

Opovo Revisited. Reconstructing Settlement Development and Social Structures in the Late Neolithic Site of Opovo Ugar-Bajbuk, Serbia

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Abstract

The Late Neolithic site of Opovo Ugar-Bajbuk (Serbia), a well-known Vinča settlement, has been re-investigated after 40 years. Earlier investigations in the 1980s offered insights into its architecture, economy, and social life. Recent research (2022–2024) used geomagnetic surveys, drilling, surface finds, and radiocarbon dating to reassess the site. Results revealed 180–220 house structures and five enclosing ditches, indicating a larger settlement with a more elaborate spatial order. Radiocarbon data indicate the site's core occupation from around 4850 to 4725 BCE, with models hinting at a larger population than previously estimated. Through an analysis of house sizes, ditch volume, and demography, we discuss implications for a potentially egalitarian social structure at Opovo. However, the social or economic factors leading to its abandonment remain uncertain.

Keywords

Social inequality, settlement archaeology, social archaeology, Vinča, prehistory, demography

Zusammenfassung – *Opovo: Rückkehr nach 40 Jahren. Rekonstruktion von Siedlungsentwicklung und Sozialstrukturen im spätneolithischen Fundplatz Opovo Ugar-Bajbuk, Serbien*

Der spätneolithische Fundort Opovo Ugar-Bajbuk (Serbien), eine bekannte Siedlung der Vinča-Kultur, wurde nach 40 Jahren erneut untersucht. Frühere Ausgrabungen in den 1980er Jahren lieferten wichtige Erkenntnisse zu Architektur, Wirtschaft und sozialer Organisation. Neue Forschungen (2022–2024) kombinierten geomagnetische Prospektionen, Bohrungen, Oberflächenfunde und Radiokarbondatierungen zur umfassenden Neubewertung des Fundplatzes. Dabei wurden 180–220 Hausstrukturen und fünf umlaufende Gräben identifiziert, was auf eine größere und strukturiertere Siedlung schließen lässt. Radiokarbonaten deuten auf einen Besiedlungsschwerpunkt zwischen etwa 4850 und 4725 v. u. Z. hin. Modellierungen legen nahe, dass die Bevölkerungszahl deutlich höher war als bislang angenommen. Auf Grundlage von Hausgrößen, Grabenvolumen und demografischen Analysen diskutieren wir mögliche Hinweise für eine egalitäre Sozialstruktur in Opovo. Dennoch bleiben die sozialen oder wirtschaftlichen Faktoren, die zur Aufgabe der Siedlung führten, bislang ungeklärt.

Schlüsselbegriffe

Soziale Ungleichheit, Siedlungsarchäologie, Sozialarchäologie, Vinča, Urgeschichte, Demografie



Fig. 1. Left: Location of Opovo (orange dot) with nearby cities/towns (black dots); top right: Site in relation to modern Opovo; bottom right: Opovo in a European context (Satellite image: Airbus, CNES/Airbus, Landsat/Copernicus, Maxar Technologies 2025, via Google Earth; Graphic: F. Wilkes).

1. Introduction

The Late Neolithic settlement at Opovo (Ugar-Bajbuk, Serbia, Fig. 1) is one of the well-known sites of the Vinča Culture (Tringham, Brukner, Voytek 1985; Tringham et al. 1992). In the research, Opovo has a special position, because aspects of the archaeological material – like the house architecture or zoological inventory (Tringham et al. 1992; Russell 1993; Stefanović 1997) – differ from typical Vinča settlements. This raises questions about the function of the settlement in the regional settlement network on the one hand, and on the other hand, it opens up questions about differences in social organization in Opovo compared to other settlements in the wider region.

Various models regarding the site's function and social structure were proposed based on the 1980s excavations. However, an international project conducted new fieldwork in 2022, yielding results which allow for a re-evaluation. The geomagnetic field campaign was carried out in late March to early April 2022, and a drilling and surface survey in October 2022 by an international team from the Christian-Albrechts-University Kiel, the National Museum in

Pančevo and the Museum of Vojvodina in Novi Sad. The fieldwork was continued by a systematic survey for surface finds in spring 2024 and an excavation in autumn 2024.

The new fieldwork in Opovo is embedded in long-term Serbian-German research on regional Neolithic and Chalcolithic settlement dynamics during the 6th to 5th millennia in the lower Tisza and Timiș regions (Medović et al. 2014; Hofmann et al. 2019a; Stanković Pešterac 2024; Hofmann et al. 2025a) and was part of the PhD project on 'The development of social inequality in the Carpathian Basin between 5200 and 1000 BCE' by Fynn Wilkes. In the context of the new research activities at Opovo, the team got into contact with Ruth Tringham, the head of the 1980s research project and exchanged thoughts about the new findings.

In this article, we provide an overview of the research conducted in Opovo from the 1980s to the present. The focus is on two central questions: first, our research aims to determine how the Late Neolithic settlement of Opovo Ugar-Bajbuk developed over its lifetime. Second, we seek to analyse the settlement structure to understand how society in Opovo was organized. Our approach combines the

findings of previous campaigns with new insights gained through targeted investigations using geomagnetics, drilling, and excavations.

2. Material and Methods

2.1. Opovo – Research History and Past Interpretations

The Late Neolithic settlement of Opovo (Ugar-Bajbuk, Serbia) is located approximately 2 km east of the modern village of Opovo, in the Southern Banat District of the Autonomous Province of Vojvodina (Fig. 1). The site lies on a small hill (114–117 m asl) surrounded by palaeomeanders of the Timiș River, which today flows about 3 km west of the settlement. The site was discovered in 1965 by the local priest and amateur archaeologist Andreas Majer (Glas Opova 2016).

Archaeological investigations intensified in the 1980s, led by Yugoslav and American teams (Bukvić, Prikić 1980; Tringham, Brukner, Voytek 1985; Tringham et al. 1992). Initial sondages (1979–1980) were conducted by archaeologists from the University of Belgrade and the National Museum in Pančevo. Between 1983 and 1989, a 16 × 20 m trench was excavated by researchers from the universities of Novi Sad and Berkeley and the National Museum in Pančevo (Tringham et al. 1992).

The 1980s excavations identified three building horizons (BH 1–3) and partially or fully excavated six buildings (Tringham et al. 1992; Russell 1993, 70–71). The material culture corresponds with the Vinča-Pločnik/C2 phase¹ (Tringham, Brukner, Voytek 1985, 437). Radiocarbon dating of bone samples from BH 2 and BH 3 suggests a short occupation period between 4860 and 4780 calBCE (Orton 2012, 20–21). The site was previously estimated at 250 × 200 m (c. 5 ha; Tringham, Brukner, Voytek 1985, 425), but our recent surveys indicate a larger extent. Compared to other Vinča settlements like Gomolava and Vinča-Belo Brdo, the houses at Opovo are small, single-room structures and were, according to Tringham, less well constructed (Tringham 1991, 16; Tringham et al. 1992, 381).

The local environment was marshy and waterlogged in prehistory (Tringham, Brukner, Voytek 1985, 426–427, 435). Elevated areas with fertile chernozem soils offered farmable land (Tringham, Brukner, Voytek 1985, 434–435). The site lay within a changing fluvial landscape shaped by the Timiș River (Tringham, Brukner, Voytek 1985, 436). It has been described as agriculturally marginal marshland (Tringham 1994, 172).

Zooarchaeological evidence shows high proportions (62–71 %) of wild animal bones – especially red deer – compared to other Vinča sites and more in line with Tisza sites (Greenfield 1986, 98–111; Russell 1993; Bartosiewicz 2005, 52; Orton 2012, 33). Botanical analysis revealed a typical Vinča plant spectrum alongside substantial evidence of agriculture. Wild plants likely served as supplementary food during periodic flooding (Borojević 2006, 162–165). These findings point to a subsistence economy combining farming and hunting, adapted to environmental conditions.

The lithic assemblage includes a broad variety of tool types (Tringham et al. 1992, 377). Due to the absence of nearby raw material sources, the lithic material of chipped and ground stones likely came from the Fruška Gora Mountains (c. 45 km from the northwest; Tringham et al. 1992, 377–378; Russell 1993, 466–467). Obsidian makes up 6–7 % of the assemblage – relatively high for the Vinča region – and is traced to the Tokaj-Eperjes Mountains in the southern fringe of the Northwestern Carpathians (Russell 1993, 466–467; Milić 2016, 212–213; Furholt 2026), indicating participation in extensive exchange networks. The low quantity of flakes and debitage suggests that core preparation and tool manufacture occurred either outside the excavated areas or even outside the settlement (Tringham et al. 1992, 378).

Regarding the past interpretations of Opovo, the international research project from the 1980s focused on questions of social and economic organization, particularly the role of the household as a social unit within the settlement (Tringham, Brukner, Voytek 1985, 427). With reference to the material analysed by the Yugoslav and American researchers so far, a number of hypotheses regarding the character and use of the settlement have been proposed and discussed. The general interpretation of the features excavated in Opovo is that of a relatively short-lived site (200 years, 5–7 generations, max. 10 simultaneous households; Tringham 1992, 141–142; Tringham et al. 1992, 381–384; Tringham 1994, 189–190).

Early interpretations of Opovo proposed three models to explain its character and function. One saw the site as a local Vinča development influenced by Tisza traditions, reflecting a blend of hunting-gathering and farming practices (Tringham, Brukner, Voytek 1985, 444). A second model suggested it was founded by groups fissioning from large Vinča settlements south of the Danube due to demographic or ecological pressures (Tringham, Brukner, Voytek 1985, 444). A third, proposed Opovo as a seasonal site for hunting and gathering expeditions. Nerissa Russell's faunal analysis ruled out seasonality and emphasized a mixed subsistence economy with high reliance on wild resources, interpreting Opovo as a permanent settlement positioned within regional exchange networks (Russell 1993, 468–471). Ksenija

¹ This correlates with M. Garašanin's Vinča Pločnik I phase (Garašanin 1993), as well as W. Schier's Vinča C2/3 phase (Schier 1995) and G. Lazarovici's Vinča C (Lazarovici 1981).

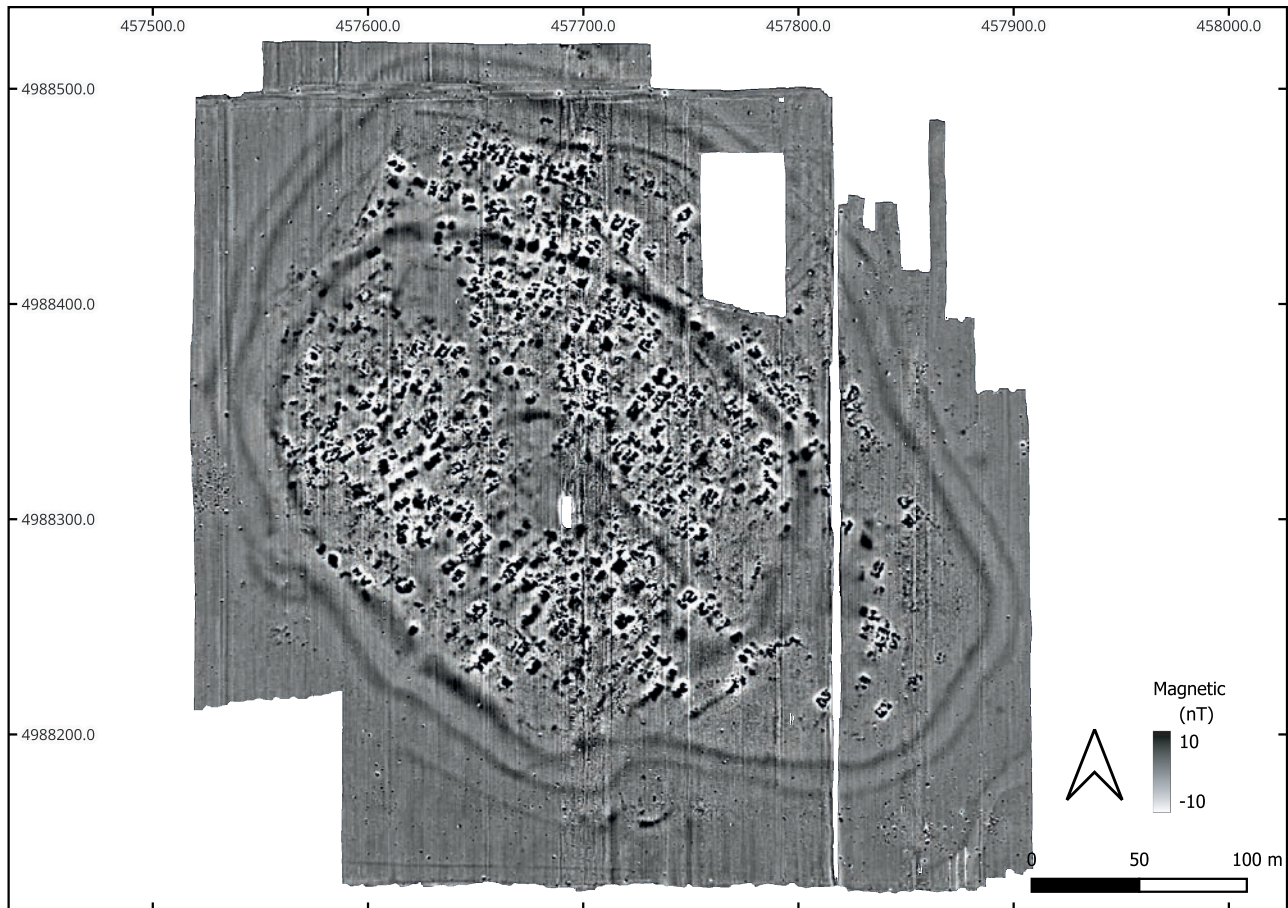


Fig. 2. Geomagnetic image of Opovo Ugar-Bajbuk. The survey was conducted in 2022 and the white spot in the northeast of the image is a waterlogged, heavily cropped patch (F. Wilkes).

