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Article

Multiscale and Multitemporal Remote Sensing for Neolithic Settlement Detection and Protection—The Case of Gorjani, Croatia

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Abstract: The decade of research concentrating on the area of Eastern Slavonia revealed an abundance of large and complex Middle and Late Neolithic sites. It changed profoundly how we perceive Middle and Late Neolithic settlements, including space, size and organization. The vast majority of these sites were detected through aerial reconnaissance and satellite image analysis. The observation of the sites was followed by intensive field surveys, which confirmed their attribution to the Middle and Late Neolithic period by surface finds. On those confirmed sites in the vicinity of Đakovo, Croatia, a magnetic survey was conducted on five sites, and the results confirmed the presence of large-scale Middle and Late Neolithic settlements with complex spatial organization and enclosure(s). The most complex remains so far are the sites Gorjani, Kremenjača and Topole, which we present in this paper, where one or two settlements remain covering an area of 70 hectares which is currently in the process of formal protection as a cultural landscape by the Ministry of Culture and Media of the Republic of Croatia. The special focus of this paper is the application of remote sensing in the detection, archaeological confirmation and protection of the site of Gorjani Topole.

Keywords: magnetic survey; aerial archaeology; Middle and Late Neolithic; Eastern Croatia; enclosure; settlement organization

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1. Introduction

The number of enclosures in Southeast, Central Europe and beyond is constantly growing, and the variety of purpose(s) of these large and complex earthworks and their interpretation remains a very active research question both on a local and pan-European scale [1–6].

The application of remote sensing techniques over the last three decades slowly enabled the broadening of the research areas and study of Middle and Late Neolithic sites on much larger scales, e.g., [7–11]. This led to changes in understanding of the size and scope of Neolithic settlements and/or monuments. The period of the Middle and Late Neolithic in Eastern Croatia is traditionally marked by the presence of Sopot culture. So far, data on the size and internal organization of the landscape are rather limited, allowing only the most general and generic conclusions, even though some sites with a complex structure are mentioned and also the possibility of mutual relations, but these are not further elaborated [12,13]. A previously known, eponymous Sopot culture site, which was systematically excavated over the last 25 years, also has an enclosure confirmed by excavations and a magnetic survey [13].

It was presumed that the Middle and Late Neolithic sites with enclosures were tell sites in a traditional sense with limited geographic and temporal expansion [14]. These new results have yet to change this traditional image. The results of ten-year remote sensing research followed by field surveys confirmed the presence of more than a hundred Middle and Late Neolithic circular enclosures on the territory of Eastern Croatia [15,16] (Figure 1).

On five of them, magnetic surveys confirmed the presence of enclosure(s) but also very dense and complex features.

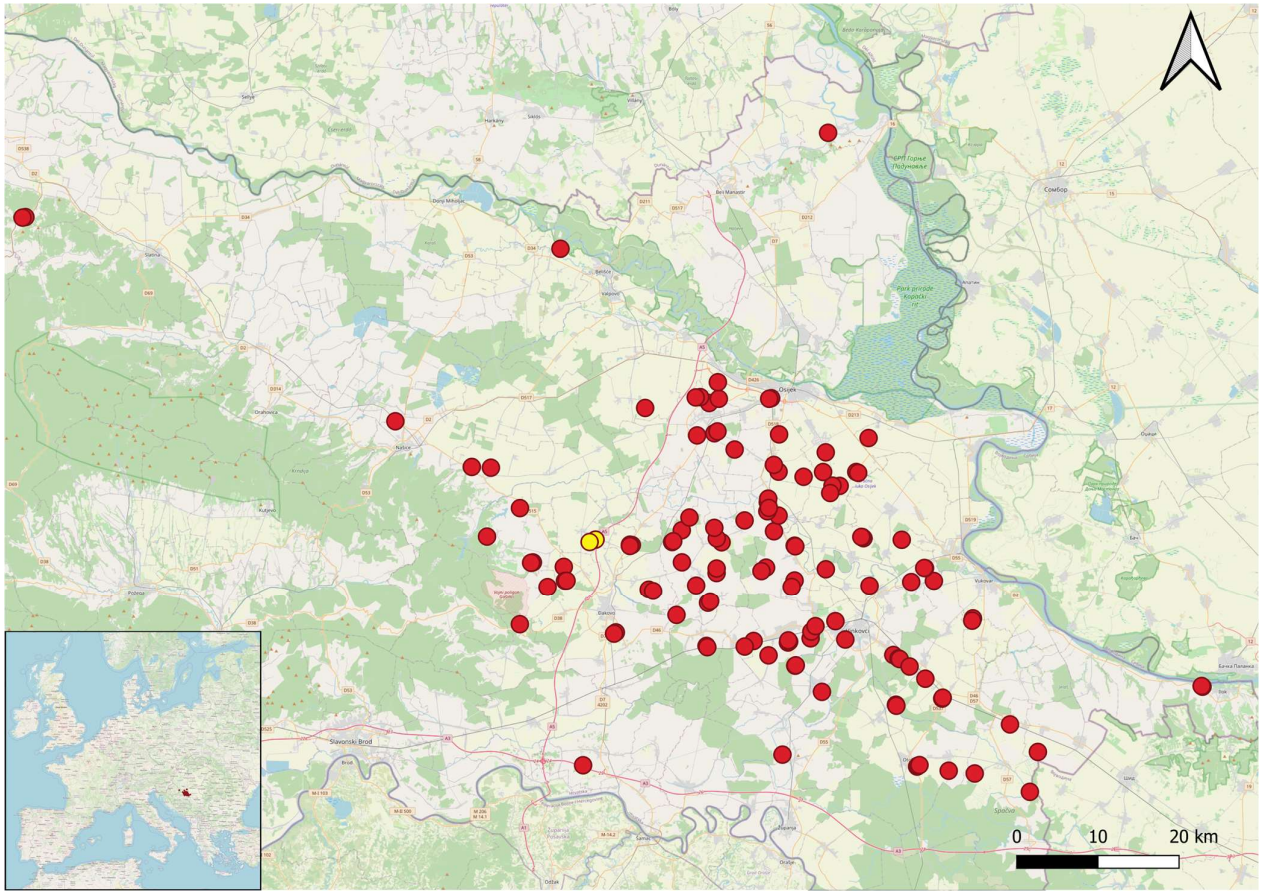


Figure 1. Map of Middle and Late Neolithic enclosures in Eastern Croatia and Europe. Basemap: Open street map. Sites marked on the map red were discovered by remote sensing in Eastern Croatia through images from Google Earth, Geoportal.dgu and airplane and drone oblique images taken in 2013. Position of Gorjani Topole and Kremenjača sites marked with yellow dot.

