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Geophysical Techniques for Determination of Areas with Increased Water Saturation in Integrated Mine Waste Storage Facility

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Abstract: The aim of this study is focused in determination of areas with increased water saturation in the integrated mine waste storage facility (IMWF) in open pit "Khan Krum" gold mine in Southeastern Bulgaria. The integrated mine waste facility (IMWF) is designed to store both dewatered process tailings and waste rock from mining. The concept of the integrated mine waste facility (IMWF) is to place thickened tailings into cells constructed from mine rock. For determination of areas with increased water saturation, is used Electrical Resistivity Tomography (ERT) – geophysical imaging technique widely applied to mineral prospecting, mining exploration and also environmental investigations. Electrical resistivity tomography is commonly used for solving complex tasks related to increasing efficiency in the open mine. In this research electrical resistivity tomography is used to detect and characterize water saturation zones by exploiting resistivity contrasts between dewatered process tailings and waste rock from mining using electrical current.

Keywords: Geophysics, Electrical resistivity, Tomography, Waste storage.

Introduction

The "Ada Tepe" open pit gold mine geological section within "Khan Krum" gold mine deposit is located 3 km south of the Krumovgrad town site, Southeastern Bulgaria, and trends in a north south direction. The morphology of the site is hilly rising in elevation from 492,4 masl abutting the major regional Krumovitsa River system, to 220 masl within the zone of mineralization. The Ada Tepe deposit is a low-sulphidation adularia-sericite gold-silver epithermal deposit formed during the Neogene within the Southern Rhodope tectonic zone and located within Paleocene sedimentary rock overlying the north-eastern end of the Kessebir core complex.

The method selected for the management of mining waste deposition usually depend on the selected extraction method, the selected mineral processing, the waste characteristics, the technical characteristics of the mine waste facility, its geographical location and the local environmental conditions (Garbarino et al., 2018). Mining and mineral processing generate waste that must be properly managed to reduce environmental risks. Several studies, for example Tayebi-Khorami et al. (2019) and Yankova (2020, 2021), have been carried out to highlights the key problems with mining and mineral processing waste and in particular tailings storage, mining waste amount reducing and safe storage. Effective waste management is the basis of sustainable development. Many experts contend the present stage of mineral-raw material industry evolution is describing by mineral deposits with complex mining-geological conditions, difficult for mining, low grade ores with complex processing, which leads to considerable waste quantities formation. Waste proper storage is critical to the planet and human health.

In the waste management early planning of „Ada Tepe" mine separate waste dump and tailings storage facility were designed but for their construction 96 ha surface area have been necessary (Eldridge et al., 2011). For

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location optimizing while, considering the terrain's characteristics, the affected area, mineral deposit volume and exploitation, Kaykov and Koprev (2020) considered the ratio between waste volume and surface area to be a variable and depends on the terrain features, waste dump features design and the construction sequence.

The concept of the IMWF is to place thickened tailings into cells constructed from mine rock. The mine rock provides strength required for overall stability and also internal drainage (Eldridge et al., 2011). The study area is composed of a highly porous, poorly sorted breccia, breccia conglomerate, breccia conglomerate with quartz inclusions, metamorphic clasts and clay. This information was claimed by several drillings around the research area. The waste rock mostly consists of breccia conglomerates with occasional boulders of metamorphic rocks – amphibolites, gneiss and schists. A total of 14,950,000 tons of waste rock are expected to be produced during the life of the Ada Tepe mine.

A recent literature review (2023) found that IMWF is challenging to construct and operate. One of the challenges is operational sequence while constructing the IMWF (Eldridge et al. 2013). Aleksandrova and her team (2021) have suggested using the Critical path method (CPM) as a tool to manage the facility's construction operational sequence. Dimitrov and co-workers (2023) suggested that constructing a IMWF with wider or narrower body can manage the facility's operational sequence, and the need for contingency storage will be decreased or eliminated. The authors have designed two types of IMWF and investigated how choosing the proper form for the IMWF can help in having better control over the operational sequence. The researchers recommend building a broader construction body since thus large cells numbers can be fitted in one bench.

