Identification of Porphyry Deposit in Papua Region Using Time Domain-Induced Polarization Data Analysis

G Rumahorbo[1*], Y Yatini[1], and Sutarto[2]

[1)]*Departement of Geophysical Engineering, Faculty of Mineral Technology, Universitas Pembangunan Nasional Veteran Yogyakarta, 55283, Indonesia*

[2)]*Departement of Geological Engineering, Faculty of Mineral Technology, Universitas Pembangunan Nasional Veteran Yogyakarta, 55283, Indonesia*

[*]*Email: jeng_tini@upnyk.ac.id*

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Abstract

Papua is part of the islands in Indonesia with abundant economic metal mineralization. The types of mineralized deposits on Papua Island are porphyry, skarn, and epithermal. An important observation is that the porphyry deposit is often identified early through the geological conditions. Therefore, this study aims to identify the presence of porphyry deposit system in the area using Time Domain Induced Polarization (TDIP) data analysis. TDIP measurements were conducted in an area of 2.24 km^2 with a total of three lines oriented southeast-northwest along 3 km. The analysis showed low resistivity values of 5.99 – 41.1 ohm-m correlated with high chargeability values of 246 – 344 mV/V at an elevation of 500 m identified as potassic bodies. There were also sericitic-clay-chlorite and serisitic-clay alterations-pyrite at the top with a metal sulfide mineral content which was more dominant than the clay up to 1100 m elevations.

Keywords: *Papua, porphyry, Time Domain Induced Polarization, resistivity, chargeability*

I. INTRODUCTION

Metal mineralization is the process of depositing valuable and economically viable minerals in a place. Indonesia is an archipelagic country formed by the convergence of subduction of the Eurasian, Indo-Australian, and Pacific continental plates. This tectonic process led to magmatism activity in several areas due to the initial occurrence of metal ore mineralization [1]. An example of the regions with metal mineralization in Indonesia is Papua Island.

The formation of the island is due to two major tectonic processes presented in Figure 1. The first was the collision of Pacific Ocean plate with Indo-Australian plate during the Oligocene. The second was a reversal process of subduction of the islands from the collision with Australian Craton during the Miocene. The presence of young magmatism activity in the Pliocene period up to the present time in the form of dioritic to monzonitic intrusion led to the formation of metal mineralization deposits such as porphyry, skarn, and epithermal at the top of intrusive rocks [2].

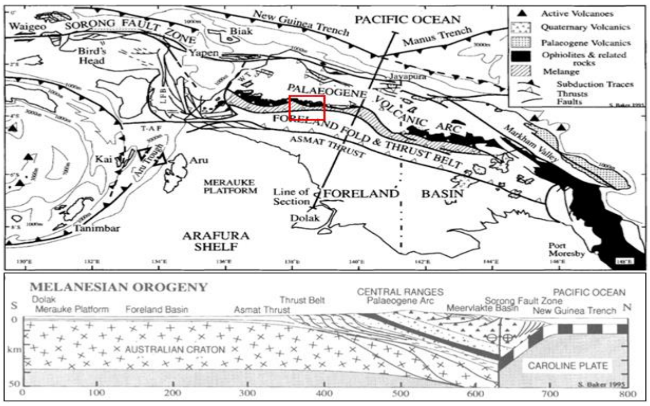

Figure 1. Orogenic Melanesia in Papua with Cross-Section Interpretation

Papua Island by metallogeny [1] has several proven mineral deposit potential, including copper and gold in Grasberg and Ertsberg as shown in Figure 1. The study area which is located in the middle part of Papua is geologically composed of clastic sedimentary and intrusive rocks. The igneous rock intrusions from old to young are diorite, monzodiorite, monzonite, and granodiorite. The structure of the study area is a shear fault dominated by sinistral shear faults with the dominant orientations being NW-SE and NE-SW. Metalogenically, the area is in porphyry and skarn mineralization zone as observed in Figure 2. Porphyry deposit is formed due to the occurrence of multiple intrusions more than twice with intermediate to felsic rock properties. This led to four types of intermediate rock intrusion in relation to the potential of forming porphyry deposit system [3].