Multiscale research on Gorjani Topole and nearby Gorjani Kremenjača sites revealed complex spatial organization and directed the research toward the search for the actual size of the settlement and its internal organization. Current results urge us to form a hypothesis on the existence of settlement planning and settlement templates during the Middle and Late Neolithic periods in the area. Also, it is clear that this new information will require new research approaches in order to understand the specific features or complexes of features.

Numerous methods developed in the last decade proved useful and efficient for the recognition and protection of archaeological and cultural heritage. Once fully established and proven effective, those methods combined present a framework for developing new multidisciplinary methods and workflows for the identification and protection of cultural heritage on a whole new level without the need to use destructive methods [17–20]. We hope that this is one of the examples of the effectiveness of multi-scalar remote sensing research.

2. Materials and Methods

2.1. Aerial Reconnaissance and Field Survey

During the period from 2012 to 2023, work focused on the Drava, Danube and Sava Rivers in Eastern Croatia, a part of Croatia characterized by fertile land divided into large agricultural plots ideal for the aerial reconnaissance of archaeological features. The basis of the research was a comparative image study of eight cyclic photogrammetric

surveys made by the Republic of Croatia State Geodetic Administration from 1997 to 2022. Satellite imagery and Internet geographic services, such as Google Earth, Bing Maps, Croatian Internet geodetic Geoportal.hr and agricultural map services ARKOD, were also extensively used in this research. Spatial analysis of aerial images was combined with historical maps and images available on the World Wide Web. A valuable resource is also the digitalized vertical images that originated before 1968, available since 2015 (Produced by Military Geographical Institute, Belgrade, Serbia). These sites were selected, according to the results of the above-mentioned analysis, to conduct a series of aircraft photographic surveys from 2013 to 2023. UAVs have been used since 2015 to record target areas and sites, which significantly increased the number of newly discovered sites. The satellite imagery and aerial photography data were compared with the results of the systematic field survey. The majority of discovered sites can be attributed to Neolithic Sopot culture from the 5th millennium BC. Besides new discoveries, it has to be emphasized that the survey has shown a surprisingly dynamic change in the landscape from the 18th century until today, which is important both for cultural heritage management and for landscape development strategies.

2.2. Magnetic Survey

A magnetic survey was conducted on several occasions from 2019 to 2023 by the company cmprospection from Berlin, Germany. Arrays of Förster fluxgate gradiometer probes with seven to ten sensors (Förster, Baden-Württemberg, Germany) were used for the magnetic measurements. The probes were mounted on a light and foldable cart and moved by hand. The Förster FEREX CON650 fluxgate gradiometer probes register the vertical 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 typically large fluctuations in the Earth's magnetic field and is determined only by the magnetization of local subsurface objects. The data positioning for the magnetic survey was realized by means of a differential GPS, using two GNSS receivers, Trimble R10 model 2 (Trimble, Sunnyvale, CA, USA) in the RTK mode (Real-Time Kinematic), to achieve a relative accuracy of 2 cm. The base was fixed via Trimble RTX corrections to an absolute accuracy of 2 cm (Table 1). The coordinate system used during the magnetic measurements was WGS84 UTM 34N (EPSG: 32634). Subsequently, the data were reprojected to the reference system HTRS96/Croatia TM (EPSG: 3765) by means of the open-source Geospatial Data Abstraction Library (GDAL) [21,22].

Table 1. Technical parameters of magnetic prospection [17,18].

Method	Magnetic Prospection
System	LEA MAX (Eastern Atlas, Berlin, Germany)
Sensors	10 Förster fluxgate gradiometers FEREX CON650 (vertical separation 65 cm) (Förster)
Data logger	LEA D2 with 10 channels (Eastern Atlas)
Measurement category	Vertical gradient in nT
Configuration	7–10 sensors, mounted on cart
Resolution	0.5 m profile distance, max. 0.1 m point distance
Topographic measurement	2 GNSS receivers in RTK mode
Data positioning	Relative error 0.02 m
Processing and filters	Ealdec and Ealmat, decoding program including offset and drift correction
Data format	ACSII, GeoTiff
Image resolution	0.25 m × 0.25 m

Magnetic data were subjected to standard processing steps such as offset and drift correction using script-based decoding and processing routines. The resulting data were merged into equidistant grid files, generated by means of the cubic spline interpolation, with a mesh size of 0.25 m, and transformed into full-dynamic-georeferenced Tiff images in the reference system HTRS96/Croatia TM (EPSG: 3765), ready for further processing and interpretation in GIS. For the data interpretation carried out in QGI, the magnetic data images were examined for anomalies that could indicate archaeological features [21,22].

2.3. Archaeological Excavation

Archaeological excavations on the site of Gorjani Topole have been carried out twice so far, in March 2020 and 2021. The 2020 research was planned to confirm the presence of the ditches, which were observed on satellite and aerial images and also confirmed through magnetic surveys (Figures 2–4). A trench was chosen with the intention of excavating the remains of circular ditches and a palisade visible on magnetograms and aerial images. During March 2021, archaeological excavations were carried out at the site of one of the houses that was recorded on magnetograms. Due to the feasibility of the research, one of the smaller houses was chosen.

