Innovative electric exploration techniques applied to pipeline-related problems: engineering, geological risks assessment, localization and diagnostics

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Development of new approaches and new tools for geological engineering survey in the field of construction and maintenance of underground structures is a challenging task for Russia since this country has a network of pipelines of huge extend. The present tools and techniques has been developed mostly in the last century. However, situation with newly designed and built trunk pipelines creates new challenges for increasing the efficiency and quality of geological engineering survey. After meetings with the leaders of the Siberian Branch of Russian Academy of Sciences, the company GASPROM Dobycha-Nadym has initiated a series of R&D which were performed by researchers and engineers from Academy; this work is directed to modernization of the scope of geophysical methods and tools currently used for pipelines designing and operation.

Some results of this R&D are presented in this report.

For the most parts of continents, the subsurface (at depths up to 50 m) is composed of sedimentary rocks, such as sandstones, clays, sandy clays, mudstones, siltstones; usually these rocks are found with horizontal layering. The presence of man-made facilities, such as pipelines, foundation of buildings, buried cables, and natural obstacles (permafrost lenses, landslide surfaces, paleo-channels) in earth’s uppermost layers damages the horizontally layered structures.

Localization and identification of artificial or natural underground objects is of great importance for practical things: geological risk assessment and monitoring, civil engineering works on designing of subsurface linear facilities, and providing safe operations of pipelines. Presence of artefacts in earth does affect the electric conductivity of the subsurface soil. Thus, subsurface objects and facilities can be found and characterized from the study of electric conductivity distribution. This was the business for geoelectric prospecting, which became a branch in geophysics about one hundred years ago.

IPGG SB RAS has developed tools, software, and various techniques for effective problem solving in designing, localization, and distant diagnostics of subsurface facilities. These techniques are also applied to geological and environmental risk management.

Near surface Electromagnetic Frequency Induction Sounding (NEMFIS) device (see Fig. 1) presents a unique practical implementation of inductive sounding technique in geoelectric prospecting. The distribution of electrical conductivity in the medium is studied at depths up to 10 m with vertical resolution of 0.7 m. Horizontal resolution is stipulated by the survey network. The equipment is controlled by one operator, with the preliminary results of sounding are displayed on the screen of a palm computer in the form of real-time graphs, geoelectric sections and maps. These images provide reliable information on location of underground structures.

Binding of measurements is performed with GPS data or measuring tapes. Comparison with competitive tools demonstrated that the operator of NEMFIS will benefit from more rich

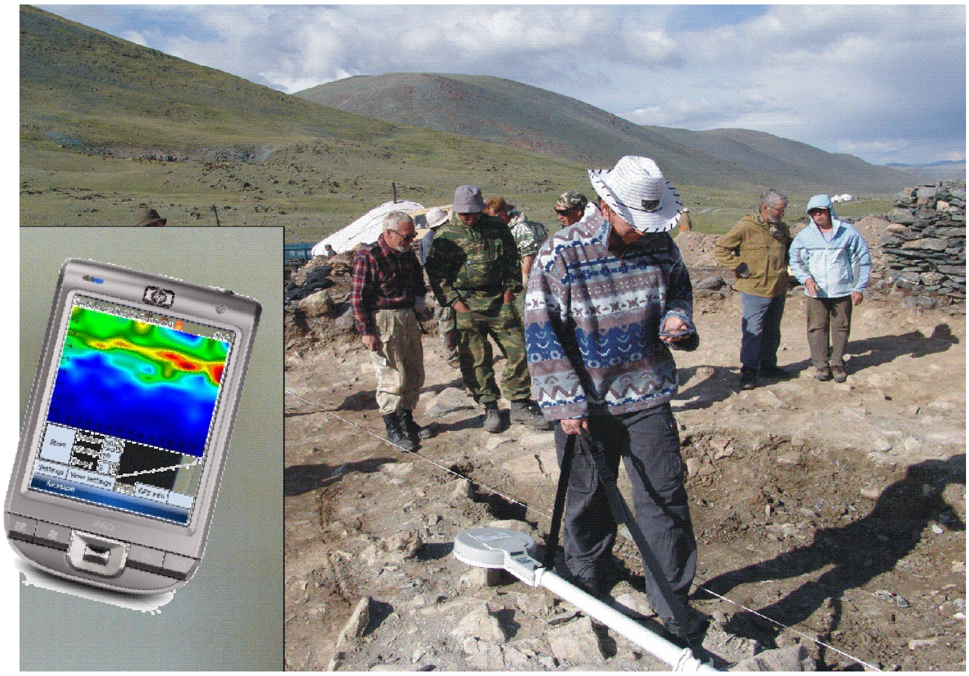


Figure 1 Near surface Electromagnetic Frequency Induction Sounding (NEMFIS) device

