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Full Length Research Paper

# Inversion Methodology for Induced Polarization Method of Geophysical Investigation

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## ABSTRACT

Over the years in both theoretical and exploration geophysics, concept of inversion of geophysical data has played an important role in the interpretation and understanding of geophysical investigation of the subsurface. This paper review the basic concepts involved in carrying out inversion on induced polarization (IP) data. The algorithm is based on the linearization of equation of IP response and the use of minimization of the corresponding objective function of the chargeability model subject to data constraints. Field example was considered where the inversion scheme was applied to measurements of chargeability in the time domain. Generated model was used to solve the resulting optimization problem defining a global objective function. Applying the algorithm, result from the application of the inversion scheme to Induced polarization data obtained from a suspected lead-zinc site in Benue state, Nigeria showed anomalous zones revealing possible mineralization having attributes of galena, sphalerite and pyrite with resistivity value range of between 100 - 300 ohm-m at an estimated depth of about 50m with an overburden thickness to the top of base-metal sulphide of about 30m.

Keywords: Induced polarization, subsurface, objective function, Inversion, chargeability and Linearization.

## INTRODUCTION

Induced polarization data are routinely acquired in mineral exploration and geotechnical and environmental problems. Geophysicist have long recognized the need for inverting their observed data to recover 1-D, 2-D, or 3-D images of the earth's physical properties. These images may directly or delineate the associated structure. Anyone using inversion algorithms, or interpreting resultant images must be familiar with the basic principles. The goal of this paper is to present these principles, discuss in details the essential elements of the inverse problem, and illustrate the technique through field examples.

It should be noted however that target detection is usually impossible using a single geophysical method, since identical geophysical anomalies maybe related to an anomaly source with different physical properties, mode of occurrence pattern and nature (Boris, 2005). Thus integration of geophysical methods is necessary in order to reveal and characterize hidden targets (a typical case is the example of the simultaneous measurement of induced polarization and resistivity data for better interpretation of observed anomalies). From the theoretical point of view, the development of integrated studies is more rational than the attempt to improve the precision of separate methods; two (sometimes three) geophysical methods are usually required for the detection of a desired target.

## **Background Theory**

Before tackling the inverse problem, it is important to be able to solve the forward problem which involves calculating the responses under the assumption that the sources and the earth model are known. Data from a geophysical investigation can be generically written as,

$$F_j(m) = d_j^{obs} \equiv d_j + n_j \qquad j = 1, \dots, N$$

Where  $F_j$  is a forward modeling operator that incorporates details of the survey design and the relevant physical equations, m is a generic symbol for a physical property distribution, and the right hand side represents the observed datum  $d_j^{obs}$  which consist of the true datum  $d_j$  plus additive noise  $n_j$ . F comes in a variety of forms, but most often it is an integral or differential operator, and the resultant equations must be solved numerically.

A typical inversion problem is its non-uniqueness nature (Aiken et al., 1973; Dwain,2005) i.e the observed data provide N – inaccurate constraints upon the earth model and there are infinitely many models that acceptably fit those data. To find a particular solution, we need some way of further evaluating each of these models so that we can distinguish between them. Since inversion is carried out by solving the equation:

$$\phi(m) = \varphi_d + \beta \varphi_m$$

......2

Where  $\phi(m)$  is a model function,  $\phi_d$  the data misfit and 0<\beta<  $\infty$ 

is a constant known as regularization parameter controlling the relative weighting between  $\phi_m$  and  $\phi_d$ . Introducing a model objective function suitable as an example for solving the 2D problems:

$$\varphi_m(m,m_o) = \alpha_s \int_s (m-m_o)^2 dx dy + \alpha_s \int_s \left(\frac{\partial m}{\partial x}\right)^2 \frac{\partial m}{\partial x}^2 dx dy + \alpha_z \int_s \left(\frac{\partial m}{\partial z}\right)^2 dx dy$$

Inversion of induced polarization data problem can either be linear or non – linear. Although the complete IP problem is non – linear, for many cases of practical interest, the chargeability  $\eta$  is small and a linearization of IP data equations is discussed in Ajani, et al., 2006. For easy analysis, we assume that the Earth model has been cellularized and that the chargeability for the K<sup>th</sup> cell is n<sub>k</sub>. The data, referred to as apparent chargeability, are expressed as

$$\eta_{aj} = \sum_{k=1}^{M} J_{jk} \eta_k$$

where j = 1, ...., N ......4

The apparent chargeabilities can be dimensionless as in Seigel's (1959) definition, or have units of ms, mrad, or Percentage Frequency Effect (PFE) depending on the system with which they are acquired (Oldenburg and Li, 1994). The matrix elements  $J_{jk}$  are the sensitivities for IP data, The matrix elements  $J_{jk}$  are the sensitivities for the IP data, and they depend upon the electrode geometry used for the acquiring data and on the electrical conductivity. The conductivity is usually estimated by inverting DC resistivity data acquired at the same time as the IP data. Typical application to field work is extracted from previous work carried out by Ajani et al., 2010, where IP method was used in the investigation of sulphide mineralization in Osina area of Benue state. Nigeria.

### Application to Field data

The developed inversion scheme is applied in the interpretation of resistivity and Induced polarization data and its reliability and clarity (Oldenburg, 1994) is satisfactory. Applying it to present work, the method and resulting results are discussed below.

