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GEOPHYSICAL SURVEY OF POST-GLACIAL DEPOSITS

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ABSTRACT
The aim of presented research was to recognize a fine geological structure of post-glacial sedimentary forms. The survey was conducted in the South Pomeranian Lake District (north - western Poland) in the vicinity of Pile Lake and Strzeszyn Lake. The geoelectrical equipment Terrameter SAS 4000 (ABEM) with LUND Imaging System was used for the measurements of apparent resistivity of rock mass. The resistivity imaging was carried out implementing Schlumberger S-protocol with 41 electrodes. Research was done along profiles crossing a border between two sedimentary forms. It allowed to recognize and compare the layered structures of the different post - glacial deposits down to 70 meters below the surface. The data were interpreted on the base of two-dimensional inversion methods. Results were correlated and compared with geological data accessible in the literature concerning of the research area. Geophysical prospecting gave good results and allowed to recognize a fine geological structure of the deposits.

KEYWORDS: Resistivity Imaging, sedimentary rocks, post-glacial sediments

1. INTRODUCTION

In the paper the study of post-glacial sedimentary forms formed during the last glacial period in northwestern Poland are presented. Measurements were carried out using resistivity-imaging method. Investigations were done in three sites localized on typical post-glacial structures.

The method of geoelectrical imaging has been widely applied in research of glacial and post-glacial sediments and its usefulness were proved in many studies (Barines et al., 2002; Kneisel, 2004, 2006; Schmitt et al., 2004; Kilner et al., 2005,) but in the area of interest such measurements have been carried out only occasionally (Gibas, 2002). The employment of geophysical methods allows to extend considerably information about structure of existing post-glacial forms. Imaging method enables two-dimensional visualization of rock mass cross-section and make possible to trace geological structure in almost continuous way. For more, according to Rudzki (2002) it allows to detect small resistivity anomalies, thus, to recognize layered structure of sediments precisely.

The present research was carried out in the part of Szczecinek Lake District, which belongs to Southern Pomeranian Lake District mesoregion (Fig. 1; Kondracki, 2001). Generally, the geomorphologic structure of the area was built-up during vistulian glaciations. Two moraine bands coming from krajeńska phase of glaciations and the occurrence of numerous small post-glacial lakes are characteristic for this lake district (Bukowska-Jania and Pulina, 1997). The area was examined in details in respect of its geomorphology (Kostrzewski et al., 1997). Not numerous publications concerning geological structure of the region exist (Karczewski, 1997). The aim of investigation was to test existing model of geological construction, to establish the sediment layers thickness and to determine possible water-bearing layers.

2. CHARACTERISTICS OF THE INVESTIGATED AREA

Characteristic features of the area are: big difference in elevation of the roof of Pliocene sediments, considerable thickness of Pleistocene sediments and numerous erosive forms made by glacitectonic processes. Glacitectonic processes and glacial accumulation processes brought about significant diversification of present-day topography of the terrain (Dobracki and Lewandowski, 2002).

The total thickness of Pleistocene sediments in the region changes from 80 to150 meters (Karczewski, 1991, 1997; Dobracki and Lewandowski, 2002; Klimek and Lewandowski, 2002). Bulder clays, glacial gravels, sands and silts are typical Pleistocene sediments on the area of interest as well as lake sands and peats coming from interglacial periods (Bukowska-Jania and Pulina, 1997). Pleistocene sediments are underplayed by older sediments like: decalcified dust silts, silts with carbonificated detritus, silts with pyrites and brown

