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APPLICATION OF RESISTIVITY IMAGING TO RECOGNITION OF GEOLOGICAL STRUCTURE IN THE AREA OF SHALLOW Zn-Pb ORE BODIES (PRELIMINARY STUDY)

Krzysztof JOCHYMCZYK *, Jerzy CABALA and Artur POREBA

University of Silesia, Faculty of Earth Sciences, Bedzinska 60, PL 41-200 Sosnowiec, Poland
**Corresponding author's e-mail*: jochym@wnoz.us.edu.pl

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ABSTRACT

Depletion of exploited mineral ore resources and their constant price increase have contributed to active interest in recognition and exploitation of new workable deposits. Exploration work which has been carried out in the vicinity of non-exploited ore areas such as Klucze, Zawiercie and Laski results in confirmation of Zn-Pb commercial deposits. In this region Zn-Pb ores occur in the Devonian and Triassic carbonate formation at a depth of 70 - 80 metres under the surface. Geological recognition is based on the analysis of data taken from bore-holes. To determine the mode of the ores occurrence and service conditions, it is necessity to work out a spatial image of overburden structure. For this reason resistivity measurements with highly distributed LUND Imaging System were introduced in the area of Zawiercie I. The studies were carried out according to three measuring protocols: Schlumberger, Wenner and dipole-dipole. The measurements were performed along three parallel six-hundred-metre profiles. The resistivity cross sections were elaborated using Res2D software. The results of the geophysical research were correlated with the data taken from bore-holes in order to testing the efficiency of applied geoelectrical methods. The study showed a significant diversification of geoelectric characteristics of the rockmass and thus it allowed to recognise accurately the overburden structure of the deposit and to locate precisely zones of faulting. In future, the applied geoelectrical methods are certainly to be used for localization ore bodies at a considarable depth range.

KEYWORDS: resistivity imaging, geophysics ore recognition, Zawiercie Zn-Pb ore deposits

INTRODUCTION

Zn-Pb ore deposits have been exploited in the Silesia-Kraków region (south Poland) for over a hundred and fifty years. Twenty new deposit areas were recognized and documented as a result of geological investigations in the years 1950-1989. The geological setting in the deposit areas was investigated with the use of borehole log data. The best recognition of the deposit geological setting was possible within areas of deep and open-pit mining of Bytom, Olkusz, Chrzanów and Jaworzno regions. The deposits mined occur in calcareous Triassic rocks and may be classified as Mississippi Valley (MVT) type deposits (Heijlen et al., 2003; Szuwarzyński, 1996).

Deposits of a particular interest with respect to the resources and the geological structure have been discovered near Zawiercie town (Kurek, 1993; Cabała, 2002). The Zawiercie area is the only region where no mining of Zn-Pb ores has been performed yet. The investigations of the Zawiercie I deposit geological setting (Fig. 1) were entirely based on the interpretation of borehole log data. At the Zawiercie I and II deposit area no geophysical investigations have been carried out until now to support identification of geological structure parts significant for the ore mineralization distribution. The following elements are of a particular interest: the relief structure of the top of Paleozoic strata, karst systems and the presence of the ore bearing dolomite.

The investigations were aimed at testing the resistivity imaging as a supplementary tool to facilitate interpretation of log data from boreholes drilled in calcareous rocks.

GEOLOGICAL SETTING OF THE ZAWIERCIE I DEPOSIT WITHIN ELEVATIONS OF DEVONIAN ROCKS

The geological setting of the Zawiercie I deposit differs from the structure of other deposits mined in the Olkusz, Bytom or Chrzanów areas. Major differences are related to the shallow occurrence of Paleozoic (Silurian and Devonian) rocks. Tectonic and karst phenomena were major factors to influence the occurrence of ore bodies, which are present not only in Triassic sediments, but also within Devonian rocks (Cabała, 2002; Kurek, 1993). The ore bodies within the Triassic rocks have mostly horizontal extent. The geometric structure of ore bodies in the Devonian rocks is, however, more complicated. The nests are irregular and their distribution is frequently related to karst systems (Figs. 2 and 3). Ore bearing layers occur at various depths and balance ore bodies are encountered at the depth interval from 60 to 130 m below the surface. As in other deposits of the Silesia-

