

# DIPOLE – DIPOLE ARRAY CONFIGURATION IN THE FRAMEWORK OF THE RECIPROCITY PRINCIPLE

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## Abstract

The dipole-dipole array configuration is considered as a symmetrical array in terms of the reciprocity principle. This paper, however, demonstrates cases when the IP/Resistivity anomaly configurations observed with a  $C_1C_2$ - $P_1P_2$  (AB-MN) array is not the same as the one observed with a  $P_1P_2$ - $C_1C_2$  (MN-AB) reversed array. The analysis includes results of some 2D and 3D mathematical and physical modeling performed in the Institute of Informatics and Applied Mathematics, and in the "Ligor Lubonja" Laboratory of Geophysics at the Faculty of Geology and Mining, Polytechnic University of Tirana, Albania.

**Key words:** Dipole-dipole array, Reciprocity Principle, IP anomaly, Apparent resistivity anomaly.

## Introduction

In the practice of electrical prospecting are employed various array configurations. The location of the current and potential electrodes is defined from the geological tasks to be solved. The dipole – dipole array is one of the most common arrays in mineral exploration. This is considered a symmetrical array in terms of the principle of reciprocity, so when the current electrodes are respectively switched with potential electrodes the same responses in IP and resistivity values are observed. However, our recent mathematical and scale models indicate discrepancies in this regard in several cases. This can lead to inaccurate target location and negative drilling results. To avoid such situations, the electrode orientation in the survey line has to be considered in the interpretation.

## Presentation of the problem

The well-known reciprocity principle stands on the basis of many array configurations in electrical prospecting like Pole - Pole, Dipole - Dipole, Schlumberger, Wenner etc (Keller and Frischknecht 1966, Zabarovsky 1943, 1963, Frasher et al. 1985). "According to the theorem of the reciprocity, no changes will be observed in the measured voltage if the placements of potential and current electrodes are interchanged. The reciprocity can readily be confirmed for an electrode array over a homogeneous earth" (Keller and Frischknecht 1966).

The heterogeneous medium presents a more complicated problem. Zabarovsky (1943, 1963) based on the electrostatic phenomena science has been observed:

$$U_M = U_A = \alpha_{AM} \cdot Q_A = \alpha_{MA} \cdot Q_M$$

Where:  $Q_A, Q_M$  - Electrical charges

$\alpha_{AM}$  ,  $\alpha_{MA}$  - Coefficients dependant on the shape of bodies A and M, their reciprocal position and the boundaries of heterogeneity.

