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ORIGINAL PAPER

THE USE OF GEOELECTRICAL METHOD IN PRELIMINARY INVESTIGATION OF THE FREDRO FAMILY'S IRON MINE ADIT IN THE VILLAGE OF CISNA, THE BIESZCZADY MOUNTAINS, SE POLAND

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ABSTRACT

The study over the historical *Rose* iron mine adit were performed to find and map its location. In order to locate the exploited adit the resistivity imaging method was applied. Measurements were carried out along six survey profiles perpendicularly intersecting the adit. Measurements done along first three profiles were performed with application of 5 m electrode spacing and the total length of electrode array reached 200 m. For the profiles 4th and 6th 10 m electrode spacing was applied what gave total profile length of 400 m. The 5th profile possessed 5m electrode spacing and total length of 470 m. Roll-along technique was designed on this profile. For all measurements the Sweden equipment Lund produced by ABEM company was applied. Each resistivity cross-section was obtained after the robust inversion using Res2Dinv software. The results showed high resistivity anomalies located in areas suspicious as the adit, beneath the main ridge of Mochnaczka-Jeleni Skok Mountain. Near the adit entrance known from the historical information, the main anomaly was disturbed, probably because of the collapse of a tunnel entrance which could be seen in terrain morphology. It is supposed that on further distances the adit retained its character, however, it can be filled with secondary deposits or flooded.

INTRODUCTION

The protection of cultural and industry relics is a peculiar obligation to the heirs of our ancestors. It should not be only paramount importance for local communities but this is also the overriding issue of the whole population. Although taking care of historic buildings or monuments of nature is complicated and time consuming, the appropriate way, of the protection of something that is not discernible at first glance must be found.

Therefore, the main aim of the study was to find a location of the Rose adit in the village of Cisna which was the 19th-century tunnel of the iron ore mine that had been formerly owned by the Fredro Family. The main effort of the study was to determine the possible course of the tunnel and the adit entrance that might create a path of great historical and natural interest being a potential touristic route in the future. To achieve the objective of research the electrical resistivity imaging was applied because of many case studies that proved this method as very successful in void and tunnels recognitions (e.g. Panek et al., 2010; Pierwoła et al., 2011; Martinez-Pagan et al., 2013; Metwaly and Al Fouzan, 2013; Krajewska et al., 2014; Martinez et al., 2014; Li et al., 2015).

SITE CHARACTERIZATION

The study area was located on the Mochnaczka-Jeleni Skok Mountain in the Cisna village, the Western Bieszczady Mountains, South-East part of Poland (Fig. 1). The geology in the vicinity of Cisna is mainly characterized by the Carpathian flysch, called the Cisna Beds (Bąk and Wolska, 2005), which is interbedded with sandstones, marls, shales and mudstones. The regional structures are composed of the Menilite-Krosno Series which form local rock masses aged the Late Cretaceous and Paleogene Periods (Malata, 2005). Moreover, the Cisna area lies on the borderland between the Silesian and Dukla Nappes within the Fore-Dukla Unit and the Michowska Sub-overthrust (e.g. Földvary, 1988; Einsele, 2000; Ślączka et al., 2008; Alexandrowicz and Margielewski, 2010).

Iron ores are occurring locally in the Bieszczady Mountains in two forms, as the surface bog iron ore (limonites) and opaque mineral nodules concentrated in the flysch layers. The iron ore, as siderite concretions occur commonly within a dark slate, both in the Dukla and Silesian Units (Fig.1) (Kukulak, 2007) and as opaque minerals (hydrated iron oxides) in Cisna-type sandstones (Bąk and Wolska, 2005). The most characteristic feature of the Cisna Beds is

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the occurrence of grey (grey-brown on weathered surfaces), thick-bedded (even more than 3m), fine-to coarse-grained, polymictic sandstones with calcareous-siliceous cement (so-called Cisna-type sandstones). The largest accumulations are in Paleogene dark slate of the Dukla Unit, which can be found, among others, around the villages of Wetlina, Cisna and Majdan (Fig. 1). They form the lens concentration and their origin is probably early diagenetic. Fresh surface is dark brown, while the yellow-gray surface is observed after weathering. Inside, they are characterized by micrite structure, composed of fine-grained carbonate minerals and dispersed clays with an admixture of pyrite and quartz (Rybak, 2000; Bąk et al., 2001; Bąk and Wolska, 2005; Karwowski and Szełęg, 2006; Kukulak, 2007).

