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Being Enclosed as a Lifestyle: Complex Neolithic Settlements of Eastern Croatia Re-Evaluated through Aerial and Magnetic Survey

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Abstract: Archeological excavations and field survey of Neolithic sites during the last 100 years have formed a certain framework within which we developed an interpretation of Neolithic life in this area. Even though researchers have stressed the importance of sites, region, or period in their publications, most of the results revealed very modest remains of Neolithic settlements, too small or too scarce to provide insight in settlement size, organization, and other aspects of life. A combination of non-destructive methods of research is proving to be a more effective means of Neolithic site detection and interpretation. Here, we present the sites Gorjani-Kremenjača, Koritna-Pašnik, Gat-Svetošnice, Ivanovac-Korođvar, Klisa-Groblje, and Brdo, whose size and shape were defined through a combination of the analysis of aerial and satellite imagery and geomagnetic survey. Experience in combined research strategies will help us in our efforts to define parameters in recognizing regularities in the remains of settlement organization visible only from the air. Our results showed a complex network of densely populated settlements with elaborate internal organization and infrastructure varying in size from 10 to 50 ha. All settlements were surrounded by at least one set of ditches. Their internal organization was complex and suggests dense habitation. Many sites have several ditched spaces organized in complex systems. Obtained data and results provide a comprehensive review in a wider European context.

Keywords: Neolithic; eastern Croatia; enclosed settlements; satellite imagery; aerial archeology; geomagnetic survey

1. Introduction

This paper presents some of the results of the remote sensing and geomagnetic survey of Neolithic enclosed sites in eastern Croatia. Until recently, very few sites from that period have been recognized as enclosures, and most of the sites were interpreted as small, flat settlements [1–3]. Our knowledge and recognition of Neolithic habitational practices in this part of Europe is still poorly understood. Enclosed sites are very well documented in other parts of Europe [4–7], but often regarded as sacred and religious places rather than habitational areas [8].

The aim of this work was to present new results and a new interpretation of Neolithic Sopot culture settlements in Slavonia, Croatia, which was supported in part by the Croatian Science Foundation under the project IP-2019-04-5344. Most of the sites were detected through remote sensing techniques [9,10] and were previously not recognized beyond the presence of pottery fragments. This research significantly broadens the average size of Neolithic settlements and for the first time provides insight into Sopot culture settlement organization and infrastructure. Sopot culture is the

name used for the late Neolithic period in the area of eastern Croatia, northern Bosnia, and SW Hungary. It is contemporary with larger recognized Neolithic complexes such as Lengyel and Vinča, but its relationship to the latter two is yet to be recognized. The majority of radiocarbon dates is distributed between 5,200 and 4,300 cal BC. The dates for the site included in this paper, Gorjani Kremenjača, fall in this time range [10]. Although several hundred sites have been documented, until recently, little was known about its settlement structure and layout.

The sites analyzed in this text were twin enclosures and sites with more than two enclosures (multiple enclosures), whose size was measured in hectares (Table 1).

For a better understanding and deeper insight into the site layouts and infrastructure, they were constantly monitored by publicly available Sentinel 2 satellite images and other publicly available images as well as periodic aerial recordings [11–13].

Table 1. Sites discussed in the text with their enclosure type and sizes.

Site	Type	Area/ha	No of Enclosed Spaces
Klisa	twin	12 + 8	4
Gat Svetošince	twin	22	3
Koritna	multiple	3.56	5
Korođvar	multiple	8.2	6
Gorjani Kremenjača	multiple	20	3

2. Materials and Methods

The recognition of sites was made through a combination of methods. We chose sites with more complex enclosure types with various sizes comparable with their layout, and settlement structure to the one provided by the geomagnetic survey of the Gorjani-Kremenjača site.

Here, we will briefly describe the methods used for site recognition and confirmation. The Institute of Archeology conducted aerial reconnaissance of eastern Slavonia and the analysis of satellite images in the period between 2014–2019 [10,14]. The analysis of the eastern Slavonia landscape was conducted using available satellite imagery and orthophotography recordings made by the State Geodetic Administration of Croatia. From its archive images, 325 images of the area between Đakovo and Vinkovci from 2002, 2009, and 2011 were analyzed.

We also used publicly available satellite images from services such as Google Earth, Bingmaps, Geoportal, etc. Following observations from thee satellite imagery, potential sites were regularly visited. We developed an efficient approach to confirm the existence of a site, the layout visible on the satellite images, and obtain chronological attribution. The sites were visited and monitored regularly during all seasons of the year. These were documented from the air taking ortho and oblique photographs from drones and airplanes. At every position, we also conducted intensive field surveys. We documented and collected archeological finds and subsequently analyzed its chronological attribution. According to surface finds, all of the sites presented in this paper belong to the late Neolithic Sopot culture.

