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Difference in Results of Galvanic and Inductive Methods on Example of Dipole-Dipole EM Profiling and Non-Contact Electri

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SUMMARY

Difference in apparent resistivity values determined in galvanic and inductive electrical and EM methods depends on macroanisotropy produced by horizontal layering and decreased penetration depth of galvanic methods without changing penetration depth of inductive methods. Joint influence of these two factors in case of high contrast of layers' resistivities results in difference in several tens of times for apparent resistivity values between galvanic and inductive methods.

Introduction

Difference in results of galvanic and inductive electromagnetic methods is well known for a long time [Vanian, 1965]. Appearance of frequency sounding and transient electromagnetic methods was a result of need to perform sounding below highly resistive horizontal layers in sedimentary cross-section of Russian platform to find oil and gas deposits in late 50-s and 60-s of XX century that was impossible with DC resistivity sounding method. Nowadays differences of VES and TEM methods above horizontally-layered macroanisotropic cross-section were analyzed in paper [Ivanov et al., 2011].

At study of smaller depths we use galvanic and inductive methods having similar differences. Department of geophysics of Moscow state university performs student summer practice in Aleksandrovka village in Kaluga region with usage of dipole-dipole EM profiling (DIP with EM-34 instrument of Geonics, Canada) and non-contact electric field measurements (BIEP with Russian ERA-Max instrument) [Electrical profiling..., 1985] methods. Frequently galvanic and inductive profiling methods perform on the same profiles to compare results. BIEP is similar to traditional galvanic resistivity profiling with dipole axial array, whereas DIP is typical representative of inductive method.

1. The first example of difference: histograms

Geological cross-section of the fist 15 m depth in the area includes Quaternary fluvioglacial sands (ρ 300-5000 Ohm.m) and moraine loam (ρ 30-70 Ohm.m). At the depth 12-15 m carboniferous limestone layer appears (Mikhailovsky horizon) (ρ 150-500 Ohm.m), laid nearly horizontally. Geoelectrical situation and its effect on resistivity data is similar to that described by Sauck [2010]. Histograms of apparent resistivity for DIP, BIEP and VES methods include ρ_a values in interval from 30 to 5000 Ohm.m. DIP data were measured with EM-34 (Geonics) with horizontal dipoles separated at 20 m (frequency 1.6 kHz) with 15 m depth [McNeill, 1980]. BIEP data were measured at 37 m distance with 15 m depth at 625 Hz. VES data were measured at distances AB/2 from 1.5 m until 110 m with depth until 30 m. Volume of measuring points of each method for histograms was from 600 to 900. In fig.1 ρ_a histograms for VES and BIEP (galvanic methods) are similar from 30 until 5000 Ohm.m, whereas for DIP (inductive method) ρ_a histogram is different with right limit at 100-140 Ohm.m. The cause of such difference is a macroanisotropy of upper layers, because galvanic methods react on $\rho_m = \sqrt{\rho_l \cdot \rho_n}$ - mean geometrical resistivity, whereas inductive methods react on longitudinal resistivity ρ_l, which is smaller then ρ_m.