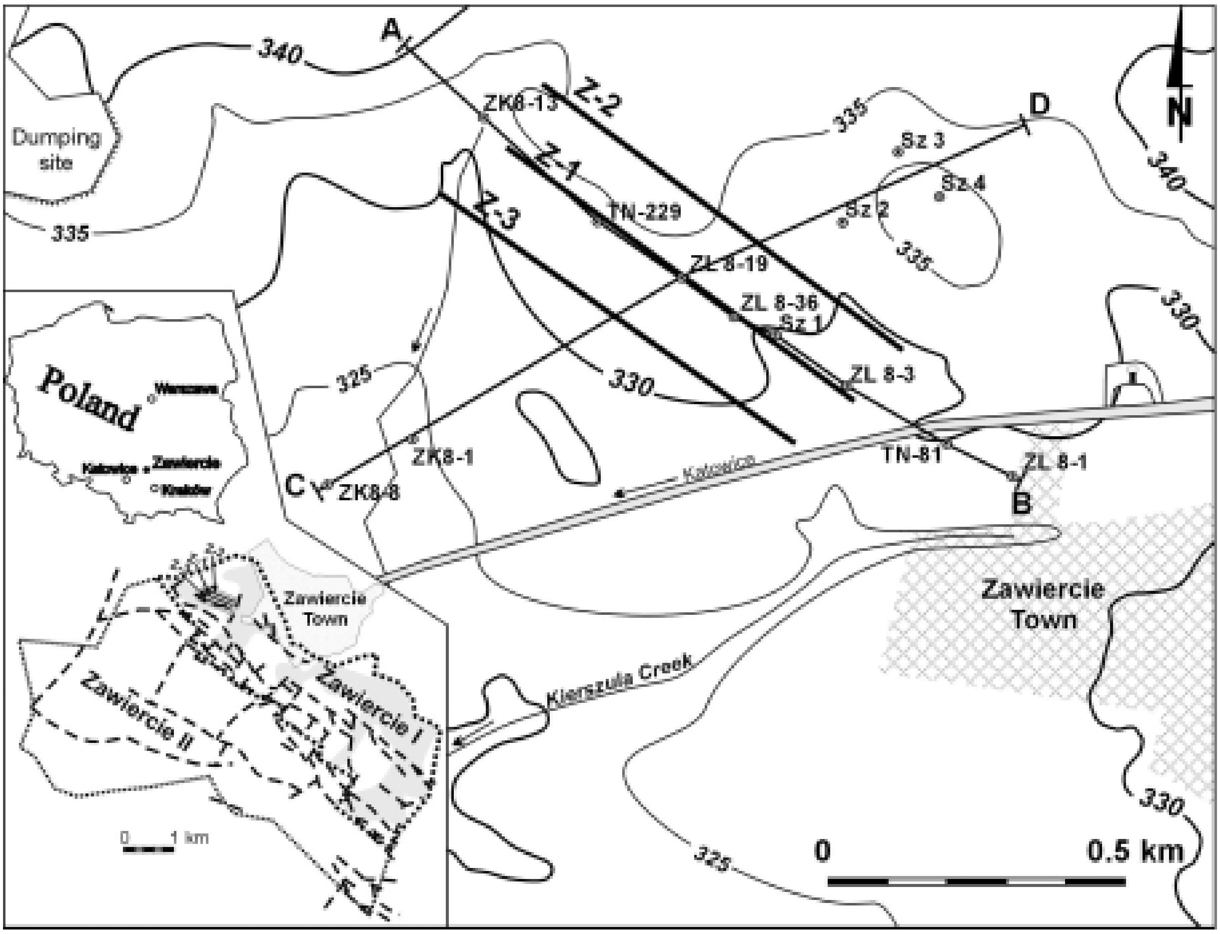

Fig. 1 Location area of investigation in Zawiercie I Zn-Pb ore deposits. Z-1, Z-2, Z-3 – profile of geophysic investigation. ZL 8-19 – bore-hole location. A-B, C-D – geological cross-section.

Kraków region and the MVT deposits, the mineralization is of a sulphide type (Szuwarzyński, 1996). The ores in the deposit under study are of a calcareous character and have simple mineral composition in which sphalerite-marcasite-galenite assemblage predominates. The ore quality is better than that of the currently mined deposits *Pomorzany* and *Trzebionka*. In the Zawiercie I deposit, the approximate average quantities of metals in balance ores are as follows: zinc - 6%, lead - 2.5% and iron - 2.7%. The thickness of ore bodies is up to 13 m (4 m on the average). The weight proportion of Zn-Pb-Fe sulphide minerals is considerable and amounts to 15.8% on the average, while the proportion of oxidized minerals amounts to 3.92% (Cabała, 1990). Such high quantities of low-resistivity minerals within high-resistivity Devonian and Triassic calcareous rocks may influence the geoelectric properties of the rock mass.

