TITLE: **Identification of historical anthropogenic layers using geophysical methods supplemented by geochemical analyses**

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ABSTRACT:

Geophysical methods allow for a comprehensive study of subsurface areas useful for the geological and engineering characterization of the ground, environmental monitoring, and the detection of anthropogenic objects. The fastest, easy to implement and not having large requirements for area of implementation, and commonly used are Ground Penetrating Radar method (GPR) and Electrical Resistivity Tomography (ERT). They play an important role in coordinating archaeological works by locating and identifying the remains of subsurface objects, especially architectural, archaeological and geological. These methods are characterized by high precision of resulting mapping of the measured center and the possibility of implementing them in the 2D and 3D geometry. In the present study two areas in the southern Poland were chosen for examination – the historic district of Old Town in Krakow and the manor in Nowe Sioło. Krakow, as the important metropolis of central Europe, lying on the historical communication routes intensively developed in Medieval period. The major determinant of that process was growth of trade and crafts, and with that a significant demand for water. For these reasons, the city developed and used complex network of watercourses, mills and sewage canals, which structure and localization still has not been sufficiently recognized. The presence in the subsurface of historic water collectors and sewage canals both natural and man-made, not only threatens the existing historic buildings, but also contributes to the migration of contaminants from ground and water. The manor in Nowe Sioło is another example of human related pressure associated with a transformation of the land surface. Built as a residential building its function was changing over time. It was utilized as a hospital, a farm and a school, and yet it managed to retain a layout with a moat typical for a defense residence. This fact made it possible to treat Nowe Sioło as a testing ground for comparative study of moat detection capabilities for highly urbanized Krakow area. In this way, the possibility of using geophysical and geochemical methods to detect residues of watercourses under weaker anthropopression both historical and contemporary was verified. As a complement to geophysical measurements, thin diameter semi-invasive method of imaging the surface of the substrate lithology, by a borehole drilling was used. Afterward, the geochemical analyzes of the physico-chemical

properties of ground samples were conducted, including studies of concentrations of metals. On this basis, one can identify the presence of deposits related to the functioning of historical moats and mill canals.

