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ARCHEOGEOPHYSICAL APPLICATION OF NON-TRADITIONAL GEOELECTRIC ARRAYS. A CASE STUDY IN A NORTH-EAST HUNGARY SITE.

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Abstract
With the continuous development of multielectrode geoelectrical tomography (ERT) as a geophysical technique, we became able to detect small size targets. In this paper, we present ERT interpretation results obtained at an archaeological site in Szendrő village in northeastern Hungary, where a 17th century fortress once stood. Several historical notes and a collapsed entrance recall the existence of tunnels under the fortress and a water well of uncertain depth. To detect these structures, geoelectrical multielectrode measurements were carried out using conventional and quasi-null arrays. The quasi-null array applies the arrangement of the current (A and B) and potential electrodes (M and N) in a special way, i.e., the electrodes A, M, B, N follow each other in line in special distances from each other. The horizontal sensitivity of the resistivity profiling method using these types of arrays has been proven to be better than that of the Wenner or other conventional arrays. The comparative study aims not just to investigate the archeological features, but to test the sensitivity of the non-traditional quasi-null arrays to these two-dimensional inhomogeneities. As a result, the optimal array can be chosen, and the identification and delineation of shallow structures can be made more reliably. In this paper, we present the very first archeogeophysical field measurements carried out by the gamma quasi null array (γqnull).

1 Introduction

The scientific methods of underground exploration that preceded archaeological excavations were greatly changed by the widespread application of geophysical tools in the 20th century. Traditional geophysical exploration methods were limited and often did not provide any additional information about the target object. The first application of geophysics in archaeology dates to the early 1970s in Hungary, Professor Csókás [2] was a pioneer in this field. The reliability of the results has increased greatly over the last 40 years, both for measurements made before and during archaeological excavations [1]. Geophysical research offers the possibility of mapping the physical parameters of rocks in the depth range to be explored, using a system of sections at a chosen investigation depth (the resolution is inversely proportional to the investigation depth). By using the

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geoelectric measurement technology correctly, useful information can be obtained, and the electric resistivity images can be used to clearly show the shape and depth distribution of certain buried artificial objects [3], [11].

One of the most common applications among geophysical research methods is electrical resistivity tomography (ERT), a measurement specifically aimed at determining the electrical resistivity of soil and rocks. The method can be used also to detect walls, cavities and other structures in the shallow subsurface. Direct current (DC) resistivity measurement is the most widely used geoelectric method. With a measurement system installed on the surface of the earth, the measurement results in a visualization of the subsurface electrical resistivity distribution. Depth variations are detected by removing the current injection points, and the apparent resistivity variation in both horizontal and vertical direction is detected by measuring in the intended direction at points with appropriate step spacing. The application of the quasi-null arrays opened up a new direction of development of the geoelectric method. Quasi null arrays were derived from null arrays, which measure null potential difference above homogenous half-space [5]. The first null array was presented by [10]. One of their specific groups' review restarted recently [9]. Their non-linearity poses a problem in 2D investigations, although they proved to be successful also in field applications. The only linear geometrical null array, which can be built into 2D multielectrode systems, is the MAN array. The problem rises from its infinite electrode, a solution to this problem can be the application of the infinite electrode at a rather large distance from the other three electrodes. This way we get the quasi-null arrays, which have a very small homogenous half-space value of electric potential, close to zero. The further away the "infinite" electrode is from the other electrodes, the closer the configuration is to the null array situation [5]. Compiled this way, these quasi-null arrays are called γ_{11n} arrays, where γ refers to the AMBN order, (A and B being the current, M and N the potential electrodes), and the *11n* refers to the distance between the neighboring electrodes, (*1* is the unit distance). According to [6], the depth of detectability of the γ_{11n} arrays is greater than that of the traditional arrays. Numerical results obtained by [7] proved that the γ_{11n} arrays also have better horizontal and vertical resolution than even the best conventional arrays.

The chosen study area gives a perfect opportunity to study the behavior of these arrays in field situations. The mentioned cavities inside the fortress are expected to be mixed structures i.e. the builders took advantage of the natural caves under the hill the fortress is located on, and built artificial tunnels for more escape routes around the city. The bedrock being of carstic origin, therefore sudden and large resistivity changes are expected above cavities. Our strategy was based on historical maps, archeologist suggestions, and the clear evidence of walled and collapsed tunnel entrances. We intended to capture the image of the tunnels with seven sections, and one section was designed for the water well. The aim of this research is to prove the applicability in archeological surveying, and better horizontal sensitivity of the γ_{qnull} array than that of the traditional arrays. Furthermore, to delineate the geometry and position of the mentioned archeological structures for future excavations.

