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Article

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

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Abstract: The decade of research concentrating on the area of Eastern Slavonia revealed abundance of large and complex late Neolithic sites. It changed profoundly how we perceive late Neolithic settlement and space size and organization. As a first step in particular site detection we mostly conducted aerial reconnaissance and satellite image analysis but also data from the field such as excavation. On detected potential sites we conducted intensive field surveys and confirmed the attribution to the late Neolithic by surface finds. On those confirmed sites in the vicinity of Đakovo, Croatia, magnetic survey was conducted on 5 sites so far and the results confirmed presence of large scale late Neolithic settlements with complex spatial organization and enclosure(s). Most complex remains so far is site Gorjani Kremenjača and Topole which we present in this paper where a remains of one or two settlements covers the area of 70 hectares and is currently in the process of formal protection as a cultural landscape by the Ministry of Culture and Media of the Republic of Croatia. Special focus of the paper is the application of remote sensing in detection, archaeological confirmation and protection of the position Gorjani Topole.

Keywords: magnetic survey; aerial archaeology; late Neolithic; Eastern Croatia; enclosure; settlement organization

1. Introduction

The introduction should briefly place the study in a broad context and highlight why it is important. It should define the purpose of the work and its significance. The current state of the research field should be carefully reviewed and key publications cited.

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

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

It was presumed that the sites with enclosures during the late Neolithic are tell sites in traditional sense with limited to a geographic and temporal expansion. [14] This new results are yet to change this traditional image. Results of a ten year remote sensing research followed by field surveys

confirmed the presence of more than 100 late Neolithic circular enclosures on the territory of Eastern Croatia [15–20] (Figure 1). On 5 of them geomagnetic surveys confirmed presence of enclosure(s), but also very dense and complex features.

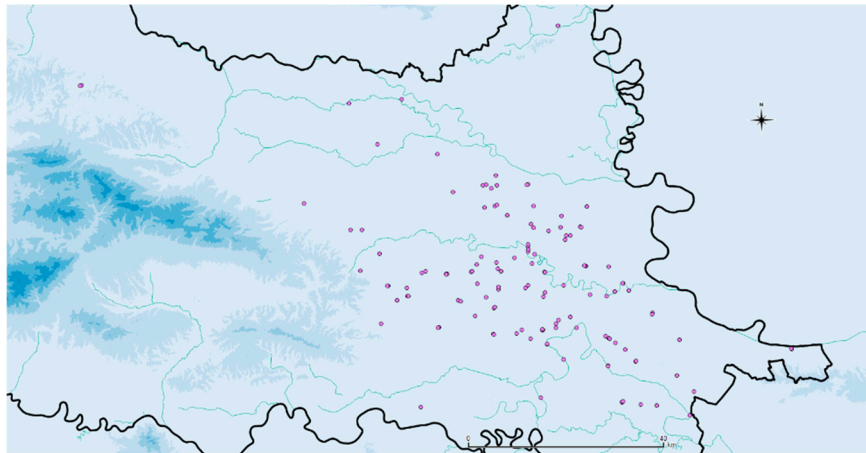


Figure 1. Map of Late Neolithic enclosure discovered by remote sensing in Eastern Croatia.

The multiscale research on Gorjani Topole and nearby Gorjani Kremenjača locations revealed complex spatial organization and directed the research towards the search for the actual size of the settlement and its internal organization. Current results urge us to form hypothesis of the existence of settlement planning and settlement templates during the late Neolithic in the area. Also, it is clear that this new information will require much focused research in order to understand specific features or complexes of features.

2. Materials and Methods

Aerial reconnaissance

Enclosures of Gorjani Topole were initially observed on the Google Earth image from August 2007 (Figure 2). On this image crop marks of three ditches are clearly visible. This is also the only image where the fragment of outer ellipsoidal ditch is visible.

