GEOPHYSICAL INVESTIGATIONS OF GEOELECTRICAL RESISTIVITY TOMOGRAPHY FOR PARK DN3C IN THE MUNICIPALITY OF CONSTANȚA

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Service contract no. *156173/27.07.2022*

Beneficiary: CONSTANȚA TAU

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1. INTRODUCTION

1.1. Purpose of the work

"Elaboration of the Archaeological survey through geophysical investigations of geoelectrical resistivity tomography (ERT) Park DN3C in the Municipality of Constanța" in order to analyze the archaeological potential of the area according to service contract no. *156173/27.07.2022*.

1.2. Location

The area for which the geoelectrical resistivity tomography investigations are carried out is located in the southern part of a new residential neighborhood in Palazu Mare. The site is located on an interfluve with small undulations and is currently used for agriculture.

Coordinates: **47°13'00"N 28°35'22"E**

Figure 1: Location of geoelectrical sections, Palazu Mare TAU, Constanța county

1.3. General information about the beneficiary

Contracting authority: **Municipiul Constanța TAU**

Tax Identification Number: RO4785631

Address: 51 Tomis Blvd., Constanța Municipality,

Postal code: 900725

1.4. Presentation of the executor

SC Fad Smart Technology S.R.L. has a team of specialists working in the following fields: water and land geophysics, landslide and earthquake risk maps, geomorphology, marine and fluvial bathymetry, cartography, remote sensing, GIS, wind studies and wind project development, underwater investigations, bridges and dams, geotechnical monitoring of critical infrastructure (highways, bridges, railways, dams, etc.).

The team is composed of people who worked as scientific researchers at the University of Bucharest and some national research institutes. We mobilize quickly, we offer modern and innovative solutions and we want to become a pole of excellence in Romania regarding the integration of cutting-edge technologies in our fields of interest. For more details, see www.fabricadecercetare.ro .

The Research Factory team

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2. METHODOLOGY OF FIELD WORKS

The resistivity method is the main geoelectrical method currently used in geophysical practice. It consists in investigating the interdependence between the structure of the subsoil and the distribution of resistivity in the subsoil, measured at the surface. It is based on the existence of resistivity contrasts between the different rocks and geological formations that participate in the geological composition of an area.

The resistivity is measured in the field with a quadripolar device AMNB consisting of an emission line AB through which a current of intensity I is introduced into the soil through 2 emission electrodes A, B and a reception line MN which measures the potential difference ΔV created between the electrodes M, N when the current passes through the resistance represented by the subsoil. The 4 electrodes are stainless steel rods that are inserted into the ground, and the connection between them and the measuring device is made by electric cables stretched on the ground, so the method is totally non-invasive and can be applied on any type of terrain.

The obtained results are represented in the form of 2D vertical sections or 3D volumes of resistivity, which show the distribution of this parameter in direction and in depth, in direct correlation with the geological structure of the subsoil up to a maximum depth that depends on the number of electrodes and the spacing between them.

The interpretation in geological terms of the resistivity sections is carried out according to the available information regarding the investigated area - geological, geophysical, geochemical data, information from the authorities and from the locals.
The applicability of the resistivity method is related to the existence of a resistivity contrast between the tracked object and the adjacent environment, a contrast that is determined by preliminary measurements or estimated based on information regarding the work area or similar areas. At the same time, it is necessary for the tracked object to have a size of at least half the distance between the electrodes and to be at a depth comparable to its size.

The existence in the immediate vicinity of the earthings of installations in operation working with direct current can affect the quality of the measurements.

The main fields of application of the resistivity method are:

1. Studies of engineering geology, hydrogeology and environment:

- Geoelectrical research and monitoring of unstable areas (landslides, subsidence, saline structures, anthropogenic processes). Determination of physical and geometric parameters of the buried structures.

- Localization of inhomogeneities in the subsoil (voids, buried objects, faults, fractures, altered areas, buried relief). Mapping the relief of the bedrock.

- Environmental surveys. Delineation of contaminated areas, detection of infiltration, design and monitoring of ecological pits.

- Land analysis for civil and industrial construction foundations (buildings, bridges, roads, tunnels). Highlighting the geological structure, the degree of compaction and humidity of the formations, the stable and unstable areas.

- Stability studies of the dams. Detecting and locating leaks and areas of low resistance in dams built of soil or rockfill.

- Localization of aquifer structures. Determining the geometric parameters in order to calculate reserves.

2. Prospecting for mineral deposits (massive and disseminated metallic, polymetallic, auriferous-argentiferous, non-metallic ores, coal, construction materials, other useful rocks). Determination of the necessary elements for the calculation of reserves.

3. Investigation of archaeological sites. Identifying and locating buried archaeological artifacts and structures.

2.1. Methodology of resistivity geophysical research

A. The classic method of direct current resistivity is based on the interdependence between the electrical properties (electrical ρ resistivity) and the geotechnical parameters of the land, on the resistivity contrasts between the various rocks and formations that participate in the geological composition of an area, so on the resistivity contrast between the object being tracked and the surrounding environment.

The electrical resistivity of rocks, measured in laboratory conditions, varies widely depending on the structure, texture, compactness, water content and degree of salinity, and the contrasts between them can reach several orders of magnitude. Measured in the field, where there are large volumes of different rocks located both along the direction of the measuring device and laterally, the resistivity contrasts between the rocks are attenuated, but the ratio between them is preserved.

In the case of sedimentary rocks, characterized by ionic conductivity, the nature of the mineralogical components does not influence the resistivity, its size depending exclusively on the porosity value, the geometry, the size and connection of the pores, the nature and concentration of fluids in the pores of the rock and their degree of filling. The resistivity of the main types of sedimentary rocks that can appear in the area varies between the following limits:

Type of rock	**Resistivity (ohmmeters)**	**Type of rock**	**Resistivity (ohmmeters)**
limestones	100 - 10 000	drilling mud	4.5
sandstones, marls	100 - 1 000	salt	10^{12} - 10^{14}
compact sandstone	1000 - 10000	petroleum	10^{9} - 10^{16}
sand, gravel	100 - 10 000	fresh water	10 - 100
clay, dusty clay	1 - 100	sea water	0.1 - 1
wet plastic clay	20	eruptive rocks	10^{3} - 10^{8}
soil, dirt	1 - 10	metamorphic rocks	10^{3} - 10^{8}

Table 1: Resistivity of the main types of sedimentary rocks

From the analysis of this table, a first criterion for the interpretation of geoelectrical data in the given geological context is outlined. Maximum resistivity anomalies can be generated by the presence of eruptive or metamorphic rocks, compact sedimentary rocks, dry or impregnated with petroleum products, as well as salt, which produces characteristic anomalies with extremely high values. Low anomalies may reflect the presence of clay or water in the rock pores, while salt water produces the most intense low anomalies. A water-saturated rock can be over one order of magnitude more conductive than the same rock with a low water content. The presence of salt water decreases the resistivity by another order of magnitude.

The determination of the apparent resistivity in the field is done with a quadripolar measuring device made up of 2 emission electrodes A,B through which a direct current of intensity **I** and 2 reception electrodes M,N are injected into the soil, through which the potential difference **ΔV** produced by the passage of current through the resistance represented by the subsoil is measured. For a device of the Schlumberger or Wenner type, the depth of penetration of the current into the subsoil, that is, the depth from which the geophysical information comes (investigation depth), is directly proportional to the length of the measuring device AB. By keeping the distance MN between the receiving electrodes constant and increasing the distance AB progressively, the current lines will penetrate deeper into the subsoil, so the information will come from an increasingly greater depth, thus recording the variation of resistivity with depth for the same point on the ground surface. This is the principle of the vertical electrical survey (VES). The finesse of the investigation is achieved horizontally by using a distance MN as small as possible and by reducing the interval between VES locations, and vertically by increasing the number of lengths AB.

In the case of the dipole-dipole device used in this perimeter, the depth of investigation is directly proportional to the distance between the means of the transmitting and receiving dipoles.

The value of the apparent resistivity is calculated according to Ohm's Law in a homogeneous medium:

$$\rho_a = K \times \Delta V / I \quad (1)$$

where K - a coefficient which depends on the geometric configuration of the electrodes:

$$K = 2\pi / [1/AM - 1/AN - 1/BM + 1/BN] \quad (2)$$

In the practice of field investigations, different electrode layout configurations (devices) can be used for different geological situations. The most common are:

- Wenner device (equal spacing between electrodes), characterized by the highest signal-to-noise ratio, excellent vertical resolution, poor lateral resolution, and an investigation depth of 30% of the length of the AB emission line. Mainly used in profiling measurements, mapping of base layers and investigations in new areas.
- Schlumberger device (AB ≥ 5MN), with good signal, reasonable lateral resolution and the depth of investigation of 20% of the length of AB. It is the most widely used device in vertical electrical surveys (VES), when investigating areas with parasites or those with low resistivity.
- dipole-dipole device, with a good lateral resolution and the depth of investigation of 15% of the distance between the emission and reception dipoles. Mainly applied to multi-channel recording instruments, to reduce working time.

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- pole-dipole device, with very strong signal and good resolution, but generating less clear images. It is mainly applied to 3D recordings.

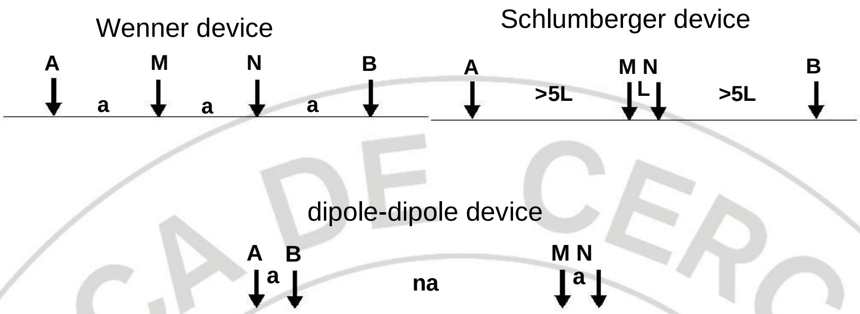

Figure 2: Common types of devices

The notion of **apparent resistivity ρ_a** refers to the fact that the value of the resistivity recorded at a point on the surface of the land represents a weighted average of the resistivities of all the rocks located in the space crossed by the current lines generated between the emission electrodes, a value in which the resistivity corresponding to the depth of the length of the respective device has the largest weight (**AB** for Schlumberger or Wenner devices, **na** for dipole-dipole device).

The data processing and the representation of the results are done in two phases. First, the apparent resistivities ρ_a are calculated and the apparent resistivity pseudo-sections corresponding to each measured profile are constructed, so called because the representation of the resistivity with depth is made not according to distance units (meters), but according to the configuration of the measuring device. A qualitative image of the spatial distribution of the resistivity is thus obtained, starting from the cause (geological structure) to the effect, an image that gives indications of the electrical properties of the subsoil. Then, each survey curve is represented in bilogarithmic coordinates and the quantitative interpretation, manual or automatic, is carried out a process that results in a sequence of electrical horizons for each SEV location, each horizon being characterized by its own "real" thickness and resistivity. The correlation of these horizons along a profile materializes in the section of real resistivities, also called "inverted image of resistivity", a name resulting from the fact that the data processing process takes place in the reverse direction, from effect to cause. The real resistivities section is the geophysical image

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closest to the real geological structure of the subsoil.

B. The method of resistivity images is the modern variant of the resistivity method, developed as a result of the improvement of the data acquisition and recording technique, as well as the implementation of programs that automatically interpret resistivity data in 1D, 2D or 3D. The resistivity of the land is recorded, according to a predetermined program, by an automatic device, with the help of special cables, then it is downloaded to a computer, where it is processed by a specialized program, and finally it is displayed in the form of vertical sections for interpretation.

The SuperSting R8/IP+56 system manufactured by the American firm Advanced Geosciences, Inc, Austin, Texas is an 8-channel automatic resistivity and induced polarization imaging system used with passive multi-electrode cables. It uses a pulsed direct current for emission with the pulse duration equal to the pause duration. Compensation of the natural potential is done automatically, throughout the measurement.

The resistivity is calculated by entering the device coordinates. Noise attenuation is at least 100 dB at frequencies higher than 20 Hz and at least 120 dB at frequencies of 16, 20, 50, 60 Hz in the transmission line, ensuring a clean signal.

The instrument includes a **distribution box** (switch box) which has the role of commanding the switching of the electrodes during automatic data acquisition, according to a previously entered program (command file). Electrode switching is done by the instrument through passive multi-electrode cables, which have a contact (take-out) at equal distances for connecting the stainless steel electrodes.

The cables used are **cables with passive electrodes (FlexLite Passive Electrode Cable)** which have 56 electrodes distributed every 6 meters, which allow to reach an investigation depth of 60 m. If it is desired to increase the degree of detail (it is aimed to highlight structures of smaller size or structures in very thin layers) the distance between the electrodes can be reduced until it complies with the requirements of the survey.

The device also includes the **Administrator software**, used to create command files and load them into the device's memory and to download data from the

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SuperSting to the computer. The command file is a text file that tells the instrument how to measure, assigning to each electrode the function of the transmitting or receiver electrode.

EarthImager inversion softwares are programs that interpret the recorded resistivity data (the inversion process) and produce images in the form of 2D sections or 3D volumes that reflect the geological structure of the subsoil.

The inversion of the resistivity data is a combination of direct simulation (forward simulation) and inverse simulation with the final result being the production of the structural model of the subsoil (the image of the subsoil obtained on the basis of the resistivity data measured on the surface of the land).

First, a direct simulation or modeling (virtual prospecting, a model-to-data, cause-to-effect application) is carried out, on a model built on the basis of some a priori information, known (distribution of apparent resistivity in the subsoil, configuration of electrodes) or presumed (the average resistivity of a sector, the user's hypothesis or the structure of the subsoil), obtaining a set of synthetic data. The direct modeling (direct solution) is obtained by solving the equation with partial derivatives in the domain of the Fourier transform:

$$\frac{\partial}{\partial x}\left(\sigma\frac{\partial V}{\partial x}\right)+\frac{\partial}{\partial z}\left(\sigma\frac{\partial V}{\partial z}\right)-k^2\sigma V=-I\cdot\delta(x)\cdot\delta(z)\,, \qquad (3)$$

where, V - is the scalar electric potential in the domain of the Fourier transform,

I - is the intensity of the electric current of the source,

σ - is the electrical conductivity, a quantity function of (x,y), the inverse of resistivity.

Then, the synthetic data set (the measured apparent resistivity section) is subjected to inverse simulation (model parameterization process, a data-to-model, effect-to-cause application) to reconstruct the distribution of resistivity in the subsoil, based on the **V** and **I** data measured at the surface. A model of the subsoil (the calculated apparent resistivity section) is thus obtained which is compared with the initial synthetic model and modified through successive iterations until the difference between them falls below a set threshold. The mean squared error (RMS Error, Rooth Mean Squared Error) characterizes the agreement between the data measured in the field and the calculated data of the model:

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$$RMS = \sqrt{\frac{\sum_{i=1}^{N}\left(\frac{d_i^{Pred} - d_i^{Meas}}{d_i^{Meas}}\right)^2}{N}} \times 100\%, \quad (4)$$

where, N - the total number of measurements,

d^{pred} - predictable data,

d^{meas} - measured data.

