Research paper

Interpretation challenges related to thick low- and high-resistivity layers in electrical resistivity surveys

Anna Lejzerowicz[1], Grzegorz Pacanowski[2], Maciej Maślakowski[3]

Abstract: Electrical Resistivity Tomography (ERT) is a versatile and widely applied geophysical method for subsurface imaging, but its reliability is strongly influenced by geological conditions. This study discusses principal challenges in surveys within thick low- and high-resistivity complexes, which distort inversion results and complicate hydrogeological and geotechnical interpretation. In low-resistivity packages (e.g., clays, marls), resistivity values are underestimated, while signals from deeper layers are attenuated, often causing downward displacement of boundaries. In high-resistivity environments (e.g., dry sands, silts), thin conductive interbeds are either masked or appear with artificially elevated resistivity values. Both situations reduce interpretational resolution and increase the risk of overlooking critical geological features. The paper emphasizes the role of survey resolution, controlled by electrode spacing, array configuration, and measurement density. Since resolution decreases with depth, small or thin structures are more reliably imaged in the shallow subsurface, whereas deeper horizons are prone to distortions. The integration of ERT results with borehole data is indispensable for constraining ambiguities and validating inversion outcomes. In addition, vertical resistivity-gradient analysis is proposed as a complementary tool, capable of revealing subtle lithological transitions that may remain undetected in conventional resistivity sections. Through case studies, it is shown how thick resistivity packages affect subsurface models and presents strategies for improving interpretation, including optimized survey design, gradient analysis, and borehole correlation. Despite inherent limitations, ERT remains effective for hydrogeological and engineering investigations, provided that methodological constraints and interpretational uncertainties are carefully addressed.

Keywords: Electrical Resistivity Tomography (ERT), geophysical methods, geotechnical investigations, high-resistivity layers, low-resistivity layers, signal attenuation

[1]PhD., Warsaw University of Technology, Faculty of Civil Engineering, Al. Armii Ludowej 16, 00-637 Warsaw, Poland, e-mail: anna.lejzerowicz@pw.edu.pl, ORCID: 0000-0002-1350-0632
[2]DSc., Eng., Polish Geological Institute – National Research Institute, Rakowiecka 4, 00-975 Warsaw, Poland, e-mail: grzegorz.pacanowski@pgi.gov.pl, ORCID: 0000-0001-9045-3262
[3]PhD., Warsaw University of Technology, Faculty of Civil Engineering, Al. Armii Ludowej 16, 00-637 Warsaw, Poland, e-mail: maciej.maslakowski@pw.edu.pl, ORCID: 0000-0002-2946-1594

1. Introduction

Conducting field electrical resistivity surveys in areas where cohesive deposits or low-resistivity weathered rocks occur directly at the surface usually does not pose technical difficulties [1]. Such measurements are relatively straightforward and quick to perform. However, the presence of thick low-resistivity complexes may introduce interpretational challenges, particularly when thin high-resistivity layers (e.g., sands) are present beneath them [2]. These difficulties are further exacerbated when the above-mentioned layers occur within inter-till horizons. In both hydrogeological investigations and engineering-geotechnical studies, this represents a significant challenge that the authors wish to highlight.

A different, yet equally important issue arises in surveys conducted in forested areas (including pine forests) developed on sandy substrate. In such environments, the groundwater table is often located at considerable depth, while the near-surface layers are dry, consisting mainly of sands and silts. This zone is characterized by very high resistivity values, ranging from several thousand up to several tens of thousands of $\Omega \cdot m$ [3]. As a result, the current injected into the ground encounters significant difficulties in returning to the potential electrodes, which may lead to situations where the signal is only weakly registered or not detected at all [4].

One of the main sources of measurement error in such cases is the high contact resistance of electrodes. This issue, together with possible mitigation strategies, has been discussed in detail by [5], who emphasized the importance of careful site preparation and proper optimization of electrode configurations under difficult field conditions. Such problems have a direct impact on the reliability of acquired data, and consequently on the interpretation process.

In the case of thick low- and high-resistivity zones, specific difficulties arise when attempting to match the resistivity model with the actual geological structure. Phenomena such as the screening of thin layers by strongly contrasting complexes, or the downward displacement of layer boundaries during inversion, represent significant interpretational challenges [6, 7]. This problem is particularly evident in geological settings dominated by thick low-resistivity complexes (e.g., cohesive deposits), within which thin layers or lenses of cohesionless sediments, such as sands or gravels, occur. In such cases, the results may be ambiguous and require detailed, case-specific analysis [8].

Comparable difficulties are encountered in the case of thick high-resistivity complexes containing low-resistivity interbeds, such as clayey or argillaceous layers. Here, the geophysical signal generated by low-resistivity horizons may be strongly attenuated by the surrounding high-resistivity formations, making their detection and accurate parameterization problematic [9, 10]. This leads to reduced interpretational resolution of the model and increases the risk of overlooking important geological features that may be critical from both hydrogeological and geotechnical perspectives.

In low-resistivity packages, an underestimation of the resistivity of underlying layers is often observed, which hampers unambiguous assignment to specific lithological units. In high-resistivity packages, the opposite occurs: thin low-resistivity layers embedded within a resistive complex tend to appear with artificially elevated resistivity after inversion. This represents a significant limitation of electrical resistivity tomography, as inversion algorithms do not always effectively compensate for these effects, potentially leading to distortions in the reconstructed geological structure [11, 12].

The study also emphasizes the importance of analyzing vertical gradient distributions, which – when properly applied – can provide more detailed insights into the geological framework than resistivity values alone. Such analysis allows for better identification of

transitional zones between layers with contrasting resistivity properties, detection of anomalies that are difficult to recognize in conventional resistivity sections, and verification of the consistency between geophysical models and geological/hydrogeological data.

In this paper, several examples are presented to illustrate the main problems encountered during the acquisition and interpretation of resistivity data in complex geological settings. The discussion addresses phenomena that degrade data quality, difficulties in imaging thin layers, and inversion effects that can distort the subsurface model. An interpretational approach is also proposed which, by combining vertical gradient analysis, preliminary modeling, and borehole correlation, can significantly improve the reliability of interpretations and reduce the risk of error. This paper does not provide a detailed description of field procedures or data processing methodologies in electrical resistivity tomography. Accounts of these aspects – including survey configuration design, electrode grounding issues, multi-model inversion strategies, and methods of data quality assessment – can be found in the literature, e.g., [13, 14].