Figure 2. Gorjani Topole crop marks of circular enclosure—rondel on the Google Earth image from 23 August 2007. On the right site, preparation for the archaeological excavation on the highway C5 sites Tomašanci, Palača and Zdenci is visible. Arrows are pointing towards the shape of the enclosure visible in the color change of the crops.

(**a**) (**b**)

Figure 3. Soil marks of Gorjani Topole circular enclosure: (**a**) DGU Geportal orthophoto image from 2017. Source: Geoportal.dgu.hr. (**b**) Oblique drone image. DJI Mavic Pro2, 15 October 2022. Arrows are pointing towards the shape of the enclosure visible in the color change of the soil. Author: Hrvoje Kalafatić.

3. Results

3.1. Archaeological Interpretation Based on Aerial and Satellite Images

In this paper, we present our workflow on the example of the Gorjani Topole site in more detail and with the application of other methods, but also four similar sites. Observations of Gorjani Topole using various methods can be used as an interpretational model for other sites where we currently have data only from satellite and aerial images.

3.1.1. Gorjani Topole

The enclosures of Gorjani Topole were initially observed on the Google Earth image from 23 August 2007 (Figure 2). In this image, the crop marks of three ditches are clearly visible. This is also the only image in which a fragment of an outer ellipsoidal ditch is visible.

Subsequent images do not reveal the details as the 2007 one does, but the area of the circular enclosure is clearly visible as a soil mark on later Google Earth images and also orthophotos from the Croatian State Geodetic Administration (DGU from here on in the text), for instance, the one from 2014 and those on drone images (Figure 3). In oblique images taken from an airplane on 10 June 2015, the crop marks are not clearly visible [16].

Following these observations, we conducted a series of intensive field surveys (2015, 2016, 2017) where pottery fragments and lithic artifacts from the Neolithic (both Starčevo and Sopot cultures) period were collected. After the magnetic survey, we decided to encompass a larger area to the east for research.

The expansion of the field survey area revealed places with high concentrations of Neolithic pottery and lithic finds, so we focused the magnetic survey on that area as well.

Figure 4. Pits visible on drone images by Hrvoje Kalafatić on 11 November 2016. There are visible dark spots to the north of the observed enclosure. These pits were confirmed by a magnetic survey (Figure 6 in this paper).

Initial archaeological interpretation based on remote sensing presumed a triple ditch enclosure on the site of Gorjani Topole. Since the feature, which is now recognized as the outer ditch, was only partly visible on satellite images and only in the area closest to the circular enclosure, by measuring mutual distances, it was concluded at the time that it was the third ditch of the circular enclosure. In Gorjani Topole, the triple enclosure was assumed to cover the area occupied by the outer enclosure of approximately 1.15 ha, with only a small part being visible; therefore, the calculation is based on the radius centered in the inner enclosure (r = 60 m). The width of the ditch is 2 m. The dimensions of the middle enclosure are 113 m × 90 m. The ditch is 4.2 m wide, and the area of the enclosure is 0.82 ha. The inner enclosure covers an area of 0.14 ha. Its dimensions are 45 m × 37 m. The inner ditch is 5 m wide.

This information remained relevant until the magnetic survey. In one drone image, dark spots were visible, which is an indication that archaeological remains could also be found in the area surrounding the enclosure. The results of the aerial and satellite studies yielded significant results, considering dozens of images from 2002 to the present day, including an archival image from 1968. It confirmed the presence of a circular enclosure, which motivated further research.

The most recent archaeological excavation confirmed the expansion of the Middle and Late Neolithic features outside the already established area. The re-examination of satellite images based on the results of the field survey and magnetic survey allowed us to observe possible pit features that were inconclusive as soil marks. But through comparison with field survey results and the magnetic survey, possible new pits were revealed, which were then tested using the new magnetic survey. It confirmed the presence of large pits and also a longhouse.

3.1.2. Klisa

The site of Klisa consists of two circular enclosures known in the literature as Klisa Brdo (Hill) and Klisa Groblje (Cemetery). Its height above the surrounding area received attention from early cartographers and was recorded in the Austrian military maps from the 18th century onwards. The east enclosure covers an area of twelve hectares and consists of three concentric ditches, the largest of which has a diameter of 390 m and width of 13 m, the middle has a diameter of 200 m and is 16 m wide, and the inner area has a diameter of 69 m and width of 2 m. The western circle occupies an area of eight hectares 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 a width of 13 m, and the inner ditch is 108 m in diameter and has a width of 2 m (Figure 5a). Both sites have been among the largest Neolithic tells in eastern Croatia, but for the most part, have been destroyed by the construction of the Osijek airport in the late seventies and early eighties of the 20th century. Rescue archaeological excavations were carried out on a very small area and revealed a several meters thick layer of Neolithic Sopot culture and a medieval cemetery at the top of one site.

3.1.3. Privlaka Gradina

The site of Privlaka Gradina is well known in the archaeological literature, and by studying the aerial photographs, we were able to confirm some researchers' previous assumptions [12,23,24].

On the recordings, the remains of two Sopot circles and a ditch and rampart of the Iron Age Celtic fortification are visible. Additionally, the outer ellipsoid circle enclosing two inner circles is visible (Figure 5b). The area of the northern circle is 1.2 ha. The dimensions are 118 m × 115 m. The width of the ditch is 6 m. The relative height of the central part is 4.4 m. The western side was partly destroyed by the erosion of the Bosut River. Both circles were damaged by a later Iron Age fortification that connected both circles into one. In Privlaka Gradina 2, the south circle occupied an area of 1.2 ha. The dimensions of the circle are 130 m × 95 m. The width of the ditch is 6 m. The relative height

of the central part is 5.8 m. The visible dimensions of the outer circle are 600 m × 400 m. The width of the ditch is 31 m.