The inversion of the resistivity data is therefore a process in which the model (the inverted resistivity section) is built starting from the distribution of the apparent resistivity in the subsoil (the measured apparent resistivity pseudosection), resistivity determined by measuring at the surface of the ground the intensity of the injection current **I** and the voltage between the measurement electrodes **ΔV**.

The final result is the Inverted Resistivity Section, which represents the resistivity distribution in the subsoil reconstructed by the inversion process of synthetic data. It is the final result of the electrical investigation, an image directly related to the geological structure of the subsoil from the point of view of the electrical properties of its various components. Based on this image and taking into account all the geological data and any other data from the researched perimeter, the user engages in the final process of geological interpretation of the geophysical results.

2.2 Resistivity measurements performed within the survey

For the geoelectrical measurements performed on the site located in the south of Palazu Mare in Constanța County, in order to analyze the archaeological potential of the area, the **SuperSting Marine System** produced by the American company Advanced Geosciences, Inc., Austin, Texas, was used, which is an automatic 8-channel resistivity and induced polarization image generator system, used with multi-electrode passive cables. It uses a pulsed direct current for emission with the pulse duration equal to the pause duration. It includes a **distribution box** (switch box) which has the role of commanding the switching of the electrodes during automatic data acquisition, according to a previously entered program (command file). The device also includes the **Administrator software**, used to create command files and load them into the device's memory and to download data from SuperSting to the computer.

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The command file is a text file that tells the instrument how to measure, assigning each electrode the function of the transmitting or receiving electrode. **EarthImager inversion softwares** are programs that interpret the recorded resistivity data (the inversion process) and produce images in the form of sections or 3D volumes that reflect the geological structure of the subsoil.

Electrode switching is done by the instrument through passive multi-electrode cables, which have a contact (take-out) at equal distances for connecting the stainless steel electrodes at equal distances, and cables used are **cables with passive electrodes (FlexLite Passive Electrode Cable).**

Considering the investigation theme, the dipole-dipole device was chosen to reach greater investigation depths and for the large number of measurements, which means more details represented on the geoelectrical resistivity section. The position of each of the 56 electrodes used in these sections was measured with an RTK GPS with an average error of less than 2 cm. From the obtained GPS data, the altitude of each electrode was extracted and the terrain file was prepared to be able to process the geophysical resistivity data collected according to the local topography.

The geoelectrical measurements made with the dipole-dipole device with a distance between electrodes of 1 m were made on two diagonal sections located in the perimeter received from the archaeologist Bejenaru Constantin from the Museum of National History and Archaeology Constanța. In addition to the contracted services, a 2D investigation with electrodes placed at 1 m and a section with electrodes placed at 0.5 m were performed.

Figure 2 shows the position of the geoelectrical profiles, for which the dipole-dipole device was used to determine the resistivity of the subsoil. 5 2D sections and one 3D section were performed. Thus, the perimeter of site 12 in the archaeology report drawn according to the coordinate table is represented in red. The perimeter made available courtesy of archaeologist Dr. Constantin Bejenaru from the Museum of National History and Archaeology Constanța is represented in yellow. In blue are represented the geoelectrical resistivity tomography sections performed with electrodes placed at 1m and the red lines are the resistivity geoelectrical tomography sections performed with electrodes placed at 0.5m where the 3D investigation was also done.

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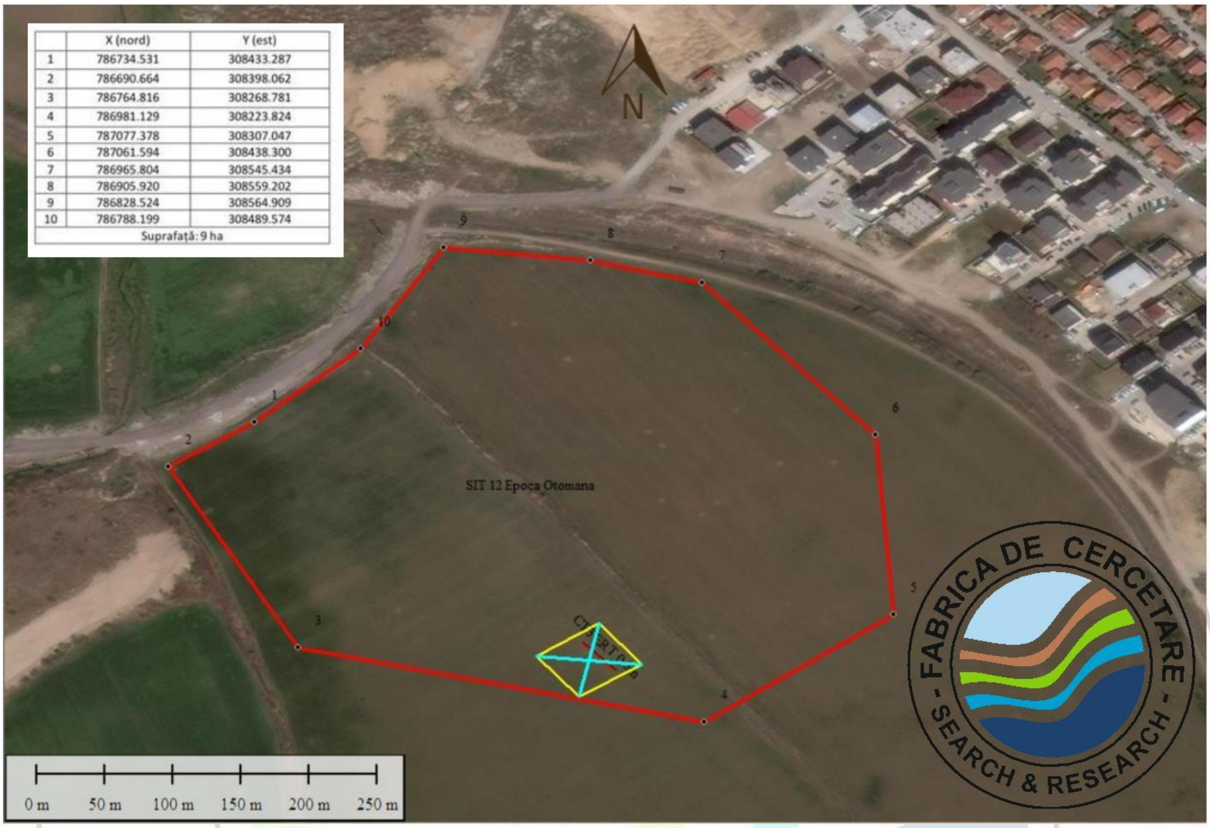

	X (nord)	Y (est)
1	786734.531	308433.287
2	786690.664	308398.062
3	786764.816	308268.781
4	786981.129	308223.824
5	787077.378	308307.047
6	787061.594	308438.300
7	786965.804	308545.434
8	786905.920	308559.202
9	786828.524	308564.909
10	786788.199	308489.574
Suprafață: 9 ha		

Figure 2: The positions of the electrodes on the geoelectrical profiles performed, superimposed on an orthophotoplane
The sections represented in blue have a distance between electrodes of 1m and those represented in red have a distance between electrodes of 0.5m.

3. PRESENTATION AND INTERPRETATION OF RESULTS

This survey aims to elucidate the hypotheses related to the existence of archaeological remains from the Ottoman era in the perimeter proposed to establish a new park. In the archaeological assessment report, the area is identified as *Site 12 - Constanța NW - Ottoman settlement and flattened tumuli*. Being located south of the intersection between Alexandria Street and the Constanța-Medgidia railway and 300-600m east of the intersection of DN3C with DC89 towards Poiana as represented on figure 2.

3.1. DIAGONAL PROFILES WITH THE DISTRIBUTION OF ELECTRODES AT 1 m

In the perimeter received from Archaeologist Constantin Bejenaru, two sections of geoelectrical resistivity tomography were carried out diagonally to identify the possible areas with archaeological potential in a length of 56m with electrodes placed at 1m and an investigation depth of 12m.

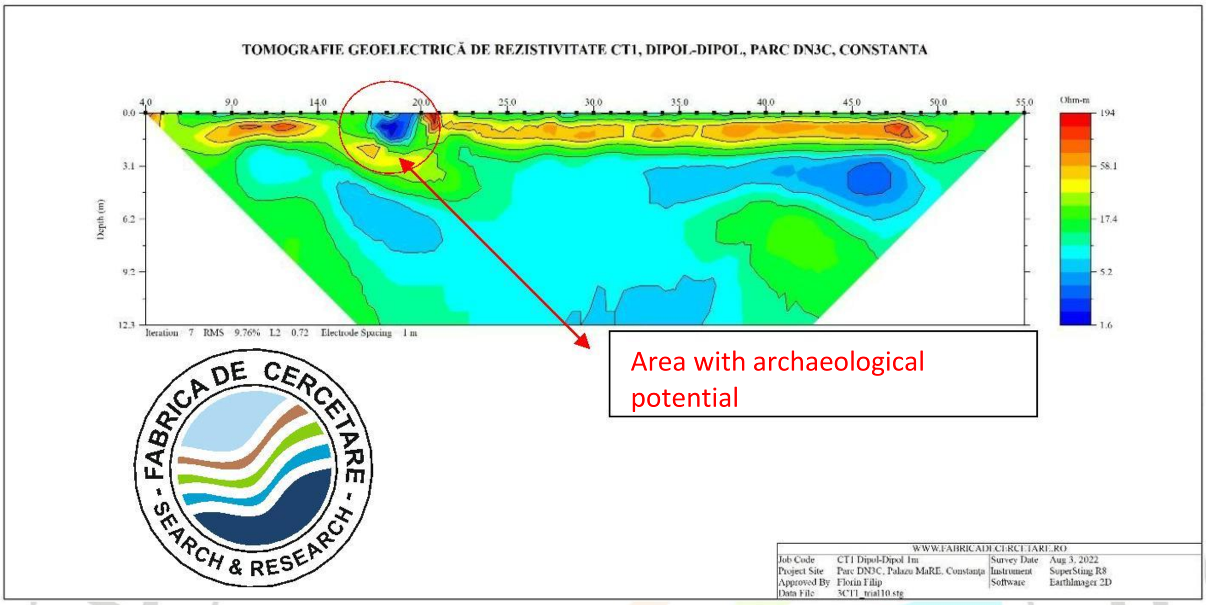

Figure 3. Diagonal profile of Geoelectrical Resistivity Tomography CT1, Palazu Mare, Constanța county

Section CT1 in a dipole-dipole device with 56 electrodes placed at a distance of 1m has an East-West orientation with electrode number 1 to the East. Resistivity values range from 1.6 Ohm-m to 194 Ohm-m. It can be seen that the upper part has a resistive horizon represented on the section by shades of orange and red with a thickness of approximately 2m which is continuous from electrode 50 to electrode 20 where there is an anomaly of minimum resistivity represented on the section by shades of dark blue so that the resistive horizon continues from electrode 14 to electrode 3. This anomaly of minimum resistivity that interrupts the upper horizon of increased resistivity can be associated with a residential area and has archaeological potential. At its base there is a more resistive horizon represented on the section with yellow shades at a depth of approximately 3m above which the area of minimum resistivity develops. Below these horizons at a depth of 3m there is a conductive horizon with lower resistivity values in the eastern part near electrode 47 at a depth of 5m which can be associated with a surface aquifer layer buried in clayey deposits with intercalations of fine sands. Below these horizons, the resistivity values indicate the existence of wet clays which are represented on the resistivity section by shades of light blue.

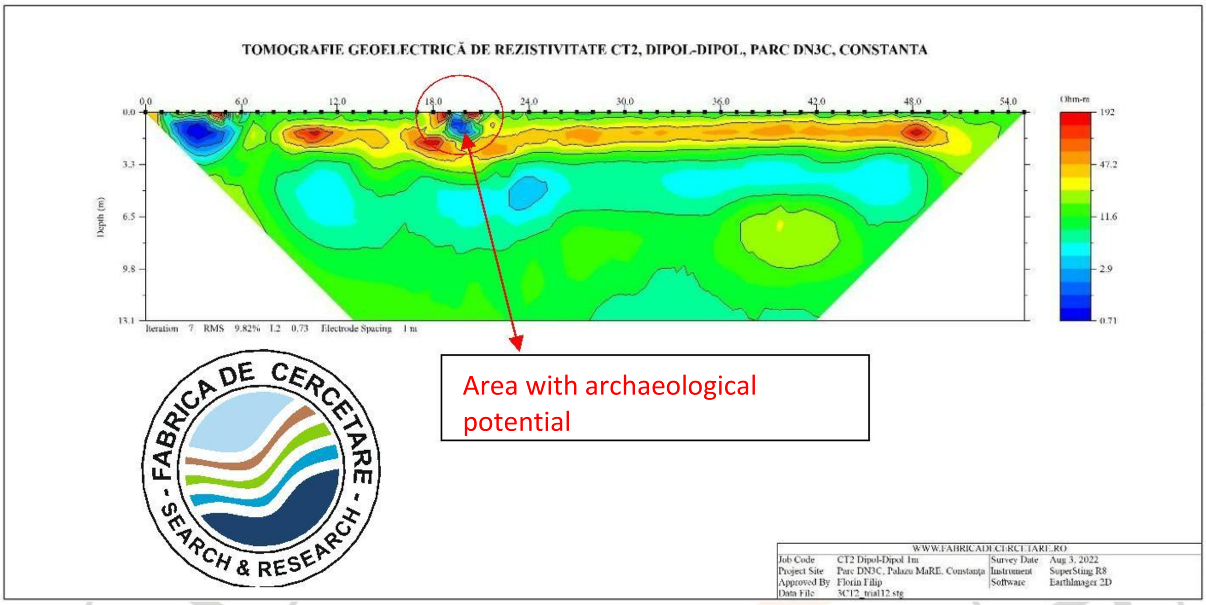

Figure 4. Diagonal profile of Geoelectrical Resistivity Tomography CT2, Palazu Mare, Constanța county

Section CT2 in a dipole-dipole device with 56 electrodes placed at a distance of 1m has a North East - South West orientation with electrode number 1 to the North East. Resistivity values range from 0.71 Ohm-m to 192 Ohm-m. It can be seen that the upper part has a resistive horizon represented on the section by shades of orange and red with a thickness of approximately 2m which is continuous from electrode 50 to electrode 22 where there is an anomaly of minimum resistivity represented on the section by shades of dark blue so that then the resistive horizon continues from electrode 17 to electrode 8 followed by an area where it disappears completely and is replaced by an area with minimum resistivity. This anomaly of minimum resistivity that interrupts the upper horizon of increased resistivity can be associated with a residential area and has archaeological potential. At its base there is a more resistive horizon represented on the section with yellow shades at a depth of approximately 3m above which the area of minimum resistivity develops. Below these horizons at the depth of 3.3m there is a more conductive horizon with lower resistivity values that are represented on the resistivity section by shades of light blue which can be associated with wet clayey deposits.