Borojević's archaeobotanical work confirmed the presence of both cultivated and wild plant use, arguing for local adaptation rather than specialization (Borojević 2006, 164–165). Tringham and colleagues ultimately emphasized Opovo's role as a marker of organizational change within the Vinča system, shifting from centralized models to more dispersed, adaptive settlement forms (Tringham et al. 1992, 353; Tringham 1994, 189–190).

2.2. New Research 2022–2024

2.2.1. Geomagnetic Survey

The geomagnetic survey at Opovo was conducted between late March and early April 2022, and the site was largely accessible. Measurements were only excluded from three small areas: a c. 75 × 40 m patch of marshland in the northeast, a shrub-covered area on the hilltop, and a modern drainage channel in the eastern part of the site (Fig. 2, blank spaces). Surveying was carried out using a Magneto® MX V3 system (SENSYS) in an 8-sensor setup, with 50 cm sensor spacing and a 20 Hz measuring frequency, similar to previous surveys in the area (Wilkes 2024). The device was mounted on

a handcart operated by two to three persons and linked to a Leica GNSS Differential GPS (VIVA GS 10) for accurate positioning. Data processing was performed using SENSYS software (MonMX, DLMGPS, and MAGNETO ARCH), and the final image was exported in Surfer grid 7 raster format with a resolution of 0.2 × 0.2 m. Approximately 13 ha were surveyed in total.

Interpretation of the geomagnetic data was based on two complementary methods. The first followed the approach adopted by Knut Rassmann et al., using the *r.contour* function in QGIS (v. 3.12.2) to digitize anomalies at five flux density thresholds (1, 5, 10, 20, and 30 nanoTesla [nT]; Rassmann et al. 2021b, 15–18). Mean flux values of polygons in the 5 nT layer were calculated using *v.rast.stats* to help identify low-intensity anomalies and enhance interpretation of contextual variation.

The second method was the 'six-eye methodology' (Müller-Scheeßel et al. 2020, 4–5), which involves anomaly identification and classification based on expert interpretation by three archaeologists. Each evaluator independently digitized features and assigned them to categories (house,

ditch, pit). Their results were then compared to identify overlapping or diverging interpretations. This method allows an assessment of interpretation confidence and serves to approximate the number, location, and orientation of buildings with greater reliability.

The geomagnetic image (Fig. 2) reveals a dense cluster of high-flux anomalies (up to 100 nT) in the settlement's centre. The identification and interpretation of the magnetic anomalies as houses is based on examples from excavated and surveyed Late Neolithic sites in the region (Crnobrnja, Simić, Janković 2009; Hofmann et al. 2019a; Perić, Miletić 2019); therefore approximately 180–220 of these anomalies – rectangular in shape and with strong signals – can be interpreted as burnt houses. This estimate is based on the six-eye methodology (details in Appendix 1) and represents the houses agreed on, which is to be seen as a conservative estimate, as further structures may remain undetectable due to overlapping features, insufficient magnetic contrast (e.g. unburnt houses), or signal depletion at depth.

Smaller anomalies with irregular or round shapes and flux densities between 5 and 15 nT likely correspond to pits, hearths or partially burnt structures. Two notable areas – one in the settlement centre (c. 40 × 20 m), the other c. 50 m northwest of the centre (c. 35 × 30 m) – show an absence of anomalies. These could represent open spaces or plazas, presumably as an element for communal activities; one might also align with the 1980s excavation trench, though its exact location is unknown. Magnetic anomaly density decreases significantly in the northwestern and western parts of the site.

The entire settlement is enclosed by two, and in parts three, linear low-flux anomalies (1–2 nT), interpreted as enclosure ditches (Fig. 3A: ditches a and b). These outer ditches define an area of roughly 9.4 ha, measuring c. 405 m (E–W) and c. 300 m (N–S). Within this enclosure, three additional, weaker linear anomalies (Fig. 3: ditches c–e) divide the interior into smaller sections. Ditch c, enclosing the core of the settlement (c. 4 ha), is partially overlain by house anomalies, suggesting it may have been filled in at some point during the settlement's life. Openings in ditches a, b, and c – one to two in the south and one in the north – are interpreted as access points. It is noteworthy that every building visible in the magnetic image is integrated into the ditch system, creating a protected space for each member of the community at Opovo.

Elevation data (see Fig. 3B) show that ditches c and d enclose the highest ground (116–117 m asl), while ditches a and b also encompass lower-lying areas (114 m asl). In the southern part of the magnetic plan, the outer ditches (a and b) curve inward around a faint, circular feature (c. 25 m diameter), which appears to have been intentionally preserved.

This suggests that the outer ditches were constructed after this feature was already present, pointing to a possible later digging of ditches a and b, as well as a later expansion of the settlement.

Taken together, the spatial organization revealed by the magnetic data supports a division of the site into two principal and consecutive occupation zones which will later be analysed further by means of radiocarbon modelling (Fig. 3A):

- Settlement area I: Enclosed by ditch c, c. 4.3 ha in size, possibly representing the founding phase of the settlement.
- Settlement area II: The zone enclosed by ditches a and b, c. 9.4 ha, likely representing a later expansion of the settlement.

The difference in house density and the presence of features in area II reinforce the interpretation of settlement growth over time.

2.2.2. Drilling Survey

In early October 2022, a drilling survey was conducted to recover dateable material from house contexts, aiming to expand the radiocarbon dataset beyond the older dates from the 1980s excavations. This strategy, successfully applied at the Linear Pottery Culture site of Vráble-Velké Lehemby/Farské (Slovakia; Meadows et al. 2019; Staniuk et al. 2020), targeted 23 house anomalies selected from various parts of the settlement and with differing orientations based on magnetic imaging.

Sampling was carried out using a vibracore drilling system with a 6 cm diameter (Wacker Neuson® and Stitz® GmbH). Drill cores reached depths of 2–4 m and were opened, described, and sieved on-site for organic material. Charcoal and bones were collected for radiocarbon dating; while charcoal samples were successfully analysed, most bone fragments were too small or poorly preserved to identify species. Burnt daub layers – resembling the remains of destroyed houses – were encountered between 0.4 and 1.5 m depth. In drill points DP008 and DP015, anthropogenic layers with daub, pottery, charcoal, and bone extended as deep as 2.9–3.1 m. These deeper layers likely represent settlement debris accumulated in ditches, as both drill points lie directly above ditch c anomalies (Fig. 4).

Findings from the drillings and surface collections indicate that the upper layers of the site have been significantly disturbed by agricultural activity. This has led to the presence of artifacts and construction materials – particularly in the central and eastern parts of the site – where ploughing has likely destroyed house remains and brought up daub and other find materials.

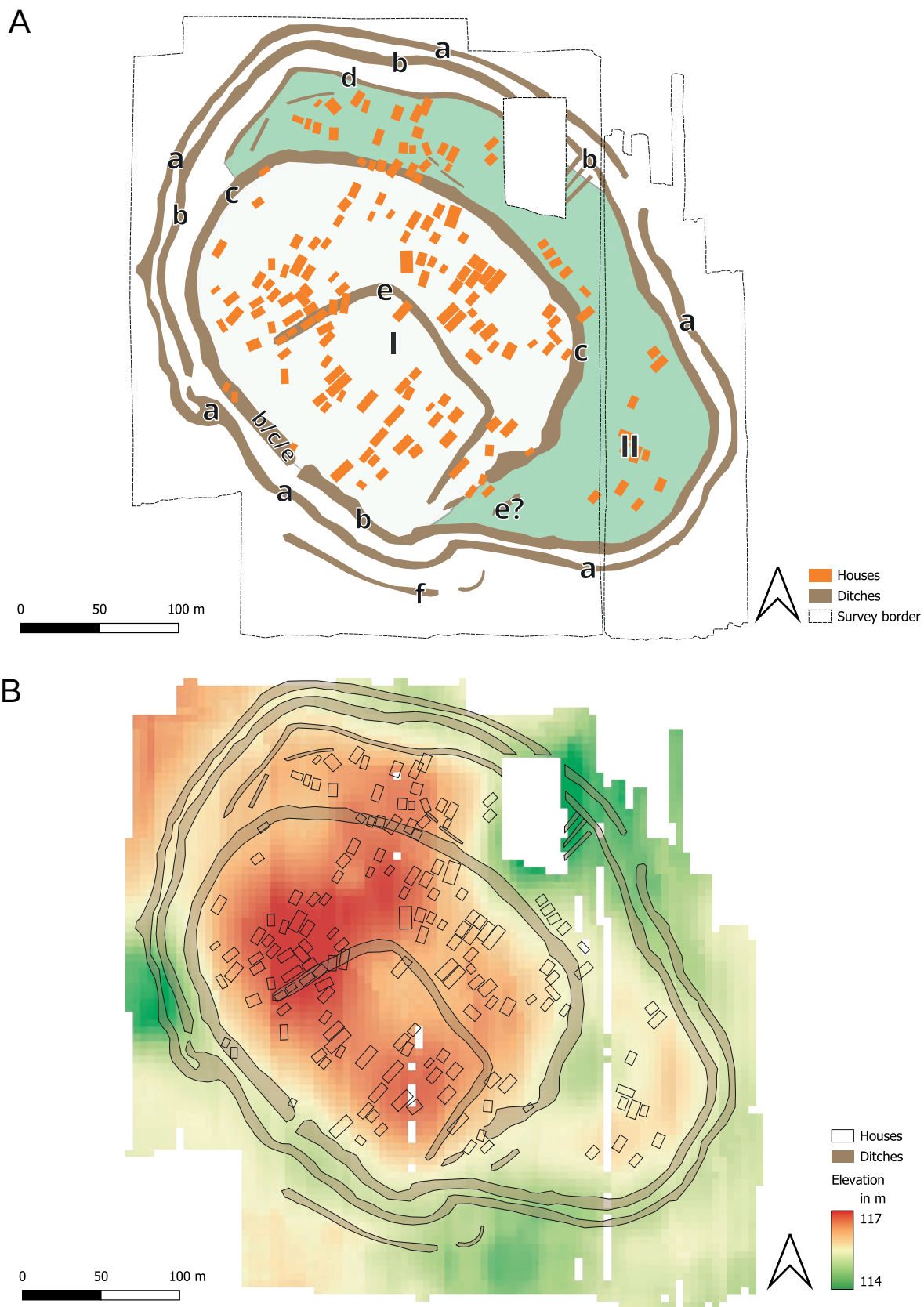


Fig. 3. A. Digitized features and interpreted anomalies from the magnetic image, showing key settlement areas and structures. Settlement areas I (white) and II (green) are marked. Named ditches (brown) are labelled in lower case, and the minimum number of digitized houses (orange) is shown (F. Wilkes); B. Elevation model of the site Opovo Ugar-Bajbuk. The information is derived from dGPS measurements during the magnetic survey. Ditches and houses are digitized based on the magnetic image (F. Wilkes).