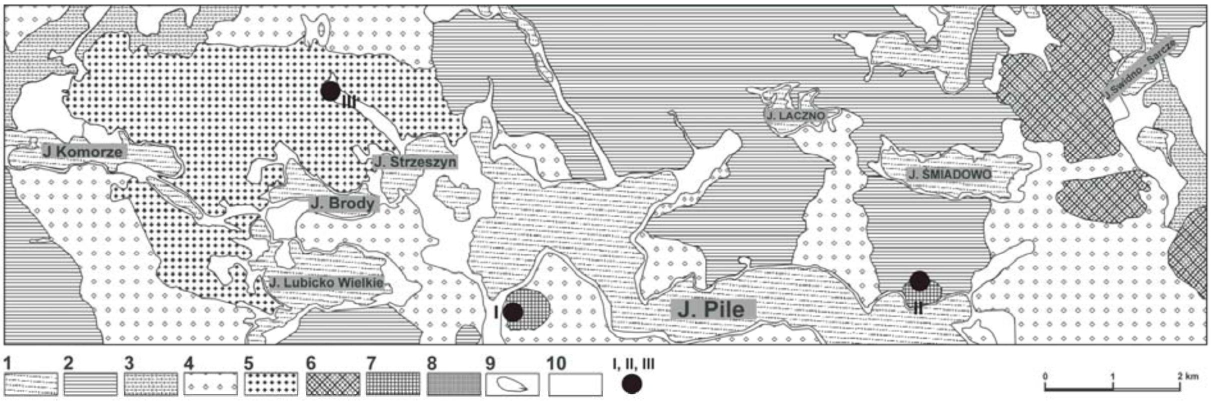

Fig. 1 Research area, Karczewski (1997), 1- lake, 2- moraine, 3- kame, 4- sandur, 5- sandur on the dead ice, 6- moraine bar, 7- kame hill, 8- interim fan, 9- outwash 10- valley bottom, I- site 1, II- site 2, III- site 3.

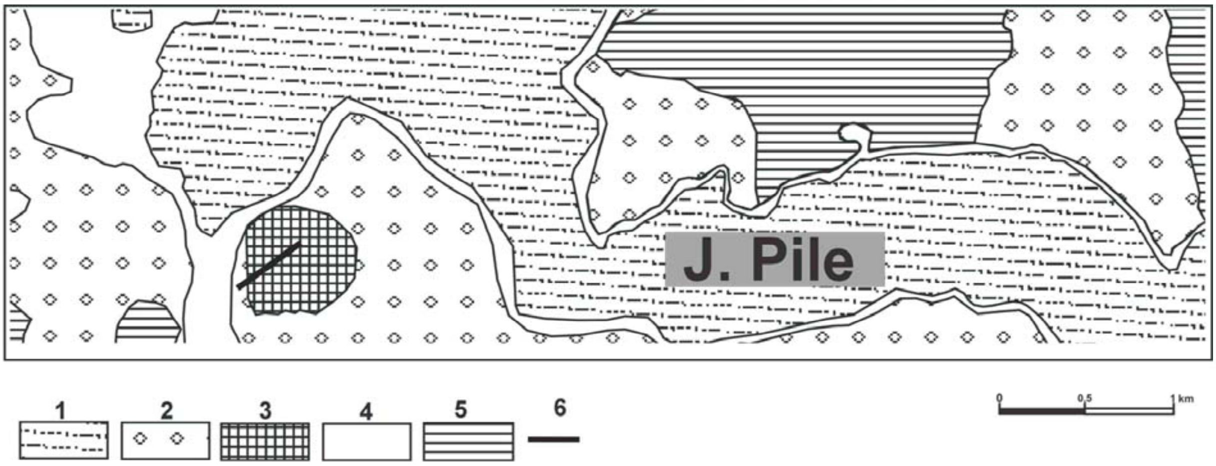

Fig. 2 Research area, site I, 1 – lake, 2 – sandur, 3 – kame, 4 – river valley, 5 – moraine, 6 – measuring profile, (Karczewski, 1997).

coal inserts and fine-grained quartz sands (Bukowska-Jania and Pulina, 1997; Geological Map 1:50000). Their total thickness is 150-200 meters (Bukowska-Jania and Pulina, 1997).

Investigated post-glacial forms are located in the Pilawa river basin, which has characteristic-gutter course and posses many lakes. The biggest reservoir in the area is the Pile Lake (surface – 9.8 km^2, depth mean - 44 meters). It is fed by water, which flows off from north, west and northern west parts of the lake district (Choiński, 1991).