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3.2. PROFILES PARALLEL WITH THE DISTRIBUTION OF ELECTRODES AT 0.5m

After performing the 2 oblique sections, we focused on the detailed investigation of the minimum resistivity anomalies that have archaeological potential and we performed three parallel sections with a distance between them of 1m and a distance of 0.5m between the electrodes on each section using 56 electrodes. Thus, the length of the sections was 27.5 m each and an investigation depth of 7 m. The position and altitude of each electrode were recorded using an RTK GPS which had an average error of 2cm. Thus it was possible to use the topography of the land on each section of resistivity, the elevation values being in absolute elevations compared to sea level.

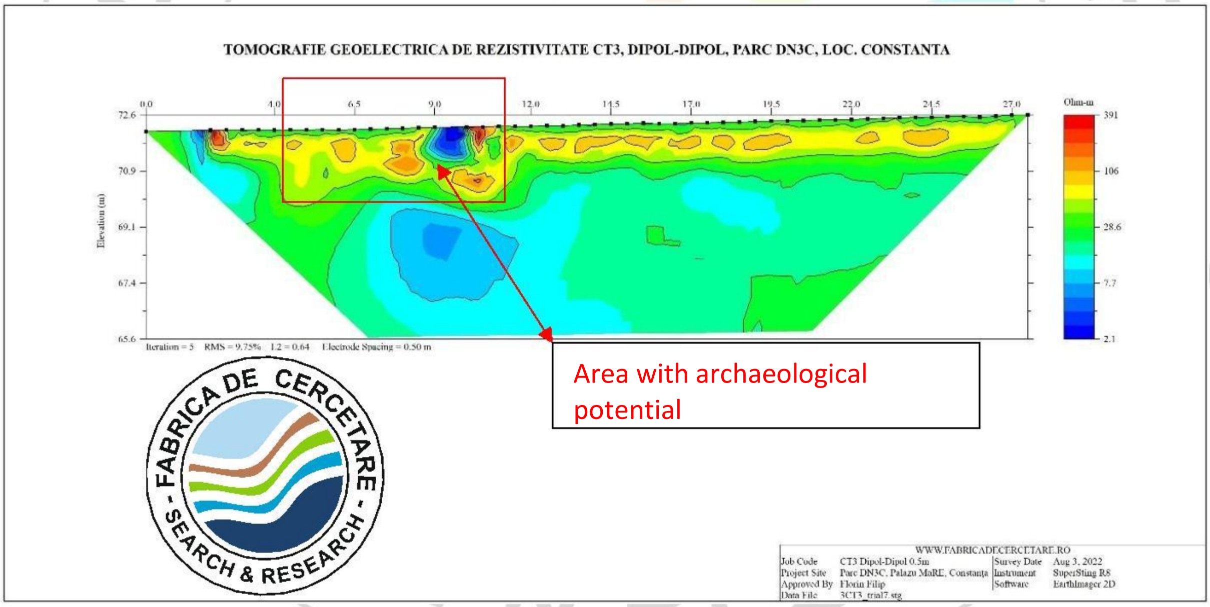

Figure 5. Parallel profile of Geoelectrical Resistivity Tomography CT3, Palazu Mare, Constanța county

Section CT3 in a dipole-dipole device with 56 electrodes placed at a distance of 0.5m has an North West - South East orientation with electrode number 1 to the South East. It has a central position in the group of three parallel sections. Resistivity values range from 2.1 Ohm-m to 391 Ohm-m. It can be seen that the upper part has a resistive horizon represented on the section by shades of orange and yellow with a thickness of approximately 2m which is continuous from electrode 56 to electrode 23 where there is an anomaly of minimum resistivity represented on the section by shades of dark blue so that the resistive horizon continues from electrode 17 to electrode 5 followed by an area where it disappears completely and is replaced by an area with minimum resistivity. This anomaly of minimum resistivity that interrupts the upper horizon of increased resistivity can be associated with a residential area and has archaeological potential. At its base there is a more resistive horizon represented on the section with orange and red shades at a depth of approximately 2m above which the area of minimum resistivity develops. Below these horizons at a depth of 2m there is a more conductive horizon with lower resistivity values that are represented on the resistivity section by shades of light blue and green which can be associated with wet clayey deposits.

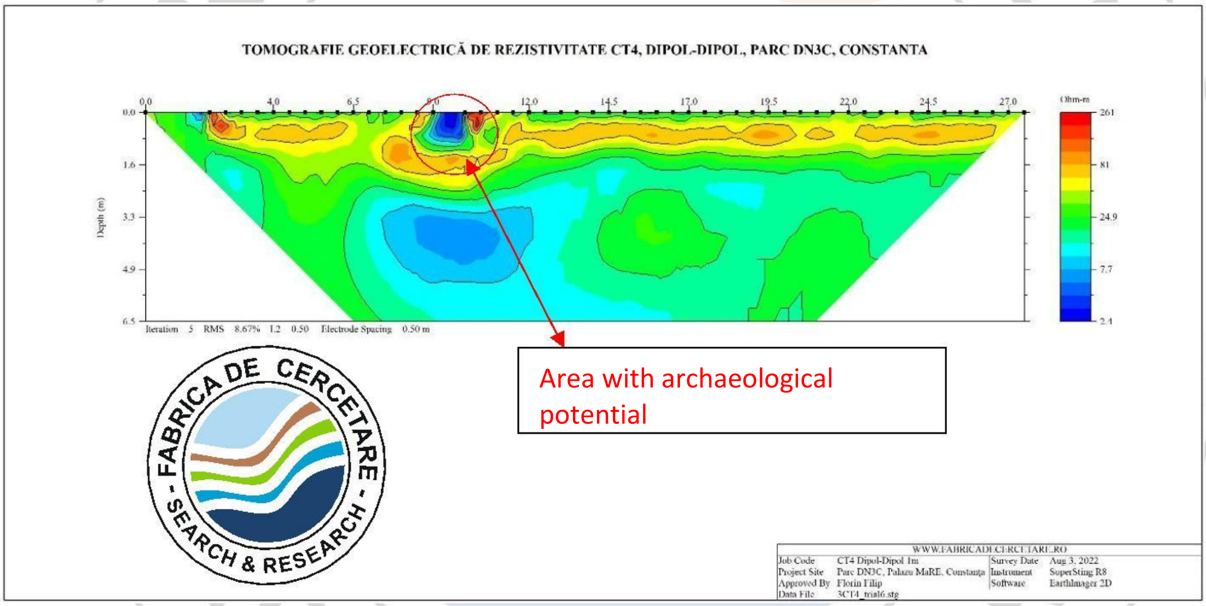

Figure 6. Parallel profile of Geoelectrical Resistivity Tomography CT4, Palazu Mare, Constanța county

Section CT4 in a dipole-dipole device with 56 electrodes placed at a distance of 0.5m has an North West - South East orientation with electrode number 1 to the South East. It has a position 1m west of CT3 section in the group of three parallel sections. Resistivity values range from 2.4 Ohm-m to 261 Ohm-m. It can be seen that the upper part has a resistive horizon represented on the section by shades of orange and yellow with a thickness of approximately 2m which is continuous from electrode 56 to electrode 23 where there is an anomaly of minimum resistivity represented on the section by shades of dark blue so that then the resistive horizon continues from electrode 17 to electrode 5 followed by an area where it disappears completely and is replaced by an area with minimum resistivity. This anomaly of minimum resistivity that interrupts the upper horizon of increased resistivity can be associated with a residential area and has archaeological potential. At its base there is a more resistive horizon represented on the section with yellow shades at a depth of approximately 2m above which the area of minimum resistivity develops. Below these horizons at the depth of 2m there is a more conductive horizon with lower resistivity values that are represented on the resistivity section by shades of light blue and green which can be associated with wet clayey deposits.

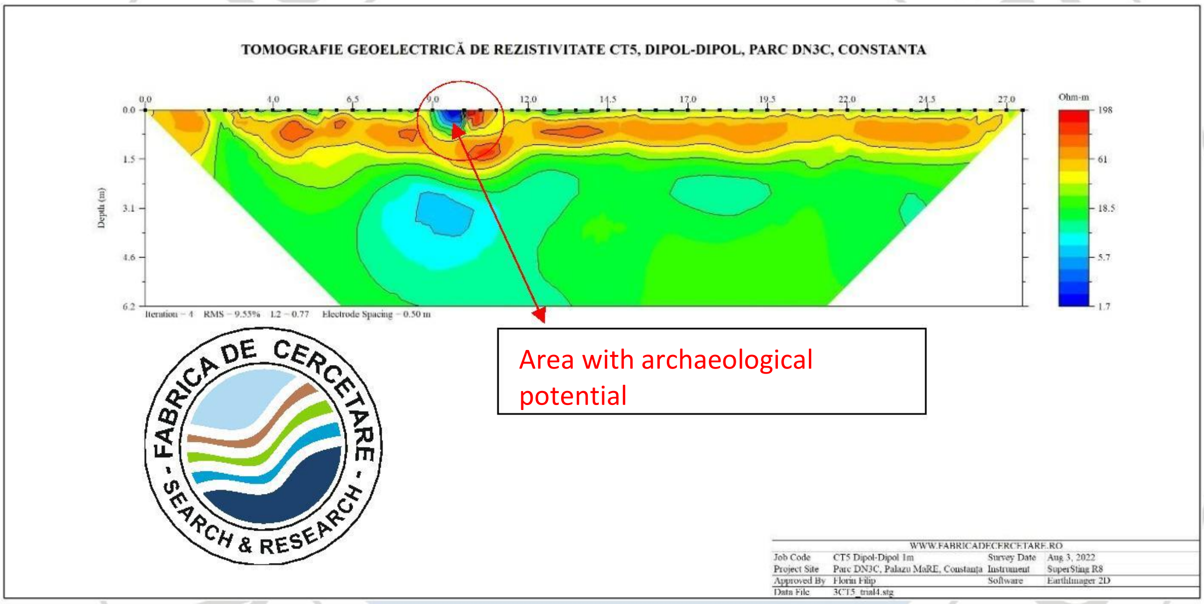

Figure 7. Parallel profile of Geoelectrical Resistivity Tomography CT5, Palazu Mare, Constanța county

Section CT5 in a dipole-dipole device with 56 electrodes placed at a distance of 0.5m has an North West - South East orientation with electrode number 1 to the South East. It has a position 1m east of CT3 section in the group of three parallel sections. Resistivity values range from 1.7 Ohm-m to 198 Ohm-m. It can be seen that the upper part has a resistive horizon represented on the section by shades of orange and yellow with a thickness of approximately 1.5 m which is continuous with a drop zone near meter 10 where an anomaly of minimum resistivity appears. This anomaly of minimum resistivity that interrupts the upper horizon of increased resistivity can be associated with a residential area and has archaeological potential. At its base there is a more resistive horizon represented on the section with orange and red shades at a depth of approximately 1.5 m above which the

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of minimum resistivity develops. Below these horizons at the depth of 1.5m there is a more conductive horizon with lower resistivity values that are represented on the resistivity section by shades of light blue and green which can be associated with wet clayey deposits.

3.3. RESULTS OF 3D DEVICE INVESTIGATIONS

To trace **the spatial distribution of the resistivity**, the three parallel resistivity sections were assembled in a 3D device using EarthImager 3D software. This resulted in a 3D section with a volume of 354.9 m^3 with a length of 27.5m, a width of 2m and an investigation depth of 6.45m.

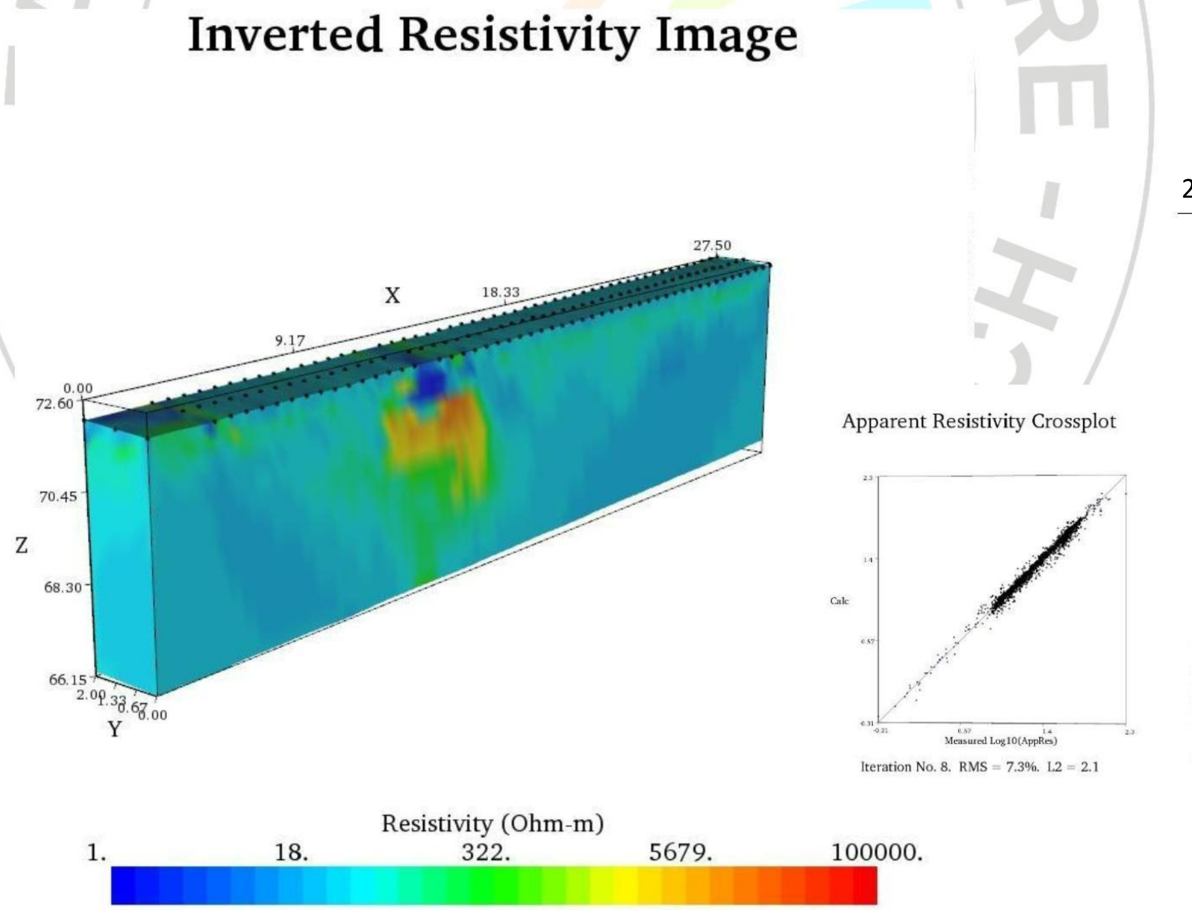

Figure 8. 3D Geoelectrical Resistivity Tomography Section Palazu Mare, Constanța county

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During data acquisition the position of each electrode was recorded using an RTK GPS such that the elevation of the points is absolute relative to sea level in the Stereo 70 coordinate system.