2. Resolution of electrical resistivity surveys

By way of introduction to the following discussion, the issue of survey resolution is briefly addressed here. This aspect is of critical importance for understanding many of the common problems that arise in the interpretation of resistivity data and models.

Spatial resolution refers to the ability of a geophysical method to detect and image geological features of a given size. In practice, it defines the minimum dimensions of structures that can be reliably recorded and interpreted. Resolution depends on several factors, including the parameters of the method, the measurement configuration, the target depth, and the physical contrast between the object and its surrounding medium [15].

Although the concept of resistivity survey resolution is relatively straightforward, it is often overlooked that the resistivity model obtained represents only a simplified and generalized image of the actual geological structure – one that is strongly dependent on the resolution of the applied method. In the case of ERT, resolution is controlled by:
– electrode spacing (measurement step),
– the measurement array applied (e.g., Wenner, Dipole-Dipole),
– the density of the survey grid (in 3D or 2.5D acquisition).

In practice, it is generally assumed that a target must have dimensions equal to at least half of the electrode spacing in order to be resolved in the model. At depths greater than 30 m, the effective resolution may drop to less than 10–15 m, even when large electrode separations are employed [16].

Whether individual layers or other geological features are resolved in the model also depends heavily on the resistivity contrast between adjacent geological complexes. If layers with markedly different electrical properties are present – such as low-resistivity clays and high-resistivity sands – the boundary between them will be clearly expressed in the resistivity section. By contrast, when layers have similar resistivity values – for example, sandy clays and clayey sands – the boundary will appear diffuse, and in some cases may be impossible to distinguish. In general, it is assumed that the ratio of the average resistivity of a higher-resistivity layer to that of the underlying lower-resistivity layer reflects the degree of contrast: the higher the ratio, the greater the contrast, and thus the better the ability to resolve the boundary in the model [17].

It should be emphasized, however, that even strong resistivity contrasts do not always guarantee accurate imaging. For example, in the case of a thick high-resistivity layer containing a thin low-resistivity interbed, the masking effect of the surrounding resistive medium, combined with the limitations of vertical resolution, may cause the interbed to appear only faintly in the model or to be represented with artificially elevated resistivity values due to inversion artifacts [17]. This represents a significant interpretational limitation in electrical resistivity tomography and calls for a cautious analytical approach.

The final quality of a resistivity model also depends on both vertical and horizontal resolution, which in turn are determined by the distribution of measurement points. The role of the field survey designer is therefore critical: the profile layout, the acquisition technique, and the choice of electrode spacing all exert a direct influence on the level of detail and accuracy of the acquired data.

Finally, it should be remembered that resolution decreases with increasing depth. This means that small objects or thin layers are much easier to detect at shallow depths than at greater depths (Fig. 1).
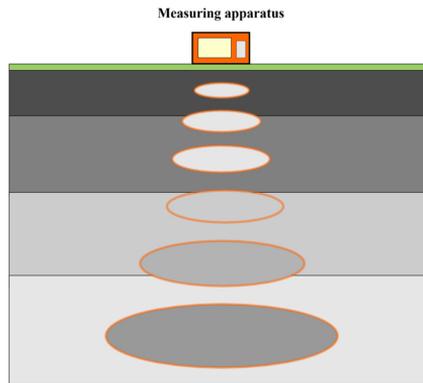

Fig. 1. Example illustrating the concept of decreasing survey resolution with increasing depth

In the ERT method, survey design requires prior determination of the measurement step, i.e., the spacing between successive electrodes. This parameter directly affects the spatial resolution of the survey, both horizontally and vertically. As shown in Fig. 2, the application of different electrode spacings results in significantly different coverage of the investigated subsurface with measurement points.

The obtained results (measured resistivity values) are significantly influenced by the chemical and mineral composition of the medium (here understood as soils, rocks, as well as the water contained within them) [18]. In addition, resistivity is affected by the structure and texture of the soils/rocks (the arrangement of layers within the medium), as well as by the thermobaric conditions of the subsurface – although the latter factor is generally negligible in the case of shallow surveys, i.e., to depths of a few to several tens of meters.

The use of different electrode spacings during measurements may yield varying resistivity distribution models. Therefore, the selection of electrode spacing can sometimes be crucial for achieving the intended objectives of the survey.
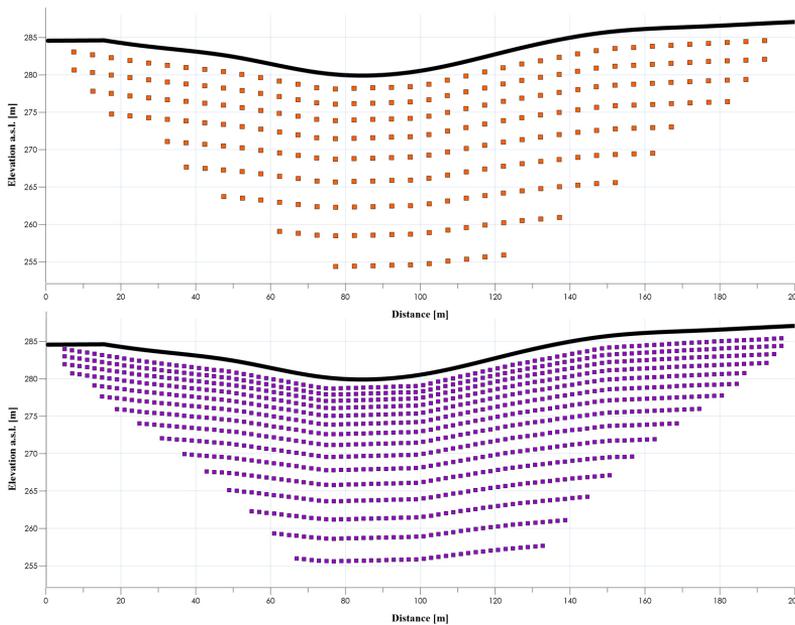
Fig. 2. Example distribution of measurement points in the investigated area for an electrode spacing of 5 m (orange) and 2 m (purple)

3. Thick low-resistivity layers

As mentioned earlier, thick low-resistivity packages pose a significant challenge in the interpretation of geophysical data, as their presence can substantially distort the images generated by resistivity models. The most commonly observed effect is the underestimation of resistivity values within such packages, along with a reduction in the resistivity of underlying layers. This phenomenon results from the conductive character of low-resistivity complexes, which can screen weaker signals originating from deeper parts of the subsurface. This issue is particularly critical in surveys performed using ERT. Under conditions of strong resistivity contrasts, the inversion process often introduces additional distortions into the model parameters. As a consequence, thin high-resistivity interbeds located within or beneath a low-resistivity package may remain undetected or be represented in a manner inconsistent with the actual geological structure [19].