Figure 5. Rondels and circular enclosures with ellipsoidal outer enclosure in Eastern Croatia: (**a**) Klisa, Groblje i Brdo; vertical orthophotography before 15 February 1968. DGU Geportal orthophoto image from 2017. Source: Geoportal.dgu.hr; (**b**) Privlaka Gradina, DGU Geportal orthophoto image 2014–2016. Source: Geoportal.dgu.hr. (**c**) Markušica Brošov salaš, Google Earth image 1 August 2020; (**d**) Gat Svetošnice DGU Geportal orthophoto image 2014–2016. Source: Geoportal.dgu.hr. Arrows are pointing towards the shape of the enclosure visible in the color change of the crops and/or soil.

3.1.4. Markušica Brošov Salaš

Markušica Brošov salaš is a circular enclosure with external double ellipsoid ditches. The area covered by the outer ellipse is 14 ha. The dimensions of the ellipse are 435 m × 399 m. The ditches are 8 m wide. The inner circle has an area of 2.2 ha. The dimensions are 164 m × 169 m. The inner ditch is 10 m wide (Figure 5c).

3.1.5. Gat Svetošnice

The enclosures at Gat Svetošnice were observed in Geoportal images from 2014 to 2016 (Figure 5d) and later in images from 2017. Some parts of the site are visible on Google Earth Pro and ARKOD images (reviewed on 7 May 2018). Drone footage from 16 May 2016 and 16 June 2016 confirmed the existence of circles. The dimensions of the southern single ditch circle are 180 × 130 m. The area it covers is 1.7 ha. The ditch is 18 m wide. The central part has a relative height of 1.5 m. The western part of the circle was destroyed by the erosion of the Karašica River. The dimensions of the northern single-ditch circle at Gat Svetošnice 2 are 214 × 80 m. The area it covers is 1.6 ha. The width of the ditch is 14 m. The central part

has a relative height of 1 m. The southern part of the circle was destroyed by the erosion of the Karašica River. Aerial photographs show a large external ditch of approximately 22 ha that surrounds both circular enclosures.

3.2. Magnetic Survey

The magnetic survey initially covered an area of over 10 ha. It confirmed the presence of three ditches (two circular and one ellipsoidal) but also a circular palisade in the inner part of the circular enclosure (Figure 6). Furthermore, it revealed the presence of a larger ellipsoidal enclosure and the presence of numerous features spreading toward the north and west of the enclosure(s) (Figure 7).

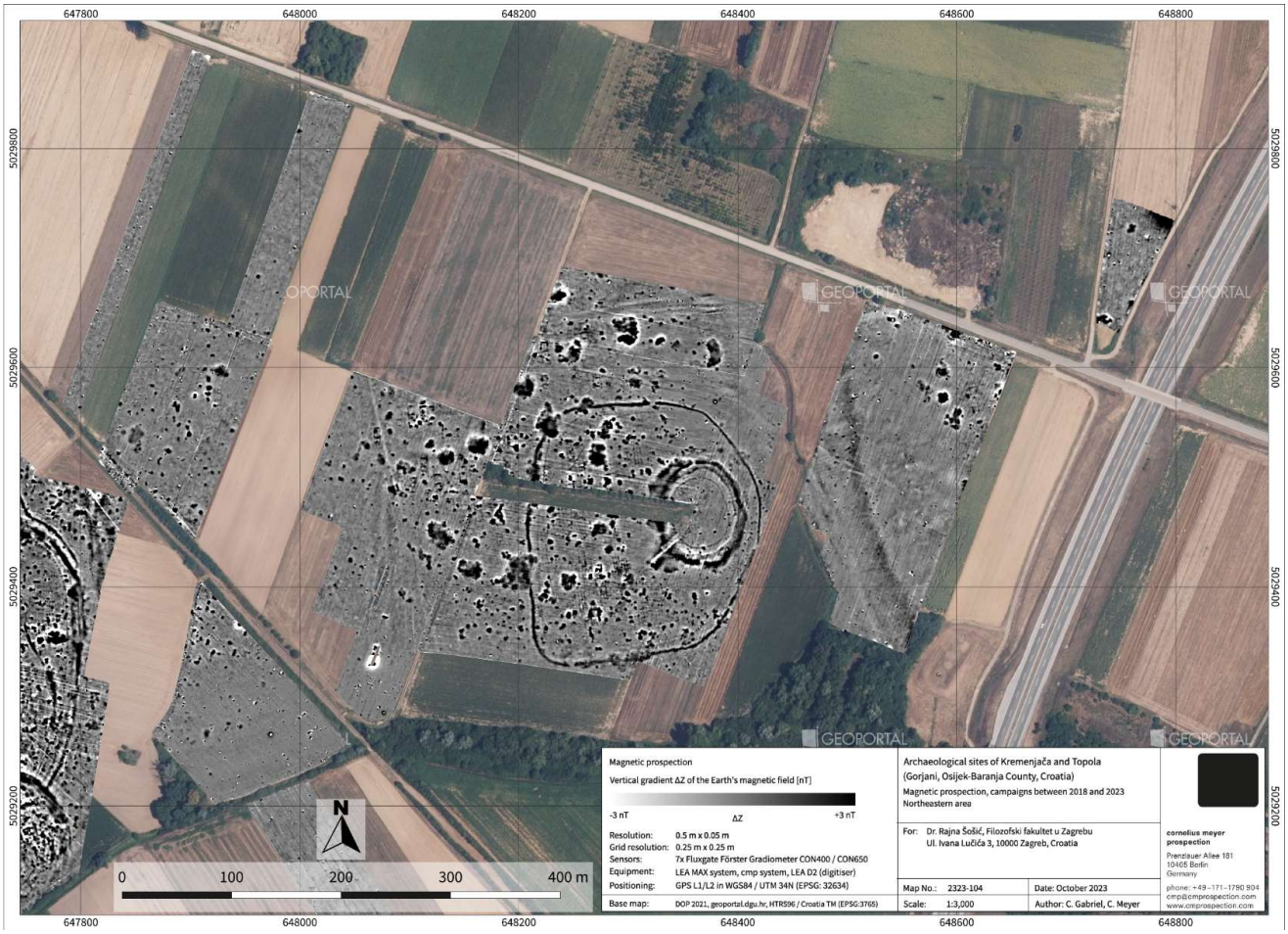


Figure 6. Magnetogram of Gorjani Topole measurements 2019–2023.