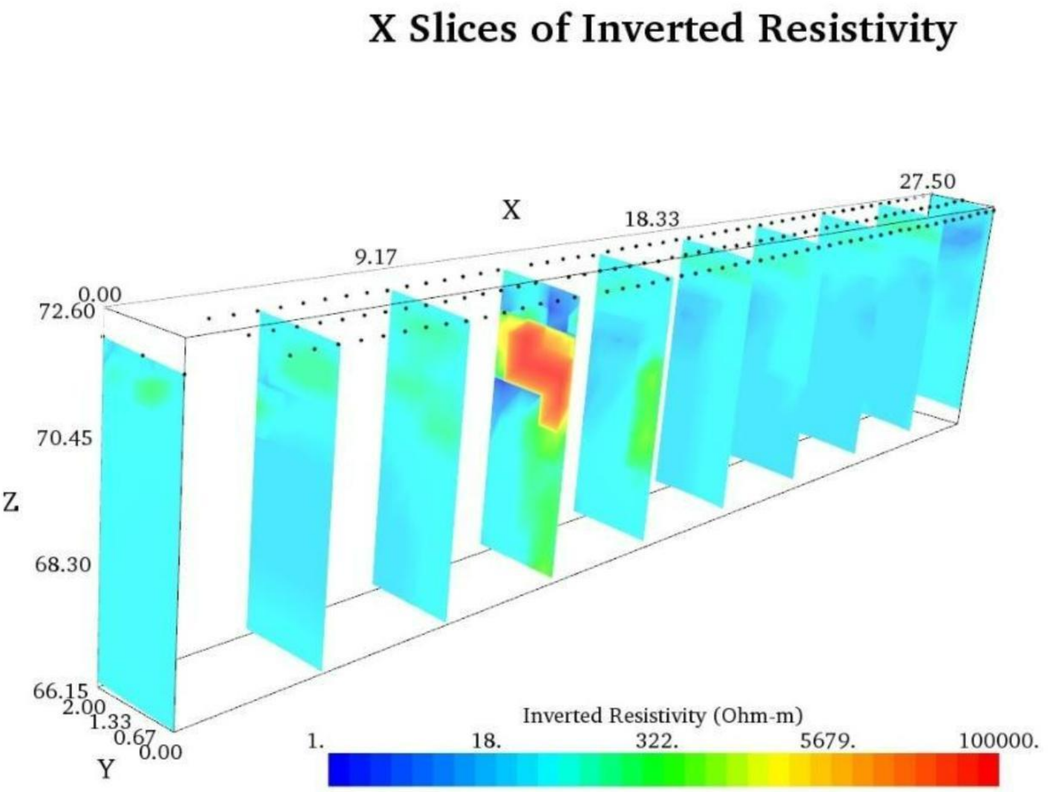

Figure 9. 3D Geoelectrical Resistivity Tomography Section on the x-axis, Palazu Mare, Constanța county

On the 3D section it can be seen that the anomalies, found in the three 2D sections (CT3, CT4 and CT5) that make up this section, are preserved but some particularities of their spatial distribution can be distinguished. Due to the fact that the data inversion is done for the 3900 data acquired for the sections, the resistivity values on the 3D section differ from those on the 2D sections. Thus, from meter 10 to meter 12.5, an anomaly of maximum resistivity with values over 6000 Ohm-m can be distinguished, which has above it an area of minimum resistivity with values below 3 Ohm-m. This resistive zone represented on the red-shaded section can be associated with the hearth of an Ottoman-era dwelling that may have several habitation levels. There is an area to the south in figure 10 represented on the section in shades of yellow that sinks a few tens of centimeters below this possible habitation area that

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be associated with a garbage pit or a food storage area.

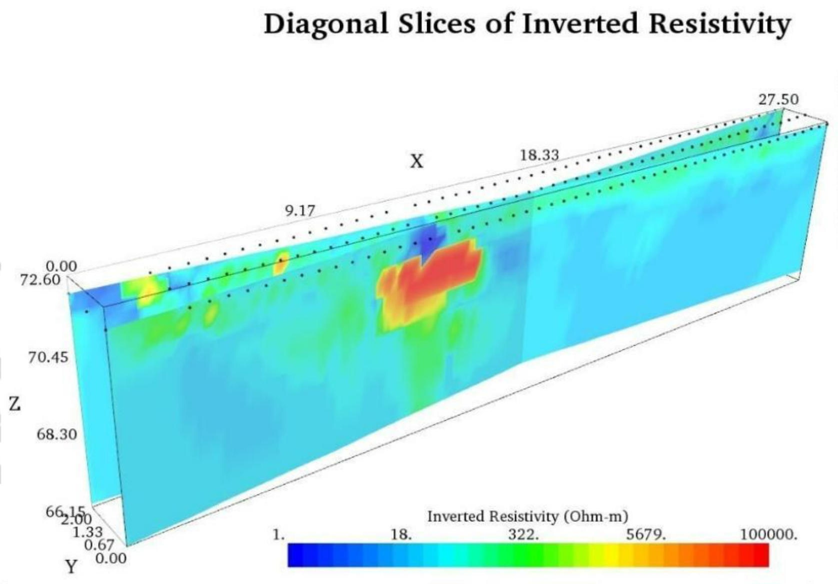

Figure 10. 3D Geoelectrical Resistivity Tomography Section with diagonal sections, Palazu Mare, Constanța county

The existence of a habitation is reinforced by the abrupt change in resistivity values on the 3D section. If on the whole profile we have low and medium resistivity values, in the area of 10-12 meters these values increase, having a vertical distribution from the depth of 1m to 3m.

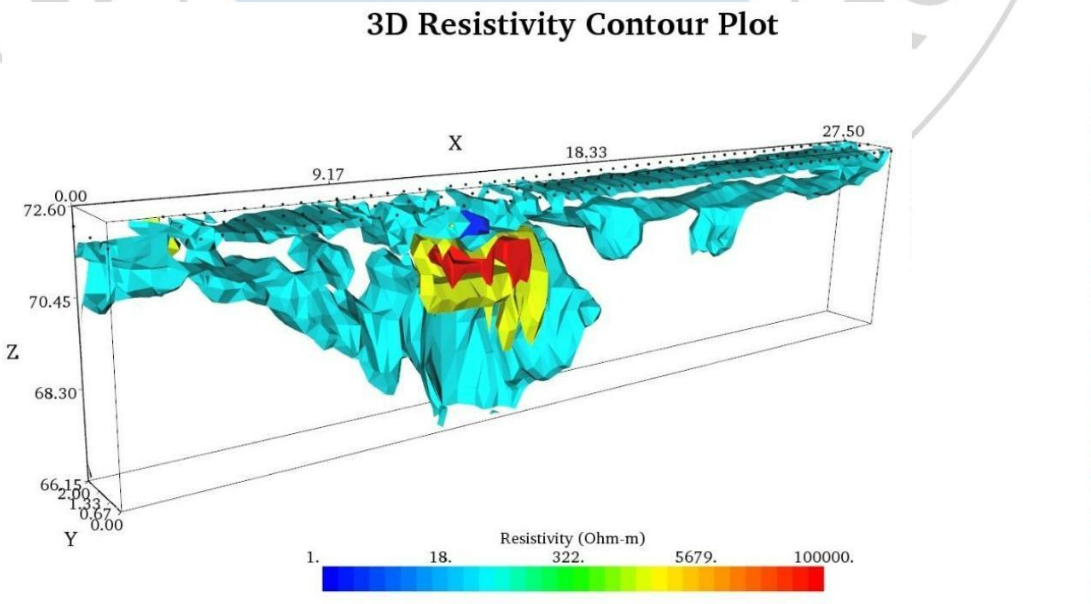

Figure 10. 3D Geoelectrical Resistivity Tomography Section with isosurfaces, Palazu Mare, Constanța county

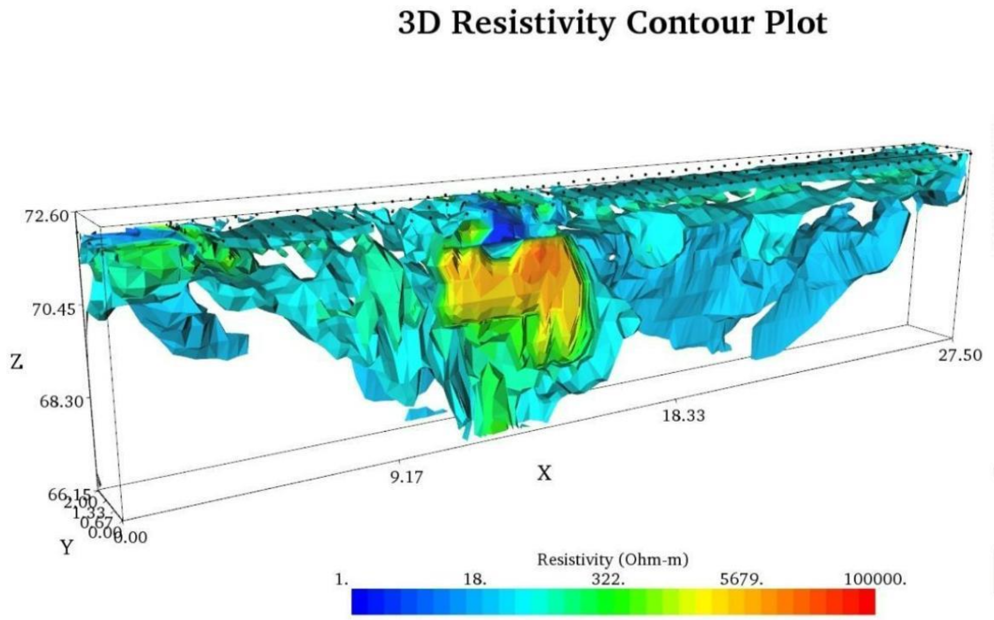

Figure 11. 3D Geoelectrical Resistivity Tomography Section with isosurfaces, Palazu Mare, Constanța county

In figure 12, there can be seen areas with increased resistivity that are found in the northern area in the depth range 0.5-1.5m may be associated with the presence of some artifacts.

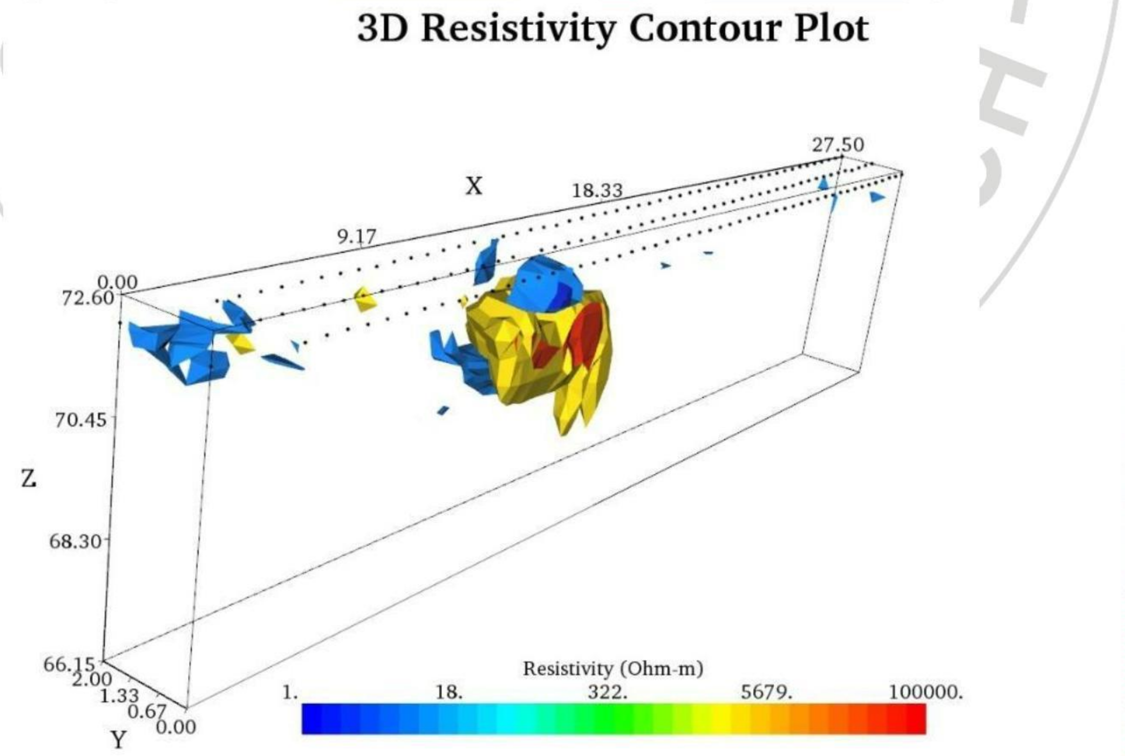

Figure 12. 3D Geoelectrical Resistivity Tomography Section with isosurfaces - maximum and minimum values, Palazu Mare, Constanța county

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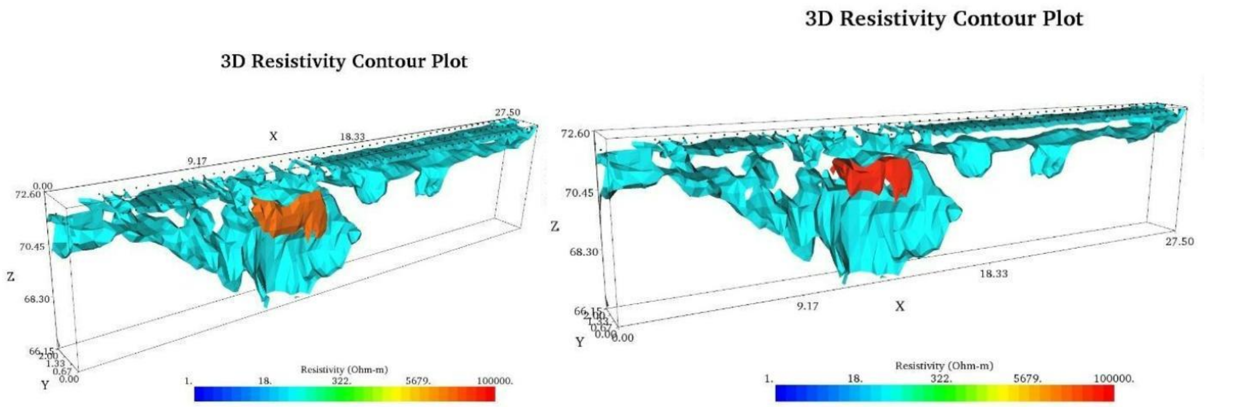

Figure 13. 3D Geoelectrical Resistivity Tomography Section with isosurfaces - with the maximum values of resistivity highlighted, Palazu Mare, Constanța county

The area identified as a possible Ottoman dwelling represented on the 3D section with shades of red and orange for the increased resistivity values as in figure 13 may be associated with several levels of habitation and may represent several levels of ash resulting from several fires but also of buried metallic objects that change the resistivity values of the substrate around them.