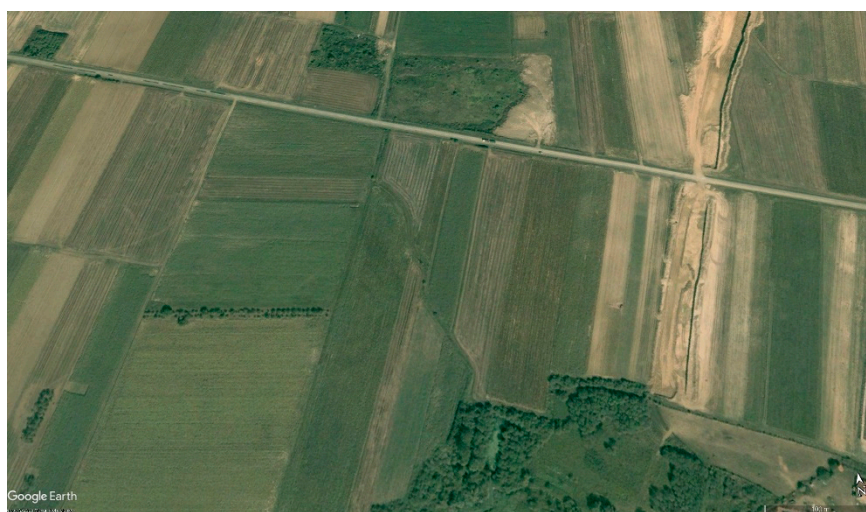


Figure 2. Gorjani Topole soilmarks of circular enclosure on the Google Earth image 23 August 2007. On the right site is visible preparing archaeological excavation on highway C5 site Tomašanci Palača and Zdenci.

Subsequent images do not reveal the details as the 2007 one, but the area of circular enclosure is clearly visible as soil mark on later Google Earth images and also orthophotos from Croatian State Geodetic Administration, for example the one from 2014 and on drone images (Figure 3), or isn't so clearly visible as crop marks on oblique images shoot from airplane in 10. 06. 2015 [16].



Figure 3. Soil marks of Gorjani Topole circular enclosure (a) Croatian State Geodetic Administration Geportal orthophoto image 2017. Source: Geoportal.dgu.hr. (b) Oblique drone image. DJI Mavic Pro2, 15.10.2022. Author: Hrvoje Kalafatić.

Field survey

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

Expansion of field survey area revealed places with high concentration of Neolithic pottery and lithic finds so we focused the geomagnetic survey to that area also.

Geomagnetic survey

Geomagnetic survey was conducted on several occasions from 2019 till 2023 by the company cm prospection from Berlin. Arrays of Förster fluxgate gradiometer probes with 7 sensors 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 the typically large fluctuations of 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 differential GPS, using two GNSS receivers Trimble R10 model 2 in 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. 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].

Archaeological excavation

Archaeological excavation on the position 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 that was observed on satellite and aerial images, which was also confirmed by magnetometric surveys (Figures 4–6). A trench was chosen with the intention of excavating the remains of circular ditches and a palisade that were visible on magnetometric and aerial images. During March 2020, archaeological excavations were carried out at the site of one of the houses that were recorded on magnetometric images. Due to the feasibility of the research, one of the smaller houses was chosen (Figure 6).



Figure 4. Pits visible on drone image by Hrvoje Kalafatić on 11.11.2016. There are visible dark spots to the north of the observed enclosure. The pits were confirmed by magnetic survey.

3. Results

3.1. Archaeological Interpretation Based on Aerial and Satellite Images

Initial archaeological interpretation based on remote sensing presumed triple ditch enclosure. Due the third outer ditch only partly visible and distance between ditches on we interpret as triple ditch. And this will stall until geomagnetic survey. On one drone images it was visible dark spot which were an indication that archaeological remains could also be found in the area surrounding 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 circular enclosure and which motivated further research.

Most recent archaeological excavation confirmed the expansion of the late Neolithic features outside the already established area. Re-examination of satellite images based on the results of field survey and geomagnetic survey allowed us to observe possible pit features that were as soil marks inconclusive. But with comparison with field survey results and geomagnetic survey new possible pits were revealed which was then tested by the new geomagnetic survey. It confirmed presence of large pits, and also a longhouse.

3.2. Geomagnetic Survey

Geomagnetic survey initially covered 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 3). Furthermore, it revealed the presence of larger ellipsoidal enclosure and presence of numerous features spreading toward the north and west of the enclosure(s).