information, lower propensity to noise interference, while sensitivity and selectivity being better or the same as for the best foreign analogues. Real-time visualization of sections and maps indicates the world level of innovation in geophysics. In this context, NEMFIS device appears to be the only electromagnetic sounding device in the world that outputs maps and profiles in real-time operation.

We would like to offer some examples of NEMFIS tool applications.

Here is the mapping for a pipeline, and the tool can see a cutting-in into the main-line (Fig. 2). Each map contains data collected from EM sounding at one particular frequency. The main pipeline can be seen on every map. The cutting-in pipe looks thinner and can be observed only on 15.6, 12.0, and 6.9 kHz maps.

For the northern areas of

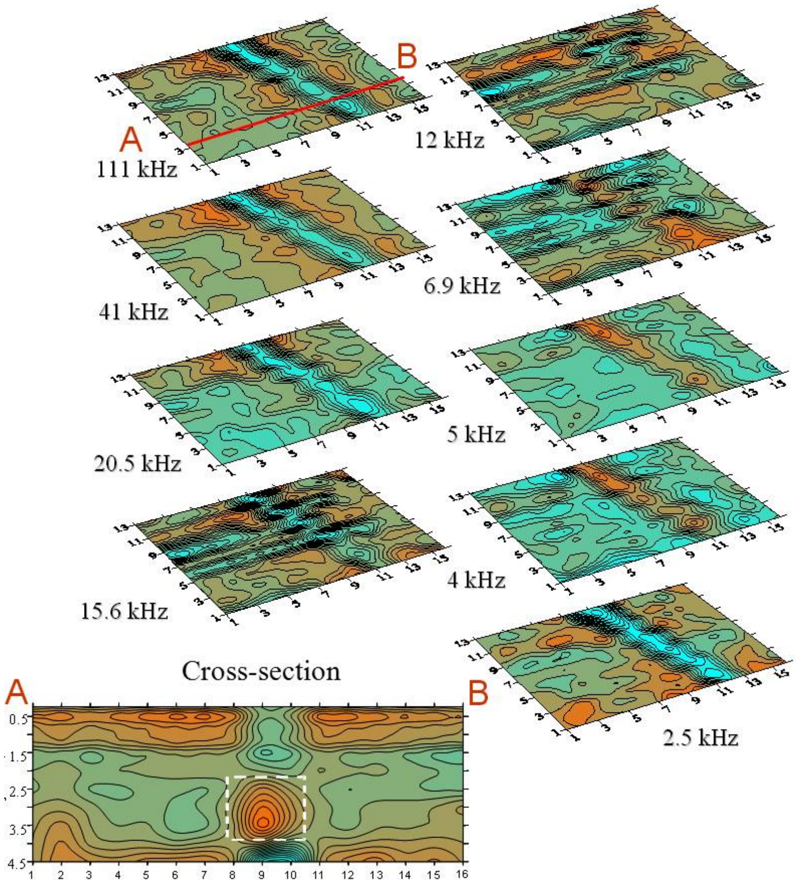


Figure 2 Electromagnetic sounding of pipeline zone (NEMFIS data)

Russia, seasonal and permanent frozen soils create a challenge in construction of pipelines and foundations. The seasonal freezing of soil (Fig.3) was studied for the goal of foundation engineering. The frozen soil depth are shown for the construction site. Blue and green coloured isosurfaces show the zones of total and partial freezing of soil.