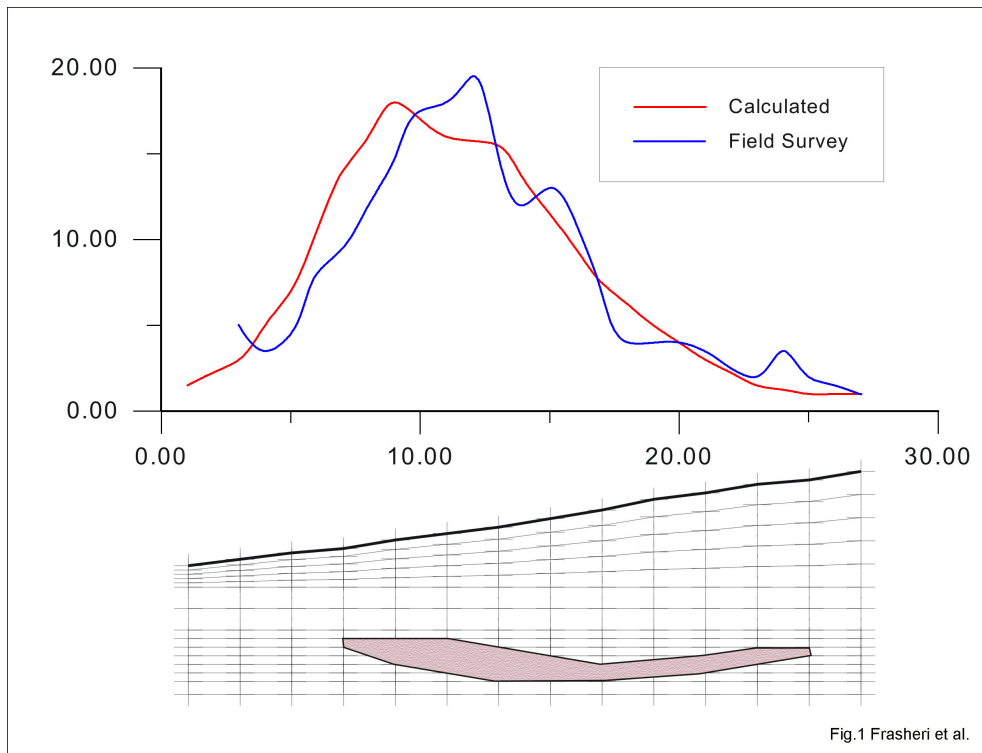
and equation  $Q_M=Q_A$  will be true if coefficients  $\alpha_{AM} = \alpha_{MA}$ . On this basis Zabarovsky (1943, 1963) has accepted that the principle of reciprocity is valid for heterogeneous media as well. Habberjam, G.M. (1967), doubt has been expressed about the validity of the reciprocity principle, from field experiments. Reciprocity principle has been discussed by Parasnis D.S. (1988), which has been observed: "Although the reciprocity theorem is often mentioned in books and papers on d.c. resistivity prospecting as well as in books on applied geophysics, no proof of it arbitrary conductivity distribution has, to the best of my knowledge, been given in geophysical literature". For vertical targets of thickness  $d > a$  ( $a$  stands for dipole spacing) the principle of reciprocity is met while for  $d$  comparable and thinner than  $a$ , the asymmetry is noticed in intensity and shape of the twin responses (Keller and Frischknecht 1966, Frasher et al 1985).

In homogeneous or linear media, as example 2D horizontally stratified section the principle of reciprocity is true for any surveying array. In a heterogeneous environment this principle is absolutely true for symmetrical four electrodes Schlumberger, Wenner and pole-pole (half-Wenner) arrays.

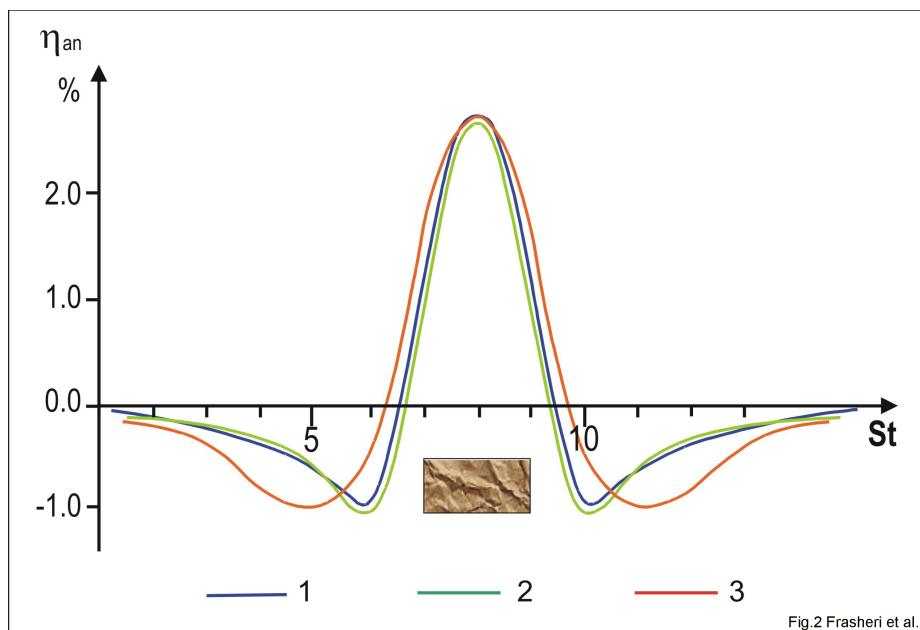
The dipole-dipole array presents a complex behavior. In IP method the principle of reciprocity application is more complicated. In several field surveys asymmetrical IP/Resistivity responses are observed with dipole – dipole array for opposite orientations of the potential and current electrodes in the survey line. To further investigate this phenomenon some mathematical models were carried out with a program of finite element method (Fraseri A. and Fraseri N. 2000). The mathematical computation of the IP effect is based on the Bleil 1953 and Seigel 1959 formulae. To perform the mathematical modeling and the inversion of IP data, we have used the Komarov's (1972) approach. For 3D modeling of IP effect from targets with massive texture in homogeneous medium we have transformed the Bleil formulae, using Green's formulae (Fraseri N. 1983, Fraseri A., Fraseri N. 2000). With the same method of finite elements, simultaneously with the IP effect, the apparent resistivity is calculated as well. Testing of the results of a mathematical IP models with a similar field situation and scale model indicates the accuracy of mathematical model is good (Fig. 1, 2) (Fraseri A. 1989, Fraseri A. et al. 1994, Fraseri A and Fraseri N, 2000).

