GEOELECTRICAL STUDY OF THE POSTMINING AREA IN RUDOŁTOWICE (POLAND)

GEOELEKTRICKÁ STUDIE VE VYTĚŽENÉM AREÁLU V RUDOŁTOWICÍCH (POLSKO)

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Abstract

The post-mining waste and salt water pumped from Silesian coal mines pose a threat to soils as well as to the surface and underground water. One of the numerous areas where post-mining waste is deposited is located in the Rudołtowice village about 200 m from the Vistula River. The waste dump consists of a salt water reservoir and the pile of the rock material. Resistivity and induced polarisation imaging methods were used to check whether contamination from the dumping area migrates towards the river. The results obtained showed the existence of contaminated zones in the vicinity of the reservoir and on the foreground of the pile. In the area examined both shallow Pleistocene water-bearing layers are affected by the waste dump.

Abstrakt

Odpad z dolů a slaná voda, které se čerpají ze slezských uhelných dolů představují hrozbu jak půdě, tak povrchovým i podzemním vodám. Jedním z četných areálů, kde jsou odpady z dolů uloženy, se nalézá v okolí vesnice Rudołtowice asi 200m od řeky Wisly. Úložiště odpadů tvoří nádrž se slanou vodou a halda horninového materiálu. Metody měrného elektrického odporu a vynucené polarizace patří k těm, které byly použity ke kontrole, zda dochází ke kontaminaci z úložiště směrem k řece. Získané výsledky potvrzují existence kontaminovaných zón v blízkém okolí úložiště a předpolí haldy. V areálu, který byl testován, se ukázalo, že obě pleistocénní vodou nasycené vrstvy jsou zasaženy odpady z dolů.

Keywords

postmining waste, Rudołtowice, salt water, resistivity and induced polarisation imaging

Klíčová slova

odpad z dolů, *Rudołtowice,slaná voda, měření měrného elektrického odporu a vynucené polarizace*

1 Introduction

All coal mines working at present in Poland produce about 70 million tons of waste substances annually. A significant number of them are located on storage yards situated in the vicinity of the mines. Large amounts of chlorides and sulphates from the stored rock material have leaked for many years. Additionally, when the pH value is low heavy metals such as Zn, Pb, Cu, Cd, which are in the rock

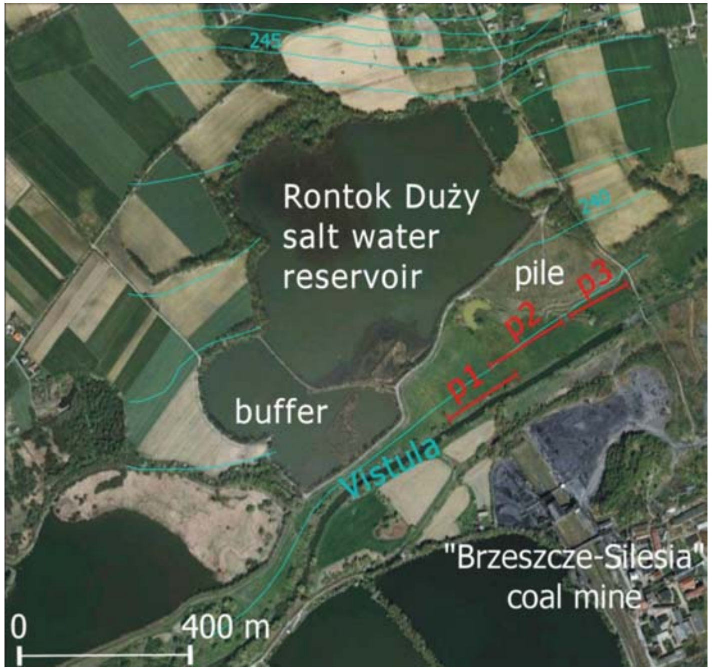

Fig. 1 Location of the survey area.The blue lines indicate hydroisohypses (accor. Kowalska and Kaczor, 2007); p1, p2, p3 survey lines

material, can also be leached. All of the outwashed compounds diffuse into soil and water. Another serious problem of mines, especially those which are situated in the southern part of the Upper Silesian Coal Basin, is salt water which is pumped out during the exploitation. The mineralisation of mine water increases significantly with the increasing depth of the mining works. On the surface, salt water is accumulated in special reservoirs and after preliminary treatment is pumped into the rivers. In years 1995-98 the average quantity of chlorides and sulphates pumped into the upper Vistula and the upper Oder amounted to 2,550 thousand tons per year. The effect of post mining waste on the ground-water environment will be traced on the example of waste dump of the “Brzeszcze-Silesia” coal mine.

