POSSIBILITIES OF GEOPHYSICAL METHODS FOR MONITORING AN INTEGRATED MINE WASTE FACILITY

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ABSTRACT. Geophysical methods have proved to be non-invasive and very efficient for providing subsurface geological information. Usually preformed along a line, these methods are widely used for different mining, geological and also engineering purposes. No doubt, one of the most applied and popular geophysical technique is electrical resistivity tomography. This method provides a high-resolution earth subsurface image of the electrical resistivity values and is based on the existing contrast in electrical properties of the measured area. Using this approach is appropriate for monitoring of water drainage, because according to resistivity contrast water is greatly distinguished from the surrounded area. This allows geophysical techniques to be used widely in monitoring of mine waste facilities, where water drainage is key issue for the construction and stability of the facility.

Key words: electrotomography, mine waste, drainage.

ВЪЗМОЖНОСТИ НА ГЕОФИЗИЧНИТЕ МЕТОДИ ЗА МОНИТОРИНГ НА ИНТЕГРИРАНО СЪОРЪЖЕНИЕ ЗА МИННИ ОТПАДЪЦИ

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РЕЗЮМЕ. Геофизичните методи са един от основните способи за събиране на информация за строежа на подповърхностното пространство. Измерванията обикновено се извършват в строга последователност на работа на уредите и по профилни линии. Резултатите често се използват в минното дело, геологията, а все по-често и в инженерните дела. Без съменние, един от най-често прилаганите способи е от групата на Електросъпротивителните методи и това е неговата най-популярна модификация - Електротомографията. При електротомографията измерените стойности на електричното съпротивление отразяват електричните свойства на средата непосредствено под измервания профил. По такъв начин метода е изключително подходящ за извършване на мониторинг на оводнени среди, които силно контрастират по отношение на електричните си свойства спрямо вместващата ги среда. Това позволява геофизичните методи широко да се прилагат за изследване на хвостохранилища, където дренирането на водата е от ключово значение за стабилността на съоръжението.

Ключови думи: електротомография, минни отдпадъци, дрениране.

Introduction

Geophysical techniques have been traditionally associated with exploration for ore and hydrocarbon deposits. However, they also offer potential for the evaluation of geotechnical parameters associated with mineral deposits or engineering purposes. In practice, mine sites or engineering projects often operate~~s~~ under conditions of high geological uncertainty. According to Tichauer, this turns mine planning into a complex and sometimes inaccurate task, resulting in low productivity and substantial variability in the quantity and quality of the mineral products (Tichauer et al., 2020). In this context, non-invasive monitoring techniques, such as electrical resistivity tomography (ERT), are promising since they provide large-scale subsurface information gathered from investigation on the ground surface and can be used as traditional monitoring tools for observations on mine waste facilities (Dimech et al., 2022).

Traditionally, geophysical methods are used in exploration for identification and delimitation of mineral deposits and have played an important role in reducing geological uncertainty in mining. As Haile and Atsbaha (2014) mentioned, geophysical techniques are routinely used as part of geological investigations to map subsurface geological structures.

Acording to Yankova (2020), a specific feature of technological progress is the significant increase in the volume of material production which results in the growth of consumption of minerals. The large mining and mineral processing volumes also lead to technological waste formation.

Mining waste results from extracting and processing of the mineral resources. It includes materials, such as topsoil overburden, mine waste rock, and waste rock and tailings derived after the extraction of the valuable mineral.

Description of the technology

The modern mining companies are a complex aggregation of interconnected technological objects existing and developing over decades. As a result of the production activity of mining companies, there is an active interaction between production complexes and nature (Grigorova et al., 2013). For many decades, human society has neglected waste due to the small volumes in the past; but the vast areas now occupied require technological solutions for their processing and disposal (Yankova, 2021). Great amounts of waste are produced as a result of mining and overburden removal, and also during the processing of ore (Nassar et al. 2022). According to Dimitrov and Koprev (2023), proper management and disposal of mine waste is of utmost importance for the mining industry to minimise environmental impact and ensure sustainable development.