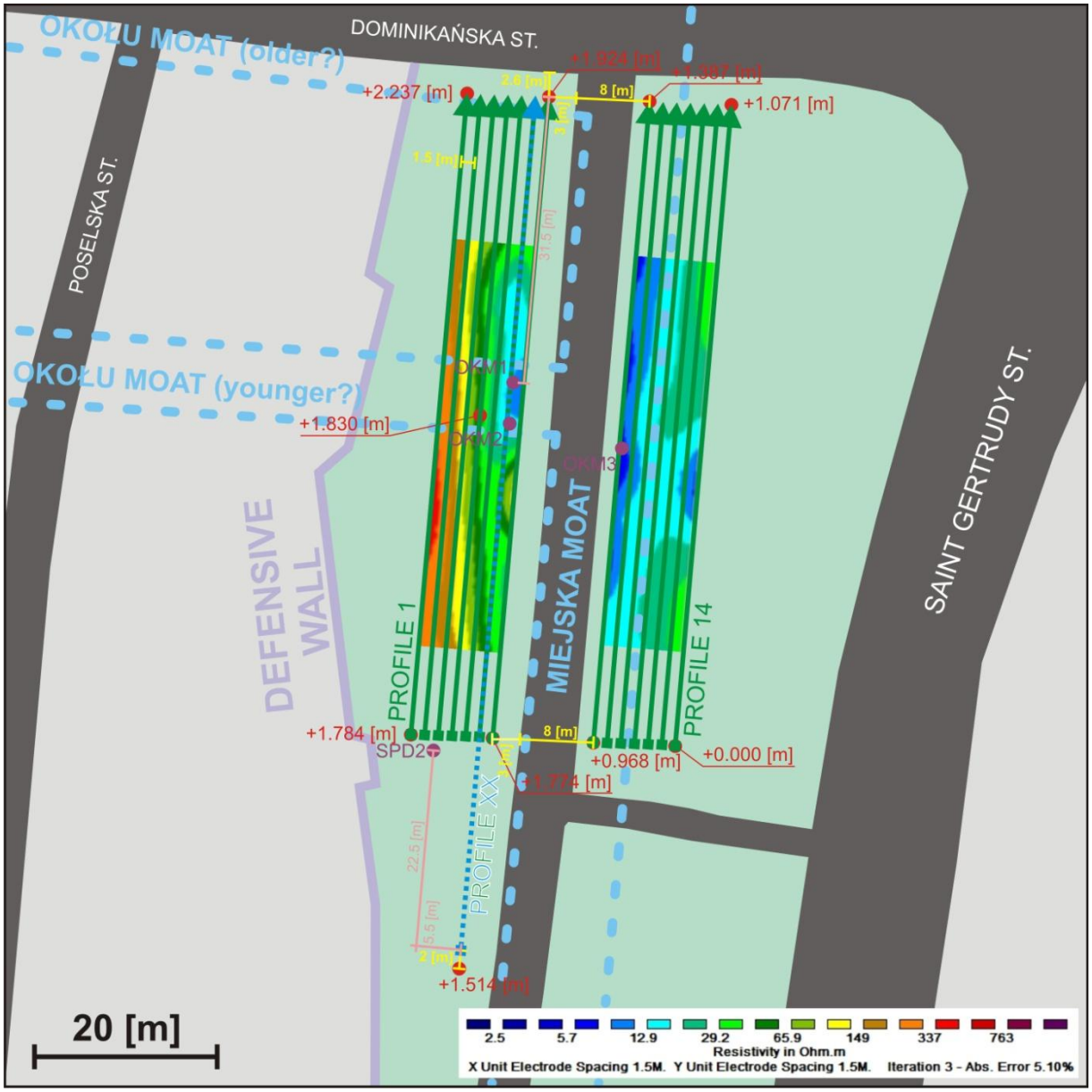
Within the Planty Park in Krakow, the reconnaissance measurements using GPR in 2010-2011 showed large wave attenuation in the highly conductive center, which are earth-and-rubble acumulations and moats sediments, gave results with poor depth range and with more noise on geophysical image. This was probably due to the technical infrastructure and the presence of numerous stratums and irregular interbeds in the form of water sediments, which was associated with the surface water migration as a consequence of historical floods and current flooding. For these reasons, in the region of Krakow for the study of the historical moats, ERT measurements were included. It was even though, that this geophysical method has a larger requirements for its implementation area. Once these conditions are met, it is possible to detect zones with saturated sediments or loosened structures, to recognize the geological medium type, or to detect of buried watercourses (Appendix 1). In Nowe Sioło one used only measurements using GPR, which gave very good results. In both cases it was possible to determine the course of water canals, which is the main objective of this work. By using minimally invasive boreholes and geochemical analysis made on acquired samples, one obtained the necessary supplementary data for surface measurements. In this way, one also was able to verify the results of geophysical surveys and determine the location and course of the fragments of buried historical watercourses. Thus, one could say that despite some inaccuracies and ambiguities of geophysical images, with help of data from boreholes it was possible to identified prospective place to carry out geoarchaeological research. Macroscopic recognition of various historical layers made it possible to determine the type and lithology of sediments building surveyed area. On the other hand, measurements of basic physico-chemical indicators (*pH, Eh potential, PEW conductivity*) and the designation of metal concentrations allowed to assess the degree of transformation of the environment from the perspective of today with use of the existing norms. In the geochemical analysis of ground samples, one also carried out unusual in this application measurements of magnetic susceptibility. This measurement is one of the geophysical methods, and is often used to study the environmental pollution in urban areas. Metal concentration was measured for elements associated with the production of everyday objects e.g. mirrors, cutlery etc. (*Cu, Pb and Fe*) used in historical cities such as Krakow during the Middle Ages, in the Nowe Sioło measurements included also Zn. The aim of that, was to check whether there is migration of anthropogenic pollution produced today to the subsurface layers. Measurement included also Ni, which along with Fe may affect the value of the magnetic susceptibility.

On the basis of carried out measurements and interdisciplinary analysis it can be concluded that the identification and designation of a place for geoarchaeological study in areas less transformed by human, the GPR method is sufficient. On the other hand, under conditions of strong human pressure very good results are obtained by ERT measurements. Structures reassembling the shape of moat on GPR images are reflection of the old watercourses canals. On the ERT, location of watercourses appears through low-resistance anomalies "climbing" in the high-resistivity layers. When both methods bring on the studied areas a positive result, geophysical images complement each other and give more precise, though simplified view of lithology. In places designated to perform drilling, one can also demonstrate a correlation between the measured values of the magnetic susceptibility and the content of metals of anthropogenic origin in the ground samples. Thus, this method can provide a standard for the selection of samples for further geochemical research (Appendix 2). It should be emphasized the results obtained in areas less transformed by anthropogenic activity are clearer.