### **Numerical results for different models**

Fig. 3 present the mathematical model results of IP and resistivity responses with dipole–dipole profiling. Two anomalies are observed on both parameters. Considering the reference plotting point in between the potential electrodes  $P_1$  and  $P_2$ , one of the anomalies is obtained over the prism while the second one at a distance  $O_1O_2$  , between the centers of the current and potential dipoles. This presentation is conditioned on the distribution of the electrical field of the dipole - dipole array. Because a mirror image is missing in the center of the profiles,



*Fig. 1. A finite element section of an IP irregular body over a rugged relief.*



*Fig. 2. IP profiling over a prism: Theoretical (1), calculated by POLARELF Program (2) and physical modeling (3).*

especially for IP, it means that  $C_1C_2P_1P_2$  array responses are not equivalent with  $P_1P_2C_1C_2$ , or in mathematical terms, the principle of reciprocity is not strictly met. Keller (1966) presents the same phenomenon for the apparent resistivity.

In pseudo section presentation, where the plotting point is located at the intersection of lines coming at  $45^\circ$  from midpoints between  $C_1C_2$  and  $P_1P_2$ , these anomalies are located in both sides of the prism (Fig. 4). For the resistivity parameter this location is almost symmetrical in shape and amplitude, for the vertical target (Fig. 3). The symmetry is perfect in cases when the thickness of the prism is equal or greater than the dipole spacing "a", and becomes poor for thinner prisms (Fig. 5).