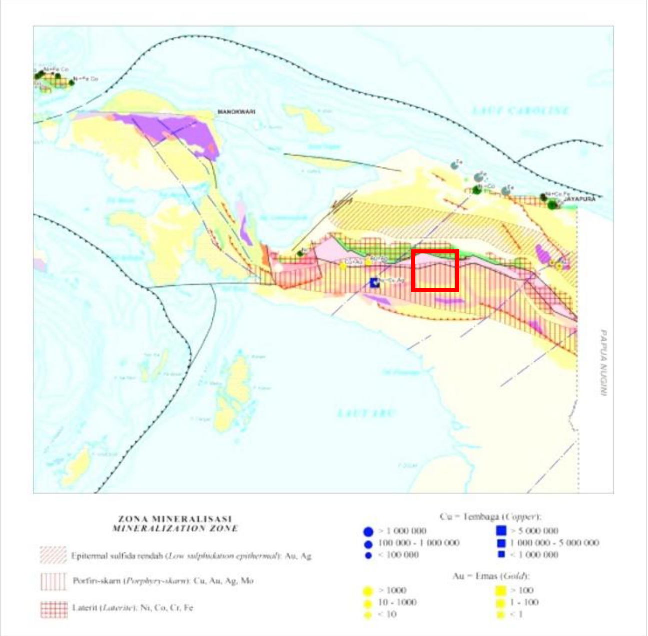

Figure 2. Map of Papua's Metalogeny with Proven Resources and Mineralization System Zoning

A geophysical method was used to determine the presence of metal sulfide mineralization zones. This was in the form of Time Domain Induced Polarization (TDIP) which was considered part of the most effective methods in metal mineral exploration [3]. TDIP method can measure the polarization decay time of a metal mineral to determine its presence. Previous studies showed the possibility of using the method to delineate gold mineralized zones [7]. The delineation was characterized by high resistivity and chargeability values in response to altered igneous rocks containing metallic mineralization in the form of gold. Therefore, this study aimed to identify the presence of porphyry deposit system in the study area using TDIP method.

II. MATERIALS AND METHODS

This study was conducted using a geophysical method in the form of TDIP. The application was to calculate the potential decay time of a material to determine the polarization of a material which was metal sulfide minerals in this specific case [4]–[6].

Data were processed by measuring three tracks with an orientation of Southeast – Northwest at a 2,800-meter length and the distance in between was 400 meters. The measurement area of TDIP was 2.24 km2 and the electrode configuration used was Dipole-Dipole. The next measurement data were calculated to determine the apparent resistivity and chargeability values and subsequently entered into the inversion software i.e. res2dinv to obtain a pseudo-section cross-section [7], [8], [9]. In this inversion processing, there were several methods of data processing and quality control implemented to achieve the desired results and ensure minimum noise.

A. Mesh Parameter

The setting of the mesh parameter was the initial step before the inversion process. It was implemented to organize and adapt the data to the inversion process because the characteristics of each were different. The method consisted of three main parameters including Finite-Mesh Grid Size, Use Finite-Element Method, and Mesh Refinement. Finite-Mesh Grid Size is a parameter to determine the datum distance on a series of electrodes and four nodes are arranged on each electrode to increase the accuracy of the data in this study. Moreover, Use Finite-Element Method is a parameter to determine the type of forward modeling associated with calculated data [9] as well as the shape of the inverse cross-section as presented in Figure 3. The method was applied in forward modeling related to opposite of the data on the topographic contact and the trapezoidal type was used to produce a cross-section according to the pseudo-section of Dipole-Dipole array.

