Geophysical survey aimed at selecting the radioactive waste repository site (Czech republic)

Jaroslav Bárta*[1]*, Michal Tesař* and *Dušan Dostál

Geofyzikální měření zacílené na výběr úložište radioaktivních odpadů (Česká Republika)

G IMPULS Praha has been executing a set of geophysical measurements for the Radioactive Waste Repository Authority of the Czech Republic from 2001 (the work continues to be carried out). The measurements are aimed at studying the behaviour of the rock massif, focusing on the Excavation Damaged or Disturbed Zone (EDZ) and on selecting an appropriate area for the radioactive material repository site. The geophysical studies use a complex of methods as follows: Airborne geophysical measurement (regional studies), Seismic measurement (detailed studies), G.P.R. (detailed studies), Resistivity tomography (detailed studies), Geoelectric measurement and magnetic survey (stray earth currents). The paper informs about first results and conclusions. The airborne work was executed as a part of the complex study of „GEOBARIERA“ the group and the geophysical measurements of EDZ were executed in co-operation with the Czech Geological Survey.

***Key words**: geophysical survey, radioactive waste repository, Damaged or Disturbed Zone*

Introduction

At present, the issues of radioactive waste repository sites are a frequently discussed theme. The authors of this paper have participated in two significant projects in the Czech Republic concerning the application of geophysical methods. The first one was the project of the application of airborne/helicopter-borne geophysics to identify optimal sites for the deep-seated radioactive waste repository. The geophysics formed a part of a wider complex of methods that allowed to reduce a further survey to six selected sites. The execution of the latter project is still under way. The project was concerned with a detailed study of the rock massif affected by mining activities. Within this project, geophysical methods become a part of a complex of research methods. The geophysical measurement is concentrated, in particular, to selected parts of drainage gallery, built in the granite massif at Bedřichov in the Jizerské hory Mountains. The gallery is very well preserved, in good conditions, and is an ideal place for an establishment of the permanent research base.

Airborne/Helicopter-Borne Geophysics

Subjects of the airborne helicopter-borne survey were six sites. Their layout plan is shown on the map (Fig. 1).

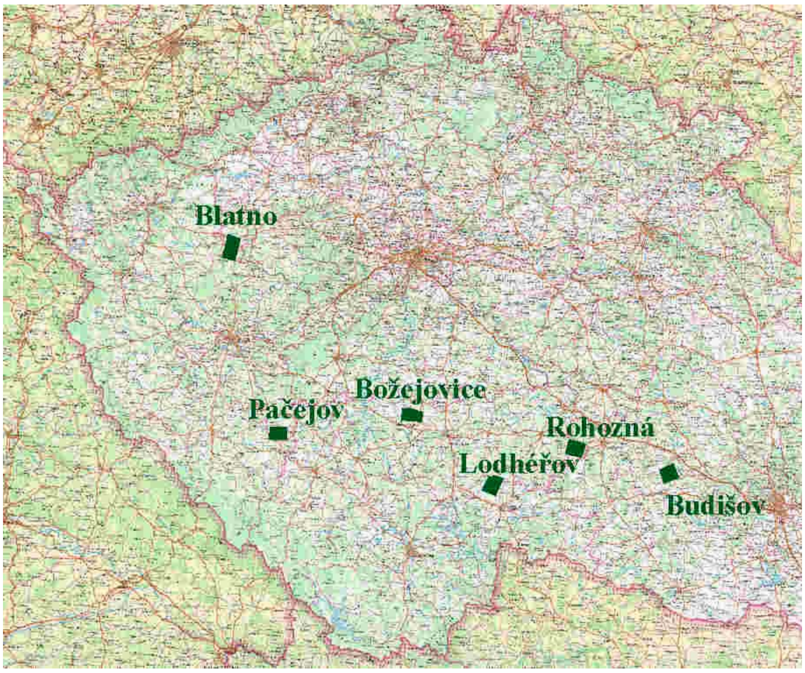

Fig. 1. Map of the Czech Republic with the six sites subjected to the survey.

In more detail, the characterization of these sites and the description of the profile grid are presented in Table 1.