To minimize pond formation, the IMWF is formed into a 'honycomb' structure which reduces the drainage pathway lengths (both horizontally and vertically) and optimizes the structure's ability to drain water away. Drainage into the IMWF is collected in an under-drain system that prevents the build-up of a water table within the rock and tailings. The drainage berms have a significantly higher permeability than the tailings, and there is no ponding expected both from the supernatant water and rainfall. However, regularly strict site control is required to the peripheral high permeability berms, which has to prevent pond formation.

The following investigation is focused in determination of areas with increased water saturation in the integrated mine waste storage facility (IMWF) using Electrical Resistivity Tomography (ERT). This technology is used for imaging sub-surface structures from electrical resistivity measurements made at the ground surface. According to Dimovski et al. (2017) results illustrate the potential of electrical tomography method to provide fast and reliable information for observed area based on electrical resistivity.

Description of the Technology

A good knowledge of the waste and its behavior over time is of a great importance to ensure the environmentally safe management of extractive waste. From an environmental point of view, the main difference between the mineral in the original deposit and the corresponding mine waste is the increased possibility for various physical, chemical or biological processes which can affect the mine waste. This means that through the extraction and floatation process some parts in the original mineral resources might become more accessible in the waste. This can result in possible reactions with the environment or leakage for mine waste. Therefore, proper mine waste characterisation is the basis for successful and safe waste management. It is also important to consider changes that can occur over time (Garbarino et al., 2018).

The IMWF is sequentially constructed from the bottom up, with mine wastes placed on starting platforms at the bottom of the valley at approximately 300m elevation and then progressively built up in benches during the mine life to elevation 450 m. This approach allows the lower, completed sections of the facility to be reclaimed and closed during the life of the mining operation. This method allows on the completed section to be performed quality control for increased water saturation within the facility and also completed sections of the facility to be progressively rehabilitated and vegetated during the life of the mining operation.

One possible way for evaluating the water saturation and the ability of the IMWF to drain water away is presented in this research using Electrical Resistivity Tomography (ERT). This non-invasive geophysical technique proved itself as very productive when it comes to determine the subsurface resistivity distribution by making measurements generally on the ground surface. As stated by Hasan et al. (2021) the basic principle of ERT is based on the varying electrical conductivity of the subsurface materials, which depends on many factors, such as rock type, porosity, permeability, connectivity of pores, temperature, salinity, cation exchange capacity, clay content, nature of the fluid/water, etc. Generally, it can be assumed that a wide range of electrical resistivity for most materials suggests the varying water content (Hasan et al., 2021).

Two-dimensional resistivity profiling is commonly used for determining the distribution of electrical resistivity in the shallow subsurface. In the field survey two electrodes are used to inject electric current into the ground and other two electrodes to measure the electric potential difference. Then, automatic computer-controlled instrumentation measures potential differences between pairs of electrodes, creates resistances by dividing by the current passed, and converts these resistances into apparent resistivities using geometrical factors determined by the relative positions of the electrodes (Park, 2009). The measurements are often carried out along a line and the observed potential differences are converted into pseudo-sections of apparent resistivities, which indicate the resistivity changes of subsurface structures (Zhou, 2014). ERT profiles consist of a modeled geological cross-sectional (2D) plot of resistivity versus depth (Ωm). Analyses of these data provide understanding of the underground resistivity anomalies such as water saturation or outline the subsurface geological structure.

Results and Interpretation

The aim of recent research is to determine areas with increased water saturation in the integrated mine waste storage facility (IMWF) using Electrical Resistivity Tomography (ERT). Apparent resistivity data were collected with a Wenner-Schlumberger array. According to Seaton and Burbey (2002) Wenner–Schlumberger configuration is considered to have good signal response, the ability to resolve horizontal and vertical structures relatively well, and greater depth of investigation than the Wenner configuration (Ward, 1990; Sharma, 1997; Reynolds, 1997; Loke, 2001).

