Geophysical prospection of submerged Neolithic settlements in Lake Sennitsa (NW Russia)

4

Andrey N. Mazurkevich[1], Sebastian Lorenz[2], Jörg Fassbinder[3], Roberto Hensel[2], Ekaterina V. Dolbunova[1,4], Eduard Kazakov[5], Elena Pavlovskaya[6]

1 – The State Hermitage Museum, Saint Petersburg, Russian Federation
2 – Institute of Geography and Geology, University of Greifswald, Greifswald, Germany
3 – Bavarian State Dept. of Monuments and Sites, München, Germany
4 – The British Museum, London, United Kingdom
5 – State Hydrological Institute, Saint Petersburg, Russian Federation
6 – Department of Geophysics, Faculty of Earth Sciences, Saint Petersburg State University, Russian Federation

The History of Discovery

The history of discovery of submerged archaeological sites on the bottom of Lake Sennitsa (NW Russia) (Figure 1) resembles the discovery of pile dwellings in Switzerland. In 1976, the water level was artificially reduced by 4 m. Upper parts of the wooden piles became visible and bottom sediments started decaying. Later, the water level was gradually increased, and currently it is about 2.5 m lower than previously. Local inhabitants began finding bone tools, clay vessels, flint, and wooden tools on the bottom of the lake and in their fish nets. Soon a small museum was opened in the local school of Dubokray village with finds from the lakes. History teacher I.A. Voschillo reported about these finds to A.M. Miklyaev, who organised investigations of these sites in 1979 by the north-western archaeological expedition of the State Hermitage museum (Miklyaev 1982, 1990).

Investigations started in 1979–1980 on the lake bottom near the Dubokray village on the Dubokray I' site, where the majority of finds were recorded. Low underwater visibility complicated underwater excavations and forced specific methods to be implemented. The whole surface of the site covered 20 x 20 m squares, facing cardinal points, where a topographical survey of the site and surroundings was conducted. These squares served as a basis for smaller square nets on the parts investigated for the more precise recording of materials. The pile-dwelling remains found in one of the squares comprised wooden piles, accumulations of wooden particles, organic objects, and clay vessels. It was noted that a cultural layer of the site located on the lake bottom at a depth of 70–120 cm started severely decomposing due to the freezing of the lake, wave motions, and anthropogenic influence. The cultural layer and materials were lifted to the surface by divers for further sieving (Miklyaev 1990).

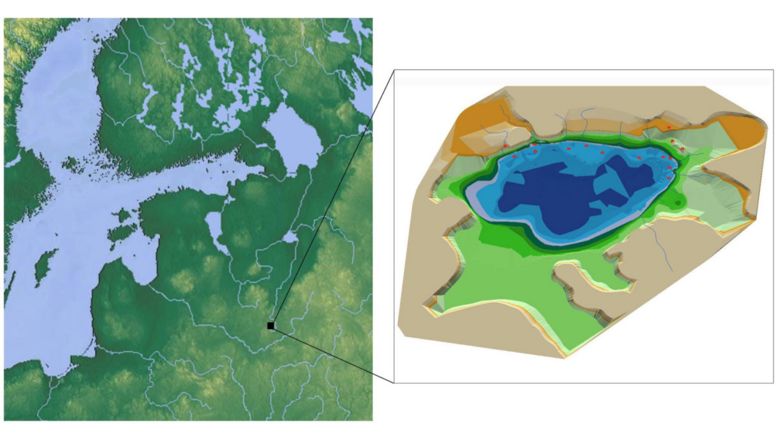

Figure 1: Sites distribution on Lake Sennitsa (NW Russia).

Mazurkevich, A.N., S. Lorenz, J. Fassbinder, R. Hensel, E.V. Dolbunova, E. Kazakov, E. Pavlovskaya (2020). 'Geophysical prospection of submerged Neolithic settlements in Lake Sennitsa (NW Russia)'. In: *Settling Waterscapes in Europe. The Archaeology of Neolithic and Bronze Age Pile-Dwellings*. Ed. by A. Hafner, E. Dolbunova, A. Mazurkevich, E. Pranckenaite and M. Hinz. Open Series in Prehistoric Archaeology 1. Bern and Heidelberg: Propylaeum, pp. 37–58. DOI: 10.11588/propylaeum.714

In 1986, in a deeper part (depth 120–150 cm) on the north-eastern part of the lake, remains of an iron workshop — named Mosty — were found, dating to the middle of the 1st millennium BC. The 8 x 8 m log construction was divided inside by chambers of 4 x 4 m. Slag was found inside this construction and on its perimeter. First, the outer corners of the construction were marked by poles seen above water. Subsequently, logs were measured and put on the plan, and other elements of construction and zones of slag accumulation were recorded and marked by poles. Fragments of pottery were put on the plan and recorded according to the nearest pole (Miklyaev 1990).

Following successful excavations at the Mosty iron workshop, investigations of the cultural layer in the eastern part of the Dubokray V site began. Drillings into the bottom sediment on the slopes of a sandy hill began, at the edge of where the site was located to record the distribution of the cultural layer. This enabled making a description of bottom sediments and choosing the place with the most prominent cultural layer. 2 x 2 m squares were made and underwater excavations were conducted according to layers made by sieving and the recording of large pottery fragments. The bottom of the excavation was only 1 x 1 m because the ground was liquid and the walls of the trench were decomposing. The stratigraphy was revealed: at a depth of 1.1 m, a 55 cm thick layer of silt was found, which covered the cultural layer deposited in the peat layer with gyttja 28 cm thick, and beneath that sand and aleurite. Pottery fragments attributed to the second stage of Usviaty culture were collected at the low part of the silt layer and the upper part of peat layer. Pottery fragments of the first stage of Usviaty culture were found in the lower part of the peat with gyttja. Fragments attributed to Linear-band pottery (LBK) were recorded on the border of peat and gyttja (Mazurkevich and Dolbunova 2011; Miklyaev 1990).

An accumulation of Mesolithic materials and hearth 70 cm in diameter surrounded by stones was revealed on the Dubokray VI site located remotely from the Late Neolithic finds.

Results of Investigations of the 1980–90s

During this period, Dubokray I, V, VI, and iron workshop Mosty were investigated. The possibility of conducting underwater archaeological excavations in such difficult conditions was demonstrated. Rare finds from the Mesolithic era were made on the Dubokray VI site, comprising flint flake scrapers and tanged blade arrowheads.

Ceramic and flint materials of the early Neolithic era were found here, belonging to two cultural groups. Material from the Serteya archaeological culture dating from the 7th–6th millennium BC were found on modern lake shores near the Dubokray I and V sites. Pottery similar to LBK was found on the Dubokray V site, along with a few bones, antlers, flint tools, cylindrical amber pendants, and flutes (Figure 2). A few Neolithic era materials of Usviaty culture were found on the Dubokray I and V sites. Late Neolithic era materials of Zhizhitsa and North-Belorussian culture and typical Corded ware vessels were found at the Dubokray I–VI sites. A few fragments of vessels covered by geometrical incised lines similar to

Figure 2: Site Dubokray V: flutes.

those of agricultural communities of the Balkans dating to the beginning of the 3rd millennium BC were also found.

A large number of wooden particles and wooden logs were detected at the Dubokray I site under water, although wooden piles were not recorded. A trench was made on a peaty shore to trace a preserved cultural layer (Miklyaev 1982, 1990) (Figure 3). The remains of North-Belorussian cultural pile dwellings were found there, destroyed by great flooding that occurred at 3240±40 BP (Le-2839). This natural disaster had a macroregional character and it also destroyed the Serteya II and Naumovo sites in neighbouring microregions. Beneath the remains of the North-Belorussian cultural layer, a Late Neolithic cultural layer dated to 3870±40 BP (Le-2840) – 3860±40 BP (Le-2838) was found. This included pottery fragments, part of a ski made from elm and the fragment of a plough (Miklyaev 1990).