The most recent magnetic survey, planned according to the results of the field survey and new satellite image observations, confirmed the expansion of the site to the east and the presence of a longhouse. We can assume that this is close to the border of the site since there is a motorway in the vicinity, during the construction of which archaeological sites were found to the north and south of this position, but not for the continuation of this site where two archaeological sites, Tomašanci Palača and Tomašanci Zdenci, were excavated [25,26], so it is reasonable to assume that the eastern edge of the Topole settlement is somewhere near this longhouse. The orientation of the longhouse at the most eastern part is the same as that of the rest of the sites in the area to the west of the circular enclosure (Figure 8).

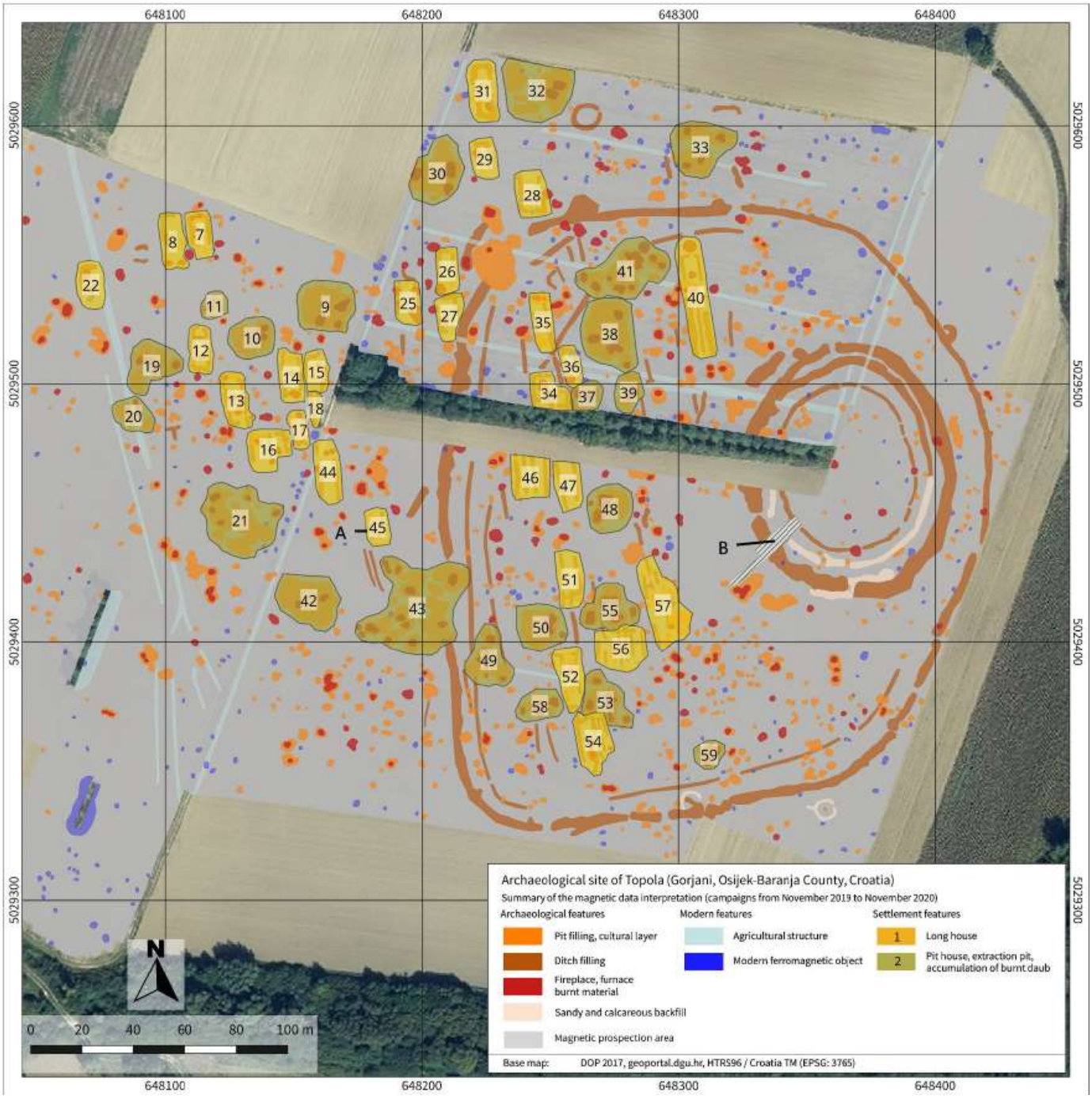


Figure 7. Interpretation of the magnetic survey of Topole enclosures and settlements with marked positions of the archaeological trenches. A—house, B—ditches. Author: Cornelius Meyer. The numbered features present houses or large pits.