Three structural stages may be distinguished in the deposit area geological structure: the old Paleozoic, the young Paleozoic and the Permo-Mesozoic stage.

The old Paleozoic rocks include Cambrian mudstones and marbles. The Silurian is represented mainly by metamorphosed mudstones and claystones with intercalations of sandstones. The young Paleozoic stage consists of Devonian rocks, which discordantly overlie the Silurian rocks. The Lower Devonian is represented by sandstones and quartzites, while the Middle Devonian rocks include dolomites and limestones.

The Devonian or Silurian rocks are discordantly overlain by Triassic sediments (Figs. 2 and 3). In the areas where Devonian structures were elevated, Triassic rocks were removed by erosion. The Lower Triassic rocks are sandstones and claystones of the variegated sandstone and dolomitic sediments of the Rhaetian. The Middle Triassic sediments represent epicontinental facies (Wyczółkowski, 1978). The lower part of these sediments, i.e. the Muschelkalk rocks, is represented by the Gogolin Beds limestones. They are overlain by limestones of the Karchowice Beds, the Terebratula Beds and the Górażdże Beds. Epigenetic dolomitization process, which occurred within a major part of the Muschelkalk profile,

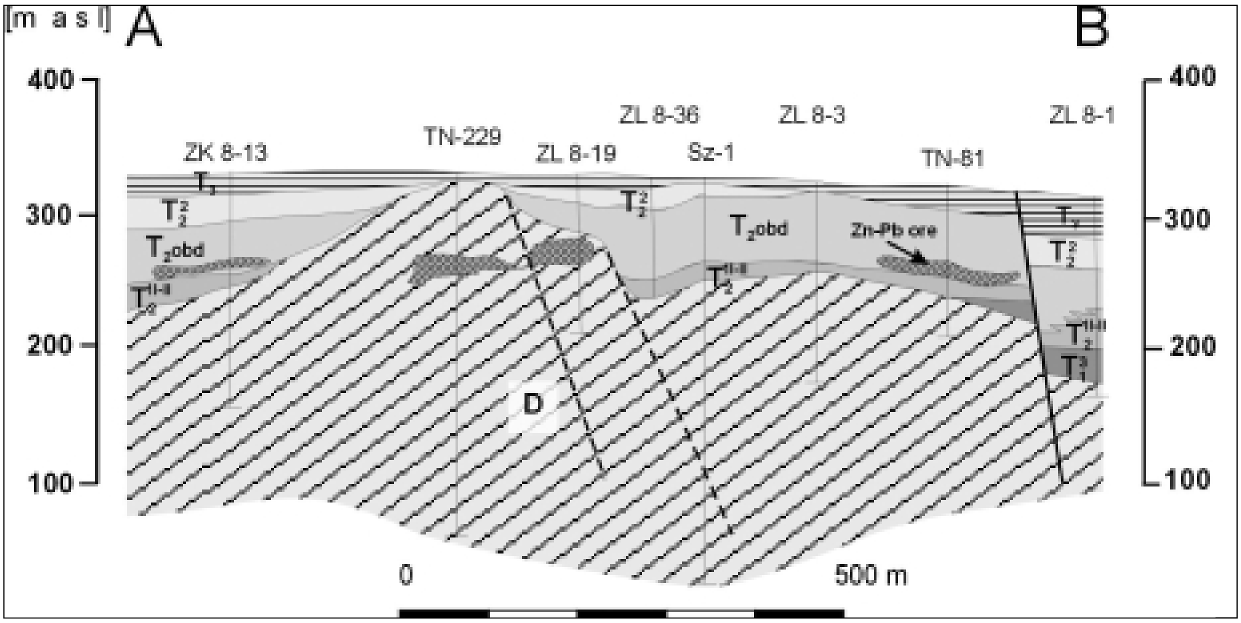

Fig. 2 Geological cross-section A-B in Zawiercie I Zn-Pb ore deposits. S – Silurian, D- Devonian, T_1^3- Rhaetian dolomites, T_2^{II-II} - Gogolin limestones, T obd - Ore-bearing Dolomites, T_2^2- Diplopora Dolomites, T_3- Keuper J – Jurrasic, Q – Quaternary.