In the beginning of the 18th century Cisna became the property of the House of Lubomirski, Polish princely family. In 1740, the Cisna estate changed the owner and it belonged to the House of Fredro, Polish noble family. In 1772, as a result of the first partitioning of Poland, the village was incorporated into the Austrian Empire. In 1790, Jacek Fredro, father of well-known Polish writer, Aleksander Fredro, inherited Cisna in 1790. Using the local iron ore deposits, Jacek Fredro set up first adit in 1796, and then, in 1804, an iron foundry which manufactured farming tools, pots and furnaces. Iron ore mines and iron foundry were closed in 1864 (Gruszczyński et al., 1996; Rejzdrowicz, 2015).

SURVEY METHOD

Geophysical studies were conducted using well-know resistivity method (e.g.: Sumner, 1976; Telford et al., 1990; Schön, 1996; Binley and Kemna, 2005; Cegrell and Martensson, 2008; Idziak and Wysowska-Świebodzińska, 2008; Żogała et al., 2008; Wysowska and Pierwoła, 2011; Kowalska et al., 2012; Kowalczyk et al., 2014). Resistivity imaging method was selected due to non-invasive measurements and simple correlations of the results. The surveys were performed using ABEM Lund Imaging System contained central unit with the computer, electrode selector and set of cables and stainless-steel electrodes. During the resistivity imaging the measurement points are collected one by one by a selection of temporary system of four electrodes from all connected electrodes. In the Schlumberger array, which was applied in the field, two outer electrodes are sending a signal (direct electric current) while two internal electrodes measure electric potential difference in the rocks. Next, the apparatus determines the resistivity value at the measured point and its pseudo-depth. When the measurement for one combination of electrodes is done the selector chooses the next one and carries out the measurement in a new place. Survey procedure is repeated until all available combinations (sequences) of electrodes are accomplished. The maximal depth of investigation is estimated as 1/5 of the distance between the first and last electrode (Roy and Apparao, 1971; Barker, 1989; Glazer et al., 2014; Loke, 2014).

The survey profiles (Fig. 1), in almost parallel direction, crossed the mountain over the probable run of the adit. The first three profiles were situated over the main entrance to the mine and in its vicinity. The first one cut the probable entrance. The second profile was located 40 m away from the first one and the third was 50 m away from the second. The beginnings of these measuring profiles were established nearby the Solinka river. The each of the above-mentioned profiles was characterized by 5m electrode spacing and was 200 m long. The 4th profile was located about next 50 m away from the 3rd profile and started from the Żwir stream. This survey line was 400 m long because of using a new set of cables with 10-meter electrode spacing. The 5th profile was the longest one and reached 470m. In this case the cables of 5-meter electrode spacing were used once again but a roll-along technique, applying cables transfer from one end of the array to another, allowed to extend profile length. This profile was situated about next 50m away from the middle of the 4th profile. The measurements over last profile (the sixth) were carried about 500 m far from the 5th profile and its length was 400 m and the set of the 10-meter electrode spacing cables was used as it had been applied to the 4th profile.

DATA PROCESSING

The collected data were processed using Res2Dinv Software (Lo, 2014). The row data were reduced by removing the points with the highest measurement errors. Next, the data were subjected to the inversion procedure. The robust inversion was applied but only for the data inversion constrain (Glazer et al., 2014; Loke, 2014) while the standard least-squares constrain was used to model inversion (Loke, 2014). This type of processing is made possible by Res2Dinv software and it is recommended to apply when a subsurface resistivity changes in a sharp manner what is expected in the case of presence of an adit, flysch and near surface soils. All resistivity data inversions were stopped after the 5th iteration providing minimum absolute error value which indicates the convergence of the inversion algorithm. Another words, the inversion was stopped when the objective error function reached the global minimum (Binley and Kenmna, 2005; Glazer et al., 2; Loke, 2014). It was assumed that global minimum had been reached because in the 4th and 5th iteration the mean absolute errors were not change much (changed less than 0.4 %). An acceptable level of the error was set as 5 what indicated that a sum of the absolute differences between model and data points (resistivity values) divided by a number of points had been smaller than five.