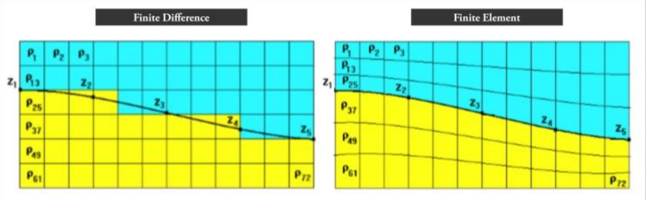

Figure 3. Mesh parameters for Finite Difference and Finite Element Method

Mesh refinement is a parameter used to adjust the mesh type in the forward modeling process with the contrast of the resistivity values in the data. This study used a normal mesh type with a resistivity contrast of less than 50.

B. Exterminate Bad Datum Point

The extermination of bad datum point is a quality control process for resistivity and chargeability data. It was conducted before and after the inversion process when RMS error value was more than 76 as presented in Figure 4. The datum points considered to be bad had random positions or cross-over with others. The cause was not in accordance with Dipole-Dipole array possibly associated with the differences in topography measurements that led to an inappropriate depth for the datum. It could be due to insufficient injection current to reach the depth of the target datum [10], [11].

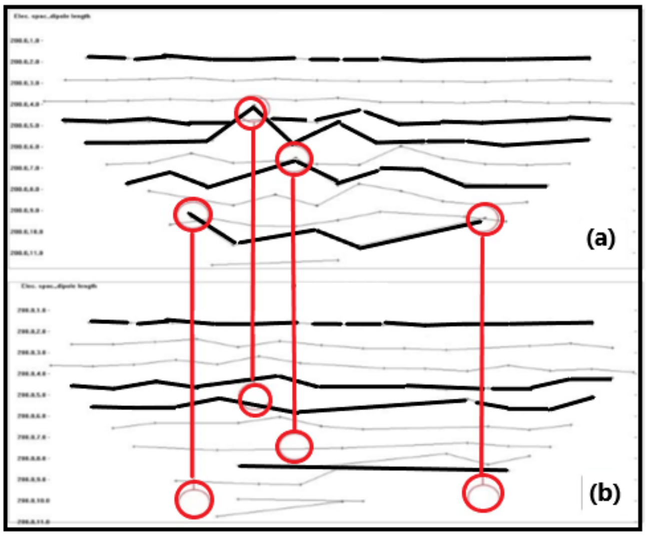

Figure 4. Exterminate Bad Datum Process, (a) Four bad datum points that cross over and (b) pseudo section after deleting the bad datum points.

C. Least-Squares Inversion

The resistivity and chargeability cross sections were produced through an inversion process applied to each recorded data set. Least-Squares Inversion is a geoelectrical method that uses a calculation in the form of a square of the difference between the calculated and observed data [12]. The method was applied with the aim of obtaining inversion data that was close to the observation with minimum noise and lesser contrast. The smoothness constraint method was adopted to obtain a smooth anomaly.

III. RESULTS AND DISCUSSIONS

The alterations formed in porphyry deposit vertically from top to bottom are potassic, sericitic -clay-chlorite, and serisitic-clay-pyrite, while the horizontal aspect was propylitic. The potassic and serisitic-clay-chlorite alterations had high metal sulfide mineral content such as bornite and chalcopyrite. This led to the consideration of TDIP as the effective method for delineating the alteration zone as a metal sulfide mineralization zone. This was achieved through the resistivity, chargeability, cross-sectional correlation, anomaly continuity, and three-dimensional analyses of porphyry deposit system.

A. Resistivity and Chargeability Analysis

The results of TDIP geoelectric inversion data consisting of resistivity and chargeability cross sections were interpreted to determine the alteration zone and mineralization in porphyry deposit. TDIP trajectory in Figure 5 shows a pattern of low resistivity and high chargeability anomalies (code C) at the 200th m. This led to the interpretation that the zone was a strong alteration [13].