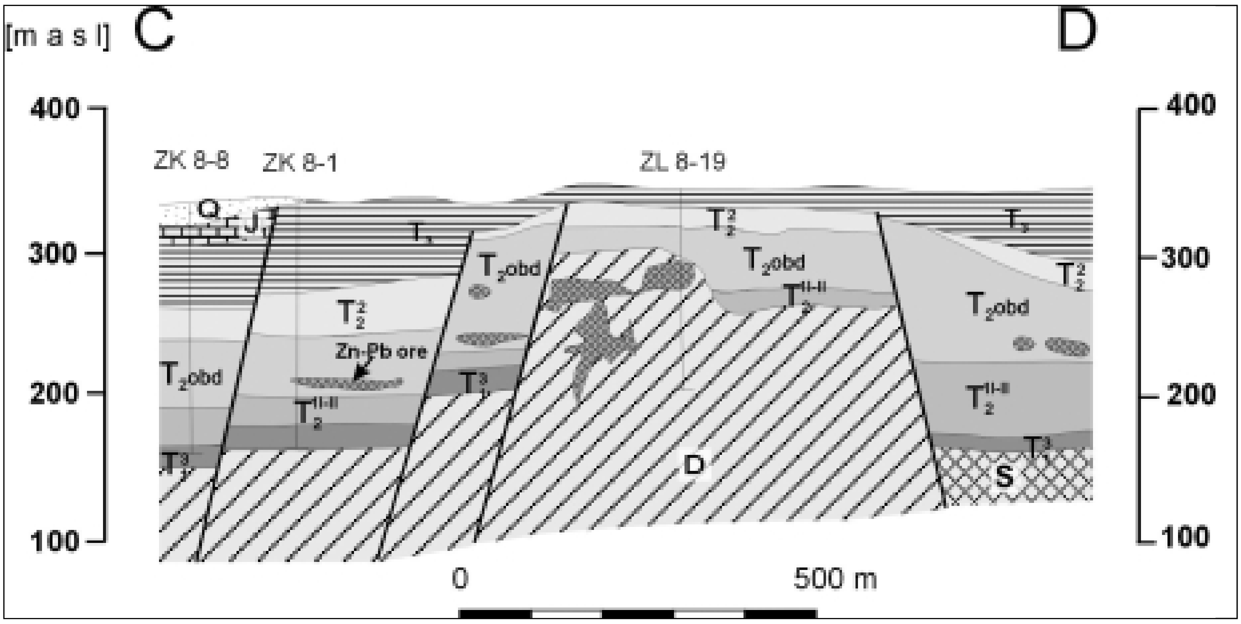

Fig. 3 Geological cross-section C-D in Zawiercie I Zn-Pb ore deposits. For explanation see Fig. 2.

resulted in the formation of the porous ore bearing dolomite. The ore bearing dolomite is, in turn, overlain by organogenic diplopore dolomite. The upper part of the Triassic unit (i.e. the Keuper) comprises clayey and marly-calcareous sediments.

Outside the elevations area, the Keuper sediments form a continuous, non-permeable cover. Within the tectonically lowered parts of the deposit the surface is covered with clayey sediments and sandstones of the Lower Jurassic (Fig. 2). The Quaternary sediments have the form of thin covers of regoliths, fluvioglacial sands and Pleistocene deluvial sediments.

The geological structure of the Paleozoic basement and the Mesozoic cover was strongly influenced by the Kraków – Lubliniec Fault Zone

(KLFZ) (Bula et al., 1997). The tectonic activity of the KLFZ during the Mesozoic was a major factor influencing the tectonic deformations evolution in the epiplatform Triassic deposits (Cabała, 1990; Cabała and Teper, 1990). A main feature of the geological structure is the block-fault style (Figs. 2, 3). The most widespread are gravity faults, and other fault types recognized include pivotal and reversed faults (Cabała and Teper, 1990; Cabała, 2002).

GEOELECTRICAL INVESTIGATIONS WITHIN METAL ORE DEPOSIT AREAS

Modern 2D and 3D geoelectrical investigation methods are commonly used to study the geological structure, also in deposit areas (Represas et al., 2005). The advantage of these methods is that a three-dimensional image of the geological structure may be obtained and the fact that the methods are non-invasive. Another important issue is the low cost of geophysical surveying in comparison with the cost of study with boreholes. K. Suzuki et al. (2000) used the pseudotomographic resistivity to locate active faults under a thick cover of Quaternary sediments. The comparison of geological and geoelectrical data pointed to the usefulness of the resistivity imaging for the investigation of geological structures in the vicinity of faults. Geoelectrical investigation methods proved also useful for performing a stratigraphic division of rocks characterized by various resistivity values. D. Baines et al. (2002) and I.A. Beresnev et al. (2002) applied the resistivity imaging to determine the location of shallow sand and gravel deposits characterized by both low and high resistivity in relation to the surrounding rocks. These authors also proved the possibility to successfully use geophysical methods to detect high-resistivity deposits occurring within low-resistivity rocks. A. T. Batayneh (2001) compared resistivity imaging results obtained during measurements carried out with various measurement arrays and at various electrode separations. It was proved that application of various electrode separations allows better determination of the ore veins extent. Measurements were preformed within a zone of dolerite dikes with vein ore mineralization. The best results in terms of ore mineralization recognition have been rendered by the Schlumberger array. The Wenner array allowed a less precise determination of the vein extent, while the polar array did not detect this structure at all. Geoelectrical methods have not been used yet to investigate the geological structure of Zn-Pb deposit in Poland.