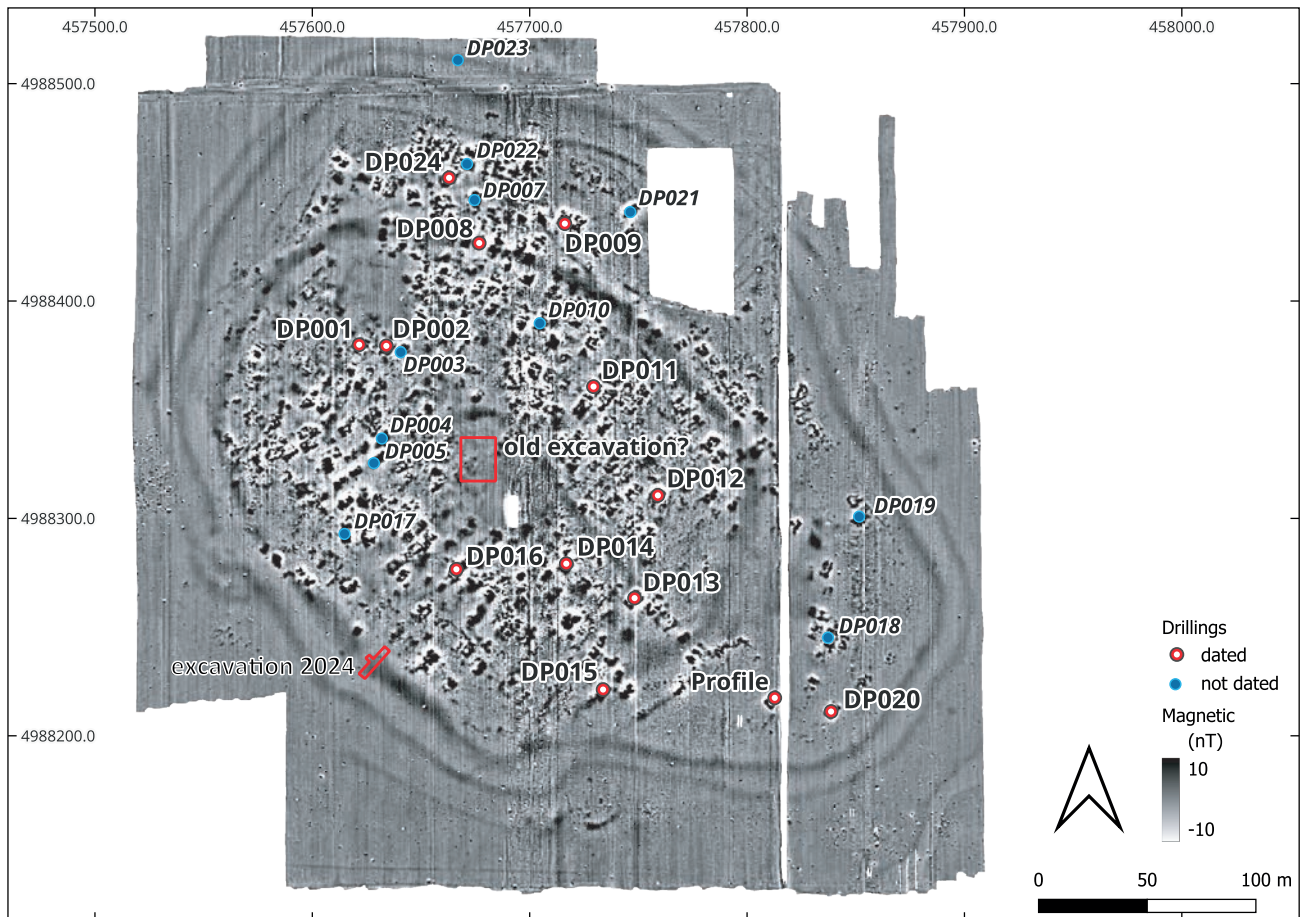


Fig. 4. Magnetic image with marked drillings and excavation areas. Of 24 drillings (2–4 m deep), 18 contained organic material; 13 provided suitable samples for radiocarbon dating (F. Wilkes).

Radiocarbon samples were carefully selected from well-defined contexts, either directly from burnt daub layers or from directly underlying strata, to ensure reliable dating of the building structures. A total of 19 samples from 13 drill cores were submitted for analysis (see Tab. 1; Fig. 4). While vibracore sampling has inherent limitations – such as a restricted view of stratigraphy and the risk of vertical displacement – the sample collection process was supervised by two specialists to ensure contextual accuracy.

2.2.3. Surface Find Collection

Surface find collection has been an integral part of all field campaigns at Opovo. The first surveys were unsystematic, using smartphone GPS for documentation. However, since autumn 2022, a structured approach has been adopted, employing a 50 × 50 m grid system for fieldwalking.²

² The quadrants in the fieldwalking grid have been assigned small letters and a number, while the excavation quadrants use capital letters and numbers (see below).

Each quadrant was surveyed for 30 to 45 minutes, after which finds were sorted by material type, then counted and weighed.

Pottery was further classified by ware type – fine, medium, or coarse – and by decoration. Fine wares are finely tempered and often polished, indicating high-quality craftsmanship. Medium wares are made from finer clay but lack finishing, while coarse wares are heavily tempered, with raw surfaces, typically from large vessel fragments. Due to seasonal field conditions, not all grids were surveyed. The focus was placed on the central, densely settled area identified through magnetic imaging.

The surface material highlights the Vinča C and D (after Lazarovici 1979; Schier 1995) occupation of the site (Pl. 1/1–3, 5; Pl. 2/8, 9, 11, 12, 14). Decorated pottery pieces, those with incisions, incrustations or painting, are very rare in Opovo, with only four pieces of decorated pottery among the total of 2230 pottery fragments collected during surveys. Besides Neolithic find material of the Vinča Culture there are other periods present at the site, such as small fractions of Early Neolithic Starčevo pottery (Pl. 2/10), Early

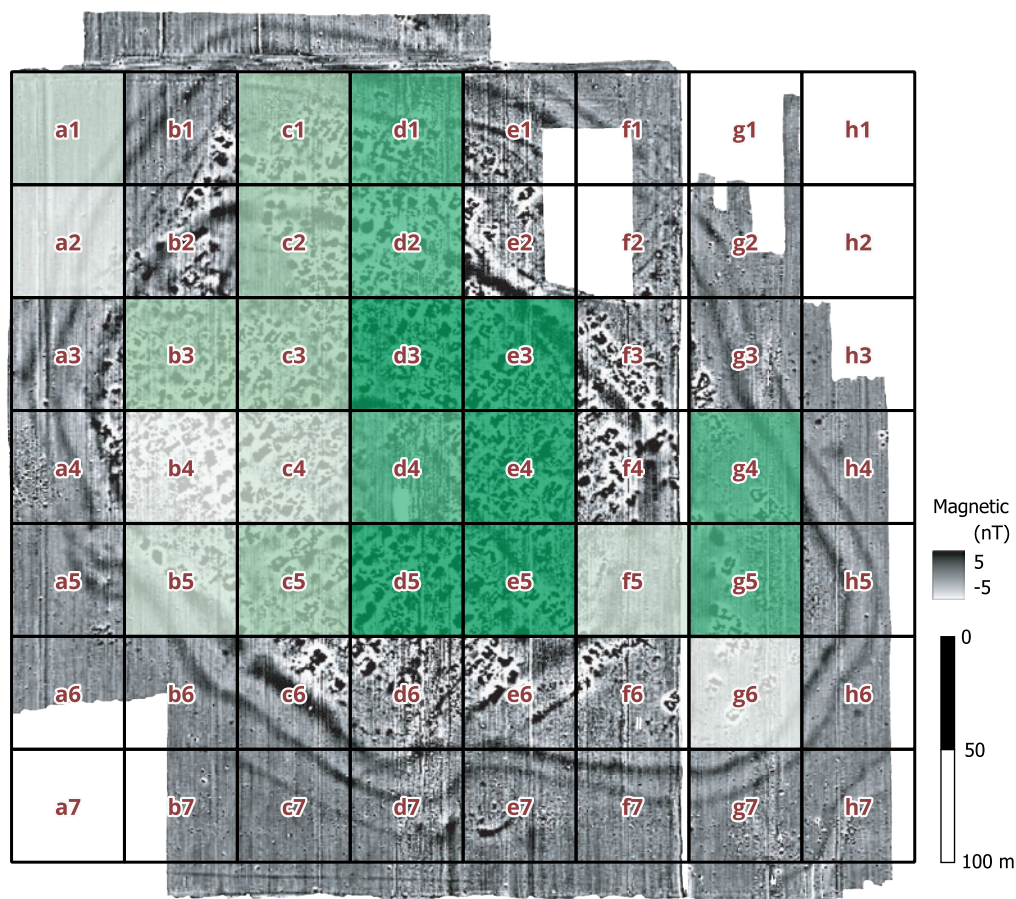


Fig. 5. Number of material groups: The gradient from white to dark green represents the number of material groups per quadrant (1 to 5). Quadrants without a colour gradient have not been surveyed (F. Wilkes).

Eneolithic (Pl. 1/4), Bronze Age (Pl. 2/13) and Sarmatian pottery (Pl. 1/6–7).

Among the notable surface finds are a figurine, a figurine arm (Pl. 3/18) or part of an anthropomorphic vessel, and an object interpreted as a bucranium (Pl. 3/15–17). The latter shows similarities to the Herpály Culture bucranium discovered at Berettyóújfalu-Herpály (Kalicz, Raczky 1987, 117) as well as to objects with zoomorphic representations from Drăgușeni, Trușești and Parța (Romania) interpreted as parts of clay sceptres (Marinescu-Bîlcu, Bolomey 2000, 142–146, Fig. 175/1–6).

The chipped and ground stone tools of the Vinča period at Opovo display a diverse range of materials. Polished adzes and axes are particularly abundant in the central area of the site. A total of 63 lithic artifacts were discovered during the spring 2024 campaign, including 52 chipped and 11 ground stone tools, all of which have been analysed in more detail.

The raw material spectrum of the chipped stone assemblage includes flint of unidentified provenance, limnic silicite, and chert, although their precise geological sources remain undetermined. Nevertheless, two pieces of Carpathian

obsidian and a single flint tool attributed to the Central Banat provide important insights into their provenance. The obsidian most probably originated from the Tokaj-Eperjes Mountains (Hungarian name) / Prešovsko-Tokajské Pohorie (Slovak name), which straddle the Hungarian-Slovak border, while the flint tool may be linked to the sources in the Apuseni Mountains or the Southern Carpathians in Romania (Comșa 1987; Biró 2014; Furholt, Medović 2024). Most of the unsourced flint tools are light to medium grey in colour and closely resemble the lithic assemblages from the Late Neolithic Bordoș tell and its horizontal settlement and from Gomolava, where a similar flint variety has also been documented (Kaczanowska, Kozłowski, Pawlikowski 1986, 14–16; Furholt, Medović 2024, 194–195).