It should also be noted that within cohesive sediments, fine clay particles can be washed out by groundwater and subsequently transported into sandy layers that serve as aquifer horizons. Such processes may reduce the resistivity of these sandy deposits, even though lithologically they would normally be classified as potentially high-resistivity formations. Another factor that must be considered is water mineralization, which – through its effect on electrolyte conductivity – often leads to a substantial decrease in the resistivity values of aquifer layers [19, 20].

The following sections will presents examples illustrating the scale and nature of this problem, along with a discussion of the potential implications for both hydrogeological and geotechnical interpretation.

3.1. Profiling of thick low-resistivity packages (marly–clayey) with high-resistivity interbeds (sandy)

The following results were obtained from geophysical surveys conducted to refine the geological structure within the framework of an existing geological-engineering documentation [21]. The main objective of the surveys was to determine the increased thickness of sandy deposits in the near-surface zone, as borehole data had indicated the possible occurrence of local depressions within the clay complex.

In the resistivity surveys, profiles were measured with an electrode spacing of 5 m along the survey line, providing a depth of investigation of approximately 30 m below the ground surface. Based on the distribution of resistivity values and their variability in the sections, three main lithological categories were distinguished (Fig. 3):

– high-resistivity unit (I), with values above 50 Ω·m and locally exceeding 1000 Ω·m – corresponding to a sand-gravel complex of variable moisture content, locally represented by silty and/or clayey sands, as well as uncontrolled fill;
– low-resistivity unit (II), with resistivity between 10 and 50 Ω·m – corresponding to a marly-clayey complex; and
– medium-resistivity unit (III), with resistivity below 20–40 Ω·m in the lower parts of the section – corresponding to weathered older formations and clayey sands.

A distinct resistivity contrast is observed at the boundary between the sandy/sand-gravel complex and the marly-clayey complex. It should be noted that the marly-clayey complex is characterized by very low variability in resistivity values. Based on the survey results, it is not possible to reliably distinguish marl from clay, as the resistivity values of these two lithologies are very similar. Furthermore, according to resistivity characteristics of marls reported in the literature [22], in the investigated area they exhibit extremely low values, which further complicates their differentiation in geophysical interpretation. This phenomenon must be carefully considered during data analysis, as it may lead to the averaging of resistivity parameters and the blurring of true lithological boundaries in inversion modelstages.
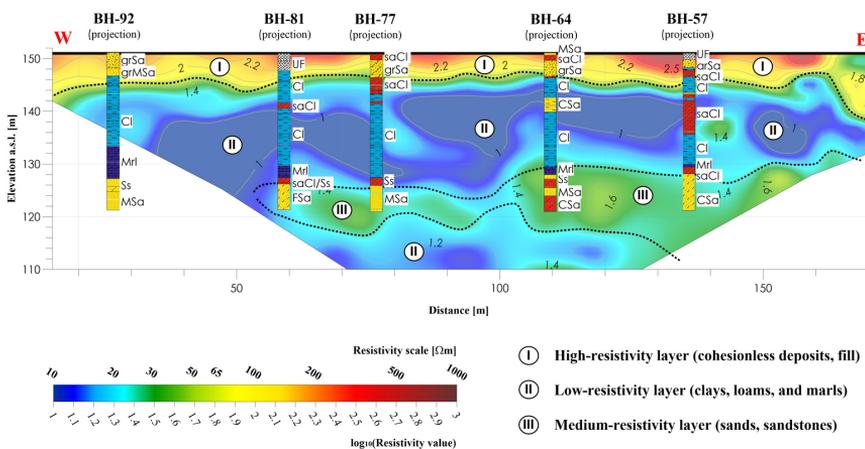

Fig. 3. Resistivity cross-section showing a thick (> 20 m) package of low-resistivity clays and marls

The resistivity cross-sections were supplemented with lithological data from boreholes located along or near the geophysical profiles. In some places, the correlation with borehole data is not perfect – i.e., boundaries interpreted from resistivity surveys are slightly displaced relative to those identified in drilling logs. This discrepancy can be attributed to three main factors:

- Resolution of the method. For the adopted survey design (5 m electrode spacing), the vertical resolution in the upper part of the section is approximately 1.5 m, decreasing to around 4–5 m at greater depths. Nevertheless, when this margin of error is considered, borehole profiles generally correlate quite well with the resistivity results.
- Projection of boreholes onto the cross-sections. A discrepancy of 1–2 m in the depth of a layer is entirely plausible for a borehole projected from a distance of 20–30 m.
- Strong resistivity gradients.

As illustrated in Fig. 3, the resistivity values of sands underlying the marly-clayey complex range from 35 to 40 $\Omega \cdot$m, which is lower than the values typically recorded for cohesionless sediments. These underestimated values (by approximately 40–50 $\Omega \cdot$m) are most likely the result of the influence exerted by the overlying clayey and marly deposits. Without correlating the geophysical data with borehole information, a correct interpretation would be difficult to achieve based solely on resistivity results. This serves as a representative example of how a low-resistivity overburden can affect the measured resistivity of underlying layers. It also illustrates the phenomenon of screening, where layers situated beneath a low-resistivity complex (marly-clayey) become masked in the resistivity response.