THE INFLUENCE OF GEOLOGICAL FACTORS ON THE ROCK RESISTIVITY IN THE STUDY AREA

The rock resistivity is controlled by several factors. The most important are the following: mineral composition, porosity, cleavage, saturation of pore space with gases and liquids. Physical parameters of Triassic and Devonian rocks were determined in bench studies of drilling cores from boreholes marked with symbols Sz and Pz. 1-meter-long core sections were used to determine porosity, toughness, specific gravity and absorbability.

The highest porosity is characteristic of the primary dolomite of the upper variegated sandstone age (Rhaetian) and the Middle Muschelkalk age. The Devonian and Triassic dolomites have lower porosity values (Cabała, 2002). The mineralization process (ore development, calcitization, dolomitization and silification) resulted in the higher toughness of the rocks and in the lower porosity and absorbability. Fissures and interstices in the ore bearing zones are filled with calcite, barite and Zn-Pb-Fe sulphides. Toughness coefficients in karst ore bearing zones are lower than in the surrounding ore bearing dolomite containing Zn-Pb ores. The bulk density of the Triassic and Devonian dolomites is higher than the bulk density of Muschelkalk limestones and dolomites (Cabała, 2002).

Physical parameters vary within relatively small ranges. The rock resistivity in the Zawiercie deposit is strongly influenced by the water content in the rock mass and the occurrence of ore nests. A strong discharge of water from fissured and karst rocks of the Triassic and Devonian ages present at shallow depths is caused by the nearby potable water intake. Perched water tables recharged from the surface are sparse.

METHODS

GEOLOGICAL INVESTIGATIONS

The investigations of the geological structure of the deposit was based on 108 boreholes drilled during several periods of the documentation research carried at the deposit (1953-1989), and on the bench studies of drilling cores. The drilling and documentation work was performed by the ‘Przesiębiorstwo Geologiczne' (Geological Company) in Kraków.

SURVEYING

The geophysical survey line location was performed with the use of GPS methods (a receiver gpsmap 60 CS). In order to present the borehole locations, their co-ordinates were transformed from the archival coordinate system 1965 to the system WGS 84. Field measurements with the GPS device made it possible to precisely determine geophysical survey lines overlapping with borehole locations.

GEOPHYSICAL INVESTIGATIONS

Geoelectrical measurements were performed on 3 parallel, 600-meter-long survey lines (Fig. 1). The distance between the survey lines was 100 m.

In the study, the authors used a multi-electrode apparatus LUND Imaging System with a measuring unit SAS-4000 and a selector ES464 produced by the Swedish company ABEM. The system makes it possible to perform a quick high-definition geoelectrical investigation of the rock mass. Field investigation data were processed with a special