Cores, raw material fragments, flakes, blades, and tools – exclusively end-scrapers – are present in the assemblage, indicating that all stages of lithic production, from the initial shaping to the final retouching, took place on-site. Only three blades and ten end-scrapers show evidence of retouching, representing a relatively low proportion. All 11 ground stone tools are polished items, consisting of eight adzes, one

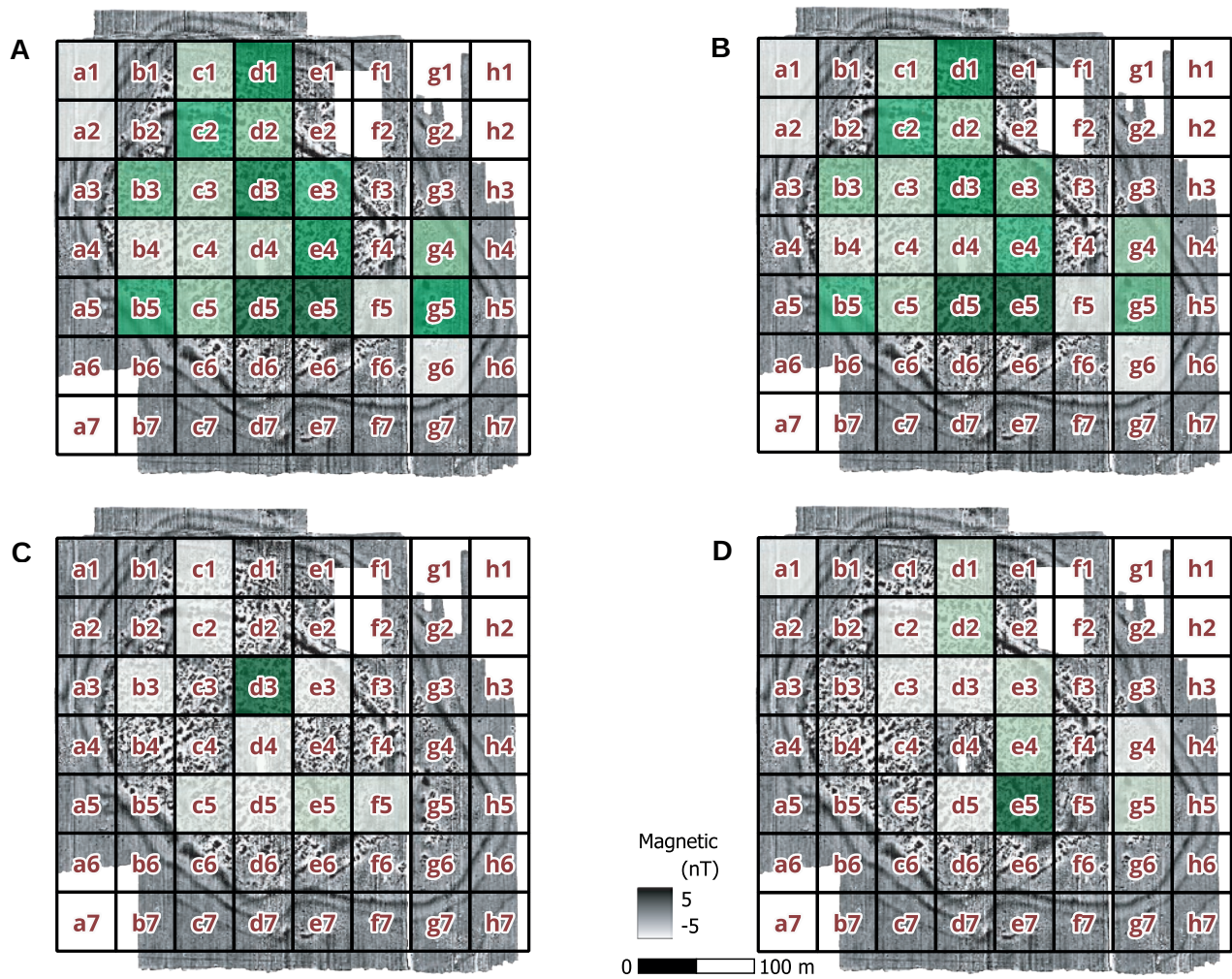


Fig. 6. Surface Find Distribution. White to dark green indicates find density; unsurveyed quadrants lack colour. – A. Total finds (n = 2495); B. Pottery (n = 2230); C. Chipped stone (n = 31); D. Polished/ground stone (n = 67) (F. Wilkes).

chisel, and two small fragments. Their raw material appears macroscopically homogeneous, likely a light grey crystalline schist, with one adze possibly made from a lighter white stone (Antonović 1997; Antonović 2003).

2.2.3.1. Find Distribution

In 2024, 22 quadrants were systematically surveyed, revealing notable spatial variation in material composition across the settlement zones (Figs. 5 and 7). A clear distinction emerges between the western and eastern parts. The central and eastern zones exhibit higher concentrations of surface finds overall (Fig. 6A), a pattern consistent across all identified material groups: pottery, bone, chipped stone, ground stone, and building clay (daub). Quadrants in lines a–c generally yielded fewer material groups than those in lines d–g.

Pottery analysis further supports this east-west divide (Fig. 7). Western quadrants show a higher proportion of medium and fine wares, while the eastern side is dominated

by coarse and medium wares. Outer quadrants (g4–5, d1–2), situated near or beyond the enclosed area, contain particularly high proportions of coarse ware. In contrast, the central quadrants (d3–6, e3–4), with the exception of e5, display a more balanced mix of medium and coarse wares and yielded the highest overall surface find quantities.

Chipped and ground stone artifacts, though generally sparse, also tend toward higher concentrations in the eastern part. Two central quadrants stand out: d3, with 13 chipped and 1 ground stone tool (avg. 1.4; Fig. 6C), and e5, with a notably high count of 22 stone artifacts (avg. 3.1; Fig. 6D). These concentrations may reflect variations in the intensity of ploughing, but the possibility of specialized activity zones or workshops cannot be excluded. Biases based on the collection year, individual surveyors, or inconsistencies in documentation have been ruled out as explanations for the observed distribution patterns.

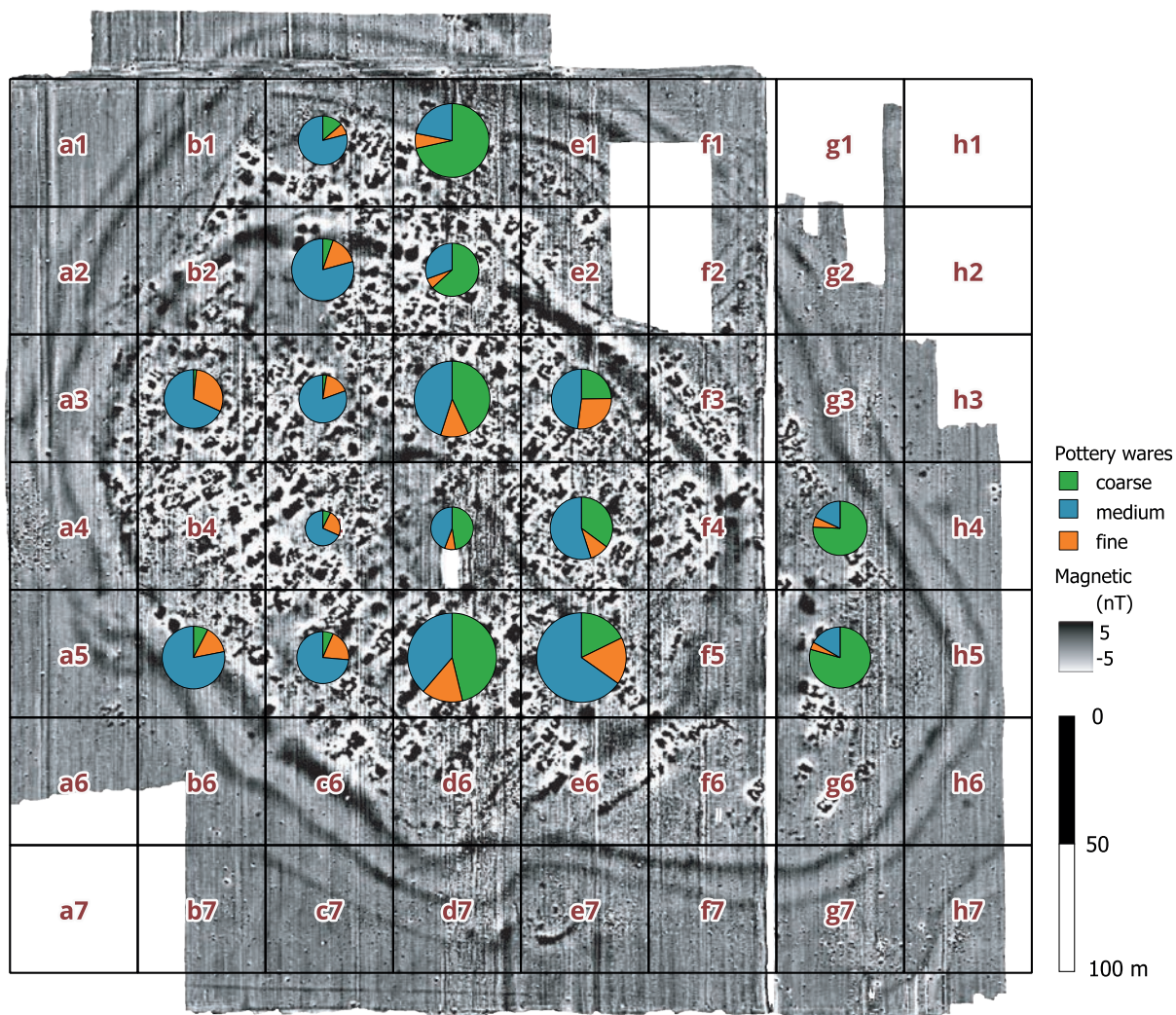


Fig. 7. Composition of the pottery wares from the survey pottery. The size of the diagrams indicates the total number of pottery finds in the quadrant. Quadrants with fewer than 50 pieces have been excluded (a1–2, b4, f5, g6) (F. Wilkes).

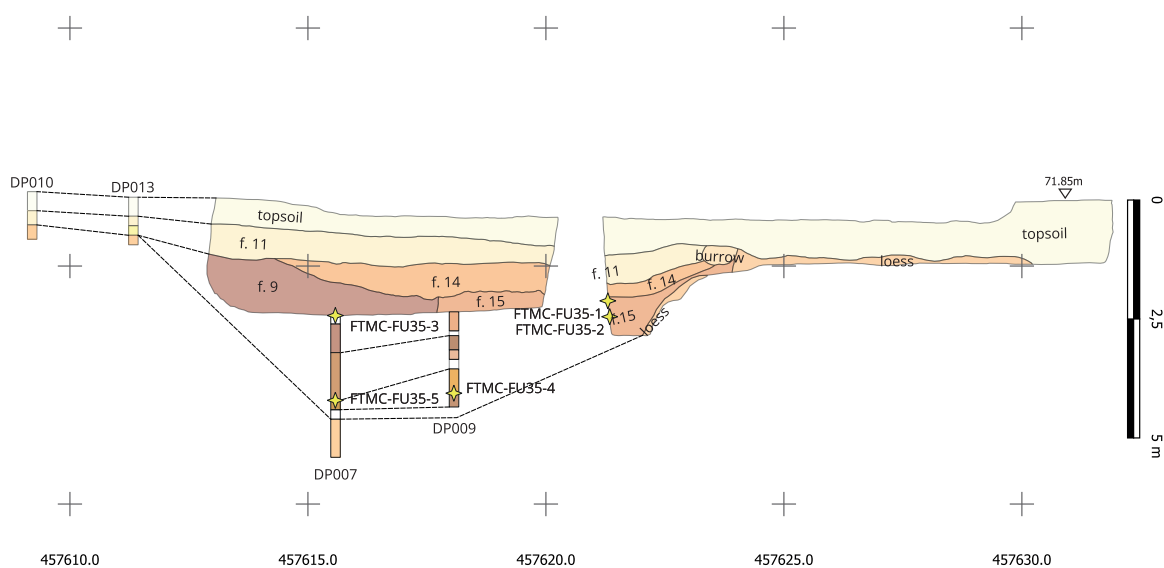


Fig. 8. South profile of the 2024 Opovo excavation trench. Ditch b was cut near an entrance, but excavation was stopped due to safety and groundwater issues. Drillings (DP007, 009, 010, 013) were conducted to assess the stratigraphy. Radiocarbon samples (yellow stars) were taken from the profile and drillings (F. Wilkes).

2.2.4. Excavation

In autumn 2024, an excavation was conducted in the entrance area of the main ditch (Figs. 4 and 8). The excavation trench, aligned southwest–northeast, measured 16×2 m, with a 2.5×2 m extension to the north at its centre. It was divided into 2×2 m quadrants (see Appendix 1) and excavated in artificial 20 cm layers, adjusting techniques whenever the soil colour or substrate changed. The 50 cm topsoil layer was removed using an excavator.

During excavation, it became apparent that the magnetic image was slightly offset to the south; the outer edge of the ditch appeared further northeast than expected. As a result, its northeastern extent was identified only via drillings, as it lay outside the trench.

Despite this, both the excavation and drillings confirmed that the ditch at the settlement's entrance measured approximately 11 m in width and 4.5 m in depth. In upper layers down to 1.2 m (feature 11), finds primarily consisted of fragmented pottery and small animal bones. At 1.2 m in quadrants C–D1,³ a concentration of pottery, larger animal bones, an unburnt animal-shaped daub object, and a goat horn were found (feature 14). Below this depth, the quantity of finds – particularly fragmented animal bones – increased in quadrants C–D1 and D2, near the outer site of the ditch. These quadrants also yielded four human bones within feature 15. In contrast, quadrants E–H1 contained fewer finds, mostly strongly fragmented pottery. From 1.8 m downward, the soil increasingly included charcoal fragments (features 14, 15). Feature 9, on the inner trench side, was especially rich in charcoal, darkening the soil to nearly black.