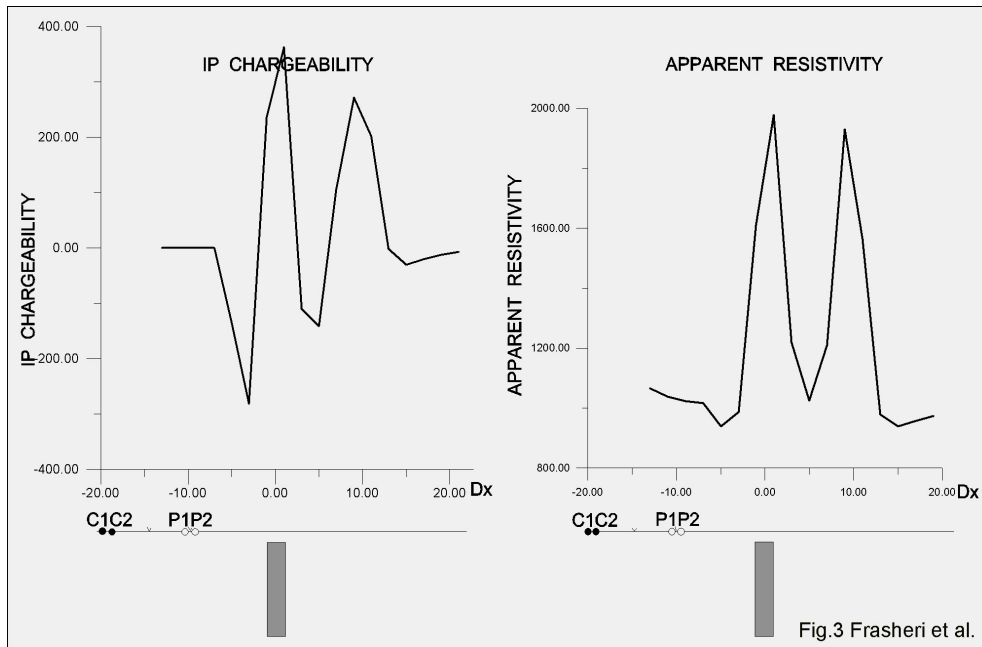


Fig. 3. IP and Resistivity mathematical modeling. Dipole-dipole profiling.  $C_1C_2$ - $P_1P_2=2 Dx$ ,  $n=1-10 Dx$ .

Model: 2D vertical prism at depth  $1 Dx$ , dimensions of the prism section  $2 x 9 Dx$ . Resistivity of the prism  $20,000 Ohmm$ , IP Chargeability  $500 mV/V$ , Resistivity of the environment  $1,000 Ohmm$ , IP Chargeability of the environment  $0.01 mV/V$ .

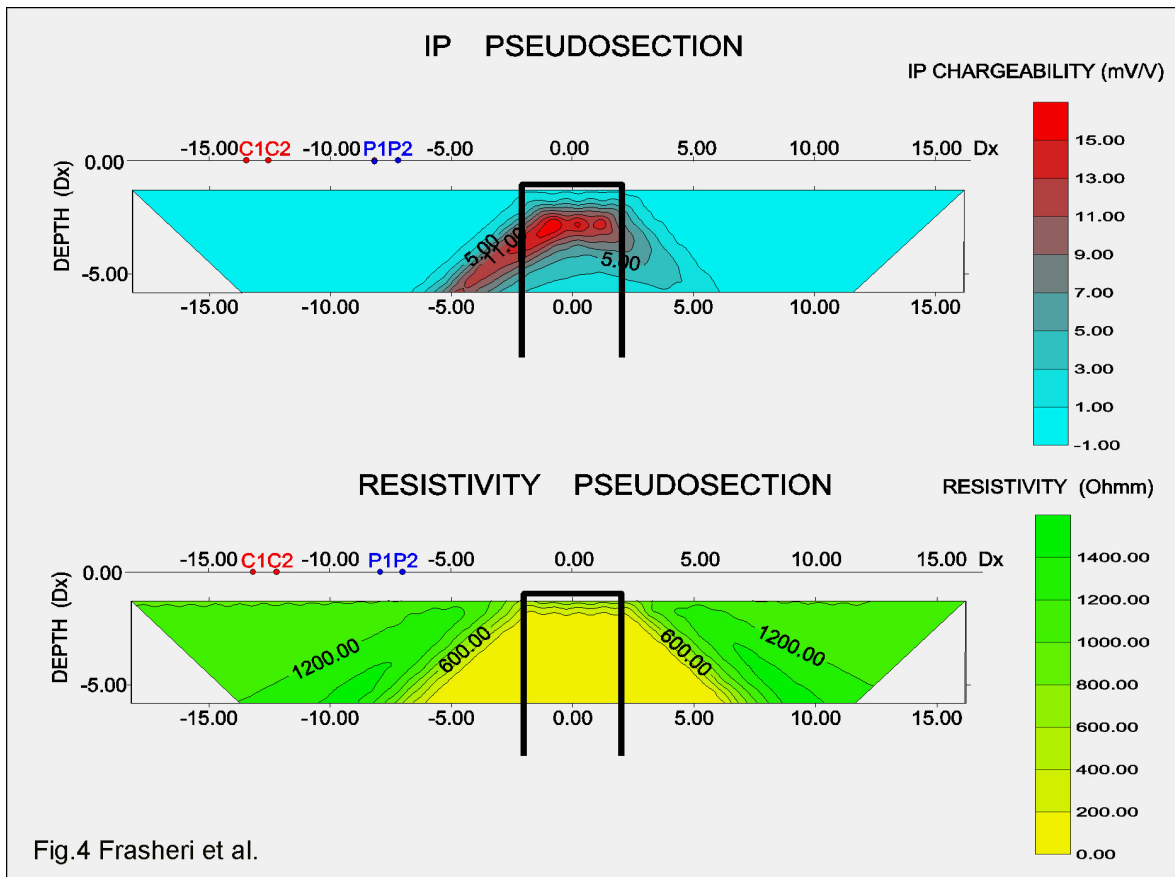


Fig.4 Frasher et al.

