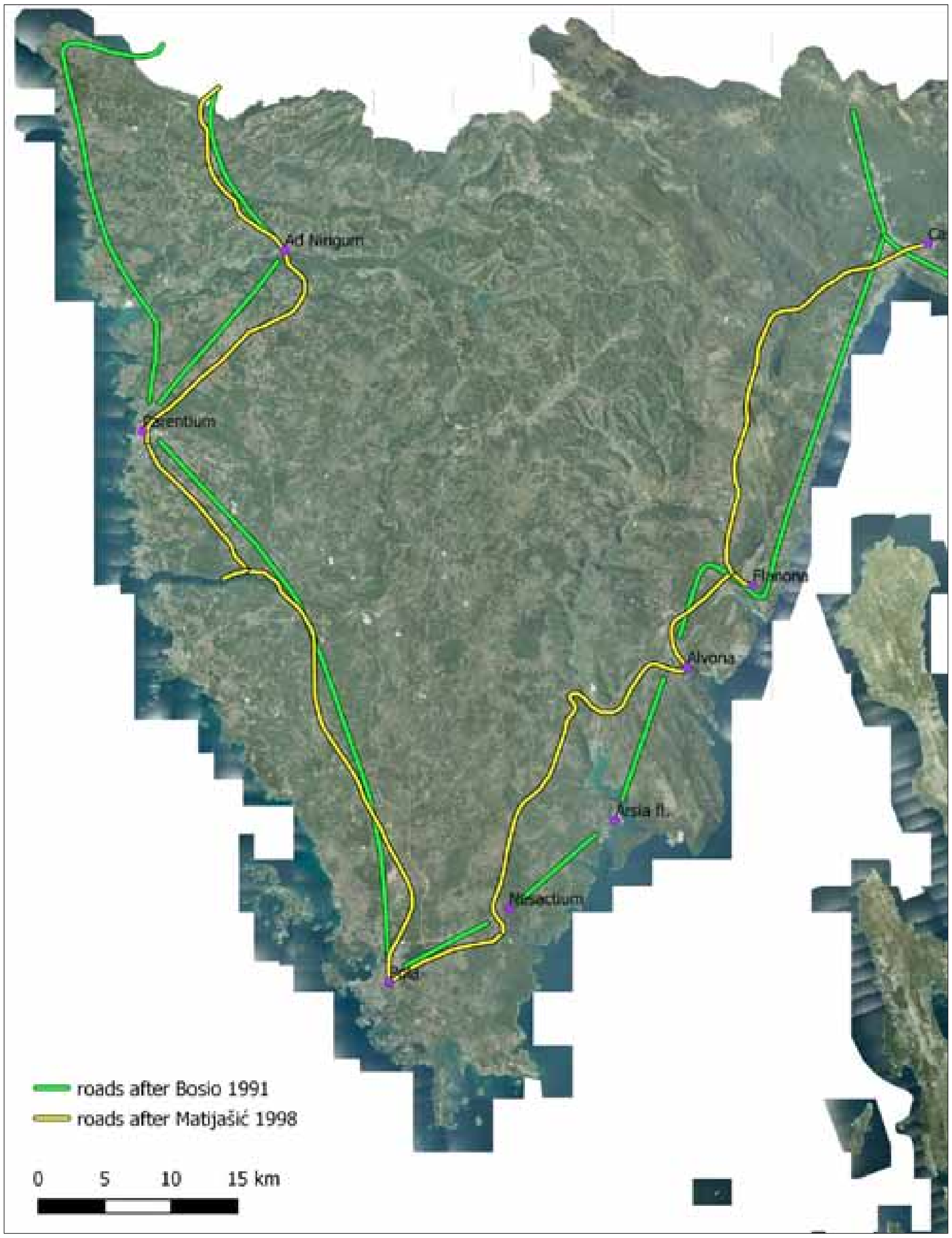


Figure 14. General direction of the Roman roads after Bosio (1991) and Matijašić (1998) (made by: Katarina Šprem).

Figure 15. Road construction at different stages (after Goldstein 2007:371).

nected Liburnian municipalities in Labin and Plomin (*Alvona* and *Flanona*) and through them reached *Tarsatica* (present-day Rijeka). From *Flanona* the road to *Tarsatica* may have gone along the coasts of Liburnia (Bosio 1991) or through the interior of Istria west of Učka (Matijašić 1998: 424). On the other side of Učka mountain, the road went down to Matulji and Kastav (*Castra*) (Matijašić 1998: 425-426). It is unlikely that the road stretched along the coast of Liburnia, as Bosio assumes since the eastern Istrian coast is inaccessible and steep (Matijašić 1998: 426). Nevertheless, Mlakar also suggests a similar direction for the road (Mlakar 1962).