Figure 3: A.M. Miklyaev on the Dubokray I site.

A few fragments of vessels dating to the middle-second half of the 1st millennium AD were also found, showing the possibility of the existence here of early Middle Age settlements. This was evidenced by the finding of the Mosty iron workshop.

Analysis of the spatial distribution of the finds showed that surfaces covered by artefacts dated to different periods of time partly overlapped. Analysis of the topography, micro-relief, and stratigraphy of bottom sediments suggested the hypothesis that all sites uncovered were located inside a modern lake, which previously had several elevations among small lakes connected by a system of rivers. These elevations were separated from the bedrock shore by small rivers.

The main reason why these investigations were stopped was that the precise recording of all objects found, sieving, and other techniques could not be implemented due to the absence of necessary equipment. Remote technology was also useful to record all of the objects prior to excavation, and these technologies were not available in the early-1990s.

Renewal of Excavations in the 2010s: Aims and Results of Underwater Investigations

In the 2010s, investigations on Lake Sennitsa were renewed (Figure 4). As the result of these investigations, new sites were uncovered and the position of already-known sites was refined. It appeared to be clear that during later years organic sediments on the sites disappeared, whereby cultural layers were either destroyed due to natural processes or covered by a sandy layer, which deposited on top during the last decennia. The artefacts were found in new areas that were not investigated earlier given that there were no Neolithic materials. Artefacts were not found at the places of former excavations. These might have been destroyed or covered by recently-deposited sand.

Renewal of excavation work on Lake Sennitsa led to uncovering several new accumulations of stones on the Dubokray I site (Figure 5b). These

Figure 4: Topographical survey of Lake Sennitsa on the Dubokray I site (2012).

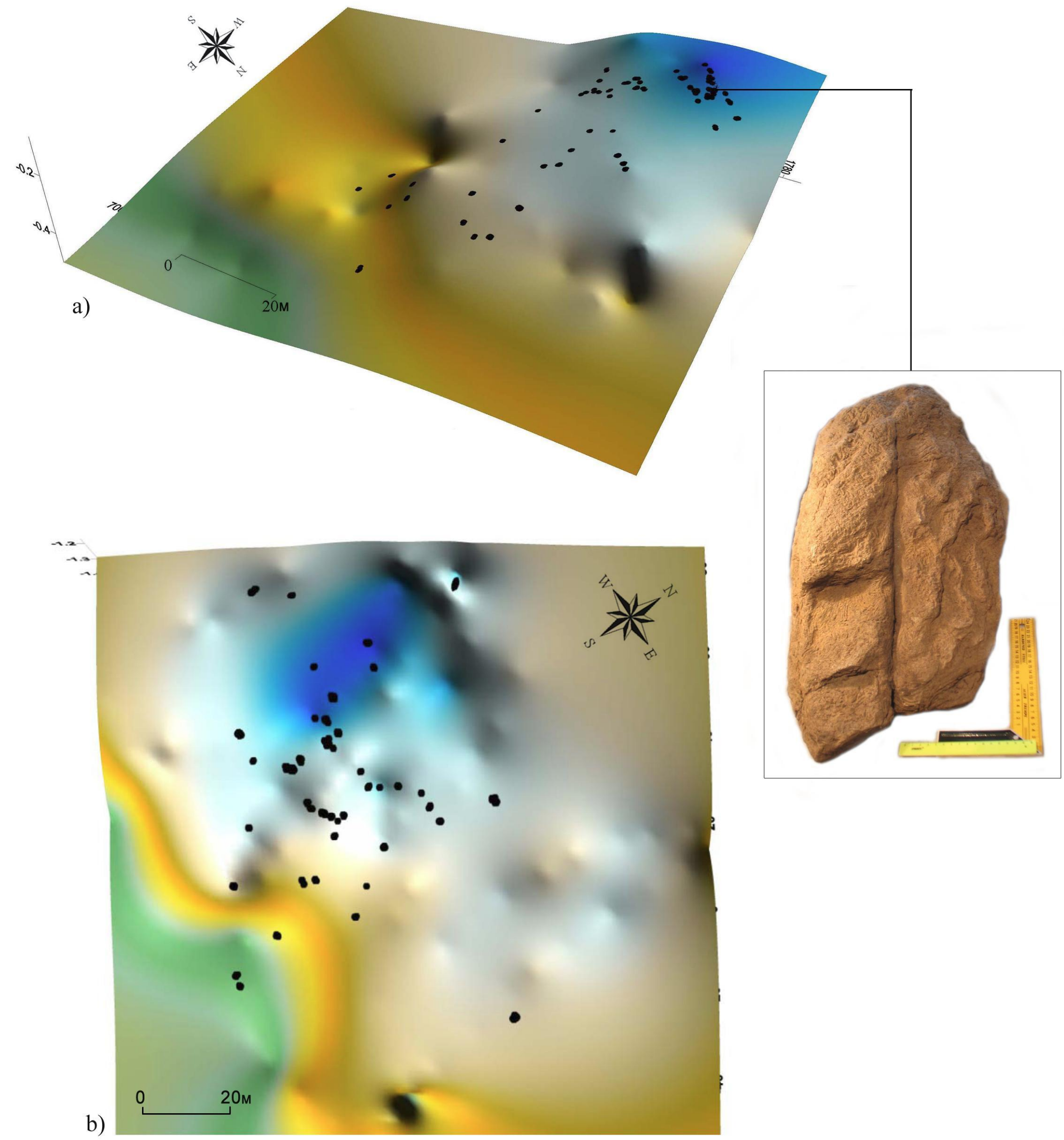

Figure 5: Plan of stones distribution on the Dubokray X (a) and I (b) site.

stones form a particular structure, organised as a circle in the central part with rays of stones coming from it. Excavations were made near the largest one, where smaller stones, an accumulation of charcoal, flint tools, and a stone adze were found. The charcoal was dated to 3690±50 BP (Le-9537). Furthermore, a large number of pottery fragments as well as complete vessels were found there. The material was concentrated in the central part of the site inside the construction on the elevation. We might suggest that this stone construction is located beyond the pile-dwelling settlement by comparing the plans of excavations of the 2010s and 1980s.

Another construction was found at the Dubokray X site (Figure 5a), comprising 83 stones 30–80 x 40–60 x 30–50 cm in size, rising 10–20 cm above the surface. The stones are organised into two parallel rows in the north-western area, the most elevated part of the site. Nearby single stones and accumulations of stones were recorded, organised in lines oriented north-east to south-west, and east to west. One of the stones 80 x 30 x 35 cm in size from the eastern row was lifted for examination. Oblong deepening with traces of pecking was recorded on it. A few artefacts were found on the site, concentrated in the pit, including a bone arrowhead, a stone polished axe, and eleven fragments of two or three clay vessels.

New sites were uncovered, named Dubokray VIII and IX, located in the northern part of Lake Sennitsa. Fragments similar to LBK pottery were found here, as well as Middle and Late Neolithic vessels of Zhizhitsa culture, Pit-comb ware, Globular Amphora culture, and Corded ware culture. A few bone tools and flint tools were also found (Figure 6). The remains of one wooden pile at the Dubokray IX site were dated to 4000±85 BP (Le-9536). Probably a pile-dwelling settlement existed here in the past, which can be evidenced by finds of vessels attributed to North-Belorussian and Zhizhitsa pile-dwelling cultures (Mazurkevich and Dolbunova 2011).