For a better understanding of any site's original settlement layout prior to modern infrastructural and agricultural interventions, we used historical records. There were two main sources used for this purpose: aerial images made in the 1968 for military purposes, which are publicly available today [15]; and historical and cadastral maps from the Austro-Hungarian Empire, of which the area in question was a part of [16]. These sources proved to be essential in recognizing the possible patterns and remains of prehistoric landscapes.

For the confirmation of the site layouts and the development of observation methods, we used data provided by European Space Agency satellite constellations Sentinel-2. For the purpose of this paper, we concentrated on the data obtained with Sentinel-2 L2A and used true color composites RGB (4,3,2). Frequent satellite images (several new images every month) provide possibilities for new observations and pattern recognition [11]. Sentinel-2 images were analyzed using the visualization tool offered by the SentinelHub service and not through direct observation of the raster files downloaded

from the Copernicus Hub. The only shortcoming is the relatively low resolution for some details. In this stage of research, we used the normal color spectrum.

2.1. Excavations

One of the sites included in this paper, Gorjani Kremenjača, was not visible on aerial and satellite imagery, but was previously documented as a Sopot culture site, though this determination was based only on surface finds. The University of Zagreb has conducted excavations of the site since 2015 on a small excavation area of 100 m^2. The excavations confirmed the site's attribution to the late Neolithic Sopot culture [10]. Prior to and during the excavations, we also monitored the site from the air with drones and a plane, but no structures similar to other sites included in this paper were visible.

2.2. Geomagnetic Survey

The initial geophysical research by the magnetic method in 2016 and 2017 covered an area of 8000 m^2 in the vicinity of the excavation trench. Research by the low-frequency electromagnetic method was also carried out in three smaller areas. The results showed the presence of a large number of burned structures and archeological features such as pits containing pieces of burnt clay [17]. The magnetic survey continued in 2018 when the Eastern Atlas company surveyed an area of 6.3 ha [8]. The 2018 recording was carried out with seven Förster fluxgate gradiometer sensors. A Förster FEREX CON650 fluxgate gradiometer records the changes of the vertical components of the Earth's magnetic field with an accuracy of 0.1 nt (Nanotesla) [18]. During 2019, the survey continued recoding an area of 9 ha. The recording was carried out with 10 Förster fluxgate gradiometer sensors. The probes were mounted on a light and foldable cart. This gradiometer array is a component of the convertible LEA MAX system. The Förster FEREX CON650 fluxgate gradiometer probes register the gradient of the vertical component of the Earth's magnetic field with an accuracy of 0.1 nT (Nanotesla). The measured gradient (the difference between two vertically arranged sensors in the gradiometer probe) is insensitive to the typically large fluctuations of the Earth's magnetic field and is determined only by the magnetization of local subsurface objects [19].

3. Results

As a result of the long-term application of various remote sensing methods and cyclical and regular site monitoring, we were able to identify and interpret large late Neolithic enclosed settlements. Here, we present a group of five much larger sites in all of their complexity.

- Research area

The remote sensing encompassed the area surrounded by the Drava, Sava, and Danube Rivers. The results presented here were concentrated on the area approximately bordered by the towns of Osijek, Đakovo, and Vinkovci (Figure 1).

Figure 1. Position of the sites mentioned in the text on a satellite image of Croatia and surrounding areas. ① Klisa-Groblje i Brdo, ② Gat-Svetošince, ③ Koritna-Pašnik, ④ Ivanovac-Korođvar, ⑤ Gorjani-Kremenjača. Satellite image of Croatia in September 2003. Cropped image, original taken from NASA's Visible Earth. Obtained from Wikimedia Commons.