[1] *Jaroslav Bárta, Michal Tesař, Dušan Dostál,* G IMPULS Praha spol. s r.o., Přístavní 24, Praha 7, Czech Republic
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Tab. 1. ***An overview of the surveyed areas.***

Site name	Area	Spacing	Flight Lines		Tie-Lines		Total	Directions
	[km²]	Lines/ Tie-Lines	# of Lines	Line-km	# of Lines	Line-km	Line-km	Lines / Tie-Lines
Site 14, Blatno	44.5	200m/500m	46	220.8	16	88.6	309.4	108°/198°
Site 30, Božejovice	43.2	200m/500m	28	212.7	18	82.3	295.0	090°/180°
Site 40, Pačejov	42.2	200m/500m	29	208.8	16	87.2	296.0	090°/180°
Site 41, Rohozná	43.7	200m/500m	37	221.0	15	88.0	309.0	126°/216°
Site 08, Budišov	43.9	200m/500m	35	222.1	14	90.0	312.1	157°/247°
Site 07, Lodhéřov	45.8	200m/500m	42	231.2	15	92.4	323.6	112°/202°
Totals	**263.3**			**1316.6**		**528.5**	**1845.1**	

Considering the fact that at present a complete geophysical instrumentation capable to meet high requirements on the technical level of realizing the requested measurements, is not available in the Czech Republic, the G IMPULS Praha initially decided to select a foreign partner, who would be able to provide for a sophisticated hardware and software for a reliable performance of the airborne/helicopter-borne geophysical measurement, its processing and interpretation. By an internal selection procedure, the McPhar Geosurveys Ltd., Ontario, Canada L3Y 7V1 company was finally chosen to carry out the airborne/helicopter-borne survey.

One of the decisive conditions for a high-quality realization of the helicopter-borne measurement is to have at least two helicopters available. They must be compatible with the geophysical instrumentation and flown by an experienced air crew. Based on the internal proceedings, it was decided that air service (helicopter including crew) will be provided for by the DELTA SYSTEM – AIR a.s., Hradec Králové.

Under the project, the G IMPULS Praha spol. s r.o. performed the following activities:

1. To lead the sub-contractors to perform their work in conformity with the project requirements. To perform the function of supervisor over the quality of the work.
2. To provide for a logistic background for the McPhar Geosurveys Ltd.
3. To perform the function of a qualified company spokesman in the issues of geophysical works.
4. To carry out a control ground geophysical measurement, aiming to verify a correctness of the helicopter-borne measurement and to gain, in more detail, an idea to what extent the helicopter-borne survey is comparable with the ground survey.
5. In the next work stages, to continue in performing the ground measurement using the VLF method in the areas selected particularly on the basis of the helicopter-borne measurement results presented here but also other important GIS-based information.

A helicopter-borne geophysical survey was preceeded by a field reconnaissance and a study of archival reports. The helicopter-borne survey itself consisted of the following geophysical methods: the gamma-ray spectrometer survey, the magnetic survey and the electromagnetic survey using the HummingBird sound.

Helicopter and Instrumentation

Helicopter

The survey was flown using the helicopter of Eurocopter AS355F2 Ecureuil type with the registration number OK-MIA (see the photo).

Fig. 2. Helicopter Eurocopter AS355F2.

The helicopter was temporarily modified to serve as a geophysical survey platform, with a mount for the pilot navigation information, a power take-off for the geophysical equipment, and a mount for the digital video flight path camera. The electromagnetic sensor is attached to the cargo hook, and the equipment rack mounted on the seat support behind the pilot.

Instrumentation installed in the helicopter included: a Geometrics G-823 cesium magnetometer installed in the HummingBird sensor system, with a resolution of 0.001nT/sampling frequency 10 times per second (10 Hz), a Pico-Envirotech GRS-410 gamma-ray spectrometer with 16.78 litres down-looking and 4.2 litres up-looking NaI(Tl) crystal detector packs, a NovAtel Millennium 24-channel GPS Receiver, & real-time OMNISTAR DGPS-Max a Picodas PNAV-2100 GPS navigation computer/pilot steering indicator, a dual HummingBird and AGIS PC-based data acquisition systems with large volume hard disks, colour LCD display, LARMOR processor with 0.001nT/10 Hz resolution, and proprietory SURVEY, REPLOT and other proprietory and commercial software, a Terra model TRA-3500/TRI-30 Radar Altimeter for measuring the helicopter´s height above the ground (ground clearance) and a Setra model 276 Barometric Pressure Transducer/Altimeter to enable recording of the barometric pressure during survey operations, and provide height above sea level.