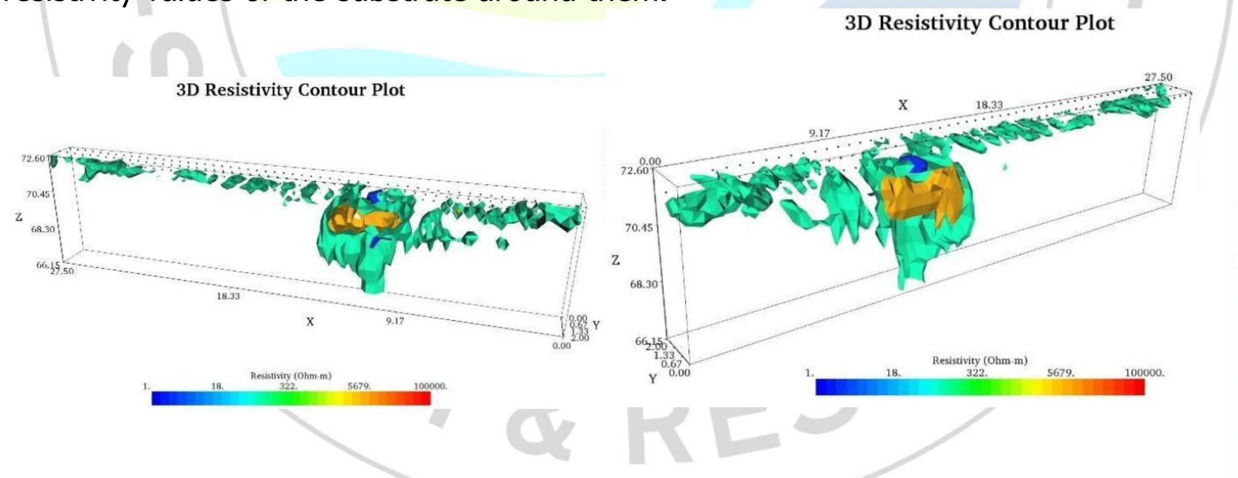

Figure 14. 3D Geoelectrical Resistivity Tomography Section with isosurfaces with average resistivity values highlighted. View from the West in the figure on the left and from the East in the figure on the right, Palazu Mare, Constanța county

In figure 14 we have a view from the West on the left side and from the East on the right side where it can be observed that the identified possible habitation area seems to be in steps suggested by the position of the more resistive area represented on the 3D section with light brown shades which is half a meter higher than the area viewed from the East.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. CONCLUSIONS

The geophysical 2D and 3D geoelectrical resistivity tomography measurements carried out on the site of the future DN3C park in Palazu Mare have highlighted, for the first time, the internal structure of some areas with archaeological potential and the interval with minimum resistivity anomalies associated with possible traces of early habitation with archaeological potential.

Thus, it is concluded that in the majority of the analyzed geophysical sections, the range of rocks with low resistivity, associated with possible traces of early habitation with archaeological potential, is located at depths from 1.5m to 3.3m. This area of minimum resistivity is covered in an impermeable resistive layer possibly of very well-compacted clays or well-compacted sandy clays with layers of ash due to the fires that affected these residential areas in the past.

4.2. RECOMMENDATIONS

Due to the fact that this study investigated only one site from those listed in the existing archaeological report for this location, it is recommended that further investigations be carried out for the other locations as well. It is also recommended to start some archaeological excavations in the area analyzed in this study, which will validate and highlight the archaeological potential. At the same time, it is considered to take into account the possibility of the existence of some archaeological vestiges that can be highlighted by the future development of the area.

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5. BIBLIOGRAPHICAL REFERENCES

- *P. Constantinescu, T Moldoveanu, D Ştefănescu, V.Vâjdea, M.Visarion, 1979- Engineering geophysics*
- *Advanced Geosciences, Inc., 2007 – Supersting: Automatic resistivity and IP system (Instruction manual)*
- *Advanced Geosciences, Inc., 2007 – EarthImager2D resistivity and IP inversion software (Instruction manual)*

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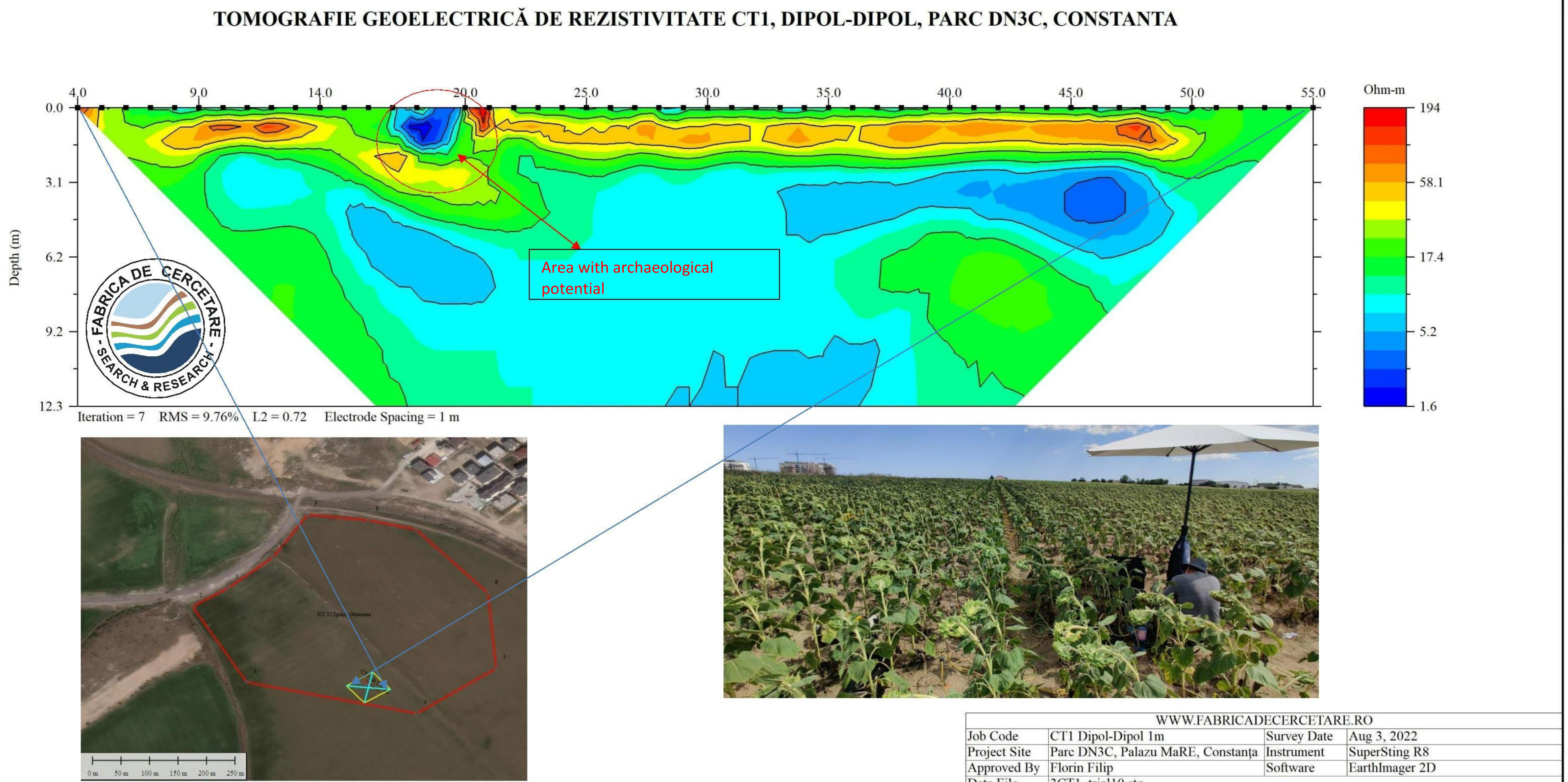
6. APPENDIXES



Job Code	CT1 Dipol-Dipol 1m	Survey Date	Aug 3, 2022
Project Site	Parc DN3C, Palazu MaRE, Constanța	Instrument	SuperSting R8
Approved By	Florin Filip	Software	EarthImager 2D
Data File	3CT1_trial10.stg		

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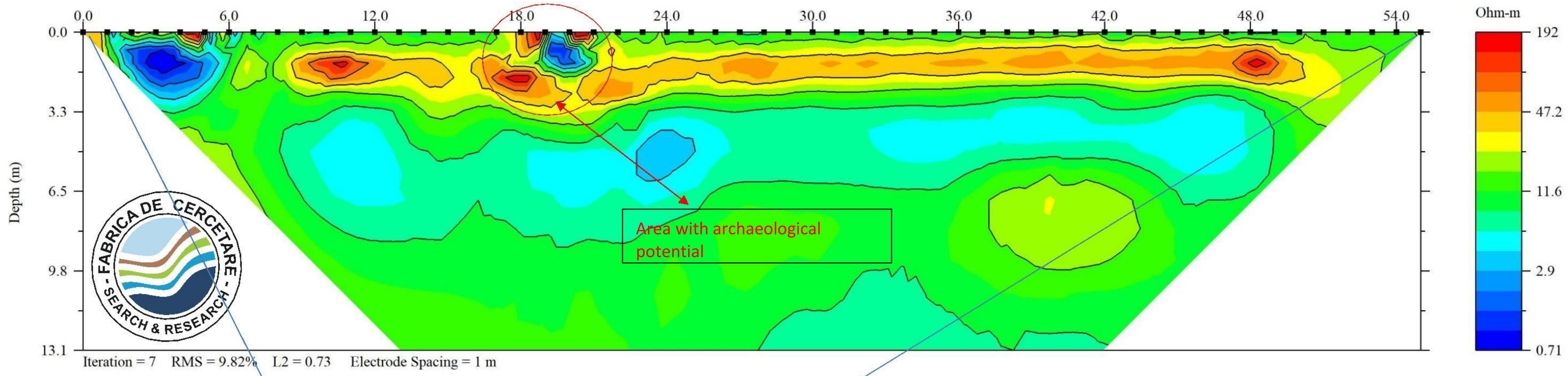
TOMOGRAFIE GEOELECTRICĂ DE REZISTIVITATE CT2, DIPOL-DIPOL, PARC DN3C, CONSTANTA



WWW.FABRICADECERCETARE.RO			
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Project Site	Parc DN3C, Palazu MaRE, Constanţa	Instrument	SuperSting R8
Approved By	Florin Filip	Software	EarthImager 2D
Data File	3CT2_trial12.stg		

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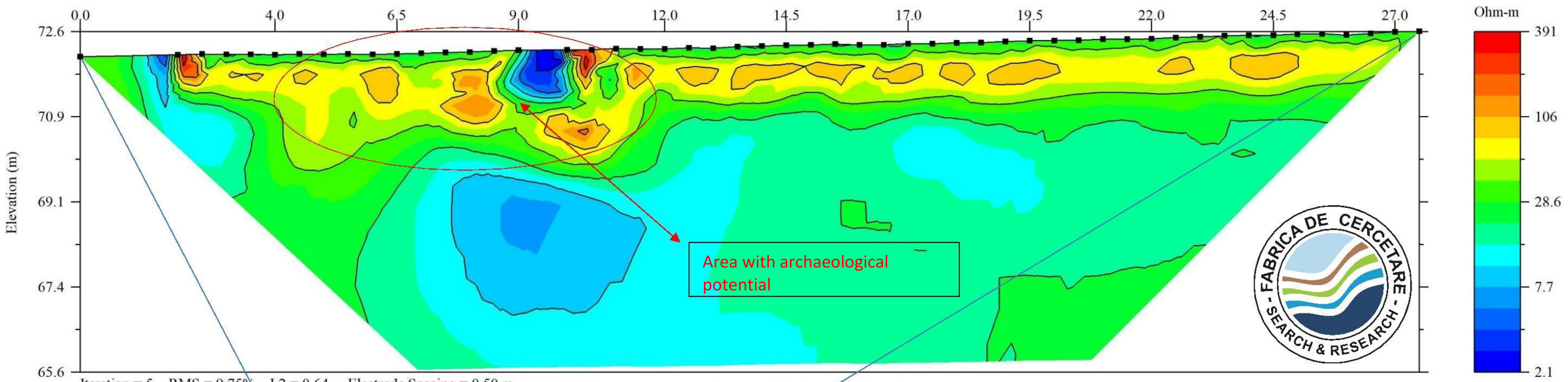
TOMOGRAFIE GEOELECTRICA DE REZISTIVITATE CT3, DIPOL-DIPOL, PARC DN3C, LOC. CONSTANTA



Iteration = 5 RMS = 9.75% L2 = 0.64 Electrode Spacing = 0.50 m

WWW.FABRICADECERCETARE.RO			
Job Code	CT3 Dipol-Dipol 0.5m	Survey Date	Aug 3, 2022
Project Site	Parc DN3C, Palazu MaRE, Constanța	Instrument	SuperSting R8
Approved By	Florin Filip	Software	EarthImager 2D
Data File	3CT3_trial7.stg		

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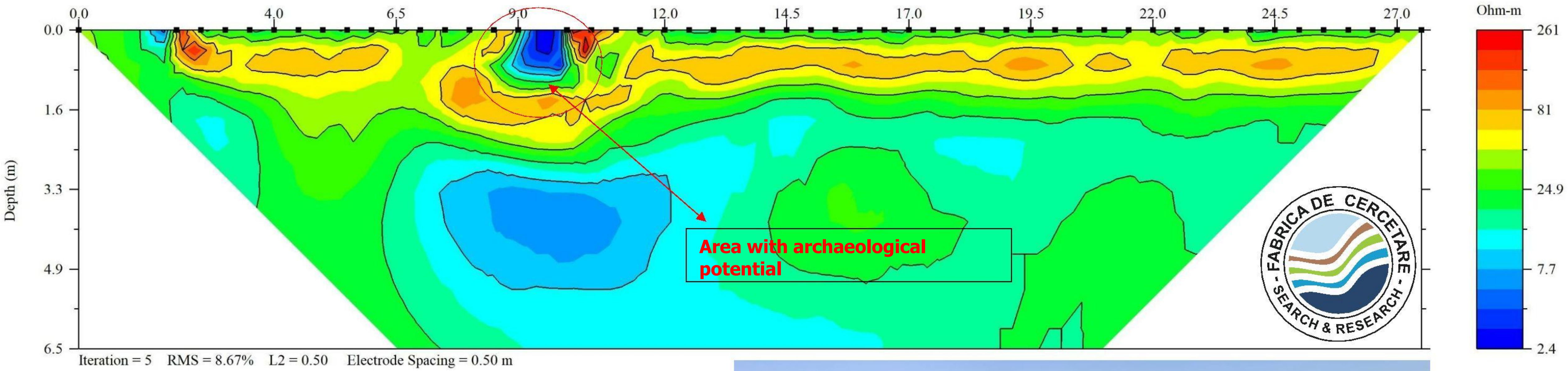
TOMOGRAFIE GEOELECTRICĂ DE REZISTIVITATE CT4, DIPOL-DIPOL, PARC DN3C, CONSTANTA



WWW.FABRICADECERCETARE.RO			
Job Code	CT4 Dipol-Dipol 1m	Survey Date	Aug 3, 2022
Project Site	Parc DN3C, Palazu MaRE, Constanța	Instrument	SuperSting R8
Approved By	Florin Filip	Software	EarthImager 2D
Data File	3CT4_trial6.stg		