3.1. Klisa

The site Klisa-Airport consists of two circular enclosures in the literature known as Klisa-Brdo (Hill) and Klisa-Groblje (Cemetery) [20]. Its height above the surrounding area received attention from early cartographers and was recorded on the Austrian military maps from the 18th century onward (Figure 2) [16]. The east enclosure covers an area of 12 ha and consists of three concentric ditches, the largest of which has a diameter of 390 m and width of 13 m. The middle one has a diameter of 200 m and is 16 m wide, while the inner enclosure has a diameter of 69 m and width of 2 m, and is possibly a palisade. The western circle occupies an area of 8 ha and also has three concentric ditches of which the largest is 320 m in diameter and has a width of 13 m. The middle ditch is 190 m in diameter and has width of 13 m, and the inner ditch is 108 m in diameter with a width of 2 m and is possibly a palisade [9] Both sites are among the largest Neolithic sites in eastern Croatia. At this stage, we have yet to establish the relationship between the two outer ditches. According to the image taken before 1968 (Figure 3), they may not be contemporary. For the most part, they have been destroyed by the construction of Osijek Airport in the late 1970s and early 1980s (Figures 4 and 5). Rescue archeological excavations were carried out on a very small area and exposed a few meters thick layer of Sopot culture as well as a medieval church and accompanying cemetery at the top of one site.

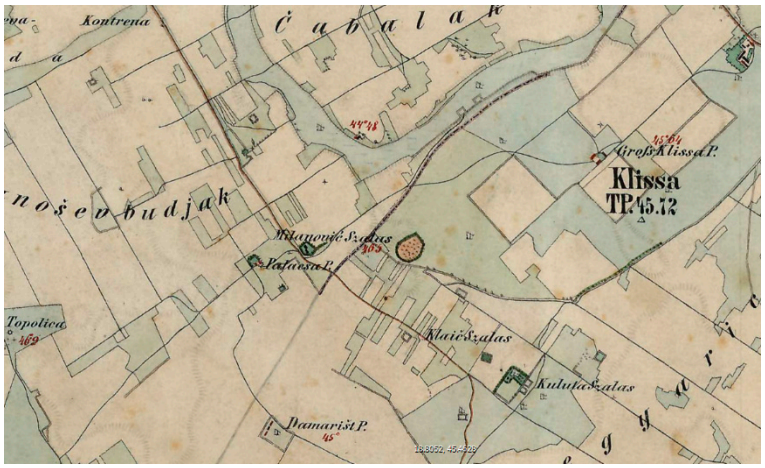

Figure 2. Klisa-Groblje i Brdo, the Second Military survey of the Habsburg Empire (1865–1869).

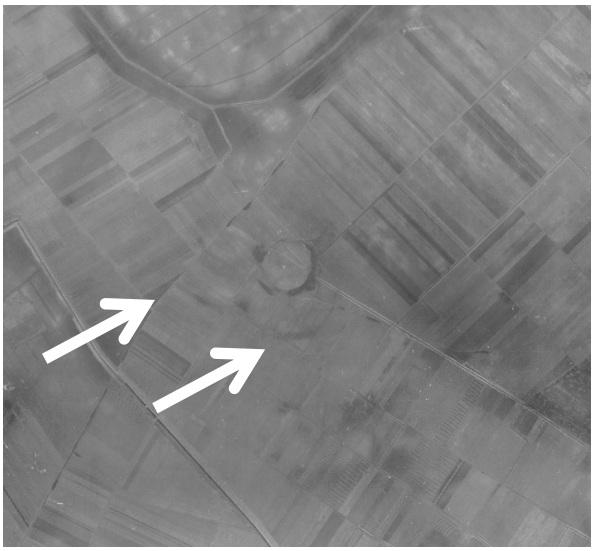

Figure 3. Klisa-Groblje and Brdo, vertical orthophoto image before 15 February 1968. Outer enclosures are marked by arrows and inner are visible as circles.

Figure 4. Klisa-Groblje i Brdo, oblique image (photo: H. Kalafatić, 2 June 2015). Inner enclosures under airport runway marked by arrows.

Figure 5. Site of Klisa-Groblje i Brdo on Sentinel-2 L2A, 8 June 2020. Outer enclosures are marked by arrows. Inner enclosures are visible as white colored circles under airport fence. Source: SentinelHub. Contains modified Copernicus Sentinel data 2020 processed by Sentinel Hub. ©Copernicus data 2020.

3.2. Gat-Svetošince

The site Gat-Svetošnice 1–2 is NE of the Gat village center, on the left bank of the Karašica River, around 600 m from the present Drava riverbed. The elevation of Gat-Svetošnice 1 is 94. m, and 93.85 m for Gat-Svetošnice 2. The enclosure Krug Gat-Svetošnice 1 was first spotted in Croatian Geoportal images from 2014–2016, and later also in images from 2017 (Figure 6). Some parts of the site are visible on Google Earth images and Sentinel-2 images (Figure 7). Drone images taken on 16 May 2016 and 16 June 2016 confirmed the ditches (Figures 8 and 9). The southern single ditch is a tell-like circle, with dimensions of 180 m × 130 m. The ditched area is 1.7 ha and the ditch is 18 m wide. The middle section has a relative height of 1.5 m. The western part is damaged by the erosion activity of the Karašica River. The northern Gat-Svetošnice 2 enclosure is also a single ditch tell-like circle, which has the dimensions of 214 m × 80 m. The area is 1.6 ha, and the width of the ditch is 14 m. The middle part has a relative height of 1 m. The southern part is damaged by the erosion activity of the river Karašica. The aerial images revealed an outer ditch enclosing the area of both circles on the area of approximately 22 ha. During the field survey, Sopot culture pottery, lithics, and polished stone tools were collected. North of the enclosures, there were some finds of medieval pottery [9]