Discussion

When it comes to the exploitation of stone, it is very important to keep in mind the link between the proximity of the source and the possibility of transportation, since there are huge differences in cost between land transport and sea transport (Matijašić 1998: 395; Russell 2014: 95). Considering the fact that the cheapest mode of transport was by a river or sea, the quarries from which stone blocks were extracted for wider distribution were most often located just near the mouth of the river or on the seashore (Russell 2014: 139). Furthermore, in the case of the Istrian peninsula, land transport was restricted to routes connecting the central parts to the west coast (Matijašić 1998: 292). If we take a look at the Dalmatian islands and their large number of Roman quarries, we can ascertain that there is a certain connection between the convenient location for cheap and cost-effective transportation of stone and the selection of places for extracting the high-quality stone (Parica 2012: 345-346). Of course, the primary reason for opening the quarry remains the quality of the stone itself.

In addition to commercial ports related to the loading and unloading of certain commercial products, *villae maritimae* ports also had economic importance. *Villae maritime* could have also had, besides residential quarters, economic facilities, while their port facilities covered the trade from the hinterland – through these ports, local products were concentrated towards a larger export port, either major or secondary. These local products were associated with a specific activity in the microregional area (Koncani Uhač 2018: 151); one of these activities could have also been stonemasonry and exploitation of stone from quarries. However, the location of the ports in the immediate vicinity of the quarries does not need to be an indication of their function as ports for loading stone from the quarries. Smaller quarries along the coast could have been used to build a nearby villa with a pier, and not necessarily for wider distribution. On the other hand, stone blocks extracted from these quarries could have easily been directly loaded onto a ship without the need for port facilities (Koncani Uhač 2018: 168). Likewise, bays could have been used for anchoring without the need for a port facility (Koncani Uhač 2018: 144).

Nevertheless, most Roman quarries in Istria have one or more Roman ports or docks within a two-kilometre radius (Fig. 16). The exception to this are the quarries in the interior of the peninsula: Šandalja – San Daniele, Marčana, Bale – Skačota, Lim, S. Angelo and a number of small quarries near the villages of Flengi and Delići in Vrsar municipality. Stone blocks from these quarries could have been used to build the surrounding *villae rusticae,* and if it was of high-quality, it could have been transported by land to the nearest port. All the afore-mentioned quarries, except the two on Biškupovi vrhi, are around