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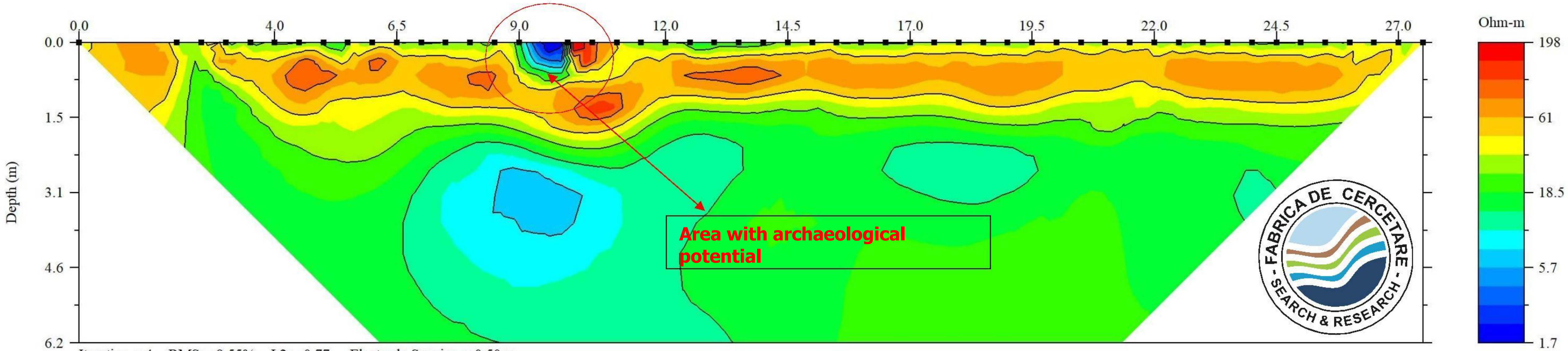
TOMOGRAFIE GEOELECTRICĂ DE REZISTIVITATE CT5, DIPOL-DIPOL, PARC DN3C, CONSTANTA



Iteration = 4 RMS = 9.55% L2 = 0.77 Electrode Spacing = 0.50 m

WWW.FABRICADECERCETARE.RO			
Job Code	CT5 Dipol-Dipol 1m	Survey Date	Aug 3, 2022
Project Site	Parc DN3C, Palazu MaRE, Constanța	Instrument	SuperSting R8
Approved By	Florin Filip	Software	EarthImager 2D
Data File	3CT5_trial4.stg		

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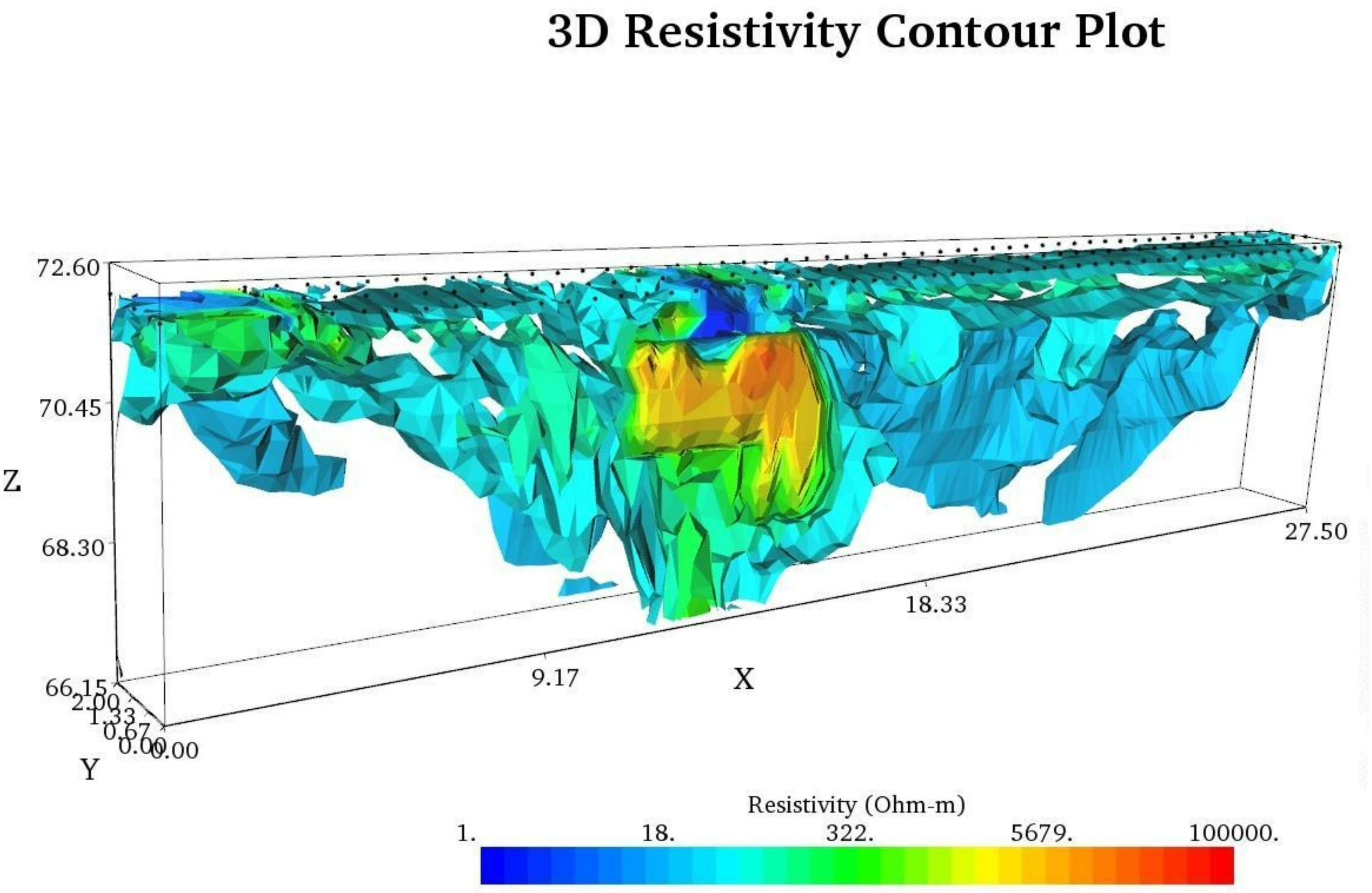
3D GEOELECTRICAL RESISTIVITY TOMOGRAPHY, PARK DN3C, CONSTANȚA TAU



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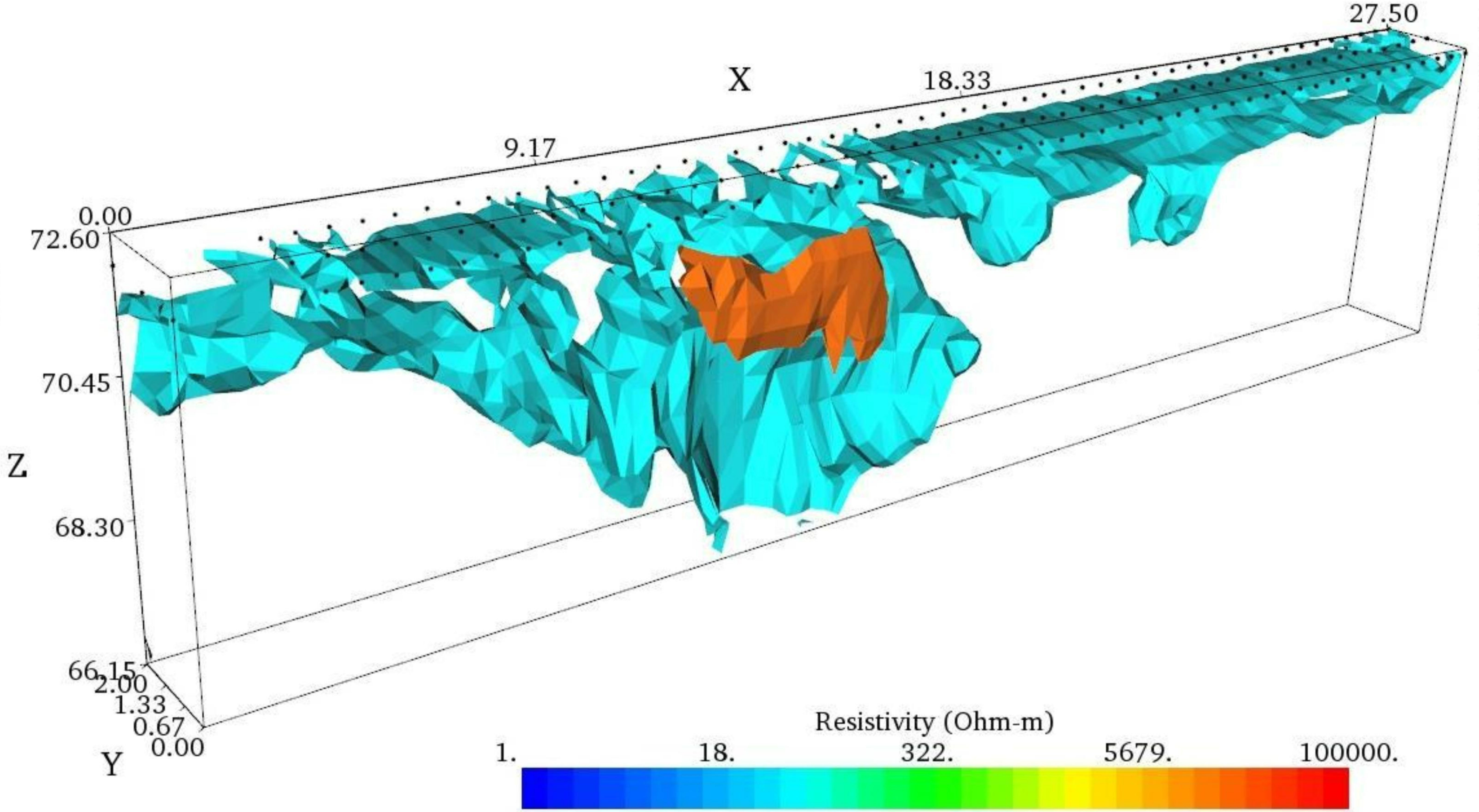
3D Resistivity Contour Plot



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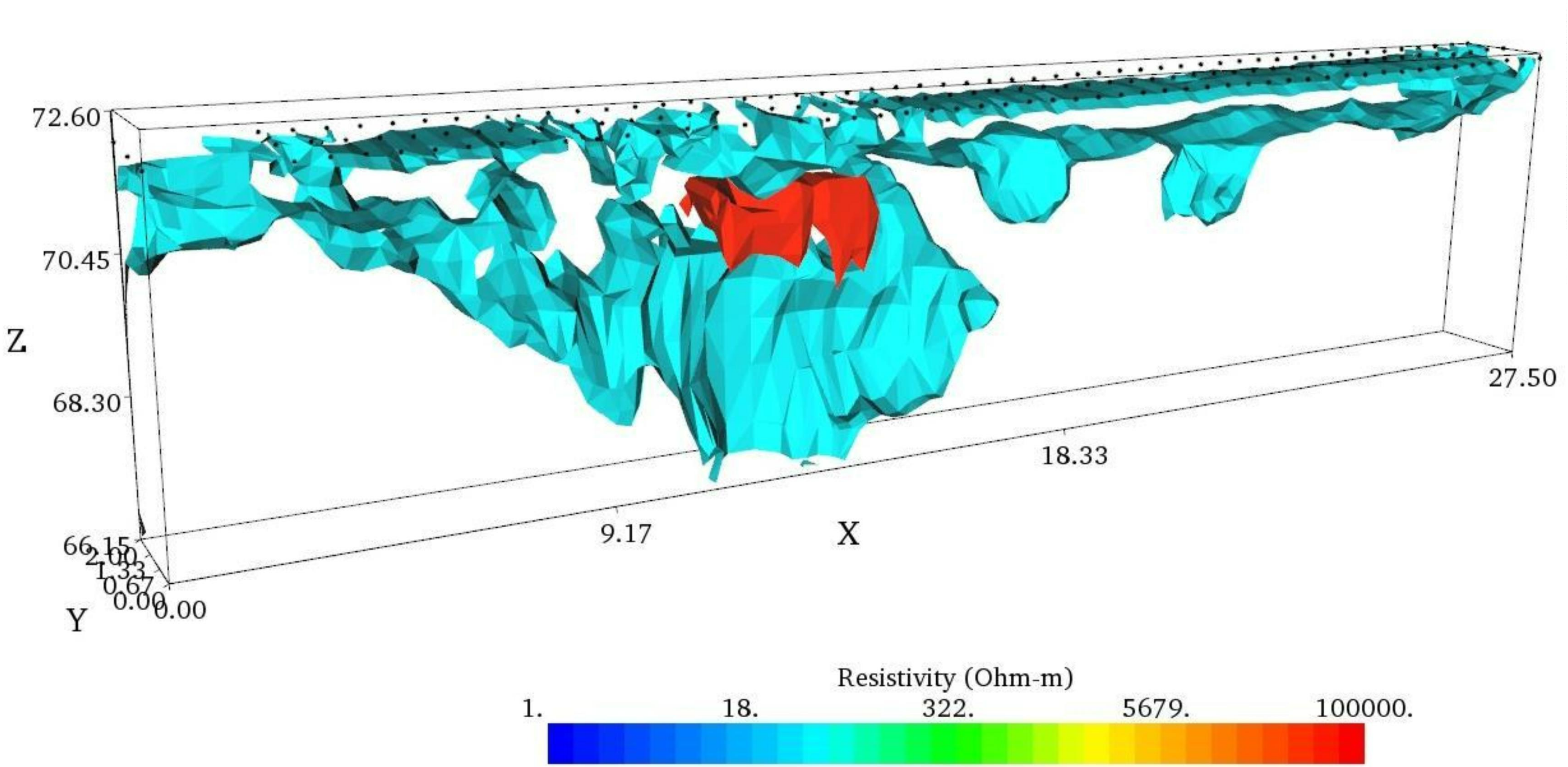
3D Resistivity Contour Plot