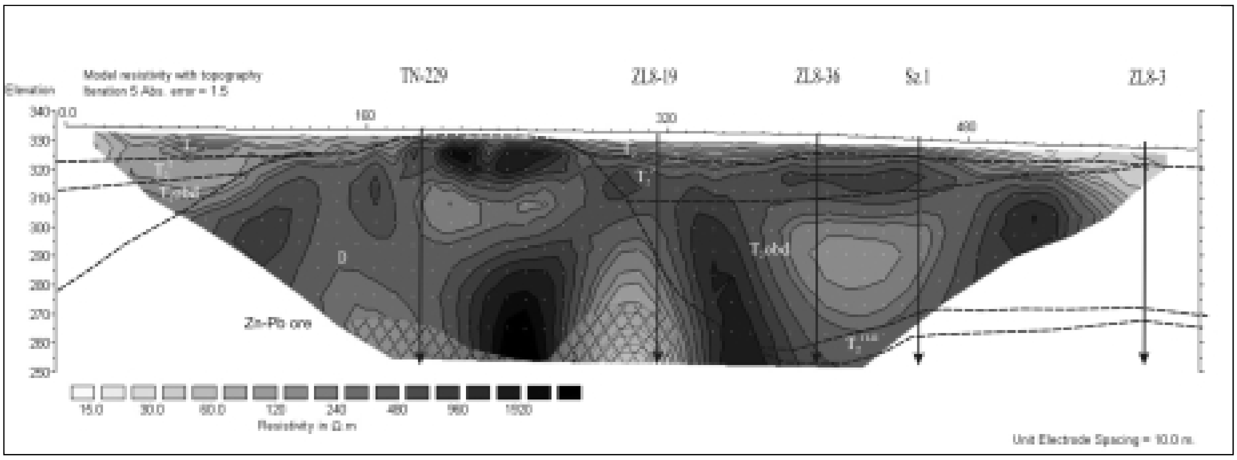

Fig. 4 Geoelectrical cross-section Z-1 – Schlumberger array, D – Devonian, T_1^3- Rhaetian Dolomite, T_2^{1I-II} - Gogolin limestones, T obd - Ore-bearing Dolomites, T_2^2- Diplopora Dolomites, T_3- Keuper.

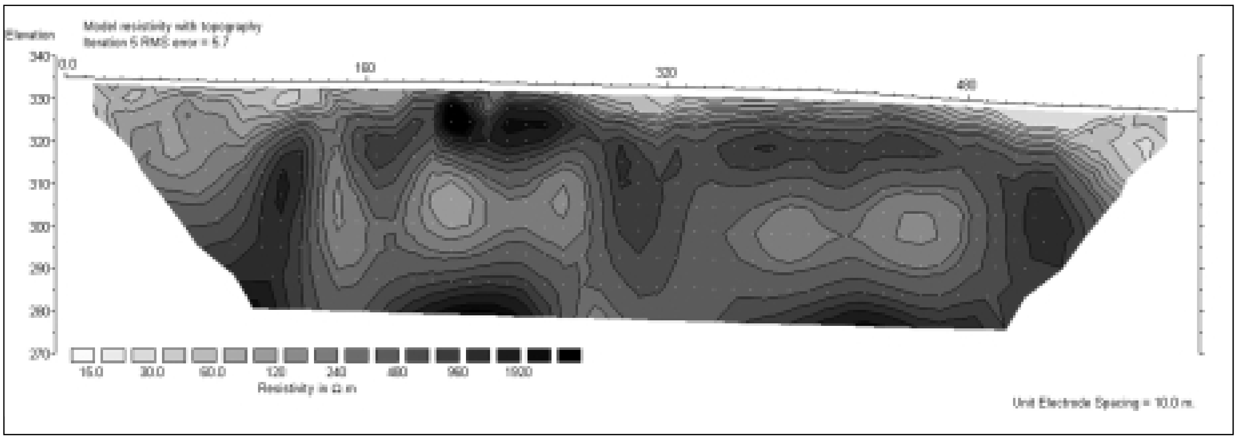

Fig. 5 Geoelectrical cross-section Z-1 – dipole-dipole array.

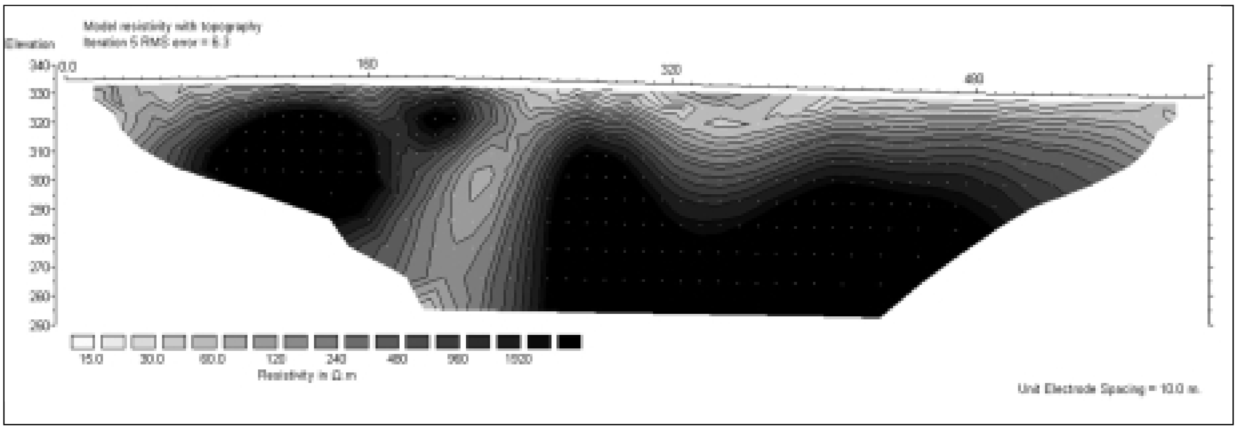

Fig. 6 Geoelectrical cross-section Z-2 – Schlumberger array.

software Res2Dinv, which uses advanced inversion algorithms in the modelling.

