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The effectiveness of ground-penetrating radar surveys on the territory of Kyiv-Pechersk Lavra

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SUMMARY

Based on the analysis of previous archaeological excavations, GPR data obtained in past years and recent measurements in Metropolitan Garden, relevant applications for the method of ground-penetrating radar in Kyiv-Pechersk Lavra were outlined.



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Introduction

There were a number of ground-penetrating radar investigations being conducted on the territory of Kyiv-Pechersk Lavra for the past 25 years, but reliable results on efficiency of the method for this time, were not received. In particular, georadar measurements were performed in 1998 during the geological research of the area near the Assumption Cathedral (*Borisov et al., 1998*), in 2011, during the archaeological research of the Trinity Gate Church (*Balakin and Tkachenko, 2012*), as well as in 2015, when the whole territory of Metropolitan Garden was covered with measurements (*Taranenko and Kadun, 2016*). The results of the first two studies were not verified for technical reasons, and the results of the third did not receive archaeological confirmation.

The described situation caused a need for careful testing of ground penetrating radar (GPR) technology on a small area in the Metropolitan Garden, containing the material remains of the past at different depths and archaeologically well investigated.

Study area

Known from written sources, at least since the middle of the XVII century, the Metropolitan Garden occupies 0.9 ha at the Upper Lavra. Archaeological study of this area began in the middle of the last century and, with some breaks, continues to this day. During this time, a number of archeological monuments of different types and chronologies have been discovered and fully or partially excavated. The presence of four main cultural and chronological horizons has been proved, namely, monuments of the Early Iron Age (VI-V centuries BC), the period of Kyiv Rus (XI-XIII centuries), Russo-Lithuanian period (XIV-XVI centuries), Modern time. Thanks to archeological research, the primary relief of the territory was reconstructed and archaeologists were able to identify two periods of natural and anthropogenic development of this location.

Early Iron Age materials, which in the form of redeposited ceramic finds sporadically occur throughout the Upper Lavra, are represented here as well-preserved archaeological object - ground burial of Pidhirtsi archaeological culture of the V century BC.

During the Kyiv Rus period, the territory was part of the economic activity of the Pechersk Monastery, first as a temporary construction site, and later - as part of the Upper Lavra. However, it is problematic to unambiguously determine the status and function of this area in the XII-XIII centuries.

In the Russo-Lithuanian period there was a fairly large settlement with stationary housing and outbuildings and pronounced signs of craft specialization.

Cultural layer of the Modern time is represented with and small objects related to activities in the garden.

In the period of 2016-2021 regular stationary archeological researches were carried out under the direction of S. Taranenko. The research was aimed on various tasks such as searching for a cemetery of the Early Iron Age and re-excavations of a glass-making workshop of XI century and the walls of the Pechersk Monastery of the XII century. The complexes of the XVII-XIX centuries were studied additionally.

Two glass-smalt production furnaces of the XI century, consisting of plinths, clay and slate slabs were found in 1951 the Metropolitan Garden by V. Bogusevych. In 2021 (excavations by S. Taranenko) the remains of one furnace were unearthed. Probably, during the operation of the glass complex in the second half of the XII century. a stone-brick monastery wall was constructed and this territory became a part of Pechersk monastery. The first archeological discovery of the monastery walls occurred in 1951



by Yu. Aseev and V. Bogusevich. In 2018 archaeological research was conducted to verify the findings of 1951. In five of the six trenches (trenches 2-6 on Fig. 1) the foundations of different degree of preservation and half-destroyed fragments of the wall were unearthed (Taranenko and Kabanets, 2019).