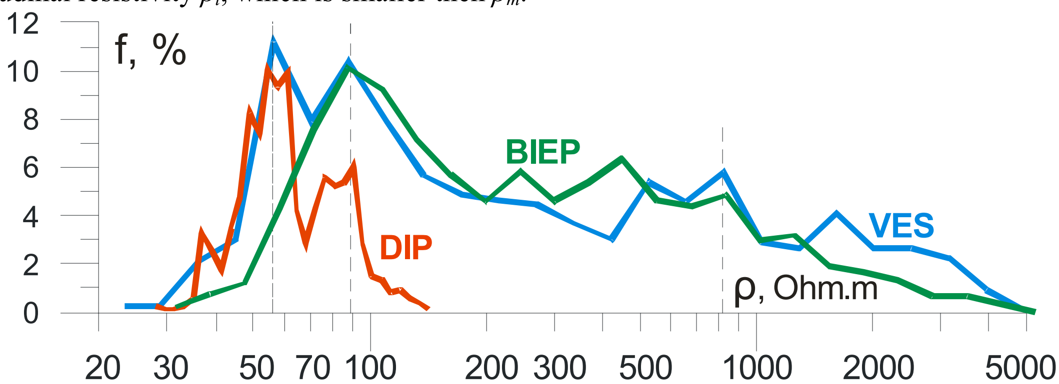

Figure 1 *ρ_a histograms for DIP, BIEP and VES data measured in 2010.*

2. An example of difference of mean geometrical and longitudinal resistivity of layered cross-section in Alexandrovka

On boreholes data drilled in 2009 and VES data on Alexandrovsky plateau, the next typical geoelectrical model was determined:

Table 1 *Part 1. Geoelectrical model near borehole 4/2009, Alexandrovsky plateau.*

Resistivity, Ohm.m	Thickness, m	Rock description

1917	0.562	soil and subsoil
3584	1.01	dry sand
74.8	0.879	loam
779	0.714	sand
18.2	6.84	loam
75.9	3.17	loam with limestone fragments
157		limestone

Using well known Dar Zarrouk formulas for macroanisotropic cross-section one can calculate longitudinal, transversal and mean geometrical resistivity and macroanisotropy coefficient λ.

$$\rho_L = \frac{H_\Sigma}{S_\Sigma}, \quad \rho_M = \sqrt{\frac{T_\Sigma}{S_\Sigma}}, \quad \rho_N = \rho_M \cdot \lambda, \quad \lambda = \rho_M / \rho_L, \quad H_{Macro} = H_\Sigma \cdot \lambda \qquad (1)$$

***Table 1** Part 2. Calculation of integrated parameters for geoelectrical model near borehole 4/2009.*

H_sum	S_sum	T_sum	Rho_L	Rho_m	λ	Rho_n	H_macro
13.18	0.43	5684.24	30.6	115	3.7	431	49.5

This calculation of integrated parameters of the model shows difference between longitudinal ρ_l and mean geometrical ρ_m resistivity attained 3.7 times. Macroanisotropy increases depth until limestone layer from 13.2 until 49.5 m. VES interpretation without a priory information can give such increasing of limestone depth [Shevnin, Bobachev, 2011].

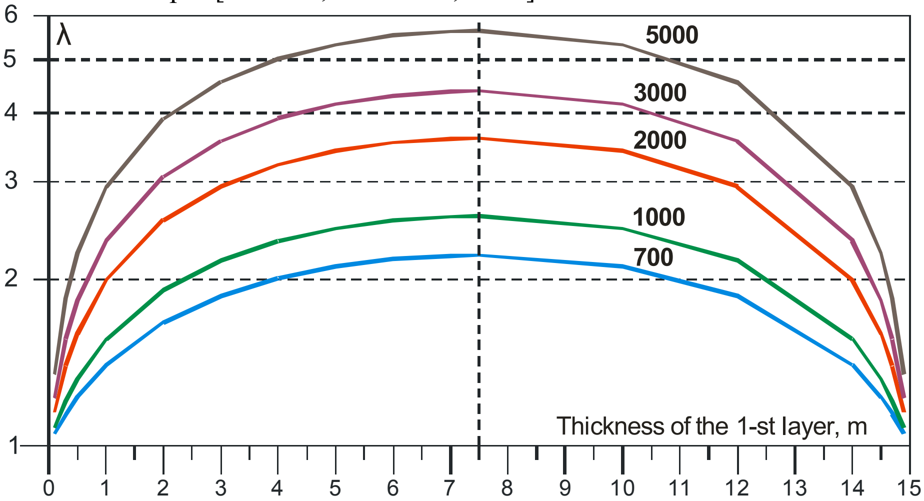

***Figure 2** Graphs λ_{Macro}. Graphs' indexes - ρ_2 values from 700 to 5000 Ohm.m. ρ_1=40 Ohm.m. Total thickness of two layers is 15 m.*

DIP method in near zone with horizontal dipoles separated at distance L [Karinsky, 2008] shows:

$$h_{xx} \approx 1 - \frac{k_t^2 L^2}{2}\left[1 + \frac{1}{3} i k_t L\left(1 + \frac{3}{\lambda^2}\right)\right] \approx 1 - \frac{k_t^2 L^2}{2}, \qquad (2)$$

that means h_{xx} depends only on longitudinal resistivity value (included in wave number k_t) and does not depend on k_n and anisotropy coefficient λ.