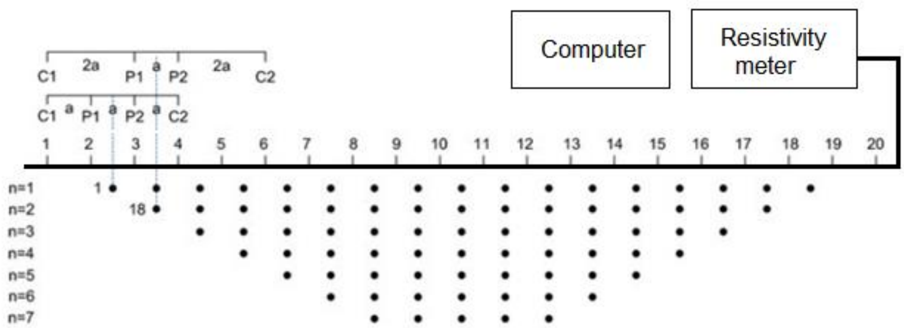

Figure 1. The Wenner–Schlumberger configuration and the sequence of measurements in ERT

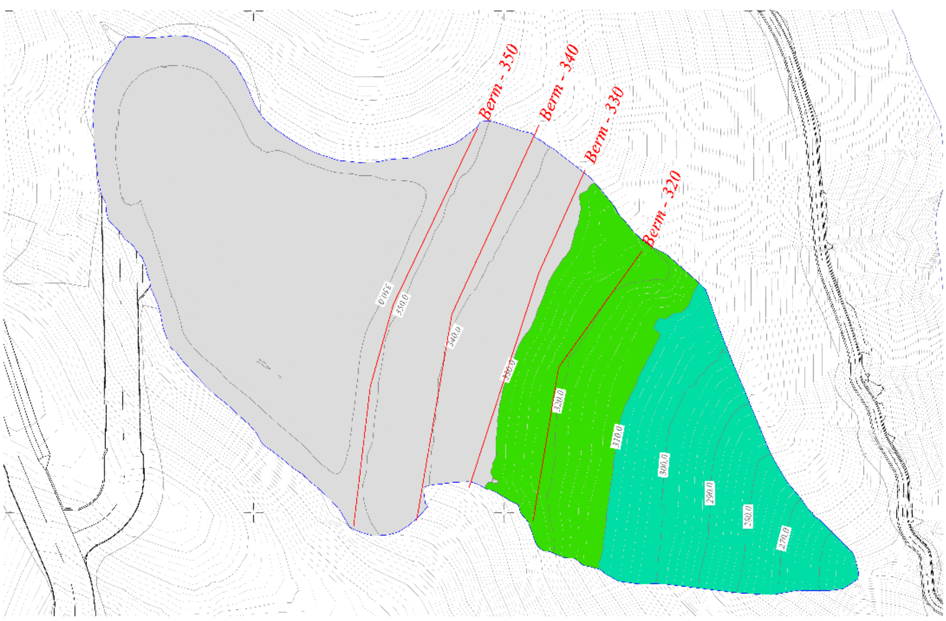

Figure 2. Field measurements situation plan

Electrical resistivity tomography data processing and modelling were done using the RES2DINV. This computer program automatically determines the 2D resistivity model for the observed data (Griffiths, 1993). The precise location of the geophysical surveying lines in the area of Integrated Mine Waste Facility is illustrated in Figure 2. The ERT field measurements were performed along 4 lines with total length of 740m.

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

Line	Line 1 (Berm 350m)	Line2 (Berm 340m)	Line 3 (Berm 330m)	Line 4 (Berm 320m)
Length, m	210	210	170	150

The interpreted ERT sections are presented below (Figure 3 to Figure 6).