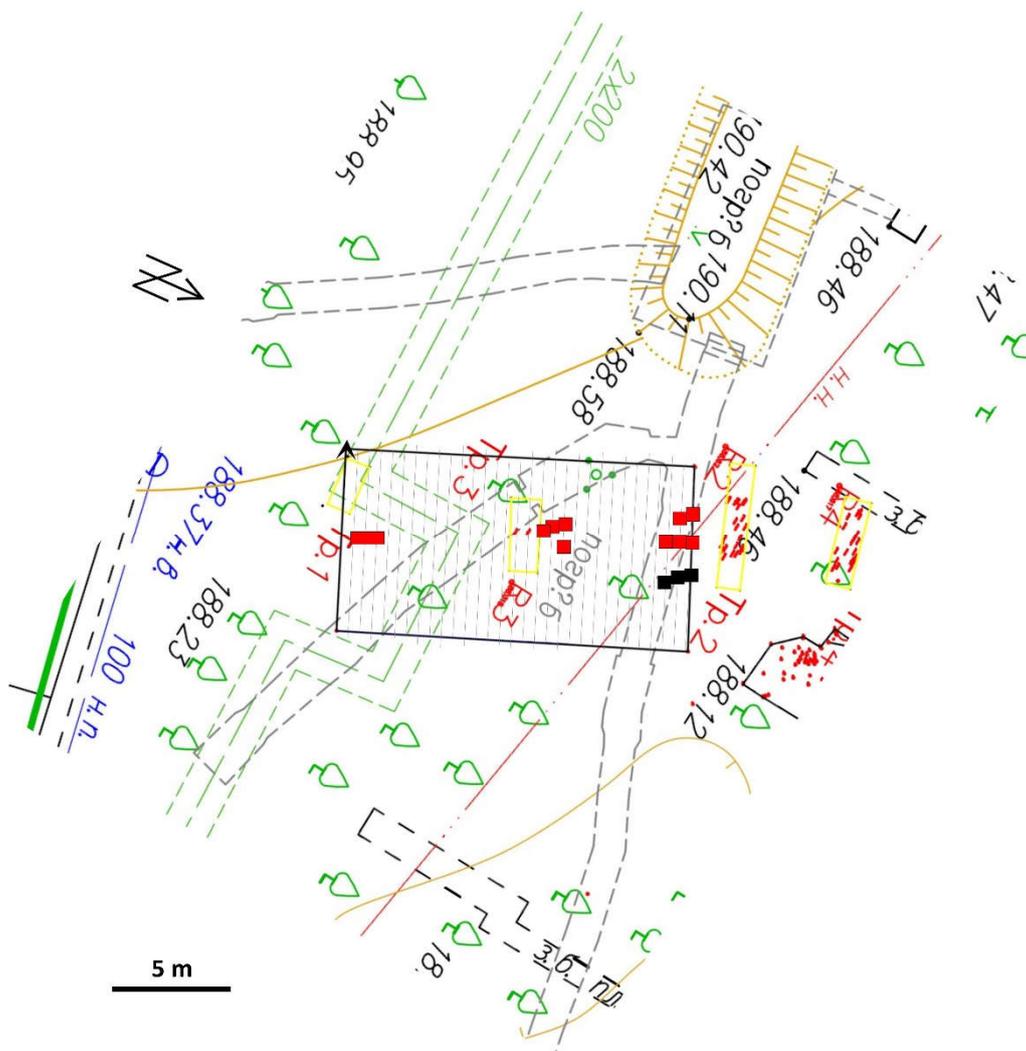


Figure 2 Map of measuring area in the Metropolitan Garden of Kyiv-Pechersk Lavra. Remains of stone-brick wall of XII century interpreted from GPR data are marked with red squares. Remains of the furnace of XI century are marked with black squares.

Method

Measurements were performed within a rectangular test site with dimensions of 15x8 m, located on the continuation of the previously excavated wall of the XII century. (Fig. 1).

The GPR prospecting was carried out with a VIY-3-300 (Transient technologies LLC, Ukraine) instrument with 300 MHz antenna. Data were acquired in continuous mode along 0.5-m spaced survey lines, using 500 samples per trace, 240 ns time range and constant sampling interval of 32mm along the inline direction. The data were subsequently processed using standard two-dimensional processing techniques by means of the Synchro3 software (Ivashchuk et al., 2021). The processing flow-chart consists of the following steps: (I) zero level setting -to determine the depth correctly, it is necessary to



match the beginning of the depth scale with a certain point of the direct pulse (e.g. maximum amplitude); (II) wavelet filtering in order to suppress effectively low-frequency fluctuations and high-frequency noise; (II) the windowed background removal tool subtracts an averaged trace from each trace of the profile, with the width of the window for averaging specified by the total number of traces; (III) manual gain, to adjust the acquisition gain function and enhance the visibility of deeper anomalies. By means of the Planner software, the radargrams were subsequently merged together into three-dimensional volumes and visualized in various ways in order to enhance the spatial correlations of anomalies of interest. The average electromagnetic wave velocity was estimated as 90 m/ μ s using hyperbola method (Conyers, 2017).

Results and discussion

Greyzem soil formed on loess loam covers the study area (Bortnyk *et al.*, 2017), ie soil contains > 20% of physical clay. As is known, the georadar method has significant limitations for use on clay soils. Clays cause signal loss due to electromagnetic wave attenuation. Soil with clay content of more than 35% effectively adsorbs electromagnetic waves and the penetration depth of the georadar becomes very low (Daniels, 2004).