The Pilawa river is characterized oneself by groundy-rainy-snowy precipitation and simple regime of water run-off with one spring freshet and period of low water level in the summer. According to meteorological data mean single run-off range from 6.9 l/s·km^2 to 7.5 l/s·km^2 (Dynowska, 1971; Bukowska-Jania and Pulina, 1997).

To recognize the shallow geological structure and hydrological regime more than ten bore-holes were made in the area. It resulted from examinations that shallow subsurface was mainly made of sands of different granulation and gravels. The level of groundwater fluctuates from 8 to 14 m. Beneath this layer a level of boulder clays is noticeable (Sołtysik and Rybka, 1993).

Measurements were done in three sites. Profiles were chosen to cross two geomorphologic forms. This allowed us to get a border between structures. The profiles were 400 meters long and 10 meters electrode gaps were applied. It allowed getting 70 meters penetration depth. The geoelectrical equipment Terrameter SAS 4000 (ABEM) with LUND Imaging System was used for the measurements of apparent resistivity of rock mass. The resistivity imaging was carried out implementing Schlumberger S-protocol with 41 electrodes.

The first site was located on the southern side of Pile lake and it contained two structures - kame and sandur (Fig. 2). Kames are constructed from gravels

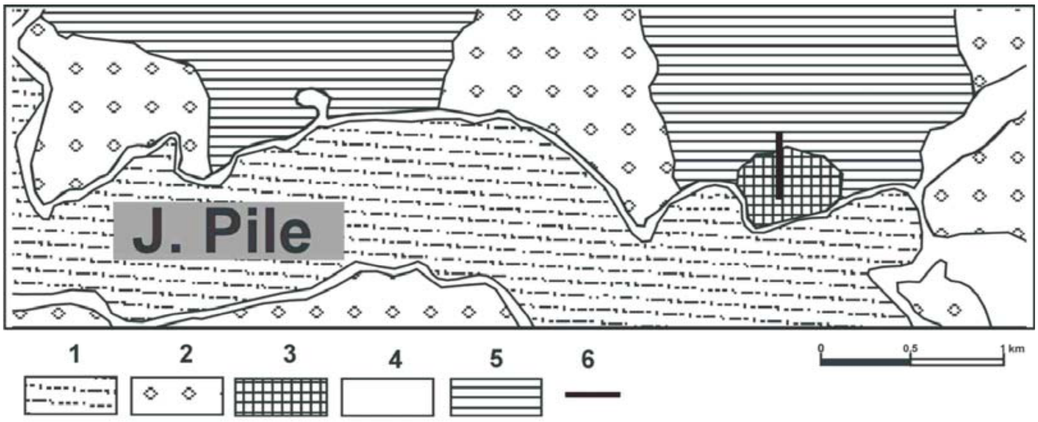

Fig. 3 Research area, site II, 1 – lake, 2 – sandur, 3 – kame, 4 – river valley, 5 –moraine, 6 – measuring profile, imaging resistivity, (Karczewski, 1997).