3.2. Influence of resolution on resistivity-based detection of thin sandy interbeds

Resistivity surveys were carried out to investigate an area of approximately 1 km^2 prior to drilling, with the aim of developing a preliminary geological model [23]. The obtained results showed very little variability within the interpreted resistivity ranges – overall, a low-resistivity model was obtained (Fig. 4), characteristic of cohesive deposits, specifically glacial tills.
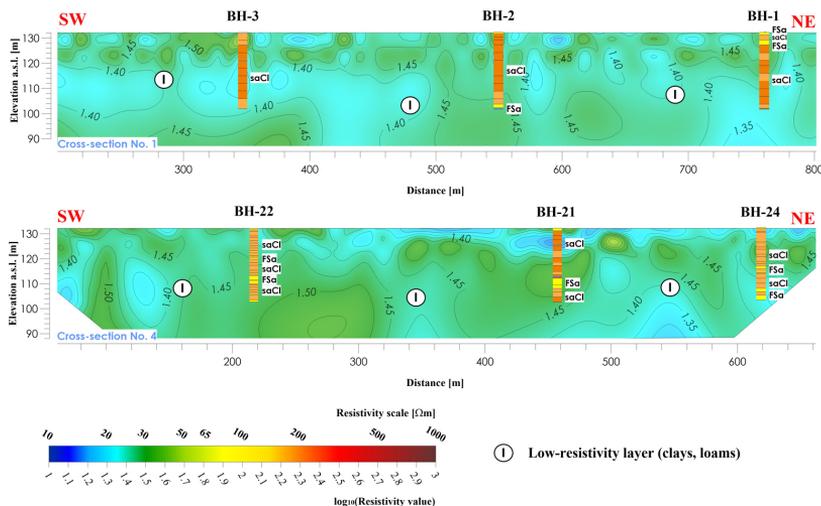

Fig. 4. Example of low-resistivity ERT cross-sections in which thin sandy layers were not detected. Subsequent boreholes confirmed the presence of these layers

All of the cross-sections revealed a very similar geological model, and the boreholes drilled in the subsequent stage of work confirmed this type of structure as dominant. However, in many locations, thin layers of fine sands with thicknesses not exceeding 2–3 m were encountered. These layers are not represented in the resistivity model on any of the sections. Likewise, resistivity distribution maps prepared on the basis of ERT data at several selected depth levels do not indicate the presence of such zones. The resistivity maps also displayed a pattern of only minor variability in resistivity values (Fig. 5).
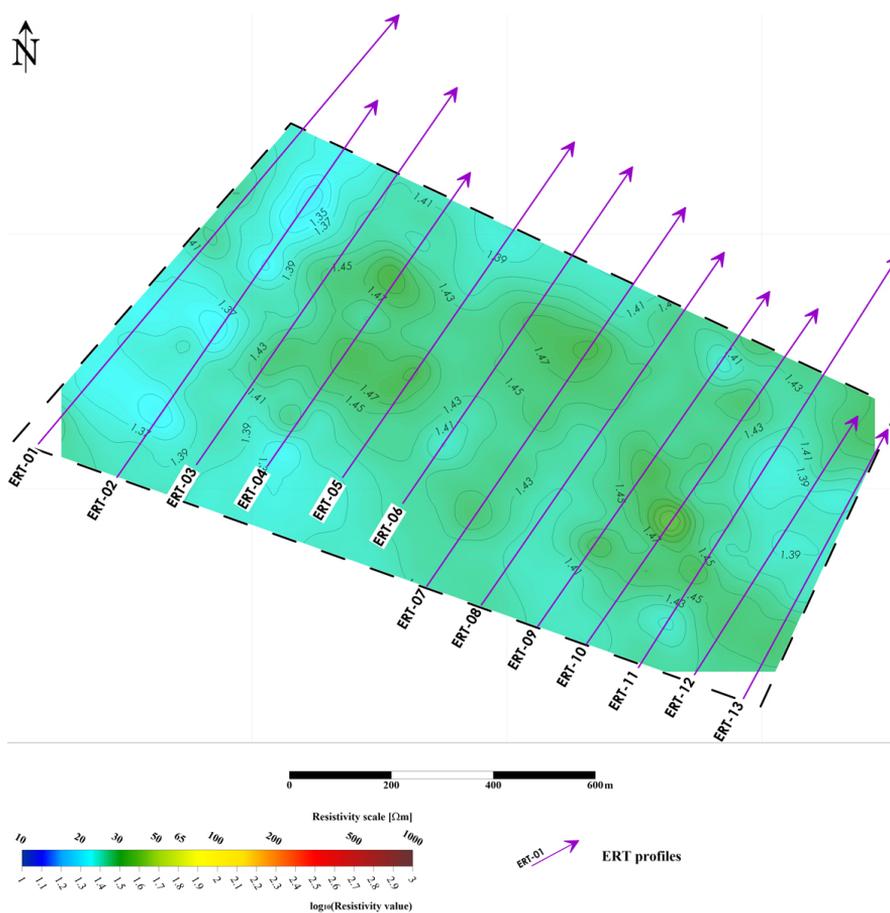

Fig. 5. Example of a low-resistivity distribution map interpreted at an elevation of 110 m a.s.l. (at a depth of approx. 20 m b.g.l.)

Most likely, the survey resolution was too low (electrode spacing of 5 m) to detect higher-resistivity zones in the resistivity cross-sections (thin sandy interbeds of limited thickness). Alternatively, the resistivity of the sands may not have been typical – i.e., in the range of 80–150 Ω·m – but instead reduced due to the leaching of dispersed clay material from the overlying layers.

4. Thick high-resistivity layers

Thick high-resistivity packages present challenges both during fieldwork and in the interpretation of geophysical survey results. The issues outlined in the introduction are examined in greater detail in the following sections. Field experience shows that data acquired in such geological settings are often subject to significant interpretational errors, resulting both from technological limitations and from the inherent properties of the subsurface.

A thick high-resistivity layer frequently prevents the accurate identification of smaller internal structures, such as cohesive interbeds or thin lenses of cohesionless sediments. These difficulties are particularly pronounced in Quaternary deposits, where sands and silts with high resistivity values dominate the near-surface strata. Under such conditions, potential low-resistivity interbeds may either remain undetected or be represented in a way that deviates from the true geological structure.