Fig. 4. IP and Resistivity Pseudo Section with dipole-dipole array.  $C_1C_2-P_1P_2=1 Dx$ ,  $n=1-11 Dx$ .

2D Mathematical model. Dimensions of the prism section  $1 \times 2 Dx$ .

Resistivity of the prism 1 Ohmm, IP Chargeability 300 mV/V, Resistivity of the environment 100 Ohmm, IP Chargeability of the environment 0.01 mV/V.

- a) vertical prism at depth 2 Dx,
- b) Inclined prism at depth 2 Dx, Western dip.
- c) Inclined prism at depth 2 Dx, Eastern dip.

Alternatively, the IP anomalies are asymmetrical even in cases of vertical prisms (Fig. 4-a). In such cases, the epicenter of the most intensive anomaly is displaced on the side of current dipole  $C_1C_2$ . For shallow inclined prisms, the epicenters of both IP and resistivity anomalies are displaced on the opposite side of the dip.

The configuration of the IP/Resistivity anomaly is also dependent on the dip angle amplitude, relative to the current electrodes location.

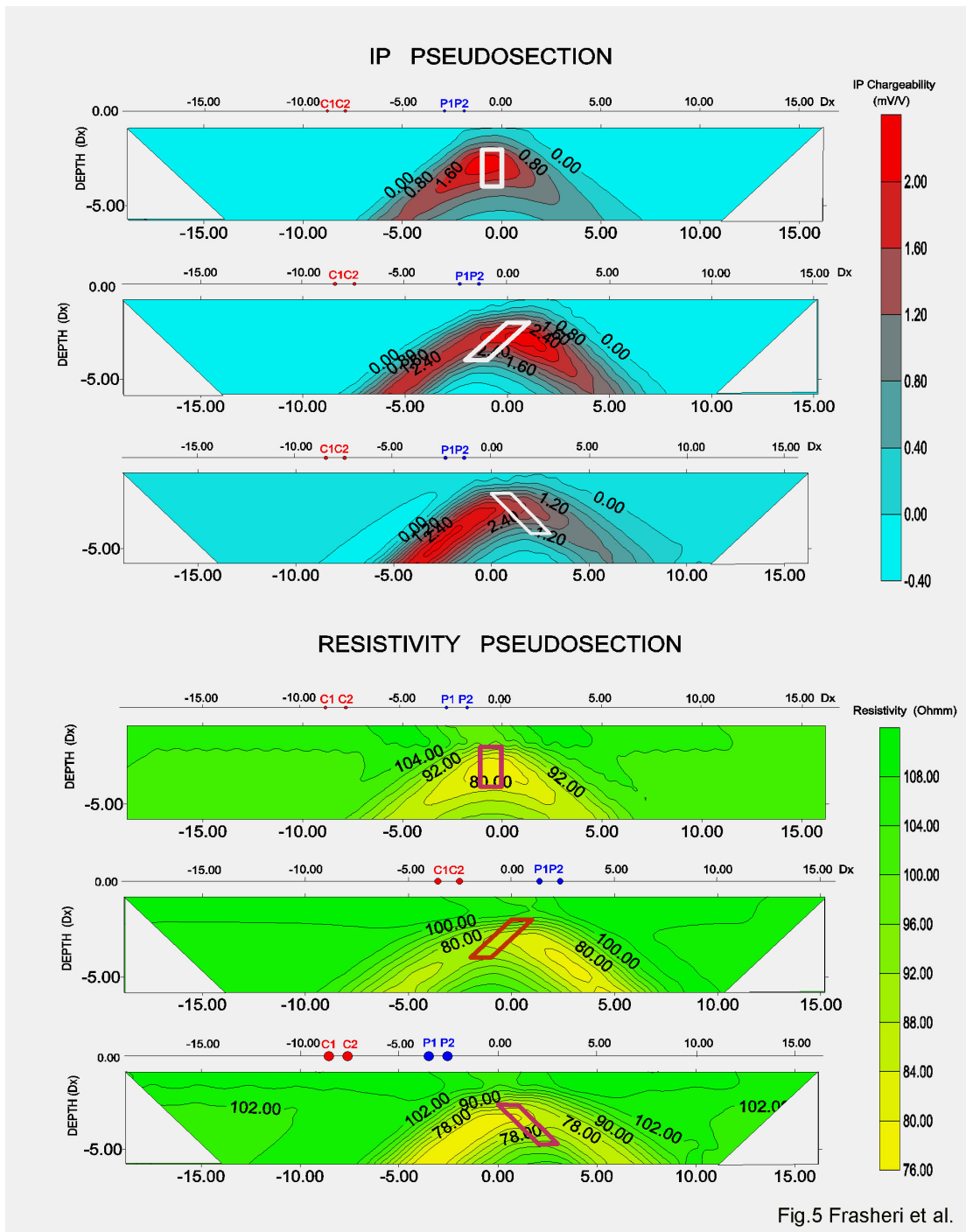
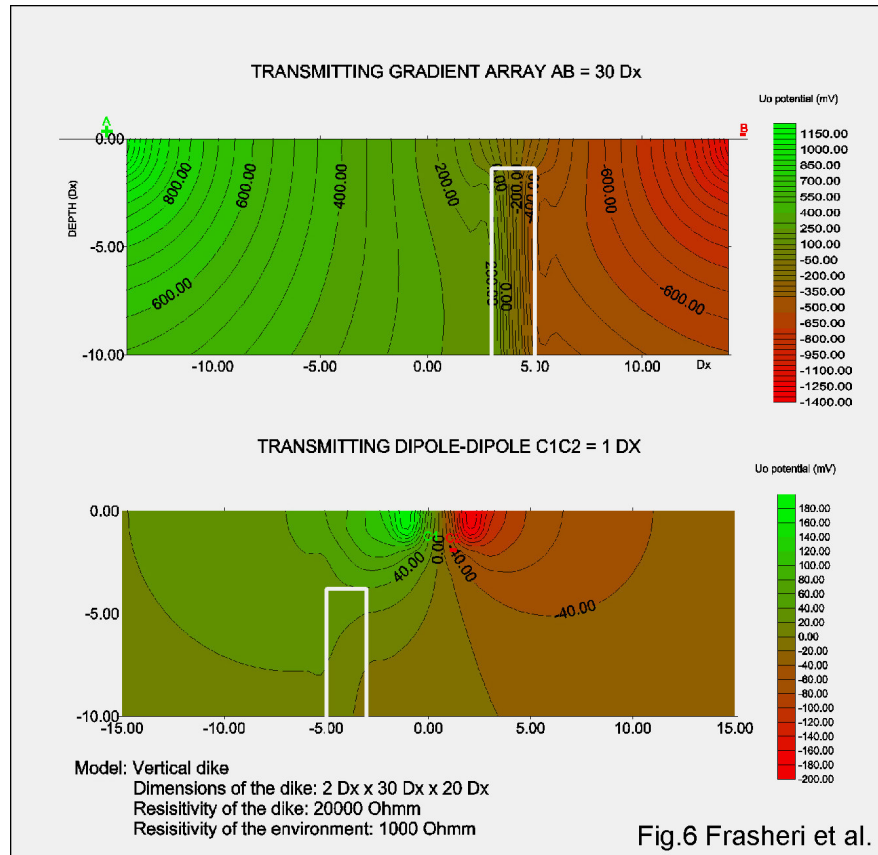


Fig.5 Frasheri et al.

Fig. 5. IP and Resistivity Pseudo Section with dipole-dipole array,  $C_1C_2-P_1P_2=1$  Dx,  $n=1-11$  Dx.

Mathematical model: 2D vertical prism at depth 1 Dx, dimensions of the prism section 4 x 50 Dx. Resistivity of the prism 3 Ohmm, IP Chargeability 50 mV/V, Resistivity of the environment 1,000 Ohmm, IP Chargeability of the environment 0.01 mV/V.