2 Methods

2.1 The quasi-null arrays

Null electrode arrays account for a quarter (25) of the known electrode arrangements [8]. For these electrode arrangements, the potential difference between the surface electrodes would return zero value when measured above a homogeneous isotropic half-space. Hence the geometric null arrangements, whose null position is provided by the geometry. Further dividing the arrangements into subgroups leads to the 2D geometric linear null arrays, including the γ_{qnull} we used for the measurement (Figure 1). The electrodes in this case are assigned in "AMBN" order. The γ_{qnull} pseudosection presented later in the paper is an apparent resistivity section, for technical reasons we could not invert their data. It doesn't mean the data cannot be used, as the pseudosection can contain useful information, which is lost during the inversion.

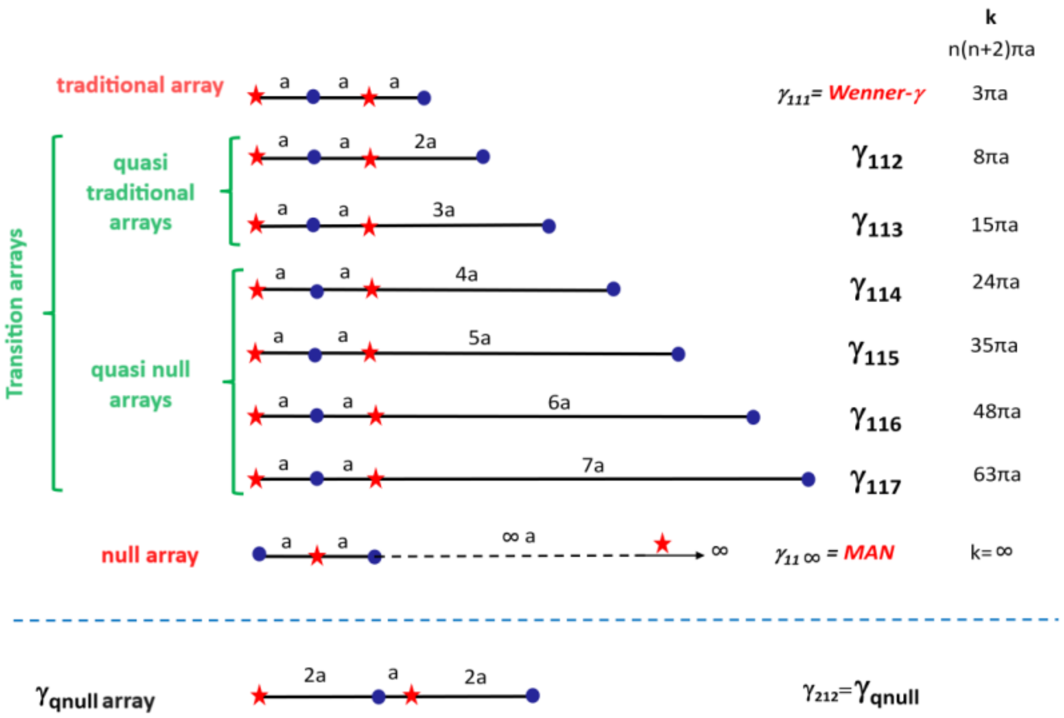

Figure 1. The γ11n and γ_{qnull} arrays. Asterisks mark current electrodes, and circles mark potential electrodes. Source: [4]

2.2 The study area and measurement parameters

The study area is an archeological site, where a 17th century fortress once stood, which had five bastions, a central tower, an inner and an outer courtyard. When designing the sections, our starting reference points were the walled tunnel entrances in the central towers' basement, and the collapsed entrance in the outer courtyard. The measurements' aim was to survey and find any remaining underground tunnels, caves, or dungeons. Designing the sections, we tried to cover the field between the central tower and the collapsed entrance (Figure 2) with SZK1, SZK2, SZK3, SZB1 and SZB2 sections respectively. The other sections, namely SZB3 and SZK4 were designed to find the other expected tunnel, leading to the north, just in the direction of the hole that remains of the former well. The long section, colored with brown, KUT25 was surveyed so that we can get geological information about its approximate depth of the formal well or water cistern. After we evaluated the results, the need arose to design another long section with greater investigation depth, namely SZK5, which was laid between SZK1 and SZK3, we will discuss the reasons later in another paper.