Figure 6. Site of Gat-Svetošnice on the vertical orthophoto image 2017 by Geoportal. Source: Geoportal.dgu.hr.

Figure 7. Site Gat-Svetošince on Sentinel-2 L2A, 8 June 2020. Outer enclosure is marked by the arrow. Inner enclosure is visible as a circle. Source: SentinelHub. Contains modified Copernicus Sentinel data 2020 processed by Sentinel Hub. ©Copernicus data 2020.

Figure 8. Site of Gat-Svetošnice on drone photography, 16 May 2016, view from the west.

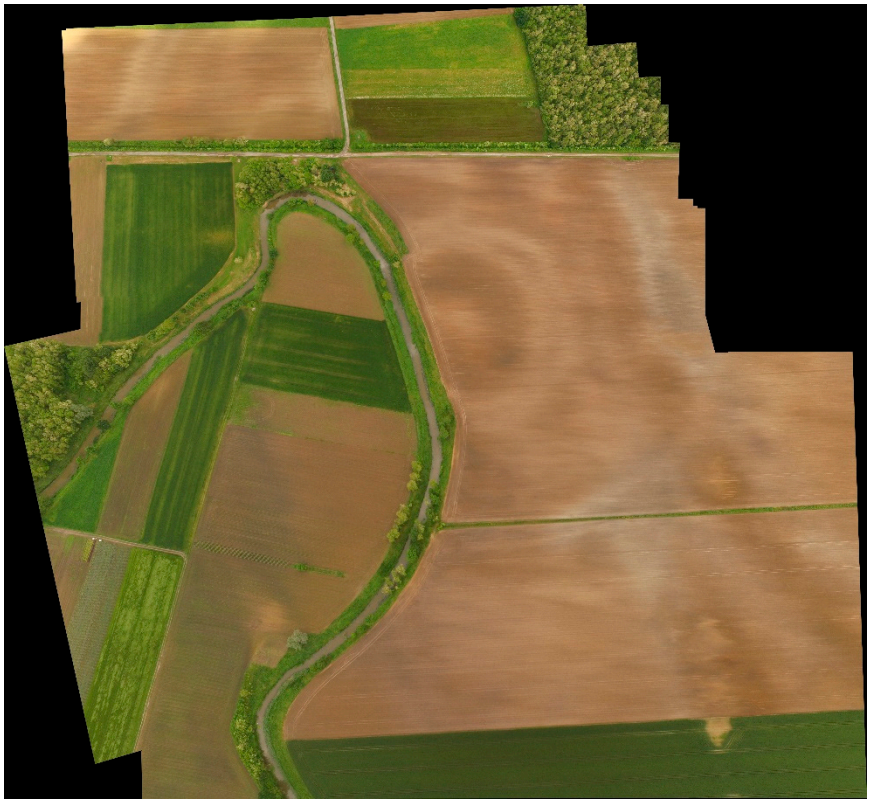

Figure 9. Site of Gat-Svetošnice vertical drone image (photo: K. Šobat, 16 May 2016).

3.3. Koritna-Pašnik

The Koritna-Pašnik site is located 2.3 km from the village of Koritna on the south bank of the old Vuka riverbed (presently Osatina Channel). The Vuka River surrounded the settlement from three sides (Figure 10) and the site consists of four enclosures. On the aerial images, the eastern and western enclosures are almost always visible, while the other two are less visible (Figures 11–13) [15]. Koritna-Pašnik 1 is a double central enclosure with an outer ditch area of 1.7 ha. The dimensions of the ditch are 163 m × 157 m, and the width of the ditch is 11 m. The inner enclosure covers an area of 0.45 ha. The dimensions are 81 m × 75 m, and the ditch is 5 m wide. On the western side, it has been damaged by enclosure 3. Koritna-Pašnik 2 is a southern single enclosure and covers an area of 0.88 ha. The dimensions are 116 m × 110 m, and the ditch is 7 m wide. Koritna-Pašnik 3 is a western single

enclosure. The visible enclosed area is 0.83 ha. The dimensions are 143 m × 80 m. The ditch width is 5 m. Koritna-Pašnik 4 is a northern single enclosure. The visible enclosed area is 0.15 ha and the visible part of the circle is 80 m with a ditch width of 5 m. Middle parts of the enclosure are 1.3 m to 3.2 m above the surrounding area. Surface finds belong to the Sopot culture. On the image from the First Military Survey of the Habsburg Empire (Figure 10) we can observe two enclosures, most probably enclosure 1 and enclosure 3 [16].