Helicopter-borne Electromagnetic System

A Geotech HummingBird frequency domain helicopter-borne electromagnetic (HEM) system was used to acquire the electromagnetic data in this project. The system is a light-weight all digital system, which is capable of providing data from the frequencies 7001, 6606, 880 and 34.133 Hz, horizontal coplanar and vertical coaxial coil sets. Both data types (real and imaginary components) are recorded as ppm (parts per million) of the primary frequency field. We note that the method of airborne/helicopter-borne electromagnetic measurement in the Czech Republic (and in Slovakia as well) has not been applied yet.

The system, which in essence consists of four transmitter-receiver coil-pairs and associated electronics, is installed in a rigid 7 metres long tubular „bird“, which is towed 30 metres beneath the helicopter (see Fig. 3). A total of eight channels of data were recorded at a sampling rate of 10 Hz, giving a set of measurements at approximately each 3 metres along the flight path. All the parameters and the data storage are software controlled from the console in the helicopter.

Fig. 3. Electromagnetic system in the gondola prepared for a flight..

Deliverable Products

All data acquired by the measurement were processed into easy to survey databases allowing a reprocessing, reuse or a reinterpretation of the data. For a purpose of the report on the measurement, maps of contour lines of the basic measured values were compiled. In addition, outputs gained by the processing, such as conversions of the electromagnetic measurements to conductivities and resistivities of the rock environment. Similarly, for the gamma-ray spectrometer survey, the potassium equivalent percent concentration map, the uranium equivalent ppm concentration map, the thorium equivalent ppm concentration map, and the K/Th ratio and the U/Th ratio maps were provided. The magnetic data were processed, in particular, to produce maps of first and second vertical derivative and of first horizontal derivative.

Fig. 4. Electromagnetic system and the suspended gondola during a flight.

Fig. 5 shows a map of resistivities from the Rohozná site, acquired through a conversion of data measured by the HummingBird system. The resistivity conditions were evaluated for depths ranging around 150 metres below the ground surface. Fig. 5 shows that the massif is divided by a distinctive N-S trending tectonic line. The image has a character of easy to survey illustration only. For the final report, maps on a scale of 1:25 000 and 1:10 000, showing more details, were printed. The system of coordinates accompanying the figure is the Křovák system of coordinates. This means that the territory of interest takes an area of approximately 10 x 9 km.

In Fig. 6, an example of the gamma-ray spectrometer survey from the same site is shown. The geological boundary is clearly shown again, which leads to an idea that, in fact, the granite massif is formed by two units with a different time of genesis.

In Fig. 7, a map of the total vector of magnetic field from the Blatno site is shown. A showing of the basalt effusion in the centre of the site is tectonically predisposed. In Fig. 8, a map of resistivities from the same site is shown. From the comparison of Fig. 7 with Fig. 8 results, among other things, a conclusion that the volcanic effusion is tectonically predisposed.

From the above mentioned examples it can be concluded that the measurements produced data that are well geologically interpretable. The data indicate distinctive regional structures but also detect a number of local informations. They can be imaged in the form of large map sheets and easy - to - survey schemes using various imaging techniques. In the data processing, first of all the information and imaging Oasis montaj software was used. The data are then exportable, for example to the Surfer, Grapher or Voxler programmes.

The selected complex of helicopter-borne measurements, i.e. the gamma-ray spectrometer survey, the magnetic survey and the HummingBird system electromagnetic survey turned out to be optimal. The methods complemented one another. The acquired data contain a number of information, and in future it will be useful to pay attention to their detailed processing and evaluation from various viewpoints. The measurement has proved that the electromagnetic survey in the conditions of central Europe (densely built-up areas, interference caused by electromagnetic sources) is technically feasible and useful, if properly and carefully processed.

