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APPLICATION OF INDUCED POLARIZATION METHOD TO DELINEATE SULPHIDE ORE DEPOSIT IN OSINA AREA OF BENUE STATE, NIGERIA*

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Abstract

The occurrence of sulphide ore bodies in Osina area of Benue state has been reported earlier in the geology of Nigeria map, but the extent and abundance of the mineral was not known. In this work, we investigated the thickness and depth of the mineral deposit.

Ground Induced Polarization (GIP) survey employing the dipole-dipole array was conducted. The survey consisted of three lines, each of length 600 m with a dipole separation of 30 m in the E-W direction covering an area of approximately 1 km^2. A total of 150 data points were taken in the survey area. Measurements were taken for chargeability in the time domain and Percentage Frequency Effect (PFE) in the frequency domain. Using an iterative process, an inversion scheme was carried out on the measured data to find a model M that minimizes the objective function ö$_m$ subject to fitting the data to a specified degree. This model was formed and used to solve the optimization problem defining a global objective function Ö. Measured data obtained from the field work and theoretical data derived from the model recovered by inverting the data set were also plotted as pseudo-sections to get the estimated depth of the ore deposit from the surface.

The results showed eight anomalous zones revealing certain mineralization having attributes of galena, sphalerite and pyrite with a resistivity ranging from 100-300 ohm-m at an estimated depth of 50 m. The plots of chargeability along the three traverse lines also showed a consistent range of values between 20-90 mV/V over the distance of 90-100 m along the lines. Different regions of high anomaly are evident in the inverse model resistivity section for the first two lines but due to bulk resistivity of the disseminated body investigated, no distinct zone could be localized. The quantitative interpretation showed that the range of overburden thickness to the top of base-metal sulphide is about 30 m.

Based on the result of this investigation, it was concluded that the sulphide ore in this area is not economically viable and can be best mined through shafts or tunnels due to the depth and dipping shape of the deposit.

Key words: Sulphide ore bodies, Osina area, induced polarization, chargeability,

1. Introduction

Disseminated sulphide minerals are types of metal / sulphur compounds, which contribute the single most important group of ore minerals. Although several hundreds of sulphide minerals are known, the most abundant members of this group are pyrites, pyrhotite, chalcolite, galena, sphalerite and the group of copper sulphides minerals.

The origin of the Benue trough leads to an expectation of finding certain types of mineral deposits of possible economic significance. Some of these are already known, at least as occurrences, while others have been inferred from indications that are not always conclusive in their interpretations. As at present, sulphides of zinc and lead, locally associated with smaller quantities of copper, occur in lodes and veins infilling open fractures in the sedimentary formations in three main areas along the axial zone of the Benue trough. Lead sulphide (PbS) is the target ore for the present survey. It occurs naturally as galena which is a member of secondary minerals. Galena is won from many different types of metalliferous deposits but especially from carbonate (hosted base metal deposits) and massive sulphide deposit.

Bleil (1953) demonstrated the viability of Induced Polarization (IP) technique in subsurface exploration. He showed that polarization due to the presence of disseminated mineral deposit was measurable and interpretable in terms of subsurface properties. Summer (1978) highlighted the principles behind the use of induced polarization for geophysical exploration. Present survey and supporting geological work were planned with the following requirement in mind.

(i) Identification of potential area of likely ore deposit from previous geological report.

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(ii) Carry out induced polarization survey with a view to determining ore potential of the area.

2. Site Description

The surveyed area is located in the middle belt of Nigeria around Osina village in Oju local government area (Fig. 1a) covering a total surface area of approximately 2 km^2. It is situated between latitude 6°452 & 6°502 and longitude 8°452 & 8°482 E (Fig. 2).The survey area could be approached from the western end through a motor able road connecting Akure – Okene – Gboko and to Ogoja – Gboko in the south-eastern part. The relief is generally undulating and slopes moderately to the south. However, the western and eastern sides are characterized by ridges and inselberg topography ranging from 750 m to 1050 m above sea level. The streams are seasonal and southward flowing. They cut deep valleys as they are apparently controlled by the structure and lithology of the underlying bedrock. Hence, a trellis drainage pattern has been developed on the geology.

Vegetation ranges in character from deciduous to woodland savanna; thick vegetation is observed along the banks of the streams. TIV farmers and cattle Fulani's inhabit this area in small villages and hamlets. At present, some illegal mining activities are going on for barite in the area.

3. Geological Setting

The Benue Trough is an 800 km long and 100-150 km wide NE trending elongated sediment-fill intracontinental rift (aulacogen) formed during the Early Cretaceous. Sedimentation, characterized by periods of transgression and regression, started in the pre-Albian with deposition of the Asu River Group followed by later Cretaceous sediments up to Maastrichtian (Fig. 1). Detail works on the evolution as well as stratigraphic setting of the Benue Trough could be found in Reyment, 1965; Offodile, 1976; Nwachukwu, 1972; Wright, 1976; Ofoegbu, 1984 and Benkhelil, 1986 among others.

The bedrock consists of the Turonian Eze-Aku Group (a highly fissile shale sequence with intercalations of sandstones/limestones with thickness of about 100-300 m in places (Mbipom *et al.*, 1990). The Eze-Aku Group is underlain by a 2000 m thick sequence of the Albian Asu-River Group (shales, siltstone, sandstones & pyroclastic). Like in the main part of the Trough, the Albian sediments (Asu-River Group) were deformed during the Cenomanian tectonic episode (Nwachukwu, 1972), while the extensive Santonian deformation affected both the Albian to Turonian sediments (Olade and Morton, 1980). The well developed folds and NE-SW and N-S trending fracture systems are the imprints of this tectonic episode. These fracture systems are not only hosts for the lead-zinc and fluorite-barite mineralization in the Benue Trough (Akande *et al.*, 1992), but also serves as conduits (media) for brines.

4. Theoretical Background

The IP method employed here is an extension of the resistivity method which involves making an additional measurement of the ability of the ground to store electric charge analogous to action of a capacitor (Vinegar and Waxman, 1984). Conventional measures of the polarization can be in either the frequency domain or time domain. In the frequency domain, measurements are taken and computed for the Percentage Frequency Effect (PFE) expressed as

$$PFE = \frac{100(\rho_{ao} - \rho_{a1})}{\rho_{a1}} \qquad (1)$$

where ñ$_{ao}$ and ñ$_{a1}$ are the apparent resistivities at low and higher frequencies (ñ$_{ao}$ > ñ$_{a1}$). Marshall and Madden (1959) modified the expression for PFE to produce Metal Factor (MF) expressed as

$$MF = \frac{A.FE}{\rho_{ao}} \qquad (2)$$

where FE is the frequency effect and A is the topography factor.