The excavation reached 2.5–3 m over two weeks but was halted due to rising groundwater and safety concerns about the trench walls. Manual drillings with a Pürckhauer auger revealed that the ditch extended another 2 m deeper. From 1.2 m downward (features 9, 14–15), the soil was loamy and dark. Drillings DP007 and DP009 showed greyish cultural layers, likely reduced by groundwater. Cultural layers between 2.5 and 4 m contained charcoal, small bone fragments, and daub, all collected for further analysis. At approximately 4.5 m, the soil changed to a silty yellow loess, marking the natural subsoil and base of the ditch.

These results indicate that at least one of the main ditches at Opovo was notably large, especially at the entrance. When compared to similar Neolithic ditches – such as those at Oreškovića-Selište (Serbia, 7 m wide, 3.6 m deep; Borić et al. 2018), Gornea-Căunita de Sus (Romania, 2–2.5 m wide,

0.6–0.7 m deep; Lazarovici 1990, 95), and Bicske-Galagonyás (Hungary, 2.9 m wide, 2.8 m deep; Tulok, Makkay 1990, 119–120) – the Opovo ditch stands out in terms of the scale. However, its inner section remains unexplored, preventing conclusions about associated features such as palisades, known from Oreškovića-Selište (Borić et al. 2018, 338–339). The function of the ditch remains uncertain: it may have served as a settlement boundary, a defensive structure, or protection against flooding in the marshy environment. Addressing these questions will require further site-level investigation alongside broader studies of the landscape and climate history.

3. Analysis and Discussion

The results of past and recent fieldwork serve as a foundation for re-evaluating the interpretations of the site, as well as adding further knowledge regarding the settlement's layout. By integrating surface surveys, geomagnetic surveys, drilling, excavation, and radiocarbon dating, a more detailed analysis of the site's development is achieved. This approach allows new insights into the settlement's development, its demography, and possible social organization at Opovo.

3.1. Radiocarbon Dating and Settlement Development

While Tringham reports one radiocarbon dating on daub (house 2 dated in the Grocka Laboratory, Belgrade; 3700 ± 100 uncalBCE; Tringham et al. 1992, 365), the first sequence of radiocarbon dates for Opovo was presented by David Orton, who analysed samples from the bone assemblage excavated in the 1980s (Tab. 1; Orton 2012). His study included 11 samples from the two oldest building horizons (BH 2 and 3). No dates were available for the youngest horizon (BH 1). David Orton concluded that BH 2 and BH 3 spanned between 4860 and 4780 calBCE (Orton 2012, 21). A subsequent analysis by Alasdair Whittle et al. incorporated these dates and added two additional radiocarbon samples, although the latter were not assigned to a specific building horizon (Tab. 1; Alasdair Whittle et al. 2016). Their findings suggest settlement activity began between 4915 and 4840 calBCE (68 %) and ended between 4820 and 4740 calBCE (68 %; Whittle et al. 2016, 20).

Using samples from recent drilling and excavations, 24 new radiocarbon samples were added to the existing 14 (Tab. 1). Most of the new measurements were conducted at the Kiel AMS Laboratory (KIA), with additional samples analysed by the Vilnius C14 Laboratory (FTMC). Of the 19 samples collected during the drilling survey, 14 are attributed to houses, while the remaining five are taken from ditches. The combined dataset of 13 earlier dates by Orton 2012 and Whittle et al. 2016 and 14 new building-related samples was calibrated and modelled in OxCal (Bronk Ramsey

³ The excavation quadrants use capital letters and numbers, while the quadrants in the fieldwalking grid have been assigned small letters and a number.

Lab. code	Context and depth	Sample type	Date BP (uncal.)	Date calBCE (95.4 %)	Reference
KIA-57397	DP001; 0.7–0.9 m	Charcoal; Cornus	5905 ± 35	4885–4703	This study
KIA-57398	DP002; 0.45–0.6 m	Bone	5870 ± 40	4840–4615	This study
KIA-57393	DP008; 2.45–2.8 m	Bone	5950 ± 40	4936–4723	This study
KIA-57401	DP008; 1.9–1.95 m	Charcoal; Quercus	5875 ± 35	4840–4620	This study
KIA-57402	DP009; 1 m	Charcoal; Prunus	5945 ± 40	4935–4721	This study
KIA-57394	DP011; 1.33–1.36 m	Charcoal; Acer	5945 ± 35	4933–4722	This study
KIA-57403	DP011; 1.4–1.55 m	Charcoal; Quercus	5930 ± 35	4902–4716	This study
KIA-57404	DP012; 1.23–1.25 m	Charcoal; Cornus	5890 ± 35	4844–4687	This study
KIA-57405	DP013; 0.8–1 m	Bone	5935 ± 40	4933–4716	This study
KIA-57406	DP014; 1.3 m	Charcoal; Acer	5945 ± 35	4933–4722	This study
KIA-57395	DP015; 2.26 m	Charcoal; Quercus	5720 ± 35	4786–4551	This study
KIA-57407	DP015; 1.79–1.82 m	Charcoal; amorphous	5820 ± 40	4899–4697	This study
KIA-57408	DP015; 2.05 m	Bone	5910 ± 40	4899–4697	This study
KIA-57413	DP016; 1.35–1.53 m	Bone	5895 ± 40	4893–4682	This study
KIA-57529	DP016; 1.35–1.53 m	Charcoal; amorphous	5970 ± 40	4883–4726	This study
KIA-57414	DP020; 0.4 m	Bone	5895 ± 40	4893–4682	This study
KIA-57396	DP024; 0.9 m	Bone	5905 ± 40	4897–4691	This study
KIA-57411	Profile; 0.3–0.4 m	Bone	5885 ± 35	4843–4683	This study
KIA-57412	Profile; 0.3–0.4 m	Bone	5785 ± 35	4721–4542	This study
FTMC-FU35-1	Feature 1 – Level 12	Charcoal; Fraxinus	5827 ± 35	4789–4613	This study
FTMC-FU35-2	Feature 1 – Level 14	Charcoal; Pomoideae	5888 ± 36	4846–4717	This study
FTMC-FU35-3	DP07 (2024)	Charcoal; Acer	5768 ± 35	4715–4552	This study
FTMC-FU35-4	DP09 (2024)	Charcoal; Pomoideae	5728 ± 35	4682–4501	This study
FTMC-FU35-5	DP07 (2024)	Charcoal; Quercus	5959 ± 37	4940–4789	This study
CAMS-4411	Feature 41	–	6030 ± 60	5205–4730	Whittle et al. 2016
CAMS-4413	Feature 41	–	5990 ± 60	5027–4723	Whittle et al. 2016
OxA-21123	Feature 30; BH3	–	5978 ± 35	4987–4731	Orton 2012
OxA-21124	Feature 30; BH3	–	6036 ± 36	5037–4805	Orton 2012
OxA-21125	Feature 30; BH3	–	5973 ± 35	4984–4728	Orton 2012
OxA-21126	Feature 41 (W); BH3	–	5966 ± 36	4946–4726	Orton 2012
OxA-21127	Feature 41 (E); BH2	–	5921 ± 35	4898–4713	Orton 2012
OxA-21128	Feature 41 (E); BH2	–	5926 ± 35	4899–4716	Orton 2012
OxA-21129	Feature 45; BH3	–	5963 ± 34	4942–4727	Orton 2012
OxA-21130	Feature 45; BH3	–	5972 ± 37	4985–4727	Orton 2012
OxA-21212	Feature 52; BH2	–	5913 ± 30	4880–4713	Orton 2012
OxA-21131	Feature 52; BH2	–	5992 ± 39	4996–4786	Orton 2012
OxA-21454	Feature 52; BH2	–	5887 ± 36	4845–4681	Orton 2012
Unknown Geophysical Institute Belgrade	House 2, daub; BH1	–	5700 ± 100	4781–4350	Tringham et al. 1992

Tab. 1. Radiocarbon dates from samples taken during the 1980s excavation, as published in Whittle et al. 2016 and Orton 2012, alongside radiocarbon samples from the 2022 drilling survey (DP: Drilling Point) and the 2024 excavation. BH indicates the building horizon from which the 1980s samples were taken.

Settlement part	Event	Modelled date calBCE (68.3 %)	Modelled date calBCE (95.4 %)	Highest likelihood (calBCE)	Modelled median date (calBCE)
Ditch c / Entrance area (n = 8; Agreement = 126)	Start ditch Entrance	4887–4795	4948–4732	4855–4805	4837
	End ditch Entrance	4701–4615	4716–4528	4680–4655	4650
	Duration ditch Entrance	116–273	27–375		193
Opovo area I (n = 20; Agreement = 163)	Start area I	4876–4806	4926–4799	4855–4845	4854
	End area I	4791–4741	4826–4697	4785–4775	4765
	Duration area I	18–132	4–211		91
Opovo area II (n = 4; Agreement = 163)	Start area II	4874–4746	5009–4725	4825–4790	4819
	End area II	4782–4692	4828–4560	4740–4715	4726
	Duration area II	0–150	0–416		98
Duration		120–266	29–440		200

Tab. 2. Radiocarbon modelling results for the chronological sequence between settlement areas I, II, and the ditch. The modelling was conducted using OxCal (methodology see Appendix 1, code see Appendix 2).

2009). The new model (Tab. 2) suggests a slightly longer settlement duration and, in combination with the results of the magnetic survey, allows for the reconstruction of the possible settlement history.

The model is based on the location of samples within the settlement (ditch, settlement areas) and the depth at which each sample was obtained (Tab. 1). Three key features have been identified and modelled separately in OxCal (description in Appendix 1, code available in Appendix 2): ditch c and the southwestern entrance area, as well as settlement areas I and II (Tab. 2). Five datings, which showed weak model agreement (see Appendix 1), had to be excluded from the model. Additionally, two older dates with unclear origins as regards the building horizon (CAMS-4411 and CAMS-4413) were also omitted. A detailed description and further illustrations of the model are included in Appendix 1.

The model's results (see Tab. 2) indicate that settlement activity at Opovo began between 4876 and 4806 calBCE (68 %; median: 4854 calBCE) with the construction of ditch c and the first houses in settlement area I. Settlement area II was occupied later, at some point between 4874 and 4746 calBCE (68 %; median: 4819 calBCE). The occupation of area I ended between 4791 and 4741 calBCE (68 %; median: 4765 calBCE), while area II remained in use until 4782–4692 calBCE (68 %; median: 4726 calBCE).

The model suggests that ditch c was still at least partly open between 4701 and 4615 calBCE (68 %; median: 4650 calBCE), which is significantly later than the abandonment of both settlement areas. This may indicate that

the ditch continued to be filled gradually after the settlement was abandoned and not in one event at the end of the settlement.

Regarding settlement areas I and II, the data suggests that the first inhabitants arrived in Opovo during the first half of the 49th century BCE and left in the second half of the 48th century BCE. According to the model, the settlement was occupied for 120–266 years (68 %) with a median of 200 years. Although small proportions of Early Neolithic find material were collected, no settlement features from that period have been found so far, leading to the assumption that there was not a considerable Early Neolithic settlement in preceding phases.

Based on the current radiocarbon data and the median values for Opovo, a settlement development scenario can be reconstructed. Around 4850 calBCE, the Late Neolithic settlement on the loess hill in the floodplain of the Timiș River was founded. The earliest inhabitants built their structures around the highest point of the hill (area I) and constructed an enclosure (ditch c). Approximately 30 years later, settlement activity expanded beyond the original core, including slightly lower-lying locations in the vicinity (area II). Area I continued to be occupied, leading to the formation of a multi-layered settlement mound indicated by the three building horizons discovered by Tringham in area I.

Following the settlement of area II, ditch c appears to have been partially filled, as magnetic imaging reveals house structures built over this anomaly. As ditch c was abandoned – and no demarcation between areas I and II existed – a new,

more extensive ditch system (ditches a and b) was likely constructed around the entire settlement, incorporating elements of the older ditch c in the southwestern part of the settlement. Around 4765 calBCE, the settlement began to decline as houses in area I were abandoned. By approximately 4726 calBCE, area II was also deserted, marking the end of the Neolithic occupation of Opovo.