The “Brzeszcze-Silesia” coal mine and its waste dump are situated near Goczałkowice, about 50 km from the border with the Czech Republic. For many years salt water was a serious problem of this mine. In 1984 the mineralisation of the pumped water exceeded 54 g/dm^3; in (Adamczyk et al., 1988). According to the data of 1992 (Sobolewski, 1992), approximately 293 tons per day of Cl^- and SO_4^{2-} were released from this mine into the Vistula River. Because of this, considerable financial penalties were paid by the mine. One of the dumping grounds of the “Brzeszcze-Silesia” coal mine is situated near the village of Rudołtowice at a distance of about 200 m from the Vistula River. The waste dump consists of a reservoir of salt water named “Rontok Duży” and a nearby pile where the development dirt was stored (Fig. 1).In recent years the Rontok Duży reservoir has become a subject of interest because of the high concentration of radioactive and metallic elements in the sediments that are at the bottom (Jankowski et al., 2005; Śleziak and Petryka, 2011), as well as because of evaporates which have formed in its inshore zone (Molenda, 2006). The deleterious effect of the pond on the nearby deposit of therapeutic mud, which is exploited for the Goczałkowice health resort, was also analysed (Adamczyk et al., 1988, Labus and Paszek, 2000).The possibility of the infiltration of the harmful substances from the Rontok Duży reservoir and from the pile directly into the Vistula River has not been specifically identified to date.

2 The area of the investigations

The Rontok Duży pond is situated on the floodplain of the Vistula River, approximately 200 m from the river bed. It was established in the 16th century for pisciculture. In the 1970s it was adapted to be a reservoir with an area of about 42 ha for saline mine water. At present, the pond is divided into the salt water reservoir (mineralisation above 30 g/dm^3) with a surface of 190,500 m^2 and a buffer with fresh water and a capacity of145, 100 m^3. The depth of the pond ranges from 0.4 to 2.0 m. The reservoir has been excluded from industrial use since 2003; however, it still contains salt water.

From the south, the post mining waste dump borders on the reservoir. During the period 1963-1999 approximately the 198,000 m^3 of the development dirt was deposited there. In the years 2000-2002 the dump and its environment were reclaimed. The slopes of the pile were formed, a band trench collecting water from slopes arose around the dump and finally the trench, which drains the water into the Vistula River, was created. Totally, 5.68 ha of the pile and 0.916 ha of the grassland were reclaimed between the pile and the Vistula River.

3 Geological and hydrogeological conditions

The area of the investigations is situated in the Upper Silesian Coal Basin, thus the Carboniferous coal formation can be found in the deep basement. The above-mentioned formation is covered by sediments which belong to the Miocene period. Its thickness exceeds 100 m. These sediments consist of clays with interbeds of the fine-grained sand. A roof of the clayey sediments can be noticed at a depth of about 7.5 m in the southern part near the Vistula bed and dips to the north up to 30 m. The Pleistocene deposits consist of the fluvioglacial sediments with a thickness of 1-30 m (Labus and Paszek, 2000). The lower part of the Pleistocene deposits is composed of pebbles, gravels and sands. Local depressions are filled with the organic sediments mainly with therapeutic mud (peloids). The upper one consists of fine-grained sands with a thickness of about 2.5 m; directly below the surface a several-meters-thick layer of clays and dusts belonging to the Holocene period is observed. The geological section through the northern part of the Rontok Duży reservoir is presented in Fig. 2.