The resistivity imaging examples presented in the following sections illustrate the impact of thick high-resistivity layers on the quality and reliability of the acquired data. The principal difficulty in such cases is the overestimation of resistivity values within high-resistivity complexes, caused by the screening effect of the surrounding medium [24]. A further inversion-related artifact commonly observed is the downward displacement of layer boundaries, which distorts the geological image and may lead to incorrect interpretational conclusions.

Particular attention should also be paid to the behavior of near-surface high-resistivity layers, which can effectively mask deeper structures and reduce the clarity of the recorded signal. In such cases, vertical gradient analysis can serve as a valuable complement to conventional interpretation, providing more detailed insights into the geological framework and improving the recognition of transitional zones [25].

The following subsections present examples illustrating these phenomena, accompanied by a discussion of potential methods for minimizing interpretational errors and optimizing resistivity imaging in geophysical investigations.

4.1. Resistivity characterization of expressway route subsurface: high-resistivity zones and resolution limits

The resistivity cross-section fragment (Fig. 6) originates from northwestern Poland and was acquired as part of surveys conducted for a planned expressway route [26].

The resistivity distribution reveals a thick (approx. 30 m) high-resistivity zone. Geological investigations based on boreholes are relatively detailed in this section, although only one borehole reached a greater depth (approx. 20 m). According to borehole lithology, the analyzed interval consists exclusively of cohesionless deposits, such as fine and medium sands.
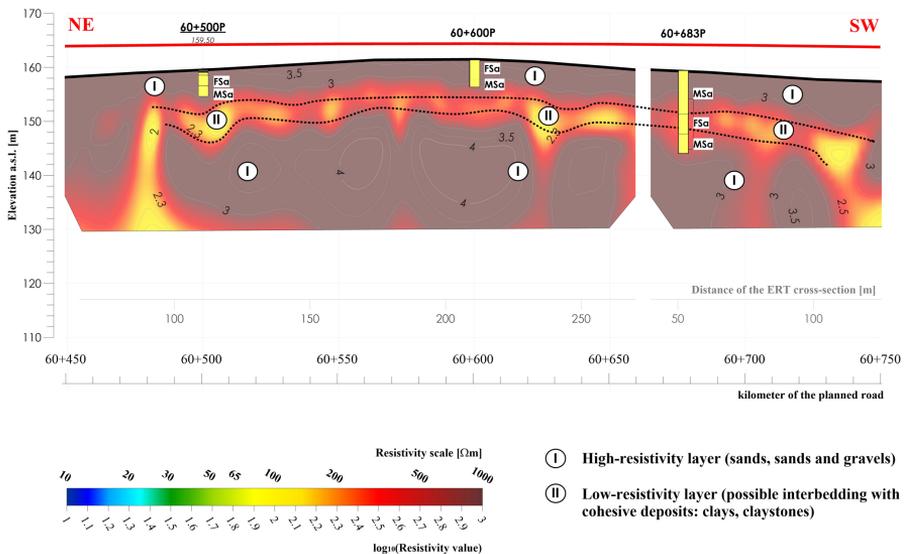
Fig. 6. Example of a high-resistivity geoelectrical cross-section acquired as part of a geological-engineering survey for a planned expressway route

Within the resistivity model, a lower-resistivity zone appears at a depth of around 10 m. Although the resistivity values in this interval remain relatively high – consistent with sandy deposits – the interpretation, albeit with some uncertainty, suggested the possible presence of cohesive interbeds. Borehole 60+683P identified fine sands within this depth range. A distinct gradient cutting through the zone, where resistivity values reach several hundred Ω·m, may indicate the presence of a lower-resistivity layer.

Due to the limited resolution of the method and the screening effect of surrounding high-resistivity formations, this zone appears with elevated resistivity values but should nevertheless be recognized during interpretation. It may reflect local lithological variations within the sands or the occurrence of cohesive deposits.