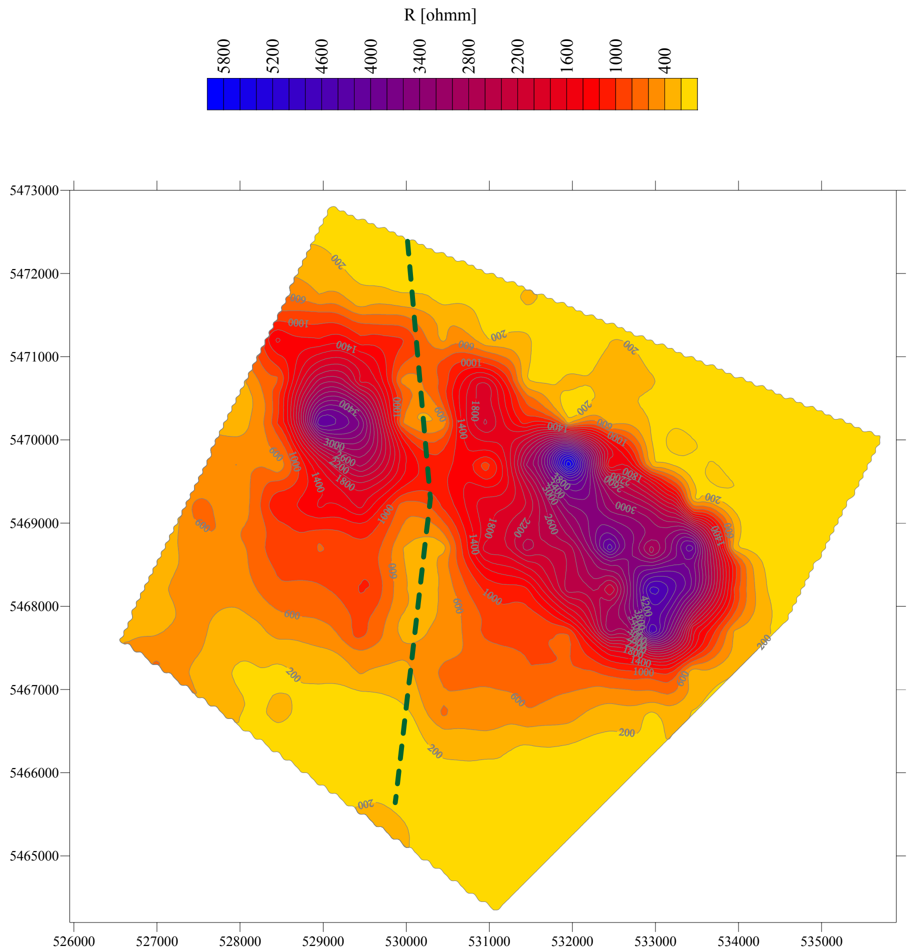

Fig. 5. Map of resistivities from the Rohozná site. A tectonic line runs through the centre.