The results of underwater excavations led to the necessity to use non-destructive techniques for investigations on the shore and the bottom of the lake. The main aims — concentrating on the area around the Dubokray I site — included recording stone ('megalithic') constructions, finding buried objects, and finding the remains of wooden piles and constructions. An aerial survey was conducted on the shore line (Figure 7) and a relief map was reconstructed basing on this data (Figure 8). Geophysical prospections were conducted on various areas of the shore of Lake Sennitsa in the vicinity of the Dubokray I site, as well as on the lake bottom near the Dubokray IV and V site, whereby cross-sections were also made (Figure 9).

Figure 6: Pottery (1–2, 12-13), flint tools (7–10), bone arrowhead (3), slate axe (4), bone spatula (5), stone sinker (6), bone point (11) found at the Dubokray I (1, 7–8, 10), VIII (2, 9, 12–13), IX (5–6, 11), and X (3–4) site.

Figure 7: Aerial survey in the vicinity of the Dubokray I site.

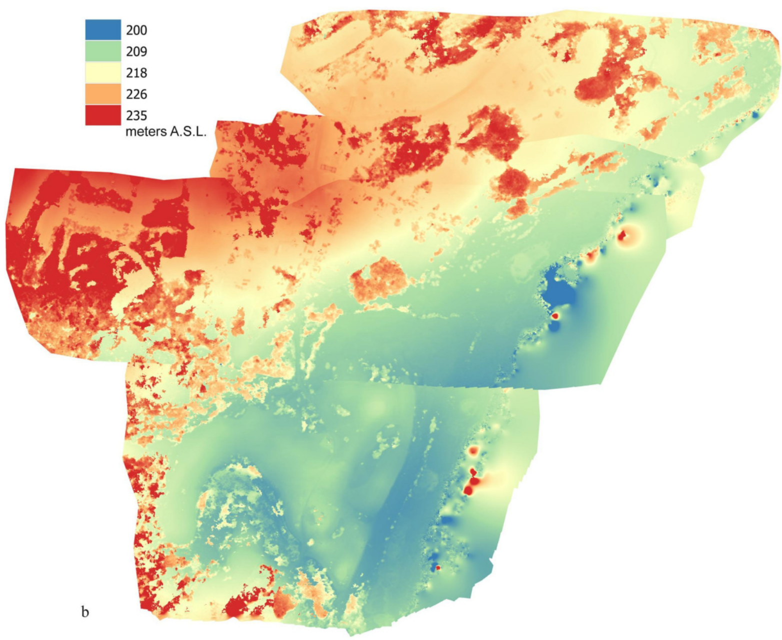

Figure 8: Relief reconstruction in the vicinity of the Dubokray I site.

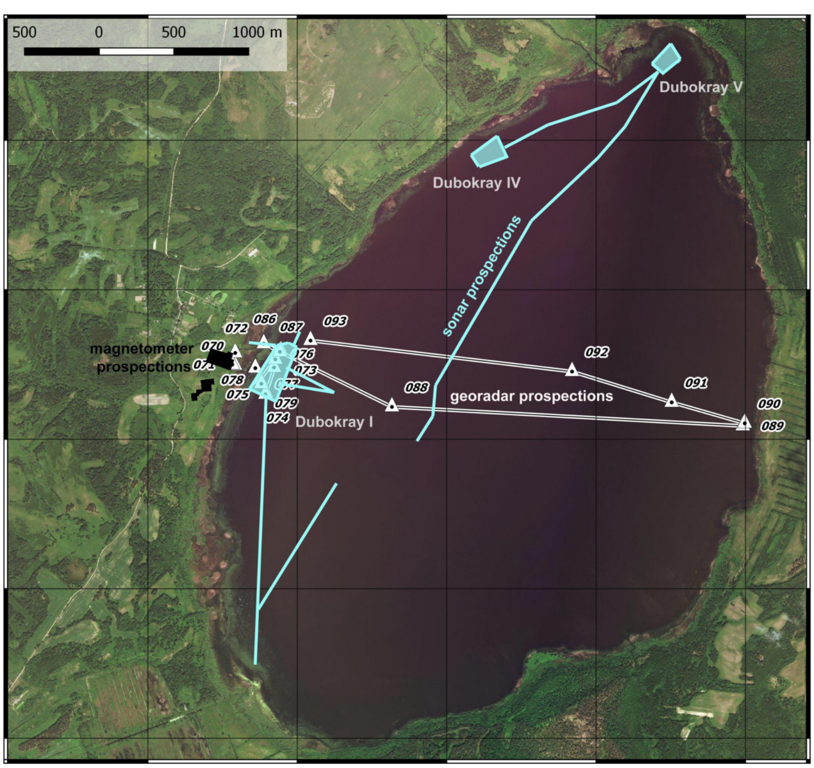

Figure 9: Map of Lake Sennitsa with indications of the places where geophysical prospections were made.

Geophysical Methods

For non-destructive and large-scale archaeological prospecting, geophysical science provides us with a multitude of different ground-based methods (Scollar et al. 1990). The most common among them are:

1. Magnetometer prospecting (passive method)
2. Radar prospecting (active method)
3. Resistivity prospecting (active method)
4. Sonar prospecting (active method)

Magnetometer prospecting is a 'passive' method, measuring a latent existing magnetic field, whereas the other methods are 'active' ones. These active methods — namely radar and resistivity prospecting — are regarded as suitable methods in the search of stone features, while the sonar method is among the most suitable method in the search of submerged features. They can be applied without being disturbed by modern technical constructions nearby, inside a modern city, or even inside a building. However, the application of these methods is more time-consuming and requires intensive and sophisticated data processing to display the results.

Several boundary conditions limit radar and resistivity prospecting methods. Saline and clayey soils, as well as swampland dramatically dampen the penetration of the radar waves. A rough and uneven topography makes a high-resolution radar survey utterly impossible. Resistivity prospecting is the most time-consuming prospecting method, and it is also limited by the conductivity differences of the mostly wet and muddy topsoil layers at the Dubokray I site.

Magnetometer prospection

The Dubokray I site is situated on the coastline of Lake Sennitsa is partly covered by water, and it extends up the slopes of slightly elevated hills. Therefore, on the swampy and wet grassland of the site, magnetometer

Figure 10: Magnetometer prospecting in action with the handheld duo-sensor cesium magnetometer at Dubokray (Photo: Dima Michaylov).

prospection remains the best suitable method for large-scale and high-resolution prospection (Aspinall et al. 2008; Fassbinder 2017). However, the muddy terrain conditions pose a major challenge. The area is partly interspersed with pools and small ponds up to 50 cm in depth and several metres wide. These conditions require a magnetometer equipment and configuration that is rather tolerant of tilting of the instruments, as well as a variation in the exact distance from the ground. For our purpose, in order to reach the highest possible sensitivity combined with a maximum speed of prospection we chose a caesium total field magnetometer (Scintrex SM4-G Special). We implemented the instrument in the so-called 'duo-sensor' configuration. Using this configuration, we mounted the probes on a wooden frame and carried them in a zigzag pattern c. 30 +/- 10 cm above the ground (Figure 10). The profiles of our 40m x 40m grid were oriented east to west to minimise technical disturbance and interactions of the magnetometer probes with the electronic parts and the batteries of the device. The instrument allows us to measure the Earth's total magnetic field by a sensitivity of ±10.0 picoTesla with a sampling rate of ten measurements per second. For comparison, the Earth's magnetic field in Dubokray I site varied in the range of 51,730 ±10 nT in May 2013 and 51,860 ±20.0 nT in May 2016.