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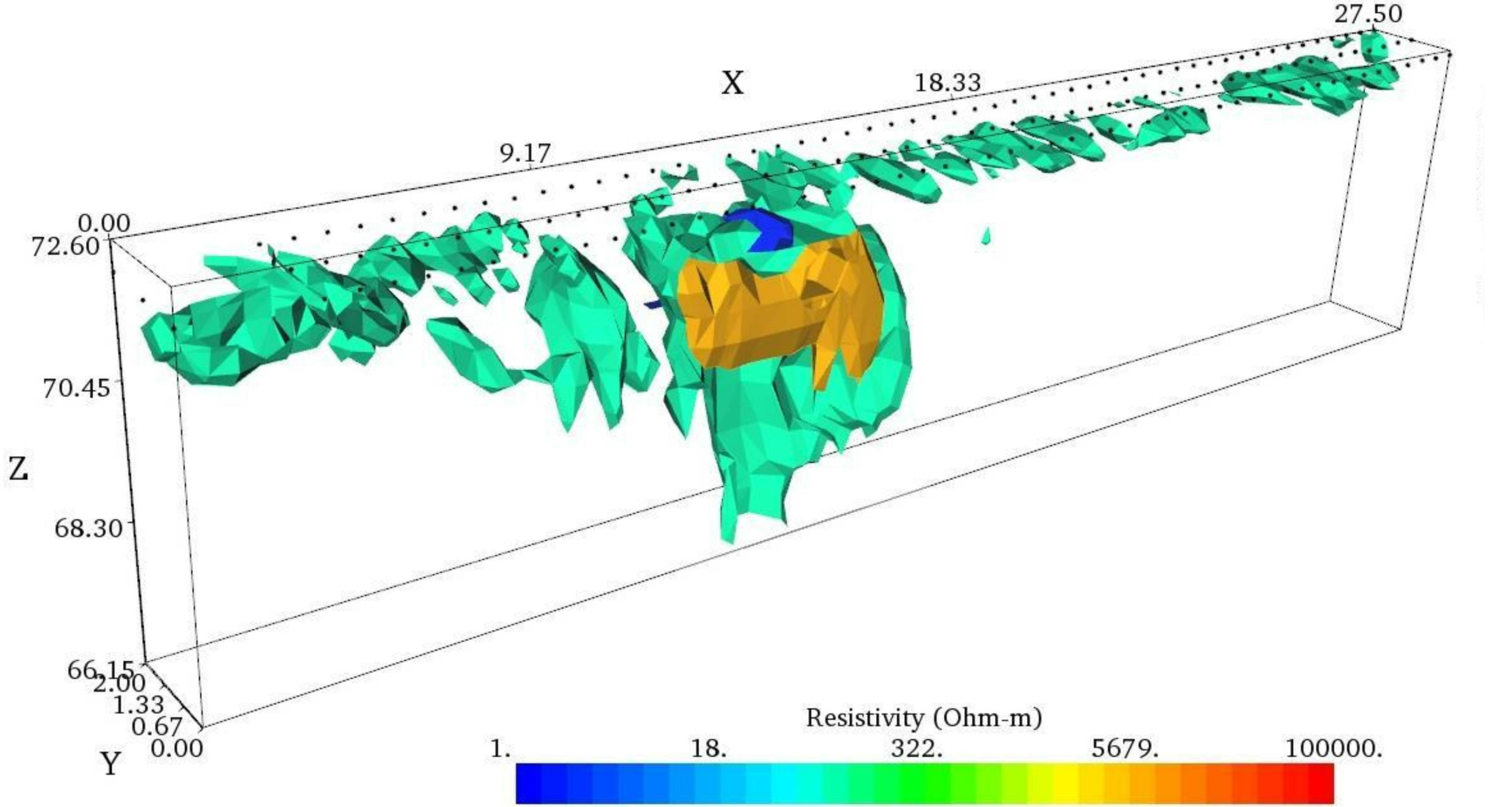

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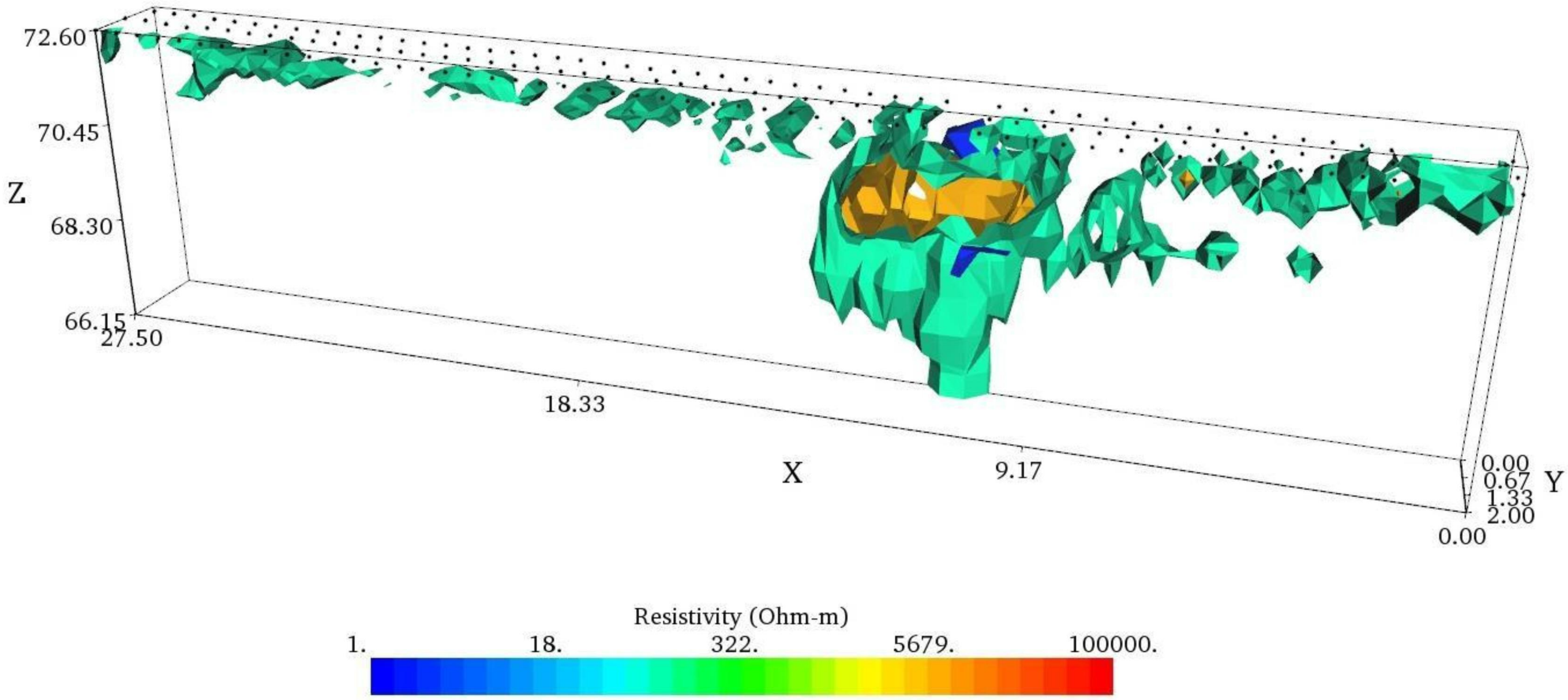

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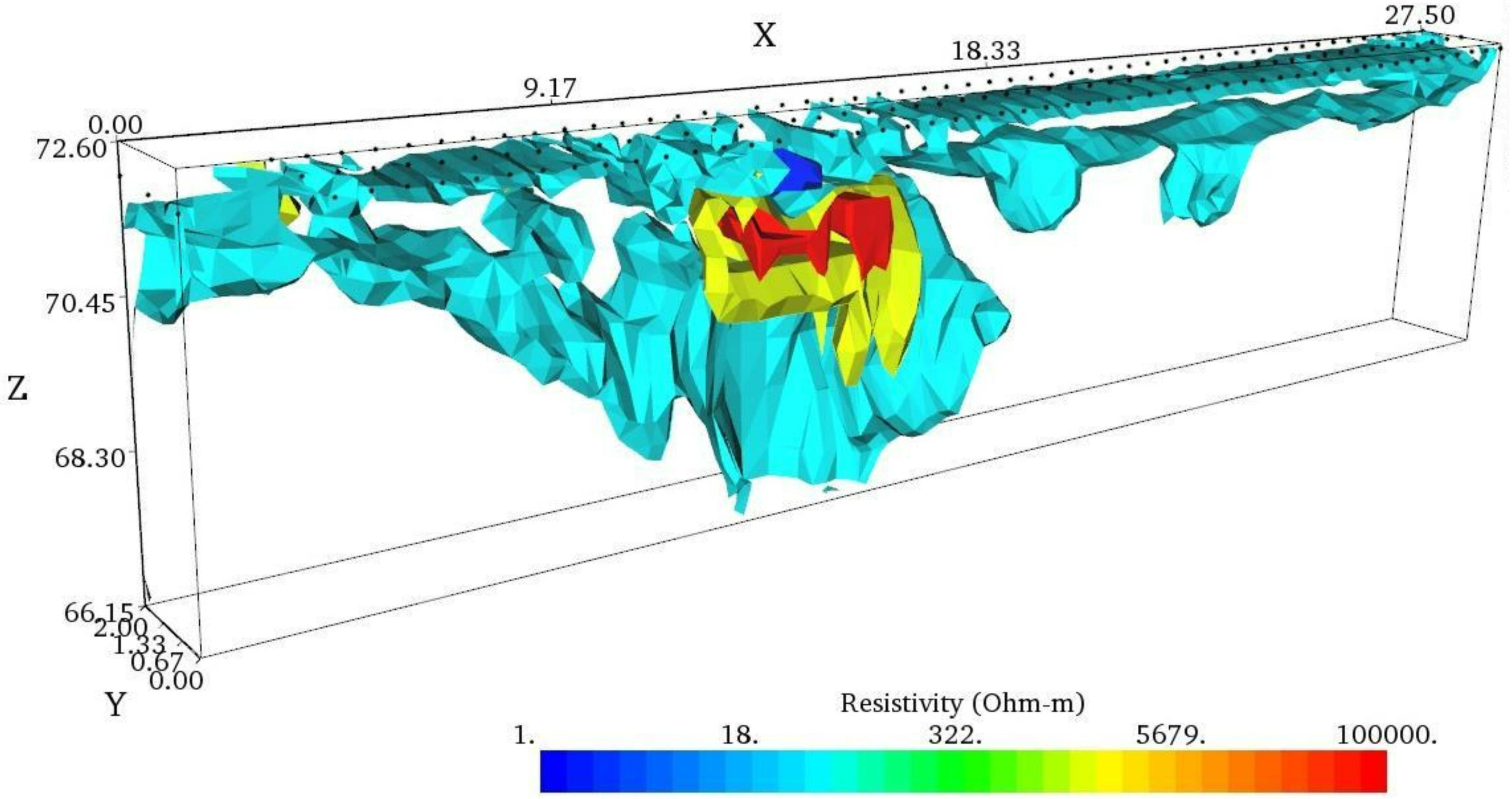

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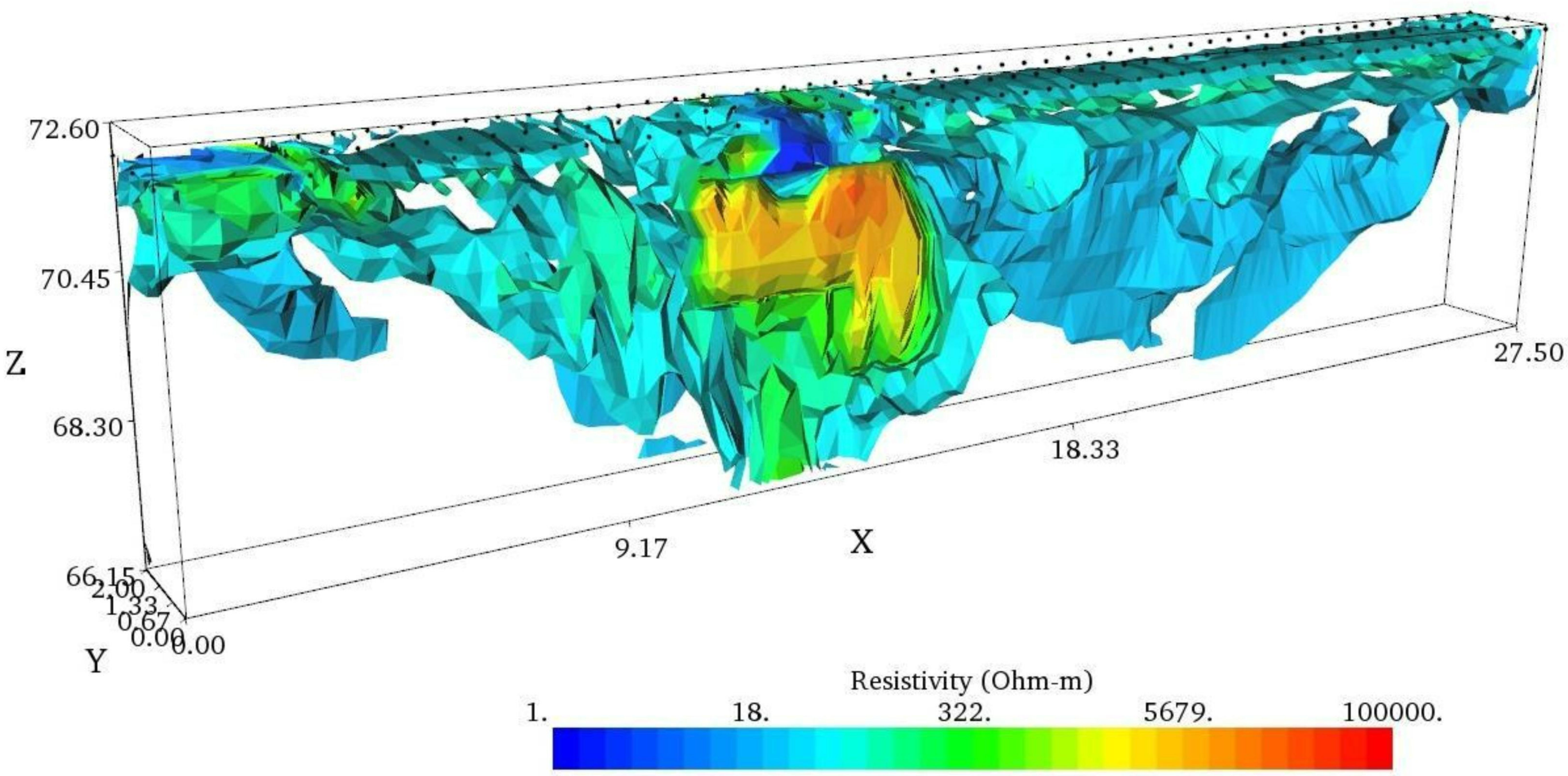