RESULTS AND DISCUSSION

The first three profiles present the results from the vicinity of the adit entrance. Resistivity anomalies indicated that the adit entrance had been collapsed. The first cross-section (Fig. 2-top) shows irregular anomaly which is similar to landslide resistivity image. The anomaly (100-150 Ωm) is not distinguished suggesting that rock mass material is intermixed what could also confirm the destruction of the entry. Moreover, the visual inspection of the site confirmed that collapsed structure (or landslide) is outlined in terrain morphology. Beside the mentioned anomaly the different lithological structures may be distinguished. The adit was probably excavated in the rocks relative immune to erosion ($\rho > 50$ Ωm). Next layer probably can consist of the rocks susceptible to erosion ($\rho < 40$ Ωm) what may have confirmed a presence of stream erosion valley on 150-th m of the profile. The second survey profile shows the similar results as the previous one (Fig. 2-middle). The anomaly with relative high resistivity value (> 250 Ωm) can be related to collapsed entrance of the adit. The composition of two types of rocks is also visible on the cross-section. Detailed Geological Map of Poland indicates that the rocks immune to erosion can be classified as Cisna bed sandstones (Oligocene) interbedded by shales and mudstones (Jankowski and Ślączka, 2014). Next, the rocks susceptible to erosion are probable black shales which had been confirmed by mineralogical study (Dziubińska and Narębski, 2004). As in the first cross-section, the areas of rock immune and susceptible to erosion are present in the geological structure of Mochnaczka-Jeleni Skok Mountain and this complex is the continuation of rock masses observed in the previous one. The stream erosion valley is also marked on 150-th m of the profile. The resistivity cross-section (Fig. 2-bottom) obtained for the third profile is characterized by the same geological situation. The both immune rock and susceptible rock can be distinguished. However, the anomaly related to the adit become more concentric what may have suggested that the adit in this section had been collapsed partially only and filled by secondary sediments. One can assume that all three profiles show the entrance zone affected by the collapse and/or landslide which had occurred over the adit.

Figure 3 shows the resistivity cross-sections under the 4th survey profile which was traced out 40m away from the 3rd one. What is more, this profile was longer and allowed to recover more geological structures. Resistivity changes indicate the Flysch composition of Mochnaczka-Jeleni Skok Mountain where the immune and susceptible rocks appear alternately. The Żwir Stream erodes the susceptible rocks characterized by lower resistivity values ($\rho < 40$ Ωm) what can be seen on 100-th m of the profile. Moreover, similar rock layer is observed between 215 m and 290 m of the profile. The layer is a continuation of the same rock mass marked in the previous three profiles. Likewise, the rocks immune to erosion with the adit anomaly is observed in the central part of the profile (100 m – 215 m). The adit is marked as a higher resistivity anomaly with value over 200 Ωm. Last immune sequence characterized by the resistivity values larger than 70 Ωm is noticed in a distal end of the profile between 290 m and 400 m.

The 5th profile is the longest profile (Fig. 4). In this cross-section the continuation of all rock layers is clearly visible, the same Flysch composition can be noticed and the adit section is distinctly marked with the resistivity value larger than 260 Ωm. During the measurements the 5-meter electrode spacing had been applied what allowed. This is probably the reason why the adit section can be better distinguished than in other cross-section. Comparing results from the 4th profile (Fig. 3) and the 5th profile (Fig. 4) it is not clear whether the adit is open without secondary sediment, or it is partially or completely filled. The observed values of the adit resistivity anomalies (260-350 Ωm) are not so strong and always are surrounded by concentric low resistivity values which may indicate the presence of cracks in the layers around the adit. Such anomaly blur could also be generated by the inversion algorithm which was not able to deal with large resistivity differences between the adit void and the surroundings. Additionally, in all profiles the measurements show other anomalies with higher resistivity values of up to 1000 Ωm. However, they are probably related to a core of the immune rock mass or artefact generated by decrease of the electrode array sensitiveness (Loke, 2014). Furthermore, high resistivity value (over 1000 Ωm) is observed near surface. They are produced by unsaturated and loose rock materials and soils covering the flysch rocks.

Figure 5 contains the result of measurements carried out on the 6th profile located 500 m far from the middle of 5th profile. Two rock types – immune and susceptible - are visible in this example. They are probably continuation of the same rocks which occur previously and are characterized by the similar resistivity values. Relatively higher resistivity values correspond to the immune rocks and low values – to susceptible rock. In contrast to the other measurements, one can noticed two concentric anomalies probably related with the run of adit. Accordingly to the information coming from local community the adit could extend beneath the road (Fig. 5) and its additional branch could also exist there. Therefore, the anomaly below the road was assumed to be the continuation of the adit and the second one seen on 130-th m of the profile may be identified as the adit branch.