Figure 5. Gorjani Topole results of geomagnetic surveys 2019-2023.

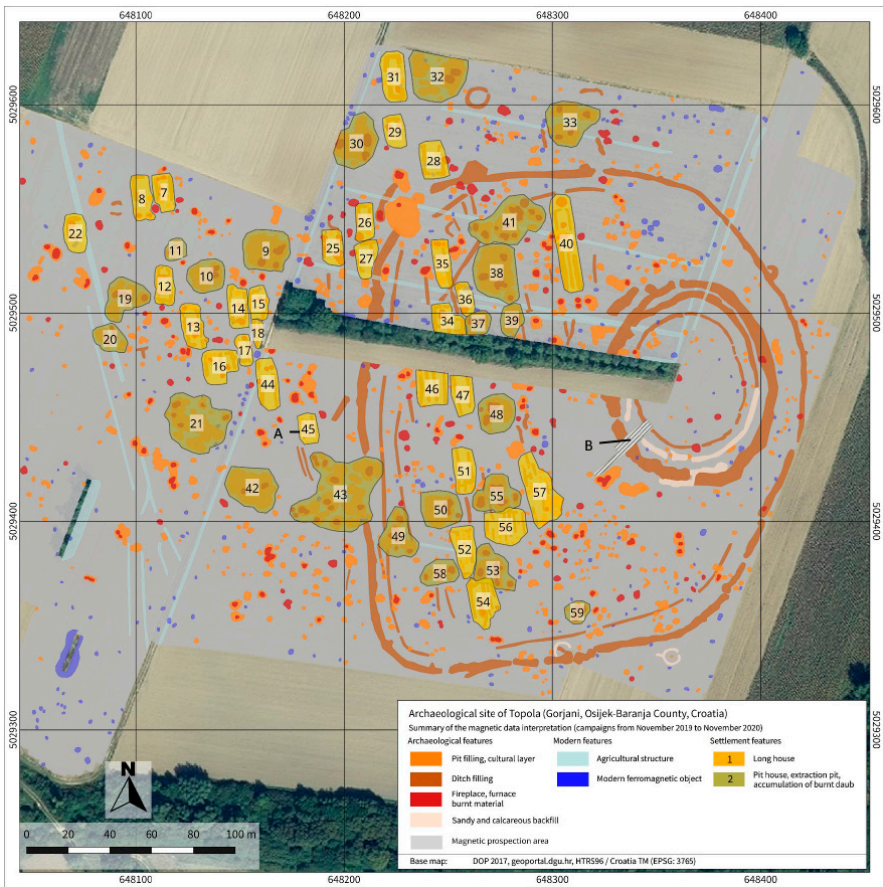


Figure 6. Interpretation of the geomagnetic survey of Topole enclosures and settlement with marked positions of the archaeological trenches. A – house, B – ditches.

Most recent geomagnetic survey, planned according to the results of field survey and new satellite image observations, confirmed the expansion of the site to the east and the presence of the long house. We can assume that this is close to the border of the site since there is motorway during which construction archaeological sites were found to the north and south of this position, but not in the continuation of this site [23,24], so it is reasonably 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 of the rest of them in the area to west of the circular enclosure (Figure 7.).

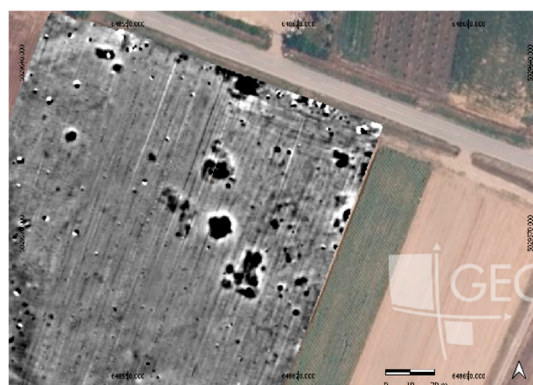


Figure 7. Longhouse at the eastern border of the researched area.