In the time domain, most commonly used is the chargeability (M) measured in mV/V. It is expressed as

$$M = \frac{V_p}{V_o} \qquad (3)$$

where V_p is the over-voltage at time t and V_o the observed voltage with an applied current. However, according to Renoynolds (1997), because of the difficulty involved in the measure of Vp at the moment the current is switched off, it is measured at a fixed time after cut-off and this gives rise to apparent chargeability defined as

$$M_a = \frac{1}{V_o}\int V_p(t)dt \qquad (4)$$

where $V_p(t)$ is the over-voltage at time t, and other terms as earlier defined.

The polar dipole-dipole electrode configuration is the most popular array for frequency-domain induced polarization (IP) measurements. The usual field procedure is to make a series of measurements with a fixed dipole length a, the dipole being separated by a variable integral number of dipole lengths *n*a (Fig. 3). Since the larger n-values are associated with greater depths of investigation, the data can be arranged in a 2-D or 3-D pseudosection plot which gives a simultaneous display of both horizontal and vertical variations in apparent resistivity (or percentage frequency effect PFE, or metal factor). The conventional presentation, introduced (and currently in use) by Hallof (1957), places each measured value at the intersection of two 45-degree lines through the centers of the dipole (Fig. 4). Each horizontal data line is then associated with specific value of *n* and by implication, with a given effective depth of investigation. The result is a qualitative picture of vertical changes in apparent resistivity.

For detailed work, the measurements are repeated using smaller dipole lengths, yielding different pseudosections. The term pseudosection recognizes that the plot is not to be viewed as assigning the data to these definite points in the vertical geologic section. The pattern of apparent resistivity associated with a given subsurface structure is complex, and in most cases does not correspond to the distribution of true resistivity.

An induced polarization survey is carried out by passing current through the ground between two electrodes (Fig.3), and measuring the potential difference between two other electrodes. Measurements at two frequencies (for frequency domain) or measurements of voltage decay (for time domain), indicate the extent of polarizability of the ground. Thus, computation of Induced polarization anomalies involves determining the potential distribution about point sources and sinks of current (electrodes) placed in a model of the ground.

Frequencies used in surveys are low enough that induction is usually negligible. Polarizable rock, which may be represented by a circuit containing resistive, capacitive and impedance components (Ward *et al.*, 1995; Slater and Lesmes, 2002), appears chiefly resistive at a given frequency, although the local impedance changes with frequency. The polarization effect may be approximated by simply assigning, two resistivities, corresponding to two "frequencies" to polarizable material.

Direct current in conductive material is distributed so that the power dissipated is minimized. For a close volume, free sources, this minimization principle may be written (Fransheri and Fransheri, 2000) as:

$$\Delta\Phi_f = \Delta\int J.Edv = 0 \qquad (5)$$

where Äö$_f$ is the variation of the power, E is the electric field intensity and J the current density. If there are sources, the power includes the contribution from the source current density Js:

$$\Phi_s = \int_v 2J_s.Edv \qquad (6)$$

For linear isotropic material, a scalar conductivity function relates current and electric field. The general variational equation for direct current flow, in terms of electric potential is thus:

$$\Delta\Phi_T = \Delta(\Phi_f - \Phi_s) = \Delta\int_v \left[\sigma(\Delta\Phi)^2 - 2J_s\nabla\Phi\right]dv = 0 \qquad (7)$$

This equation leads to poisson's differential equation, which is the basis for most methods of calculating potential distributions. However, the finite element method to be used here start directly from the variational equation.

Many useful geologic models can be represented by structures of uniform cross-section. Mathematically such a structure is described by a conductivity function depending only on x (horizontal coordinate normal to strike), and t (vertical coordinate, positive down). If sources are restricted to the x-z plane, the potentials will be symmetric about this plane, and the dependence y (strike coordinate) may be transformed (Coggon, 1973):

$$\Phi(x,k,t) = \int_0^\infty \Phi(x,y,t)\cos(ky)dy \qquad (8)$$

The variational equation in (x, k, z) space equivalent to (7) is:

$$\Delta\iint\left(\sigma\left[\frac{d\Phi}{dx}\right]^2 + K^2\Phi^2 + \left[\frac{d\Phi}{dt}\right]^2 + 2I\delta(x-x')\delta(z-z')\Phi\right)dxdt = 0 \qquad (9)$$

where Φ is a function of x, k, t and there is a point source at (x, o, z). The potential must be found for several values of **k** so that the inverse Fourier transform can be carried out.

Theoretical induced polarization anomalies presented here are based on numerical solutions to equation (8). A desired geological model is represented as a cross-section of regions of various resistivities. Polarizable regions are assigned two resistivities one higher ("low frequency" value) and one lower ("higher frequency" value). The potential distributions about suitable sources are computed by the finite element method, transformed, and converted to apparent resistivity, chargeability, percent frequency effect and metal conduction factor (as defined above) for the desired electrode array.

5. Field Work and Data Analysis

The field work consisted of running induced polarization survey over suspected galena sites, which was giving an insight to by the geological map of Nigeria (1990). The survey was limited to three traverses cut through an approximated area of about 1 km^2 (Fig.1b). In carrying out this investigation, ABEM 1000 resistivity meter was utilized. A double dipole array was used with a dipole separation of 30 m. For ordinary self- potential (SP) data, the level of interpretation is to approximate the shape of the ore body to one of known geometry, usually a sphere or an inclined rod, with an assumed direction of polarization. The direct or forward approach is to calculate the corresponding electrical potential for the model and to compare the synthetic anomaly with that observed. Since for this study, the target is a disseminated ore, which does not conform to a given