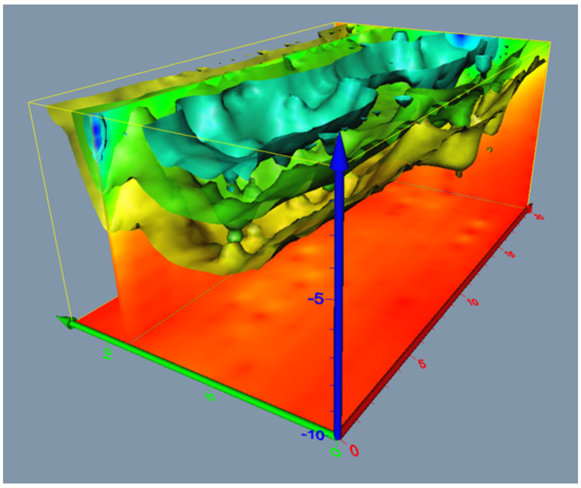
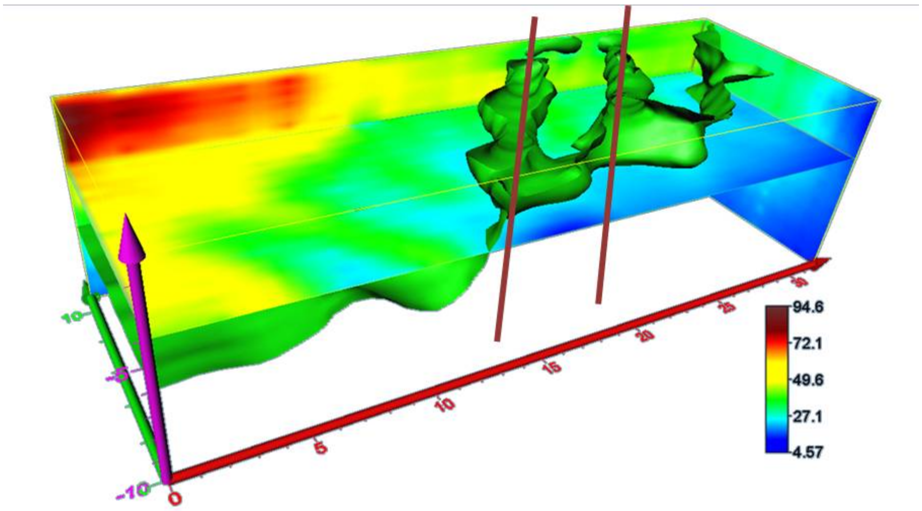


Figure 3 Study of seasonal cycle of soil freezing (NEMFIS data)



The communication cables and other subsurface communications layout must be

Figure 4 Study of plastic pipes layout (NEMFIS data)

properly identified before launching the repair and construction works, and archive documents do not always help in that. Fig. 4 presents visualization of plastic pipeline (two threads with 120 mm diameter) buried at the depth less than one meter.

A metallic pipeline (loaded at 2 m depth) can be seen after scanning in Fig. 5. In the left part of this figure we see interference signal produced by chunks of reinforced concrete; these pieces spoil the initial horizontally layered pattern of soil. The presence of this kind of objects in the soil brings local disturbance to the mode of freezing-thawing cycle; this creates additional risk for pipeline operation. The area of buried waste can be identified for environment risk assessment.

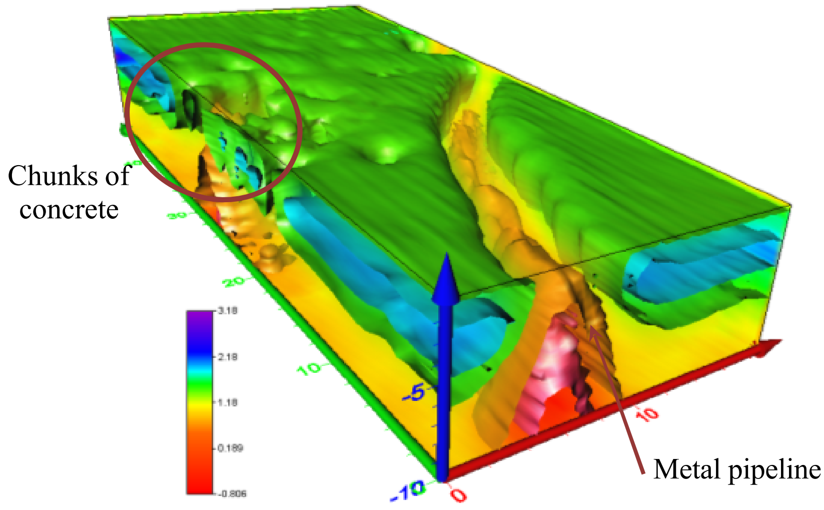


Figure 5 Pipeline and horizontally layered structure (NEMFIS data)