The measurement array of each survey line consisted of 61 electrodes placed along the survey line at 10-meter separations. The measurements were performed in the following arrays: Schlumberger, Wenner and dipol-dipol.

RESULTS

Geoelectrical profiles for the survey line Z-1, Z-2, Z-3 in the Schlumberger and the dipol-dipol arrays are presented in Figures 4-9. The rock resistivity values range from 20 to 2000 ohmmeters.

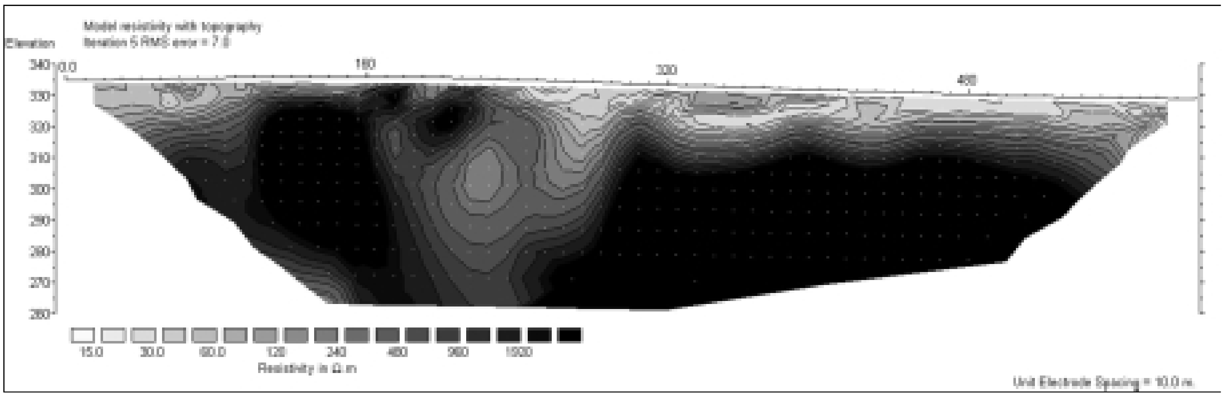

Fig. 7 Geoelectrical cross-section Z-2 – dipole-dipole array.

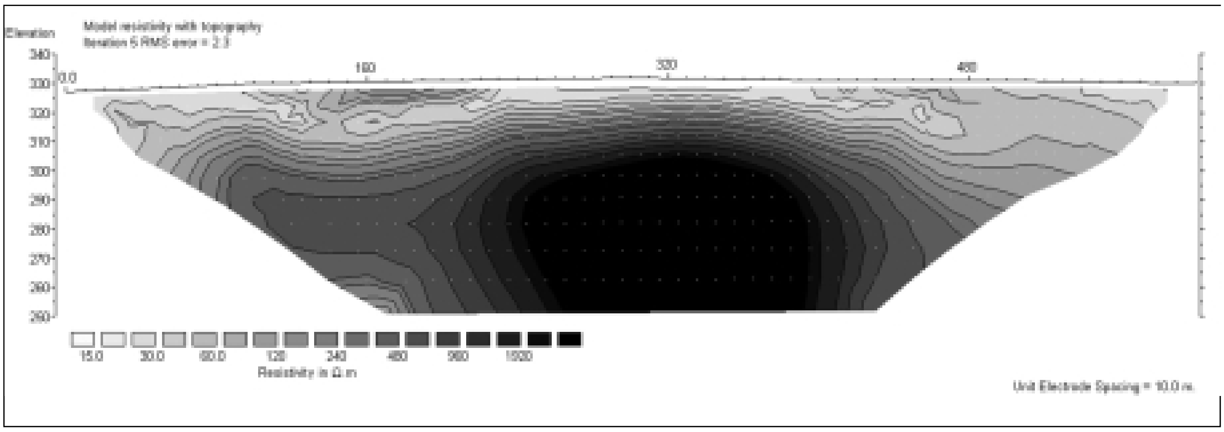

Fig. 8 Geoelectrical cross-section Z-3 – Schlumberger array.