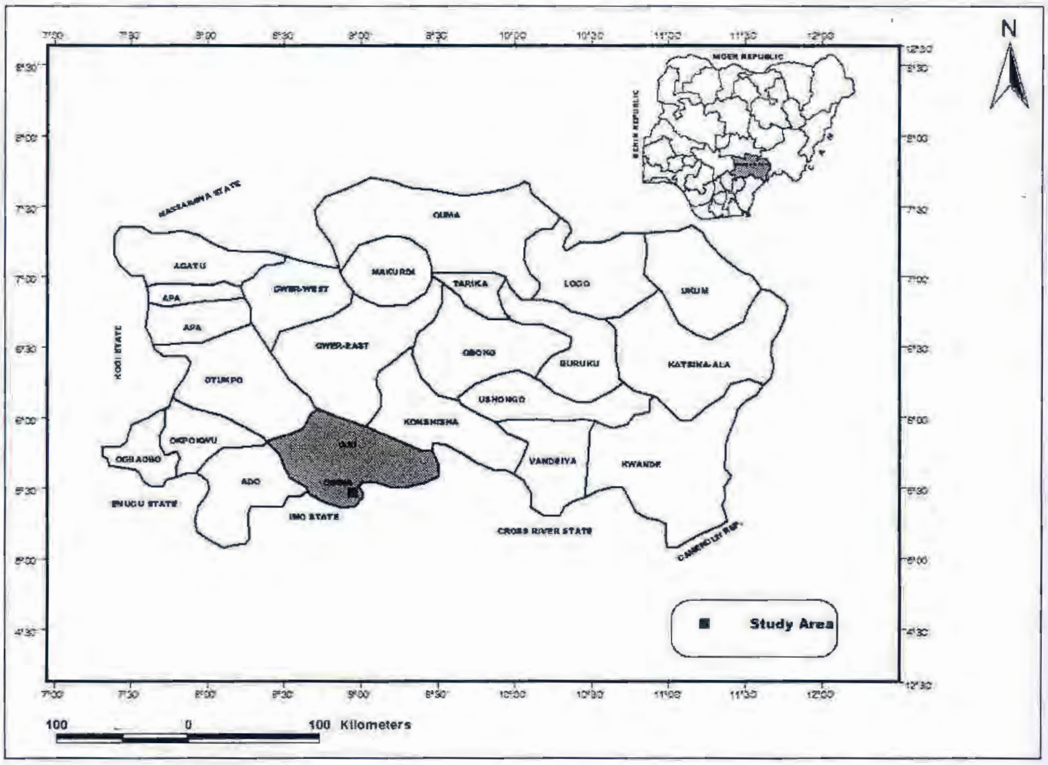


Fig. 1: Map of Benue state showing study area (Osina) in Oju local Government area (Inset shows location of Benue state)

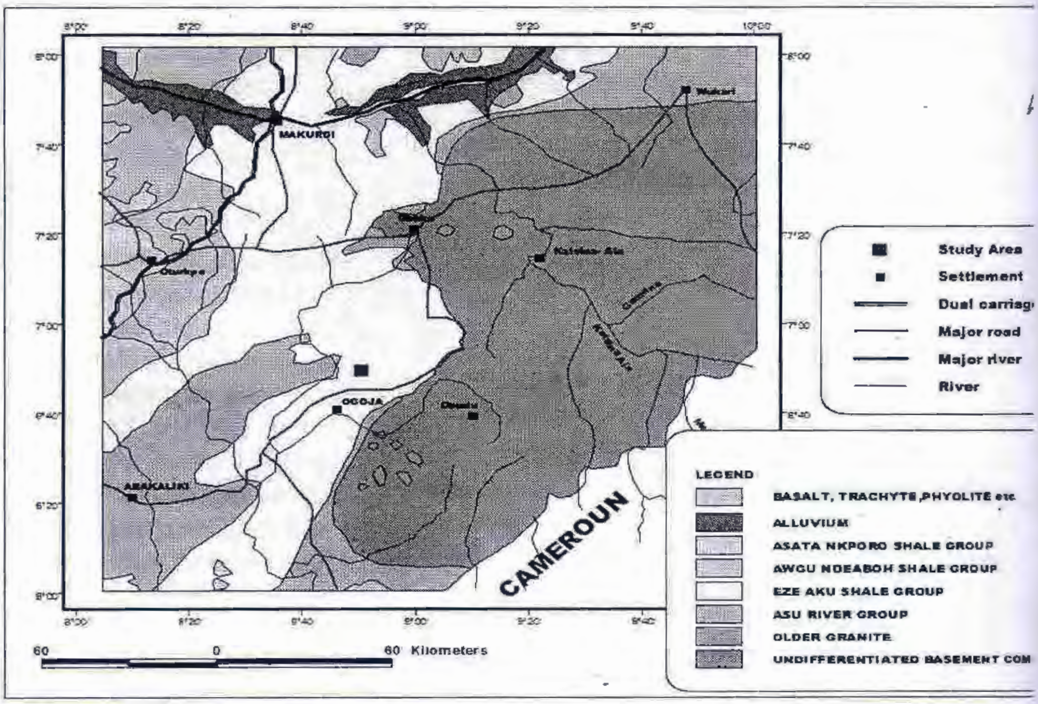


Fig. 2: Geological map of the study area.

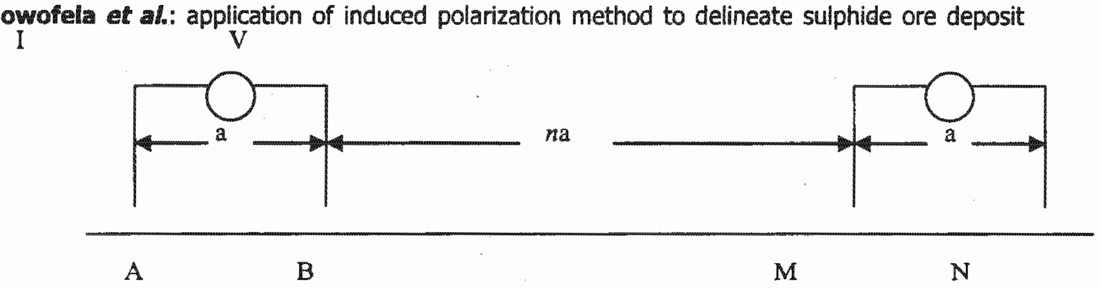
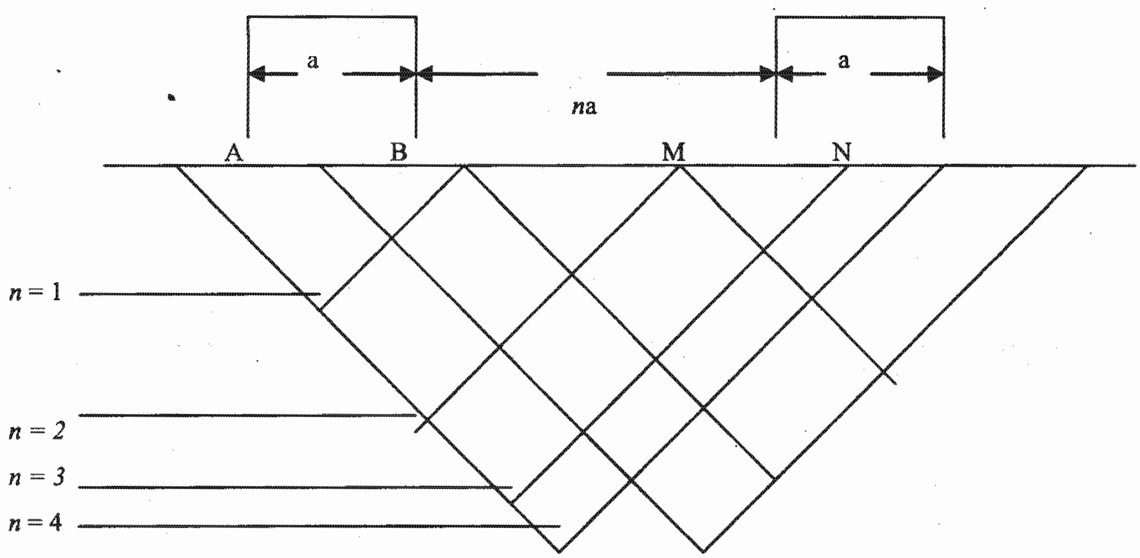