In the *Ada Tepe* open pit gold mine, the Integrated Mine Waste Storage Facility (IMWSF) has been designed. The concept of the IMWSF is to place thickened tailings into cells constructed from mine rock. This facility is great to minimise the environmental impact as it needs less surface area to be built than a separate waste dump and tailings storage facility (Eldridge et al. 2011). The disadvantage about such a facility is the operational sequence as it includes many operations. Aleksandrova et al. (2021) suggested the critical path method (CPM) to be used to ensure that the facility would be constructed on schedule. Waste rocks are composed of coarse materials that are highly heterogeneous, especially in terms of particle size distribution, as opposed to tailings, which are more homogeneous (Amos et al., 2015; Vriens et al., 2020). The waste rock in the IMWSF in the *Ada Tepe* gold mine mostly consists of breccia conglomerates with occasional boulders of metamorphic rocks – amphibolites, gneiss, and schists. The rocks provide strength to the facility and also helps for the better drainage of the water.

Geophysical methods respond to the physical properties of the subsurface media (rocks, sediments, water, voids, etc.) and can be used successfully when one area differs sufficiently from another in some physical property.

The aims of an electrical resistivity survey are to measure the resistivity distribution in the subsurface layers by conducting measurements along the ground surface. In resistivity methods, the current is injected through the ground using a pair of electrodes and the resulting distribution of the potential field in the ground is mapped by using another pair of electrodes. Very often, it is employed in engineering geophysics to map bedrock.

The electrical resistivity tomography method is an important geophysical exploration method used to provide a high-resolution earth subsurface image of the electrical resistivity values (Xayavong et al., 2022). Variations in electrical resistivity typically correlate with variations in lithology, water saturation, fluid conductivity, porosity, and permeability, which may be used to map geological structures, fractures, and groundwater.

Understanding the drainage potential of the contaminated cell has a great importance for the rate of mining and overburden removal and also for planning the processing of the ore. For that reason, monitoring of the integrated mine waste storage facility (IMWSF) is very important for optimal planning of the work process of the whole mine.

According to Xu (Xu et al., 2022), geophysical methods and especially the electrical resistivity tomography (ERT) has the advantages of high working efficiency and high detection accuracy, which allow to delineate the boundaries of a highly moisturised area.

Geoelectrical methods have been successful in mapping humid zones inside the tailings facilities and this information is used for mapping zones of attention and risk assessment.

Field measurements and results

Electrical resistivity tomography (ERT) was used to determine the resistivity value of the contaminated cells of the Integrated Mine Waste Facility in the *Ada Tepe* gold mine.

The method of electrical resistivity tomography is performed along survey lines in the terrain, resulting in a two-dimensional profile for each line. The precise location of the geophysical surveying lines in the area of the Integrated Mine Waste Facility is illustrated in Figure 1.

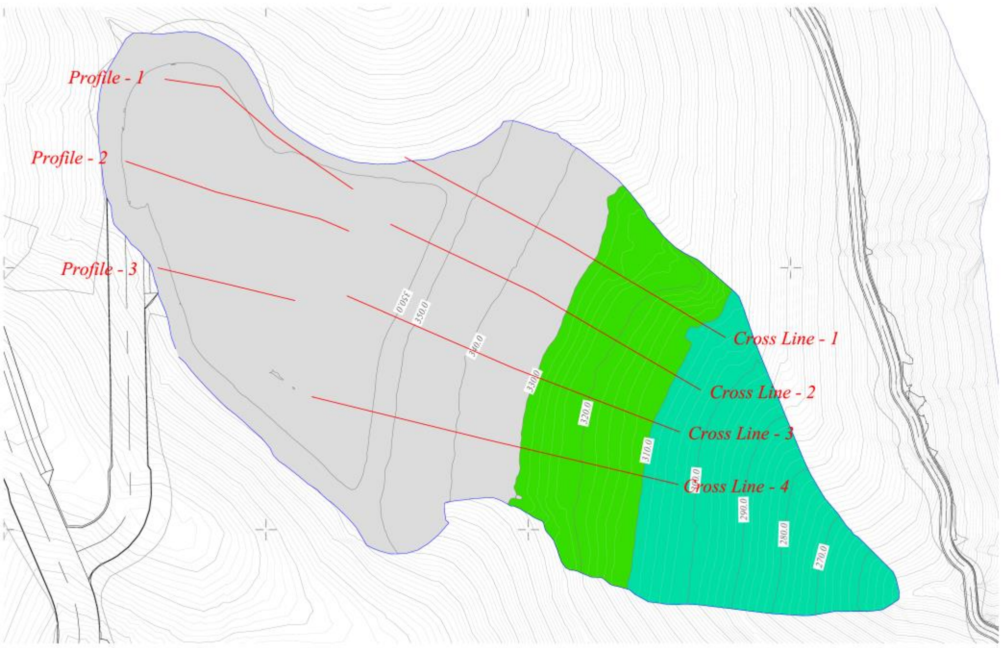

Fig. 1. Field measurements situation plan

To evaluate the drainage potential of the newly created cells, electrical resistivity measurements were performed along 7 profiles. The total length of the measured profiles is 1024m, and their exact location is presented in Figure 1.