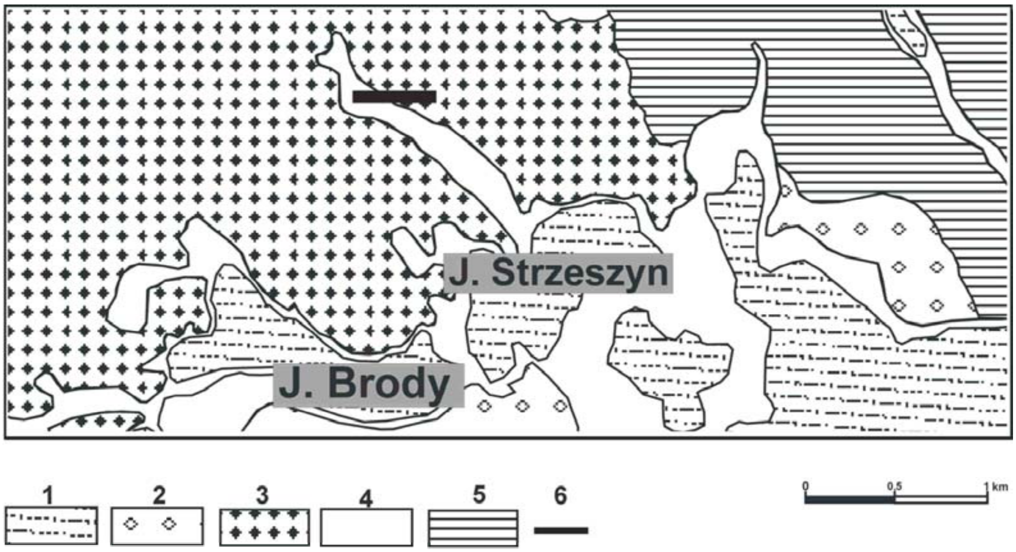

Fig. 4 Research area, site III, 1 – lake, 2 – sandur, 3 – sandur on the permafrost, 4 – river valley, 5 –moraine, 6 – measuring profile (Karczewski, 1997).

and sands, which have high electrical resistivity. Probably, they were formed in gaps of dead ice. They can be for a few to tens meters high, and their diameter can be equal to several hundred meters. Sandures are very vast and flat alluvial fans. They are built from gravels and sands, which were planted and swilled by glacial water (Klimaszewski, 1978).

Second profile was chosen in northern side of Pile lake to cross two structures - kame and moraine (Fig. 3). Moraine refers to any glacially formed accumulation of unconsolidated deposits. Moraines may be composed of deposits of different grain size - from silt like glacial flour to large boulders. The grains are typically angular (Klimaszewski, 1978).

The third site was laid near Strzeszyn Lake and it including a fragment of sandur and lake valley (Fig. 4). Valleys carved by glaciers or glacial water are normally U-shaped. When the glacier receded or thawed it left the valleys often littered with small boulders transported within the ice. A material called boulder clay was deposited on the floor of valley (Klimaszewski, 1978).

3. RESEARCH METHOD

The purpose of electrical resistivity survey is to define the resistivity distribution in a volume of investigated rock mass using generated electric current supplied to the soil. The pattern of potential differences on the surface provides information on the subsurface structure and of its electrical properties (Kearey, et al., 2002; Samouëlian et al., 2005).

Resistivity Imaging Method connects features of resistivity prospecting and resistivity sounding (Loke and Barker, 1996; Rudzki, 2002; Loke, 2004). Process of inversion is essential for this method. Determined apparent resistivity values are used during this process to determine resistivity distribution of the rock mass based on theoretical model of the medium.

Measured electrical resistivity data d_i ($i = 1$ to n) depend on medium properties and measurement inaccuracies e_i which are errors of the observational data:

$$d_i = F_i(m_1, m_2, ..., m_m) + e_i \tag{1}$$

F_i is the forward mapping, which allows to calculate the model response c_i for a given set of model parameters m_j ($j = 1$ to m):

$$c_i = F_i(m_1, m_2, ..., m_m) \tag{2}$$

The aim of inversion is to find such set of model parameters, which minimizes the squared differences between the observed and computed data for all data points (Samouëlian et al., 2005):

$$e_i = d_i - c_i \tag{3}$$

The inversion routine used by the program is based on the smoothnes-constrained least-squares method (de Groot-Hedin and Coustable, 1990). A new implementation of the least squares method based on a quasi-Newton optimisation technique (Loke and Barker, 1996a) can also be used. This technique is more than 10 times faster than the conventional least-squares method for large data sets and requires less memory. The smoothnes-constrained least-squares method is based on the following equation:

$$(J'J + uQ)m = J'd \tag{4}$$

where $Q = q_x q_{x'} + q_z q_{z'}$
q_x – horizontal flatness filter
q_z – vertical flatness filter
J – matrix of partial derivatives
u – damping factor
m – model perturbation vector
d – discrepancy vector

One advantage of this method is that the damping factor and flatness filtres can be adjusted to suit different types of data. The process started with initial model parameters which are modified in following iterations to fit the theoretical data to the empirical one. Iterative process is continued while the required convergence level or the assigned number of iterations is achieved (Sjödahl, 2006).