4.2. Imaging thin cohesive layers beneath high-resistivity sands with dense electrode spacing

ERT surveys were conducted for the planned section of the Eastern Bypass of Warsaw [27]. In this area, the geological structure is dominated by sandy deposits. However, at a relatively shallow depth of about 5 m, a cohesive layer is present. This layer, composed of lacustrine clays and tills, exhibits variable thickness ranging from 1 to 3 m (Fig. 7). Based on archival information confirming its presence, geophysical surveys were carried out across the area using an electrode spacing of 2 m. The application of such a measurement step allowed this layer to be imaged, although the vertical correlation of its precise position is not perfect. This is due to methodological limitations such as screening by overlying high-resistivity sands, distortions associated with lower-resistivity layers, and the presence of deeper-lying structures.
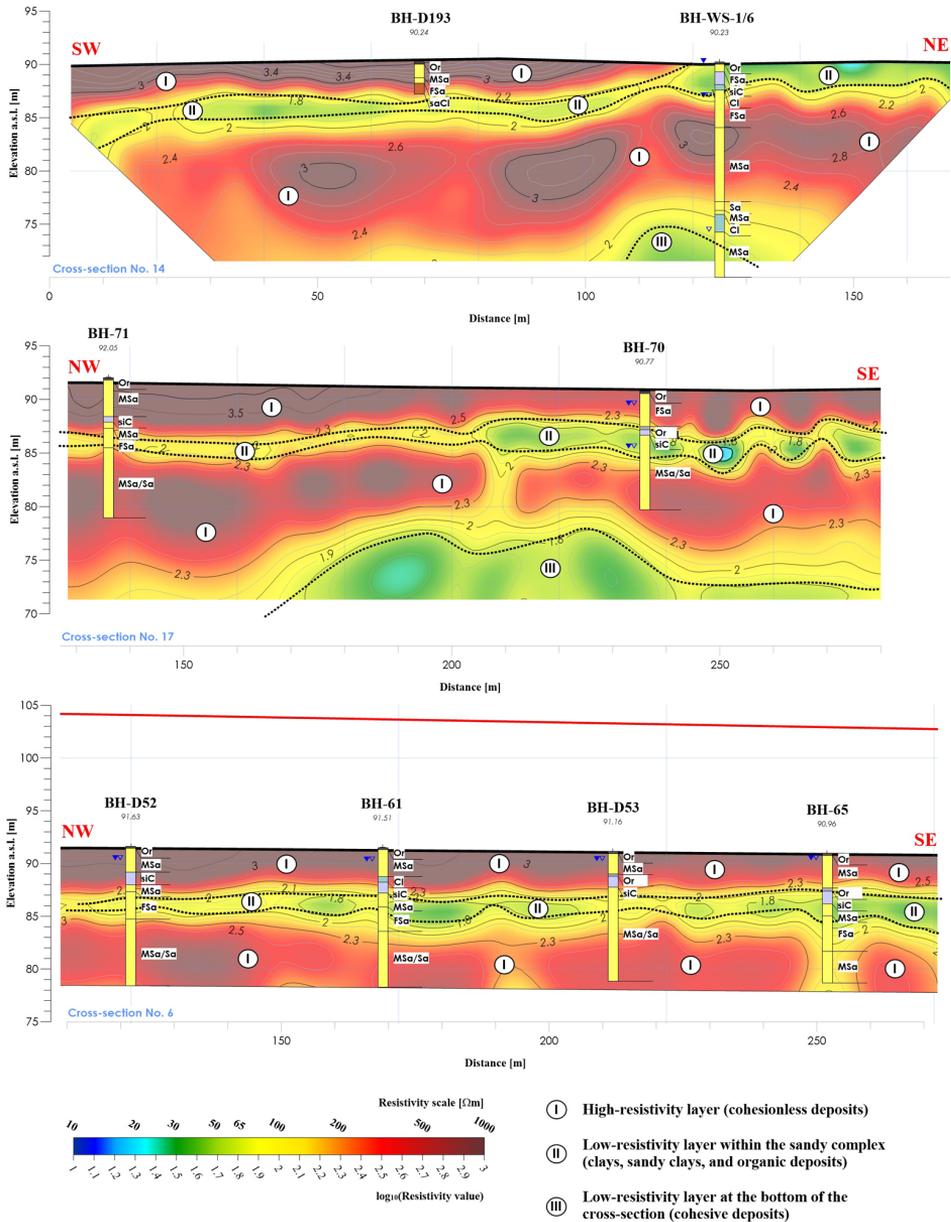
Fig. 7. Example of high-resistivity resistivity models in which cohesive interbeds were identified

Despite these limitations, the resistivity surveys provided a reliable representation of the overall geological framework, although the spatial distribution of the layers was reconstructed with reduced precision. Nevertheless, the results indicate that ERT can be an effective tool for characterizing the geological structure of areas with such conditions.

As shown in Fig. 7, the clay layer, which typically displays lower resistivity values (5–30 Ω·m), in this case exhibits significantly higher resistivity. However, by correlating with borehole lithology and accounting for strong vertical gradients, it was possible to delineate the extent of the cohesive layer.

It is also worth noting that in the upper section, between 120 and 160 m along the profile, where the clays crop out at the surface, the resistivity values are low (typical for clays). In this case, the clays are not screened by overlying high-resistivity sands, which facilitates their identification.

This example demonstrates that, in certain cases, relatively thin interbeds such as cohesive layers can be delineated even within high-resistivity formations. The feasibility of such analysis, however, depends on several factors, including the depth of the layer, its thickness, and the electrode spacing applied.

5. Summary and conclusions

Electrical Resistivity Tomography (ERT) is a widely applied geophysical method for imaging geological structures; however, its effectiveness may be constrained by the specificity of geological settings and the properties of the investigated layers. Particular interpretational challenges arise in the presence of thick low- and high-resistivity complexes, which significantly affect the accuracy of subsurface imaging and the reliability of interpretational conclusions.

In the case of thick low-resistivity packages, the primary issue is the systematic underestimation of resistivity values, both within these packages and in the underlying layers. The screening effect attenuates the geophysical signal, making it difficult to detect deeper horizons. As a consequence, layer boundaries may appear artificially shifted downward, and their true position can only be constrained through correlation with additional data, such as borehole information. Conversely, thick high-resistivity packages often lead to an overestimation of the resistivity of underlying layers and hinder the identification of internal interbeds. These challenges are particularly pronounced in thin cohesive or cohesionless layers whose resistivity values are close to those of the surrounding medium.

Another important limitation arises from the resolution of the resistivity method, which decreases with depth. With larger electrode spacings – typically applied in surveys of extensive areas – the resolution in the shallow subsurface may be sufficient, but at greater depths it results in blurred boundaries and reduced ability to differentiate individual layers. Selecting an appropriate electrode spacing is therefore critical to achieving an optimal balance between depth of investigation and the level of structural detail in ERT results. In many cases, employing a denser electrode spacing allows for more accurate imaging of thin layers, albeit at the cost of longer survey times and increased labor requirements.

The correlation of resistivity survey results with current or archival borehole data is indispensable for improving the interpretation of ERT cross-sections. Such integration enhances the understanding of relationships between resistivity values and lithology, which is particularly valuable in geologically complex settings. Vertical resistivity gradients play a key role in this regard, offering additional insights into the distribution and properties of layers. Analyzing these gradients may reveal subtle lithological variations that remain undetected when resistivity values are considered in isolation.

Further interpretational challenges stem from the inversion process, which can introduce errors in estimating the depth and extent of layers. Resistivity models often require iterative refinement to account for ambiguities inherent to the method. Without proper correlation and supplementary analysis – such as evaluating resistivity variability across the section – misinterpreted ERT results may lead to erroneous geological conclusions.

The effectiveness of electrical resistivity tomography depends on multiple factors, including the characteristics of the subsurface, the applied measurement methodology, and the extent to which results can be correlated with independent geological data. Thick low- and high-resistivity packages constitute a particular challenge, demanding careful survey design, appropriate adjustment of measurement parameters, and rigorous data interpretation. Nevertheless, despite these limitations, ERT remains an indispensable and versatile tool for investigating subsurface geological structures.