Fig. 3: Dipole –dipole array



A and B are the current electrodes, M and N are the potential electrodes, a is the electrode spacing

Fig. 4: Convectional dipole-dipole pseudo-section plot.

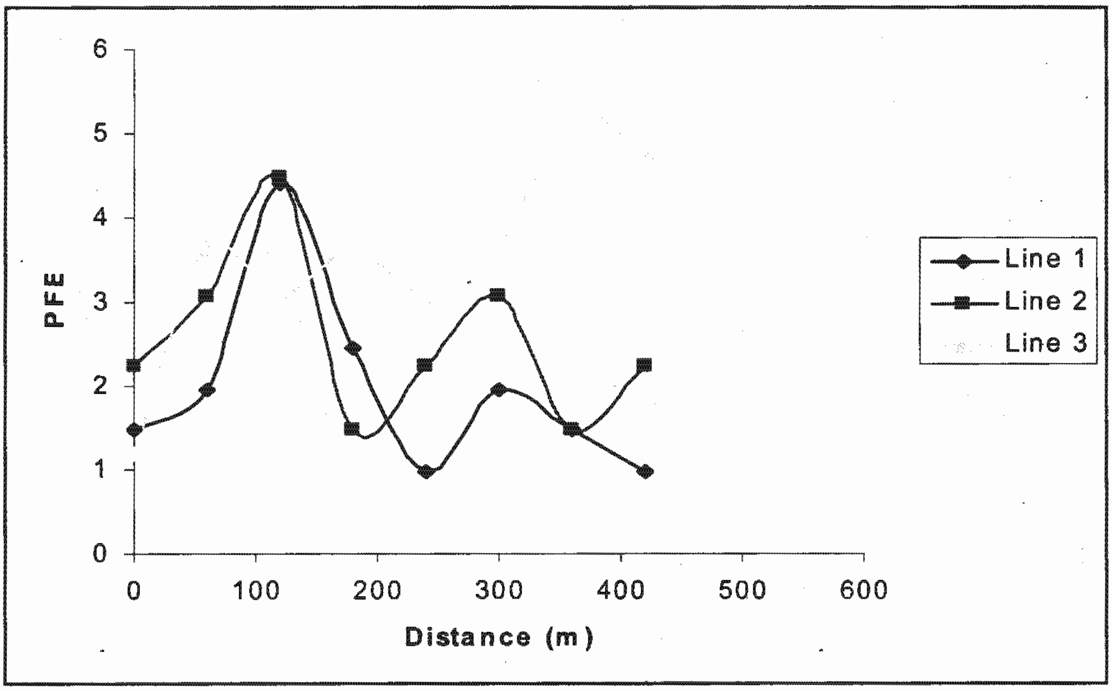


Fig. 5a: Plot of Percentage frequency effect at 0.3 Hz for the lines

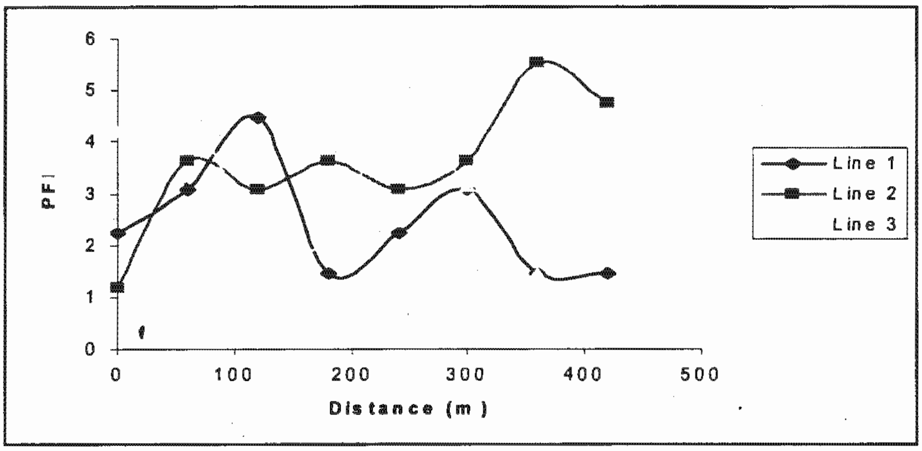


Fig. 5b: Plot of Percentage frequency effect at 3 Hz for the lines