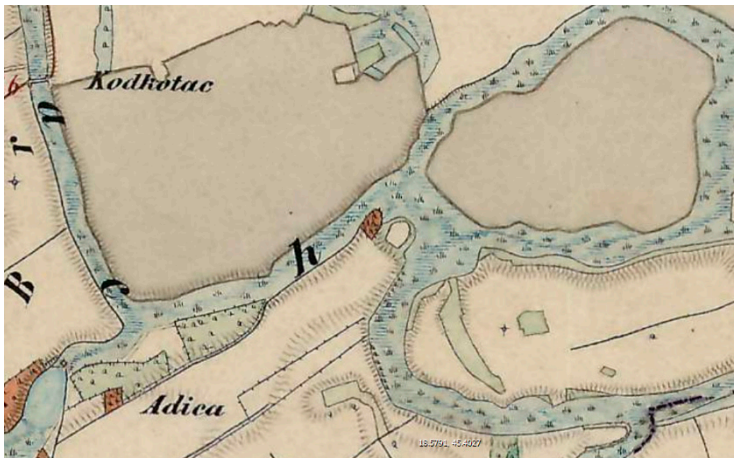

Figure 10. Koritna-Pašnik, the First Military survey of the Habsburg Empire (1763–1787).

Figure 11. Koritna-Pašnik, vertical orthophoto image before 15 February 1968.

Figure 12. Koritna-Pašnik, drone image (photo: K. Šobat, 6 October 2015).

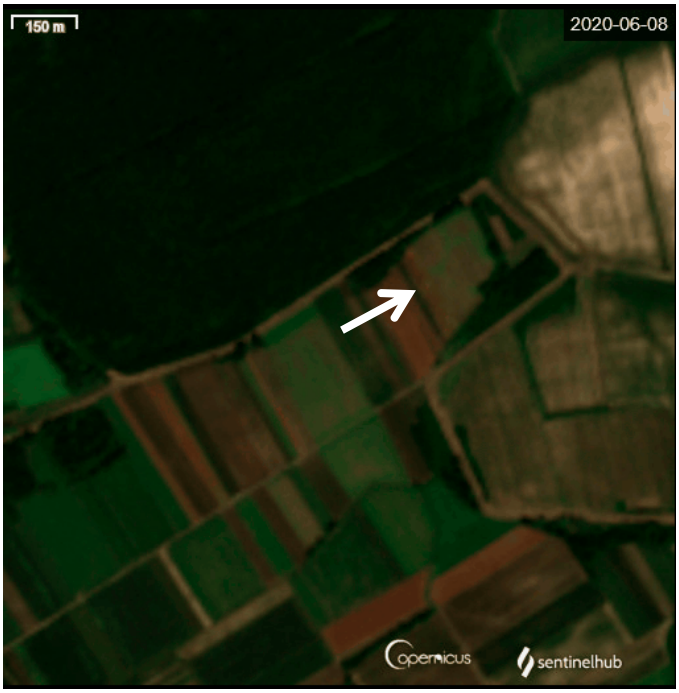

Figure 13. Site Koritna-Pašnik on Sentinel-2 L2A, 8 June 2020. Largest visible enclosure is marked by an arrow. Source: SentinelHub. Contains modified Copernicus Sentinel data 2020 processed by Sentinel Hub. ©Copernicus data 2020.