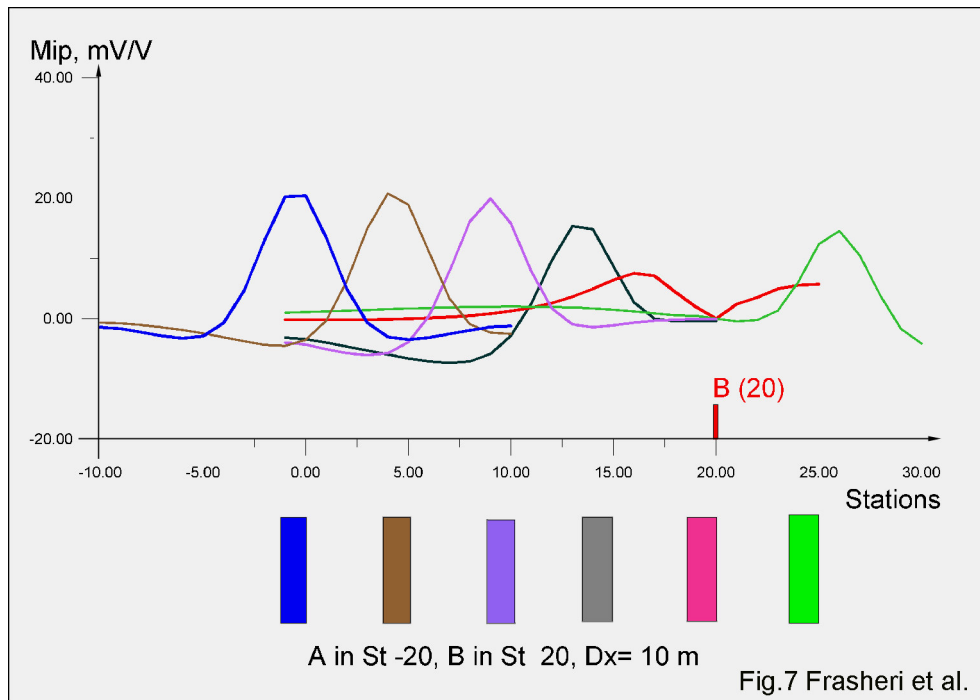
The amplitude and the asymmetry of IP anomaly depend on the orientation of the polarizing vector of the primary electric field in connection to the prism location (Figs. 6, 7). The substantial difference between the electric field distributions in both cases clearly expresses the changes in IP anomaly configurations for gradient and dipole-dipole arrays.



*Fig. 6. Distribution of the primary electric field potential ( $U_0$ ) of a transmitting dipole: Gradient array  $AB_{max} = 30 Dx$  Dipole-dipole array  $C_1C_2 = 1 Dx$ . Mathematical model: Vertical prism. Dimensions of the prism  $2 \times 30 \times 20 Dx$ , Resistivity of the prism 20,000 Ohmm, Resistivity of the environment 1,000 Ohmm.*

The response becomes more complicated when several targets are located under the surveying line. For a situation with two parallel polarizable inclined prisms like that in figs. 8-a, b, both  $C_1C_2P_1P_2$  and  $P_2P_1C_2C_1$  dipole-dipole arrays obtain a single IP anomaly in the center and present some differences in contours shape. A





*Fig. 7. IP anomaly configuration dependency on location of the target. Mathematical model: Vertical prism.*

formal interpretation or even an inversion on these results cannot outline the presence of two distinct targets. Our mathematical model with IP Realsection array (Alikaj 1981, Langore, Alikaj and Gjovreku 1989, Lubonja, Frasher and Alikaj 1994) over the same targets, however, provides a different picture with two distinct anomalies (fig. 8-c).

Asymmetrical IP and resistivity anomalies, depending on the location of current and potential dipoles in relation to target is not always without problems in manual or inversion interpretations of the IP/Resistivity data surveyed with a dipole–dipole array.

