Introduction

Electrical resistivity tomography (ERT) is widely used in civil engineering surveys and common deposit researches in Poland. Most of the previous ERT surveys were restricted to simple glacial and fluvioglacial geological settings. PBG Exploration Geophisics Service Ltd. implemented ERT surveys for purpose of geological mapping in complex settings recently.
This paper presents three case studies of ERT surveys, aiming to detail geology of the Andrychów Klippen Belt, Muszyna area and Przeczyce dam basement.

Methods

ERT sections for geological mapping purposes were measured using ARES tomograph produced by GF Instruments company. Schlumberger electrode array was applied. The length of the electrode spread allowed to penetrate the rocks to 40 m deep. Applied spacing of electrodes of 5 m yielded image of required resolution. Data obtained were processed using Res2Dinv software.

Example 1: Andrychów Klippen belt – the nature of exotic blocks in Carpathian flysch.

The Andrychów Klippen Belt (ATB) is located in the Western Carpathians, in the base of Silesian nappe. The Belt is latitudinally elongated. Its length is several kilometres and width does not exceed the quarter of kilometre. ATB is composed of blocks of Upper Jurassic to Lower Cretaceous reef (stramberg facies) limestone (Olszewska et al., 2008; Waśkowska-Oliwa et al., 2008) and Proterozoic metamorphic rocks (Książkiewicz 1972). Size of the blocks range from tens to one hundred meters in diameter. Blocks of ATB lay on siliciclastic siltstone and mudstone composing Subsilesian nappe and infill of the Carpathians foredeep and are overlain by sequence of flysch type alternations of sandstone and siltstone beds, composing the Silesian nappe. Both underlying and overlying flysch rocks are Cainozoic in age (Książkiewicz, 1972).
The nature of the ATB is the matter of debate. It is widely accepted, that the Belt is an olistostrom and was formed by redeposition of rock blocks from the edge of the Silesian flysch basin to its centre (Cieszkowski, Golonka 2006; Golonka et al. 2005). The alternative explanation of the occurrence of exotic blocks is, that they were tectonically incorporated into the base of Silesian nappe during orogenesis. Although limestones of the ATB were exploited, and mapped carefully, its inner composition, and size and shape of blocks are poorly recognised.
The aim of the ERT surveys, was to detail inner composition of the AKB – size and shape of blocks, nature of contacts between blocks and surrounding rocks, and definition of borders of the Belt.
Three parallel ERT sections were measured near the Inwałd village where Andrychów Klippen belt is prominently exposed.
The medium in the analysed area can be divided into three main categories of different resistivity characteristics (figure 1):

- Homogenous medium of high resistivity ranging from 70 up to 300 Ωm interpreted as flysch sandstone containing minor intercalations of siltstone and mudstone. Zones of lowered resistivity correspond to rocks of increased content of fine grained beds. This type of medium represent rocks of Silesian nappe.
- Homogenous medium of low (below 20 Ωm) resistivity, interpreted as siltstone and mudstone of Subsilesian nappe and the Carpathians foredeep infill.
- Medium of highly variable resistivity, containing irregular blocks with resistivity exceeding 100 Ωm and matrix of resistivity ranging from 20 to 70-100 Ωm. Blocks of high resistivity were interpreted as blocks of exotic rocks in Andrychów Klippen belt, while medium of reduced resistivity is interpreted as fine clastic matrix of the belt.

Zone of high resistivity gradient on the basis and top of the variable resistivity medium were identified as trust or fault zones.
Interpretation of ERT imaging allowed to:

- Estimate the size of exotic blocks, which range between 20 and up to 100 m in diameter
- Illustrate the irregular shape of exotic blocks, that exclude simple tectonic origin of the AKB

- Demonstrate the variability of the matrix of the AKB caused by admixture of exotic clasts smaller than ERT resolution
- Illustrate local steepening of trust zone below AKB caused by mechanic heterogeneity of the belt
- Indicate the possibility of occurrence of secondary trust between AKB and Silesian nappe
- Illustrate the effect of brittle deformations (tectonic graben) in front of the Silesian nappe