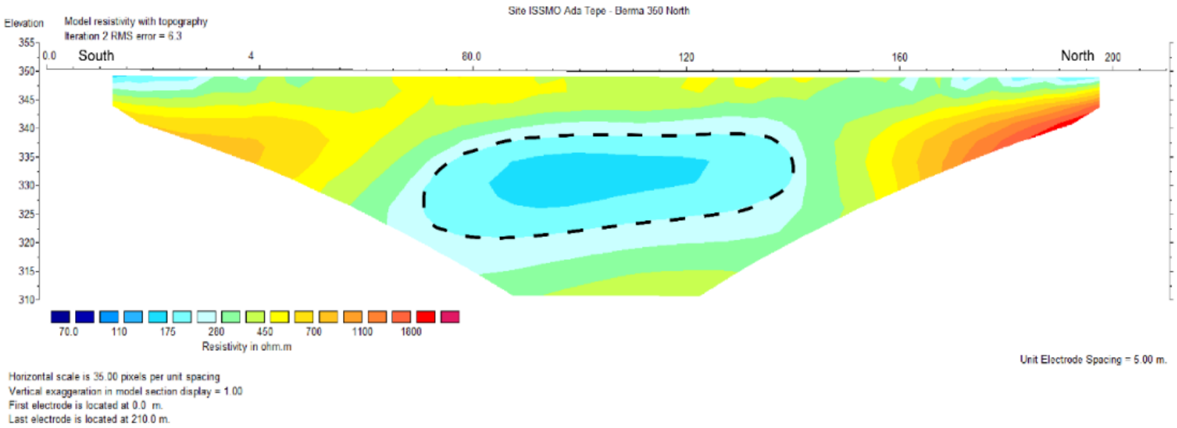

Figure 3. ERT section along Line 1 - Berm 350m

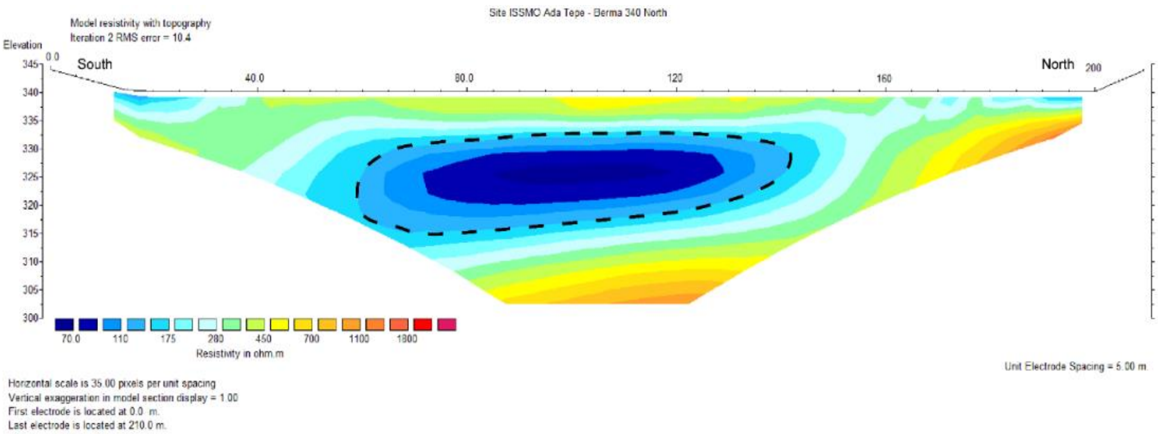

Figure 4. ERT section along Line 2 - Berm 340m

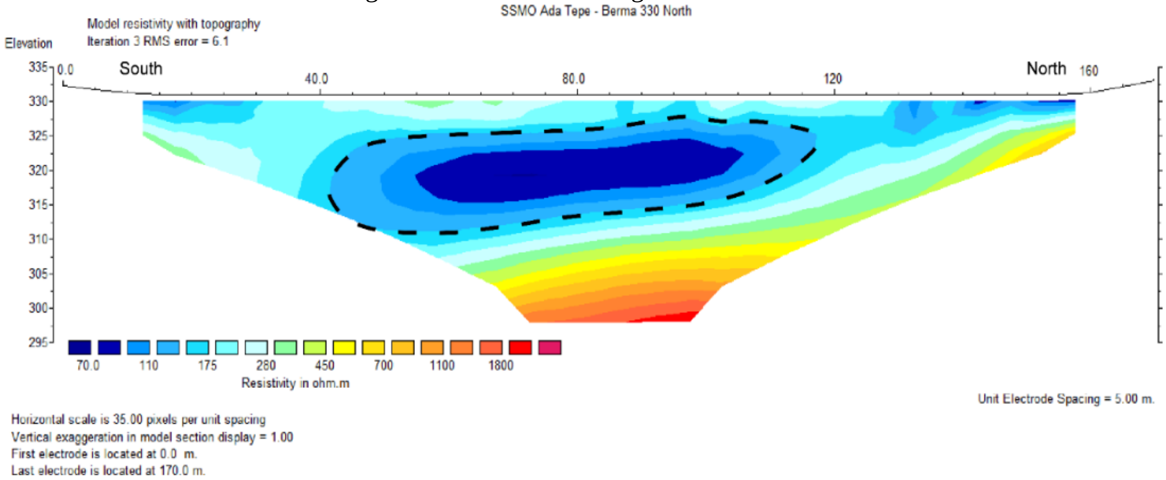

Figure 5. ERT section along Line 3 - Berm 330m

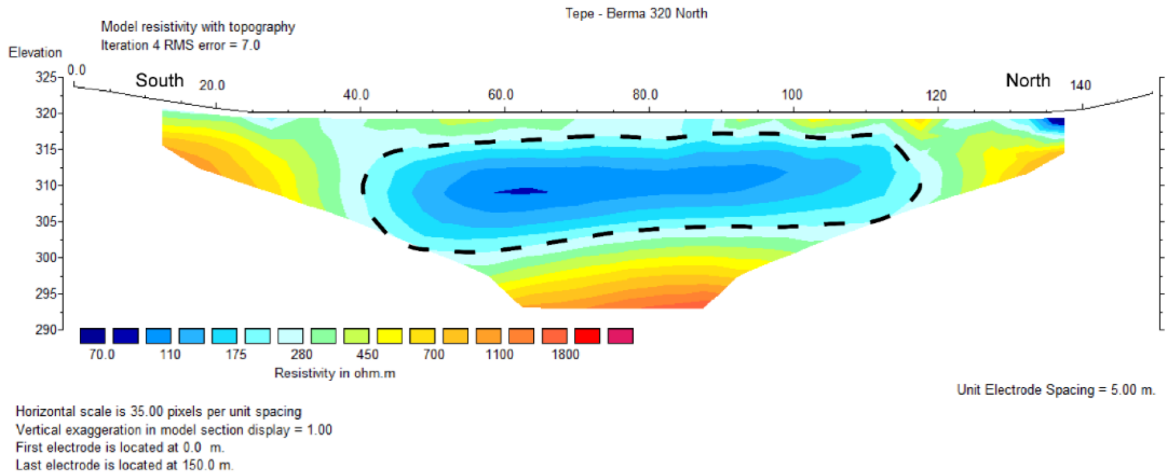

Figure 6. ERT section along Line 4 - Berm 320m

Based on interpretation of ERT lines at the IMWF can be assume that the electrical resistivity distribution in depth along all profiles is well differentiated. According to the measurement results and the interpretation of the ERT lines is considered that specific electrical resistance of the observed area varies from 70 Ωm to more than 2000 Ωm. It can be considering that along all the lines, in the central part, are distinguished zones with relatively low values of electrical resistance in the range from 70 Ωm to about 200 Ωm. Most likely, these zones mark the spatial distribution of an area with increased water saturation due to the incomplete drainage of the deposited material.

Conclusion

Mining industries are the very first link of a long supply chain. The raw materials are feedstock materials many industries and significantly contributes as such to technological development. The extractive industry has very important role in the economic and also societal development of every country. Mining and ore processing operations around the world produce significant amounts of waste, predominantly non-profitable solid residues, i.e., waste rock and tailings.

In the last few decades many efforts have been made by the mining industries to prevent, reduce and minimise as far as possible the negative impacts due to its operations. Over the years, mining waste management strategies and techniques have evolved considerably to achieve these objectives. One possible prevention, in order to minimise and reduce as far as possible the generation of mine waste, may be performed by implementing appropriate equipment and technology modifications during the extraction of the mineral resources.

The "Ada Tepe" deposit can be assuming as high-grade open pit mine, which use modern and environmentally sound methods for mine waste management as well as suitable mining techniques. Furthermore, minimising the environmental impacts contributes to making the extraction of mineral resources more environmentally responsible. So, to ensure the effectiveness and long-term stability of the IMWF is recommended monitoring the results within six months.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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