The electric resistivity sounding system SibER-48 (with 48 electrodes) was developed by IPGG SB RAS (with participation of subsidiaries). The equipment is designated for work with various modifications of resistivity method run in automatic mode (so-called Electric Resistivity Tomography, or ERT). The program-controlled switch-board allows making hundreds of measurements in one hour with this 48-electrode set. The information obtained can be processed by 2D and 3D inversion program with outputs as highly informative subsurface electrical profiles and 3D images. With different geoelectric arrays, the maximum depths of geoelectric profiling account for 43, 80, and 200 m (using the multicore cable length of 235 m). Unlike other electric resistivity meters, SibER-48 is designed for operation in the media with conductive top layers like marsh land, wet clays, etc. The device with cable reels is shown at Figure 6.

Figure 6 SibER-48 tool with cables

The task of localisation of pipes under water of swamps, lakes and rivers can be solved using SibER-48 device (Fig. 7).

The pipelines design for geologically dangerous areas requires geoelectric prospecting. Landslide hazard area (Fig. 8) of a linear object construction site was surveyed to locate the slip planes (marked red).

A channel of fluid filtration through the rock-fill embankment was found and described (see Fig. 9). The picture shows the zone of high water content (isosurface contoured in dark blue) and a channel for fluid seeping (purple isosurface). The possible destruction of a rock-filled embankment can be revealed before any essential damage through regular geoelectric monitoring.

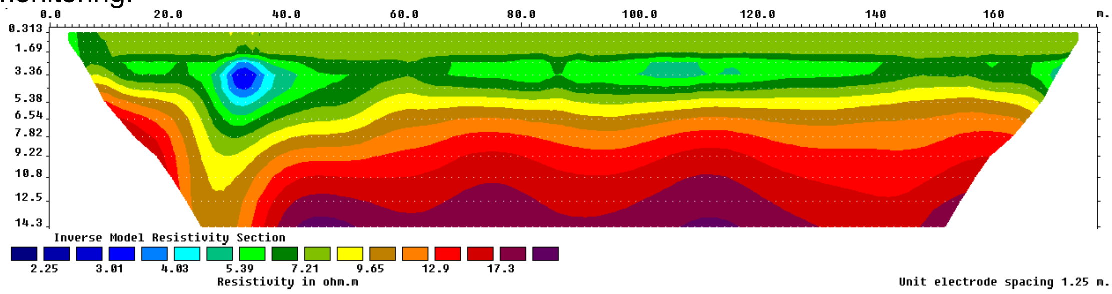


Figure 7. Geoelectric section across armoured concrete main drain

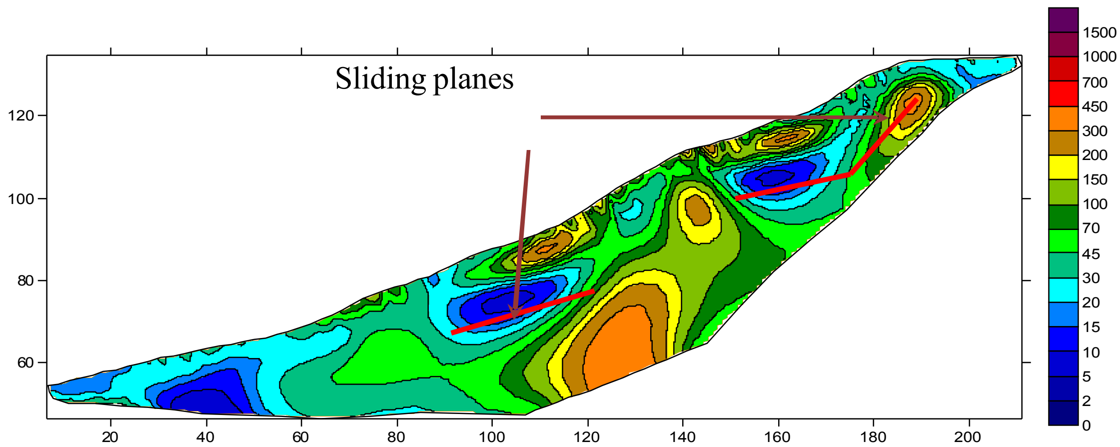


Figure 8. Landslide hazard area (SibER-48 data)