3.3. Archaeological Excavation

The excavations revealed that below the ploughed layer, there is a natural layer of thickness 0.5 - 0.8 m 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 [23]. 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 [25], which was confirmed by this research. The excavations revealed the remains of two ditches and a wooden palisade (Figure 6). While the internal ditch is relatively shallow and has homogenous fills, the external ditch is of bigger depth (more than 2 m) and width and contains several fills (Figure 8b), which would mean that the ditch were filled slowly over time [26], and were 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 is extremely damaged by atmospheric action 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 indicates multiple fillings of the ditch: alternating two 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 that includes fragments of housewares, ceramics, coal, organic matter.

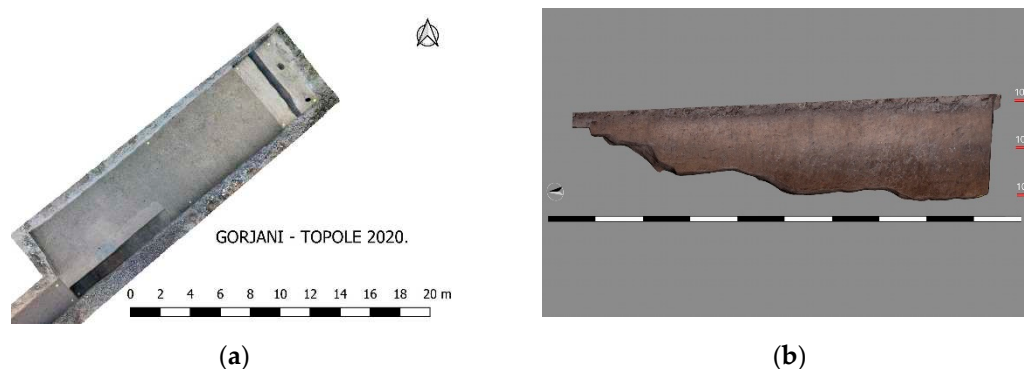
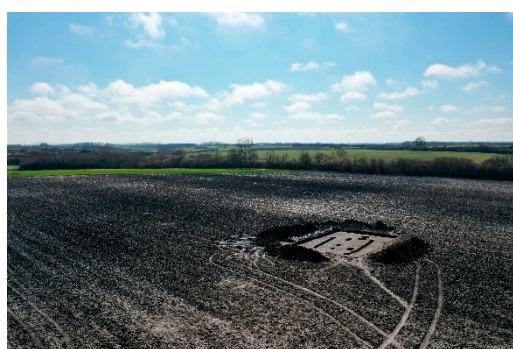


Figure 8. Excavated features of the ditches and palisade. (a) palisade, inner ditch and segment of outer ditch (b) profile of the outer ditch.

The remains of the house were preserved as negatives of channels and holes from the columns of its original wooden construction (Figure 6). Since the house was abandoned and slowly deteriorating, there were not many finds, only a small amount of fragments of ceramic vessels from the Sopot culture.



(a)



(b)

Figure 9. (a) Oblique drone image of excavated house. DJI Mavic Pro2, 15.03..2021. Author: Rajna Šošić Klindžić. (b) ortophoto of excavated house.

Radiocarbon dates confirm attribution of the site to the Late Neolithic period. For the chronological attribution of the site, 12 samples of bone and charcoal were dated by AMS radiocarbon at Hertelendi Laboratory of Environmental Studies, Debrecen, Hungary. The samples originate from four contexts: excavated remains of the house, the postholes of the palisade, the circular inner ditch and circular outer ditch. Due to the very poor preservation, we managed to date only three bones samples, others are charcoal. The results of radiocarbon dating place all the features in the period of late Neolithic, to its later phases (Table 1). Dates from the outer ditch belong to the latest for the Neolithic in the area, even the beginning of the Eneolithic on the nearby Lasinja culture site [25], and similar date from the posthole of the house suggest occupancy of the site in the final phases of Neolithic in the area. As mentioned before, ditch was probably filled during the longer period of time. Other dates are concentrated in the period c. 4800-4500 which suggest long duration of the settlement.

Table 1. Radiocarbon dates from excavated house and parts of ditches and palisade.