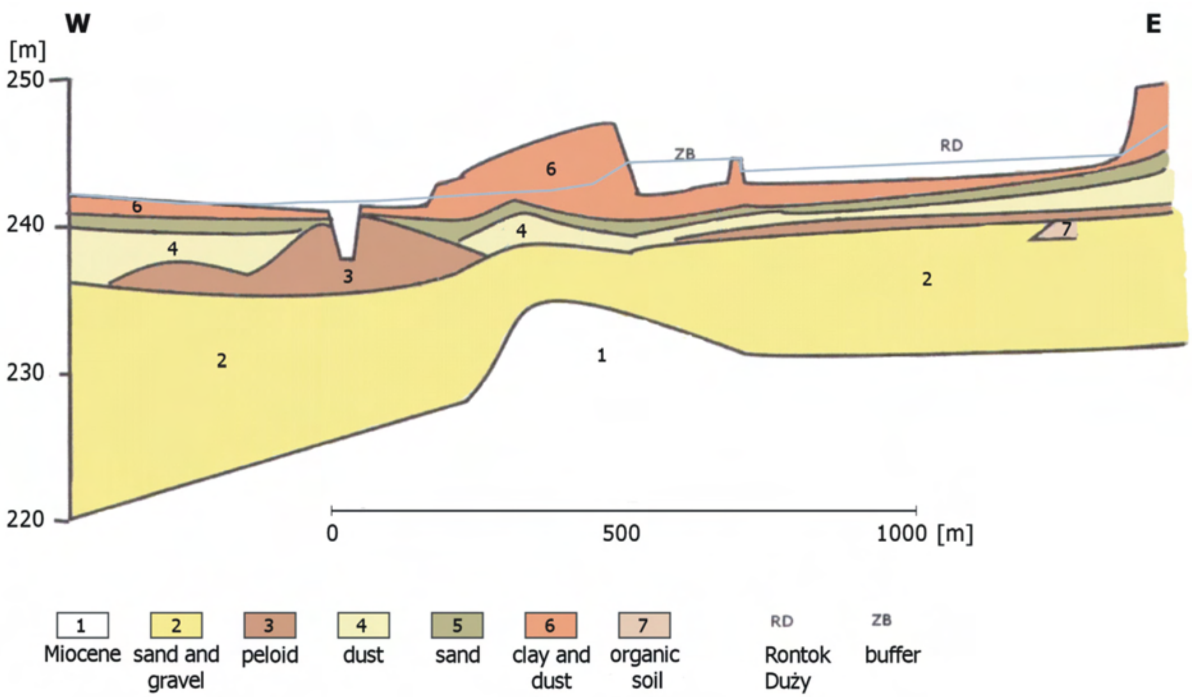

Fig. 2 The geological section through the northern side of Rontok Duży reservoir (accor. Labus and Paszek, 2000)

Underground water exists in the area examined in the Pleistocene and Miocene sediments. The Miocene water level is non-contiguous. It includes sand or dust lenses. This is the saline water level with a mineralisation 4-10 g/dm^3. It is isolated from higher levels by impermeable clays, thus it is not important due to the infiltration of contamination. In this case the Pleistocene level is of essential importance. This level is supplied by rainfalls and is drained by ponds and the Vistula River. The general underground water flow direction is S-SE towards the Vistula River which justifies the advisability of the research undertaken. The mineralisation of pure water ranges from 0.1 to 0.6 g/dm^3.

The Pleistocene water level is divided into two sublevels. The lower one, with a thickness of 3-10 m, is built of gravels and sands.