A similar pattern of settlement development and ditch construction can be observed at other Late Neolithic sites in the Balkans. In Bordoš (Serbia), for example, a flat settlement enclosed by a ditch emerged in close proximity to the also enclosed tell settlement (Hofmann et al. 2019a). In Uivar (Romania), settlement dynamics involved phases of expansion and contraction. Initially, a tell settlement with an enclosing ditch was established, and in later phases, a surrounding and flat settlement developed around this settlement nucleus, also enclosed by a ditch (Draşovean et al. 2017; Schier, Draşovean 2020). Over time, various modifications were made to the ditch system. In Okolište (Bosnia and Herzegovina), continuous changes in both the settlement layout and the ditch system can also be observed. However, in this case, the settlement gradually shrank, leading to the successive adaptation of the ditch system and finally the abandonment of the settlement (Müller, Rassmann, Kujundžić-Vejzagić 2013, 41–50).

While the sequence of ditches at Opovo in particular seems plausible based on the recent results, at the current stage of research, the precise relationship between the individual ditches remains unclear. Specifically, the integration of ditch d and e into the settlement development needs investigation. Furthermore, the abandonment of ditch c and the construction of ditches a and b cannot yet be dated due to the lack of radiocarbon data from ditches a and b.

An attempt was made to apply the pseudo-neglect model (Hofmann, Müller-Scheeßel 2020; Müller-Scheeßel et al. 2020) as a possibility for obtaining a more refined sequencing of houses within the individual settlement areas of Opovo. This approach was particularly relevant since Robert Hofmann and Nils Müller-Scheeßel, using data from Ruth Tringham, identified a slight shift in house orientation over Opovo's entire occupation period. However, their analysis was based on only four houses. With the currently available dataset of 11–14 dated houses, their findings cannot be confirmed.

No conclusions can be drawn regarding the presence or absence of pseudo-neglect. The only observable trend is that houses dated after 4800 calBCE exhibit a slight tendency toward a north-south orientation (4850–4800 calBCE: 36°; 4800–4725 calBCE: 33°). However, this subtle shift cannot be statistically validated.

In addition to the still limited number of dated houses, several sample-specific factors may contribute to the inconclusive results regarding parts of the site chronology. These include potential shifts within the sediment cores, old wood and reservoir effects, or secondary sample intrusions caused by factors such as animal activity or sedimentation. Expanding the drillings to more parts of the settlement, as well as conducting targeted excavations of ditches and houses on top of ditches would improve the current model of settlement development.

3.2. Society and Demography

With a chronological model for Opovo established, we can now explore broader social and demographic questions. One important topic is estimating the population throughout the settlement's lifespan. Two lines of reasoning inform this analysis: the volume of the ditches and population development models, which are based on a set of assumptions. Further, based on the magnetic anomalies of possible houses and the surface finds, the social structure within the settlement will be discussed.

3.2.1. Demography

3.2.1.1. Ditch Volume

We begin with the volume of the five ditches revealed by the geomagnetic imaging in Opovo (see Figs. 2–3). The ditches range from 230 to 1,100 m in length and have widths varying from 3 to 11.5 m. Drilling and excavation give some indication about the depth of ditches at certain points, although it is important to mention that ditches might have varying depths throughout their course and often underwent several episodes of recutting and improvement. However, the depths derived from our field data serve as an indication of the depth, width and length range into which the respective ditches fall. Our field data shows that at least the inner ditch (ditch c) and possibly one of the outer ditches (ditch b) reach depths of 3 to 4.5 m. Excavation data suggest that the shared southwestern section of ditch b and c is generally U-shaped, although the possibility of V-shaped sections within the profile remains. Further, due to their partly shared course, deriving the workload for ditches b and c might be regarded as impossible. As with the variability in depth and width, the workload calculation undertaken in the course of this study serves the purpose of giving an indication of a range of the extent of work necessary to build the ditches. While the ditches do not exhibit a uniform width and depth, it is possible to estimate their minimum and maximum volumes based on the available measurements. Two scenarios have been considered (for the methodology, see Appendix 1):

- Minimum Scenario: The ditches are V-shaped, with the minimum widths listed in Appendix 1 and a depth of 3 m.
- Maximum Scenario: The ditches are nearly rectangular, with the maximum widths indicated in the Appendix 1 and a depth of 4.5 m.
- By considering a labour cost of one day (8 hours) per person to excavate 1 m² with simple tools (Vinci, Vanzani 2025, 11–12), the construction of the five ditches at Opovo would require an estimated 17,000 to 176,000 person-days. For a population of 200 inhabitants, this equates to 85 to 879 days of work if everyone participated. Similarly, for a population of 500 inhabitants, the construction would take approximately 34 to 352 days.

With a population of 200 individuals, assuming that each person contributed to the construction, the digging of ditch c would have taken between 13 and 134 days, whereas with 500 individuals, the process would have taken approximately 5 to 54 days. For ditches a and b, the effort required is estimated at 63 to 672 days for 200 people and 25 to 269 days for 500 people.

Given that other Neolithic ditches in the region are typically more V-shaped (Borić et al. 2018; Hofmann et al. 2025b), we can reasonably assume that most ditches align more closely with the Minimum Scenario. However, our excavations and drillings indicate that U-shaped or even mixed-profile ditches are also possible. As a result, while the workload estimates span a broad range, they consistently suggest that, even under the Minimum Scenario, a substantial population would have been required to complete the ditch digging within a practical time frame. This is especially true considering that the calculations are based on the assumption of full-time labour (8 hours per day). In reality, work on the ditches was likely restricted to specific time windows. It would have been strongly shaped by how much labour a community could divert from other essential tasks (c.f. IGZA 2023, 69–72) and further constrained by seasonal weather conditions. The estimates given above should therefore be understood as illustrative, highlighting the substantial effort required to construct and maintain a multi-ditch system.

As for the sequence of construction, it can be assumed from the radiocarbon model above that ditch c was constructed at the beginning of the settlement, while ditches a and b were established at a later stage. The smaller ditches, d and e, cannot yet be integrated into the sequence and are therefore not considered in detail here.

3.2.1.2. Site Size and Population Modelling

Opovo was traditionally regarded as a relatively small Vinča site, estimated at approximately 5 ha. In the past, Tringham reconstructed the settlement as consisting of up to ten simultaneous households at any given time (Tringham et al. 1992, 381–382; Tringham 1994, 189–190), describing it as a ‘small hamlet’ (Tringham 1992, 141). This aligns with John Chapman’s population estimates for sites between 4 and 4.9 ha, which range from 200 to 500 inhabitants (Chapman 1981, 48–50). Tringham further estimated the settlement’s duration at about 200 years, corresponding to five to seven generations of inhabitants.

The magnetic survey in particular has reclassified Opovo as a medium-sized Vinča settlement with a revised area of approximately 9.4 ha. The survey revealed between 180 and 220 potential houses in the magnetic imagery. While radiocarbon dating confirms a settlement duration similar to previous estimates (Orton 2012; Whittle et al. 2016), the significantly larger site size implies a much greater population over its five to seven generations or across its three building phases, as inferred from the 1980s excavations.

It is likely that the up to 220 houses visible in the magnetic survey represent only a minimum estimate (for reasons described above). The total number of houses over the settlement’s lifetime was likely much higher. Traditional methods for the calculation of population sizes use ethnographic data, such as household size (4–5 inhabitants per household; Diachenko, Zubrow 2015, 8) or population density (one inhabitant per 6–10 m²; Porčić 2012, 171; Porčić, Nikolić 2021, 479). Applying these methods to the 180 to 220 identified houses yields a total population estimate of 842–1,960 inhabitants. However, these approaches often do not consider several settlement phases or different models of population development and are thus outdated.

A more dynamic probabilistic approach introduced by Marko Porčić and Mladen Nikolić uses logistic growth models to simulate population changes over time (Porčić, Nikolić 2021). This method considers variables such as the starting population, carrying capacity, settlement duration, growth rates, and household size (see Appendix 1, code available in Appendix 2). Two scenarios were modelled for Opovo:

- Model 1 (Rapid Abandonment): Population grows logistically until rapid abandonment.
- Model 2 (Gradual Abandonment): Population grows initially, but decline or gradual abandonment sets in midway through the settlement’s lifetime.

Both models were validated against constraints which are described in detail in Appendix 1. After 1 million simulations, valid results provided potential population estimates,

growth rates, and possible settlement duration ranges (detailed results in Appendix 1). Given that extreme minimum and maximum values are unlikely scenarios, the 25th and 75th percentiles were used for interpretation.

- Model 1 (Fig. 9; Appendix 1: Figs. 1–4): The initial population is between 158 and 283 inhabitants (median: 216), and the population peaks at 346–711 inhabitants (median: 481) before the rapid abandonment of the settlement. The interquartile range (IQR) of the settlement duration of the valid iterations ranged from 166 to 273 years (median: 210 years), and the median growth rate is 0.04. A total of 4989 out of 1 million simulations matched the constraints.
- Model 2 (Fig. 10; Appendix 1: Figs. 5–9): The initial population is between 167 and 293 inhabitants (median: 226), and the population peaks at 349–581 inhabitants (median: 449) before being gradually abandoned. The interquartile of the settlement duration of the valid iterations ranged from 269 to 376 years (median: 323 years). The median growth rate is 0.04, and the median negative growth rate -0.07. A total of 8676 out of 1 million simulations matched the constraints.

These findings suggest that the population at Opovo likely ranged from 158 to 293 inhabitants at its lowest and 346 to 711 inhabitants at its peak. Further, the models suggest a settlement duration between 166 and 376 years, possibly suggesting a slightly longer duration than the radiocarbon model based on the median values.

3.2.2. Spatial Organization

Observations regarding the spatial organization based on the magnetic image reveal two key features. First, anomaly-free areas between the house anomalies suggest the presence of plazas, which, due to their central location (see Fig. 4; north of DP001 and around and south of the box ‘old excavation’), might have served as communal spaces. Similar features have been observed in other Late Neolithic settlements of the region too (Rassmann et al. 2021a; Hofmann et al. 2025a, 150). The row-like pattern and grouping of house anomalies further suggests the presence of social subunits (see Fig. 3); however lacking more conclusive stratigraphic and chronological data, this remains hypothetical.

Second, the absence of buildings outside the enclosed area suggests an inclusive settlement society. As outlined in a previous chapter, the enclosure system was expanded after the abandonment of the initial inner ditch c. This expansion likely took place in response to population growth, similar to other Late Neolithic sites (Schier, Draşovean 2020, 551–558; Hofmann et al. 2025a, 149–150). It appears that the initial and the expanded ditch system included every house and, by implication, every member of the community. This

would lead to the interpretation that there was no pronounced residential differentiation, in contrast to patterns documented at other Neolithic settlements (Chapman, Gaydarska, Hardy 2006, 29–33; Wunderlich et al. 2020).

The inclusive character of ditches in general has been discussed by Dušan Borić and colleagues (Borić et al. 2018, 344–345). They highlight the communal labour involved in creating and maintaining the ditch system as a ‘[...] powerful and cohesive social bond in creating and maintaining a sense of belonging for groups who identified with particular settlements’ (Borić et al. 2018, 345).

3.2.3. Social Organization

Given the likelihood of such a high number of inhabitants, we have to expect site-internal social structures facilitating collective decision making and organizing subgroups within the site. This could have involved hierarchical or heterarchical structures. What we want to explore further is to what degree there was material wealth inequality and to determine whether it may have reached an unsustainable level, potentially contributing to the site’s abandonment. In the following, we investigate house sizes as a marker for intra-settlement material wealth inequality. Doing so, we have to stress again that it is likely that the up to 220 houses visible in the magnetic survey represent only a minimum estimate due to underrepresentation of deep or slightly burnt house structures. However, the houses present in the magnetic image most likely provide a representative transect of the house sizes of the settlement throughout its lifetime.

The house anomalies based on the magnetic image are used to analyse the size and orientation of buildings in Opovo (measurements in Appendix 1). The median width of houses is 5 m (IQR: 4.3–5.6 m) and their median length 8.6 m (IQR: 7.5–9.2 m). The buildings size ranges from 19 to 111 m² in size, with a median size of 44 m² (IQR: 34.9–55.7 m²), which is well within the range of Vinča (Hofmann et al. 2025a) and in general Late Neolithic houses (Lichter 1993; Bami 2021).

Apart from the median angle (total settlement: 41.9°), there are no clear differences in the width, length or area of houses between settlement areas I and II. As indicated above, the angle of houses shifts only slightly when considering the radiocarbon dated houses (36°–33°). Considering settlement areas, houses in the earlier starting settlement area I show a median angle of 42.4° (IQR: 34.2°–51°), while houses in settlement area II have a median angle of 38.6° (IQR: 21.4°–54.8°).