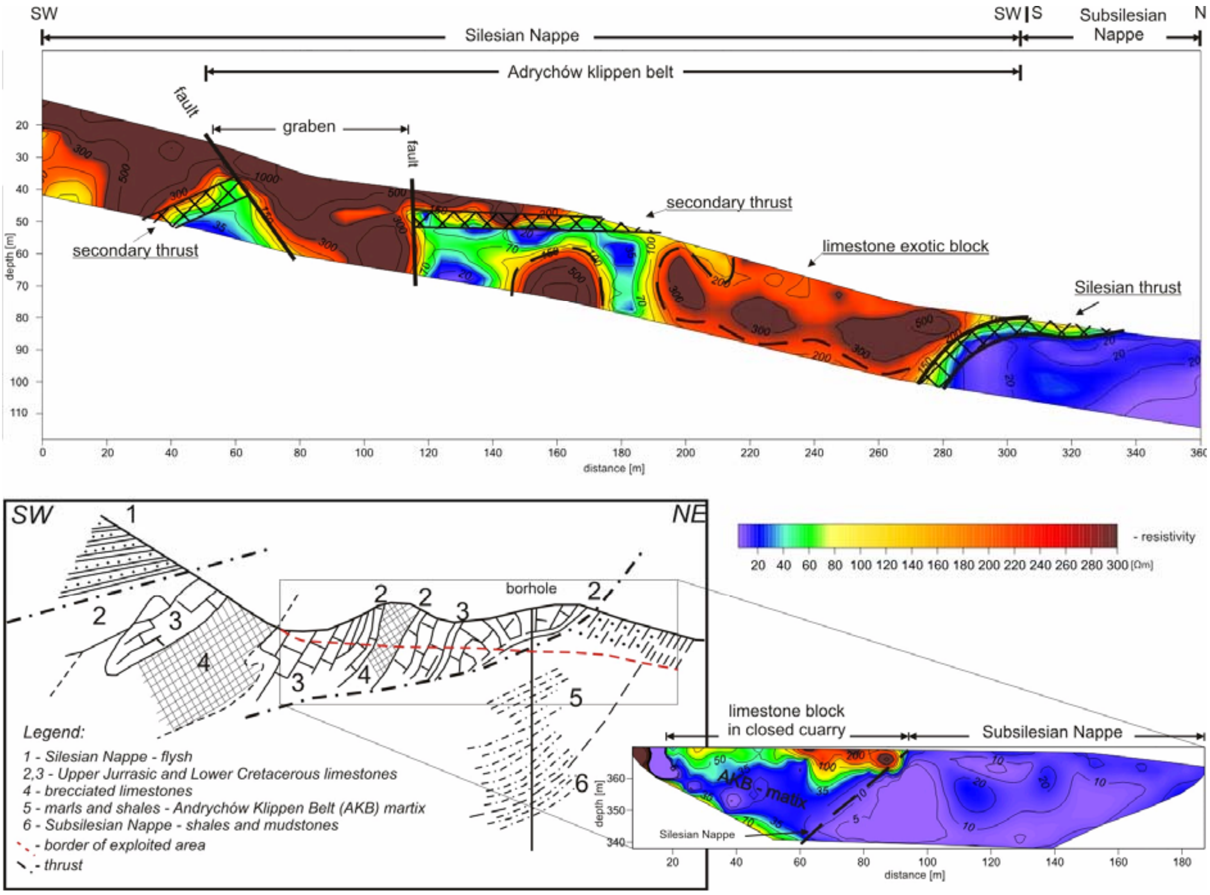

***Figure 1** ERT section through Andrychów Klippen belt and adjacent Silesian and Subsilesian nappes (top). ERT section through Andrychów Klippen belt within old Inwałd quarry compared to geological section based on drill core and field data (after Książkiewicz 1972). Notice general similarities in internal composition and the exact match with the drill core (bottom).*

The quality of ERT imaging and its usefulness in detailed geological mapping was shown by comparing geological interpretation of the ERT image with geological data obtained from archival drill cores and section logs of old quarry (figure 1 bottom).

Example 2: Przeczyce dam stability – possible geological hazards

Przeczyce earth dam is located on the Czarna Przemsza river, in northern part of Silesia region. Spread of the dam is above 600 m and its height reach 12 m in the centre of the valley. Deformations of the dam motivated its operator to employ geophysics investigation of the dam body and basement to identify possible hazards. Set of geophysics tools applied revealed that the cause of deformation is exterior to the dam body, thus geology of the basement must be investigated. ERT imaging was performed to determine the resistivity of the basement, and interpret its geology.
The valley of Czarna Przemsza river is cut in Middle Triassic beds composed of limestone and dolomite. Triassic beds form monocline of gentle regional dip toward north-east (Biernat, 1955), locally undulated. In the direct vicinity of dam, Triassic strata are composed of thick-bedded dolomite covered by thin-bedded intercalations of limestones and marls. Lower Jurassic deposits composed of

bauxite-like clays filling paleokarst cavities are known from the region. The valley is partly filled by Quaternary alluvial sands and gravels of thickness not exceeding 10 m.
The medium in the analysed area was divided to four categories of different resistivity characteristics (figure 2):