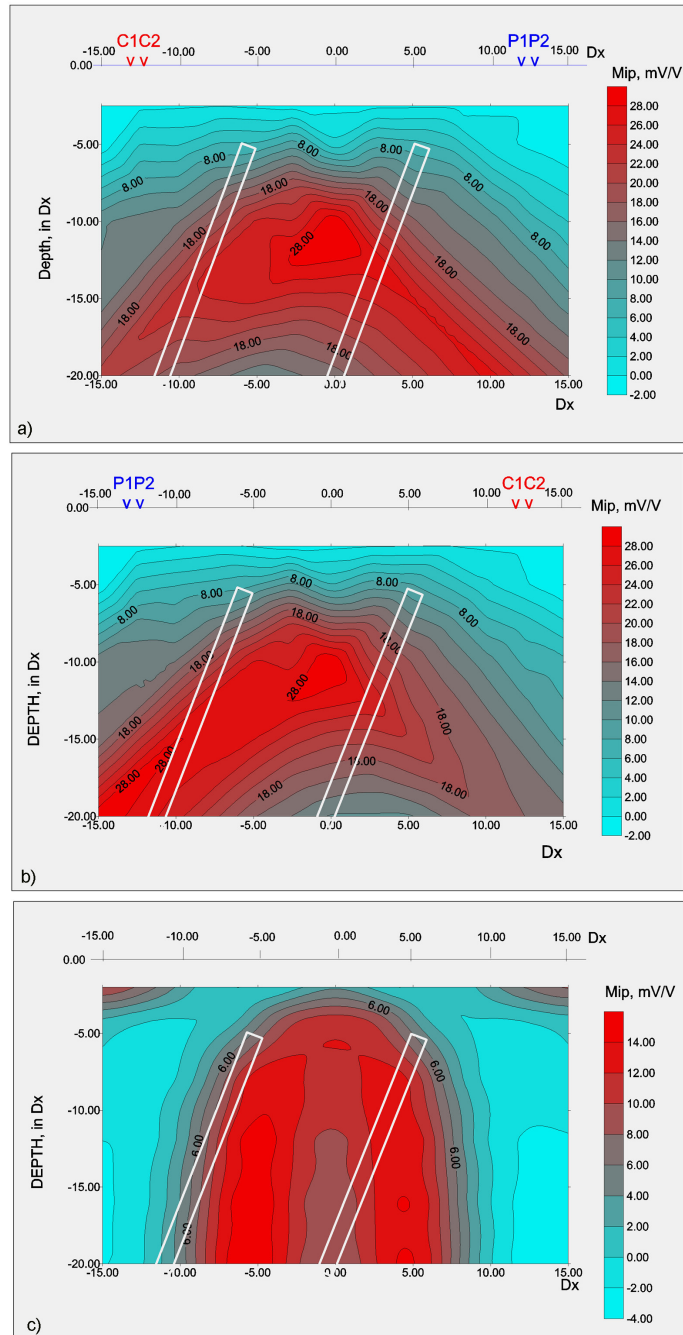


Fig.8 Frasher et al.

Fig. 8. IP Pseudo Section with dipole-dipole array,  $C_1C_2=P_1P_2=1$  Dx,  $n=1-39$ .

Mathematical Model: Two parallel inclined prisms ( $dip=70^\circ$ ) at depth 5 Dx, dimensions of the prisms  $1 \times 20 \times 20$  Dx. Distance between the prisms 10 Dx, Resistivity of prisms 2000 Ohmm, IP Chargeability 500 mV/V, Environment: Resistivity 500 Ohmm, IP Chargeability 0.01 mV/V.

- a) Dipole-dipole  $C_1C_2=P_1P_2$ ,
- b) Dipole-dipole  $P_1P_2=C_1C_2$
- c) Real Section with multiple gradient arrays.

## **Conclusions**

1. The anomaly configuration in an IP/Resistivity survey with a dipole–dipole array is dependent on the location of the current and potential electrodes in connection to target. In this regard, logistical information about the survey should include the array orientation (left-array or right-array). The position of the array must be shown in plots and pseudosections. During the survey, it is necessary to keep the same orientation of current and receiving dipoles.
2. An accurate interpretation of IP/Resistivity data with dipole-dipole array should consider the information on electrode orientation on the survey line. The same recommendation is valid for the process of inversion interpretation.

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