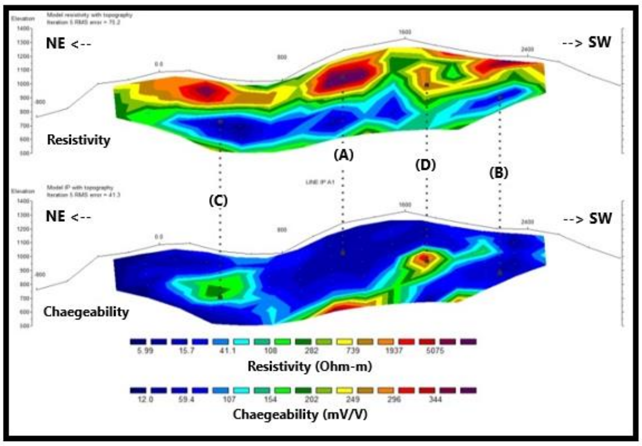

Figure 5. Resistivity and chargeability section Line 1 with interpretation code refers to a geological condition in Table 1

The zone was associated with sericite alteration due to the dominance of sulfide minerals compared to clay as listed in Table 1. The high resistivity and chargeability values in the cross-section are a response to the massive quartz vein zone with high sulfide content at 1800 meters which is a depth of 400 meters below the surface. There are other zones that are interpreted with different geological conditions on the track. Moreover, the interpretation code and table apply to the other two TDIP tracks.

Table 1. Interpretation Table for each TDIP Line

Code	Resistivity		Chargeability		Interpretation
	High	Low	High	Low	
A	✓			✓	Weak Alteration, Fresh Rock, Exoskarn with minor sulphide, Silica-rich Zone
B		✓		✓	Cavity Structure, Clay-rich zone, Sericitic Alteration (Sericite>Sulphide)
C		✓	✓		Strong Alteration, Vein sphread zone, Sericitic Alteration (Sulphide>Sericite)
D	✓		✓		Silification Zone, Major Sulphide in Vein Quartz, Weak Altered with High Magnetite

B. Cross-Section Correlation Analysis

TDIP geoelectrical section consisting of three tracks was subjected to 3D correlation to delineate the continuity of the resistivity and chargeability data in Figure 6. A continuous low resistivity value was identified in the middle of the cross-section which tended to be massive on L1 and L2 lines to form a large closure. The low resistivity value tended not to form a large closure on the next track in the southeastern part but showed continuity.

The trend led to the interpretation of a continuous north-south structure but the domination of clay mineral alteration in the southeastern part of L2 and L3 as presented in Table 2. A high resistivity anomaly was identified in the western part of each track and interpreted as a continuation of fresh intrusive igneous rocks or incomplete alteration.

The chargeability cross-section correlation in the following figure shows a high chargeability anomaly which is interpreted as a rich sulfide zone carrying metal mineralization. The trend tends to be spotted in different places but there are massive high chargeability values at the bottom of L800 and L1000 tracks which can be associated with the sericite alteration zone at targeted porphyry bodies as presented in Table 3.