- Near-surface, homogenous medium of resistivity exceeding 200 Ωm, corresponding to lower part of dam body and alluvial infill of the valley.
- Medium of resistivity ranging from approximately 50 to 100 Ωm, interpreted as Triassic thin-bedded limestones and marls
- Medium of resistivity exceeding 100 Ωm, reaching locally over 300 Ωm interpreted as Triassic thick-bedded dolomites
- Medium of resistivity bellow 50-70 Ωm, composing irregular bodies up to 30 m in diameter, penetrating basement. Such bodies are interpreted as Lower Jurassic bauxite-like clays filling paleokarst cavities.

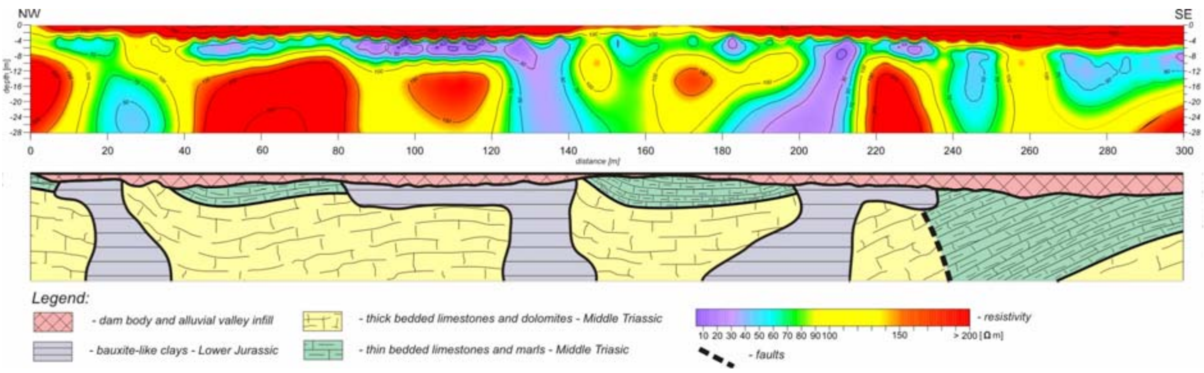

Figure 2 *Fragment of ERT section across Czarna Przemsza valley and its geological interpretation*

ERT imaging in the area of Przeczyce dam allowed to recognise the geology of valley basement. The main features of the basement geology are:

- Slightly undulated, two layer composition of the basement
- Occurrence of fault zones in the Triassic rocks
- Occurrence of paleokarst cavities filled by Lower Jurassic bauxite-like clays

Indicating the existence of paleokarst cavities filled with ductile clay, surrounded by rigid Triassic carbonate rocks may explain the deformation of the dam. Until our survey, possibility of existence of basement heterogeneity was not recognised as a cause of dam deformations.

Example 3: Muszyna mineral water resources – tectonic controls on confined aquifer

The Muszyna region (central part of the Polish Carpathians) is well known for its mineral springs. Intensive exploitation of aquifer demanded new estimation of water resources. Location and spread of horizon of marls confining sandstone aquifer were regarded as a key factor in aquifer recognition, thus ERT survey was employed.
Examined area is located within the Magura nappe, Outer Carpathians. Rocks are composed of Paleogene thick bedded flysch type sandstone (Chrząstowski et al. 1991). Two distinct horizons of marls and marly shales reaching a few tens of meters are known from the lower part of the sandstone sequence (Birkenmajer, Oszczypko 1989). Beds are generally dipping gently to south-west and are undulated locally. The system of regional faults cuts Magura nappe from NE to SW.
A set of parallel ERT sections were measured in the area of interest that allowed to recognise three main categories of medium (figure 4):

- Homogenous medium of high resistivity exceeding 100-150 Ωm interpreted as sandstone beds
- Homogenous medium of low resistivity not exceeding 50 Ωm interpreted as impermeable marly horizon confining the aquifer
- Medium of variable resistivity ranging between 35 and 100 Ωm, corresponding to saturated sandstones and alternations of thin beds of sandstones and shales.

Zones of high resistivity gradient were interpreted as fault zones.