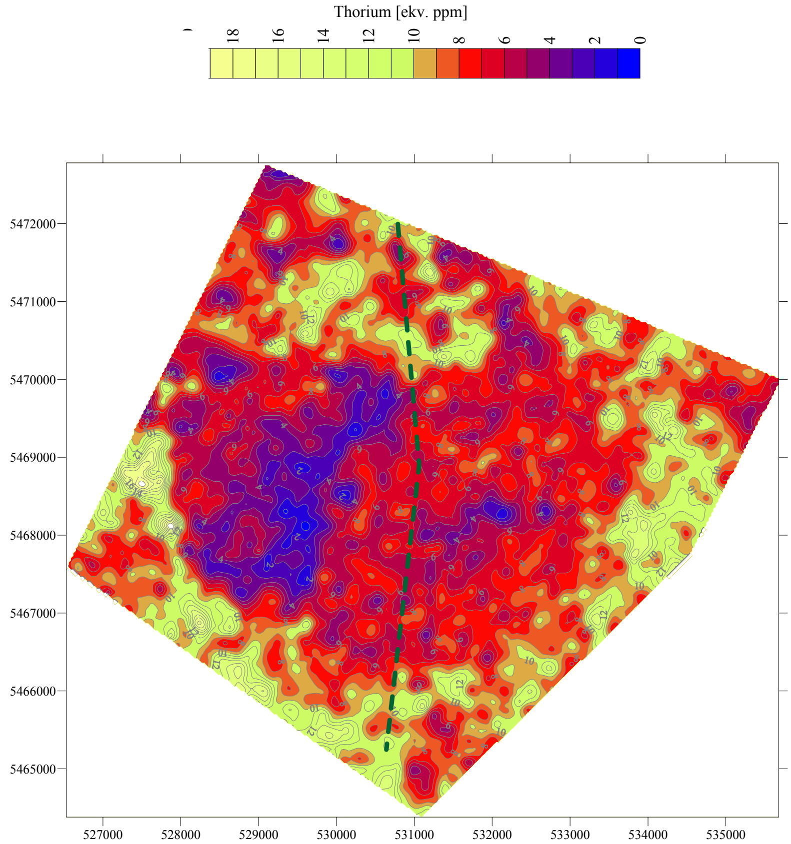

Fig. 6. Map of the thorium concentrations from the Rohozná site.The geological (tectonic) boundary through the centre can be observed.

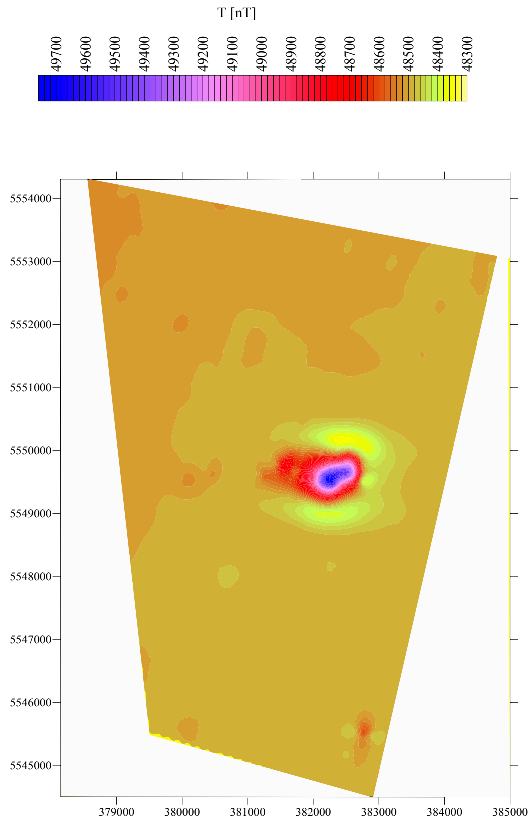

Fig. 7. Map of the total vector of magnetic field from the Blatno site. A distinct magnetic anomaly in the centre of the area is a showing of basalt effusion.

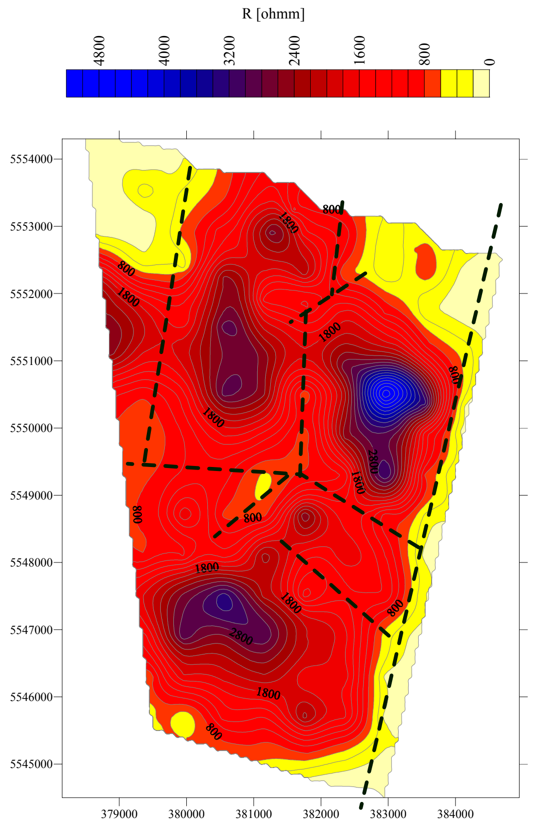

Fig. 8. Resistivity map from the Blatno site. The interpreted tectonic lines are highlighted by the green dashed line. From the comparison of Fig. 7 with Fig. 8 it results that the volcanic effusion is tectonically predisposed.