4. RESULTS

4.1. SITE I

Obtained model contains five layers (Fig. 5). Electrical resistivity of the first layer range from 4500 to 5000 Ωm. Probable, it is connected to sediments, which build the kame (coarse-grained sands and gravels). One can suppose that these sediments are unsaturated because they occur higher up of the lake water level. Second layer has electrical resistivity about 1000 Ωm, which replay to saturated sands and gravel. Presumably it is water-bearing layer. Sands and limno-glacial silts (150 Ωm) create third layer. The occurrence of the layer is spatially limited what may be connected with way of its sedimentation. The fourth layer is probably made of low-resistive (3 – 50 Ωm) silts and clay. The last layer have electrical resistivity in the range of 400 – 600 Ωm. Correlating the geoelectric data with existing geological data, one can suppose that it contain Miocene sands.

4.2. SITE II

The first layer has resistivity changing from 4500 to 5500 Ωm, which suggests that it is made of dry coarse-grained sands and gravels. The fluwioglacial sands and gravels (resistivity 100 – 200 Ωm) may be sediments making the second layer which is probably water-bearing. Presumably, the third layer (resistivity 3000 – 4000 Ωm) is build from coarse-grained gravels and sands. It can be kame fragment, which was buried through fluvioglacial fine-grained sediments. The fourth layer has low electrical resistivity from 10 to 50 Ωm, what point to occurrence of Pleistocene silts and clays.

4.3. SITE III

For the third site, a three- layers model was obtained (Fig. 7). On the cross-section one can see a facial border between sediments building a sandur and a river valley. The sandur is built of the distinguished layer 1 and it has the resistivity between 3000-4000 Ωm characteristic for dry sediments such as sands and gravels. Elevation of the layer is higher up the water-level of Strzeszyn lake. Second layer has electrical resistivity of about 1000 Ωm. Probably, they are water-bearing layer, which is built with sands and gravels. Both layers make the typical structure of the sandur. The fluvial sediments form the third layer. They are vari-granular sands, seldom gravels, aggregated muds and humus sands, which have electric resistivity of 20-100 Ωm. The sediments build a valley bottom. Presumably, the disturbances of the layer structure come from intensive glacitectonic processes. The sandur could originate on the dead ice buried under debris. When the ice was thawing over-laid sediments were probably pushed into the valley sediments.

5. CONCLUSION

Resistivity Imaging survey carried out on chosen post-glacial structures proved to be useful for recognizing their shallow geological structure. This method is an excellent supplementing of borehole data since it allows to track borders between different post-glacial sediments in the continuous way. Multilayer structure of sediments with different layer number depending on the sites was distinguished in the studied area. Appointed values of resistivity of examined rocks agree with the resistivity data presented in the literature (Teleford at al., 1990; Plewa

