University of West-Hungary

PhD thesis

GEOELECTRIC NULL-ARRAYS

Sándor Szalai

Sopron
2002

PhD School: „Environmental Sciences" PhD School
(supervisor: Dr. Csaba Mátyás)

Program: Geoenvironmental Sciences (supervisor: Dr. László Szarka)

Science: Environmental Geophysics

Advisor: Dr. László Szarka

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 seperately 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 charecteristic 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 1. Depth of investigation values for dipole-dipole arrays; the meaning of ϑ and the different dipole-dipole arrays can be seen on *Fig. 1.*

ϑ	parallel	perpendicular	radial	azimuthal
	dipole-dipole array			
0°				
10°				
20°	0.195			
30°				
40°		0.2	0.195	0.25
50°	0.17			
60°	0.10			
70°	0.30			
80°	0.26			
90°	0.25			

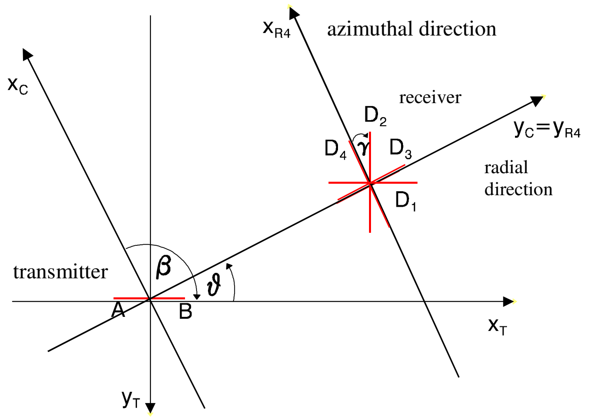

Fig.1. Illustration of different dipole-dipole arrays
AB and D1 –parallel dipole array, AB and D2 – perpendicular dipole array
AB and D3 –radial dipole array, AB and D4 –azimuthal dipole array

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

	dipole axial-	**dipole equatorial-**	**arrays, belonging to neither of these groups**
	like arrays		
	-parallel array, if $0° \le \vartheta \le 45°$ **-radial array** **-perpendicular array**	**-parallel array, if $\vartheta \ge 85°$** **-azimuthal array**	**-parallel array, if $45° < \vartheta < 85°$**
depth of investi-gation (*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 ϑ=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 distuingish 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 spred 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 at the first time succesful 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 succesful 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

1. Szarka L., Nagy Z., Szalai S. (1994): 3D CSAMT analogue modeling studies. EAEG Meeting (extended and refereed abstract), P121, 1994 Vienna
2. Szalai S.(1997): 3D Parameter-Sensitivity of D.C. Dipole Arrays. EAGE Conference (extended and refereed abstract), P136, 1997 Geneve
3. Szalai S., Szarka L.(2000): An approximate analytical approach to compute geoelectric dipole-dipole responses due to a small buried cube, *Geophysical Prospecting*, Vol. 48, pp. 871-885
4. Koppán, A., Szalai, S.,Kis, M., Szarka, L., Wesztergom, V. (2000): Analogue modelling experiments for determination of humidity distribution within the trunk of standing trees by using geophysical technique, XXX ESNA Conference, 2000 (extended abstract), Keszthely
5. Koppán, A., Kis, M., Szalai, S., Szarka, L., Wesztergom, V. (2000): In vivo electric soundings of standing trees, 12th International Symposium on Nondestructive Testing of Wood. West-Hungary University, (extended abstract), Sopron
6. Szalai S.,Abd Alla M., Ahmed S., Szarka L. (2001): Localisation and direction determination of fissures with geoelectric methods in narrow, elongated measuring areas. (extended and refereed abstract), EEGS-ES Conference, Birmingham
7. Szalai S.,Szarka L., Prácser L.,Bosch F., Müller I.,Turberg P. (2001): Geoelectric mapping of near-surface karstic fractures by using null-arrays. Submitted to Geophysics

In Hungarian journals, in English language

8. Szalai S. (2000): About the depth of investigation of different d.c. dipole-dipole arrays. Acta Geod. Geoph. Hung., Vol. 35 (1), pp. 63-73
9. Szalai S.,Abd Alla M., Ahmed S., Szarka L. (2001): Localisation and direction determination of fisures with geoelectric methods in narrow, elongated measuring areas. Acta Geod. Geoph. Hung., Vol. 36 (3), pp. 285-296