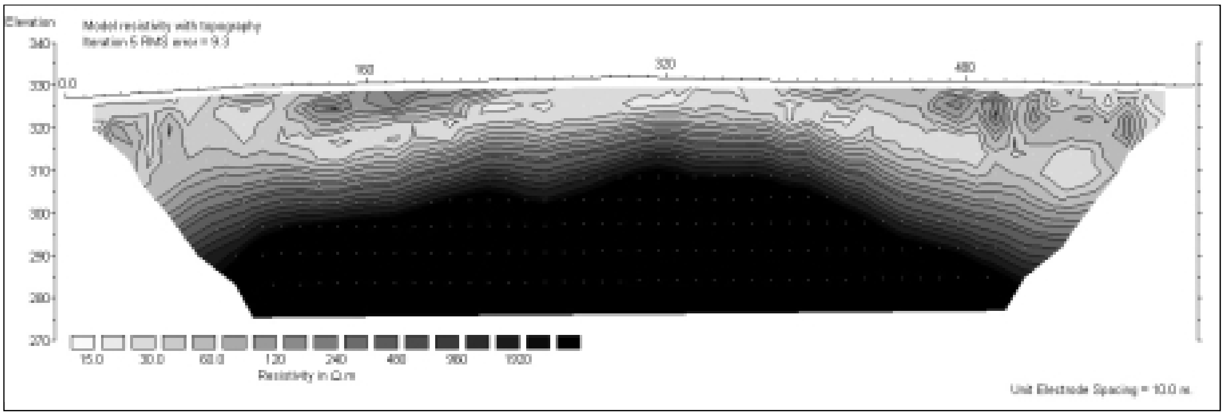

Fig. 9 Geoelectrical cross-section Z-3 – dipole-dipole array.

For the survey lines Z-1 (Figs. 4 and 5) and Z-2 (Figs. 6 and 7) the geoelectrical profile has not revealed a layered structure. The boundary between the clay deposits of the Keuper age, characterized by low resistivity, and the older calcareous rocks is clearly marked. Within the Devonian and Triassic dolomites there are horizontally arranged zones of the both low- and high-resistivity. This could point to the existence of various hydrogeological conditions in the rock mass. Moreover, in the profile Z-2, there occurs an almost vertical, clearly defined low-resistivity zone dividing blocks of high resistivity. The geological investigations indicated that this image reflects a water saturated fault zone that divides the Devonian and Triassic rocks. At the 320th meter of the profile *Z-1* (Figs. 4 and 5), down from the depth of 50 meters, a clearly defined low resistivity zone is marked. This zone is related to a balance sulphide mineralization documented in the borehole ZL8-19.

A different geoelectrical model was obtained for the profile Z-3 (Figs. 8 and 9). A well defined vertical zonation is visible in this profile, and is also justified by the geological structure. This profile was made in the downthrown wall of a fault cutting an elevation of Devonian rocks (Figs. 2 and 3).

CONCLUSIONS

The rock mass model obtained as a result of geoelectrical investigation is compliant with the geological structure recognized in boreholes and geological cross-sections. The results of investigations performed with the use of the Schlumberger array and the dipol-dipol array are very similar. In the resistivity images, the boundary between clayey sediments of the Keuper age and the Devonian dolomites is particularly well marked. Within the Triassic and the Devonian rock mass it was difficult to distinguish packets of rocks characterized by similar resistivity values that could be correlated with respective lithostratigraphic units. The Devonian and the Triassic rocks have similar resistivity values and local variations of this parameter are influenced by the porosity, the fissure content, the level of pore saturation with water, and the mineral composition. In profiles obtained using the resistivity imaging method some areas are marked that may be interpreted as fault zones or buried karst systems. The depth of the top of the Devonian strata and the occurrence of fault zones is much more precisely determined on the basis of geophysical investigations than on the basis of borehole log data. With the help of geophysical methods it is possible to determine an angle of fault inclination, a width of tectonic zones and a thickness of regoliths.

In the lower part of the profile Z-1 in the Schlumberger array and the dipol-dipol array there occurs a clearly defined low-resistivity anomaly. It is related to the presence of sulphide mineralization documented in the borehole ZL8-19. The results of resistivity imaging for the profiles Z-1 and Z-2 are very similar to one another, whereas the character of the profile Z-3 is entirely different. The reason is the geological structure of the study area.

The determination of low-resistivity anomalies overlapping with balance ore bodies justifies the usefulness of performance of further geophysical studies in order to investigate shallow Zn-Pb ore deposits. In future, supplementary measurements will be performed at greater electrode separation in order to increase the depth of investigation. It is planned to lead survey lines perpendicular to the main fault zone that divides the Zawiercie I and II deposit area (Fig. 1). The investigations under planning are aimed at testing geoelectrical methods as a tool for the preliminary study of shallow ore bodies, the determination of fault zones and the study of the surface relief of the Paleozoic strata top.

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