The sampling frequency of the magnetometer (ten readings per second) allowed the survey of a 40 m profile in less than 30 seconds, maintaining the spatial resolution of a data sampling (ten measurements per second) of approximately 10–15 cm by normal walking speed. Every 5 m, in parallel to the magnetic data, a manual switch set a marker. This helped us to perform the best and most exact interpolation of data during the subsequent laboratory processing work. We removed the slight linear changes in the daily variation of the geomagnetic field by a reduction filter and calculated the mean value of the 40 m profile. Additionally, we calculated the mean value of all data of the 40 × 40 m grid and subtracted this value from the survey data. Hereby, we assumed that the variation of the Earth's magnetic field during the measurement of one 40 m profile followed a linear increase or decrease in the intensity of the Earth's magnetic field. Thus, it was possible to eliminate this variation for each traverse line by a reduction to the mean line value. This procedure filtered apparent linear structures parallel to the profile. Alternatively, in magnetically quiet areas, it is also useful to calculate the mean value of the whole 40 × 40 m grid and use this value for further data processing as described above. In order to create discrete field values, we used a resampling program, setting the data to a sampling interval of 25 × 25 cm. Accordingly, we obtained the intensity difference between the measurement of both the magnetometer probes and the theoretically-calculated mean value of the Earth's magnetic field. The data (displayed as a grey shade image) reflects the apparent magnetic anomaly caused by the magnetic properties of the archaeological structure, the soil magnetism, and the geology. In order cancel the natural micro-pulsations of the Earth's magnetic field, we applied a band pass filter in the hardware of the magnetometer processor. Usually more than 98 per cent of the magnetometer data in a 40 m grid on archaeological sites varies within the range of ± 10 nT from the corrected mean value of the geomagnetic field. We ascribe the stronger anomalies to burned structures, lightning strikes, or pieces of iron containing slag or iron rubbish. In-situ burning, pieces of iron, and traces of lightning strikes are easily distinguishable not only by their different direction of magnetic dipole anomalies, but also by their high intensities (> ± 50 nT).

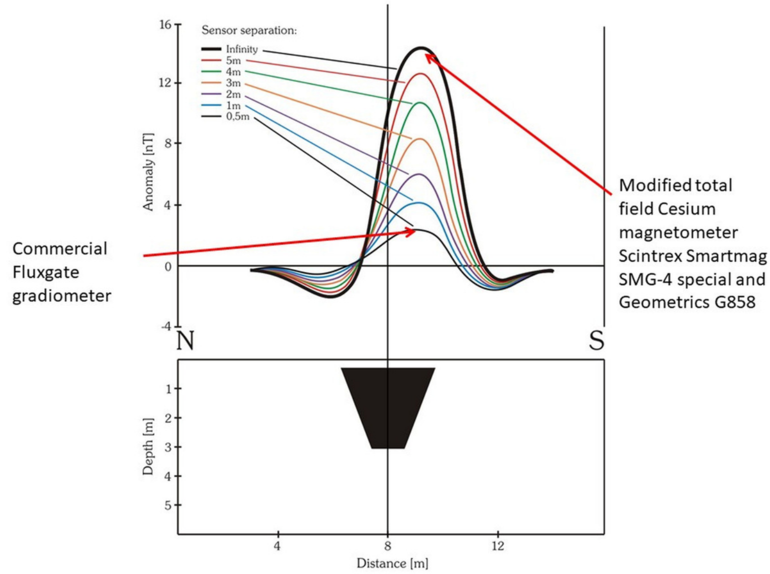

Figure 11: Dependence of the intensity of a magnetic anomaly of a typical prehistoric feature such like a ditch, on the sensor separation (gradient) of a commercial fluxgate gradiometer (50–65 cm gradient) and a total field cesium magnetometer with a virtual gradient of > 5 m.

The implementation of the optical pumped cesium magnetometer Smartmag SM4G-Special in the so-called duo-sensor configuration allowed setting the reference value — e.g. the virtual gradient of the Earth's magnetic field — to infinity, and measured magnetic anomalies with full intensity (Figure 11). The major advantage of this configuration is rather obvious: the resulting data and the grey shade image delivers more information about the site, including from the deeper parts of the archaeological structures. The application of a high-pass filter to the data allowed us to discriminate geological features (such as paleo-canals) from deeper soil layers, as well as extensive distributions of highly magnetic ash layers from discrete and detailed archaeological features in the top soil.

The instrument itself allows us to measure the Earth's total magnetic field by an intrinsic sensitivity of ±10.0 picoTesla with a sampling rate of ten measurements per second. For comparison, the daily fluctuations of the Earth's magnetic field in Dubokray (5/2016) varied within the range of 51,850 ±20.0 nT. The data were stored as binary files on the read-out unit, then downloaded to a Panasonic Toughbook and unpacked to ASCII data. For image processing and further treatment of the data (resampling), we applied special self-made software, the program Geoplot (Fa. Geoscan Ltd. UK) and Surfer (Golden Software, USA). The visualisation as a greyscale image (magnetogram) allowed us to trace even the smallest anomalies provoked by the remains of single posts and palisades beneath the surface. The application of a high-pass filter removed the deeper and mainly geological features and gave us supplemental information on the type of the anomalies. We displayed the later results by a second magnetogram image.

For the integrated interpretation, we classified the findings by:

1. the shape of the feature (based on archaeological background knowledge);
2. the intensity of the magnetic anomaly;
3. the direction and intensity of the remnant magnetisation; and
4. the induced magnetisation (volume magnetic susceptibility).

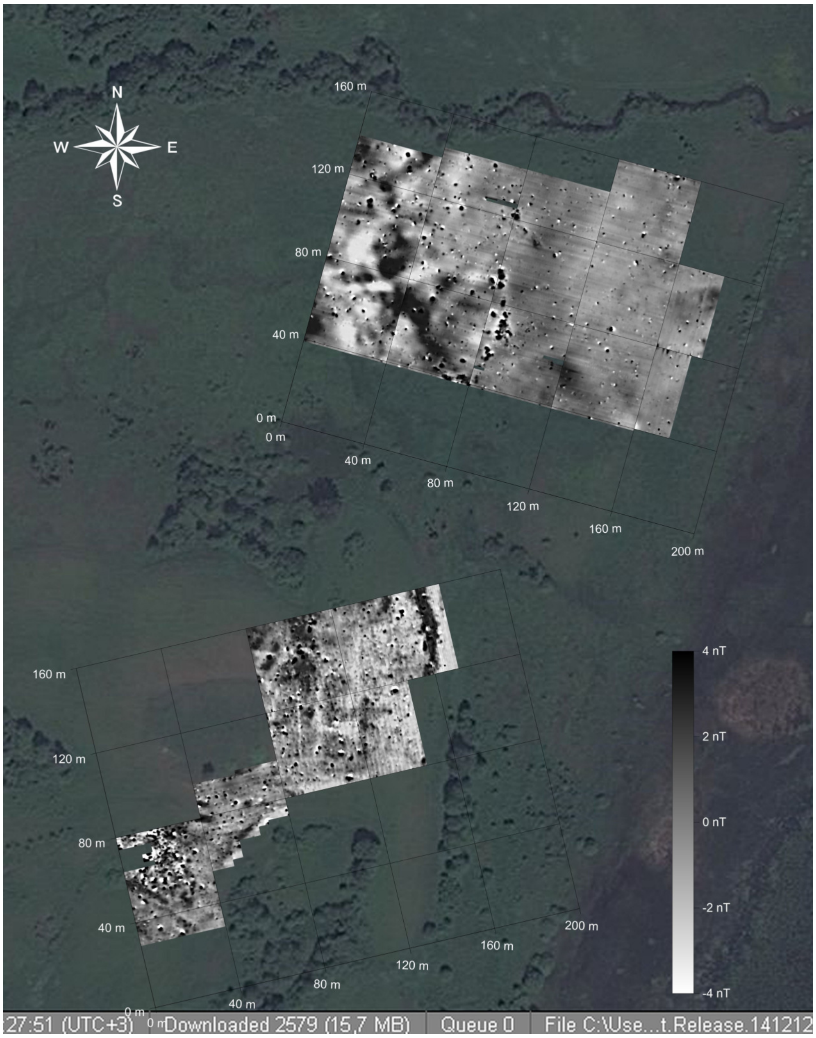

Figure 12: Dubokray. Satellite image overlaid by the magnetogram images from 2013 and 2016 of the site as a grey shade plot. Cesium-Smartmag SM4G-special-magnetometer, duo-sensor configuration, sensitivity ±10 pT, sampling interval 12,5 x 50 cm interpolated to 25 x25 cm in 40 m grid. Total field values were reduced to the mean value of a 40 m square and partly fused by a high-pass filter magnetogram, dynamics ±4 Nanotesla from black to white.