In Hungarian journals, in Hungarian language

10. Szalai, S. (1994): „ Geophysical tecniques in urban and industrial environment" on basis of the Dec. 1992 article by Henderson in the Exploration Geophysics. Magyar Geofizika, 35. (4), pp. 204-212

Presentations
Presentations held at International Conferences

11. Szarka L., Nagy Z., Szalai S. (1994): 3D CSAMT analogue modeling studies, EAEG Conference, 1994 Vienna

12. Viljanen A., Szarka L, Szalai S., Pirjola R. (1994): Analogue model studies of induction effects at auroral electrojet region. XII. Workshop on Electromagnetic Induction in the Earth, Brest, France, 1994 (International Union of Geodesy and Geophysics)

13. Szalai S. (1997): 3D Parameter-Sensitivity of D.C. Dipole Arrays, EAGE Conference, 1997, Geneve

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

15. Bosch F., Szalai S., Turberg P., Müller I. (1999): Continuously recording Radio-Frequency Electromagnetic (RF-EM) without ground contact: A powerful tool for vulnerability mapping in fissured rocks. EEGS Conference, Budapest

16. Szalai S., Bosch F.,Turberg P., Müller I., Prácser E., Szarka L. (1999): Field meauserements by using geoelectrical null-arrays on fissured limestone in the Swiss Jura. EEGS Conference, Budapest

17. Koppán A., Kis M., Szalai S., Szarka L., Wesztergom V. (2000): Analogue modelling experiments for determination of humidity distribution within the trunk of standing trees by using a geophysical technique ESNA Conference, Keszthely

18. Koppán A., Kis M., Szalai S., Szarka L., Wesztergom V. (2000): In vivo electric soundings of standing trees. Wood NDT 2000, Sopron

19. Szalai S. (2000): Geoelectrical null-arrays on the field. National Research Institute of Astronomy and Geophysics, Helwan-Cairo-Egypt, Helwan-Cairo

20. Szalai S.,Abd Alla M., Ahmed S., Szarka L. (2001): Localisation and direction determination of fissures with geoelectric methods in narrow, elongated measuring areas. EEGS-ES Conference, EGSI18P, Birmingham

Presentations in Hungarian held in Hungary

21. Szarka L., Ádám A., Papp G., Pásztor P., Prácser E.,Szalai S.(1995): Interaction of natural and man-made fields, MÁELGI, 1995. Presentations of OTKA posters

22. Szalai S. (1996): Investigation of soil pollution caused by a waste deposit (Müllberg, Karlsruhe). Meeting of Young Geophysicists, 1996. Balatonvilágos

23. Szalai S. (1997): 3D parameter-sensitivity of d.c. dipole arrays, Meeting of Young Geophysicists, Tata

24. Szalai S. (1997): Dipole arrays having extremly high parameter-sensitivity, Meeting of Young Geophysicists, Tata

25. Szalai S. (1999): Should we involve into the inversion the geoelectrical null-arrays? Geophysical Inversion'99, Scientific Meeting, Miskolc

26. Szalai S., Bosch F. (1999): Field measurements by geoelectrical null-arrays, Meeting of Young Geophysicists, Siófok

27. Szalai S. (1999): 1. On the Kuril islands with vulcanologists, 2. Tsukotka (an unknown volcano in Sibiria) "Our environment: the Earth" scientific lecture for the general public, University of Sopron

28. Szalai, S. (2000): Geoelectrical field work, „Springwind" 4. World Conference of the Young Hungarian Scientific Researchers and PhD students, Gödöllő

Reports

29. Szarka L., Szalai S.(1993): Analog model measurements above 3D structures, Report for the Hungarian Oil Company, GGRI HAS, Sopron

30. Pásztor P., Szalai S. (1994): Investigation of the theoretical background of the radio-frequency soildetector MFA 1., Report , GGRI HAS, Sopron

31. Szalai S., Pásztor P.(1994): Investigation for sand and gravel using d.c. vertical geoelectric sounding. Report for the Agricultural Cooperative Szombathely GGRI HAS, Sopron

32. Szalai S. (1996): Developement of geoelectrical methods used in mines. Report for the Mining Company Mecsek, GGRI, Sopron