Using the Gini index (methodology in Appendix 1) – a well-established measure of wealth inequality ranging from 0 (maximum equality) to 1 (maximum inequality) – on house sizes enables analysis of material wealth inequality (Kohler

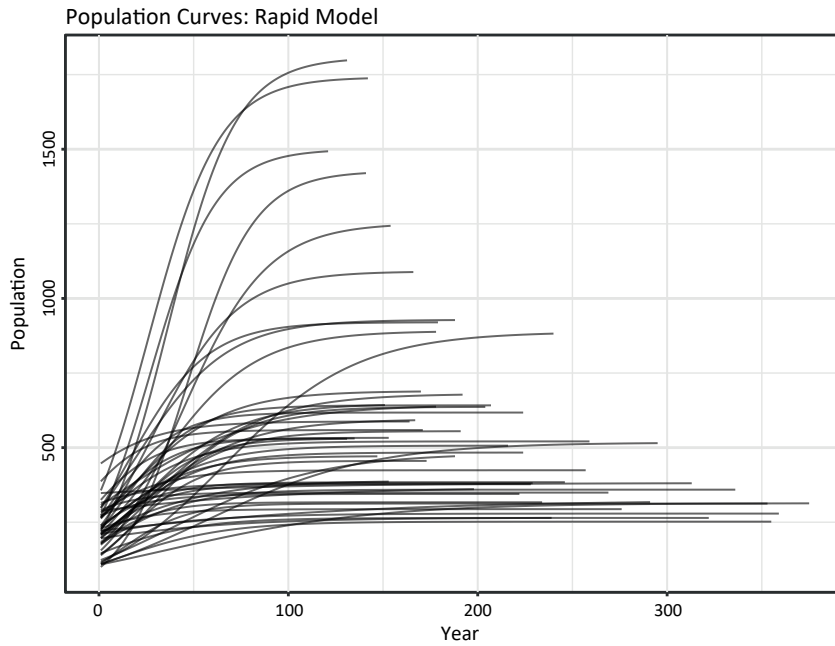


Fig. 9. Plot of 50 randomly picked valid simulations of the Rapid Abandonment Model (Model 1) (F. Wilkes with R ggplot2).

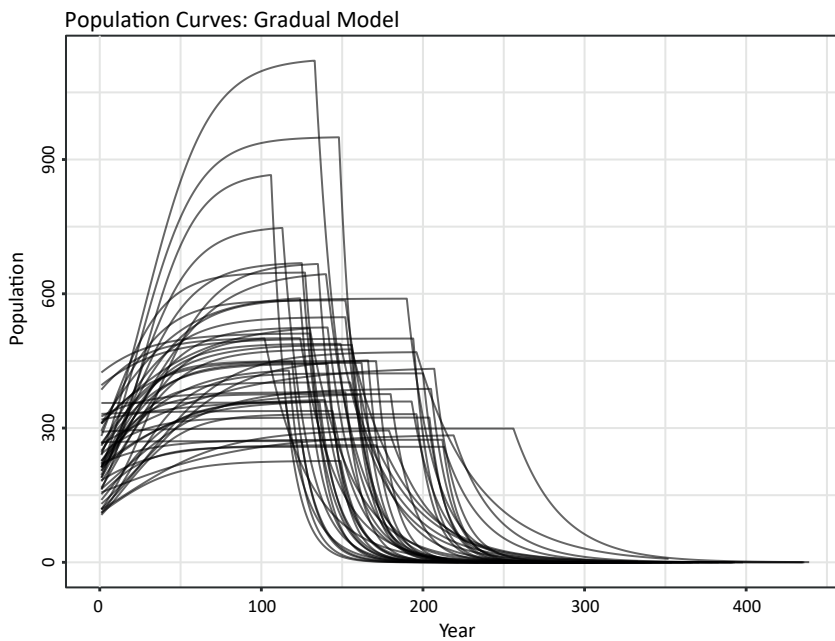


Fig. 10. Plot of 50 randomly picked valid simulations of the Gradual Abandonment Model (Model 2) (F. Wilkes with R ggplot2).

et al. 2017; Porčić 2019; Kerig et al. 2022; Duffy et al. 2025). This is because, as essential spaces for storage, living, and work, the size of houses can often be constrained by the material wealth available to their builders. Beside the mere construction costs of the houses, the size also includes information regarding the number of people that might have lived in it (workforce) and the number of resources that could potentially have been stored in it, expressing potential wealth disparities in a multi-faceted way. However, since houses by their nature have certain architectural requirements and limitations (no possibility for negative or zero-values; dependent on measures of building resources like tree width/

length) and that our magnetic record only shows the final moment of a house's life cycle, it is important to mention that house size-based inequality analysis constitutes an approximation of a society's social disparities.

In Opovo, the house size-based Gini index is 0.22, which is slightly below the average Gini index for Neolithic sites in the Carpathian Basin (Duffy et al. 2025). The Gini index can therefore be considered relatively low. This becomes evident when comparing it to house size-based Gini indices from a global and historical perspective (Kohler et al. 2017; Basri, Lawrence 2020) or to those of modern societies (World Bank 2025). Furthermore, comparing house

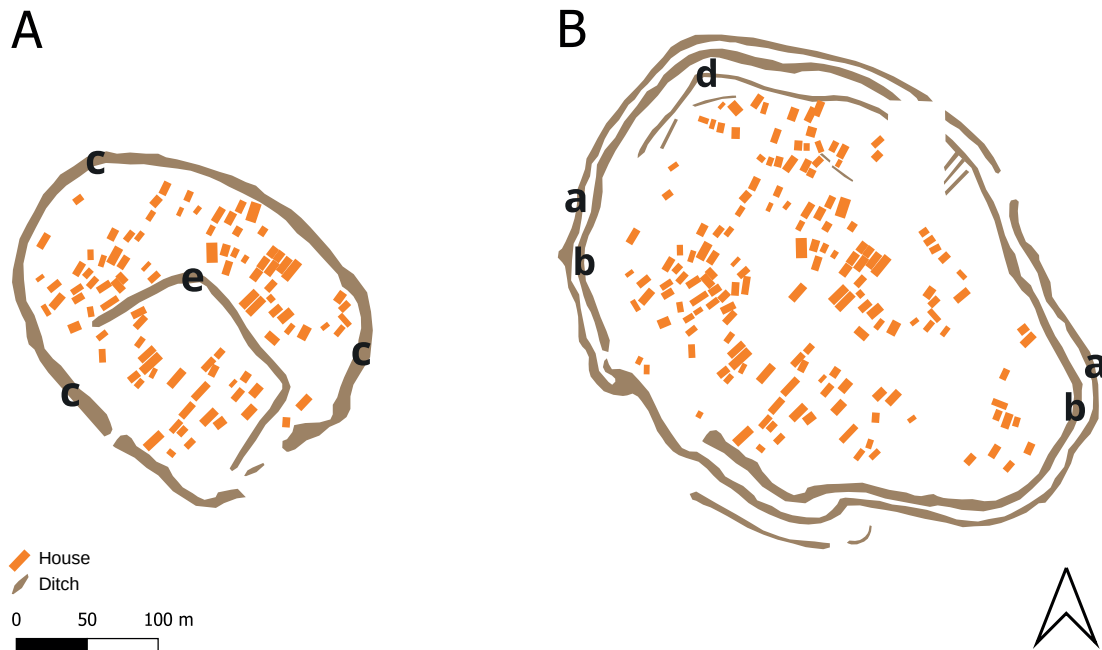


Fig. 11. Possible settlement development of Opovo Ugar-Bajbuk based on radiocarbon analysis. Ditches (brown) are phase-specific, while houses (orange) are shown schematically due to the unclear chronology. In phase A (~4850 calBCE), the site was enclosed by ditch c. By phase B (~4820 calBCE), ditch c was abandoned, the settlement expanded, and ditches a and b were built (F. Wilkes).

size inequality between the two settlement areas, area I has a slightly higher Gini index of 0.23, while area II shows a lower value of 0.19.

One might argue that, due to the uncertainty surrounding the contemporaneity of individual houses, the calculated Gini indices are of limited interpretative value. However, if the structures visible in the magnetic image are assumed to represent a reasonably unbiased sample of all houses that existed at the site over time, it becomes possible to assess the potential variability of inequality. To explore this, we randomly sampled between 10 and 100 house size values from the full dataset of house sizes, repeated 500 times – as indicated by Monte Carlo error estimation (methodology and results see Appendix 1). This approach produced 500 hypothetical house groupings, each representing a plausible composition of contemporaneous dwellings. For each sampling run, a Gini index was calculated, resulting in a median value of 0.22 with an interquartile range from 0.20 to 0.23. Even the maximum observed Gini value of 0.3 remains relatively low. These results suggest that, at any given point during the site's occupation, disparities in house size, and by implication house-size-based material wealth, were modest, indicating a generally low level of socioeconomic inequality within the settlement.

4. Social Structure of Opovo

By combining radiocarbon modelling, demographic data, and inequality studies, we set out a model of the society of

Opovo. Population estimates and ditch sizes point to a more complex form of social organization. Constructing ditches a, b, and c required a significant investment of labour. This suggests that a considerable founding population was present, likely increasing over time. Its growth would have enabled the filling of ditch c and the construction of ditches a and b by a sufficiently large society, as well as creating the need for an expansion of the settlement area. Furthermore, such large-scale construction required social coordination for both building and maintenance of the ditches.

While ditches are common in Late Neolithic settlements throughout the region (Crnobrnja, Simić, Janković 2009; Perić et al. 2016; Hofmann et al. 2019a; Rassmann et al. 2021a), the ditches at Opovo are particularly large. Their construction and maintenance would have required significant communal effort and certain degrees of social structuring.

Studies suggest that once communities surpass approximately 150 members, increasing social structuring is often required to mitigate scalar stress. If such structuring is not implemented, social groups may fragment (Johnson 1982; Alberti 2014). Therefore, population estimates have implications for social organization, stratification, and inequality. Gregory Johnson identifies increasing group size as a driver of 'scalar stress' (Johnson 1982), while Gianmarco Alberti calculates that scalar stress significantly impacts societies at population thresholds of 122–170 individuals (Alberti 2014). Archaeological and anthropological studies

(Bandy 2004; Parkinson 2006; Porčić 2012; Porčić 2019; Ellyson 2022) show correlations between the size of the population and levels of social stratification. Opovo's population size of well over 150 at its peak likely required the implementation of structured forms of decision making and within-group differentiations of subgroups, which could be organized horizontally or vertically.

However, analyses of significantly larger settlement agglomerations than Opovo (Hofmann et al. 2019b; Green 2021; Hodder 2022; Hofmann, Müller-Scheeßel, Müller 2024) challenge the widely held assumption that larger populations necessarily require hierarchical stratification (Johnson 1982). Non-hierarchical forms of social organization, such as heterarchy (Crumley 1995) or segmental organization (Sigrist 2004), should also be considered. The construction, maintenance, and organization of up to five enclosures suggest the presence of a social system capable of coordinating large-scale communal labour. However, given the absence of effective coercive mechanisms (Lund, Furholt, Austvoll 2022; Furholt in press), such projects were likely collaborative endeavours rather than top-down initiatives, potentially serving to strengthen group cohesion (Duffy et al. 2025). In this context, the ditches, which enclosed all parts of the settlement in both the early and later phases, suggest an inclusive society with no excluded settlement areas or houses. Likewise, the presence of open spaces, or plazas, within the settlement might be a further sign of communal organization.

To underpin this and as discussed above, house size differences do not indicate a significant potential for material wealth inequality within the settlement.

To sum up, given the considerable population size, some form of social structuring would have been necessary. Further observations regarding the social structure are the size and sequence of the ditches, which required continuous communal effort, as well as the spatial layout, in which every building was integrated into the ditch system and thereby protected. Together with the low level of material wealth inequality based on house size, these factors suggest that Opovo, showing modest material differentiation in built space consistent with low inequality, might even have been a largely egalitarian society. Based on these observations, the abandonment of the settlement most likely was not caused by material wealth disparities.

5. Conclusions

Recent investigations at Opovo Ugar-Bajbuk, building on excavations from the 1980s, have substantially revised our understanding of Opovo's development and structure. Earlier research had suggested a settlement of approximately 5 ha and a population of around 200 people, based on a small

set of radiocarbon dates placing occupation of the site between 4860 and 4780 BCE (Tringham et al. 1992; Tringham 1994; Orton 2012). These interpretations framed Opovo as either a small agricultural hamlet or a modestly active centre of the regional trade networks (Russell 1993; Borojević 2006; Marić 2015; Milić 2016).