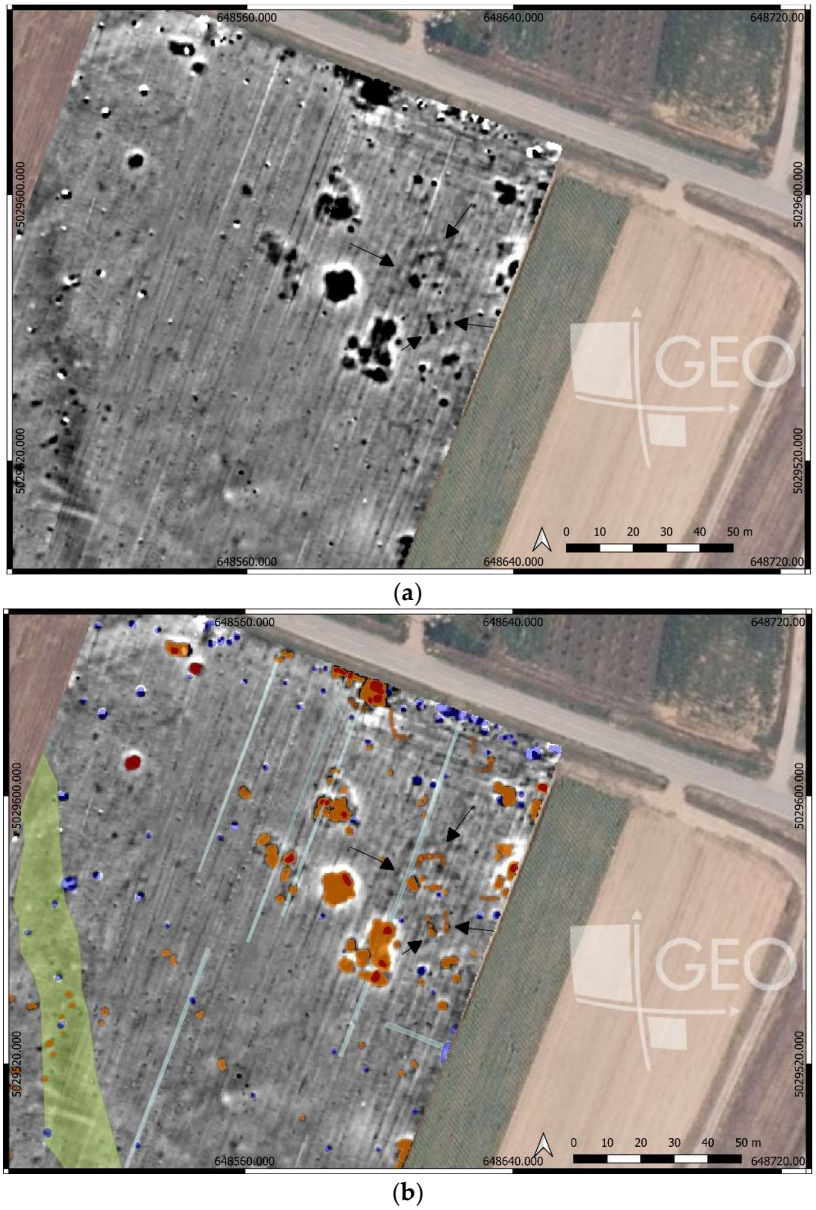
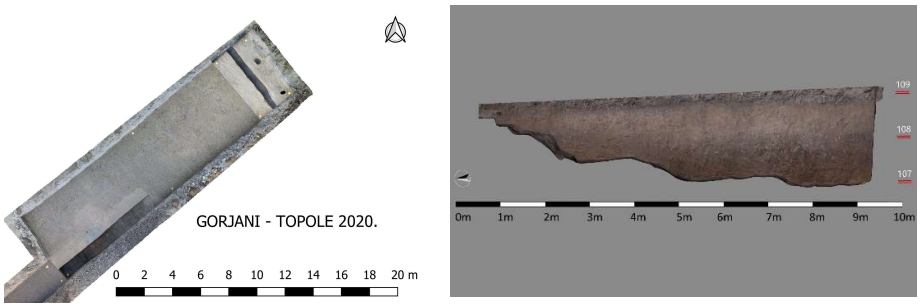


Figure 8. (**a**) Longhouse at the eastern border of the researched area on magnetogram (details are from Figure 6 in this paper), marked with arrows; (**b**) interpretation.

3.3. Archaeological Excavation

The excavations revealed that, below the plow layer, there is a natural layer between 0.5 and 0.8 m thick at this site, below which archaeological structures occur. The occurrence of such layers was recorded at the nearby Tomašanci Palača site, which is located only 500 m to the north and was investigated during protective archaeological work during the construction of the A5 motorway [25]. Fragments of pottery from the Sopot culture were found in those layers at that site, and it was presumed that there was a Sopot culture settlement somewhere nearby [27], as confirmed by this research. The excavations revealed the remains of two ditches and a wooden palisade (Figure 9). While the internal ditch is relatively shallow and has evidence of homogenous fills, the external ditch is of a larger depth (more than 2 m) and width and contains several fills (Figure 9b), suggesting that the ditch was filled slowly over time, as documented at the Neolithic enclosure Velm [28], and was probably exposed to atmospheric and depositional processes that did not occur evenly and simultaneously on all parts of the excavated ditch. The ceramic fragments are very fragmented and washed out, which is another argument that the ditch stood

open for a longer period before being filled, so the material was extremely damaged by atmospheric and later post-depositional processes. Like today, waste was probably occasionally dumped in the channels, which the structure of the found material also indicates. Preliminary thin section analysis also indicated multiple fillings of the ditch: two alternating homogenous sediments without or with very little anthropogenic material, or only occasionally appearing organic matter when the channel was filled relatively quickly, and two sediments with more anthropogenic material, including fragments of housewares, ceramics, coal and organic matter.



(**a**) (**b**)

Figure 9. Excavated features of the ditches and palisade. (**a**) Palisade, inner ditch and segment of outer ditch; (**b**) profile of the outer ditch. Author M. Mađerić.

The remains of the house were preserved as negatives of channels and holes from the columns of its original wooden construction (Figure 10). Since the house was abandoned and slowly deteriorated, there were not many finds, i.e., only a small number of fragments of ceramic vessels from the Sopot culture.

(**a**) (**b**)

Figure 10. (**a**) Oblique drone image of excavated house. DJI Mavic Pro2, 15 March 2021. Author: R. Šošić Klindžić. (**b**) Orthophoto of excavated house. Author M. Mađerić.