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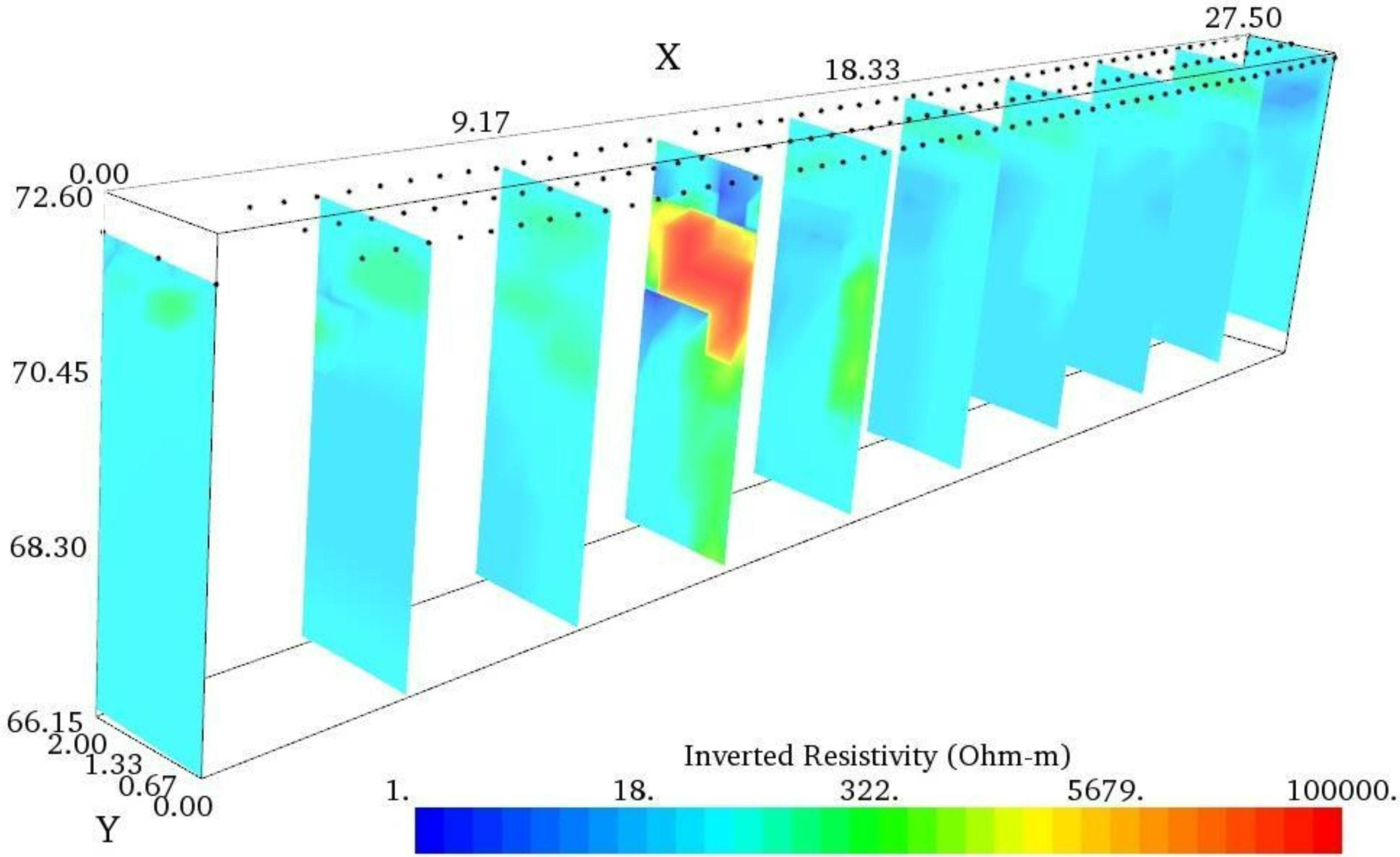
X Slices of Inverted Resistivity



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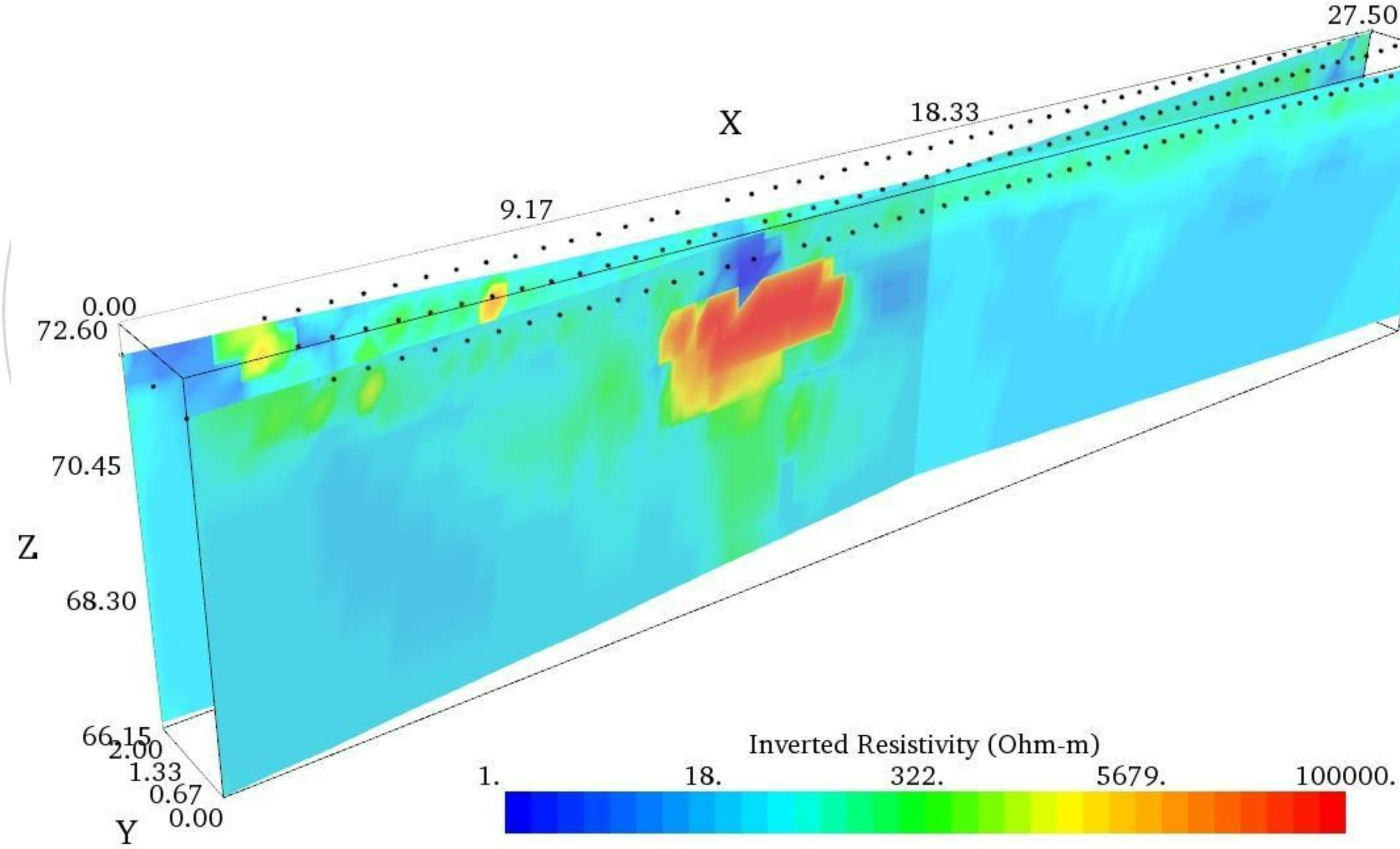
Diagonal Slices of Inverted Resistivity



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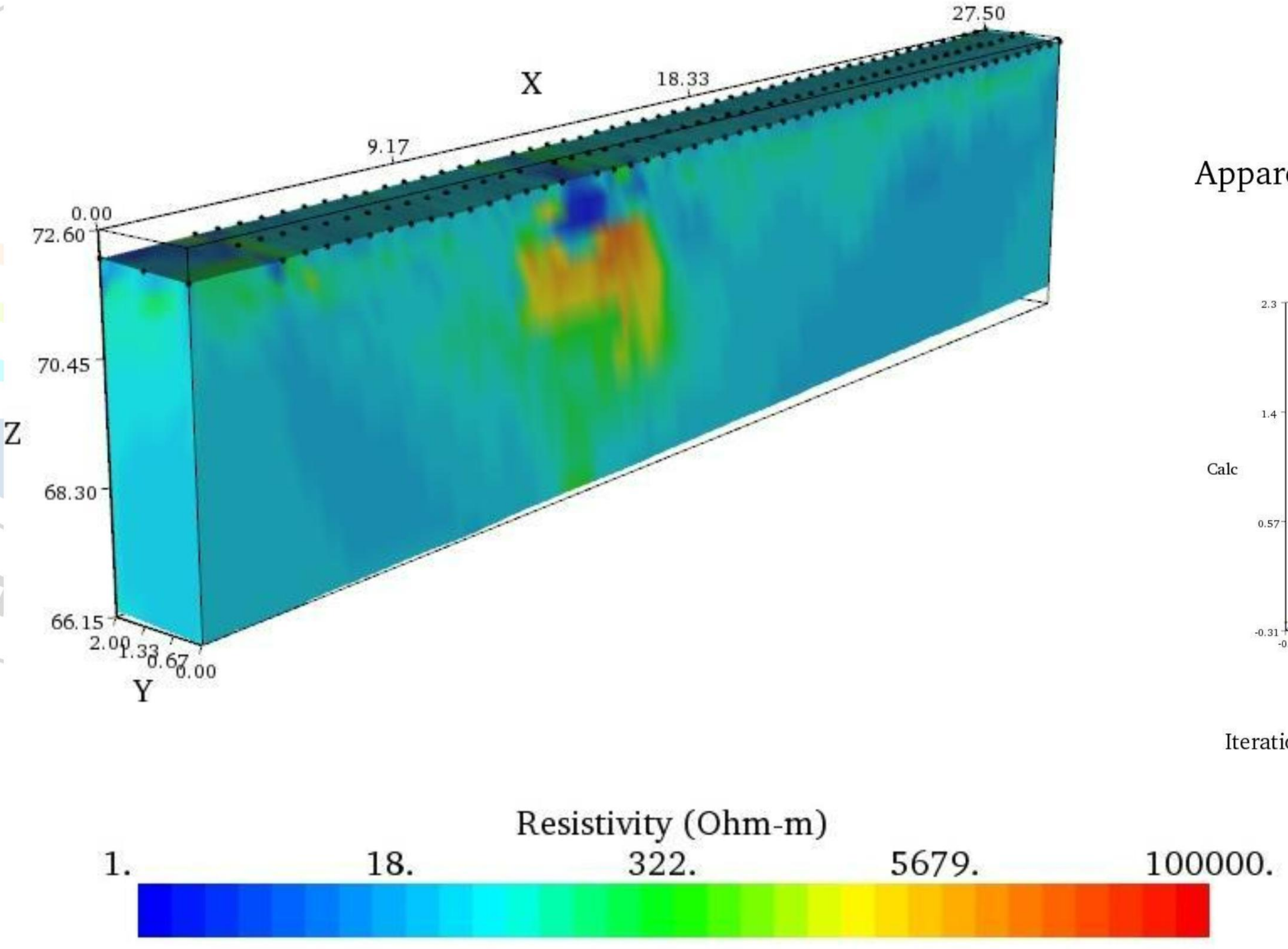
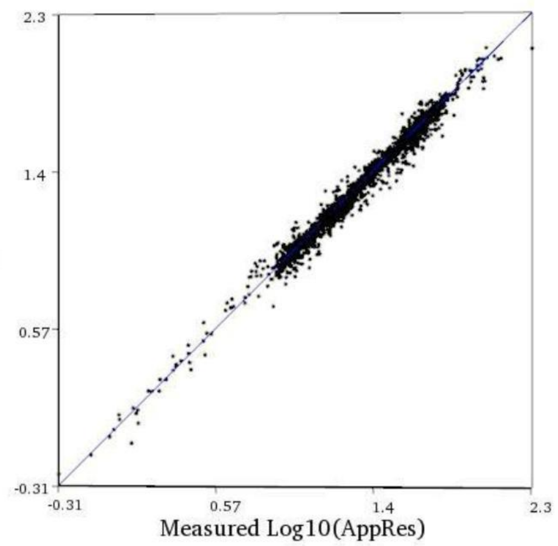
Inverted Resistivity Image



Apparent Resistivity Crossplot



Iteration No. 8. RMS = 7.3%. L2 = 2.1

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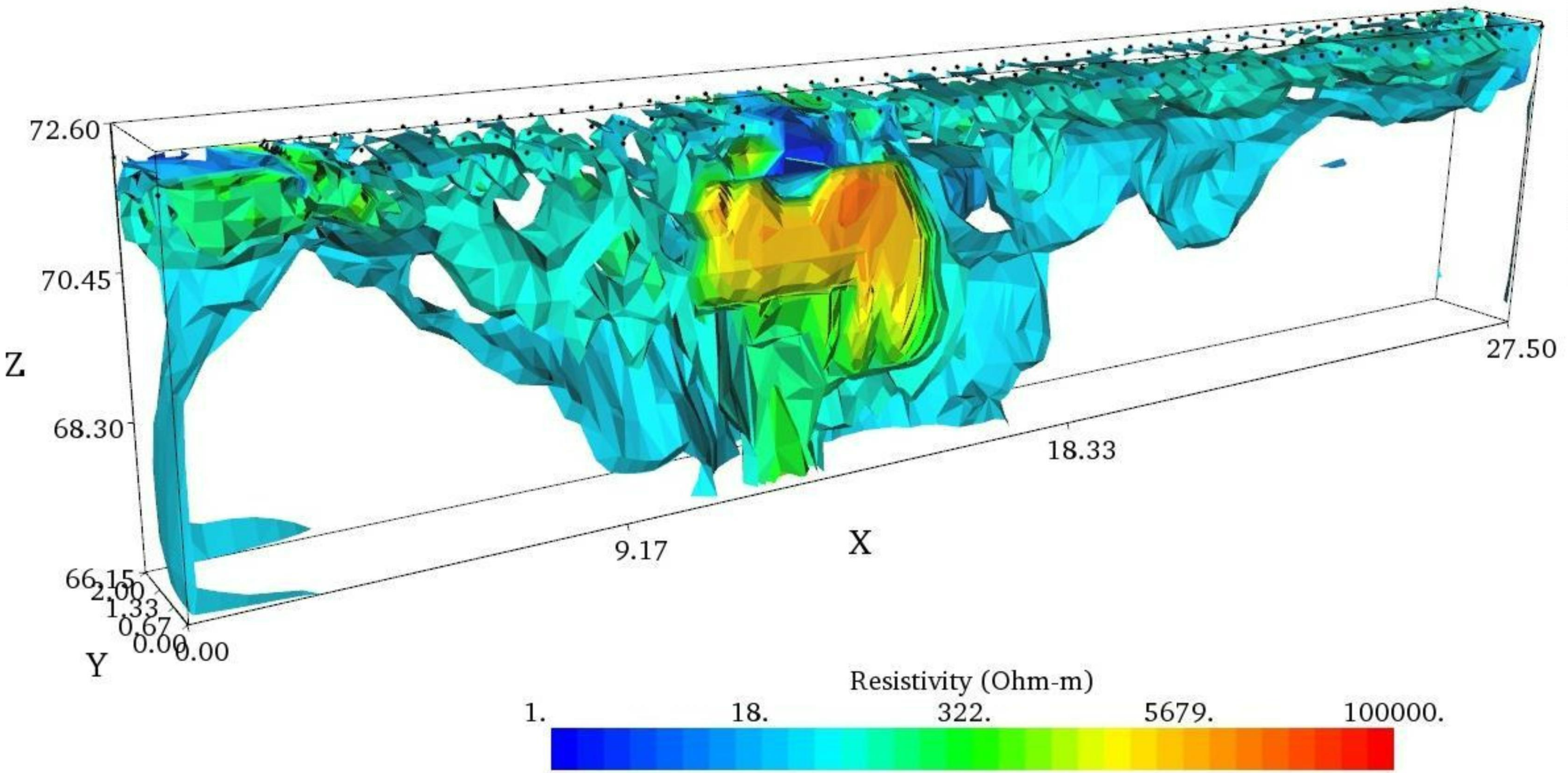
3D Resistivity Contour Plot



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3D Resistivity Contour Plot