The data acquired through the helicopter-borne measurement were verified by a control ground measurement with very good results. The helicopter-borne survey served as significant grounds for the selection, at the particular locations, of the optimal sites (at least 10 per cent of the original area) appropriate for a further detailed survey. The ground reconnaissance was carried out by a group of geological specialists together with a geophysicist with an apparatus for the VLF measurement. In agreement with these geologists, regional profiles were realized and tested from the viewpoint of frequency of tectonic pattern indications. The frequency of the tectonic showings on the ground was logically higher than shown by the helicopter-borne measurement. The airborne/helicopter-borne geophysics detects a decisive and probably also deeper tectonic pattern. The VLF method also detects shallow second-rate showings, including interfering showings caused by artificial conductors.

Underground Laboratory – Bedřichov in the Jizerské hory Mountains

The step by step built underground laboratory in the gallery from the hydraulic structure Josefov to the water treatment plant in Bedřichov already is off but in the future will be of larger significance. A very good access to the gallery and an easy movement on the flat floor allow to apply a wide range of research and investigation methods. The gallery, whose layout plan is shown in Fig. 9, is built in the granite massif which is only slightly disturbed tectonically or by weathering. The gallery bottom is levelled by a concrete layer. The gallery walls are largely entirely uncovered (without protective coating). Along the gallery margin, a large-diameter water supply piping is routed. Approximately in the first third of the gallery length (in total approx. 2300 metres) there is a boundary between the machine-driven (Demag system) part and the part where classical excavation with the use of explosives was carried out.

Fig. 9. Underground water conduit at Bedřichov (white line)

Within the complex of research methods, the following geophysical methods have been used in the gallery: the seismic method, the resistivity tomography method, the radar (GPR) method and the complex of methods applied in the issues of parasitic electric fields.

The main tasks to be accomplished by the geophysical measurements is: a study of the character of the rock massif affected by excavations. The highest attention is paid to the EDZ (Excavation Damaged or Disturbed Zone) issues, and a study of parasitic electric fields that in the future might pose risks to the safety of the repository metallic structures.

At the beginning and at the end of the water conduit, two hydraulic turbines (small power plants) are situated. On the ground surface, overhead electric mains is routed. Stray currents propagate through the rock environment, and for this propagation, they also make use of the conduit metallic piping. In the conduit gallery, an intensively disturbed magnetic field was demonstrated (troubles with the geologic compass, exactly measured data by the magnetometer, an analysis of induced noise on the testing cable). On the ground surface and in the gallery, the measurement of stray currents and the resistivity measurements (VES) were carried out in line with the Czech State Standards ČSN 03 8375 – Protection against the corrosion of metallic pipings deposited in soil or in water and ČSN 03 8372 – Principles of the protection against the corrosion of non-line facilities deposited in the ground or in water. The issues of parasitic currents at the Bedřichov site are a model situation, where we may learn about risks associated with the presence of stray currents in the area of the future underground (deep-seated) repository. In Fig. 10, a scheme of a preliminary model of electric fields in the area of the gallery conduit is shown. The works relating to this theme will further continue.