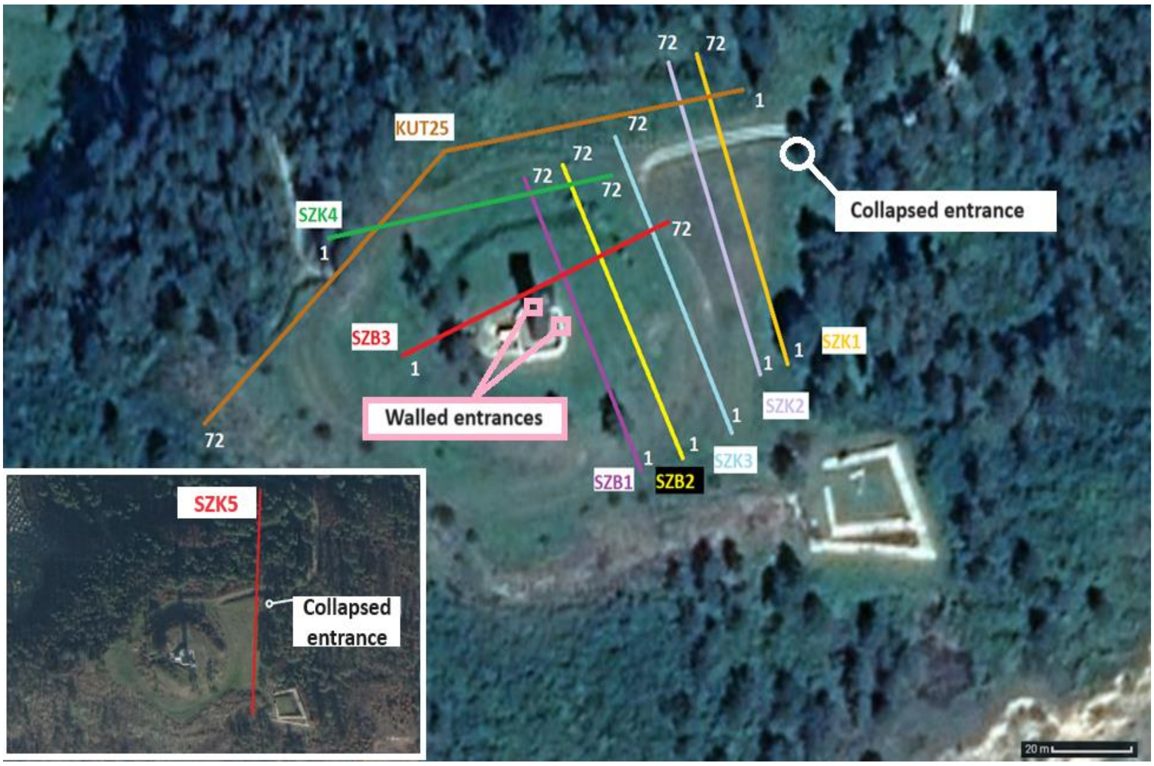

Figure 2. The study area with the sections, with SZK5 long section in the bottom left corner

3 Results and discussion

For the sake of short, but representative showcasing, we present the results of SZK5 for the north-east tunnel, and SZK4 for the north direction tunnel. As one can see on Figure 3, three different types of arrays are compared, between which, the Wenner-α and the Dipole-Dipole (later see DP) represent the traditional, and γ_{qnull} the non-traditional array. We chose the γ_{qnull} result image for comparison, because of its interesting sensitivity for the given artifacts. It should be noted that the investigation depth for each method is different, being the DP the shallowest, and another presentation problem is with the topography which distorts significantly when trying to fit the three images together.

Although it would not allow a precise comparison of the anomalies whereabouts, one can still clearly see the anomaly no.2 between meters 100 and 120 in depth of around 215 meters (the meters on Figure 3 are altitude above Baltic sea). The mentioned anomaly is considered to be the expected cavity or tunnel we were looking for, appearing just at the location under the collapsed entrance. Our theory is that, the collapsed entrance is not the original one, but a later dug hole, from which someone tried to reach the cavity. Between 60 and 100 profile meters, a large size anomaly declined in the middle (blue color) no. 5 appears unexpectedly on Figure 3c, which expresses the depression of the bedrock seen on Figure 5b. Next to it on the left, still on section (c) under meter 40, at 217 meter depth, appears a smaller, but still conductive anomaly no. 4, which can be a conductor expanding clay body, which we interpret knowing the surface excavations' soil material. Under section length 20 and 140 meters, remains of the fortress' walls can be seen clearly on anomalies no. 1 and 3, the γ_{qnull} proved to be very sensitive to those also. Because of the γ_{qnull} arrays are sensitive only to horizontal resistivity variations, they present only dots at their positions.