3. An influence of macroanisotropy

Fig. 1 shows that right boundaries of DIP and BIEP-VES histograms differ until 36 times. Why? First of all, the difference resulted on macroanisotropy. At small depth there is interleaving of fluvioglacial sand and moraine loam and these two rocks appear more than once (after different phases of sedimentation). Macroanisotropy coefficient (Fig.2) can reach 5.6 at equal thicknesses of both layers. But 5.6 is not equal to 36, we need to find another factor increasing the difference additionally 6 times.

4. Decreasing penetration depth of galvanic methods

The second factor of difference between DIP and BIEP results is decreasing penetration depth of galvanic methods due to influence of macroanisotropy. Macroanisotropy does not influence on inductive methods and does not change their penetration depth.

Let's consider such 4 layered model (Fig.3, A), typical for the study area:

***Table 2** Parameters of layered model*

Layer	Resistivity	Thickness	Rock description
1	500	1	superficial sand layer
2	ρ_2-var	3	fluvioglacial sand
3	50	8	moraine loam
4	200		limestone

The second layer (fluvioglacial sand) has different resistivity ρ_2 1000, 2000, 3000, 5000. Let's calculate macroanisotropy coefficient until the top of limestone layer (4-th layer) depending on ρ_2:

Table 3. Values λ_{Macro} as a function of ρ_2 for model in table 2

ρ_2	λ_{Macro}
1000	2.1
2000	2.8
3000	3.3
5000	4.2

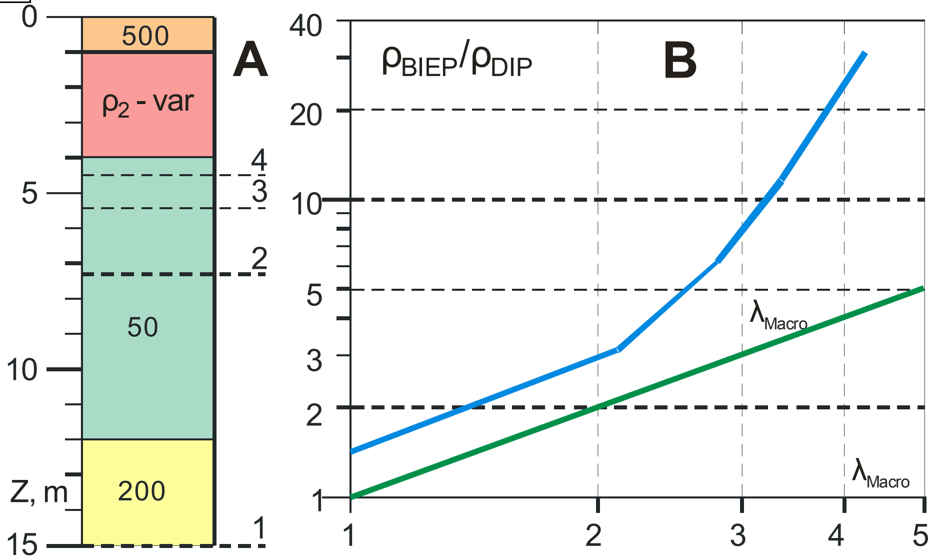

***Figure 3** Results of modeling and calculation of ρ_a BIEP - DIP ratio for model A. B - graphs of ρ_a BIEP - DIP ratio total (blue line) and caused by only macroanisotropy (green line) for model A*

Macroanisotropy influences on galvanic methods in such a way that estimated thicknesses of layers and boundaries depths increasing (without use of a priory information at interpretation process) equally to macroanisotropy coefficient. This phenomenon we can consider as equivalent diminishing of investigation depth (Fig.3, A). If estimated depth of any galvanic method is equal to 15 m, and macroanisotropy coefficient is correspondingly equal to 1, 2, 3, 4, real depth will be 15/λ, as it shown at Fig.3, A with dotted lines. For models with "decreased" depth we can calculate mean geometrical resistivity ρ_m, equal to apparent resistivity of BIEP method. Macroanisotropy does not influence on DIP and its apparent resistivity will be constant and equal to ρ_l of model in Fig.3,A. Ratio ρ_{aBIEP}/ρ_{aDIP} is shown in Fig.3, B with blue line, and at λ=4 it reaches 30, that is more than macroanisotropy coefficient λ_{Macro}.