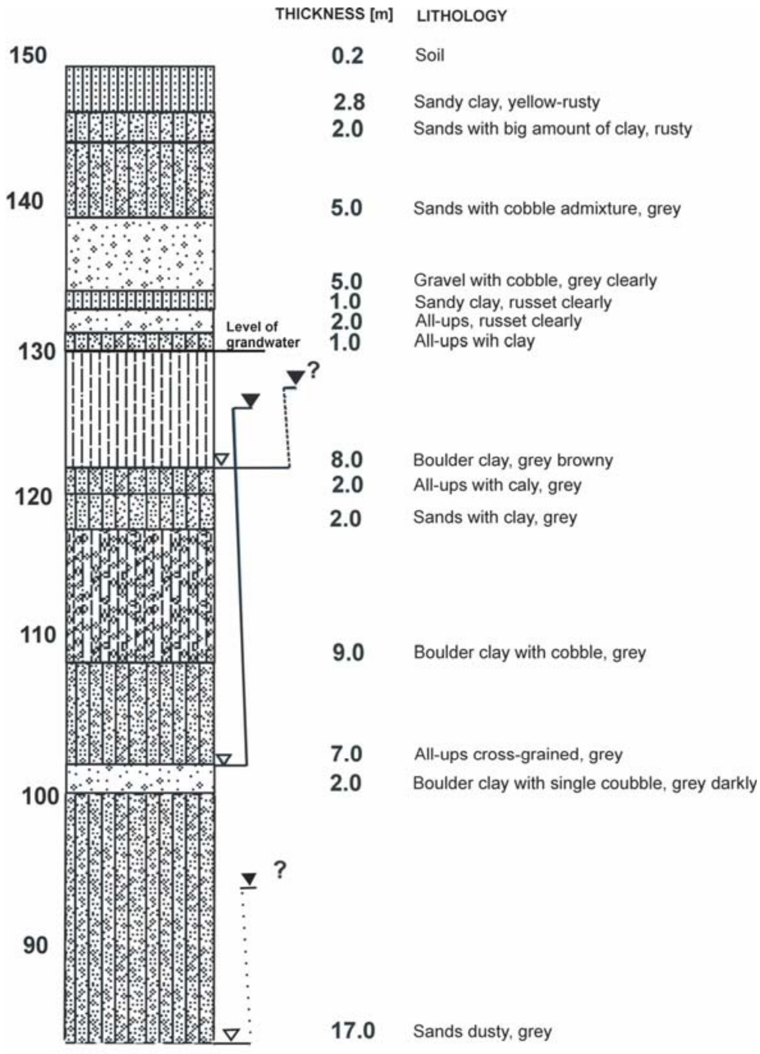

Fig. 8 Geological profile Liszkowo PGR (card of the bore-hole of hydrogeologic No. 1638, Liszkowo PGR, 1973).

and Plewa, 1992; Schön, 1996; Reynolds, 1997). It was possible to correlate obtained geoelectrical models with geological data of deposits building the checked structure (Bukowska-Jania and Pulina, 1997; Karczewski, 1997; Dobracki and Lewandowski, 2002; Klimek and Lewandowski, 2002). Presumable water-bearing levels were also interpreted (Fig. 8).

Analyzing obtained results one can prove, that the use of Resistivity Imaging Method give a possibility to get the precise continuous model of the medium by the invasion-less way.

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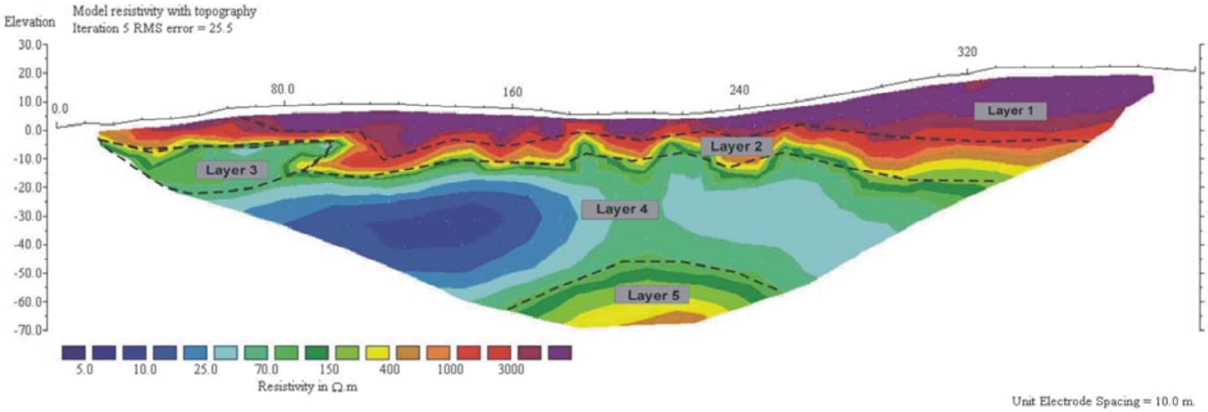

Fig. 5 Resistivity inversion model, site I.