Regarding the traditional arrays, the Wenner-α was capable to only detect the wall at anomaly no.3 and less clearly anomaly no. 1. The remains of the walls still can be identified in the archeologic site. The DP array could detect both walls, but not with as clear contrast as on the γ_{qnull}. The main anomaly (no. 2) we were looking for under 100 and 120 meters at the depth of 215 meters marked with red color appears totally distorted on the traditional arrays' pictures. One would easily interpret it as part of the limestone bedrock, until the γ_{qnull} picture comes into consideration, which clearly shows that it is a standalone anomaly, likely the tunnel.

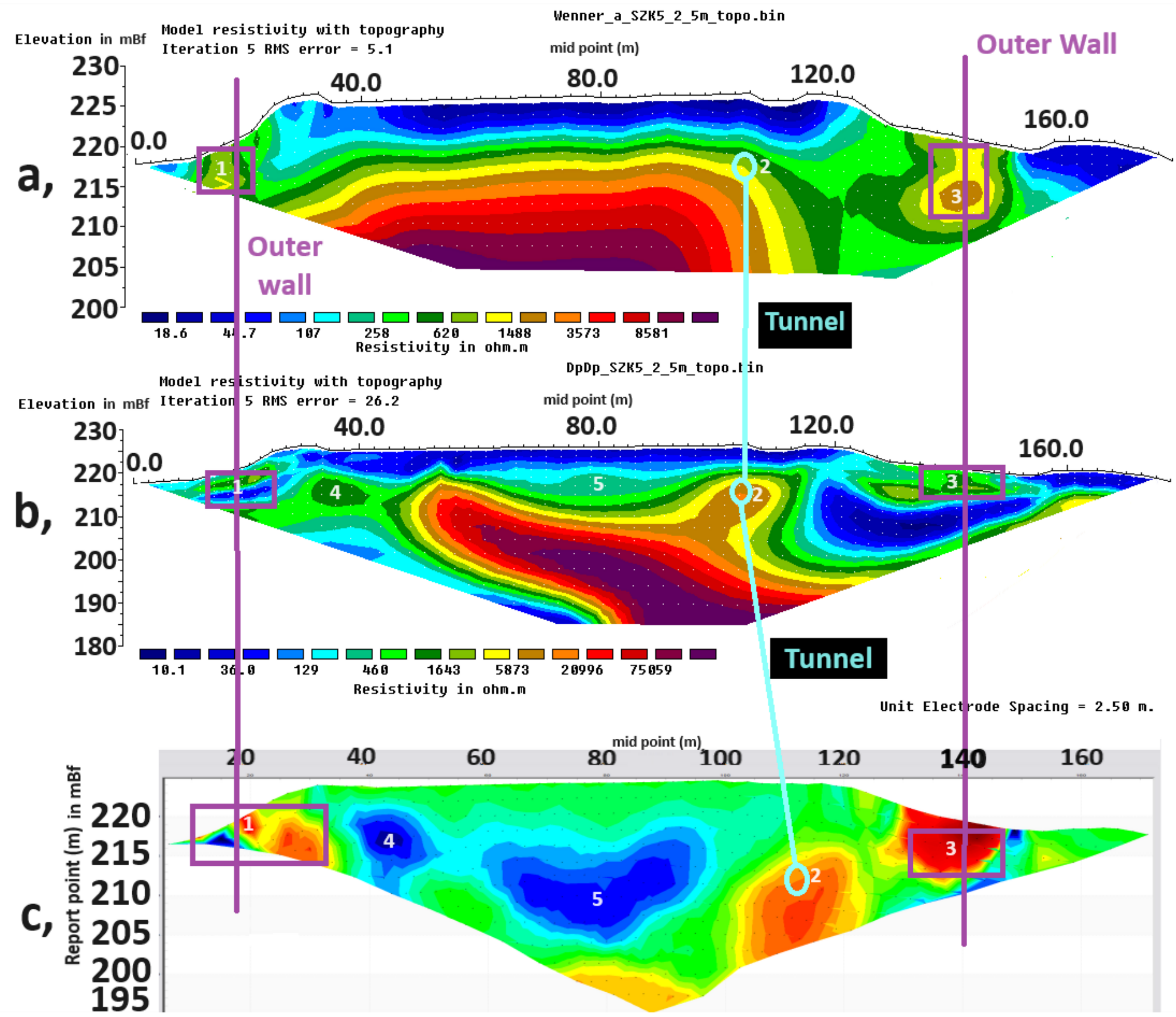

Figure 3. Resistivity sections of three different arrays on survey line SZK5. Array types from top to bottom: (a) Wenner-α, (b) DP, (c) γ_{qnull} pseudosection. The blue ellipsoids mark the expected tunnel anomaly and the purple rectangles mark the wall anomalies.

As can be seen from the inverted section for the Wenner layout in Figure 3, this layout, due to its robust and less noise-sensitive properties, displays the anomalies along the section in a more clustered fashion. The inverted DP array shown in Figure 3b already better isolates the subsurface inhomogeneities. The pseudosection of Figure 3c for the γ_{qnull} array best decomposes and separates structures of different sizes and conductivities for historical information. After this phase of the research, it is expected that exploration work will soon be able to start, when the geoelectrical mapping and the information from the contemporary descriptions will be combined to validate the geological and man-made structures involved along the section.

The north direction tunnel was captured by two sections, SZB3 and SZK4, of which SZK4 is shown on Figure 4. The sections of the two compared arrays the DP and the γ_{qnull}. Note the 6m difference in the investigation depth, which must be taken into account in the interpretation. The continuation of the walled entrance in the basement of the central tower is likely the smaller anomaly no. 7 at section length 42 meters, in 2m-depth. A bigger anomaly (no. 6) is seen on both section, but with less certainty on the DP, between 18 and 32 meters, in 4 meter depth. The figure (a) shows two large anomalies (no. 8) at the middle of the section at 7 meters depth, and the right side of the section (no. 9), from 3 to 6 meters depth. Again, these anomalies are unexpected, and are not examined in this paper, but the origin of these remains is an exciting question. Both may be carstic cavities, or limestone bedrock.