Points 2–4 are justified by the theoretical background of applied geophysics and the knowledge of rock magnetism and supplementary susceptibility measurements (Dunlop and Özdemir 1997; Fassbinder 2015; Jordanova 2017).

The outer conditions at the site were particularly difficult due to small bushes, water ponds, and swampy grassland, but no other limitations. We staked out a 40 x 40 m grid in a north-south orientation and measured the location of the stakes separately by GPS. We marked the direction of profiles by plastic ropes at a distance of 2 m to guarantee an exact sampling density of 12.5 x 50 cm (Figure 10).

Results of Magnetometer Prospection at Dubokray I

The northern part of the survey area forms a swamped area, partly covered by water of Lake Sennitsa. In the summer, large parts of the area are inaccessible due to the high reeds and grass. The southern area is slightly elevated, and it has probably never been covered by water in the last 8,000 years (see Figure 12). Here, on uneven terrain, we found traces

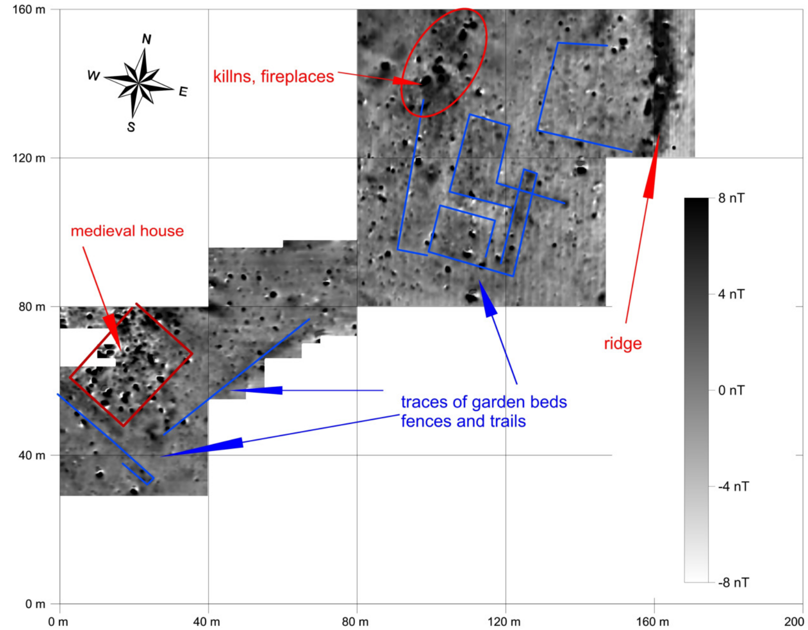

Figure 13: Dubokray. Magnetogram image from the southern part of the site as a grey shade plot. Cesium-Smartmag SM4G-special-magnetometer, duo-sensor configuration, sensitivity ±10 pT, sampling interval 12,5 x 50 cm interpolated to 25 x 25 cm in 40 m grid, total Earth's magnetic field in Dubokray: 51 860 ±20 Nanotesla (Mai 2016). To highlight the features, we overlaid total magnetic field data by a high-pass-filter image (a). Magnetometer image with interpretation (b).

of an old farmstead and the ruins of a monastery from the medieval period. Parts of the area seemed to serve as gardens or fields of vegetables. Therefore, the two areas strongly differ with respect to their geochemical conditions and their soil magnetic properties.

The magnetometer data of the southern area was visualised as a grey shade plot in 256 greyscales with dynamics of ± 1–4 nT from white to black (Figure 13). The measurements revealed features mostly from the medieval period. We detected a rectangular area that is very probably the remains of a house. Moreover, there are rectangular aligned traces of palisades or wooden fences that enclose areas of highly magnetic soil, which could be the remains of garden beds and small plots of land subdivided by trails. The beds are visible by a slightly darker anomaly, while the trails show up as white traces.

Besides these linear and rectangular features that very probably belong to the medieval period, we traced a multitude of pits and postholes, as well as fireplaces or kilns that cannot easily be dated by our magnetometer survey. However, on the surface, we also found pottery fragments from the Neolithic period, indicating that at least some of the pits and undefined features could be traces from a Neolithic settlement.

The northern area of the survey site is situated on low-moor soil. The anomalies that we traced on this swampy area considerably differ from those in the southern part not only by their intensity (Figure 14). Nevertheless, we are able to suggest a comprehensive interpretation of the place. The site is dominated by ancient water channels and paleo channels meandering through the survey area. In between the paleo channels (slightly white), we see zones of magnetic enrichments (in the magnetogram image, they appear dark/grey) and highly magnetic features that could be hearths, fireplaces, or the ground floors of Neolithic houses. Some of these anomalies form a group (inside the ellipse), while others are found more erratically in the western part of the area (Figure 14, Figure 15). The whole area shows traces of single posts, some of them ar-

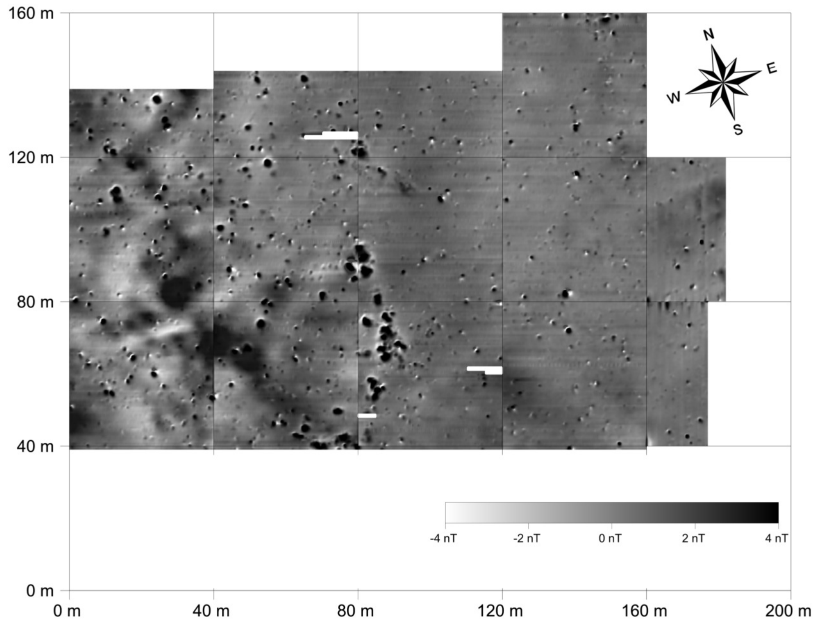

Figure 14: Dubokray. Magnetogram image from the northern part of the site as a grey shade plot. Cesium-Smartmag SM4G-special-magnetometer, duo-sensor configuration, sensitivity ±10 pT, sampling interval 12.5 x 50 cm interpolated to 25 x 25 cm in 40 m grid total Earth's magnetic field in Dubokray: 51 730 ±10 Nanotesla (Mai 2013). To highlight the features, we overlaid total magnetic field data by a high-pass-filter image (a).