The total length of the measured lines and their individual lengths are shown in Table 1.

The interpreted ERT cross lines are presented below (from Figure 2 to Figure 5). A field measurement plan is presented in Figure 1.

Table 1. *Total length of each line of Integrated Mine Waste Facility*

Line	Cross Line - 1	Cross Line - 2	Cross Line - 3	Cross Line - 4	Profile 1	Profile 2	Profile 3
Length, m	190	180	180	190	105	110	69

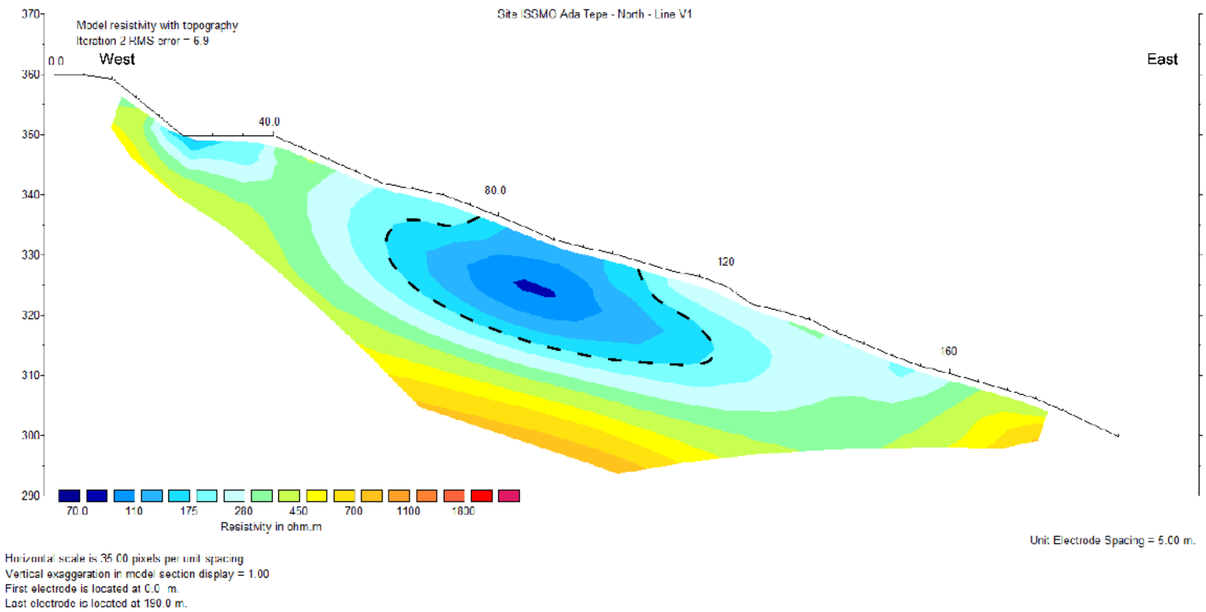

Figure 2. ERT section along Cross Line 1

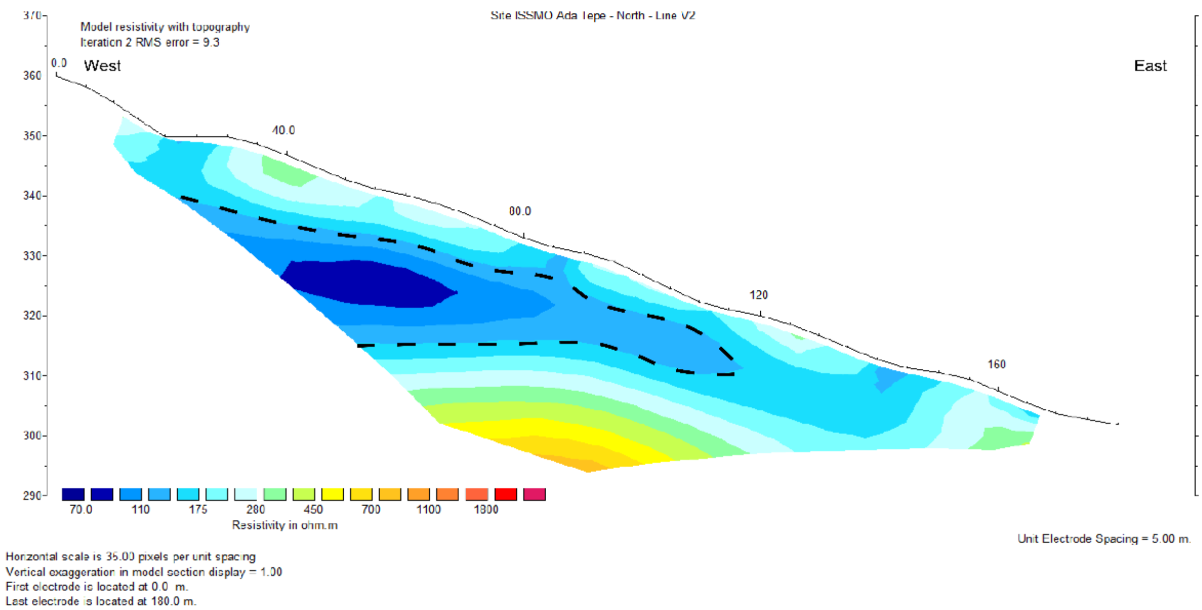

Figure 3. ERT section along Cross Line 2

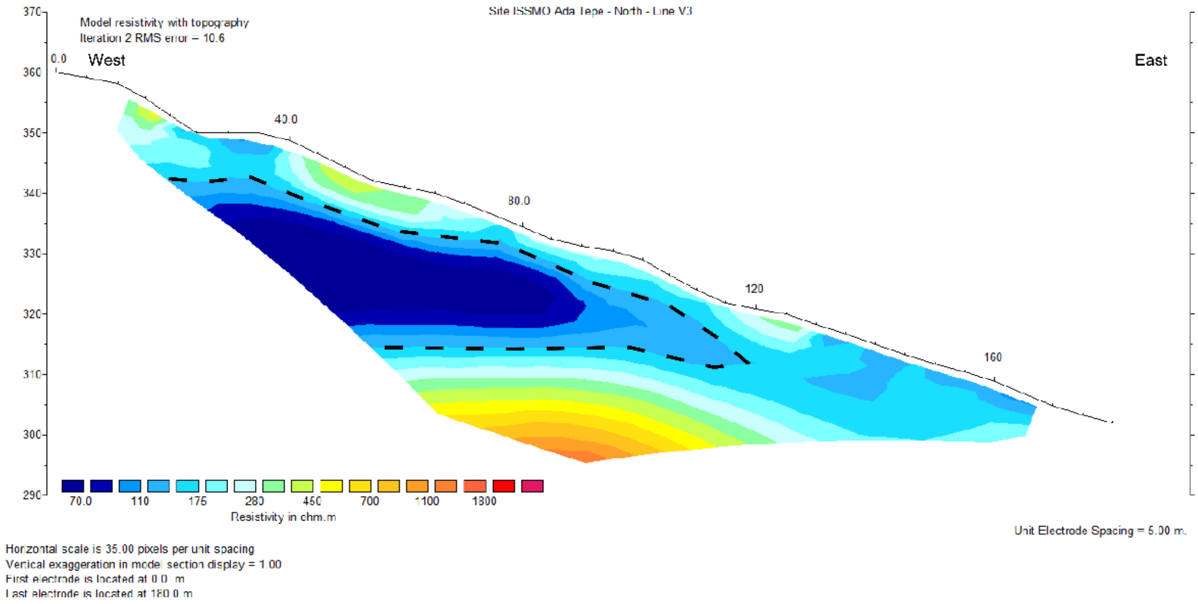