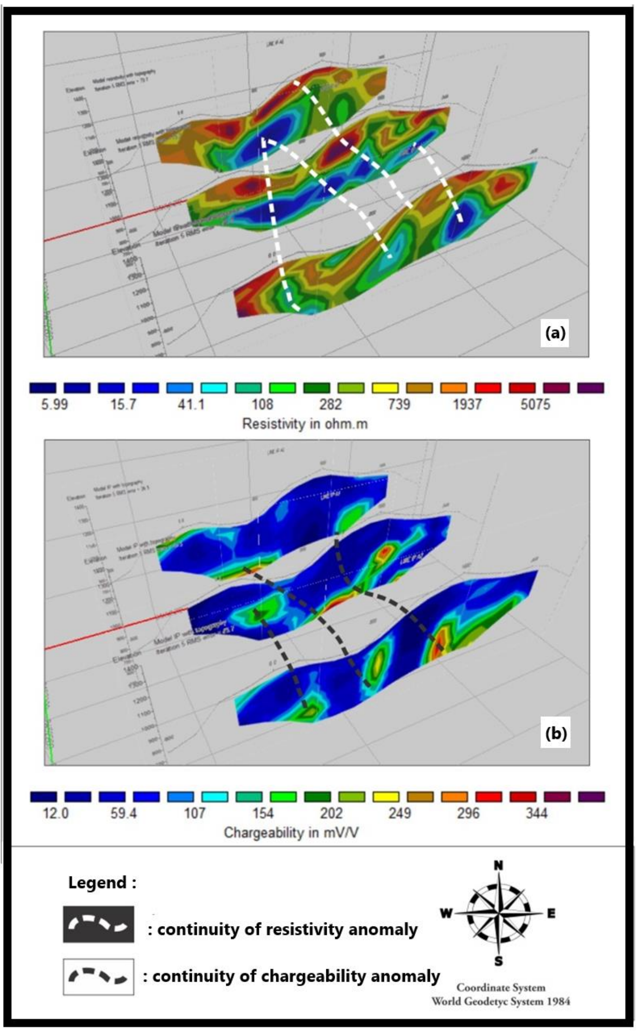

Figure 6. TDIP geoelectrical correlation to determine the continuity of the anomaly that is the target in the form of mineralized areas (a) resistivity and (b) chargeability.

Table 2. Classification of Resistivity Values Against the Geological Condition of the Study Area

No	Classification	Resistivity Range (Ohm-m)	Interpretation
1	Low	< 215	Clay mineral, Strong alteration
2	Medium	215-2670	The moderate alteration, Fresh rock with moderate silica, Quartz Vein, SCC alteration
3	High	>2670	Fresh rock, Quartz vein, Propylitic alteration

Table 3. Classification of Chargeability Values Against the Geological Condition of the Study Area

No	Classification	Chargeability Range (mV/V)	Interpretation
1	Low	< 80	Clay mineral with minor sulphide, barren ore
2	Medium	80-215	Rich of both clay and sulphide minerals, weak alteration
3	High	>215	Sulphide dominant, Sericite alteration, Vein with high ore

Anomaly Continuity Analysis

The resistivity and chargeability values in TDIP geoelectric were produced in the form of horizontal distribution with different elevations. The difference was 200 m which started from an elevation of 500 m to 1300 m and stacked vertically as presented in Figure 7.

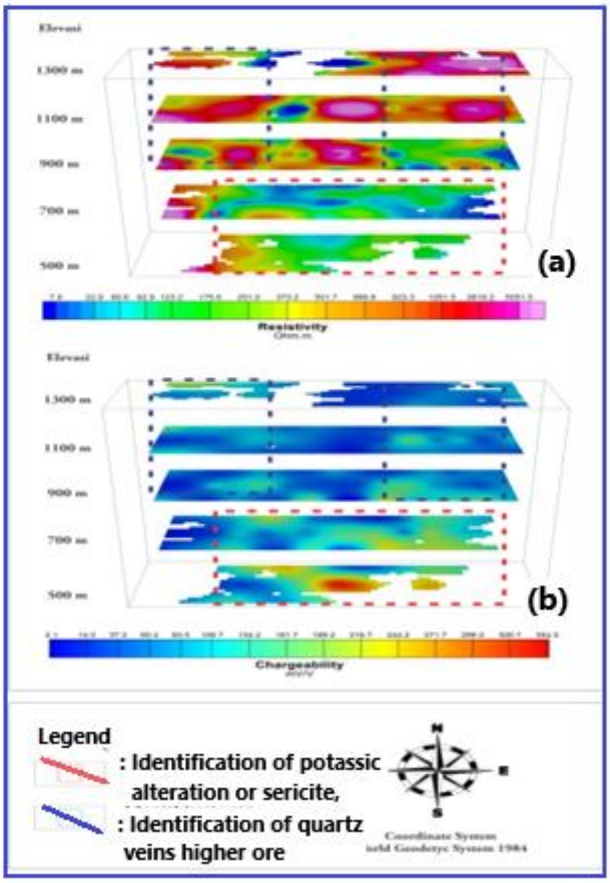

Figure 7. Stacking plan map of TDIP to determine the horizontal continuity for each elevation per 200 m (a) resistivity and (b) chargeability

The stacking plan map shows a low resistivity anomaly at the bottom right which continues to an elevation of 700 m but changes to high at 1300 m. The low resistivity values at 500 to 700 m are interpreted as zones with structures or veins that spread and the presence of a large amount of clay minerals. The comparison at the same elevation showed that low resistivity and high chargeability zones represented the presence of potassic to potassic or neritic-clay-chlorite alteration.