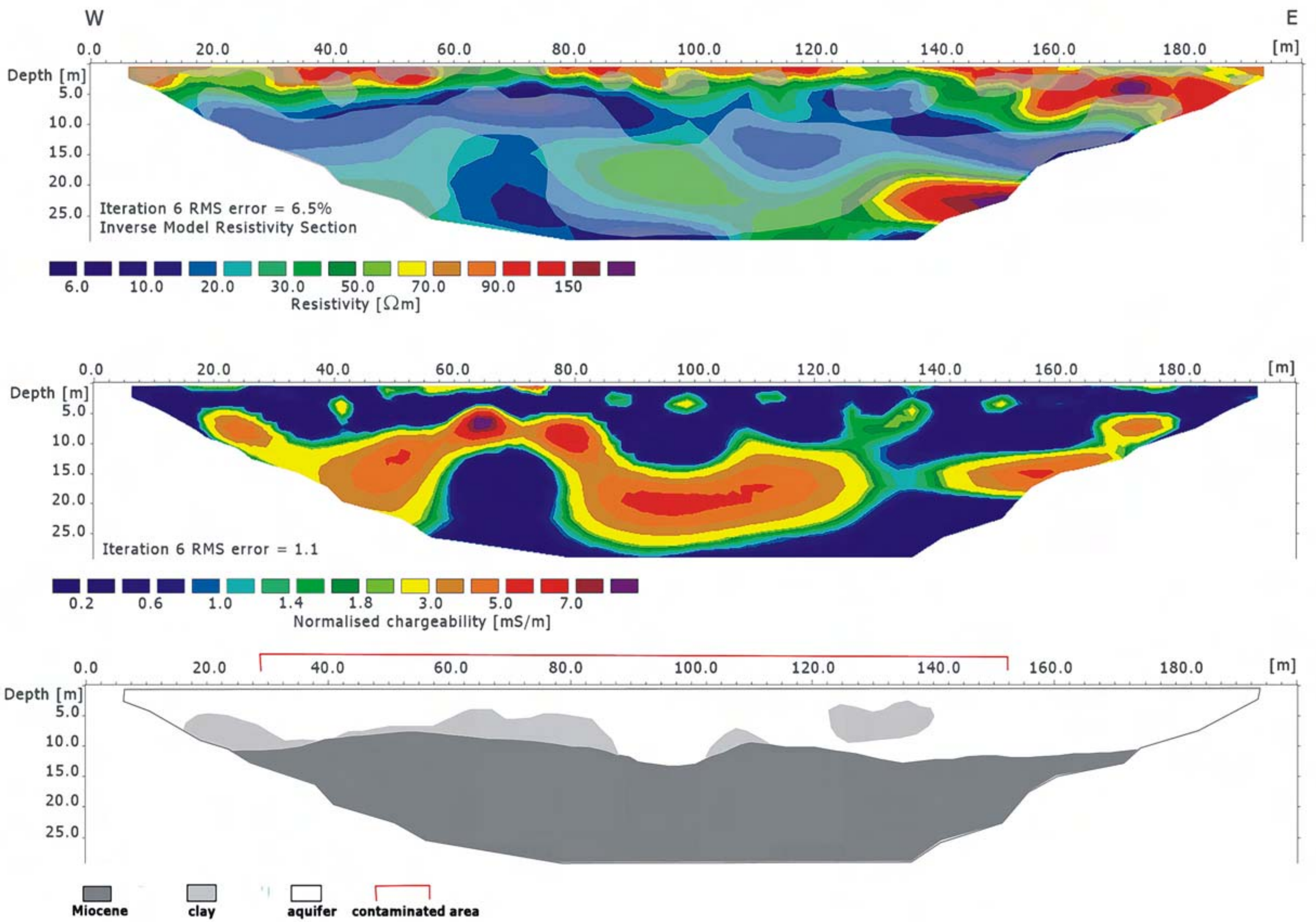

Fig. 3 Inverted sections of resistivity and normalised chargeability along profile 1 and its interpretation

Due to its thickness, this level is regarded as the main horizon – a path where the expansion of contaminants occurs. The upper consists of fine-grained, dusty, locally clayey sands. Its thickness reaches 1-2 m. Its effect on the migration of contaminating compounds is not known well.