Radiocarbon dates confirm the attribution of the site to the Middle and Late Neolithic period. For the chronological attribution of the site, twelve samples of bone and charcoal were dated using the AMS radiocarbon method at the Hertelendi Laboratory of Environmental Studies, Debrecen, Hungary. The samples originate from the following four contexts: the excavated remains of the house, the postholes of the palisade, the circular inner ditch and the circular outer ditch. Due to the very poor preservation, we managed to date only three bone samples, and the remainder were charcoal. The results of radiocarbon dating placed all the features in the period of the Middle and Late Neolithic, or more precisely, in its later phases (Table 2). Dates from the outer ditch are the youngest for the Neolithic in the area and are even contemporary with the beginning of the Eneolithic on the nearby Lasinja culture site [27]. A similar date from the posthole of the house suggests the occupancy of

this site in the final phases of the Neolithic period in this area. As mentioned before, the ditch was probably filled during a longer period of time. Other dates are concentrated in the period c. 4800–4500, which suggests the long duration of the settlement.

Table 2. Radiocarbon dates from the excavated house and parts of the ditches and palisade.

Archaeological Context	LabNo	Conventional 14C Age (yrs BP) (±1σ)	Calibrated Calendar Age (cal BC) (2σ)
House postholes	DeA-37013 (charcoal)	5732 ± 33	BC 4683–4462
	DeA-37012 (charcoal)	5545 ± 39	BC 4453–4335
Palisade	DeA-26047 (bone)	5911 ± 33	BC 4890–4710
	DeA-26046 (bone)	5898 ± 33	BC 4850–4700
Circular inner ditch	DeA-26254 (charcoal)	5929 ± 30	BC 4895–4722
	DeA-26045 (bone)	5918 ± 33	BC 4900–4710
	DeA-26246 (charcoal)	5846 ± 29	BC 4790–4617
	DeA-26250 (charcoal)	5839 ± 29	BC 4786–4614
	DeA-26253 (charcoal)	5764 ± 34	BC 4707–4354
	DeA-26247 (charcoal)	5739 ± 29	BC 4685–4504
Circular outer ditch—lower level	DeA-26251 (charcoal)	5573 ± 30	BC 4457–4352
	DeA-26248 (charcoal)	5491 ± 29	BC 4444–4263

The nearby complex of several circular and ellipsoidal enclosures at Gorjani Kremenjača also suggests the long duration of the settlement and, in part, overlaps with the dates for the Topole rondel and house [16].

4. Discussion

Over the last two decades, numerous research projects have slowly but significantly changed the image of settlement appearance, size and complexity in the Middle and Late Neolithic periods throughout Central and SE Europe. Besides numerous regional differences, what has been observed as a large-scale phenomenon is the circular organization of the settlements. The second important observation is the complex spatial organization of the various components of the settlement's infrastructure and recognition of the entire cultural landscape rather than isolated and fragmented features "floating in the landscape". Probably the most famous and paradigmatic landscape is the one to the north of our area of interest, i.e., the network of enclosures, monuments and settlements surrounding Stonehenge in the United Kingdom [29]. That these circular enclosures are far from isolated monuments but part of an elaborate organizational pattern is also confirmed in lower Bavaria [30, Abb. 6], where rondels with large surrounding ellipsoidal enclosures were documented [30].

In the Central European context, rondels are classified into two major groups—Western and Eastern [31]. The Eastern group covers the area from the Southern Czech Republic to Southern Hungary. In all of these areas, sites with single and multiple enclosures were documented.

So far, the most southern expansion of rondels has been considered the Drava River [31]. Our research suggests that the area of expansion is somewhat larger, at least to the Sava River to the south. Through satellite image analysis, among circular enclosures, we detected several sites where enclosures could be interpreted as rondels in a strict sense. We suggest the interpretation of the Gorjani Topole circular enclosure as a rondel since it has clearly marked entrances, it is mostly empty space and is constructed as a series of parallel ditches, palisades and entrances, and it is confirmed by a magnetic survey. The spatial relationship of this rondel to other ditches and archaeological features is the focus of our future research. Rondels surrounded by a simple ditch (usually ellipsoidal) are documented in other regions as well, for example, in Germany at Ippesheim, Künzing Unternberg and similar sites [30], or at Bylany in the Czech Republic [11]. Such rondels or circular enclosures with surrounding ditches were discovered in Croatia and also on the sites of Gat Svetošnice, Privlaka Gradina, Klisa Groblje and Brdo, and Markušica Brošov Salaš, with emphasis that

Markušica Brošov Salaš is a typical rondel (Figure 10). The Künzing Unternberg complex suggests that the rondel predates the ellipsoidal enclosure [30]. The more detailed internal chronology of sites mentioned in this text is yet to be established.

The datation and duration of the Gorjani Topole rondel and settlement are also in accordance with other European rondels between 4800 and 4500 cal BC [28,30–32] (Table 2 in this paper). The orientation of the houses is northwest–southeast (Figure 7), which is common for the area and the time period as defined in recent research, where detailed analysis shows patterns in house orientation throughout Central and Southeastern Europe during the Middle and Late Neolithic period [32]. Acceptance and respect for the empty space in the rondel is also suggested by the fact that it remained as such, which is not the case for the other parts of the site, where the overlapping of features is documented in numerous places (Figure 7).

This research is complimentary with recent results, where it has been proven that remote sensing enables the discovery of many Neolithic rondel sites in an area where they have not been previously documented, like Poland [33], and it represents an efficient and reliable methodology for new site detection providing better insight into cultural landscapes and enabling research on a bigger scale. Multi-rondel sites are also documented in a wider Central European context [31]. Sites with multiple enclosures and rondels quite close to each other are documented at multiple places through the continuous monitoring explained in Figure 11, which enabled the observation of new sites [34]. With the most recent research, it has been established that the complex of Neolithic settlements and features in Gorjani is even larger than previously thought, covering an area of 1500 m in length and encompassing an area of c. 70 hectares (Figure 12). This partial temporal overlapping is an important factor for understanding the cultural landscape in the early-to-mid 5th millennium BC. Higher resolution research provides us with more information to conclude whether this is a Middle and Late Neolithic landscape or a Middle and Late Neolithic settlement. In both cases, but especially in the latter, this approach urges us to expand our area of research and understanding of spatial organization in the Middle and Late Neolithic period.