References

[1] S. Kowalczyk, M. Maślakowski, and P. Tucholka, "Determination of the correlation between the electrical resistivity of non-cohesive soils and the degree of compaction", *Journal of Applied Geophysics,* vol. 110, pp. 43–50, 2014, doi: 10.1016/j.jappgeo.2014.08.016.

[2] M. Maślakowski, A. Lejzerowicz, G. Pacanowski, and R. Kuszyk, "The use of non-invasive ERT method to diagnose karst in road engineering in the Lublin Upland (Poland)", *Archives of Civil Engineering*, vol. 70, no. 1, pp. 557–571, 2024, doi: 10.24425/ace.2024.148928.

[3] D. Millette, B.J. Butler, E.O. Frind, Y. Comeau, and R. Samon, "Substrate interaction during aerobic biodegradation of creosote-related compounds in columns of sandy aquifer material", *Journal of Contaminant Hydrology*, vol. 29, no. 2, pp. 165–183, 1998, doi: 10.1016/S0169-7722(97)00015-6.

[4] Y. Wang, Z. Su, S. Chu, and Z. Ling, "Investigation of autonomous ground current field injection signal characteristics", *IET Conference Proceedings*, vol. 2024, no. 9, 2024, doi: 10.1049/icp.2024.2799.

[5] G. Pacanowski, M. Maślakowski, and A. Lejzerowicz, "Practical aspects of field work carried out by Electrical Resistivity Tomography", *Archives of Civil Engineering*, vol. 68, no. 4, pp. 331–346, 2022, doi: 10.24425/ace.2022.143041.

[6] M.A. Talebi, S.H. Hosseini, M. Abedi, and A. Moradzadeh, "3D inverse modeling of electrical resistivity and chargeability data through unstructured meshing, a case study for travertine exploration", *International Journal of Mining and Geo-Engineering*, vol. 57, no. 2, pp. 131–140, 2023, doi: 10.22059/ijmge.2022.347290.594991.

[7] K.A. Kloesel and B.A. Albrecht, "Low-Level Inversions over the Tropical Pacific – Thermodynamic Structure of the Boundary Layer and the Above-Inversion Moisture Structure", *Monthly Weather Review,* vol. 117, no. 1, pp. 87–101, 1989, doi: 10.1175/1520-0493(1989)117<0087:LLIOTT>2.0.CO;2.

[8] L. Orlando, "Some considerations on electrical resistivity imaging for characterization of waterbed sediments*", Journal of Applied Geophysics*, vol. 95, pp. 77–89, 2013, doi: 10.1016/j.jappgeo.2013.05.005.

[9] Y. Qiao and H. Zhang, "Methodology and Application of Deep Geothermal Sounding in Low-Resistance Cover Areas", *Applied Geophysics*, vol. 22, no. 1, pp. 99–109, 2025, doi: 10.1007/s11770-023-1026-y.

[10] Y. Wu, Y. Fan, L. Cai, Z. Fang, and C. Li, "Detection Performance and Grading-Selection-Based Inversion of Low-Frequency Alternating Current Resistivity Logging in Moderate-High Resistance Formations", *SPE Journal*, vol. 28, no. 01, pp. 355–370, 2023, doi: 10.2118/212273-PA.

[11] F. Magnin, M. Krautblatter, P. Deline, L. Ravanel, E. Malet, and A. Bevington, "Determination of warm, sensitive permafrost areas in near-vertical rockwalls and evaluation of distributed models by electrical resistivity tomography", *Journal of Geophysical Research: Earth Surface*, vol. 120, no. 5, pp. 745–762, 2015, doi: 10.1002/2014JF003351.

[12] F.D. Day-Lewis, K. Singha, and A.M. Binley, "Applying petrophysical models to radar travel time and electrical resistivity tomograms: Resolution-dependent limitations", *Journal of Geophysical Research: Solid Earth*, vol. 110, no. B8, 2005, doi: 10.1029/2004JB003569.

[13] G. Pacanowski, P. Czarniak, A. Piechota, and R. Mieszkowski, "Analiza możliwości zastosowania metody tomografii elektrooporowej (ERT) do rozpoznania miąższości pokrywy laterytowej", *Przegląd Geologiczny*, vol. 64, no. 4, pp. 245–253, 2016.

[14] E. Cardarelli and G. De Donno, "Chapter 2 – Advances in electric resistivity tomography: Theory and case studies", in *Innovation in Near-Surface Geophysics: Instrumentation, Application, and Data Processing Methods*, R. Persico, S. Piro, and N. Linford, Eds. Elsevier, 2019, pp. 23–57, doi: 10.1016/B978-0-12-812429-1.00002-7.

[15] M.H. Loke, D.F. Rucker, J.E. Chambers, P.B. Wilkinson, and O. Kuras, "Electrical Resistivity Surveys and Data Interpretation", in *Encyclopedia of Solid Earth Geophysics*. Springer, 2021, pp. 344–350, doi: 10.1007/978-3-030-58631-7_46.

[16] G. Zhang, G.B. Zhang, C.C. Chen, and Z.Y. Jia, "Research on Inversion Resolution for ERT Data and Applications for Mineral Exploration", *Terrestrial, Atmospheric and Oceanic Sciences Journal*, vol. 26, no. 5, pp. 515–526, 2015, doi: 10.3319/TAO.2015.05.06.01(T).

[17] G. Morelli and D.J. LaBrecque, "Advances in ERT inverse modelling", *European Journal of Environmental and Engineering Geophysics,* vol. 1, pp. 171–186, 1996.

[18] M.A. Dafalla and F.A. AlFouzan, "Influence of Physical Parameters and Soil Chemical Composition on Electrical Resistivity: A Guide for Geotechnical Soil Profiles", *International Journal of Electrochemical Science*, vol. 7, no. 4, pp. 3191–3204, 2012, doi: 10.1016/S1452-3981(23)13946-0.

[19] A. Samouëlian , I. Cousin, A. Tabbagh, A. Bruand, and G. Richard, "Electrical resistivity survey in soil science: a review", *Soil and Tillage Research,* vol. 83, no. 2, pp. 173–193, 2005, doi: 10.1016/j.still.2004.10.004.