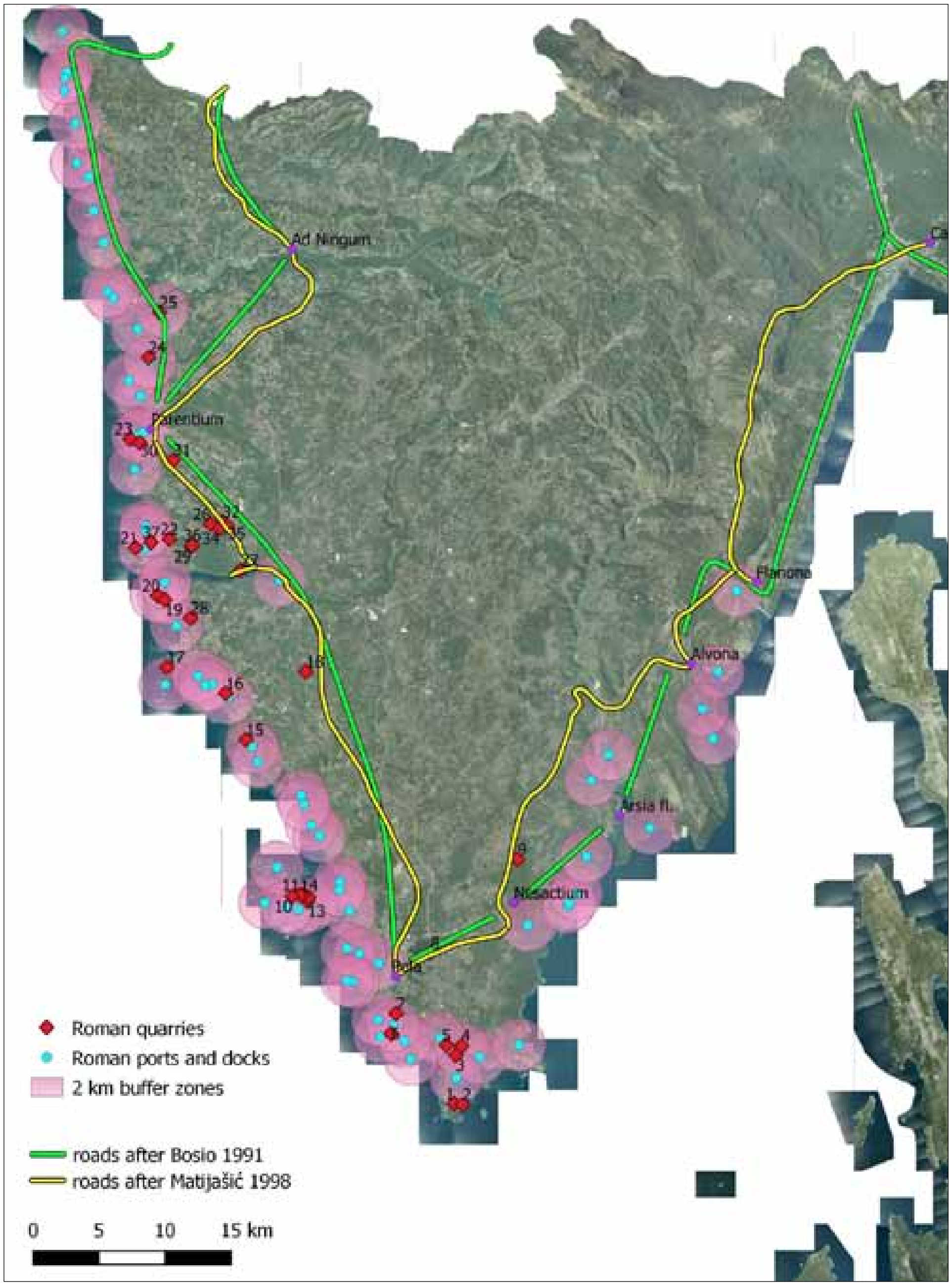
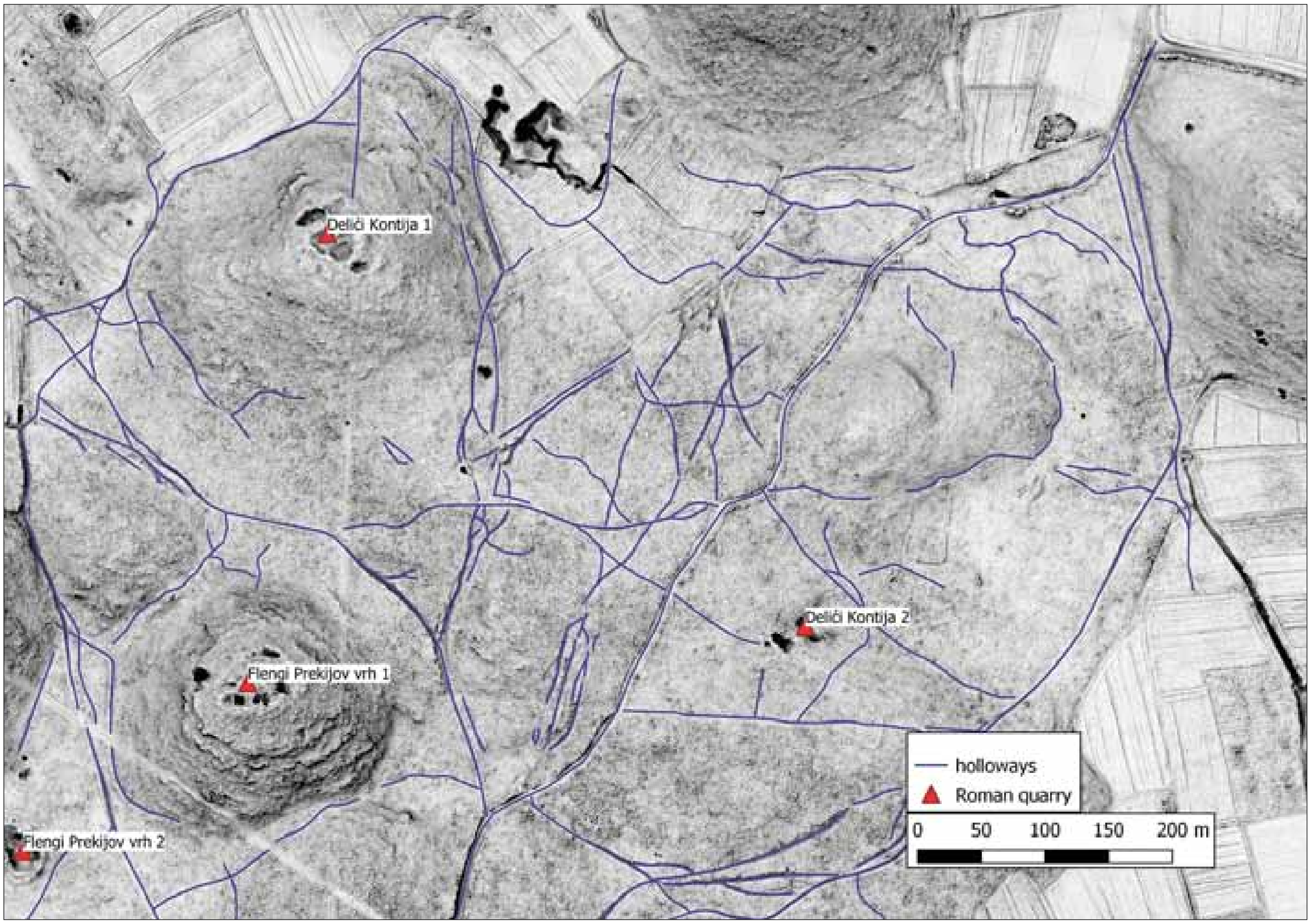