4 Geoelectrical survey

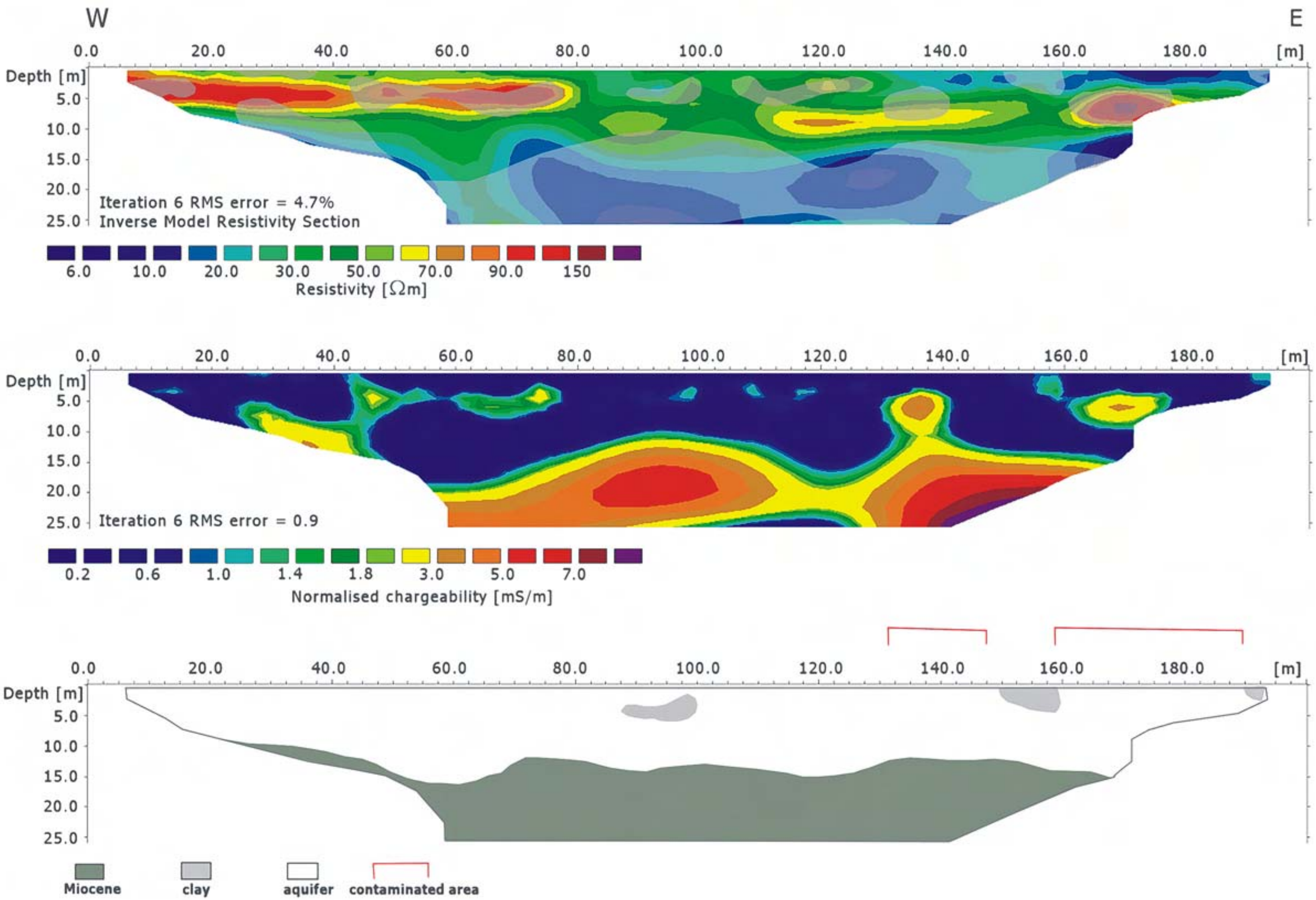

Fig. 4 Inverted sections of resistivity and normalised chargeability along profile 2 and its interpretation

Three survey lines for electrical surveys were traced among the pile, the Rontok Duży pond and the Vistula River. The length of profiles was respectively 200 m for profiles 1 and 2, and 160 m for profile 3. The length of profile 3 was limited by field conditions.

For all of the selected lines, the resistivity and induced polarisation (IP) imaging using an ABEM Lund imaging system were performed. The extent of the survey for measurement of the induced polarisation was justified by the expected co-occurrence of clayey rocks and infiltrating pollution. Distinguishing between clayey layer and the contaminated water-bearing horizon is a crucial issue in environmental geoelectrical studies. Unfortunately, on the basis of the only resistivity measurement it is difficult, because the resistivity values typical for these two sediments are almost the same.