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

Nearby complex of several circular and ellipsoidal enclosures Gorjani Kremenjača also suggest long duration of the settlement and in part overlaps with dates for Topole rondel and house [16]

4. Discussion

We suggest the interpretation of the circular enclosure as rondel since it has clearly marked entrances, it is mostly empty space and is constructed of series of parallel ditches and palisades and entrances. The spatial relationship of this rondel to other ditches and other archaeological features are the focus of our future research. Rondels that are surrounded by the simple ditch (usually ellipsoidal) are documented in other regions as well, for example, in Germany Ippesheim,, Künzing-Unternberg and similar sites [27], or Bylany in Czech republic [28]. Such rondels with surrounding ditches are discovered in Croatia also on sites of Gat-Svetošince [15], Privlaka-Gradina [13,17], Klisa Groblje i Brdo [17] and Markušica – Brošov Salaš (Figure 10).

The datation and duration of the rondel and settlement are also in accordance with other European rondels [27–29]. The orientation of the houses is northwest-southeast (Figure 6) which is common for the area and time period as defined in recent research [30] Acceptance and respect of 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 part of the site where overlapping of features is documented on numerous places (Figure 6).

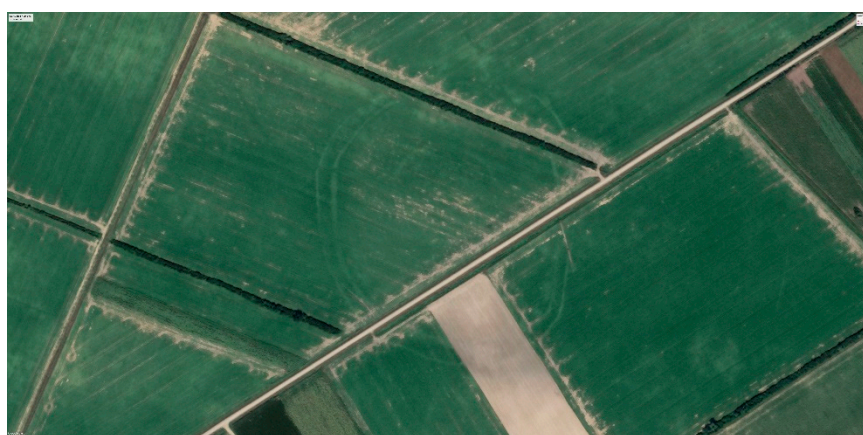


Figure 10. Markušica-Brošov salaš. Eastern Croatia. Rondel with outer ditch. Google Earth image 01.08.2020.

This research is complimentary with recent new results where it is proven that remote sensing enable discovery of many Neolithic rondel sites in area where they were not previously documented, like Poland [31], and the remote sensing is efficient and reliable methodology for new site detection that provides better insight in cultural landscapes and enables research on bigger scale. Multi-rondel sites are also documented in wider Central-European context [29]. Sites with multiple enclosures and rondels quite close to each other are documented at multiple places through continuous monitoring explained in Figure 11 that enabled observation of new sites [32]. With the most recent research, it is established that the complex of Neolithic settlements and features in Gorjani is even larger that established [33] so it covers the area of 1500 m in length, encompassing the are of c. 70 hectares (Figure 11). This partial temporal overlaping is important factor for understanding the cultural landscape in early to mid 5th millennium BC. Higher resolution research will provide us with more information to conclude whether this is Late Neolithic landscape or Late Neolithic settlement. In both cases, but especially the latter, this approaches urges us to expand our area of research and understanding of spatial organization in Late Neolithic.

Results of remote sensing multiscale and multitemporal research the Croatian Ministry of Culture and Media to start the procedure of protection of the entire area as cultural heritage site in its total.

