University of West-Hungary

PhD thesis

GEOELECTRIC NULL-ARRAYS

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Science: Environmental Geophysics

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Objectives of the research and its precedents

Analogue modeling experiments carried out in the modeling laboratory of the Geodetic and Geophysical Research Institute of the Hungarian Academy of Science led us to the conclusion, that some special electrode arrays could be more sensitive to near-surface inhomogenities, than the traditionally used arrays. These so called null-arrays are such configurations of the current and potential electrodes, by using of which the signal above a homogeneous halfspace is zero. This definition can be extended to situations, where not the directly measured potential difference but the interpreted signal is close to zero.

By some arrays belonging to certain groups of the null-arrays were carried out measurements earlier. But there are not known succesful experiments, which were carried out by null-arrays on the field. The objective of this dissertation is to investigate these null-arrays.

For this investigation I needed some tools, which were not at my disposal at the start of my research work. So at first I had to calculate the effect caused by a small buried cube, having different resistivity than that of the embedding halfspace. In this way it became possible to construct parameter-sensitivity maps and depth of investigation characteristic (DIC) functions of the null-arrays. These tools served as a basis of the theoretical investigation of these arrays.

The methods of the investigations

The first step towards the theoretical basis was an analytical derivation, which calculates (in the case of direct current injection) the effect due to a small cube, having different resistivity, than that of the embedding halfspace. This made possible to construct parameter-sensitivity maps of different arrays, which help us to understand the behaviour of null-arrays.

By using this result it was possible to calculate the depth of investigation function and the value of the depth of investigation of certain dipole arrays. On basis of these results almost all studied dipole arrays could be divided into two groups. This classification facilitates the forthcoming theoretical investigations.

To control the results of theoretical investigations analogue modeling and field work were carried out, too. In the first field measurement the three-dimensional subsurface structure, in the second one the multi-directional fracture system complicated the situation. In spite of this difficulty (or from the other side due to this complicated situation) the null-arrays proved to be useful in the field.

Summary of the results

The parameter-sensitivity maps and the depth of investigation function of the null-arrays are important to know these arrays. In order to construct the maps and the DIC functions at first

1a.) the effect of a small buried cube, having different resistivity than that of the embedding halfspace for all possible surface dipole arrays was analytically calculated.

Then – because formerly in absence of available numerical codes or in absence of convenient computer background it was not possible –
1b.) the author has compared this simple analytical result by the numerical one and concluded, that if the side length of the cube is shorter than one tenth of the transmitter-receiver distance, the two solutions not differ considerably from each other.

I gave a general description about the parameter-sensitivity maps, since they are very important in the knowledge of all d.c. arrays. Furthermore no papers about the interpretation of these maps have been published until now.

It was illustrated by some examples that the parameter-sensitivity maps are very useful in the practical application. Some arrays were developed just from the investigation of these maps.

Parameter-sensitivity maps of some characteristic dipole arrays were presented in three different depths separately for the x-, y-, and z components and their sum. In this way not only the effect of the whole cube, but also the effect of the three pairs of cubesides were illustrated one after the other.

2.) It was verified using the parameter-sensitivity maps, that the Schlumberger null-, three-electrodes null-, dipole axial null-, and dipole equatorial null-arrays not only above a homogeneous halfspace, but also above any symmetrical structure to the characteristic lines of the arrays (namely to the AB line) is zero.

Using again the result of thesis 1., from the DIC functions of the dipole arrays

3a.) the depth of investigation values defined by Roy and Apparao (1971) were determined for different dipole-dipole arrays (see Table 1),

<table>
<thead>
<tr>
<th>θ</th>
<th>parallel</th>
<th>perpendicular</th>
<th>radial</th>
<th>azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10°</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20°</td>
<td>0.195</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30°</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40°</td>
<td></td>
<td>0.2</td>
<td>0.195</td>
<td>0.25</td>
</tr>
<tr>
<td>50°</td>
<td>0.17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60°</td>
<td>0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70°</td>
<td>0.30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80°</td>
<td>0.26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90°</td>
<td>0.25</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3b.) On basis of the above mentioned depth of investigation values, the dipole arrays were divided- with a few exception - into the groups as dipole axial-like and the dipole equatorial-like arrays (Table 2.).