[20] P. Brunet, R. Clément, and C. Bouvier, "Monitoring soil water content and deficit using Electrical Resistivity Tomography (ERT) – A case study in the Cevennes area, France", *Journal of Hydrology*, vol. 380, no. 1-2, pp. 146–153, 2010, doi: 10.1016/j.jhydrol.2009.10.032.

[21] G. Pacanowski and P. Czarniak, "Dokumentacja badań geofizycznych wykonanych metodą tomografii elektrooporowej (ERT) dla uszczegółowienia budowy geologicznej na terenie Elektrowni Opole". Wykonawca: PIG-PIB, Warszawa, Archiwum PIG-PIB, 2014.

[22] H. Moulouel, et al., "High Resistant Sand Injected Marl and Low Resistant Damaged Marl to Locate and Characterize the Thénia Fault Zone in Boumerdes City (North-Central Algeria)", *Pure and Applied Geophysics,* vol. 174, no. 1, pp. 103–115, 2016, doi: 10.1007/s00024-016-1400-2.

[23] Z. Frankowski, T. Bąk, P. Czarniak, L. Lasocki, S. Ostrowski, and G. Pacanowski, "Raport z badań geofizycznych efekt rzeczowy zadania XII pt.: "Wykonanie nowoczesnych badań geofizycznych (Sejsmiczna tomografia refrakcyjna, tomografia elektrooporowa, badania georadarowe, zdjęcie grawimetryczne), wraz z ich interpretacją dla wytypowanej lokalizacji SOP – Pogorzela" zrealizowane w ramach przedsięwzięcia pt.: "Opracowanie metodyki oceny bezpieczeństwa i wskazanie optymalnej lokalizacji płytkiego składowania odpadów promieniotwórczych nisko- i średnioaktywnych". Wykonawca: PIG-PIB, Warszawa, Archiwum PIG-PIB, 2016.

[24] M.H. Loke, D.F. Rucker, J.E. Chambers, P.B. Wilkinson, O. Kuras, "Electrical Resistivity Surveys and Data Interpretation", in *Encyclopedia of Solid Earth Geophysics*. Springer, 2021, pp. 344–350, doi: 10.1007/978-3-030-58631-7_46.

[25] E. Serge, G. Sauret, J. Beaujean, F. Nguyen, S. Wildemeersch, and S. Brouyere, "Characterization of superficial deposits using electrical resistivity tomography (ERT) and horizontal-to-vertical spectral ratio (HVSR) geophysical methods: A case study", *Journal of Applied Geophysics,* vol. 121, pp. 140–148, 2015, doi: 10.1016/j.jappgeo.2015.07.012.

[26] M. Stefański and A. Ładoń, "Raport z badań geofizycznych wykonanych dla zadania „Zaprojektowanie i wykonanie badań geofizycznych (metoda tomografii elektrooporowej – ERT) wraz z opracowaniem ich wyników dla inwestycji drogowych w podziale na 2 części". Część nr 1: Droga ekspresowa S6 na odcinku Słupsk – Bożepole Wielkie. Odcinek 5: Węzeł Leśnice (bez węzła) – węzeł Łęczyce (z węzłem)". Przedsiębiorstwo Badań Geofizycznych, Kraków, 2018.

[27] M. Stefański, M. Krupa, A. Ładoń, "Raport z badań geofizycznych wykonanych metodą tomografii elektrooporowej dla wstępnego rozpoznania budowy geologicznej dla zadania "Budowa Wschodniej Obwodnicy Warszawy w ciągu drogi krajowej nr 17 na parametrach trasy ekspresowej na odcinku węzeł"Drewnica" (z węzłem) na dr. S8 – do km ok. 3+600". Przedsiębiorstwo Badań Geofizycznych, Kraków, 2019.

Wyzwania interpretacyjne związane z miąższymi warstwami nisko- i wysokooporowymi w badaniach elektrooporowych

Streszczenie:

Tomografia elektrooporowa (ERT) jest wszechstronną i powszechnie stosowaną metodą geofizyczną do obrazowania budowy geologicznej, jednak jej wiarygodność jest silnie uzależniona od warunków geologicznych. W artykule omówiono główne trudności napotykane podczas badań prowadzonych w obrębie grubych kompleksów nisko- i wysokooporowych, które istotnie zniekształcają wyniki inwersji i komplikują interpretację hydrogeologiczną oraz geotechniczną. W pakietach niskooporowych (np. iły, margle) obserwuje się systematyczne zaniżanie wartości oporności oraz tłumienie sygnałów z głębszych warstw, co prowadzi do pozornego przesuwania granic ku większym głębokościom. Z kolei w środowiskach wysokooporowych (np. suche piaski, pyły) cienkie przewodzące wkładki są maskowane lub prezentowane z zawyżonymi wartościami oporności. Oba przypadki skutkują obniżeniem rozdzielczości interpretacyjnej i zwiększają ryzyko pominięcia istotnych elementów budowy geologicznej. Podkreślono znaczenie rozdzielczości badań, kontrolowanej głównie przez rozstaw elektrod, konfigurację pomiarową oraz gęstość siatki pomiarowej. Ponieważ rozdzielczość maleje wraz z głębokością, niewielkie obiekty i cienkie warstwy łatwiej wykrywać w strefach płytkich, natomiast głębsze horyzonty obarczone są większym ryzykiem zniekształceń. Integracja wyników ERT z danymi otworowymi okazuje się niezbędna dla ograniczenia niejednoznaczności i weryfikacji rezultatów inwersji. Dodatkowo, analiza gradientów pionowych rezystywności została wskazana jako narzędzie wspomagające interpretację, pozwalające wykrywać subtelne przejścia litologiczne niewidoczne w klasycznych przekrojach. Na przykładach terenowych przedstawiono wpływ grubych kompleksów oporowych na dokładność modeli podłoża oraz zaprezentowano strategie poprawy interpretacji, obejmujące optymalizację projektu pomiarów, wykorzystanie analiz gradientowych oraz korelację z wierceniami. Pomimo ograniczeń, ERT pozostaje skuteczną metodą badań hydrogeologicznych i inżynierskich, o ile uwzględnia się specyfikę warunków terenowych oraz potencjalne niepewności interpretacyjne inwestycji.