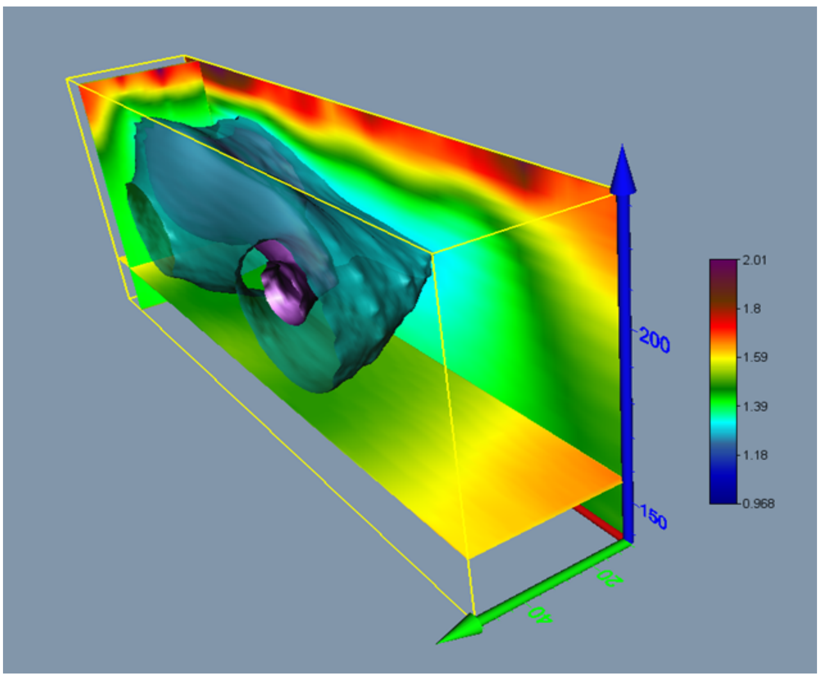


Figure 9. Rock-fill embankment (SibER-48 data)

While exploring the zones for future construction of linear objects, the river crossing sites require a special attention. Obviously, traditional development drilling is costly on these sites. Besides, the river beds often coincide with axes of tectonic dislocations. A typical example of 3D electrical tomography performed with the SibER-48 tool for designers of a bridge over the Ob river is shown in Fig. 10 (the plane of water level). The isosurfaces fro resistivity 550 Ohm*m indicate the consolidated sandstone on the left bank of river and the crust of weathering of a granitic dike on the right-bank part of the bridge construction site.

The problem of classifying of sedimentary rocks into disperse rocks (sands, clays, pebble bed) and consolidated ones (sandstone, siltstone, mudstone) is an important task in prospecting of river valleys. The percentage of dispersion rocks dictates the type of designed basements and mounting bases, and the price of tunneling for communication lines. An example of 3D description of the consolidated rock roof in a valley of mountain river (Afghanistan) is shown in Fig. 11. One can see three depressions in the consolidated rock roof (blue isosurface) with high-resistivity filling (washed pebble shown as green

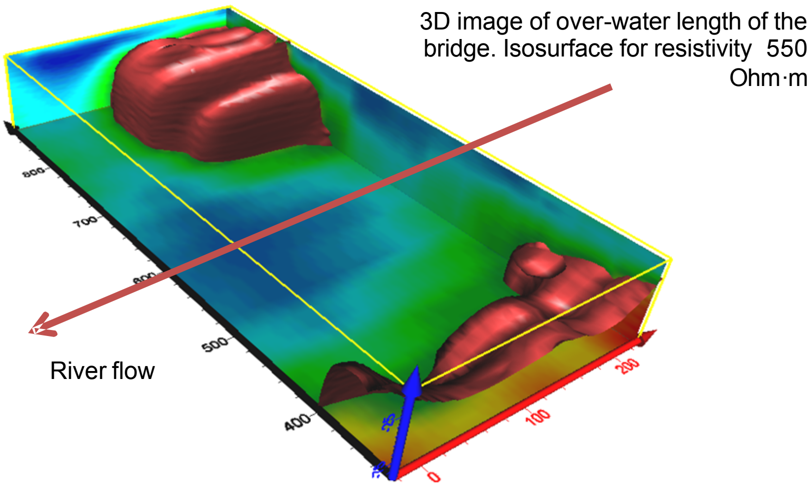


Figure 10. River cross-over for Ob river (Novosibirsk) (data obtained by SibER-48) isosurfaces).