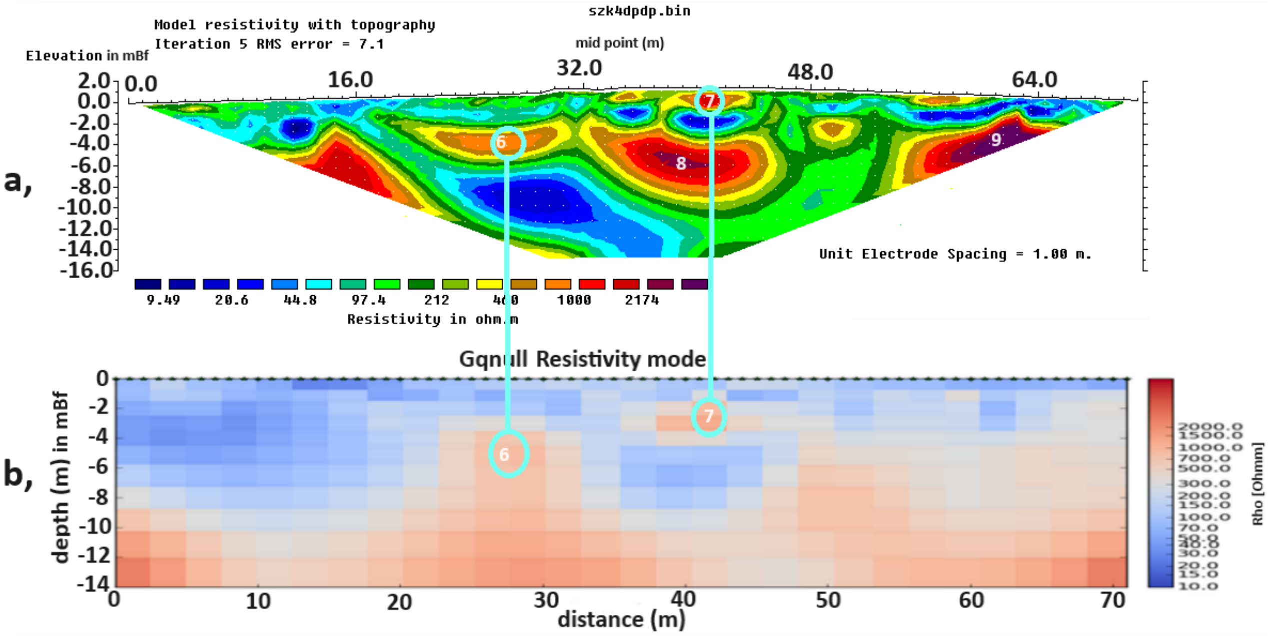

Figure 4. SZK4 DP section, inverted with the RES2DINV software (a), compared with the γ_{qnull} section inverted in RES2DHUN (b). The anomalies expected to be cavities are outlined with blue ellipsoids.

4 Conclusions

Based on the results, lessons learned, and experience gained so far, the application of quasi null electrode arrays for cavity search in archeology is very promising as a method, clearly more sensitive to sudden changes in resistivity than conventional arrays. The key to our future work will be the development and choice of an appropriate inversion and evaluation procedure, and a proper validation method which will further clarify the behavior of quasi-null arrays. We suggest that future excavations should focus on a shallow drilling above SZK4 section and clear the collapsed entrance of the north-east direction tunnel captured by SZK5 section.

Not presented in the present manuscript, but also included in the measurement profiles was a section (KUT25) that was laid in the area to clarify the depth of the former well or rainwater collection cistern. The results of this are intended to be published as a continuation of the present manuscript. Also in our next manuscript, we would like to present our results from the monitoring measurements of the measured geoelectric sections.

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References:

[1] Bagaloni V. N., Perdomo S., Ainchil J., 2011, Geoeletric and magnetic surveys at La Libertad archaeological site (San Cayetano County, Buenos Aires Province, Argentina): A transdisciplinary approach. Quaternary International 245 (2011) 13-24 https://doi.org/10.1016/j.quaint.2011.01.026

[2] Csókás J, Gádor J.,Gyulai Á., Geofizikai módszerek az archeológiai kutatásokban,1977, Herman Ottó Múzeum évkönyve 0544-4225 16 7-33