3.4. Ivanovac-Korođvar

The multi-phase site Ivanovac-Korođvar, is around 2 km west of the village of Ivanovac. The site is on the lowermost part of the area which was a marshland until the 19th century, which is clearly visible on the historical Habsburg empire maps [16] (Figure 14). During the 19th and 20th centuries, a drainage system of channels was built and created the present environment. The part most visible today is the medieval fortress Korođvar (Figures 15 and 16). During the archeological excavations of the fortress, a layer with Sopot culture was found, so we assumed that there was another Neolithic enclosure destroyed by the medieval fortress. This medieval fortress lies north of the prehistoric enclosures. The medieval outer ditch dimensions are 140 m × 103 m and covered an area of 1 ha. The building dimensions are 37 m × 36 m, covering the area of 1046 m^2 (Figure 16). Prehistoric Ivanovac-Korođvar

1 is a northern single enclosure. The dimensions are 158 m × 202 m, covering an area of 2.5 ha, and the ditch is 10 m wide. Ivanovac-Korođvar 2 is a central single enclosure. The dimensions are 214 m × 211 m, and the ditch is 14 m wide. The area of the enclosure is 3.2 ha. On the eastern side, it was damaged with enclosure no 3. Ivanovac-Korođvar 3 is an eastern single enclosure (Figure 17). It is visible on most satellite images from Google Earth, Sentinel-2, etc. (Figures 16 and 18). The dimensions are 147 m × 160 m, the ditch width is 14 m, and it covers an area of 1.8 ha. Ivanovac-Korođvar 4 is a single enclosure. It covers an area of 0.82 ha, its dimensions are 104 m × 106 m, and the ditch width is 3 m. In its southern part, it overlaps with Ivanovac-Korođvar 2. Based on the aerial images alone, it is not possible to conclude which enclosure is older. Ivanovac-Korođvar 5 is a southern single enclosure on the area of 0.2 ha. The dimensions are 53 m × 49 m, and the ditch is 2 m wide [14,20,21].

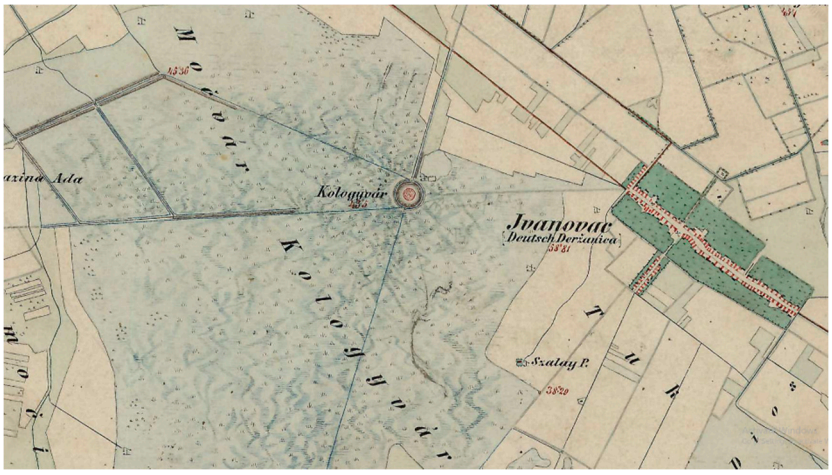

Figure 14. Ivanovac-Korođvar, the First Military survey of the Habsburg Empire (1763–1787).

Figure 15. Ivanovac-Korođvar, drone image (photo: K. Šobat, 24 April 2018).

Figure 16. Ivanovac-Korođvar, Google Earth image 24 September 2011 [22].

Figure 17. Ivanovac-Korođvar, drone image (photo: K. Šobat, 1 June 2016).

Figure 18. Site of Ivanovac-Korođvar on Sentinel-2 L2A, 19 February 2019. Medieval enclosure is marked by the upper arrow and the Neolithic enclosure is marked by the lower arrow. Source: SentinelHub. Contains modified Copernicus Sentinel data 2019 processed by Sentinel Hub. ©Copernicus data 2019.

3.5. Gorjani-Kremenjača

The position where excavations are conducted is called Kremenjača, which is a toponym that, in lowland areas with Quaternary deposits, mainly refers to an archeological site, due to the surface findings of lithic artifacts (Croatian kremen-flint). Gorjani-Kremenjača consists of a triple outer enclosure (Figures 19 and 20). The area occupied by the outer enclosure is visible on about 20 ha. The visible dimensions of the outer enclosure are approx. 400 m × 430 m. The ditch is 7 m wide. The central circle occupies an area of 10 ha. The length of the recorded part of the enclosure is 240 m and the width of the ditch is 4.5 m. Gorjani-Kremenjača has an inner double enclosure. The area of the enclosure is 2.4 ha. The dimensions of the outer ditch are 180 m in diameter and the ditch is 7.3 m wide. The inner ditch diameter is 138 m and the ditch is 3 m wide [10]. During 2019, we confirmed another similar, though a bit smaller, enclosure to the east with the dimensions of 140 m × 130 m. In the inner part, palisade remains are visible [19]. This smaller ditch cuts the outermost ditch and is of later origin. The excavations at the site began in 2015. In the wider area in the fields around the excavation site, large amounts of prehistoric artifacts have been found. The 2016 and 2019 excavations continued at the position of Kremenjača. Objects containing layers of burnt daub, compacted yellow loess, and post holes extended over almost the entire excavated surface. The layers of compacted loess, burnt daub, and layers of charcoal occurred on several levels, suggesting that the feature had been rebuilt several times. The feature was rectangular in shape, extending in the southwest–northeast direction. The orientation of the features was also confirmed by the results of the magnetic survey.