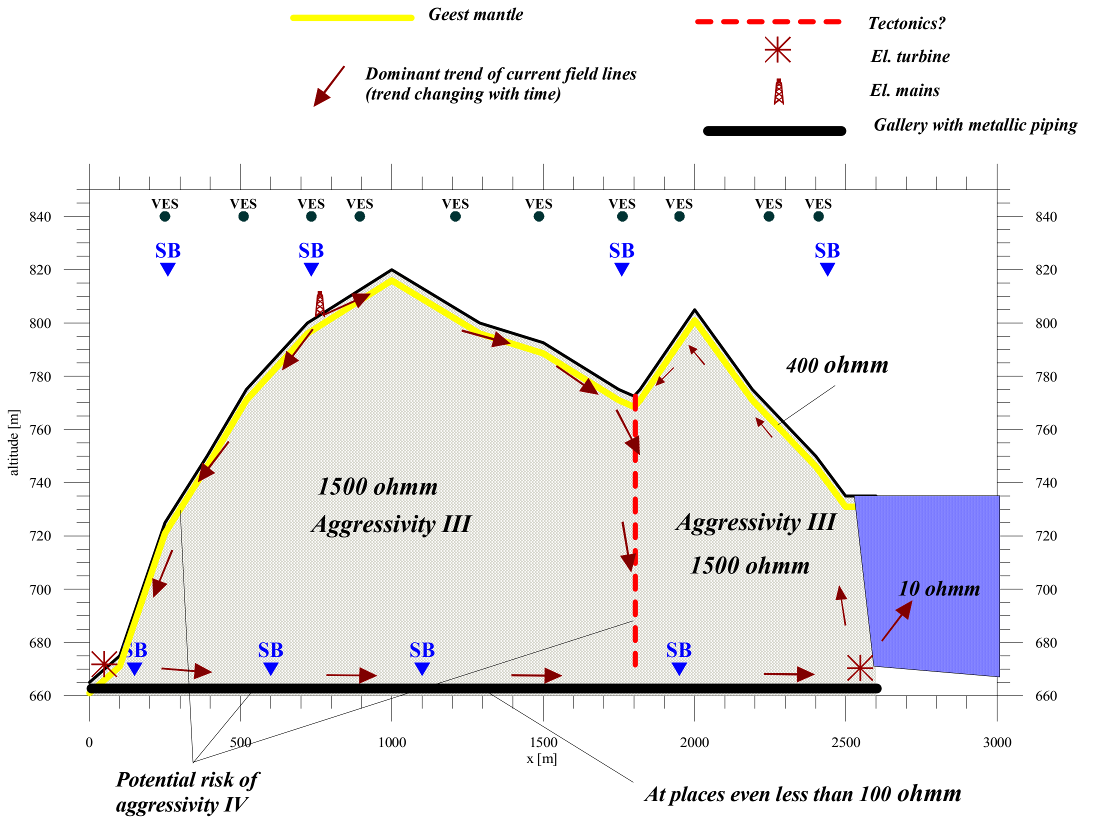

Fig. 10. Preliminary model of the distribution of parasitic electric fields at the Bedřichov site. The points marked as SB show bases of observation of stray earth currents. VES isan abbreviation for the Vertical Electric Sound.

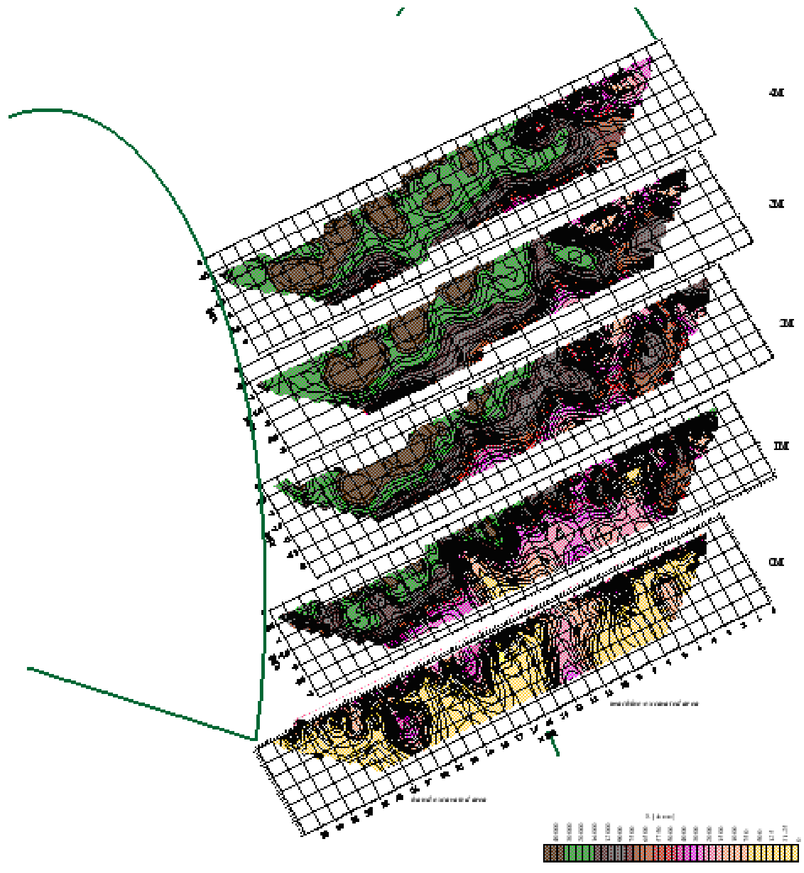

Fig. 11. 3D image of results of the resistivity tomography at the transition between the machine-excavated (right site) and the hand-excavated (left site) area.