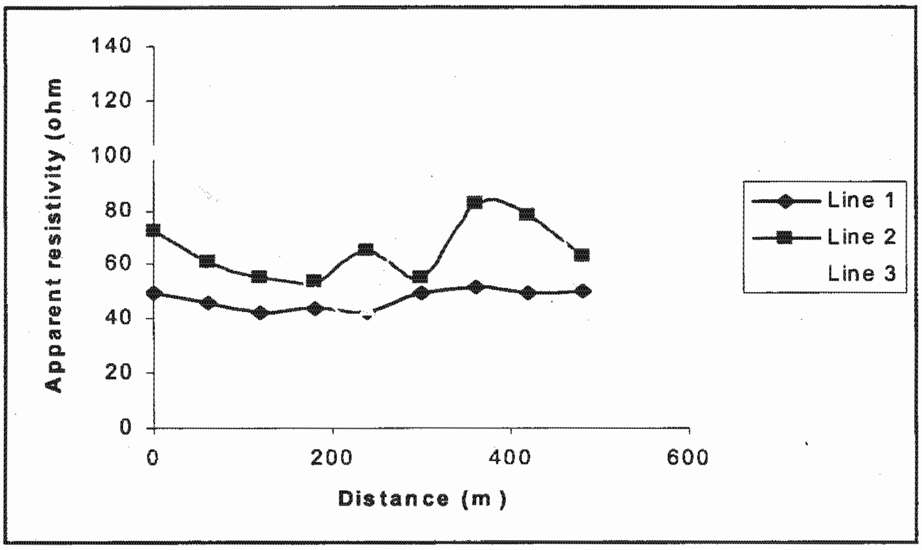


Fig. 6: Plot of Apparent resistivity vs distance for the lines

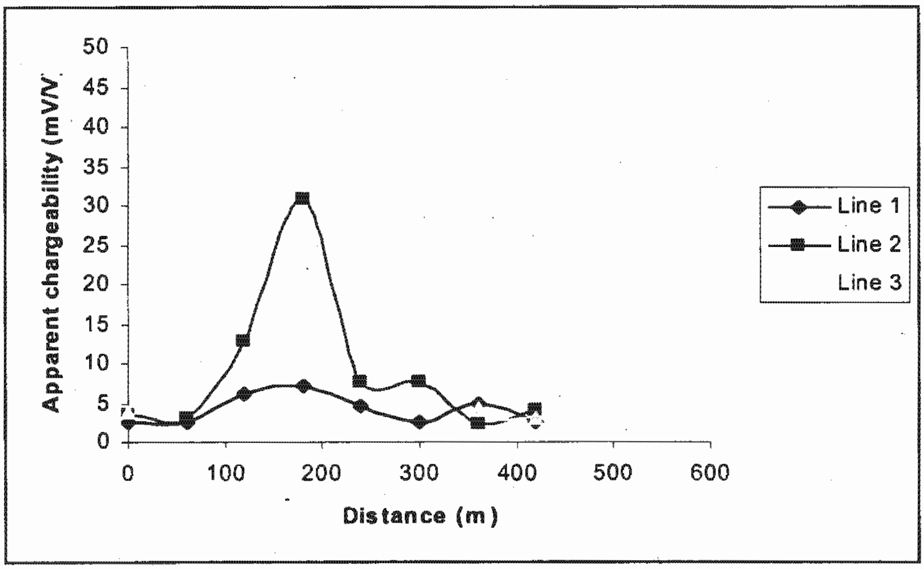


Fig. 7: Plot of Apparent chargeability vs distance for the lines

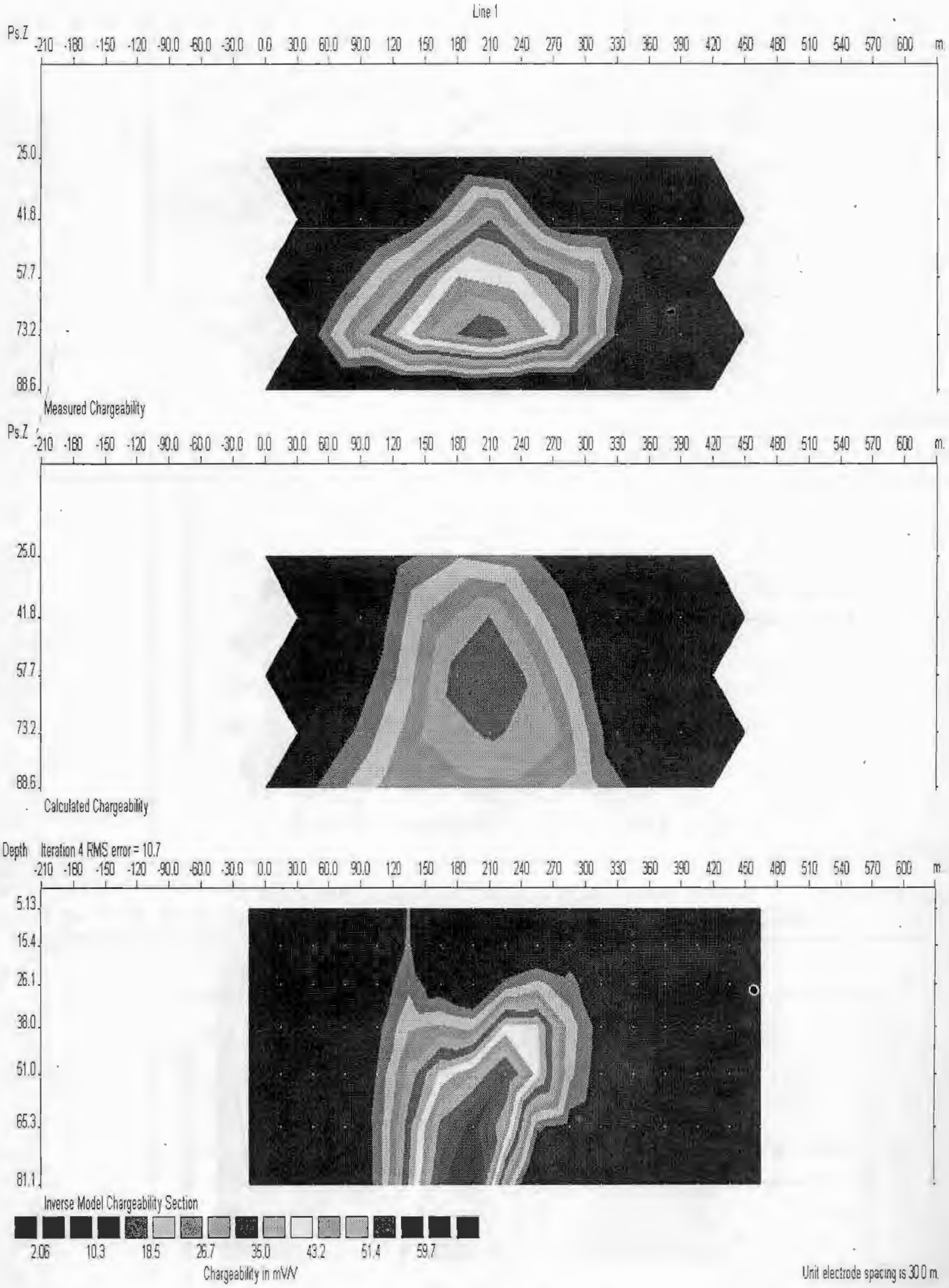


Fig. 9: Pseudosection for measured chargeability, calculated chargeability and inverse model chargeability section for line 1.