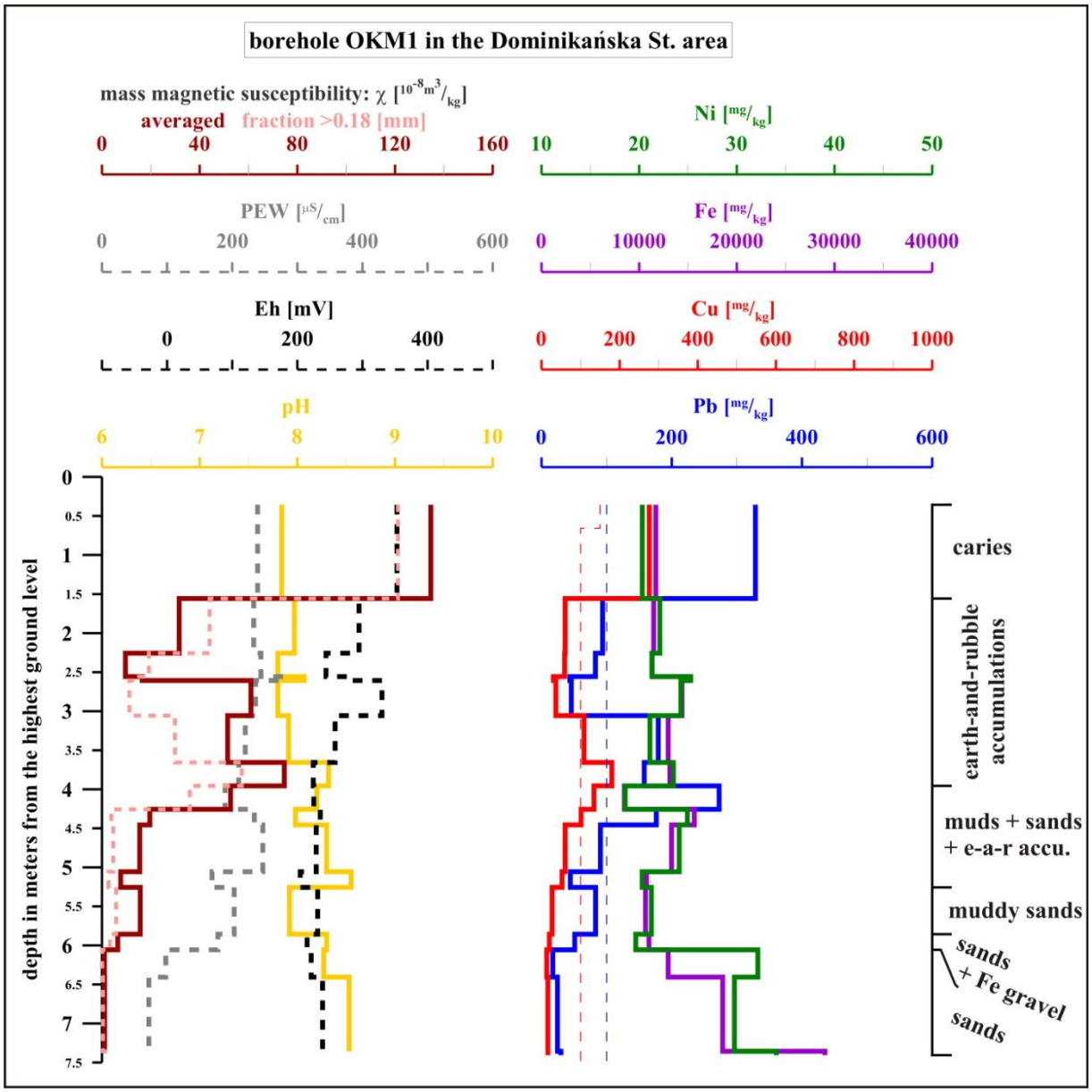
Visible similarities such us variability line of magnetic susceptibility and metal concentrations correlate well with the measured value of PEW conductivity. In Krakow, the most layers of medieval age above the virgin ground characterized in increased and growing with the depth content of lead and copper of anthropogenic origin. A clear decrease in their concentrations can be seen only in the virgin ground, which in Krakow within Planty Park are the sands. Nickel, and iron, as elements associated with the geogenic processes do not show this trend. In Krakow, one observed decrease in the Cu and Pb in samples when they are away from the main sewage canals. Visible changes in their concentrations, supported by the diversity of the physico-chemical indicators allow to identify the boundaries between earth-and-ruble accumulations and the saturated moats sediments.

In conclusion, one can say that the geophysical methods supplemented by geochemical analyzes constitute very good measurement tool. Therefore, an interdisciplinary approach to the geoarchaeological research is appropriate and effective. Only a comprehensive geophysical-geochemical-lithogenic analysis allows to recognize the historical anthropogenic layers including those contaminated with metals, and to indicate presence of utility strata.

APENDIXES:



Appendix 1. Map with ERT profiles in the area of Dominikańska St. with the geoelectrical depth-section image on 5.06-6.57 m with projected moat watercourses. Distribution of low-resistivity anomalies on the depth section allowed precise determination of the watercourses layout. On this image, the Okól moat (younger?) connected from west with the City moat running parallel to the profiles direction. Low-resistance values up to 20 Ωm indicate the presence of saturated clay sediments (resistance in the range of 1-100 Ωm) or sands with gravels (30-225 Ωm).



Appendix 2. Chart of physico-chemical properties and metal content in historical anthropogenic layers in borehole OKM1 in the area of Dominikańska St. Thin dashed lines on the chart mark the metal standard of quality by Dz.U.2002.165.1359 group B land. The values of metal content were compared to this standard allow to conclude that in anthropogenic layers they are exceeded. Visible on the graph is correlation between changes in the value of the magnetic susceptibility and PEW conductivity values, which illustrate characteristic increase in salinity with the depth and the appearance of watered sediments. Those changes also correlate with changes in metal content of anthropogenic origin. Physico-chemical indicators, pH and Eh, do not indicate a clear tendency determined by a specific factor, and therefore on theirs basis various lithological layers cannot be distinguished.