In Fig. 11, the result of the resistivity tomography method realized by means of the multielectrode apparatus ARS 200E is shown. The data were processed and interpreted using the Res2div (Locke) programme. The measurement was conducted at a transition between the machine-excavated and the hand-excavated area. The imaged interpretation planes correspond to the measurement at the gallery bottom (OM profile) and further every 0.5 m towards the gallery top. While at the bottom, due to its water-bearing character, the resistivities are reduced, the resistivities upwards show unusually high levels of thousands to tens of thousands ohms. Close to the wall surface, a high-resistivity layer is formed, which at the time of the measurement was probably entirely dried up, in consequence of the aerage. It is probably a layer showing a dense hairy breaking up caused by mining which, from the geoelectric viewpoint, correspons to EDZ (Excavation Damaged or Disturbed Zone).

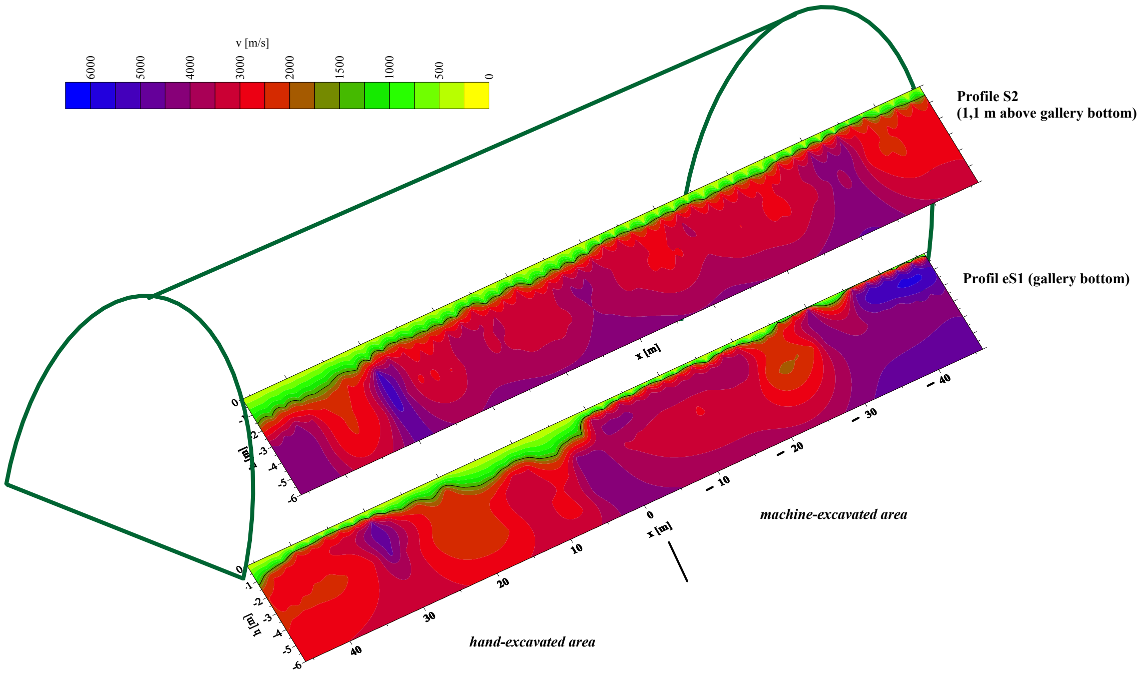

Fig. 12. 3D image of the results of the basic seismic measurement at the transition between machine-excavated (right site) and hand-excavated (left site) area

In Fig. 12, the results of the seismic sections from the two basic seismic profiles are shown. The surface layer (close to the gallery wall) shows reduced velocities up to 1500 m s^{-1}. This layer characterizes the EDZ from the seismic viewpoint. It is evident that the EDZ is a factor whose detailed characterization also depends on the method of measurement, and physical field characterizing the zone and may also change with time. It is a question for a future discussion on the EDZ, which is frequently used, to describe it in a more detail and to define it in relation to the basic geotechnical and geophysical tests.

The authors of this paper would like to express their thanks to the whole team which hascooperated in research activities performed for the future deep-seated radioactive waste repository. In particular, the authors express their thanks to the Radioactive Waste Repository Administration, an organization which released financial resources to carry out the above described and from the professional viewpoint highly desirable research.

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