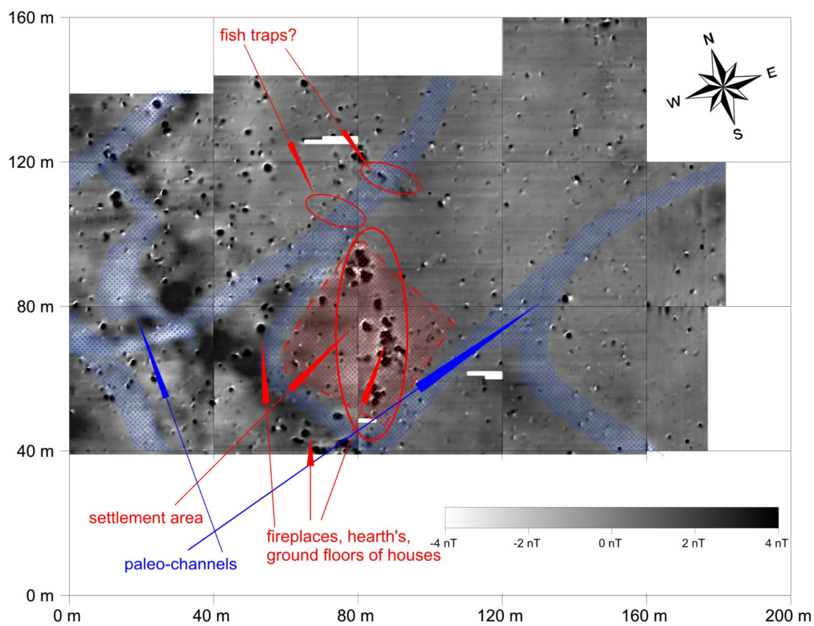

Figure 15: Magnetometer image with interpretation.

ranged in a row of three or four posts. Some rows of posts are arranged inside the paleo-channel, indicating traces and remains of fish traps.

The interpretation that some areas are paleo channels due to the depletion of magnetic minerals while other areas are the fireplaces and ground floors of houses due to high-magnetic ashes, and the general enrichment of magnetic minerals around the ancient settlements is quite comprehensive and plausible. However, the occurrence of distinct positive magnetic anomalies of wooden posts adjacent to the low-moor soils requires further rechecking and verification by mineral magnetic measurements and soil samples (Fassbinder 2015; Fassbinder et al. 1990).

Figure 16: Side sonar processing.

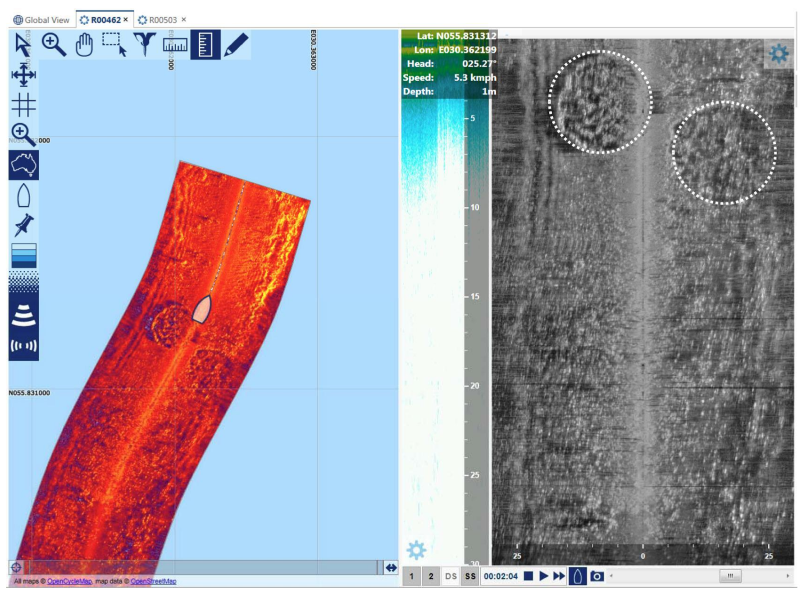

Figure 17: Sonar survey. Stone structures with echo quality and water depth. Red colour indicates a hard lake bottom with good echoes and diminished water depth.

Sonar prospection

Supplemental archaeological underwater survey investigations of the bottom of modern Lake Sennitsa were conducted (Figure 16). Three sites in the littoral fringe were investigated by dense side scan sonar tracking with varying frequencies. The Hummingbird 1198 SI Combo sonar device using down- and side-beam frequencies of 83/200 kHz was used. The sonar mapping revealed details in the lake bottom morphology, which was recently enveloped by soft sediments. It also revealed a range of different anomalies, interpreted to be the remains of different wooden and stone constructions (Figure 17, Figure 18, Figure 19). The length of the shadow indicated a >0.4 m elevated structure with ~12 m diameter. The structure was very sharply defined by a hard and plateau-like surface with

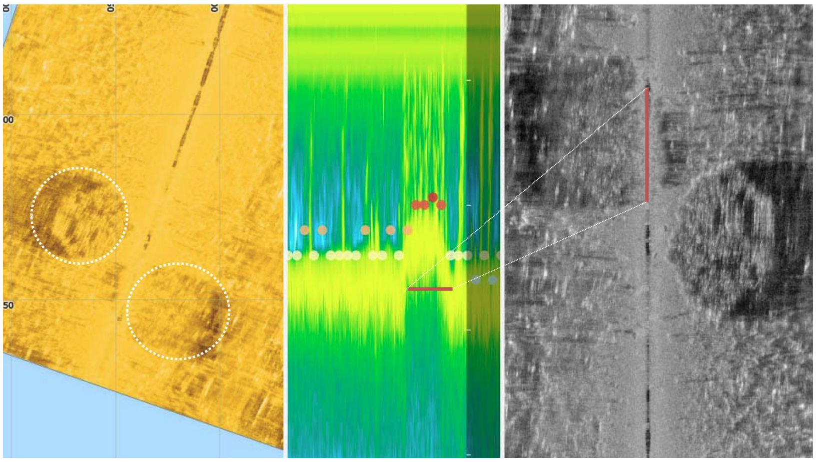

Figure 18: Sonar survey. Stone structures with echo quality and water depth.

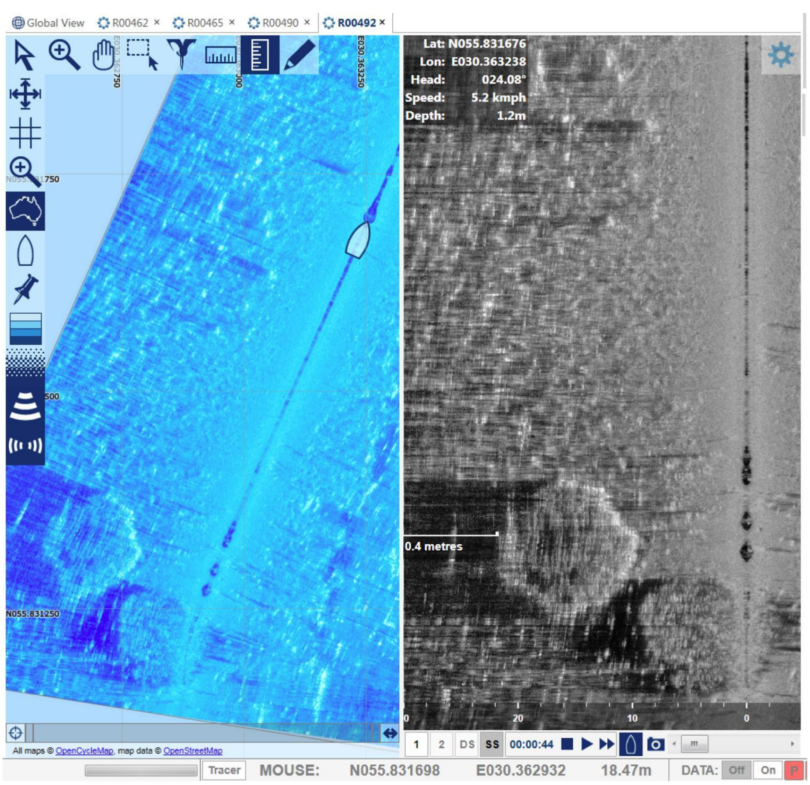

Figure 19: Sonar survey. Stone structures with echo quality and water depth. The length of the shadow indicates a >0.4 m elevated structure with approximately 12 m diameter.