Is this model close to reality? In Fig.4 there are practical results of BIEP and DIP along profile crossing Alexandrovsky plateau from river Ugra until Alexandrovka village. Additional scale on fig.4 shows ratio ρ_{aBIEP}/ρ_{aDIP} that reaches 20-30, whereas macroanisotropy gives no more than 5.6. Difference between 20-30 and 5.6 shows that BIEP has decreased depth caused by macroanisotropy influence.

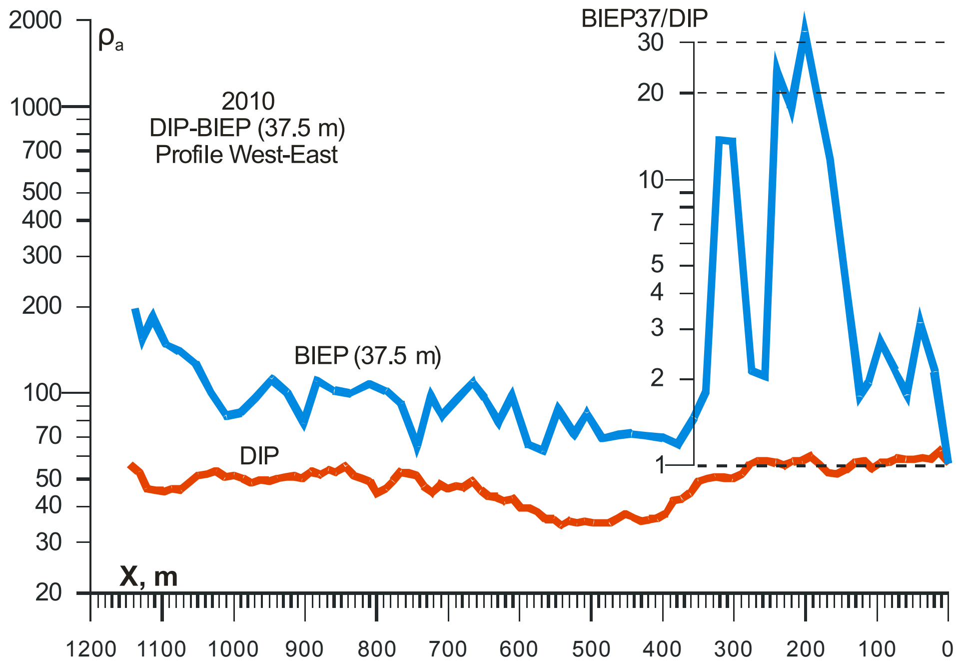

Figure 4 *ρ_a graphs for BIEP and DIP methods along profile "west - east".*

Conclusions

Joint use of BIEP and DIP (galvanic and inductive) methods in the area near Aleksandrovka (Kaluga region) shows difference in apparent resistivity values (until 30 times) due to high difference in true resistivity values of fluvioglacial sands (ρ 5000 Ohm.m) and moraine loam (ρ 40 Ohm.m).

The difference in ρ_a values for BIEP and DIP resulted on macroanisotropy of contrast cross-section, because BIEP reacts on mean geometrical value ρ_m, and DIP reacts on longitudinal mean resistivity ρ_l, and also results from decreased penetration depth of galvanic methods under the influence of macroanisotropy without changing penetration depth of inductive methods. Change of penetration depth of galvanic methods under the influence of macroanisotropy one need to investigate more.

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www.geoelectrical.com Freq_EM program for forward modeling and interpretation of DIP data with EM-34.