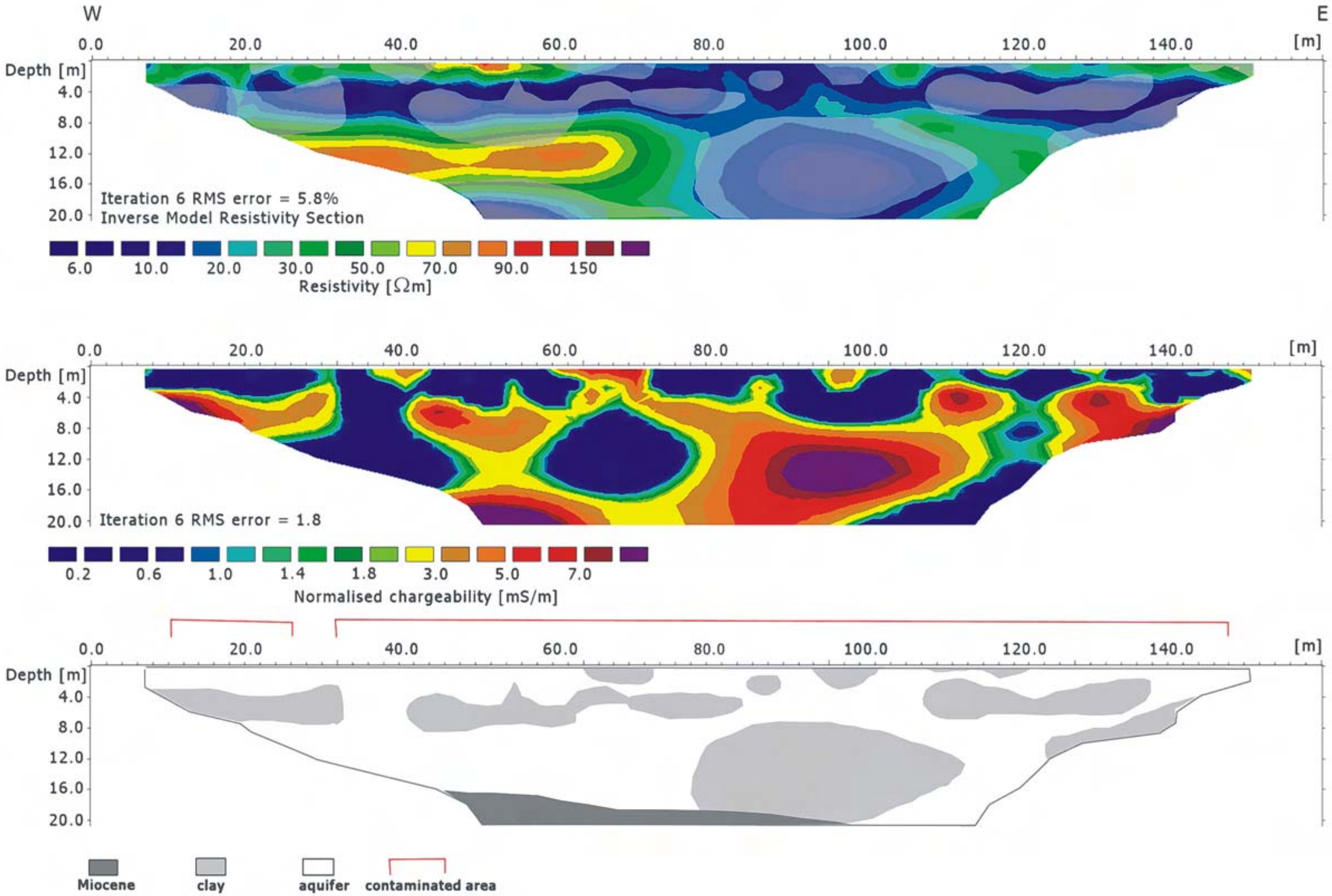

Fig. 5 Inverted sections of resistivity and normalised chargeability along profile 3 and its interpretation

Introducing the induced polarization measurement helps to solve this problem. The IP effect which is observed in sediments with the absence metallic minerals is called the membrane polarization. This phenomenon occurs in sediments containing the clayey minerals and it is caused by the attraction of the positive ions toward negatively charged clayey particles in the pore space. The applied current disturbs the electric charges which return to the equilibrium state when the current is off. The magnitude of the IP effect depends on the clay mineral concentration (max. at about 10 % of clay), grain size, and water content and water mineralization.

Because of the induced polarisation measurement, the no polarisable $Cu/CuSO_4$ electrodes and the dipole-dipole electrode array instead of standard stainless steel electrodes were chosen. In order to provide the desired depth of the recognition, the distance between electrodes was fixed at 5 m for profiles 1 and 2 and 4 m for profile 3. The survey line started from the west crossing the ditch filled with water flowing from the Rontok Duży reservoir (Fig. 1) and included the area where previous studies had shown the possibility of contamination (Kowalska and Kaczor, 2007). The IP survey was performed during a time domain where polarisation effect is expressed as chargeability. The chargeability which is measured by Lund system is defined as the area under the potential decay curve, normalized relative to initial potential V_0. Chargeability was measured in 10 time windows, each 20 ms long. Finally, the integration time 50-210 ms was chosen for the interpretation.