All excavation trenches were located in the area outside of the central enclosure, and yielded findings of the Sopot culture, confirming (combined with surface findings) the attribution of most of the structures outside of the central enclosure to the Sopot culture. At least four complex ditch systems could be observed. In the southern and central part, two complex ring ditch systems were recognized with axis lengths of about 150 m. In combination with the two outer ditch systems with estimated diameters of 400 m and 500 m, respectively, the ring structure can still only be assumed. The total

size of the area, enclosed by the outer triple ditch, can be estimated minimally at 20 ha. The density of prehistoric structures decreases from the center of the site toward the outer limits. The highest densities of structures were observed inside the ring ditch systems and in the north between the central ring ditch and the intermediate ditch.

After obtaining the results of the geomagnetic survey (Figures 19 and 20), re-evaluation of previous aerial images was conducted. With the layout provided by the geomagnetic survey, it is possible to detect soil and cropmarks following the layout, but different than usual. On the vast majority of the sites, the ditches were observable as lines, whereas on this site, they formed full circle or other shapes. One of the reasons that the site of Gorjani-Kremenjača was not visible is perhaps due to the density of structures, so the cropmarks and soil marks were not recognized as such because of the lack of the usual shapes (Figures 21–23). Geological drilling using 10 cm cores confirmed anthropogenic layers of 2–3 m thickness [23]. In the entire area, we collected surface finds of Sopot culture pottery fragments, lithics, polished stone tools, and pieces of daub.

This site also belongs to the "twin circle" phenomena (previously defined in [9]) with a surrounding big outer enclosure, similar to Gat and Klisa. Two ditch systems in close proximity to each other, but not overlapping, suggest their simultaneous existence. We can conclude that the smaller circle partly intersects with the outer ditch, suggesting its younger age. It is our future task to define fine chronological details in this settlement's existence and temporal and architectural changes.

Figure 19. Gorjani-Kremenjača, results of the geomagnetic survey of the site.