Comparing the position of the adit anomaly in relation to elevation of 550 m above sea level (a.s.l.) it can be noticed that at the beginning adit was operated on one level (Figs. 2 and 3) and after its position rises (Figs. 4 and 5).

CONCLUSIONS

The conducted geophysical research allowed map the probable location of the *Rose* adit of the nineteenth-century iron ore mine, which was created on the basis of the adit section position (Fig. 6). The results indicate the presence of the mining tunnels in Mochnaczka-Jeleni Skok Mountain but exact designated location of the entrance to the tunnel must be revised yet. Only the likely area of the entrance to the adit was recognized.

The study showed typical structures of the Flysch forming Mochnaczka-Jeleni Skok Mountain with laying alternately the layers of immune and susceptible to erosion rocks. Probably they are sandstones and mudstone respectively. Geological inspection of the study area indicated the presence of sandstone in the vicinity of the profile centers what suggest that the adit was bored in the sandstone layers with iron ore concretions. Furthermore, the observations near the Solinka River and the Żwir Stream revealed that water had carved the valley in the rock complex of mudstones and shales. These observations can confirm the resistivity measurements which indicated that the relative high resistivity anomalies are related to sandstones and relative low resistivity – to shales and/or mudstones. However, geological study requires more research. It is difficult to say that the adit was carried out in the Cisna-type sandstones with hydrated iron oxides or in dark shale insert in the sandstone.

Moreover, the presented results confirmed that the resistivity imaging method is an excellent tool which can be used for recognition of the adit and other voids in rock masses. However, the conductivity methods are also recommended as complementary geophysical measurements to confirm the location of an entrance and the course of the adit. Such measurements followed by seismic measurements are planned in near future.

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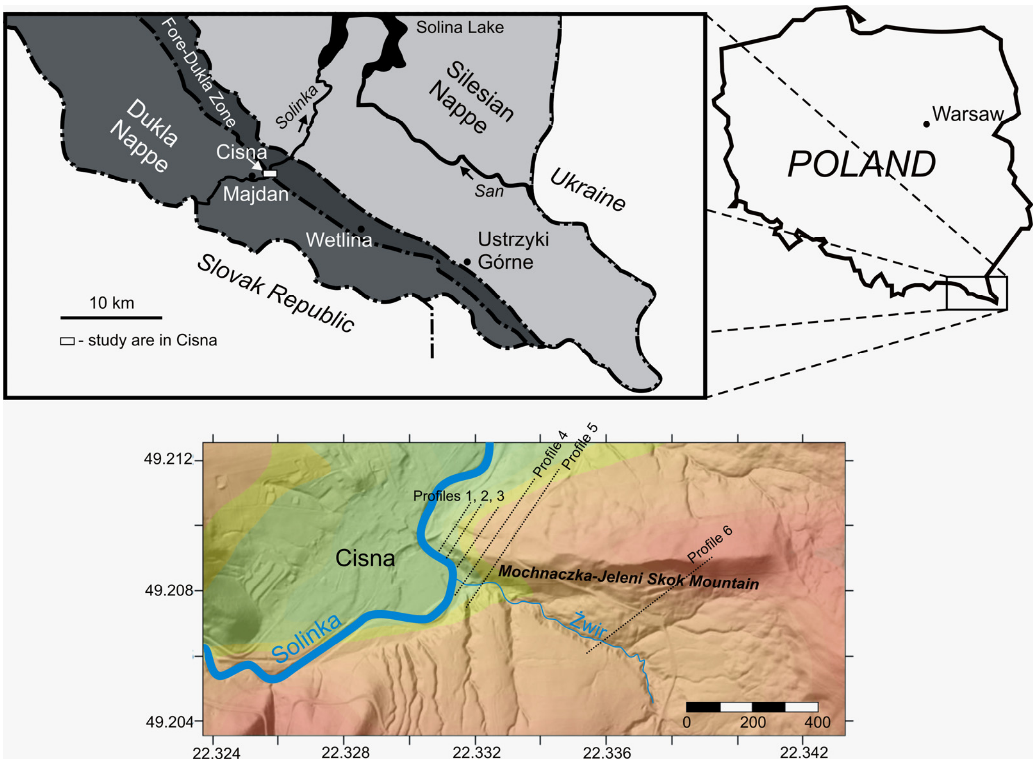

Fig. 1 Location of the study area and survey profiles.