The stacking plan map of 900 to 1300 m elevation had high resistivity anomalies on the left and right. The high resistivity values were correlated with moderate chargeability values and interpreted as quartz vein zones spreading with high sulfide content in response to nericitic-alteration changes and clay-pyrite.

C. Porphyry Deposit Setting Analysis

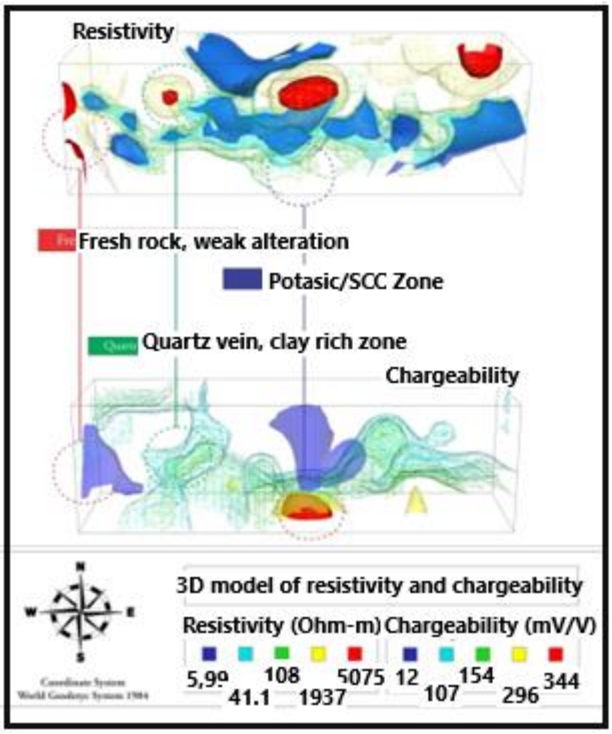

Figure 8. 3D Model of iso-surface resistivity and chargeability

The 3D iso surface resistivity modeling in Figure 8 shows a high resistivity anomaly pattern in the west which is correlated with low chargeability values. The zone is interpreted as fresh or unaltered igneous rock or quartz vein barren ore. The middle part is south of the 3D model with a low resistivity anomaly which is correlated with a high chargeability anomaly. The zone is interpreted as potassic or sericitic-clay-chlorite alteration with the domination of sulfide content compared to clay and the spread of vein which leads to a low resistivity value.

The upper zone of potassic body has a low resistivity anomaly which correlates with a high chargeability anomaly. The zone is interpreted as a continuation from serisitic-clay-chlorite to serisitic-clay-pyrite with sulfide content approximately comparable to clay. This shows that the chargeability response has a value which is being...

The 3D iso-surface model shows that porphyry deposit system in the study area consists of potassic alteration at a depth of 500 m with serisitic-clay-chlorite and serisitic-clay-pyrite alterations in the upper part and quite abundant sulfide mineralization. Meanwhile, propylitic alteration is located around the potassic body with host in the form of incompletely altered igneous rock.

IV. CONCLUSIONS

In conclusion, the results of TDIP Data analysis showed a correlation between resistivity and chargeability values related to porphyry deposit system in the study area. The low resistivity values of 5.99 – 41.1 ohm-m correlated with high chargeability values of 246 – 344 mV/V at an elevation of 500 m which was identified as potassic bodies. Meanwhile, there were sericitic-clay-chlorite and sericitic-clay alterations at the top with the domination of a metal sulfide mineral content over clay.

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