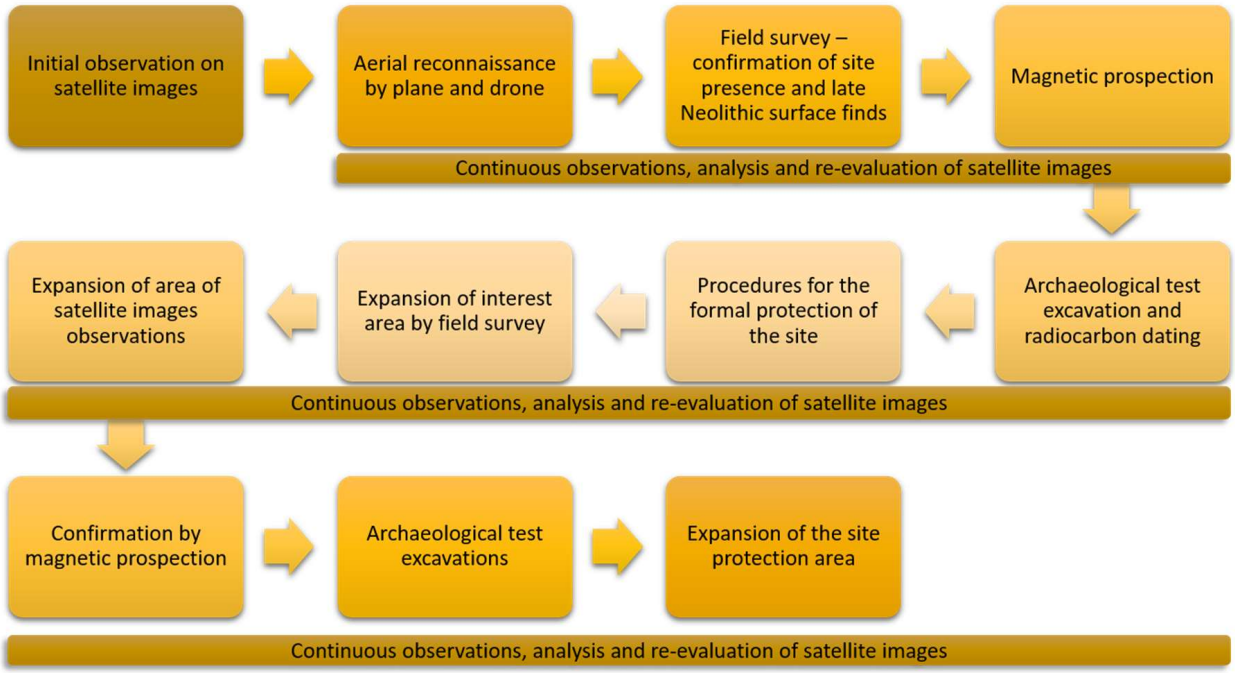


Figure 11. Workflow established for detection of Middle and Late Neolithic enclosures in Eastern Croatia.

Figure 12. Results of magnetic survey at Gorjani Kremenjača and Topole 2018–2023.

In the end, we conclude that the rondels in Eastern Croatia, by their characteristics and geographic position, present a continuation of rondel phenomena to the south and should be regarded as a part of the Eastern complex of Neolithic rondels.

We can observe circular enclosures as a widespread phenomenon with mutual characteristics such as datation and the presence of circular shape, but also fine differences in shape, organization and surroundings. These similarities and differences call for a more detailed but, at the same time, general research approach.

Our approach includes the combination of various archaeological methods, but the biggest potential is in the constant monitoring and re-evaluation of satellite images and aerial photographs combined with magnetic prospection.

With this approach, we established a workflow (Figure 11) that consists of the initial observation of satellite images, followed by monitoring through aerial images from drones and airplanes, before confirmation through field inspection and magnetic surveys, which so far have shown us that it is necessary to expand the area of observation of satellite images and we found that these sites almost always expand and that their area is much larger. These additional observations were confirmed through further field surveys, excavations and magnetic surveys, followed by new observations, additional expansions and, ultimately, the expansion of the formal official protected zone. The detailed and repeated analysis of satellite images provides us with a deep insight and, so far, no sufficiently explored possibilities of soil and crop marks. Marks manifested as dark spots are confirmed at the site of Topole as large pits (Figure 4). This can also strengthen our interpretation of pits on other still unpublished sites.

5. Conclusions

Despite numerous confirmations, strong skepticism still remains about the attribution of large earthworks visible on satellite images to the Middle and Late Neolithic period.

Therefore, there are still demands, both from academia and heritage administration, for confirmation via destructive methods (i.e., archeological excavations). We hope that this and similar research will show the interpretational possibilities of combined remote sensing archaeological research and the interpretation of prehistoric landscapes.

An old rule of aerial archaeology says that it can determine whether something is there but not if something is not there. In accordance with this, magnetic research has shown that these sites have a larger area than initially observed, and in this way, knowledge about the settlements and the cultural landscape is being expanded. These additional observations allow us to revise and supplement the identification of marks in the soil and crops that we did not recognize before and that we recognize today.

The sites of Gorjani Kremenjača and Topole were initially protected as cultural heritage sites over an area of eight hectares. The results of remote sensing multiscale and multitemporal research led the Croatian Ministry of Culture and Media to start the procedure of protecting the entire area as a cultural heritage site in total, resulting in an area of 70 hectares.

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