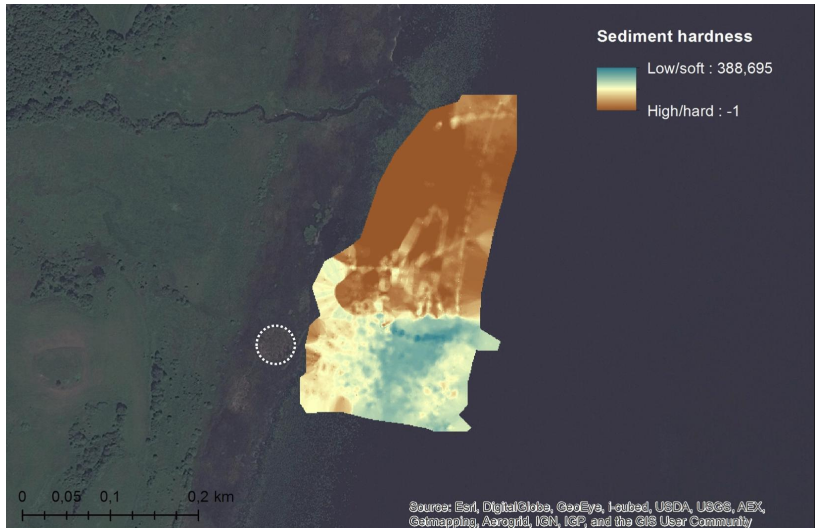

Figure 20: Sediment hardness in a littoral zone.

a ring wall. Further underwater surveys conducted here confirmed this interpretation.

The littoral zone can be divided into a northern hard bottom part and a southern muddy part (Figure 20). The location of the former river bed or anthropogenic structure (ditch?) can be suggested. Some possible circular structures 11–20 m diameter can be seen on the modern muddy shore of the river.

Georadar prospection

A ground-penetrating radar (GPR) survey was conducted in the water area and the shore of Lake Sennitsa (Figure 21). The 'OKO-2' GPR with an antenna with a centre frequency of 150 MHz (LOGIS-GEOTECH company)

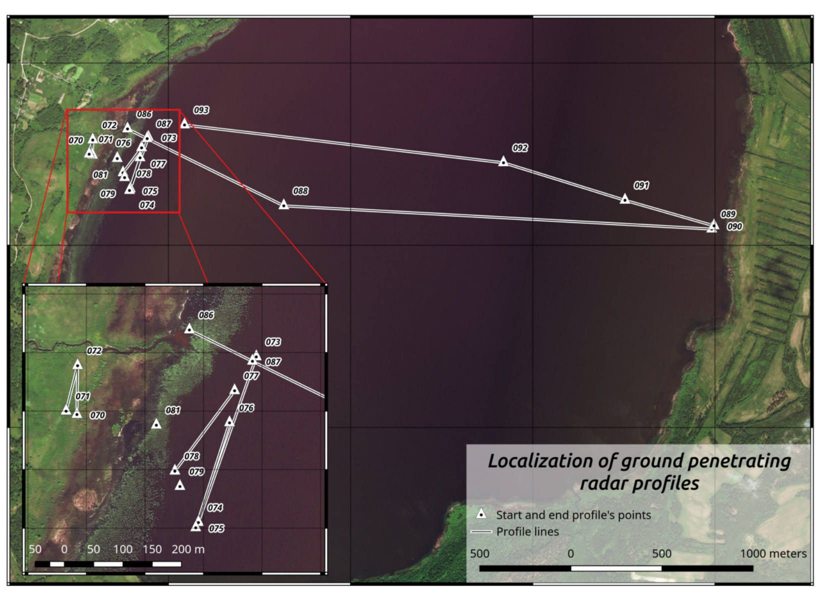

Figure 21: Localisation of GPR profiles. Picture made by E. Kazakov.

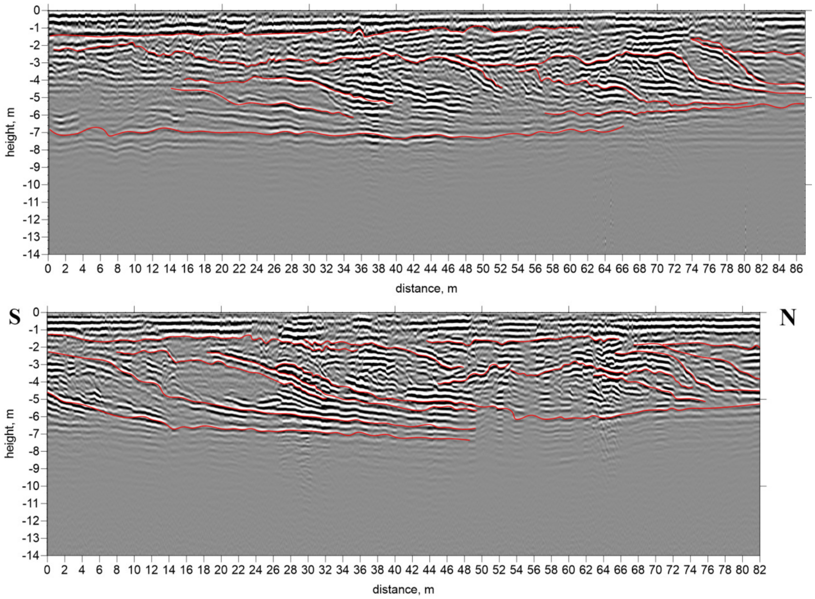

Figure 22: Radargrams from Lake Sennitsa, from point 070 to 072 (upper) and from point 071 to 072 (lower).

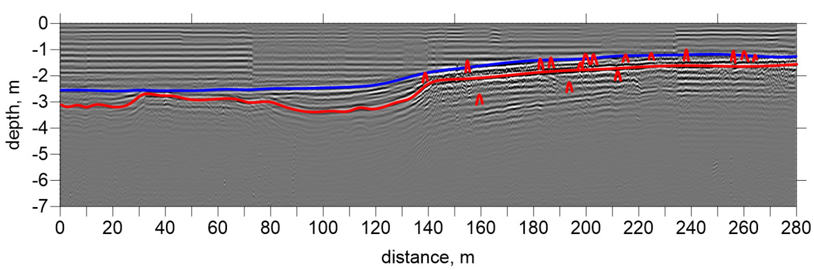

Figure 23: Radargram from Lake Sennitsa, from point 081 to 082.

was used. This GPR survey on the shore of the lake showed a series of clinoforms on the radargrams, which might to be alluvial origin (Figure 22). Their orientation indicates the general direction of the flow from south to north, although it might have also been in the west to east direction. The thickness of the river deposits is up to 6 m. The composition is predominantly sandy with interlayers of silty-clay material. For more accurate determination, drilling data should be obtained. On the lake surface, the GPR survey was conducted using a boat. Near the shore, in the area where the largest number of finds were discovered as a result of underwater archaeological work, six profiles from 170 to 310 m long were laid. Due to the problems with the GPS receiver, not all of them are precisely tied to the terrain, and only three profiles are rendered on the map (Figure 21, Figure 23). The data obtained were largely noisy, whereby the boundary of the bottom of the lake (shown in blue) and the bottom of the upper layer of bottom sediments (shown in red) are distinguished. On all radargrams in the area near the coast, there are many hyperbolas that indicate the presence of local diffracting objects. The antenna gives a resolution of objects to 0.35 m, whereby it is not possible to detect smaller piles. However, it might be groups of them, or other objects. In Figure 24, detected objects on the profiles are shown with red dots.