Analysis of the obtained results allowed to:

- Determine the position of impermeable marly horizon
- Precise the location and geometry of regional faults and describe unknown faults featuring geology of the investigated area (figure 5)
- Indicate the existence of tectonic horst in which confining horizon is uplifted

Demonstration of block tectonics of the investigated area, and relationship of tectonic features and aquifer geometry allowed to better understand hydrogeology of the aquifer.

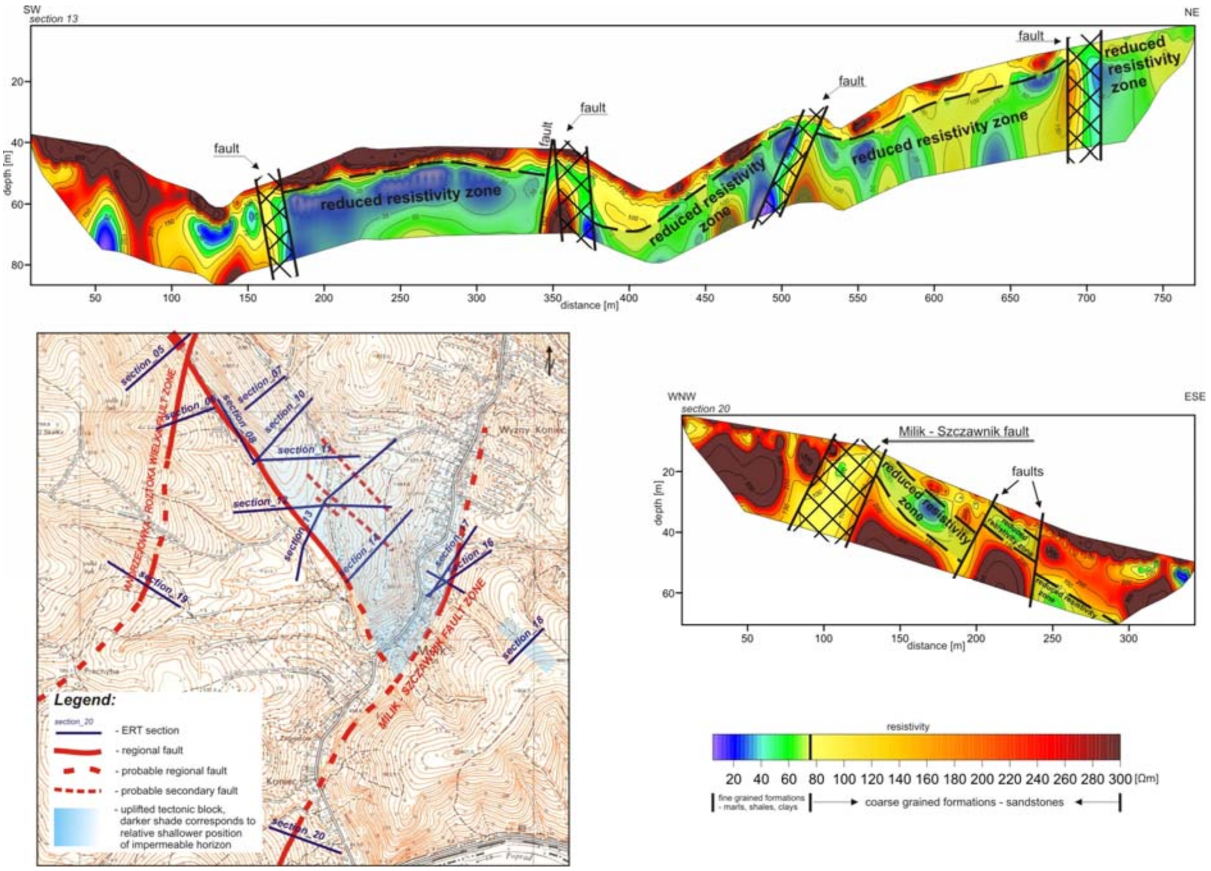

Figure 4 *Schematic map of tectonic features of investigated area and selected ERT sections. Shaded part on the map represent tectonic horst where impermeable marly horizon is uplifted. The edges of this block are perspective locations of productive wells.*

Conclusions

Presented examples demonstrate usefulness of ERT imaging for geological mapping in complicated geological settings. Interpretation of the ERT cross-sections require however careful consideration of other geological data available. Changing of electrode spread and spacing permit adjustment of depth of imaging and resolution for the problem to be solved.

References

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