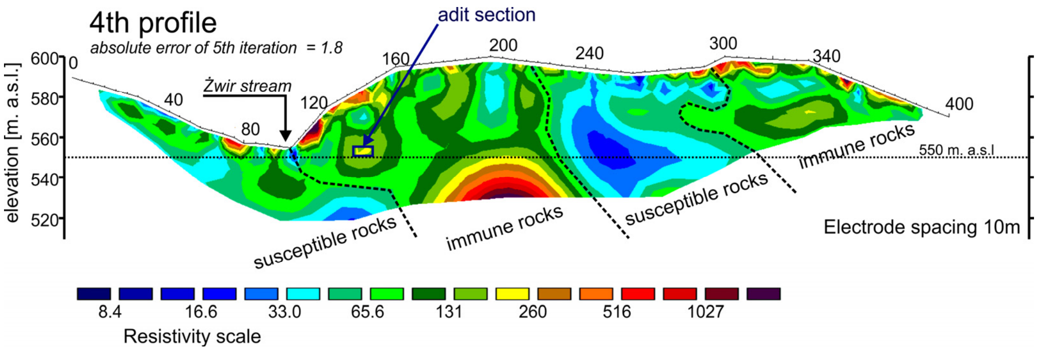

Fig. 3 The resistivity cross-section obtained for the fourth survey profile.

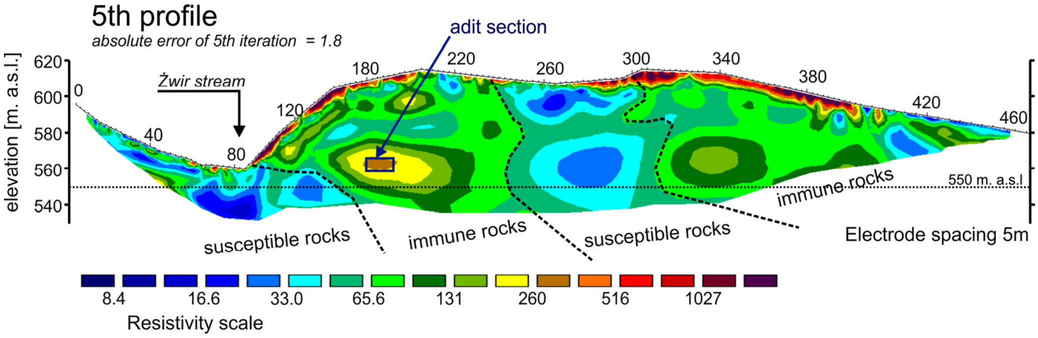

Fig. 4 The resistivity cross-section of the fifth survey profile.