Two GPR profiles were also laid across the lake in the west to east direction (Figure 21). Hyperbolas were only observed on the western shore of the lake, in the same area where they were found on the rest of the profiles, while in the central and eastern parts of the lake there were none.

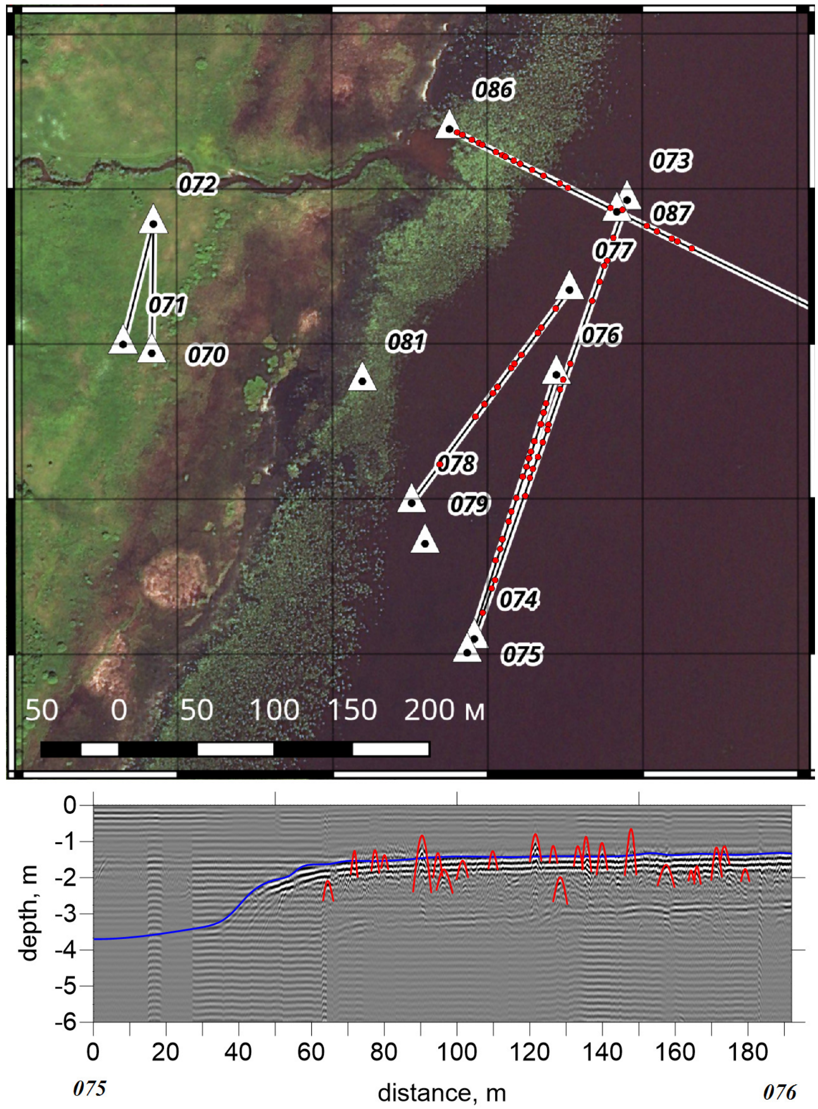

Figure 24: Detected objects at the bottom of the lake (red dots on the map) and radargram from point 075 to 076.

Conclusion

A variety of lacustrine sites from Mesolithic to Middle Ages were found on the bottom and shore of Lake Sennitsa. They were located along the shorelines of small lake basins and rivers distributed on the recent lake bottom. Neolithic sites comprise the first settlements of LBK communities in this region, comprising prehistoric pile dwellings, and the eastern-most megalithic construction of the 3rd millennium BC known in Europe thus far.

During the last twenty years, the cultural layer on the bottom of the lake has been either destroyed due to lake-level drawdown or buried under modern lake sediments. In order to find further traces of archaeological constructions and cultural layers, a range of remote sensing and geophysical methods — both underwater and on the peat-bog shore — were applied and the first results were gained. These prospections allowed reconstructing detailed paleorelief maps, the precise distribution of ancient stones and wooden constructions on the sites, and offered suggestions of places for further excavations. Moreover, this provided a comprehensive approach to the site. Aerial surveys show clear traces of roundish objects, which were also traced by sonar prospections of the littoral part of the lake. Some of them might represent stone platforms up to 15–22 m in diameter. Mapping revealed details in lake bottom morphology — which was recently enveloped by soft sediments — and revealed a range of different anomalies, interpreted to be the remains of different wooden and stone constructions. This was confirmed by underwater archaeological prospections showing the accumulations of stones and the concentration on these exact places of vegetation, which might be the marker of organic-rich areas located here. For the first time, a new type of previously-unrevealed stone construction was found, round stone platforms, most probably attributed to Neolithic times.

Magnetic prospections made on a shore muddy area of the Dubokray I site revealed a series of ancient water channels and paleo channels meandering through the survey area. In between the paleo channels, some features can be identified and interpreted as hearths, fireplaces or ground floors of Neolithic houses. The whole area shows traces of single posts or rows of posts. Previous excavations had already revealed remains of pile dwellings, including pottery, wooden ski and other artefacts, and remains of destroyed constructions found in the trenches made on a peat-bog shore part.

These results show strong potential for future investigations on these sites including its underwater and shore parts.

Acknowledgements

Archaeological research was supported by grant of Russian Science Foundation (project ‘Lacustrine sites of the 4th-3rd mill BC - the origins and development of pile-dwelling settlements phenomenon in NW Russia’ №19-78-00009).

References

Aspinall, A., C. Gaffney, and A. Schmidt (2008). *Magnetometry for Archaeologists*. Lanham, Maryland: Altamira Press.

Dunlop, D. and Ö. Özdemir (1997). *Rock Magnetism: Fundamentals and Frontiers*. Cambridge: Cambridge University Press.

Fassbinder, J. (2015). ‘Seeing beneath the farmland, steppe and desert soil: Magnetic prospecting and soil magnetism’. In: *Journal of Archaeological Science* 56, pp. 85–95.

– (2017). ‘Magnetometry for Archaeology’. In: *Encyclopedia of Geoarchaeology*. Ed. by A. Gilbert. Dordrecht: Springer Reference, pp. 499–514.

Fassbinder, J., H. Stanjek, and H. Vali (1990). ‘Occurrence of magnetic bacteria in soil’. In: *Nature* 343.6254, pp. 161–163.

Jordanova, N. (2017). *Soil Magnetism. Applications in Pedology, Environmental Science and Agriculture*. Boston: Elsevier/Academic Press.

Mazurkevich, A. and E. Dolbunova (2011). ‘Underwater Investigations in Northwest Russia: lacustrine archaeology of Neolithic pile dwellings’. In: *Submerged Prehistory*. Ed. by J. Benjamin, C. Bonsall, C. Pickard, and A. Fischer. Oxford: Oxbow Books, pp. 158–172.

Miklyaev, A. (1982). ‘O razvedkah svajnyh poselenij III–II tysjacheletija do n.je. v Pskovskoj i Smolenskoj oblastjah’. In: *Drevnie pamjatniki kulâtury na territorii SSSR* 1982, pp. 6–29.

– (1990). ‘Podvodnye arheologicheskie issledovanija ozera Sennica v 1982–1987 gg’. In: *Soobschenija Gosudarstvennogo Jermitazha* 54, pp. 17–21.

Scollar, I., A. Tabbagh, A. Hesse, and I. Herzog (1990). *Archaeological Prospecting and Remote Sensing*. Cambridge: Cambridge University Press.