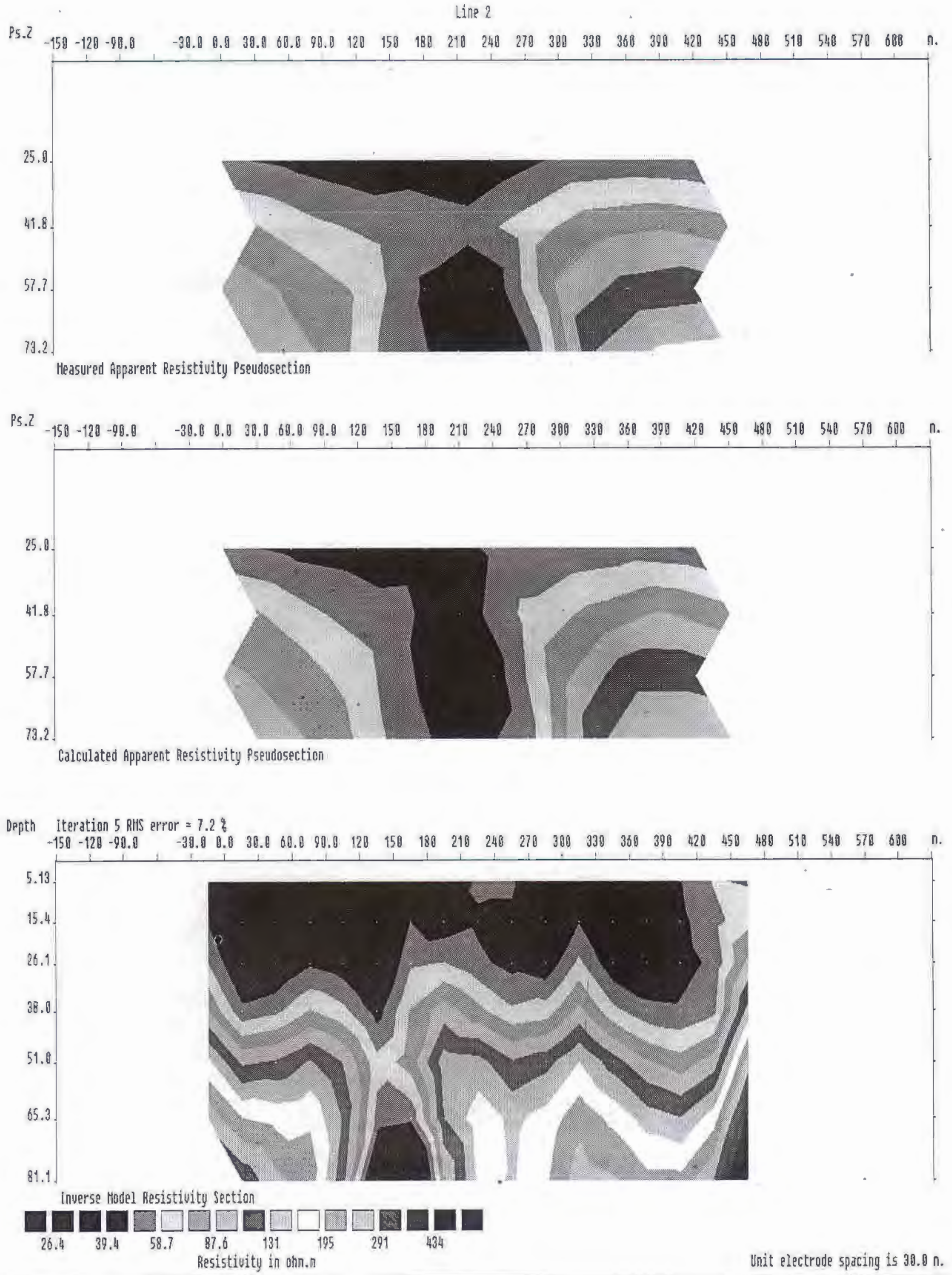


Fig. 10: Pseudosection for measured, calculated and inverse model resistivity section for line 2