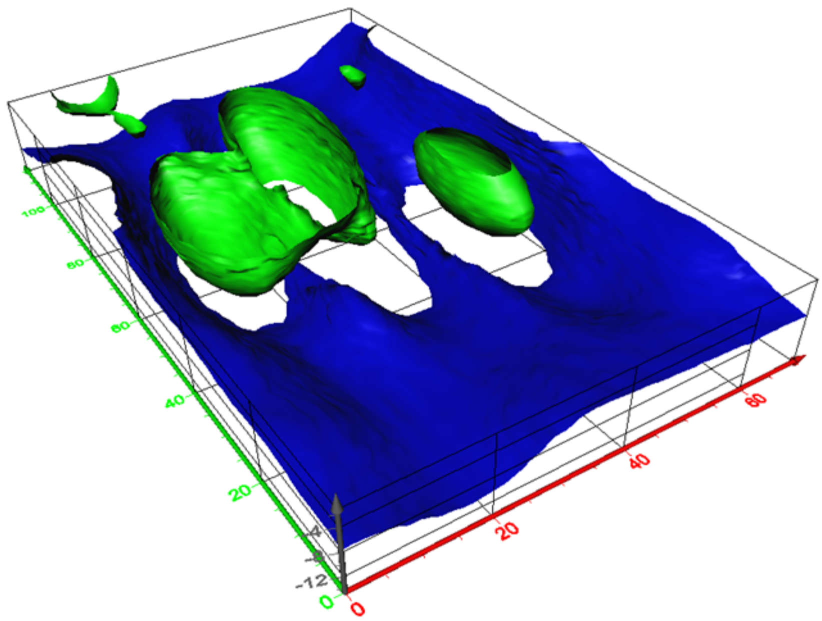


Figure11 Roof from consolidated rocks (measured with SibER-48)

There exist areas which are not accessible for transportation of heavy drilling equipment (e.g., high mountains). For this situation the use of tools MEMFIS and SibER-48 offers a low-cost option for electric surveying of rocks. The example of that type of job is presented in Fig. 12. The Figure shows a piece of geoelectric section scanned to the depth up to 30 m (data obtained with SibER-48). This prospecting was carried out in mountain area at the height of 2447 – 2760 m above the sea level. The plotting can distinguish two types of objects: the permafrost zones that reach the surface (pikes of 200-300 m) and have the resistivity above 7000 Ohm*m (plotted by red hue) and unfrozen dispersed rocks below 500 Ohm*m (shown in blue hue).

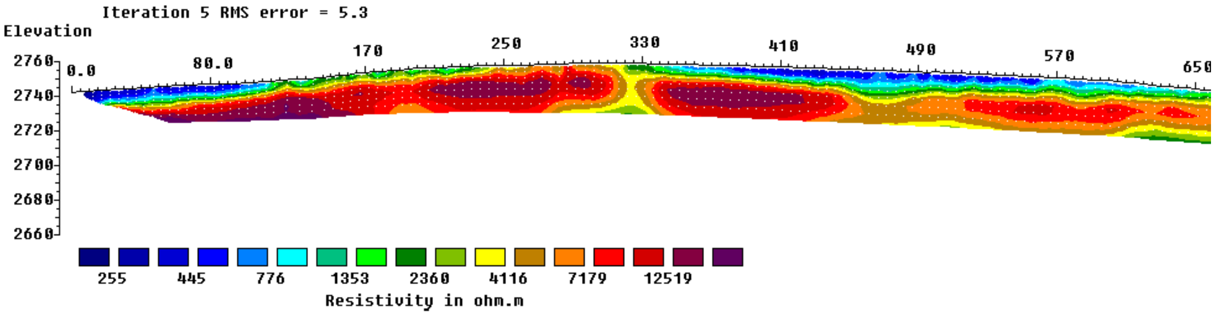


Figure 12. Permanent frozen ground in mountings (SibER-48 data)

The use of the NEMFIS tool and resistivity tool SibEr-48 offers the user the best information about man-made underground structures and host geological medium. This information is required for civil engineering and operation services. Data about the medium can be viewed in the form of two-dimensional maps, sections, and three-dimensional isosurfaces featuring the spatial distribution of electrical resistance.

It is methodically wise to apply both tools depending on the problem configuration (consolidated or dispersed rock on the surface, water content, depth of study).