New research conducted between 2022 and 2024 has more than doubled the estimated site size to 9.4 ha, identified up to 220 house structures, and raised the peak population estimate to up to 711 inhabitants. These findings, coupled with updated radiocarbon analysis, suggest continuous occupation from approximately 4850 to 4725 BCE – slightly extending the known lifespan of the site. In addition to identifying a more complex enclosure system, geomagnetic surveys have revealed an internal spatial organization that points to dynamic changes in the settlement layout over time.

Our first research aim was to trace the physical and demographic development of Opovo (Fig. 11). Early occupation was concentrated within a roughly 4.3 ha area (settlement area I), enclosed by ditch c in around 4850 BCE. Expansion into a larger area (area II) occurred around 4820 BCE, coinciding with the partial infilling of ditch c and the construction of larger ditches (a and b). This expansion implies at least subtle population growth and a need for structural reorganization. Radiocarbon dating suggests that the settlement remained occupied until at least 4725 BCE, after which it was abandoned. The environmental, economic, or social reasons for this abandonment are still unclear.

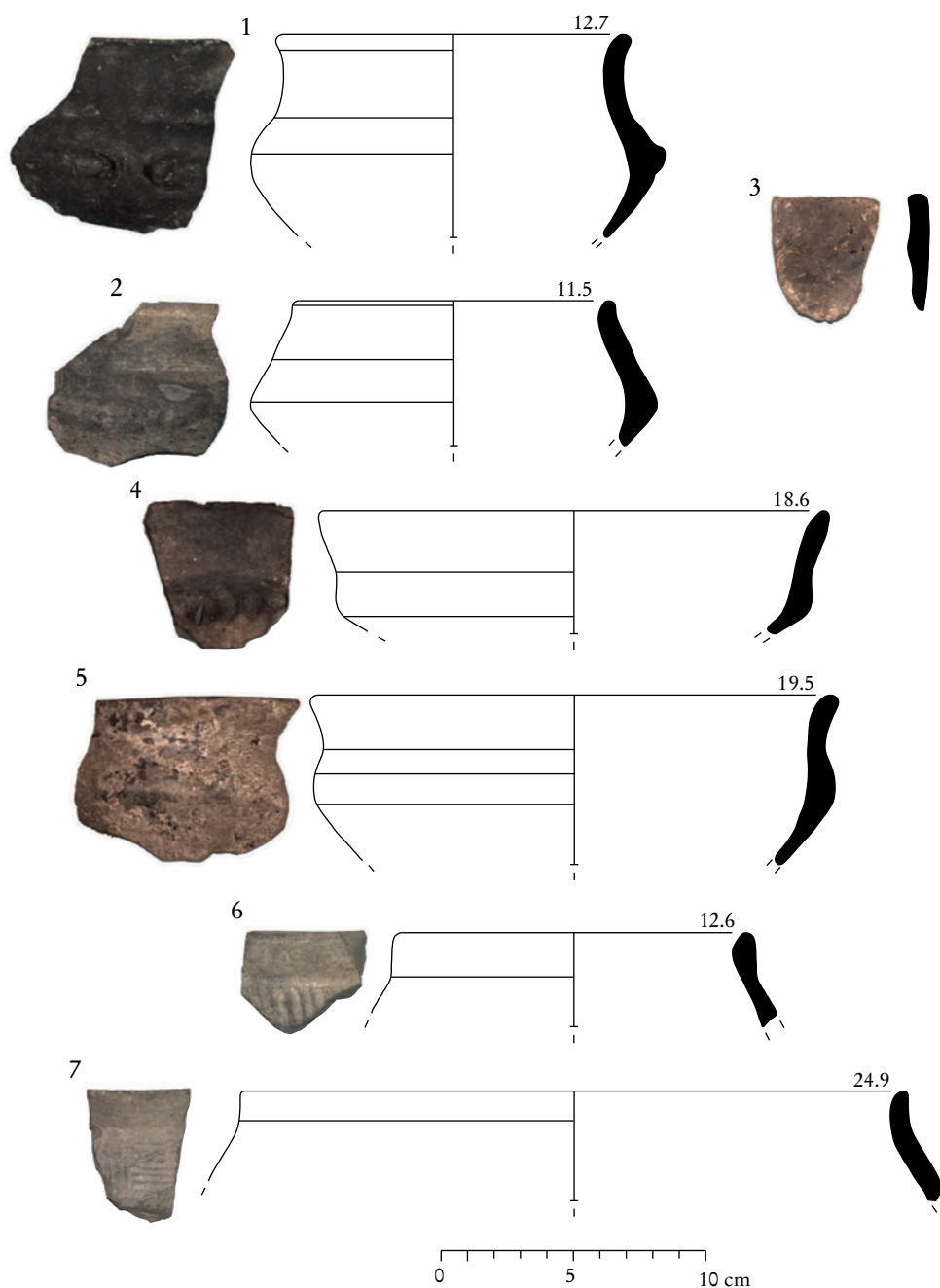
The second research question addressed how society at Opovo was structured. The analysis of house size data suggests a relatively low material wealth disparity. House size analysis using the Gini index (median: 0.22) indicates low inequality in material wealth. This implies that economic differentiation existed but did not result in significant social stratification and likely played only a minor role. The construction of up to five ditches points to a well-organized community capable of coordinating large-scale labour efforts. However, the absence of evidence for coercion implies that these efforts were cooperative rather than hierarchical.

While we have expanded the already impressive body of research on Opovo Ugar-Bajbuk, several questions remain open for future investigation. One key question is the precise sequence of ditch construction and its implications for settlement expansion. Additionally, further research on the spatial organization of production activities could shed light on the social structure and the nature of specialized crafts within the settlement. Building on the findings of our German-Serbian collaboration (Stanković Pešterac 2024), a broader regional comparison with other Late Neolithic

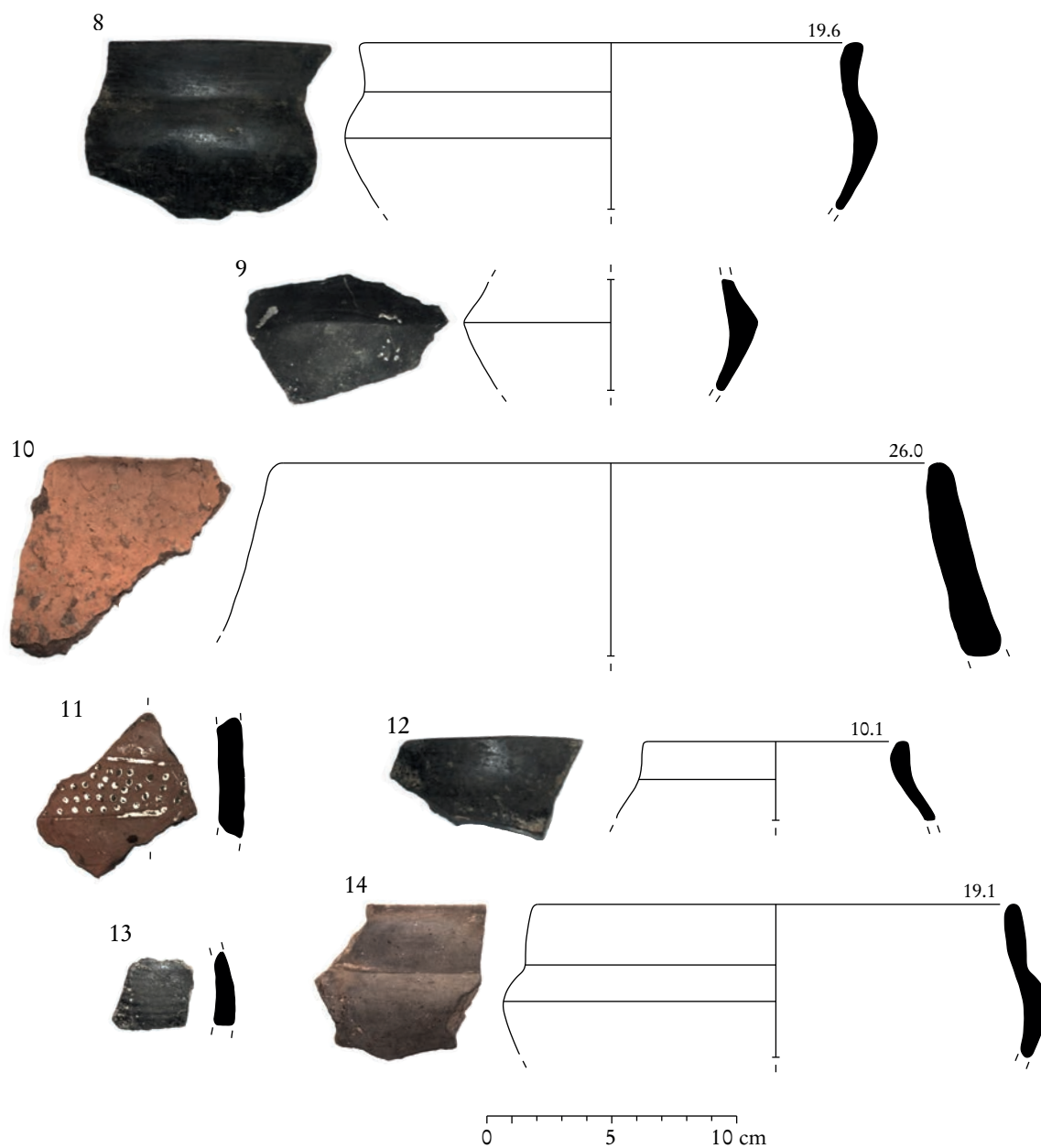
sites is essential to understand better Opovo's role within exchange networks and regional settlement patterns.

Overall, our research has led to a reassessment of Opovo, identifying it as a medium-sized Vinča settlement. These new insights refine previous interpretations, reinforcing its characterization as an organized community with a relatively low level of social inequality. It is important to note that our approaches to assessing the demography, chronology, and social structure are often based on assumptions, which are well justified and based on field and laboratory data (Appendixes 1 and 2). So far, our quantitative study of

inequality has been limited to material wealth as indicated by house size. However, based on observations of the ditch system, surface finds, and spatial organization, we assume that our conclusions regarding social inequality will not be significantly changed when analysing other domains of wealth, such as relational or embodied forms (Borgerhoff Mulder et al. 2009). Nonetheless, this remains an open question, that future research must address. Upcoming studies and fieldwork will contribute to a deeper understanding of the social structure, settlement development, and Opovo's role within the broader Late Neolithic landscape.



Pl. 1. Surface finds from Opovo. – 1–3, 5. Vinča Culture pottery (Vinča C–D); 4. Early Eneolithic pottery; 6–7. Sarmatian pottery.



Pl. 2. Surface finds from Opovo. – 8–9, 11–12, 14. Vinča Culture pottery (Vinča C–D); 10. Starčevo Culture pottery; 13. Bronze Age pottery.



Pl. 3. Special surface finds from Opovo. – 15–17. Clay object interpreted as a bucranium or zoomorphic sceptre element; 18. Figurine arm or fragment of an anthropomorphic vessel.

Acknowledgements

The authors would like to express their gratitude to Yasmin Dannath and Tim Schroedter for their invaluable help in classifying charcoal samples prior to radiocarbon dating. This research would not have been possible without the support and dedication of a group of motivated students, to whom we owe a great deal of appreciation. These students are: Erik Riese, Ryley Löber, Victoria-Luise Boensch, Julian Schönebaum, Maike Schildbach, Freya Steinhagen, Christine Spliesgart, Katharina I. Kaczmarek, and Melissa C. Villumsen. Lastly, we would like to thank the two anonymous reviewers for their valuable comments and deep engagement with our research; their comments helped us to improve the paper. The project is funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC 2150 – 390870439 and the Provincial Secretariat for Culture, Public Information and Relations with Religious Communities within the work programme of the Museum of Vojvodina. Kata Furholt's work on the lithic material and the further petrographic analysis is supported by the 'Comparative petrological, petrophysical and geochemical investigations of polished stone artefacts and potential source rocks from the point of prehistoric raw material selection strategy project NKFI-Advanced 150223' (HUN-REN Centre for Energy Research).

Appendix 1

Detailed methodology, calculations and model results can be found at: https://austriaca.at/onlineArchA110_Wilkes_et_al_Appendix1.

Appendix 2

The R scripts and OxCal code used for the analyses can be found at: https://austriaca.at/onlineArchA110_Wilkes_et_al_Appendix2.

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