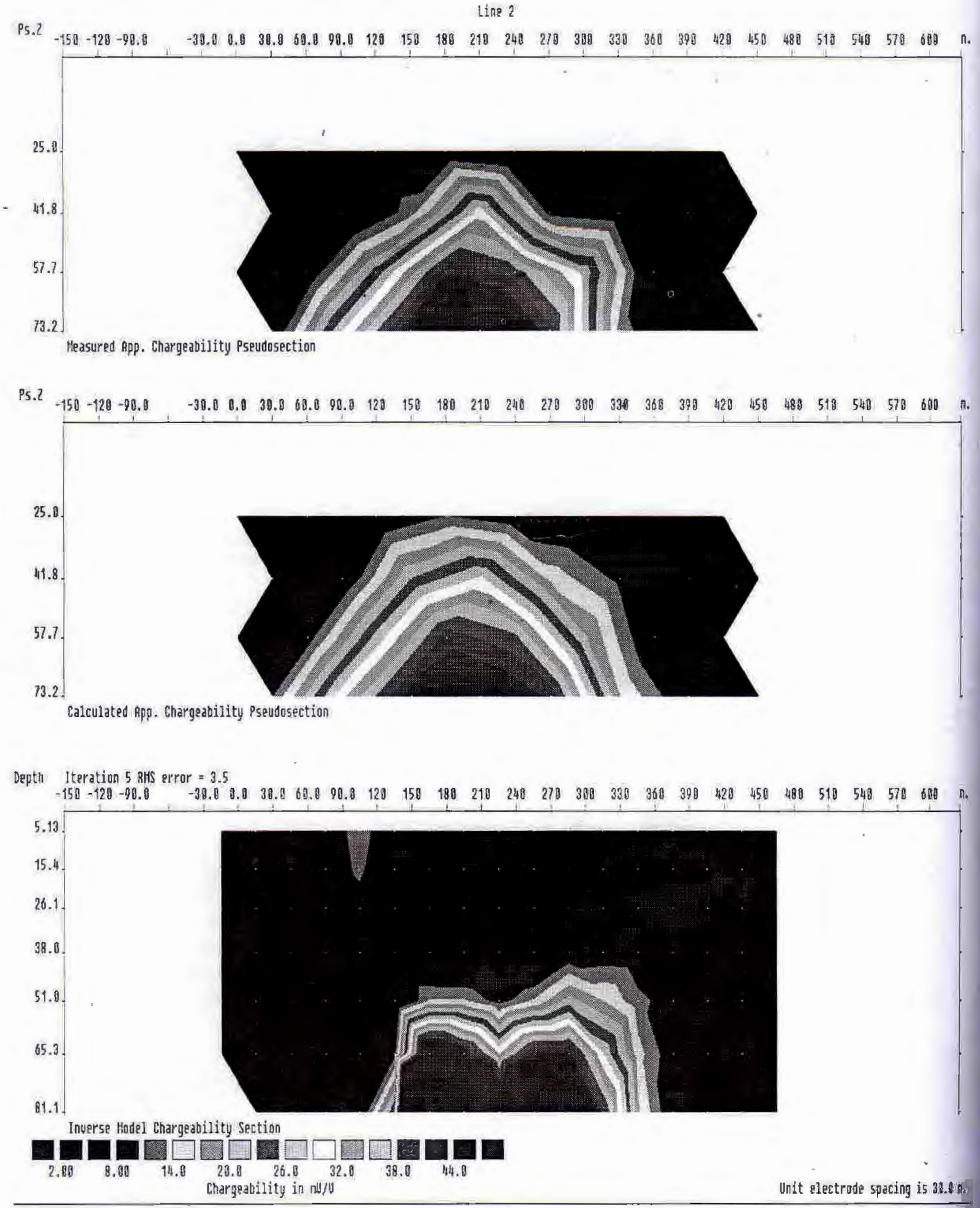


Fig. 11: Pseudosection for measured, calculated, and inverse model chargeability for line 2

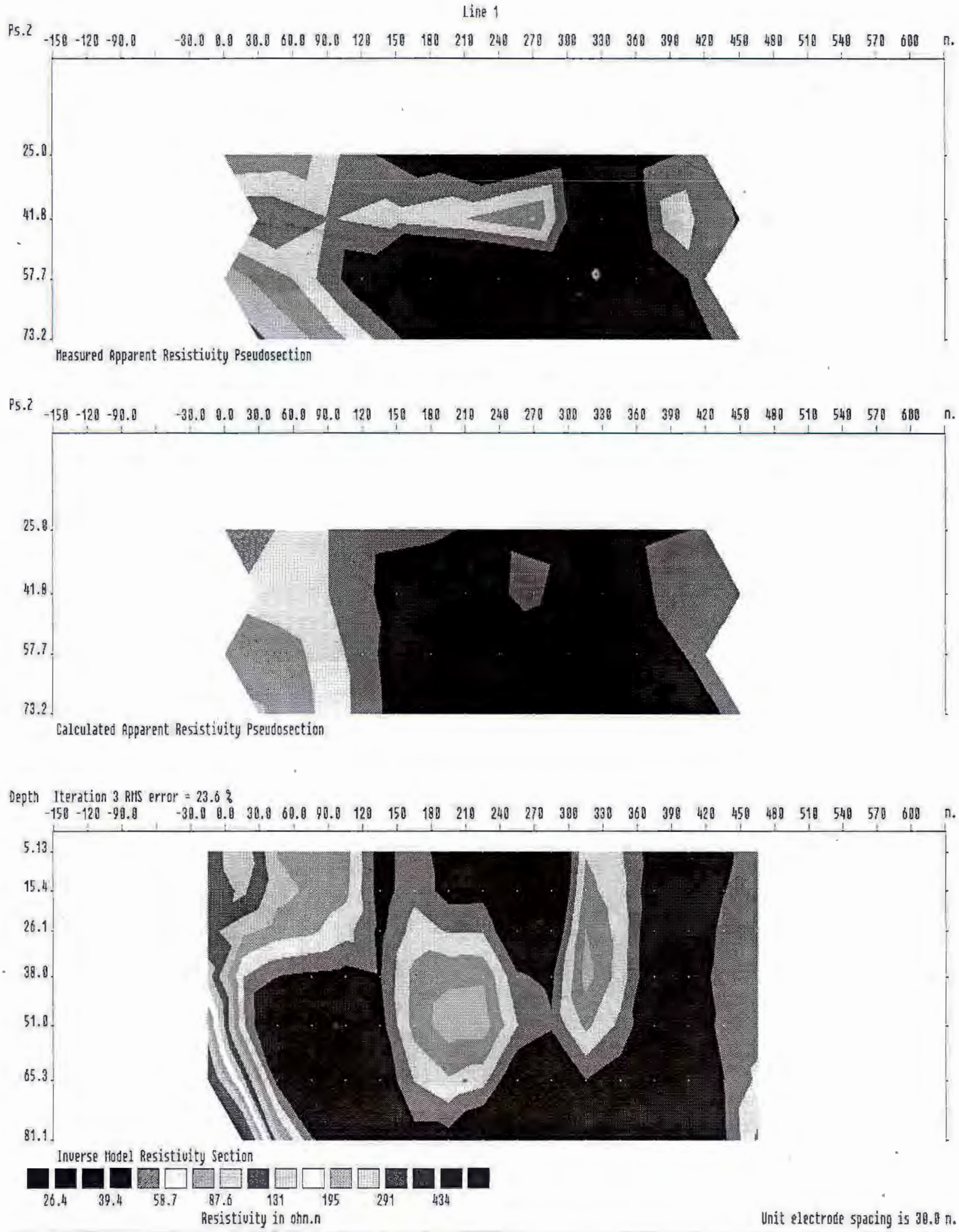


Fig.12: Pseudosection for measured, calculated and inverse model resistivity section for line 3