Figure 4. ERT section along Cross Line 3

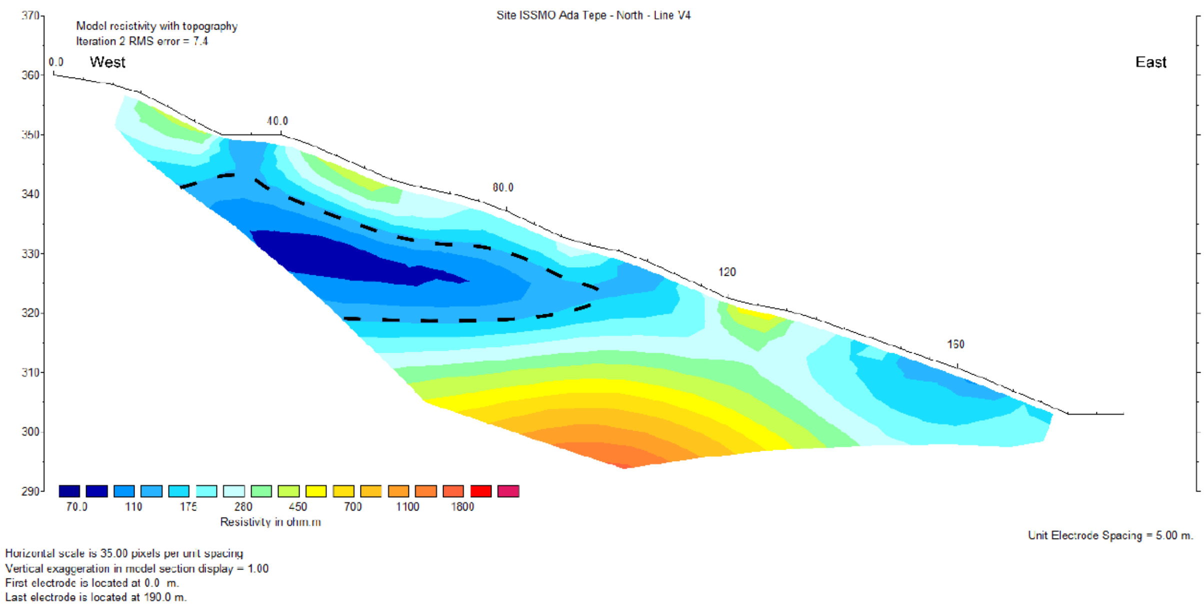

Figure 5. ERT section along Cross Line 4

The data obtained from ERT field measurements was interpreted with the *RES2DINV* software through the process of inversion by least-squares, which transforms field data in modelled resistivity profiles that show values of the actual resistivity and depth (Griffiths et al., 1993).

All of the ERT sections provided well differentiated electrical resistivity distribution in depth. The electrical resistance of the environments that make up the studied section varied within relatively wide limits – from about 70 Ωm to 2000 Ωm and more.

Additionally, three more profiles on the top of containment cells were provided (Figure 6 to Figure 8). A field measurement plan is presented in Figure 1.

The profiles on the top of the containment cells (Figure 6 to Figure 8) shows that the process of drainage was at the beginning and the water saturation was significant.

On the cross lines and on the profiles, zones with relatively low values of electrical resistance in the range from 70 to about 200 Ωm are distinguished. Most likely, these zones mark the spatial distribution of a zone with increased water saturation due to the incomplete drainage of the deposited material.