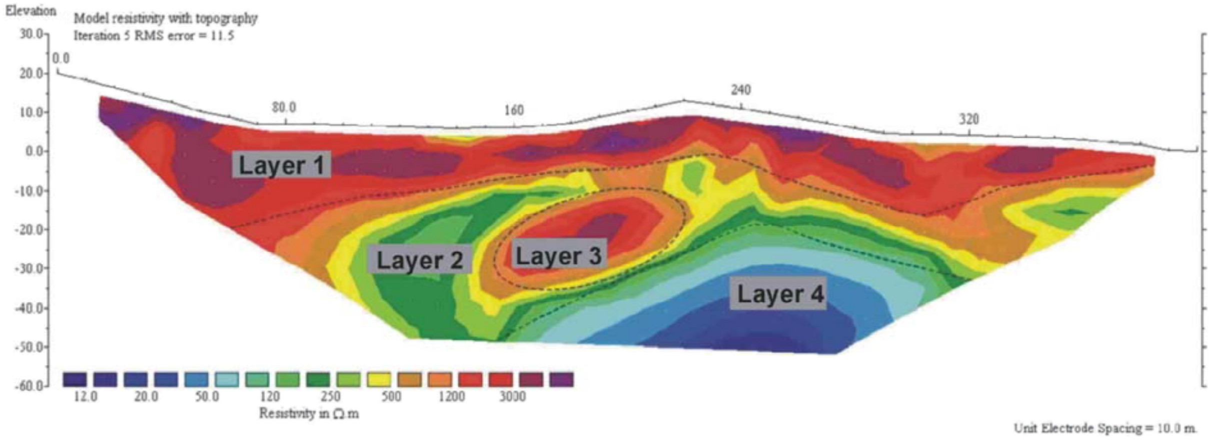

Fig. 6 Resistivity inversion model, site II.

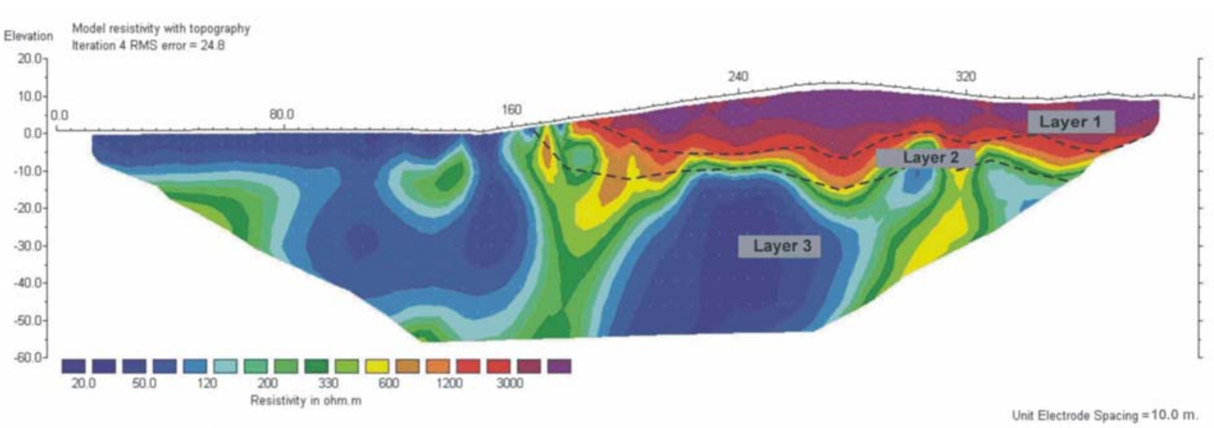

Fig. 7 Resistivity inversion model, site III.