### METHODOLOGY

Inversion programs have recently become available that allows a more definitive interpretation, although the process remains subjective. The purpose of the inversion process is to convert surface IP/Resistivity measurements into a more realistic 'interpreted depth section'. The use of the inversion routine is a subjective one because the input into the inversion routine calls for a number of user selectable variables whose adjustment can greatly influence the output (Fiadaca et al., 2012). The output from the inversion routine assist in providing a more reliable interpretation of IP/Resistivity data.

Typical field application is extracted from previous work carried out by Ajani et al., 2010, using induced polarization method in the investigation of sulphide mineralization in Benue state. Nigeria.

The inversion programs used here (figures 1, 2 and 3) is applied iteratively to achieve the following:

- Evaluate the output with regards to what is geologically known
- To estimate the depth of detection, and



**Figure 1**. Pseudo section for measured app. Resistivity, calculated app. Resistivity and inverse model resistivity section

• To determine the viability of specific measurements.

The inversion program used for this work is the RES2DINV program. The DC potentials are first inverted to recover the special distribution of electrical resistivities, and secondly, the chargeability data (IP) are inverted to recover the spatial distribution of IP polarizable particles in the rocks.

The interpreted Depth section maps represent the cross sectional distribution of polarizable materials, in the case of IP effect, and the cross sectional distribution of apparent resistivities, in the case of the resistivity parameter.

The 2-D model used by this program divides the subsurface into a number of rectangular blocks. The purpose is to determine the resistivity of the rectangular blocks that will produce an apparent resistivity pseudo section that agrees with the actual measurements. For the dipole – dipole array used, the thickness was set to about 0.9, 0.3, and 0.6 times the electrode spacing. 10-25% normally increases the thickness of each subsequent deeper layer. The individual can also change the dept of the layers manually. The method basically tries to reduce the difference between the calculated and measured apparent resistivity values by adjusting the resistivity of the model blocks. A measure of this difference is given by the root-mean- square (RMS) error.

### RESULT

From the apparent resistivity plots shown in Figure 1 above, variation in the magnitude of the apparent resistivity highlighting anomalous area along the traverses is noticeable over the distances of between 80-120 m. Consequently, since the region of high



Figure 2. Pseudo section for measured chargeability, calculated chargeability and inverse model chargeability

chargeability shown from the plot in Figure 2 corresponds to the region observed for low resistivity Figure 1 along the traverse, then this area of distinct anomaly exhibiting the expected characteristics of region containing massive sulphide can be mapped out as possible area of disseminated sulphide ore. Since it is equally important to know in addition to the likely spread of the disseminated sulphide the possible depth of investigation (DOI),(White, et al.,2003). Figure 3 shows the interpreted depth section for the apparent resistivity, a high resistivity unit is observed on the south western and south eastern portion of this line; this zone appear to have a considerable depth extent and are likely a discrete geological unit. This anomalous zone appears to dip steeply to the south west. The estimated depth of this zone lies between 40-80 m. It should be noted however that the pseudo-section is not conclusive for localization of the body because the pseudo-plot





Figure 3. Display of inverse model resistivity section and inverse model chargeability section.

shows that the type of resistivity here is bulk, which is due to the disseminated nature of sulfides currently under investigation.

As shown also in Figure 3, the corresponding interpreted depth section for the apparent chargeability shows prominent anomalous zone at the center of the line forming a south-eastern dipping zone approximately 40 m wide and about 30 m thick. Because this zone opens at the bottom, its thickness is not conclusive, but the body can be said to lie at an estimated depth of 50 m from the surface. This anomaly coincides with a fairly localized low resistivity zone as seen in Figure 1. The low resistivity surface layer across the line indicates that these responses are all at or very near the surface and could be reflecting highly variable overburden.

Measurement for the percentage frequency effect (PFE) as fully discussed on sulphide mineralization investigation in the paper by Ajani et al.,(2010)was computed for the traverse data at 0.3Hz and 3Hz in order to identify possible type of sulphide mineralization in the study area. The relatively high value (between 3 - 6 PFE) obtained over 80 - 200 m distance along the line shows the proximity of more polarizable well connected and conductive disseminated ore localized in this area. The

observed PFE values are indicative of very conductive sulphide – rich rocks.

#### CONCLUSION

From the brief discussion using the field example involving the use of the IP method of geophysical investigation, it is noticeable that a good inversion method must simultaneously minimize the effects of data error and model parameter errors. The necessary requirements for inversion of any geophysical data set are a fast forward algorithm for calculating theoretical data from input model parameters, and a technique for calculating derivatives of the data with respect to the model parameter.

Consequently, from the apparent resistivity pseudoplots, variation in the magnitude of the apparent resistivity highlighting anomalous area along the traverses was noticeable over the distances of between 80-120 m. The pseudosection plots shows three anomalous zones revealing certain deposited minerals having the attributes and properties of sulphide minerals with an average thickness of 25 m and at an average depth of 40 m. Three linear zones via those of the western and eastern direction were interesting for further detailed investigation. However, the third central geophysical anomalous zone corresponding to those of the southern part of the study area were regarded as non-significant anomalies which may be due to discarded slag from the current mining activities for barite and gypsum going on in the area.

Conclusively, the sulphide target was quite clear with the chargeability pseudo-plots at an estimated depth of between 40-80 m and a horizontal spread of about 300 m. The quantitative interpretation showed that the range of overburden thickness to the top of base-metal sulphide is about 30 m. With the result from the investigation carried out, it was concluded that the sulphide ore in this area was not economically viable and can be best mined through shafts or tunnels due to the depth and dipping shape of the deposit.

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