[3] Sultan S. A., 2004, Geoelectrical mapping and tomography for archeological prospection at Al Ghouri mausoleum, Islamic Cairo, Egypt. International Journal of Applied Earth Observation and Geoinformation 6 (2004) 143-156 https://doi.org/10.1016/j.jag.2004.10.001

[4] Szalai S., 2020, Geoelektromos kvázi null elrendezések és kis skálájú repedésrendszerek vizsgálata (MTA Doktori Értekezés)

[5] Szalai S., Baracza M.K, Kárpi M., Szűcs P., Metwaly M., Turai E., Facskó G., Zubair M., Szarka L. and Gribovszki K., 2022, Improving ERT Imaging of Small Size 2D targets Using Different strategies. Pure and Applied Geophysics. https://doi.org/10.1007/s00024-022-03204-8

[6] Szalai, S., Lemperger, I., Metwaly, M., Kis, Á, Wesztergom, V.,Szokoli, K., & Novák, A., 2014b, Multiplication of the depth of detectability using c11n arrays. Journal of Applied Geophysics, 107, 195–206.

[7] Szalai, S., Kis, A., Metwaly, M., Lemperger, I., & Szokoli, K., 2014a, Increasing the effectiveness of electrical resistivity tomography using y11n configurations. Geophysical Prospecting 63(2), 508-524

[8] Szalai S., Szarka L., 2008, On the classification of surface geoelectric arrays, Geophysical Prospecting, 2008, **56**, 159–175 https://doi:10.1111/j.1365-2478.2007.00673.x

[9] Szalai, S., Szarka, L., Prácser, E., Bosch, F., Müller, I., & Turberg, P., 2002, Geoelectric mapping of near-surface karstic fractures by using null arrays. Geophysics, 67(6), 1769–1778.

[10] Tarkhov, A. G., 1957, On electric geophysical exploration methods of the pure anomaly. Bulletin Izvestia Akademii Nauk USSR, 8, 11.

[11] Yilmaz S., Balkaya C., Cakmak O., Oksum E., 2019, GPR and ERT explorations at the archaeological site of Kilic village (Isparta, SW Turkey). Journal of Applied Geophysics, Vol. 170. https://doi.org/10.1016/j.jappgeo.2019.103859