Table 2. Classification of dipole-dipole arrays on basis of their One-dimensional behaviour

<table>
<thead>
<tr>
<th>dipole axial-like arrays</th>
<th>dipole equatorial-like arrays</th>
<th>arrays, belonging to neither of these groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>-parallel array, if $0^\circ \leq \theta \leq 45^\circ$</td>
<td>-parallel array, if $\theta \geq 85^\circ$</td>
<td>-parallel array, if $45^\circ &lt; \theta &lt; 85^\circ$</td>
</tr>
<tr>
<td>-radial array</td>
<td>-azimuthal array</td>
<td></td>
</tr>
<tr>
<td>-perpendicular array</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| depth of investigation $(z/R)$ | 0.19-0.20 | 0.25 | 0.1-0.3 (or more than 0.3) |

4.) A widely accepted erroneous statement, that the parallel array with an angle $\theta = \arctg \sqrt{2}$ would have an infinitely large depth of investigation, was disproved.

This misleading statement is the consequence of normalisation by the value measured above the homogeneous halfspace. This means a division by zero in case of this null-array. In order to get a correct depth of investigation value not the normalised, but the secunder value itself should be taken into account.
I have not dealt with all possible null-array, since I preferred those arrays, which can be used easily in the field. The best arrays from this point of view are the Schlumberger null-, the three-electrodes null-, the dipole axial null-, and the dipole equatorial null-arrays, since they represent all types of electric fields: around a point source, around a two-pole source and around a dipole source, respectively.

5.) It was shown from the field measurements carried out by using these null-arrays, that these arrays are capable to detect not only fissures in limestone, but they also „see” fissures from greater depth and in a more characteristic way, than their traditional array pairs do.

The null-arrays and the traditional arrays have some complementary features, therefore their common use in the field does not need much more time, than their’s single use would need. From this reason a joint use of the null-arrays and their traditionally used pairs are recommended.

6a.) In determination of the direction of fissures – as it was verified also by analogue modelling – the Schlumberger null-array proved to be much more precise, than the most commonly used Schlumberger array. The variation of signals in the direction of the fissures is namely much quicker in case of the null-array, than in case of the traditional array.

6b.) It was shown, that the Schlumberger null-array works very well also in the case of more complex field situation. The Schlumberger null-array proved to be capable to distinguish away three fissure directions only by a combination of the Schlumberger array and the Schlumberger null-array, so the common use of both of these arrays is recommended.

Summarising the results the most important tools – have not yet existed before - are necessary to investigate the null-arrays seemed to be succesful. Using the theoretical-analytical and the field results it is possible to understand better both the null-arrays and the traditional arrays.

Application of the results of the dissertation

Thesis 1a. results in parameter-sensitivity maps and depth of investigation functions of geoelectric arrays, and in this way the depth of investigation values can be determined.

Thesis 1b. shows, that equation in thesis 1a. is valid not only for small cubes, but also for certain realistic cubes.

Thesis 2. is a direct consequence of thesis 1a. for parameter-sensitivity maps. This thesis provides the theory of null-arrays. Without this thesis it would be much more difficult to understand the null-arrays. Understanding of null-arrays is the basis of succesful field application.

Results of Thesis 3a. have not been known before. The better knowledge of the dipole arrays needs this result. Thesis 5. Is also based on this thesis.

Thesis 3b. allows a simplification the theory of the dipole arrays and a starting point to the forthcoming theoretical and practical investigations.
Thesis 4. clarifies a misleading statement which is widely spread in the geophysical literature. This problem raises the question: which values should be presented and how the presented values influence the conclusions.

Thesis 5. presents the first time successful field measurements carried out by such null-arrays. The description of the background of the measurement helps in the planning, carrying out and interpretation of other measurements, too.

The result of 6a provides a precise direction determination of fissures.

Thesis 6b. shows, that the null-array may be capable for the determination of the fissure direction also in case of a complicated fissure system.

Some of the theses serve as basis for other theses, some of them have practical meaning. As a conclusion can be stated, that the theses and the dissertation itself led to a better knowledge of the null-arrays and consequently to their successful use in field. I am convinced, that a better knowledge of null-arrays helps to understand better the traditionally used arrays, too.
Publications

Abroad, in foreign language


In Hungarian journals, in English language


In Hungarian journals, in Hungarian language

**Presentations**

**Presentations held at International Conferences**


14. Szalai S., Bosch F., Turberg P., Müller I. (1998): Comparative geophysical test survey on karst and epikarst (Swiss Jura) under the influence of artificial electromagnetic disturbance - What is possible?
   Part 1. Continuously measuring Radio-Frequency-Electromagnetics (RF-EM), Seismics
   Part 2. Geophysical profile measurements by null-arrays and by traditionally used arrays
Final Conference of the Hungarian-Swiss Cooperation about electromagnetic methods and about the project results, 1998, Sopron


Presentations in Hungarian held in Hungary


Reports