The basic model (Ward, 1997) for low-frequency electrical current flow in rocks incorporates a conductive (electrolytic) flow pathway in parallel with a frequency dependent complex-conductivity element. The complex surface-conductivity consists of surface conduction and the diffusion-controlled electrochemical surface polarization. The complex surface-conductivity depends on the pore geometry, bulk fluid composition and surface chemistry. The bulk conductivity is significantly greater than the surface conductivity, and thus the measured chargeability is related to the ratio of the surface conductivity to the bulk conductivity. The so-called field chargeability is a function of the grain-surface polarisation and the pore-fluid conductivity. The field chargeability may be scaled to receive parameter which is a direct measure of surface conduction, proportional to the polarisation. This parameter is called the normalised chargeability and its value can be obtained by dividing the field chargeability by resistivity.

An increase in the field chargeability depends of both clay content and water content, which is in contrast to the normalised chargeability, which is independent of the pore-fluid properties; the latter of the above-quoted parameters was used to identify the clay-rich zones.

5 Obtained results and conclusions

The resistivity and IP sections should be analysed concurrently. Slater and Lesmes (2002) demonstrated that the zones, where low resistivity values correspond with high normalised chargeability, can be considered as areas with the presence of clayey sediments, whereas low resistivity correlated with low normalised chargeability indicates where the infiltration of salt water (contamination) occurs.

The obtained resistivity and the IP data were inverted using Res2DInv software. The depth of recognition was about 25 m for profiles 1 and 2, and 20 m for profile 3.

The roof of the clayey Miocene sediments is found at a depth of 9 m in the western part and falls gradually to about 16 m in the eastern part of the studied area. The depth of the roof of the Miocene obtained from the geoelectrical study was correlated with the data from the nearest archival borehole which is situated in the vicinity of the profile 1. The obtained result coincides with the geological information.

For all investigated profiles (Fig. 3 - 5) one can ascertain the presence of areas within the water-bearing layer which are characterised by the low resistivity and low chargeability thus indicating the presence of contamination.

The results of resistivity and chargeability imaging obtained confirmed that in the western part of the area examined (profile 1) contamination from the Rontok Duży reservoir spreads towards the Vistula River through the lower, sand-gravel Pleistocene sublevel, as was expected. The resistivity value obtained for this layer, which is over a dozen of Ωm and the normalised chargeability is very low - below 0.6 mS/m (Fig. 3).Within the water-bearing layer, several clay lenses can be noticed.

The lowest resistivity value (below 8 Ωm) observed between 70-75 m of the profile within the water-bearing layer is connected with the presence of clay. The thickness of the upper water-bearing layer is not significant and nothing indicates the presence of contamination within this layer.

Eastward, (profile 2), you can see the resistivity of the sand-gravel level increases. Unlike the low resistive zone, which does not correlate with the increase of chargeability, appears just below the surface in the eastern part of the profile, at a length of 135 m (Fig. 4) and it continuous in the east direction. This points out that the increased water mineralisation probably connected with the proximity of the pile. In the vicinity of pile the upper sublevel, which is built of fine-grained sand, seems to be the main path where the migration of contamination occurs.

For this profile, several locations (50-75 m, 165-175 m), which are characterised by the increase in resistivity and chargeability can be noticed. They are interpreted as organic sediments (Slater and Reeve, 2002).

For profile 3, the lower water level does not show any sign of contamination. The area of the low resistivity within it, which is observed between 80 and 110 m of profile at a depth of 14 m, is caused by the clay lens (Fig. 5). The zone interpreted as polluted the water-bearing layer continues just below the surface to a depth of about 4 m.

The results of our investigation confirmed the occurrence of the migration of contaminating substances from the waste dump area of the "Brzeszcze-Silesia" coal mine southward. The horizontal ranges of the pollution for profile 1 and profile 3 correlate with results obtained with the use of VLF method (Kowalska, 2011). Contamination is transferred not only through the lower sandy-gravel Pleistocene water level but also through the upper sublevel which is built of fine-grained sand. In the western part of the area studied the lower sublevel plays a dominant role in the spread of contamination, particularly in the vicinity of the pile. The size of applied array (a = 5 m) is large enough that the subsurface layer of the Holocene clays characterised by variable thicknesses is noticed only in the eastern part of the area studied. However, in the western part of the area (profile 1), it appears only in the form of isolated patches. The lack of the isolation can allow the unhindered infiltration of fresh water connected with precipitation. Furthermore, this may partially decrease in the desalination of water within the first water-bearing sublevel.

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