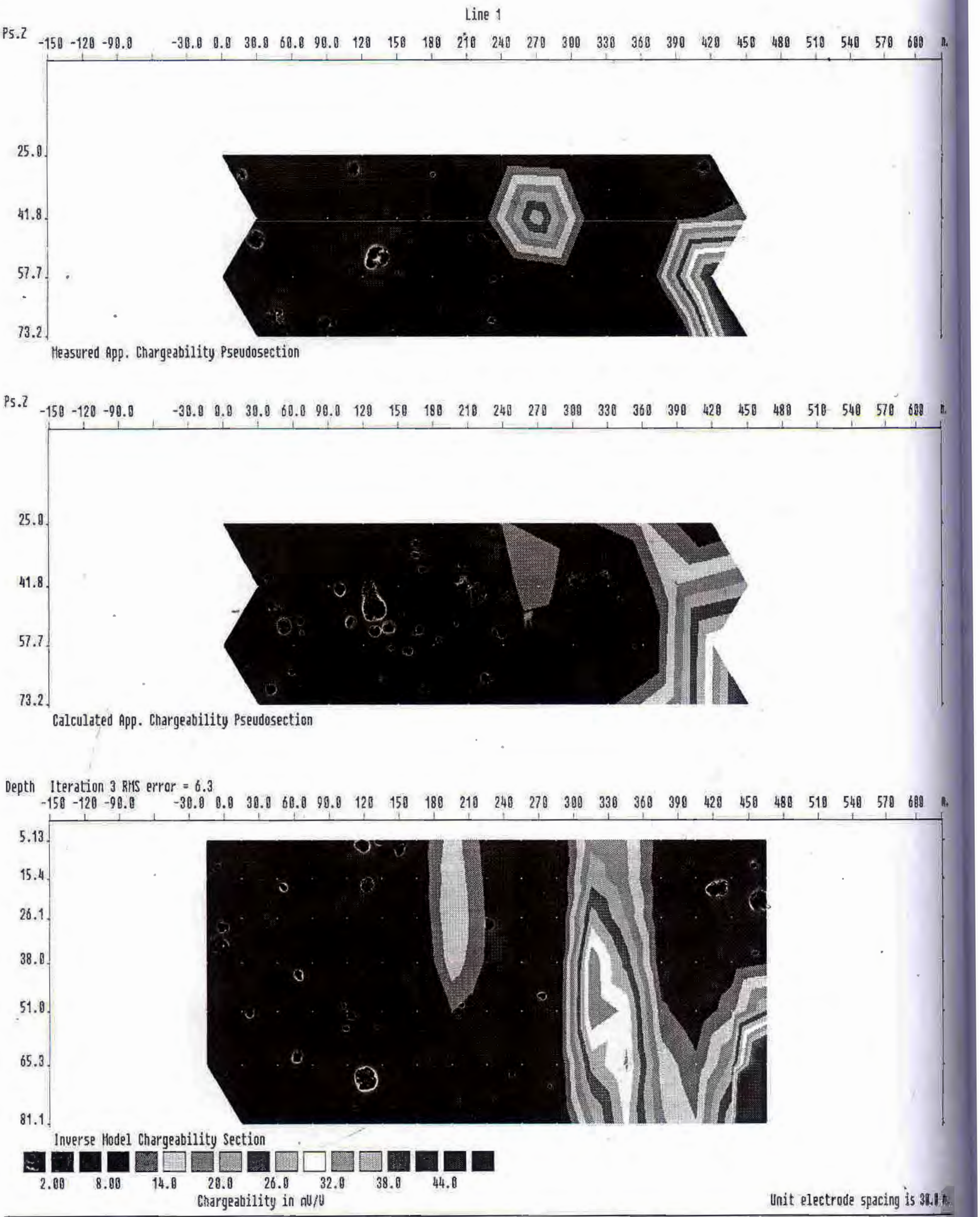


Fig.13: Pseudosection for measured, calculated and inverse model chargeability for line 3.

geometrical shape, the problem becomes more complicated mathematically and numerical method of computation is required (Oldenburg & Li, 1994; Erika, 1999).

The inverse approach used here is to manipulate the observed anomaly to produce a model. This method is used to estimate the size of the geological feature. A 2-D forward modeling program (RES2DMOD – Loke, 1999) which calculates the apparent resistivity pseudosection for a user defined 2-D subsurface model was employed in the inversion of the data obtained.

6. Results and Discussion

The plot of percentage frequency effect as indicated in Fig. 5a shows a consistent high PFE over a distance of between 80-200 m along the three traverses at 0.3 Hz. There is no distinct anomaly pattern at 3Hz (Fig. 5b). Similarly, from the apparent resistivity plots shown in Fig. 6, 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 chargeability shown from the plot in Fig. 7 corresponds to the region observed for low resistivity Fig. 6 along the various traverses, 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), the inversion result was used to generate model for this purpose.

Fig. 8 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 pseudosection is not conclusive for localization of the body because the pseudo-plot shows that the type of resistivity here is bulk, which is due to the disseminated nature of sulfides currently under investigation.

As shown in Fig. 9, 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 Fig. 8. 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.

The apparent resistivity pseudosection for line 2 (Fig. 10) reveals a similar pattern with those observed on line 1. A high resistivity unit was observed on the south-eastern portion of the line. This zone opens at the bottom and its spread which reflects bulk resistivity makes any conclusive deduction very difficult. The anomaly spread out through the entire length of the line which indicates a scattered dissemination. The low resistivity surface layer across the line reflects highly variable overburden. The corresponding apparent chargeability pseudosection shown in Fig. 11 identifies a wider localized anomalous zone at the central portion of the line. It open also at the bottom, thereby making it difficult to have an estimated thickness but the body can be said to have a spread of about 150 m, and at an estimated depth of about 65 m from the surface.

As shown in Fig. 12, the resistivity pseudosection for line 3 reveals virtually a uniform low resistivity through this line except for a little portion at the extreme south-west part of the line. It could be suggested therefore that little could be said of any anomaly present in this zone, though certain mineralization are present in this type of formation. From the corresponding apparent chargeability pseudosection (Fig.13), two anomalous zones are noticeable at the south-eastern part of the line. The anomalous zone at the extreme south-east end appears more promising but since it opens both at the bottom and the right side, its thickness cannot be estimated, but could be said to lie at an estimated depth of about 50 m. The second anomalous zone lying at a depth of about 26 m has an estimated thickness of about 55 m and 60 m wide. This anomaly coincides with the localized low resistivity zone shown in Fig. 12.

Measurement for the percentage frequency effect (PFE) was computed for the three traverses data at 0.3 Hz and 3 Hz 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 lines 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.

7. Conclusion

From the interpreted depth sections, the first two lines appear to have significant anomaly while the third has little information about the ore body. Three main regions of high anomaly are evident in the inverse model resistivity pseudosection for the first two lines though due to bulk resistivity, no distinct zone could be localized. The IP inversion results identifies the anomalous zones, the bottom central point appears closed at a depth of about 80 m while the bottom left is open at a depth of 60 m and above suggesting that we cannot tell from these data to what depth that region extends. A similar inference could also be made for the third bottom right region of high anomaly. The overburden at the top of the pseudosection plot has an estimated thickness of about 20 m. The strong chargeability observed at various depths on traverse lines 1 and 2 requires additional surveying in order to verify and delineate a probable source.

Consequently, from the apparent resistivity pseudo-plots, 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 slags 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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