In the study area, the informative reflections are observed in the depth range down to 2 m. So, one can't expect to detect any objects below this level. The radar images show reflections both from point targets (individual boulders and fragments of construction) and surfaces of different geometry (Fig. 1).

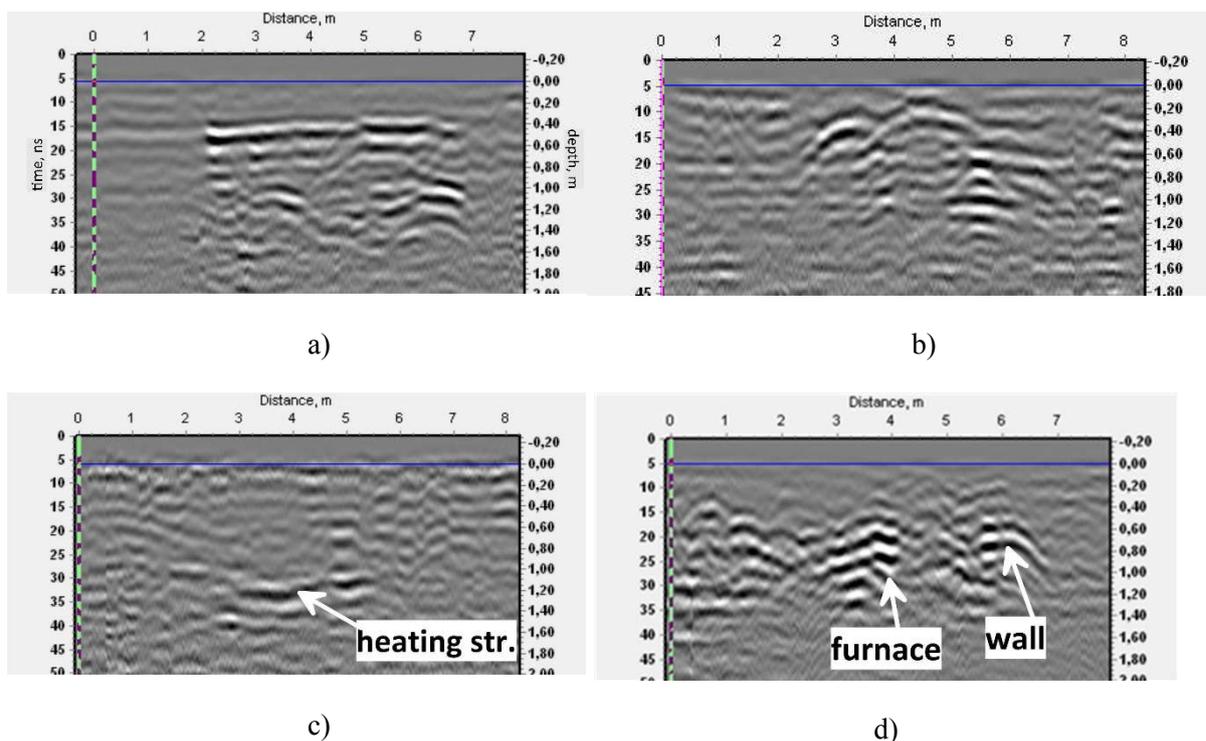


Figure 2 Selected radargrams, obtained in Metropolitan Garden of Kyiv-Pechersk Lavra: a) anomaly from old excavation, conserved with plastic panels; b) hyperbolas from individual boulders; c) heating supply structure; d) remains of a furnace of XI century and fortress wall of XII century.

After comparing location of known archaeological objects against the revealed georadar anomalies we can conclude that the remains of the fortress wall of XII century are confidently registered (Fig. 1). They are defined as zones of enhanced amplitude of EM signal at the depth of approx. 0.5 m (Fig. 2,



d). An anomaly nearby, namely, marks the remains of the furnace of XI century. The wall was partly destroyed during the construction of heating supply system, which was also detected on radargrams as a reflective surface (Fig. 1, c).

It must be noted, that within the measured area at a depth of 4 m is located an underground structure of the XIX century (Fig. 1), which was not detect due to the high attenuation of electromagnetic wave in the loess loam.

Conclusions

Relevant applications for the method of GPR utilizing 300 MHz georadar in Kyiv-Pechersk Lavra comprise searching for massive archaeological objects at the depth interval of 0-2m, as well as shallow buried communications.

Acknowledgements

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