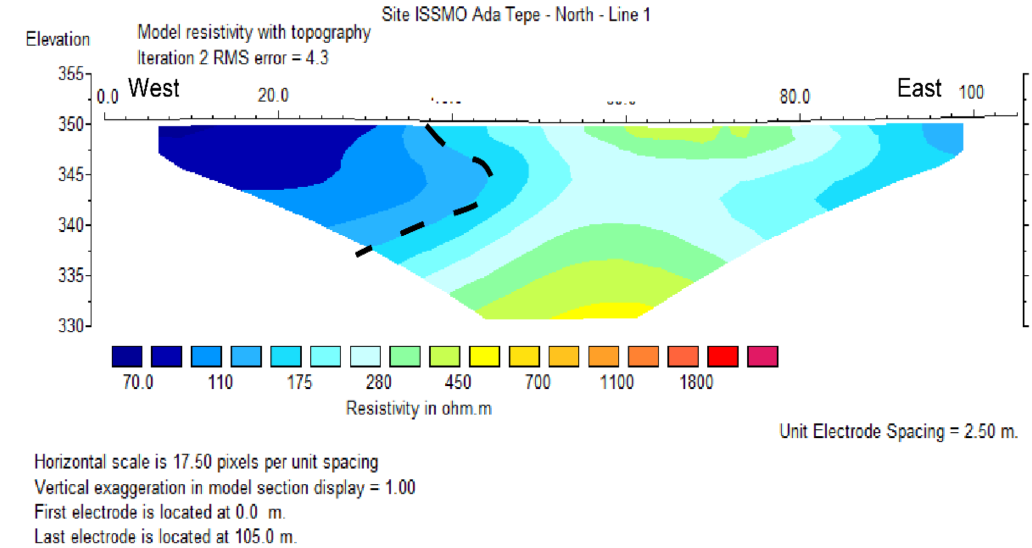

Figure 6. ERT section along Profile 1

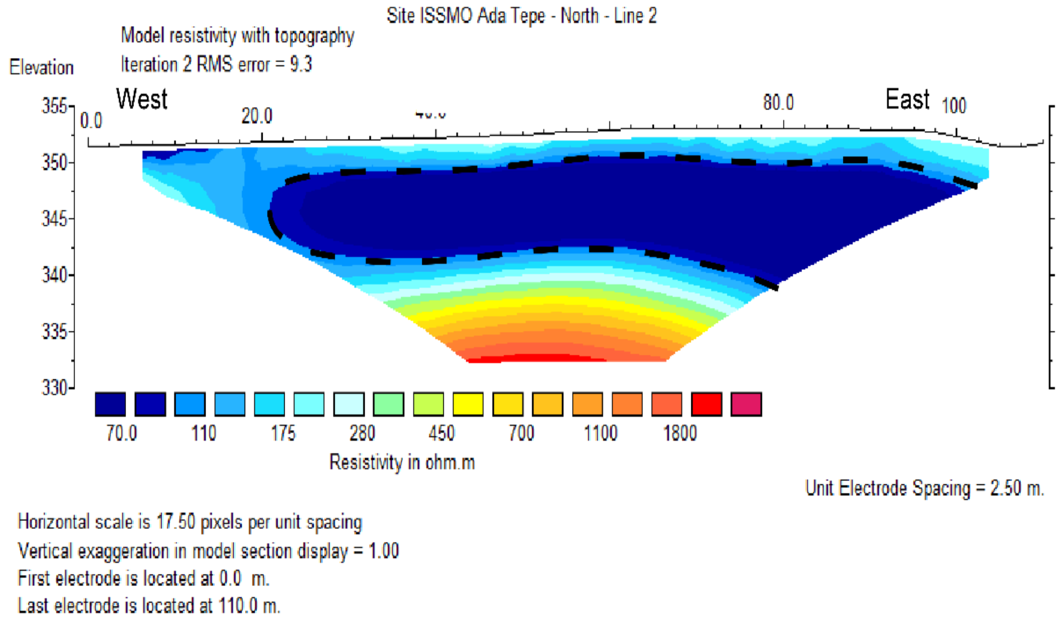

Figure 7. ERT section along Profile 2

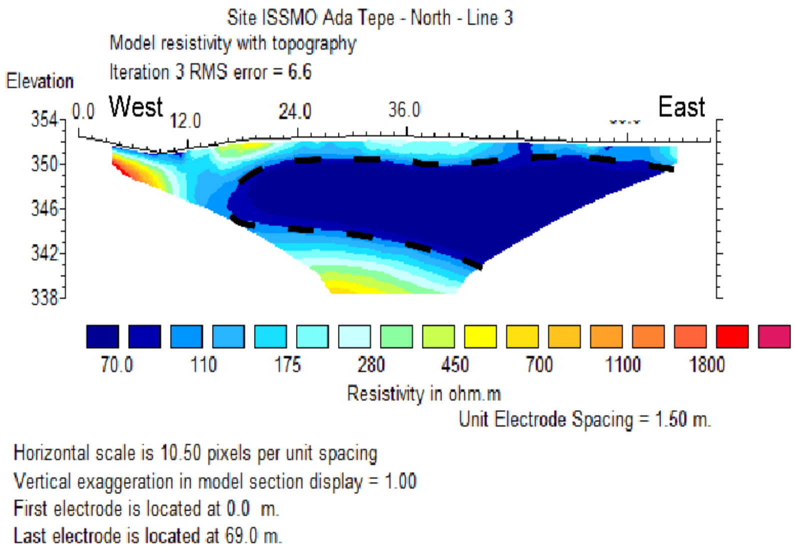

Figure 8. ERT section along Profile 3

Conclusion

Mining operations generate large amounts of wastes which are usually stored into facilities that differ in scale. Occasionally, they cause some environmental concerns and must be properly monitored to manage the risk of catastrophic failures and also to control the possibilities of contaminated mine drainage.

The application of geophysical methods during all phases of mining projects of different scale can reduce geological uncertainty by assisting the identification and delineation of mineral deposits and by delivering important information for decision-making in mine planning. ERT is one of the best understood near-surface geophysical techniques, and is particularly sensitive to water driven processes which play a key role in the stability of mine waste storage facilities.

Geophysical technologies give a non-destructive and cost-efficient way of gaining a better understanding of the ground conditions both for engineering and mine conditions, providing a good data coverage across the investigated volume.

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