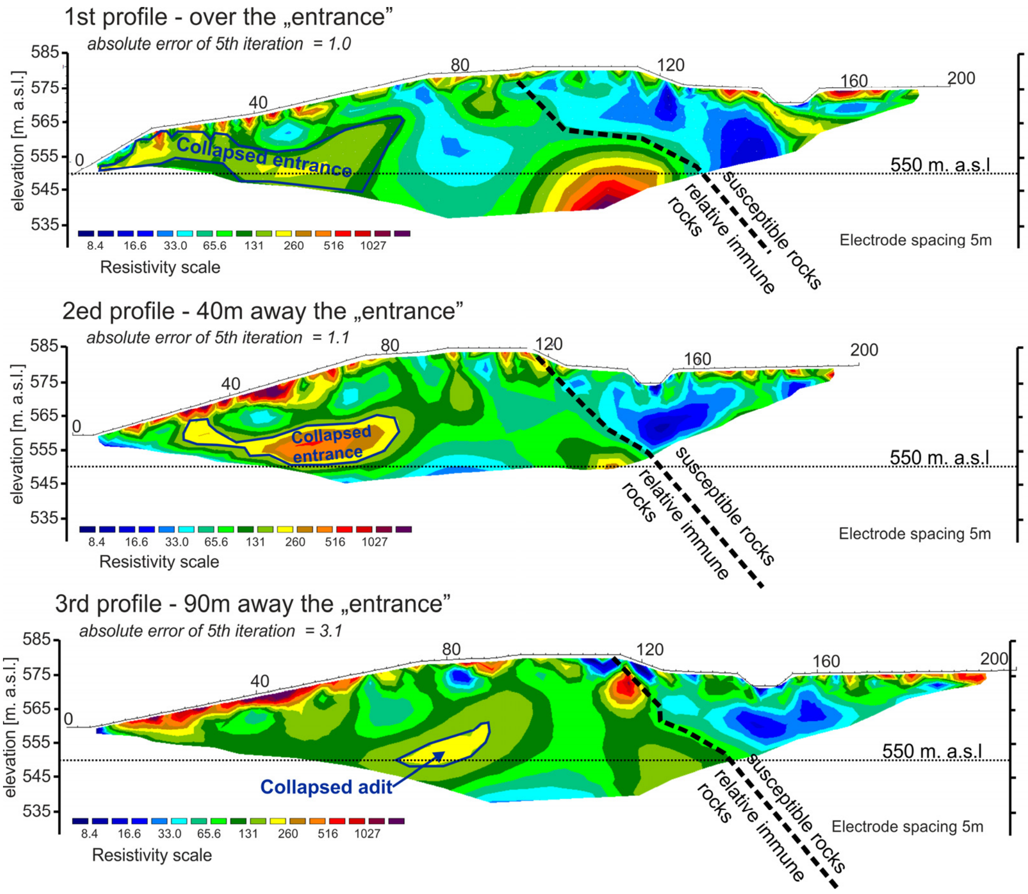

Fig. 2 The resistivity cross-sections under the first three survey profiles.

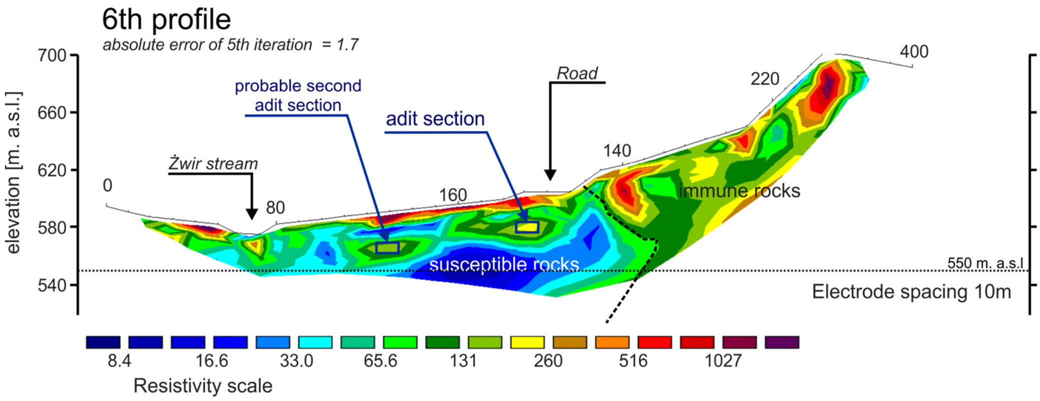

Fig. 5 The resistivity cross-section under the sixth survey profile.

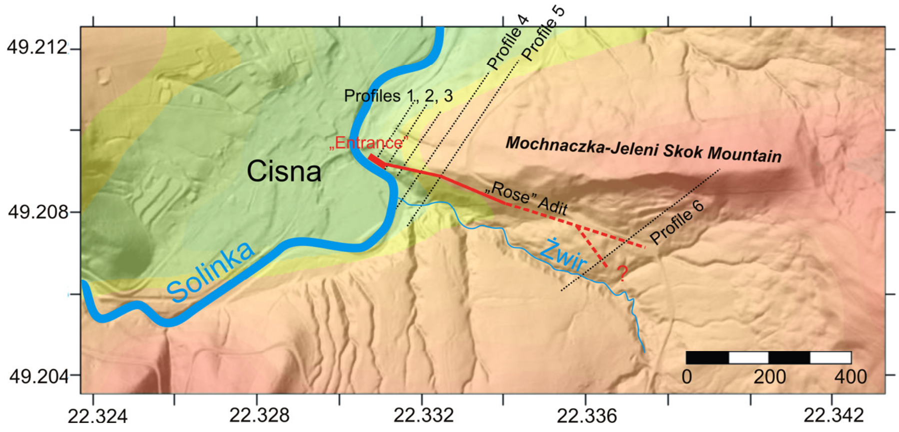

Fig. 6 The probable run of the “Rose” iron mine adit created on the basis of the resistivity surveying.