Figure 16. Supposed stretch of the Roman road, locations of the Roman ports and docks, and Roman quarries (made by: Katarina Šprem).

1 km from the supposed stretch of the Roman road. As for the nearest ports, for the quarry in Šandalja, it is Pula's main port, for Marčana quarry the nearest port is in Budava Bay, for the Bale-Skačota quarry it would be the ports in Vištar Bay or St. Paul near Rovinj. Stone blocks from the quarry on the slopes of the Lim Bay could have been directly loaded onto a ship a few meters lower. Stone blocks from S. Angelo quarry could have been transported by roads to the port in Mulandrija Bay or the main port of *Parentium*, both of which are some 3 km away.

The analysis of Airborne Laser Scanning images, which through different visualisations enables us to detect quarries overgrown in vegetation, also allows us to observe a different kind of negative features – the so-called *holloways.* According to Mlekuž, holloways are "material traces of past movement, a movement that is being materialised in the form of traces left in the soil" (Mlekuž 2013: 37). Holloways are not built but are eroded due to the constant flow of people, animals or carts. Eventually, they become water conduits as well, which erodes these lanes even further. Then, some alternative routes are taken by people, which leads to the formation of "river-like braided channels" (Mlekuž 2013: 38; see also Edgeworth 2011). These holloways can also be seen in the landscape of Vrsar municipality (Fig. 17). They can be seen branching close to all the quarries so far surveyed in the municipality which suggests human movement around these sites.

Figure 17. Holloways seen reaching out to the quarries in the vicinity of Flengi and Delići, Vrsar municipality (made by: Katarina Šprem).



Conclusion

Istria is rich in surface deposits of high-quality limestone. Romans were also aware of said quality and exploited the stone from several positions on the peninsula. Some of the Roman quarries have been mentioned in the bibliography of the last decades (e.g. Šonje and Matijašić), while new technologies in archaeology help to discover quarries that are overgrown in vegetation and therefore hard to spot. Such is the case with quarries in Vrsar municipality, e.g. Flengi, Delići and Biškupovi vrhi which were only discovered using the Airborne Laser Scanning technique. On the other hand, the possibility of transporting the extracted stone blocks is an essential element of raw material exploitation. Maritime and river transport is cheaper compared to inland transport that is a more expensive and time-consuming option. The Istrian coastline is richly indented and offers a large number of bays suitable for anchoring, most of them close to the remains of Roman *villae rusticae* where seafarers could load, unload or reload their goods or rest a while. The western Istrian coast allows for the so-called long-distance cabotage, meaning sailing on shorter routes with stops in smaller ports. Quarries that were probably exploited in Antiquity are mostly located on the coastline or near the supposed direction of ancient roads. Their location allowed for faster and more efficient distribution.

The presented data is a valuable start to the study of the Roman exploitation of Istrian stone raw material. Further analyses – like petrographic or even geochemical – can provide us with information on the distribution of the extracted blocks. The question worth asking is whether a particular quarry was used for the needs of the inhabitants of the Istrian peninsula, or it was sought over greater distances because of its quality (as Šonje suggested for the building of Theodorik’s Mausoleum). In any case, the issue of the use and distribution of Istrian limestone in ancient times must be approached with more analyses in mind, and certainly with caution.

Acknowledgements

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