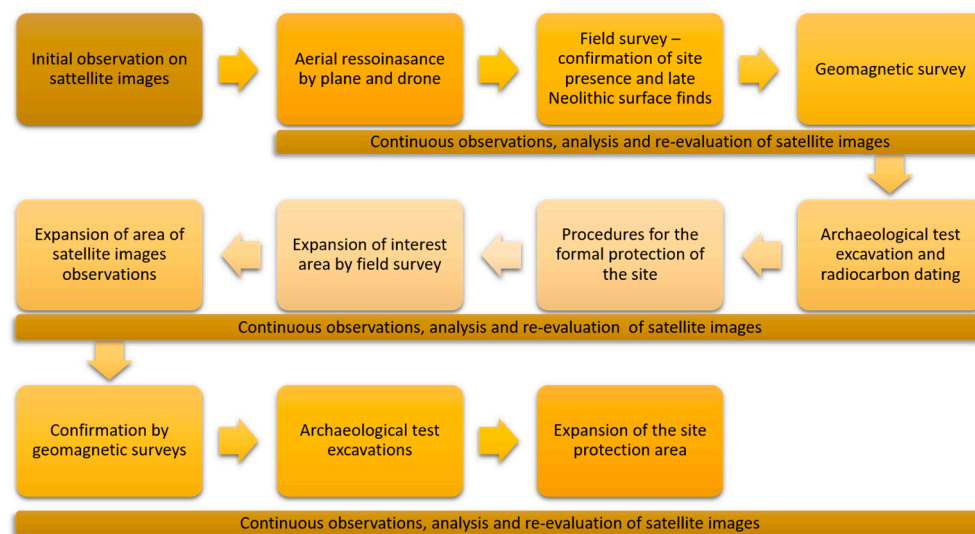


Figure 11. Workflow established for detection of Late Neolithic enclosures in Eastern Croatia.

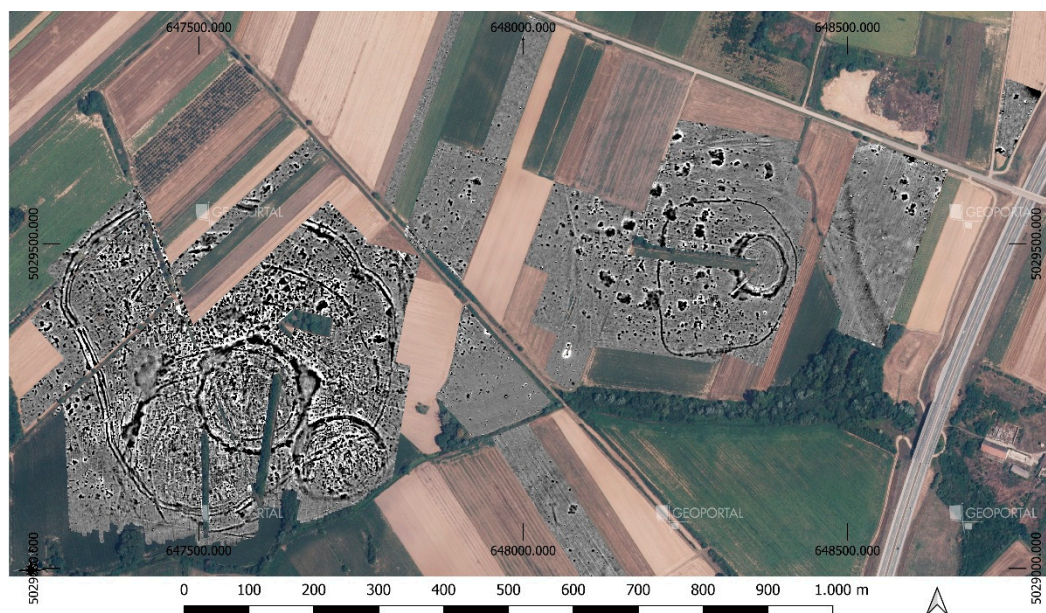


Figure 12. Results of geomagnetic survey at Gorjani Kremenjača and Topole 2018-2023.

Author Contributions: Conceptualization, RŠK, BŠ, HK.; methodology, BŠ, HK, RŠK.; investigation, RŠK, BŠ, HK.; resources, RŠK, BŠ, HK.; writing—original draft preparation, RŠK, BŠ, HK writing—review and editing, RŠK, BŠ, HK; funding acquisition, RŠK, BŠ, HK. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Data is contained within the article.

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