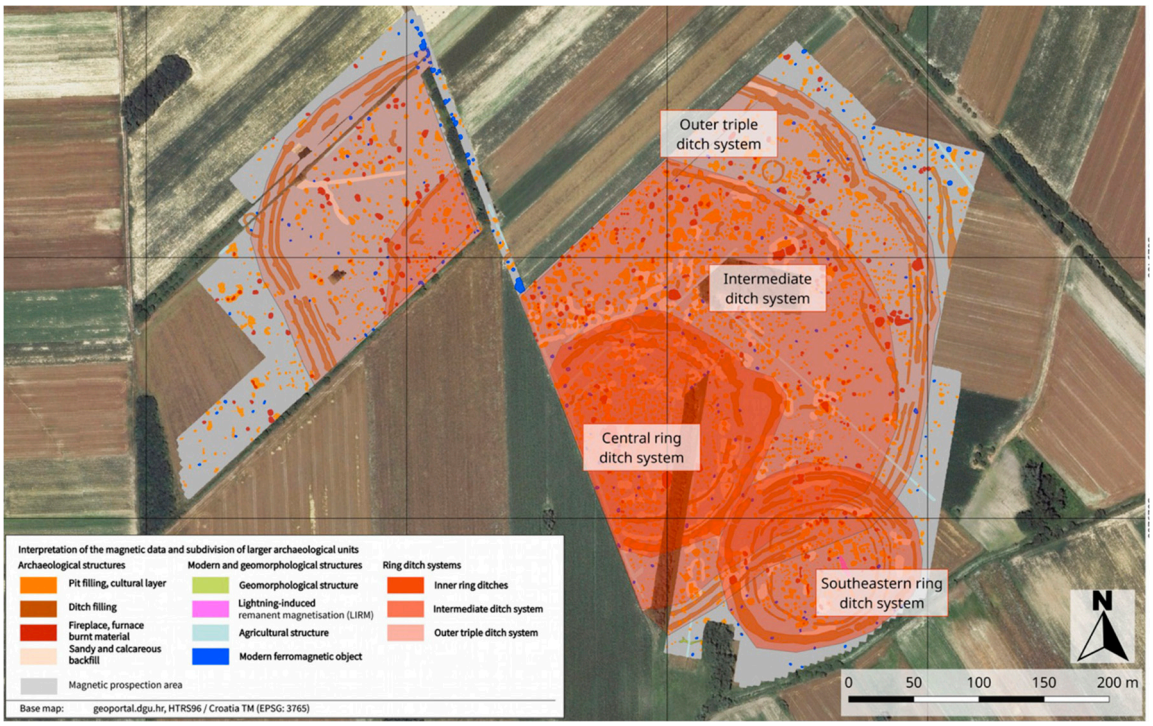

Figure 20. Gorjani-Kremenjača, interpretation of the magnetic survey.

Figure 21. Gorjani-Kremenjača; shape of the part of the most outer enclosure is marked by arrows. Sentinel-2 L2A 9 May 2020. Source: SentinelHub. Contains modified Copernicus Sentinel data 2020 processed by Sentinel Hub. ©Copernicus data 2020.

Figure 22. Gorjani-Kremenjača, drone image from 28 May 2018. Shape of the part of the inner enclosure is marked by arrows.

Figure 23. Gorjani-Kremenjača, oblique image from drone (photo: H. Šobat, 29 May 2015).

4. Discussion

Land division is an obvious obstacle in defining the size and shape of prehistoric settlements. This is especially visible in the cases of sites such as Ivanovac-Korođvar and Gorjani-Kremenjača. As documented throughout this research, visibility varies significantly depending on the period of the year, moisture, and crop type. Due to these factors, constant monitoring is crucial in creating settlement layouts through a mosaic of images. Therefore, the availability of satellite images on an almost daily basis is an invaluable tool that will significantly improve non-destructive archeological research in the future. We also observed different visibility at different sites, for example, on 8 June 2020, when visibility was optimal at the sites Koritna, Klisa and Gat, almost nothing could be observed at the sites of Gorjani-Kremenjača and Ivanovac-Korođvar. In previous times, with limited access to aerial and satellite images, many of the sites could have been omitted simply on that criteria. Spectral characteristics of Sentinel-2 for crop mark distinction are already recognized as better compared to other satellite sensors [11–13]. Furthermore, it is recognized as suitable for larger features, even using only most common bands, B2, B3 and B4 [14]. In this case, it was proven effective for the recognition

of large soil and crop marks, even without the pre-processing of images. We are confident that more detailed analysis, which we are working on, will provide even better results.

What is now confirmed beyond any doubt is that Neolithic settlements were of the size of contemporary small villages. This means that their size was far larger than previously thought. A system of ditches points us in the direction of investigating prehistoric habitational and technological practices as well as questions of communal work and other types of choices dictated by living in a large enclosed community. The size and complexity of such sites prevent us from investigating it using standard archeological methods, therefore, using remote sensing methods and developing observation practices using available satellite images will become a mandatory part of Neolithic settlement research.

These sites showed a wide range of settlement (layouts) patterns, which might indicate different chronological phases or different social relations/needs. All mentioned sites, especially Gorjani-Kremenjača, were among the sites with the most complex internal settlement structure in the Carpathian Basin and Central Europe. These sites are also large Neolithic settlements such as Borđoš in Serbia [24], Polgár-Csoszhalom [25] and Öcsöd-Kováshalom [26] in Hungary, and by complexity and geographical proximity are more comparable with Belvárdgyula-Nádas [27], Geredlak-Hosszú hát [27], Szemely-Hegyes [27]), Zengővárkony-Igaz-dűlő [27], and in Hugary Baraya [28] (and Bylany in the Czech Republic [29], which all present a similar organizational pattern.

The combination of the analysis of aerial and satellite images provides the most comprehensive results and enables capturing sites in their entirety. Using traditional methodologies, archeologists could only detect small portions of their sites, and as a result, much smaller areas have been protected as cultural heritage compared to their actual size. Historical records are also an integral part of developing site caption methodology. In the end, excavations are required only to confirm the precision of observed structures and chronology. Satellite imagery has become the best cost effective method for systematical monitoring of archeological sites with various sequences of soil marks and cropmarks throughout the seasons. Higher frequency of new images on Sentinel constellation satellites provides a powerful tool for remote sensing analysis. All these methods can also be augmented by LiDAR technology, and future research plans will include LiDAR as soon as financial resources allow it.

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